# AN INTEGRATIVE APPROACH TO PRIORTIZING AQUATIC HABITAT RESTORATION SITES IN THE WOODEN'S RIVER WATERSHED, NOVA SCOTIA

by

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This research project report titled *An Integrative Approach to Prioritizing Aquatic Habitat Restoration Sites in the Wooden's River Watershed, Nova Scotia* has been examined and approved for the Department of Geography/Department of Environmental Studies, and it completes the requirements for Geography 4526.0 and Environmental Studies 4599.0: Honours Research Project.

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## ABSTRACT

# AN INTEGRATIVE APPROACH TO PRIORTIZING AQUATIC HABITAT RESTORATION SITES IN THE WOODEN'S RIVER WATERSHED, NOVA SCOTIA

by Oliver C. Woods

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Presently, there is a gap in the literature where Local Ecological Knowledge (LEK), Community-Based Monitoring (CBM), mapping technologies, and fish habitat models are collectively incorporated into site selection, monitoring, and aquatic habitat restoration. This thesis attempts to bridge this gap by developing an approach to site selection which incorporates CBM, LEK, mapping technologies, and fish habitat models to assess aquatic habitat quality and quantity and to identify sensitive areas requiring added protection and/or restoration.

The Wooden's River Watershed, located on the Chebucto peninsula, Nova Scotia, was the study area used to test the methodology. The results generated from this research have identified that the temperature variable appears to be a significant limiting factor, therefore highlighting the importance of the cool, groundwater fed tributaries likely acting as refuge areas in times of maximum summer temperature. Furthermore, the results indicate that the drumlins cored by Lawrencetown till existing in the lower portion of the watershed do in fact benefit local pH, however their capacity to buffer the larger bodies of water appears to be minimal.

The methodologies used in this research have proven to effectively prioritize several aquatic habitat restoration initiatives in a manner which can be easily adopted by members of the community and stewardship groups alike.

# RESUME

## UNE APPROCHE INTÉGRATRICE DE PRIORITATIONS D'EMPLACEMENTS AQUATIQUES DE RESTAURATION D'HABITAT DANS LA LIGNE DE PARTAGE EN WOODEN'S RIVER, NOUVELLE-ÉCOSSE

Par: Oliver C. Woods

Avril, 2007

Présentement, il y a un espace dans la littérature où la connaissance écologique locale (LEK), la surveillance Communauté-Basée (CBM), tracer des technologies, et les modèles d'habitat de poissons sont collectivement incorporés au choix d'emplacement, à la surveillance, et à la restauration d'habitat aquatique. Cette thèse essaye d'établir un lien en développant une approche au choix d'emplacement qui incorpore CBM, LEK, traçer des technologies, et des modèles d'habitat de poissons pour évaluer la qualité et la quantité d'habitat aquatiques et pour identifier des secteurs sensibles exigeant la protection et/ou la restauration supplémentaires.

La ligne de partage en Wooden's River, située sur la péninsule de Chebucto, Nouvelle-Écosse, était le secteur d'étude employé pour examiner la méthodologie. Les résultats produits de cette recherche ont identifié que la variable de la température semble être un facteur limiteur significatif, donc accentuer l'importance du frais, tributaires alimenté de d'eaux souterraines agir probable comme secteurs de refuge en période de la température maximum d'été. En outre, les résultats indiquent que les drumlins creusés par Lawrencetown existant encore dans la partie inférieure de la ligne de partage bénéficient en fait le pH local, toutefois leur capacité de protéger les eaux superficielles plus grandes semble d'être minimale.

Les méthodologies utilisées dans cette recherche se sont avérées donner la priorité efficacement à plusieurs initiatives de restauration d'habitat aquatiques en quelque sorte qui peut être facilement adopté par des membres des groupes de la communauté et d'intendance de même.

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# Chapter 1

# INTRODUCTION AND LITERATURE REVIEW

## 1.1 Introduction

Water of suitable quality and quantity is, and has always been, essential to all life. It shapes and beautifies the landscape, controls climate, determines the nature of the surrounding environment, and provides a wide range of habitats. However, in our rapidly developing world, water is a vital necessity in industry, agriculture, power generation, recreation and tourism. Unfortunately, water quality can deteriorate over time, limiting future use and decreasing available habitat.

Human-induced changes on the aquatic environment have become extremely apparent during the past several decades and increased environmental awareness has acted as a catalyst, promoting water quality monitoring on a global scale. These anthropogenic changes affect the amounts and distribution of water, sediment and nutrients released from the landscape as well as provide opportunity for chemical contamination and bioaccumulation (Imhof et al. 1996). Although a tremendous amount of work has been undertaken to protect, conserve and restore aquatic habitats, collective efforts do not keep pace with the rate of decline (Hendry et al., 2003).

Management of aquatic systems requires a comprehensive understanding of the physical environment and must be approached in a manner that draws information from many disciplines. Because of the seemingly infinite number of parameters that could be taken into account when considering watershed management, and the often large geographical area of study, it is important that goals are well defined and research is focused.

Recent literature indicates that many aquatic environments and unique habitats throughout Canada (as well as on a global scale) have suffered in terms of water quality as a result of increased development (Imhof et al., 1996; Borsuk et al., 2006). The literature also indicates that many observed habitat losses at a specific site may have been due to changes at a watershed scale (Naiman et al. 1992; National Research Council, 1992). Therefore, it is believed that habitat restoration must reach further than a specific site of concern. As mentioned previously, effective aquatic restoration must draw information from an array of sources, and especially the surrounding environment/landscape. Because Brook trout, *Salvelinus fontinalis,* are known to act as an excellent environmental indicator, this thesis will attempt to provide a primary habitat assessment (at the secondary watershed scale) based on several essential trout habitat requirements including: pH, dissolved oxygen, and temperature. This habitat assessment will aid in developing an approach to watershed planning which uses community-based monitoring, local ecological knowledge, modern mapping technologies, landscape characteristics, and fish habitat models to assess habitat quality and quantity, and to identify sensitive areas requiring added protection and/or aquatic habitat restoration.

## 1.2 Habitat Requirements for Brook Trout (*Salvelinus fontinalis)*

Brook trout (*Salvelinus fontinalis*) are native to eastern North America (Raleigh, 1982; Menendez, 1976). Its extensive distribution throughout the Atlantic Provinces makes it one of the most preferred fish for anglers. The abundance and distribution of Brook trout throughout eastern North America is strongly influenced by both aquatic habitat and state or provincial management practices (Armstrong et al., 2003).

Habitat is understood to be the range of physical and chemical factors affecting an animal (Armstrong et al., 2003). According to Armstrong et al. (2003), “these factors are those considered to be acting in the immediate vicinity of the animal” (p.144). In reality, factors may result from processes that impinge across a broad range of scales and therefore when considering habitat management and/or restoration, water quality, water quantity and physical structure of the riverine environment must be taken into account. The literature suggests that management and/or restoration practices to resolve problems in just one of these areas will often be ineffective due to the interrelated and complex nature of aquatic systems (Naiman et al., 1992; National Research Council, 1992; Armstrong et al., 1999).

The literature consistently states that temperature, dissolved oxygen (D.O.) content, and pH are among the most important factors limiting Brook trout distribution and production (Menendez, 1976; Raleigh, 1982; Armstrong et al., 2003). Although many specific variables exist when considering Brook trout habitat (some of which will be mentioned briefly), pH, D.O., and temperature alone provide good insight into the overall state of an aquatic system. For example, pH will typically indicate local geological structure (buffering capacity), degree of acid rain, as well as chemical contamination. D.O. concentrations typically indicate concentration of organic substances, water velocity, and pool-riffle ratio's (keeping in mind the temperature D.O. relationship). Finally, temperature is an excellent indicator of forest cover, ground water input and water depth. Hendry et al (2003) suggests the inter-related components of aquatic habitats should be viewed as a continuum and in fact, it will be necessary to share this view in order to properly quantify the importance of these three variables.

According to Raleigh, (1982), optimal Brook trout habitat is characterized by clear, cold spring-fed water; a suitable dissolved oxygen content and pH range; a silt free rocky substrate in riffle-run areas; an approximate 1-1 pool-riffle ratio with areas of slow, deep water; well vegetated stream banks; abundant in-stream cover; and relatively stable water flow, temperature regimes, and stream banks. Spawning typically occurs in streams with temperatures ranging from 4.5-10 $^{o}$ C however it is not uncommon for spawning to occur in gravels surrounding cold groundwater upwelling in lakes and ponds (Raleigh, 1982). An introductory habitat assessment does not require monitoring all these parameters and therefore only D.O., pH, and temperature will be investigated (for reasons discussed above).

Laboratory studies and individual research have proposed a wide range of tolerable pH ranges on both extremes. However, the literature indicates that the optimal pH range for Brook trout appears to be 6.5-8.0 with a tolerance range of 4.0-9.5 (with few exceptions) (Daye & Garside, 1975; Raleigh, 1982; Hendry et al., 2003).

In terms of tolerance, upper and lower temperature limits for Brook trout vary. Raleigh, (1982) indicates that this may be a reflection of local and regional population acclimation differences. The general consensus indicates that the tolerable temperature range for brook trout is 0-24$^{o}$ C with an optimal range for growth and survival of 11-16$^{o}$ C (Raleigh, 1982; Hendry et al., 2003). It has been suggested however, that populations are more subject to disease where temperatures exceed 20$^{o}$ C for prolonged periods of time (Raleigh, 1982, Rutherford, 2007). Therefore, trout will move within the watershed to find optimum temperature conditions rather than tolerate stressful levels (Rutherford, 2007). It has been indicated by many, including Rutherford (2007), that the size of summer cold water refuges, in areas of springs or below thermo-clines, often become limiting factors on the size of the population.

Dissolved oxygen (D.O.) concentrations also exhibit a wide range of acceptable limits however the direct relationship with temperature explains this variation to some extent. For example, an increase in temperature causes the dissolved oxygen saturation level to decrease. At the same time, this increase in temperature (decreasing D.O. saturation) also increases D.O. requirements for the trout (Raleigh, 1982). Due to this relationship, optimum D.O. levels for Brook trout are characterized by specific water temperature and appear to be $\geq$7 mg/l at temperatures $<$ 15 $^{o}$C and $\geq$ 9 mg/l at temperatures $\geq$ 15 $^{o}$C (Raleigh, 1982).

It is important to note that brook trout can often survive towards the tolerance limits however stress is experienced when outside of the optimum range. This stress on the fish will often decrease productivity and alter feeding habits; therefore Brook trout are known to move within the system in order to occupy water bodies with the most suitable balance between variables (Abraham, 2007; McCormick et al., 1972; Menendez, 1976).

### 1.3 Brook Trout Habitat Models

The literature suggests that many Brook trout habitat models exist, all of which are designed to aid in habitat management activities and/or impact assessment (Fausch et al., 1988; Raleigh, 1982). Models vary in scope, required resources, scientific methods, and targeted populations. For the purposes of this thesis, it is important to adopt a model that is adaptable, comprehensive, applicable to all levels of academia, and encompasses the entire geographical range of the species (as it is hoped this research can be applied elsewhere).

The model chosen to represent habitat suitability is entitled “Habitat Suitability Index Models: Brook trout”, written by Raleigh, (1982) of the U.S. Fish and Wildlife Service. This habitat suitability index was chosen on the basis of criteria discussed above and is expected to provide great insight when analyzing the collected data. Literature concerning the specific habitat requirements and preferences of Brook trout have been synthesized into Habitat Suitability Index (HSI) models and scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat) (Raleigh, 1982). The model will be discussed in more detail in the methodology chapter of the thesis.  The framework can be used and interpreted on an individual model level (concerning only one habitat variable), or can be looked at collectively depending on the specific circumstances of those involved in monitoring. As the next sections will discuss, citizen involvement in environmental monitoring is on a steady rise however many challenges are faced including: data that is not comparable, limited financial/material resources, availability of robust sampling protocols, and integration into decision making processes (Sharpe & Conrad, 2006). Therefore, the use of Raleigh’s suitability index is expected to help overcome many of these challenges as community members become involved in aquatic habitat assessments and/or prioritizing restoration initiatives.

## 1.4 Community Based Monitoring

In recent decades, government agencies have attempted to undertake the majority of environmental monitoring activities, however it has become apparent that collective efforts of the government alone are not enough (Vaughan et al., 2001; Savan et al., 2003).

There is therefore a desperate need for community members and organizations to be involved in environmental monitoring activities. In fact, the United Nations Environmental Programme proclaims that citizen engagement is fundamental to sustainability (Au et al., 2000). Sharpe and Conrad (2006) indicate that citizen involvement is on a steady rise in response to the apparent gaps in monitoring activities. There is also an incredible potential for the inclusion of local knowledge into the environmental management structure. While keeping in mind the many challenges community groups face, this thesis will attempt to create a framework which can be easily adopted by concerned citizens and/or community groups.

Community-Based Monitoring (CBM) is extremely important as organizations attempt to monitor, manage, and/or restore local environments. Whitelaw et al., (2003) describes CBM as being “a process where concerned citizens, government agencies, industry academia, community groups and local institutions collaborate to monitor, track and respond to issues of common community concern” (p. 410). In many cases, community members/groups have taken on the burden of monitoring the local environment (traditionally done by the government) and have proven to be effective on many levels. Although community level environmental monitoring activities have been the focus of criticism from professional scientists and decision makers in recent years, it has been documented by many that “on the whole, water quality data gathered by community groups can be comparable to that gathered by professionals” ( Sharpe & Conrad, 2006 . p. 396.; Engel & Voshell, 2002; Fore et al., 2001).

At present, many watershed groups in Nova Scotia are monitoring a variety of aquatic environmental variables; however, due to the absence of peer-reviewed, scientifically robust water quality protocols and methodologies in the province, the data is not comparable in many cases (Sharpe & Conrad, 2006). Another problem faced by these groups is determining what variables should be monitored and how the collected data should be applied or used. Sharpe and Conrad (2006) suggest that it is therefore likely that many parameters currently being measured in the province are unwarranted (in terms of individual project intentions) creating a waste of limited resources and lost opportunity to pursue more important monitoring activities. The integration of Local Ecological Knowledge (LEK) into monitoring activities can help avoid such problems however LEC is also subject to criticism by decision makers and government authorities (Hazel et al., 2006).

It is important to note that there are several groups in the province who exist primarily to help community groups overcome many of the discussed problems or barriers that limit the success of community-based monitoring. For example, the Saint Mary's University Community-Based Environmental Monitoring Network (CBEMN) is a non-profit organization designed to provide community members with resources necessary to properly monitor and understand their local environment (CBEMN, 2006). The CBEMN provides interested members of the community with monitoring protocols, proper equipment, and information on how to access scientific and social scientific data related to the environment in an effort to promote community involvement and standardize data collection. Finally, the CBEMN encourages networking and information sharing between community groups promoting effective use of resources and avoiding the duplication of work. It is highly recommended that prior to community level monitoring, interested individuals contact an organization such as the CBEMN and take advantage of the opportunity; because it is likely to aid in the credibility of collected data and most importantly conserve resources.

This thesis does not attempt to propose solutions to all of the problems and challenges discussed above. It does, however, take these problems and challenges into account, and attempts to provide community members and stewardship groups with a set of methodologies and guidelines which can aid in prioritizing restoration initiatives and conducting primary aquatic habitat assessments. Because the goal is to provide the community with such methodologies and guidelines, it is important to integrate LEK into the framework as it often proves to save time, resources and energy. In fact LEK and both digital and hard copied mapped information are the first resources drawn upon to identify potential areas of suitable fish habitat for the purpose of prioritizing restoration initiatives in this thesis.

## 1.5 Ongoing Problems in the Environmental Monitoring Community

It is apparent that collective efforts to protect, conserve and restore aquatic habitats do not keep pace with the rate of decline (Hendry et al. 2003). Quite often, community members and stewardship groups spend substantial amounts of time and resources in an effort to become involved in management and/or decision making processes. Similarly, professionals and governmental organizations often use resources in an ineffective manner as they pay little attention to what has been monitored by the public (due to data credibility issues). Furthermore, it has been noted that there is a tendency for individual groups to pay little attention to what is being monitored and restored elsewhere (Bradshaw, 1996).

It is obvious that all levels of the environmental monitoring community must come together in a way which operates more efficiently. On the community level, networking must increase in order to promote information and resource sharing, avoid duplication of work, and develop standardized methodologies and protocols (Savan et al., 2003). On the professional level (assuming the above is achieved), CBM must be taken more seriously and incorporated into decision making processes. Bridging the gap between professional and community monitoring is a necessary step towards sustainability. If this can be achieved, all parties involved will inevitably benefit, and most importantly, combined efforts will more effectively monitor, manage and restore the environment.

## 1.6 Previous Studies

The literature suggests that many trout habitat assessments have been undertaken. Projects have been conducted internationally and locally, ranging from large to small in scale, using various techniques and monitoring a wide range of parameters. It is important to note that articles written by professionals are widely available, while community-based documents are much more difficult to access and are generally not submitted for peer-review. Two general categories become apparent when examining the literature on trout habitat assessments. First, there are papers written by professionals which require extensive resources and use complex statistical models. Secondly, there are studies conducted by stewardship groups which often have an unclear scope, questionable methods (due to lack of resources and proper equipment) and unclear conclusions. Most importantly, the literature demonstrates that there is no intermediate between the two extremes, and adoptable assessment/restoration models applicable to all levels of academia appear to be absent.

Many international studies exist and it becomes obvious that aquatic environments are suffering due to similar anthropogenic causes experienced here in Canada. Borsuk et al. (2006) have developed a comprehensive model which can be used in site-specific habitat assessments. This model developed in Switzerland takes into account many variables including, gravel bed conditions, water quality, disease rates, water temperature, stocking practices, and flood frequency. The statistical model (using a Bayesian probability network) is used to reproduce population patterns (Borsuk et al., 2006). The constructed model in this article does prove to be useful, as introductory monitoring data could be input and estimated population numbers would result. Although the model has proven to be useful in some circumstances, it could not be easily adopted by members of the public or stewardship groups. The model requires the measurement of many variables and its inflexible character proves to cater to only an academic audience. The statistics used are also very complex limiting the adoption of the model to only those familiar with Bayesian probability networks.

As discussed previously, this thesis will use Raleigh's (1982) suitability index models to characterize habitat. Unlike the model constructed by Borsuk et al. (2006), this model proves to be flexible and can be adopted by a much wider audience. Because individual parameters can be input and modeled, this index may have the potential to be utilized by community-based groups. For example, depending on available resources, community groups can input data from a specific parameter and obtain an index score. Therefore, groups will not feel pressured to monitor a large set of parameters, and the monitoring of the desired parameters is likely be conducted in a more comprehensive and complete manner. Furthermore, because of the flexibility of this model, groups can monitor and obtain specific habitat suitability index scores as resources become available, therefore decreasing the possibility of data fragmentation. Although this method proves useful to both community-based and professional monitoring, and also provides the opportunity to standardize results (promoting information sharing), it does not provide the user with a means of specific site selection. Although this is not necessarily the purpose of the document, a universal means of determining site selection would be beneficial.

Water quality monitoring in Nova Scotia appears to be a common practice although it becomes immediately obvious that the majority is undertaken by community groups. According to Sharpe & Conrad (2006), community watershed groups are monitoring more than 10 of the provinces watersheds and since the 1990’s, and have gathered more than 55 years of water quality data at over 200 monitoring sites. Therefore, the need for groups to network and share information once again becomes obvious although there seems to be little evidence of this occurring. A clear example of problems experienced by community monitoring can be seen in the paper entitled “Introductory and Advanced Habitat Survey of the Wooden’s River Watershed” written by Bower et al. (2000). This community-based report attempts to provide data that can be used as a starting point for future habitat and water quality monitoring. It also attempted to provide detailed monitoring instructions in an effort to standardize methodologies. Although the paper is well structured, uses techniques such as identifying monitoring sites based on topographic maps, and attempts to incorporate prior information pertaining to the watershed, the research was apparently abandoned. In fact, the document can be termed inconclusive because the appendices are missing and the conclusions section is scattered and incomplete. It is likely that the project was abandoned as resources became exhausted or the final report was not released to the public. Whatever the reasoning, this displays the ongoing problems experienced by the local monitoring community.

### 1.7 Summary and Thesis Objectives

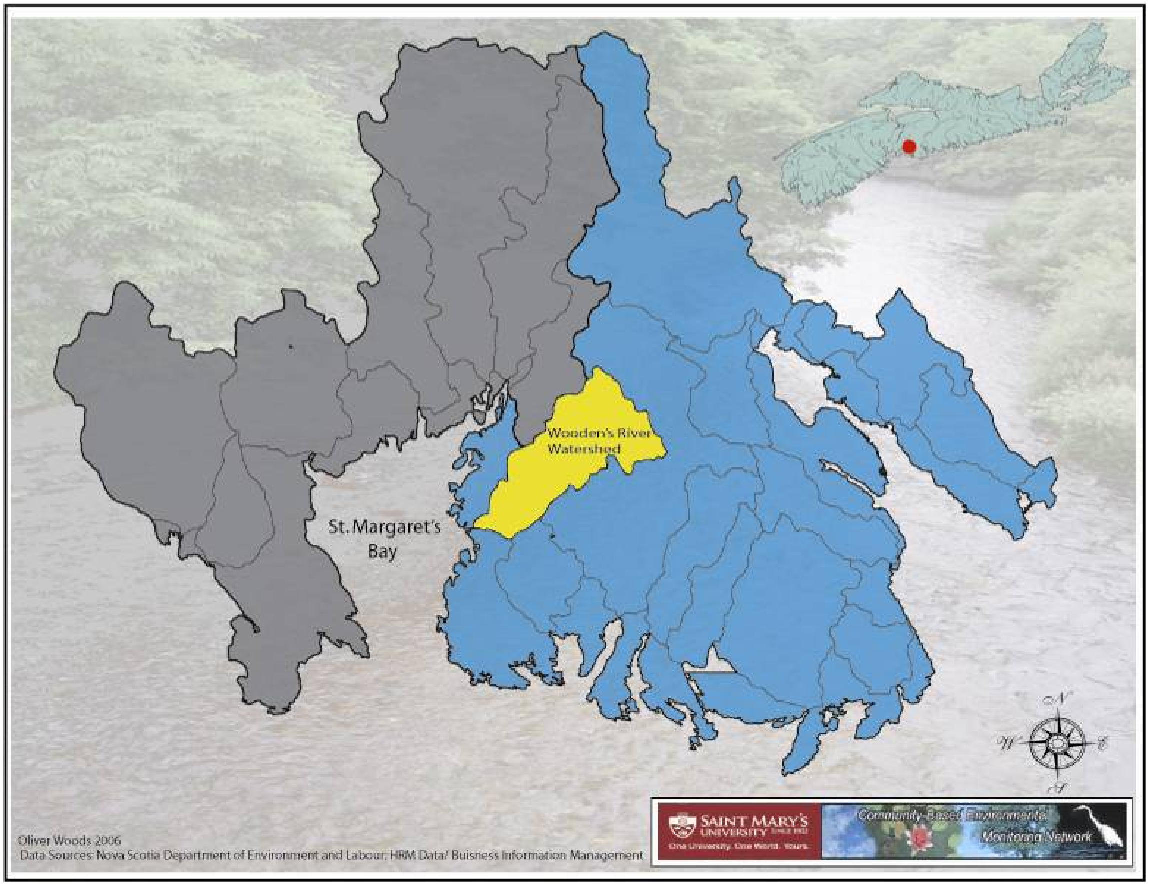
After examining the literature, many conclusions can be drawn. First and most important is the realization that there is no intermediate between monitoring techniques conducted by professionals and that of community-based groups. There exists a great need to overcome the separation between community-based and professional research and to achieve the standardization of water quality data collection. Secondly, there is a notable gap in the literature where LEK, mapping technologies, prior findings, and CBM are collectively incorporated into site selection, monitoring and restoration practices. This paper attempts to bridge this gap by developing an approach to watershed planning which uses CBM, LEC, modern mapping technologies, and fish habitat models to assess habitat quality and quantity, and identify sensitive areas requiring added protection and/or aquatic habitat restoration; therefore providing a significant contribution to the literature.

# Chapter 2

# STUDY AREA

## 2.1 Description of Study Area

The Wooden's River watershed encompasses an area of approximately 65 km$^2$ on the Chebucto Peninsula; 20 kilometers west of Halifax, Nova Scotia (De Gooyer, 1994). Drainage patterns in the watershed are similar to that of other Nova Scotia watersheds. The system is comprised of 19 connected lakes and drains into St. Margaret's Bay, just 20 kilometers south-west of the headwaters (Wooden's River Watershed Environmental Organization, 2006).



Oliver Woods 2006
Data Sources: Nova Scotia Department of Environment and Labour; HRM Data/ Buisness Information Management

**Figure 2.1. Geographic Location of the Wooden's River Watershed**

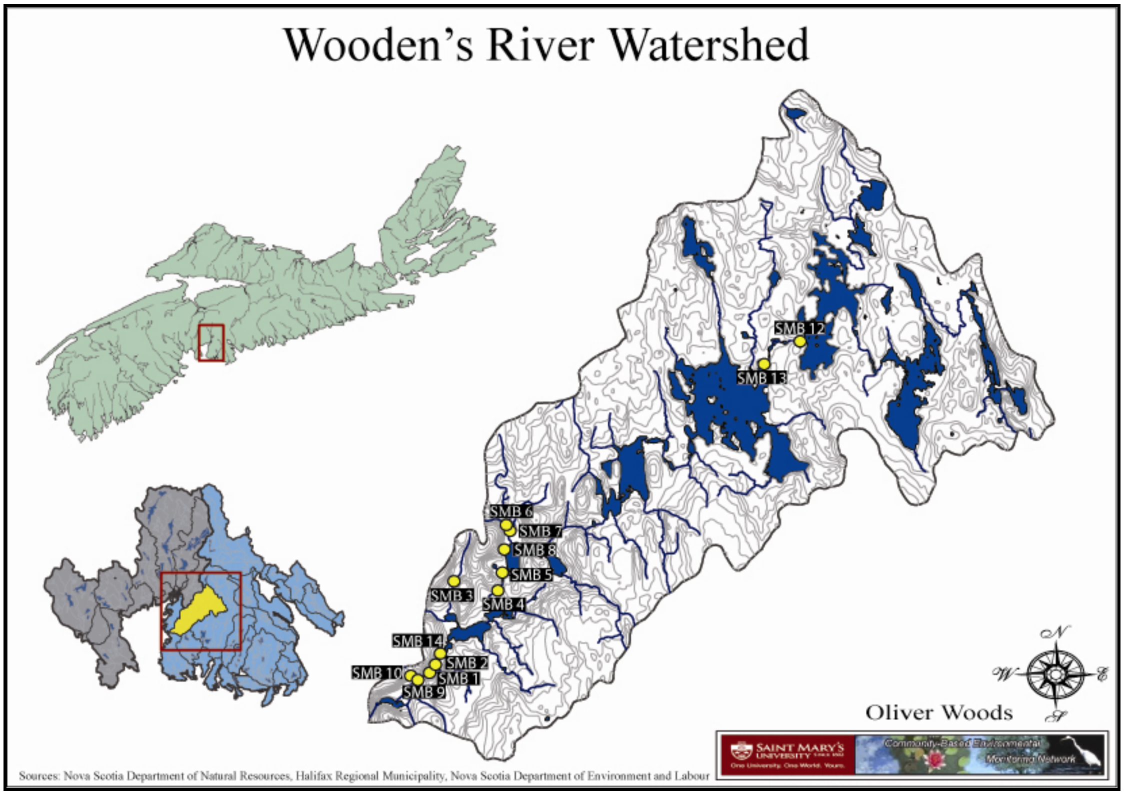


**Figure 2.2. Wooden's River Watershed with Monitoring Locations.**

Elevation profiles indicate that the gently rolling or undulating terrain has a maximum elevation of roughly 140 meters above sea level (Nova Scotia Topographic Database, 1997). The majority of the watershed is located between 60 and 90 meters above sea level and there are areas with abrupt changes in relief (Tough, 1993, Nova Scotia Topographic Database, 1997).

In the lower portion of the watershed, there are drumlins cored by Lawrencetown till (Stea & Fowler, 1980). It is anticipated that these glacial deposits will improve local water quality, as a result of their potential buffering capacity. Drumlins are hills of glacial deposits which have a distinctive elongated profile as a result of shaping by ice movement (Tough, 1993). They can often be identified on topographic maps (at appropriate scales) where contour lines form concentric ovals (Tough, 1993). These glacial deposits can be most easily identified through the use of geological maps however, ground truthing is often necessary to confirm their presence.

## 2.2 Bedrock Geology:

The entire system (or watershed) is underlain by granite (leucomonozogranite) bedrock, which is part of the South Mountain Batholith (Tough, 1993). “The South Mountain Batholith is located within the Meguma Terrane, a suspect terrane of the Appalachian Orogen” (MacDonald, 2001. p.3) According to MacDonald & Horne (1987), pre-granitic rocks in the Meguma Terrane include the Cambro-Ordovician Meguma Group and consist of metagreywacke of the Goldenville Formation and metapelite of the overlying Halifax Formation. The extensive granite intrusion running across southwestern Nova Scotia was emplaced roughly 400 million years ago in the Devonian period (Tough, 1993). For the most part, granite in the area exhibits characteristics common to such intrusions, however there are slight variations in color and crystal grain size. Granite is typically very hard and is resistant to chemical and physical erosion, due to its hardness and coarse grain size (Goodwin, 2007). Soils developed on granite are generally of poor quality and very bouldery. Due to its mineralogical composition, granite and soil derived from granite are characterized by their lack of buffering capacity (Tough, 1993; Goodwin, 2007).

## 2.3 Surficial Geology:

Most of the watershed is covered by till, which is glacial debris of bedrock that has been eroded, transported and deposited over the past 70, 000 years by glacial ice. For the most part, granite facies of the Beaver River Till formation covers the majority of the watershed (Stea & Fowler, 1980; Goodwin, 2007). Covering approximately 10 percent of the watershed, Lawrencetown till formation is the only other dominant surficial deposit (Stea & Fowler, 1980; Tough, 1993). This till unit is mostly clay and typically contains rock fragments of distal provenance (Stea & Fowler, 1980). It is assumed to have good buffering capacity because it is derived largely from Carboniferous sedimentary rocks including limestone and gypsum which are easily eroded. As a result, Lawrecetown deposits are hypothesized to greatly improve local water quality due to buffering capacities.

## 2.4 Surficial Hydrology:

The surficial and bedrock geology, combined with local topography, determine the surface hydrology of the watershed. It is believed that the main river in the system was once fault controlled and exhibited a more regular pattern however recent glaciations are said to have reorganized the formation (deepening stream valleys, and scouring the landscape) creating a more deranged pattern (Tough, 1993).

The watershed contains four sub-watershed systems (tertiary or third order) within the larger system, with a total drainage area of approximately 65 $km^2$ (Tough, 1993). The sub-system encompassing the largest area covers all of the land south of Big Hubley Lake as well as a small strip going north of Hubley to the west of Five Island Lake (Tough, 1993). There are three headwater systems, the largest of which drains an area of approximately 7 $km^2$ in the north-west. The remaining 2 are in the far north and north-west of the watershed draining areas of 6 and 4 $km^2$ respectively (Tough, 1993; Maritime Resource Management Service, 1980).

The waters in the system range from mild to strongly acidic depending on the physical location of the waterbody or stream relative to bogs, glacial deposits or development (Tough, 1993; Abraham, 2006; Scott et al. 2000). Bogs or wetlands are found throughout the watershed in low, poorly drained areas (often associated with streams or seasonal streams) and are generally characterized by low pH values because of their high organic content (Tough, 1993). Acid precipitation is known to affect the water quality in the area as is experienced throughout much of the province. Moreover, the low to non- existent buffering capacity of the underlying granite and granitic soils indirectly influences the water quality as acidic rain has no means of being neutralized (buffered).

### 2.5 Land use

Within the past 25 years significant development has occurred within and around the Wooden’s River watershed (Hope, 2006; Wooden’s River Watershed Environmental Organization, 2006). This increased development has occurred because of its desirable location, which has high perceived real estate values for both present and future development (Abraham, 2006). This increasing trend is especially apparent in the far

Northern and Southern portions of the watershed where the physical landscape caters better to development and desirable locations are more easily accessed by major road networks.

As will be discussed in subsequent sections, the Wooden’s system appears to have suffered in terms of water quality due to this increased development. Among one of the most threatening infrastructure developments in recent years is the twinning of highway 103 (Hope, F. 2006; St. Margaret’s Bay Stewardship Association 2006; Wooden’s River Watershed Environmental Organization, 2006). This project has become a central community focus, as it intercepts several secondary watersheds and has had significant impact on local fish habitat (St. Margaret’s Bay Stewardship Association 2006; Wooden’s River Watershed Environmental Organization, 2006). The twinning of the highway has been characterized as a significant threat specifically to the Wooden’s River watershed as it intercepts a major headwater, potentially threatening the entire system. Furthermore, this northwestern reach of the watershed is already an area experiencing negative impacts due to increased residential development and associated degradation.

As a whole, the watershed is extremely vulnerable to development because the “connectivity throughout the area increases the potential for impacts to affect not only water quality, but to directly affect the aquatic and terrestrial habitats that play a crucial role in the healthy functioning of the landscape” (Lovett, 1997).

## 2.6 Wooden's River Watershed Brook Trout *(Salvelinus fontinalis*)

The Woodens River watershed contains a well established native Brook trout population (Abraham, 2006; Rutherford, 2006, Law, 2007). At present, the watershed is designated as a hook and release 'Special Management' area for trout fishing, the only secondary watershed in the province holding this strict regulation (Abraham, 2006). This designation was implemented by the Inland Fisheries Division of the Department of Agriculture and Fisheries, due to PCB concerns in Five Island Lake (Law, 2007). Although these concerns have long been addressed, the fishing restrictions remain in place (Abraham, 2006; Law, 2007). This has become frustrating to many anglers who would like to see a reasonable bag limit reinstated. Officials maintain that the Brook trout population may now be vulnerable due to other factors, indicating 'further studies are needed' to determine habitat quality, quantity and species health before the reintroduction of a bag limit (Law, 2007).

The present debate on whether to reopen the watershed for recreational fishing is on-going and one which is by no means straight forward. Although the PCB concerns have been addressed, more recent factors such as increased development have placed stress on the watershed and the effects on trout population are not well documented at present.

## 2.7 Water Quality

The Wooden’s River watershed is unique in that community groups, citizens and governmental organizations have undertaken many water quality studies. Although the latter is more uncommon, water quality data goes back decades in some portions of the watershed. Currently there are a number of Non-Governmental Organizations (NGO’s) that have conducted, or are planning to conduct relevant water quality studies. Such organizations include: The Wooden’s River Watershed Environmental Organization, St. Margaret’s Bay Stewardship Association (SMBSA) and the Watershed Environmental Taskforce (WET) (Law, 2007).

Because citizen involvement in environmental monitoring has been the primary source behind the collection of water quality data, effectively determining the state or situation of the system has become difficult. As discussed in previous chapters, limited financial/material resources combined with few standardized monitoring protocols have lead to incomparable and inconsistent data. It also becomes apparent that with few exceptions, there exists a tendency for individual groups to pay little attention to what has been monitored and restored elsewhere.

Although the majority of the water quality data in the area is fragmented, incomparable, or simply incomplete, an overall impression of the water quality in the area can be drawn because of the vast amounts of data/studies that exist. It appears that on the whole, pH and temperature throughout the system are at levels nearing the upper most tolerance range for the species and therefore, prioritizing restoration initiatives becomes extremely important. Dissolved oxygen content appears to be generally suitable, with the exception of several lakes existing in the upper watershed which apparently have become increasingly anoxic over recent years.

The existing water quality data also indicates that on the whole, water quality improves at most locations moving down the system, indicating that increased development has taken a toll on the watershed. In an effort to confirm this possibility, 2 permanent monitoring locations were set up in the upper to mid portion of the watershed. A total of 6 permanent stations were chosen in the lower (or north-western) part of the watershed as water quality is expected to be more favorable to the species and the surficial geology is expected to improve local conditions.

## 2.8 Summary

The Wooden’s River watershed has been subject to significant development in recent years and community groups, concerned citizens and governmental organizations alike have responded by undertaking a broad range of water quality studies. It has become evident that there is a need to standardize monitoring protocols, promote information sharing and develop monitoring techniques that will reduce unnecessary spending and increase the effectiveness of monitoring.

The Wooden’s River watershed has a well established Brook trout population which may serve as an environmental indicator of a healthy system. However, it does appear that local degradation is and has been occurring rapidly. The next chapter will deal with the methodology for this thesis, highlighting the methods used to effectively prioritize restoration initiatives while reducing frequent problems experienced in the monitoring community.

# Chapter 3

# METHODOLOGY

## 3.1 Introduction

The purpose of this research was to provide a primary habitat assessment through the collection of baseline water quality data in the Wooden's River watershed. The identification of monitoring sights drew from numerous sources of information and was also largely influenced by local knowledge of the watershed. Through the collection of water quality data at the selected monitoring locations, restoration initiatives were effectively prioritized in a manner which could be easily adopted by others. This chapter will discuss all of the methods used, from the identification of the study area, to the analysis of the collected data.

## 3.2 Identification of Study Area and Monitoring Locations.

As described in Section 2.6, community groups, concerned citizens, and governmental organizations have undertaken a wide range of water quality studies in the Wooden's River Watershed. In an effort to conduct research which will contribute to a better understanding of the watershed and associated processes, a preliminary study was undertaken which involved the collection of existing literature and data sets relating to the watershed. This process not only helped to shape and define the study area for this research and avoid the duplication of work, it also lead to the early stages of a Wooden's River water quality data base.

Next, a series of topographical, geological, and watershed maps (**Appendix C**) were used to identify where previous studies had been undertaken (based on the preliminary watershed study), and to identify areas for potential research. Many factors were taken into account including: site accessibility, apparent gaps in monitoring activity, geological features, topography, local knowledge, and development.

A hard copy of the Nova Scotia Topographic Database Coastal Series map (**Appendix C**) was used to determine entrance points into the watershed, assess topography, and manually plot where other studies had been undertaken. Next, a Pleistocene Geology map (**Appendix C**) helped to identify potential Lawrencetown deposits in the watershed, as they were expected to benefit surrounding water quality. Finally, meetings were scheduled with Bob Rutherford, director of the Nova Scotia Adopt-a-Stream program and environmental consultant, Lawrence Abraham, Director of Trout Nova Scotia, and Terry Goodwin, Project Geochemist with the Department of Natural Resources. Collective efforts helped to narrow the study area to the lower portion of the watershed, an area characterized by favorable surficial geology (Lawrencetown deposits present), minimal development, and apparently an area which is less frequently monitored.

The watershed was visited for the first time on June 21st 2006. Lawrence Abraham and Bob Rutherford were present to assist in identifying locations where monitoring would be carried out, and equipment would be deployed. Their local knowledge of the area proved to be extremely beneficial, as they helped to identify suitable entrance points, navigate through the watershed, and point out areas where Brook trout are known to exist. On this day, 8 monitoring locations were identified (**Appendix A**; SMB Sites 1, 3, 4, 5, 6, 7, 8, 10) and data collection began by testing water quality with a YSI 556 MPS unit.

On July 20th, 2006, the watershed was visited for a second time by Terry Goodwin, Lawrence Abraham and this author. Terry Goodwin helped to ‘ground truth’ the existence of the potential Lawrencetown deposits present on the Pleistocene geology map. Although Terry proposed that the drumlins present were likely cored by Lawrencetown Till and draped with a thin veneer of Beaver River Till (granite facies), he indicated till analysis would be necessary to confirm this possibility. A total of 4 monitoring locations were identified on this day based largely on proximity to the potential deposits (**Figures 4.9, 4.10; Appendix A**; SMB Sites 2, 9, 12, 13). Once again water quality at these sites, as well as at those previously identified, was recorded with the YSI unit (**Appendix A**; SMB Sites 2, 9, 12, 13). A final monitoring site was determined on an August 1st, 2006 field trip, based solely on its proximity to glacial deposits (**Figures 4.9; Appendix A**, SMB Site 14).

The coordinates of the 13 monitoring sights discussed above were stored in a Garmin eTrex GPS unit and assigned a number (prefixed by SMB).

Following preliminary analysis of the water quality collected up to this point in the research, 8 locations were chosen to deploy data loggers which would collect temperature data for the remainder of the summer and into the fall months.

It is extremely important to emphasize that several of the monitoring sites (SMB 3, SMB 5, SMB 6, SMB 7, SMB 10, and SMB 14) are all located in tributaries of the Wooden’s River and were chosen based on their close proximity to Lawrencetown deposits. Although SMB 3, SMB 6, and SMB 7 were selected as areas for potential restoration, the remainder of the tributary sites were selected only to highlight the relationship between surficial geology and water quality. This becomes important when comparing the collected data and identifying spatial and temporal variations.

### 3.3 Equipment Used in Data Collection:

In an effort to collect valid and reliable water quality data, two types of equipment were chosen which included: Onset Hobo Data Loggers, and a YSI 556 Multi-probe System (MPS) unit. Most importantly, these data acquisition tools are among the most commonly used pieces of equipment in the environmental monitoring community, and are known to collect reliable and scientifically accurate data (assuming proper procedures are followed). The equipment used, therefore, is expected to produce baseline water quality data which is directly comparable to what has been monitored elsewhere in the province. Finally, to ensure monitoring sights were relocatable, a Garmin eTrex Legend Global Positioning Unit (GPS) was used to record location.

Onset HOBO data loggers used in this research are a 2 channel logger with 10 bit resolution capable of recording up to 28, 000 combined temperature and light readings. The logger is ‘launched’ through the use of a coupler and base station with USB interface, and recorded data is ‘read out’ and plotted with special computer software. A total of 8 data loggers were anchored to stream/river bottom in various locations throughout the watershed. The loggers remained in the field from August 11th, 2006 through October 10th, 2006 recording water temperature readings on 15 minute intervals. All loggers were launched in the CBEMN office for calibration, and underwent several tests prior to deployment. Determination of specific locations within the watershed was based several factors discussed in Section 3.2.

The YSI 556 MPS is a universally used and trusted piece of water quality monitoring equipment which simultaneously displays pH, dissolved oxygen, temperature, conductivity, TDS, salinity, ORP, and barometric pressure. All parameters were recorded each time sites were visited (for future reference) however for reasons discussed in chapter 1, this thesis is only concerned with pH, dissolved oxygen content, and temperature. Parameters were recorded at each monitoring location on every visit to the watershed (**Appendix A**). The YSI was originally calibrated by staff at Hoskins Scientific however due to popular request and significant usage at the CBEMN, both pH and D.O. were re-calibrated prior to every field trip, therefore ensuring accurate and comparable data sets.

The Garmin eTrex Legend was the GPS unit used to relocate monitoring sites throughout the study period. It is a full featured GPS unit with sufficient accuracy and user friendly navigation. Individual monitoring location coordinates were stored in the GPS using the 1983 North American Datum (NAD 83) and a Universal Transverse Mercator (UTM) Zone 20 N map projection.

### 3.4 Brook Trout Habitat Model

As discussed in chapter 1, the model chosen to represent habitat suitability for the purpose of prioritizing restoration initiatives is entitled “Habitat Suitability Index Models: Brook Trout” compiled by Raleigh, (1982). The model is adaptable, comprehensive, applicable to all levels of academia, and encompasses the entire geographical range of the species.  The fact that the model is extremely adaptable, allowed the three water quality parameters being studied in this thesis to be analyzed separately, then directly compared through assigned suitability index (SI) scores. This section will discuss the methods used to assign SI scores to the pH, temperature, and dissolved oxygen values recorded throughout the study period.

Raleigh, (1982), compiled literature concerning the specific habitat requirements and preferences of Brook trout, synthesized these requirements into Habitat Suitability Index (HSI) models and then scaled them to produce an suitability index score between 0 (unsuitable habitat) and 1 (optimal habitat). This research assumed that the specific habitat requirements set forth by Raleigh (1982), are representative of the requirements and preferences experienced by trout populations in Nova Scotia, and therefore the associated models can be directly adopted. This thesis is only concerned with 3 water quality parameters, and therefore three suitability graphs were produced acting as a mechanism to generate SI scores (**Appendix B**).

The temperature suitability graph represents the most important parameter recorded in this research, and was the graph used to determine SI scores for both the data collected by the data loggers and the YSI unit. Temperature is the single most limiting factor in terms of Brook trout productivity and survival, as it alone will determine presence or absence of the species in a given area. Temperature values collected by the data loggers were downloaded by special computer software then exported to Microsoft excel and plotted. The data recorded by the loggers is summarized in **Table 4.1**. Finally, monthly mean temperatures were calculated by using the filter function in excel, and then assigned SI scores (**Table 4.2**) as determined by the temperature suitability graph (**Appendix B**). Temperature data recorded by the YSI unit was organized in table format (**Appendix A**; SMB Sites 1-10, 12-14) and all readings taken throughout the study period were assigned a SI score.

Dissolved Oxygen content was the second parameter used to determine habitat suitability in this research. Due to fluctuations in D.O. saturation levels which are directly influenced by temperature, 2 suitability index curves were created on the same graph **(Appendix B**). Therefore, when SI scores were assigned, the D.O. / temperature relationship (discussed in chapter 1) was taken into account and SI scores are directly comparable. All D.O. values recorded during the study period were organized in table format (**Appendix A**; SMB Sites 1-10, 12-14) and assigned a S.I. score.

The final parameter chosen to determine habitat suitability and aid in prioritizing restoration was pH. A pH suitability graph was created based on findings compiled by

Raleigh (1982), and used to determine habitat suitability. SI scores were assigned to all pH readings recorded by the YSI and organized in table format (**Appendix A**; SMB Sites 1-10, 12-14).

Upon assigning all values an associated SI score, it is possible to make direct comparisons between water quality parameters. Because the SI scores represent a universal meaning, it is possible to effectively draw conclusions and identify trends.

## 3.5 Summary

The methods used in this research were designed to create a framework, or guide, which could be directly adopted by members of the community wishing to conduct primary habitat assessments and/prioritize restoration initiatives. Integrating local knowledge and drawing information from an array of sources prior to water quality testing has proven to effectively narrow the study area, focus the research, identify areas with apparent monitoring gaps, and save significant financial resources. Therefore, community-groups choosing to adopt some or all of the discussed methods will inevitably benefit, and most importantly, resources will be utilized in an efficient manner. The following chapters will discuss the results and associated conclusions which have been drawn.

# Chapter 4

# ANALYSIS AND RESULTS

## 4.1 Water Quality Results

The methods used to identify monitoring locations and collect water quality data in the Wooden's River watershed were described in the previous chapter. This chapter describes the results of the data collected over the study period highlighting the spatial and temporal variations of the physical parameters.

As described in chapter 3, field measurements including pH, dissolved oxygen (D.O.), and temperature were manually collected at 13 locations using an YSI 556 MPS unit, and water temperature data was collected at 8 of these monitoring locations using Onset Hobo data loggers. In an effort to avoid confusion and maintain consistency, the results of data collected by the Onset Hobo data loggers and the YSI 556 MPS will be discussed as separate data sets initially, and will be analyzed as a whole in later sections. Water temperature data collected by the YSI unit will be discussed only briefly focusing primarily on maximum summer temperatures.

## 4.2 Onset Temperature

Depending on time of deployment, each Onset Hobo data logger recorded between 5, 841 and 5, 859 temperature readings. Temperature data from all 8 permanent monitoring locations has been categorized into 3 groups including optimal, suitable, and poor/limiting conditions (**Table 4.1**) as determined by the literature. Optimal summer conditions represent temperatures between 11 and 16 $^{o}$C (or < 11 $^{o}$C caused by seasonal variation), suitable conditions are characterized by temperatures ranging between 16 and 20 $^{o}$C, and poor/limiting conditions are experienced at temperatures $\geq$ 20 $^{o}$C. Finally, although not included in **Table 4.1**, a fourth category has been included in the temperature graphs representing unsuitable temperatures ($\geq$ 24 $^{o}$C). The data loggers did not record any temperatures exceeding 24 $^{o}$C, however this category has been included to help visually inform the reader just how close maximum summer temperatures exist to the lethal range. Furthermore, as will become apparent in the next section, temperature readings taken by the YSI unit do exist in this range at several locations.

It is important to note that temperatures $< 11$ $^{o}$C were included in the optimal range category based on the idea that in these instances, low temperatures were a result of seasonal variation and do not pose a threat to the species but just represent the end of the growing season and a transition to over-wintering conditions. For example, temperatures began to exist below 11 $^{o}$C for significant amounts of time only in late September and October, at which point the species will begin to occupy areas of lower temperature. Specifically, at this time trout will begin to seek preferred water temperatures around 9 $^{o}$C or the warmest they can find below 9 $^{o}$C for winter habitat.

The results of the temperature data collected by the Onset Hobo data loggers indicate significant variation between monitoring locations on both temporal and spatial scales. Maximum temperature ranged from 15.86 $^{o}$C on August 22nd, 2006 at SMB 6 to 23.85 $^{o}$C on August 17th, 2006 at SMB 4 (**Table 4.1; Figure 2.2**). Minimum temperature ranged from 6.57 $^{o}$C on October 8th, 2006 at SMB 7 to 13.46 $^{o}$C on October 8th, 2006 at SMB 12 (**Table 4.1; Figure 2.2**).

Monitoring locations SMB 3, SMB 6, and SMB 7 (**Figure 2.2**) stand out significantly, with temperature readings during the study period falling within the optimum range 97.2%, 100%, and 95.5% respectively (**Figures 4.1, 4.2, 4.3; Table 4.1**). August mean temperatures at these locations were 14.23 $^{o}$C, 13.29 $^{o}$C, and 14.09 $^{o}$C respectively; all receiving suitability index scores of 1.0 which were maintained throughout the study period (**Table 4.2**). These three locations are similar in that they are not located within the main Wooden's River system; instead they are small tributaries feeding into the larger system.

| | SMB 1 | SMB 3 | SMB 4 | SMB 6 | SMB 7 | SMB 9 | SMB 12 | SMB 13 |
|---|---|---|---|---|---|---|---|---|
| **Total events logged** | 5,855 | 5,856 | 5,849 | 5,841 | 5,856 | 5,856 | 5,859 | 5,856 |
| **Occurrences in optimal range.** | 1,027 | 5,689 | 898 | 5,841 | 5,595 | 1,087 | 949 | 2,008 |
| **Percentage** | 17.5% | 97.2% | 15.3% | 100.0% | 95.5% | 18.6% | 16.2% | 34.3% |
| **Occurrences in suitable range.** | 2,782 | 167 | 3,111 | 0 | 261 | 2,806 | 3,014 | 2,830 |
| **Percentage** | 47.5% | 2.8% | 53.2% | 0.0% | 4.5% | 47.9% | 51.4% | 48.3% |
| **Occurrences in poor/limiting range** | 2,046 | 0 | 1,844 | 0 | 0 | 1,963 | 1,896 | 1,018 |
| **Percentage** | 35.0% | 0.0% | 31.5% | 0.0% | 0.0% | 33.5% | 32.4% | 17.4% |
| **Maximum temperature $^{o}$C** | 23.39 $^{o}$C<br>(Aug.17th ) | 17.57 $^{o}$C<br>(Aug.22nd) | 23.85 $^{o}$C<br>(Aug.17th ) | 15.86 $^{o}$C<br>(Aug.22nd) | 17.09 $^{o}$C<br>(Aug.22nd) | 23.48 $^{o}$C<br>(Aug.17th ) | 22.81 $^{o}$C<br>(Aug.18th) | 23.1 $^{o}$C<br>(Aug.18th) |
| **Minimum temperature $^{o}$C** | 12.01 $^{o}$C<br>(Oct. 8th) | 6.76 $^{o}$C<br>(Oct. 8th) | 13.59 $^{o}$C<br>(Oct. 8th) | 6.76 $^{o}$C<br>(Oct. 8th) | 6.57 $^{o}$C<br>(Oct. 8th) | 11.92 $^{o}$C<br>(Oct. 8th) | 13.46 $^{o}$C<br>(Oct. 8th) | 10.26 $^{o}$C<br>(Oct. 8th) |

**Table 4.1. Onset Data Logger Summary Table**

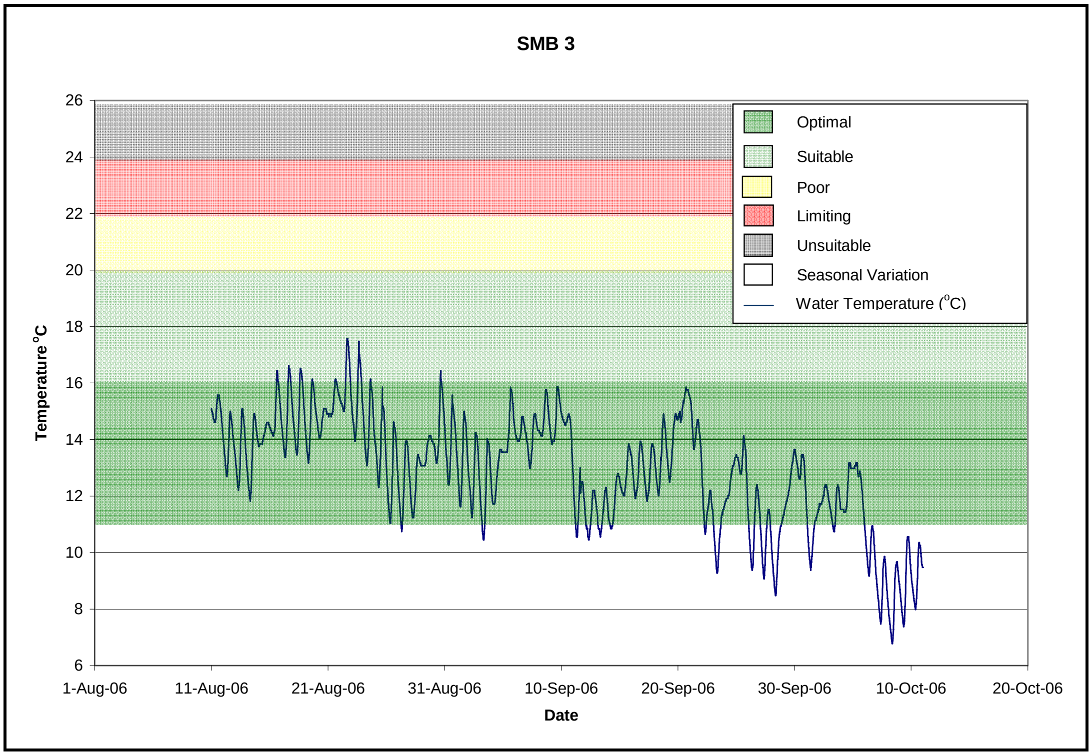


**Figure 4.1. Temperature Profile at SMB 3, August 11th, 2006 – October 10th, 2006**

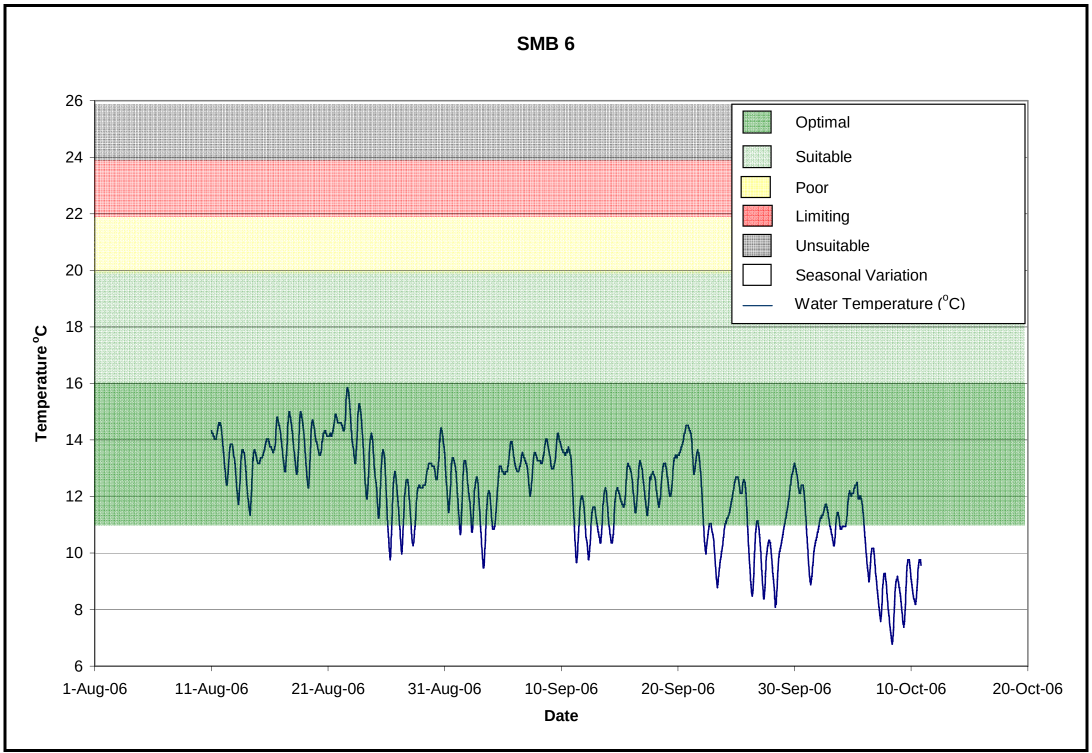


**Figure 4.2. Temperature Profile at SMB 6, August 11th, 2006 – October 10th, 2006**

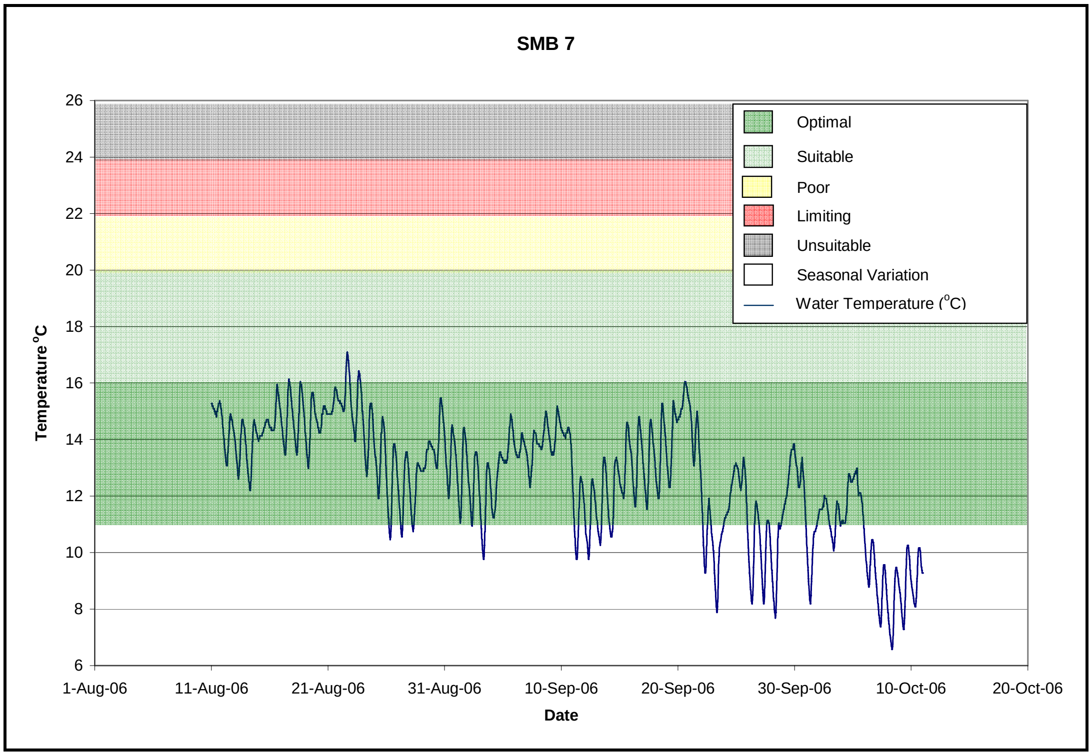


**Figure 4.3. Temperature Profile at SMB 7, August 11$^{th}$, 2006 – October 10$^{th}$, 2006**

Monitoring locations SMB 1, SMB 4, SMB 9, and SMB 12 (**Figure 2.2**) experienced temperatures falling within the suitable range 50% (+/- 4%) of the study period (**Table 4.1**). These locations experienced significant amounts of time (32% +/- 3%) in the poor/limiting category and only experienced temperatures in the optimal range between 15.3 % (SMB 4) and 18.6 % (SMB 9) of the study period. (**Figures 4.4, 4.5, 4.6, 4.7; Table 4.1**). August mean temperature for all 4 locations was 20.82 $^{o}$C (+/- 0.01 $^{o}$C) all with a generated suitability index score of 0.55 (**Table 4.2**). September mean temperatures for these locations were calculated to be 18.31 $^{o}$C, 18.26 $^{o}$C, 18.23 $^{o}$C, and 18.36 $^{o}$C respectively, all receiving a suitability index score of 0.84 (**Table 4.2**). Similar to locations SMB 3, SMB 6, and SMB 7, all suitability index scores were a perfect 1.0 in terms of October mean temperature (**Table 4.2**).

|  | Aug. Mean | S.I. Score | Sept. Mean | S.I. score | Oct. Mean | S.I. Score |
|---|---|---|---|---|---|---|
| **SMB 1** | 20.83 | 0.55 | 18.31 | 0.84 | 14.64 | 1.00 |
| **SMB 3** | 14.23 | 1.00 | 12.80 | 1.00 | 10.40 | 1.00 |
| **SMB 4** | 20.82 | 0.55 | 18.26 | 0.84 | 15.12 | 1.00 |
| **SMB 6** | 13.29 | 1.00 | 11.98 | 1.00 | 9.97 | 1.00 |
| **SMB 7** | 14.09 | 1.00 | 12.53 | 1.00 | 10.06 | 1.00 |
| **SMB 9** | 20.83 | 0.55 | 18.23 | 0.84 | 14.55 | 1.00 |
| **SMB 12** | 20.81 | 0.55 | 18.36 | 0.84 | 15.14 | 1.00 |
| **SMB 13** | 19.78 | 0.68 | 16.47 | 0.97 | 12.83 | 1.00 |

**Table 4.2. Monthly Mean Temperature (Onset data loggers)**

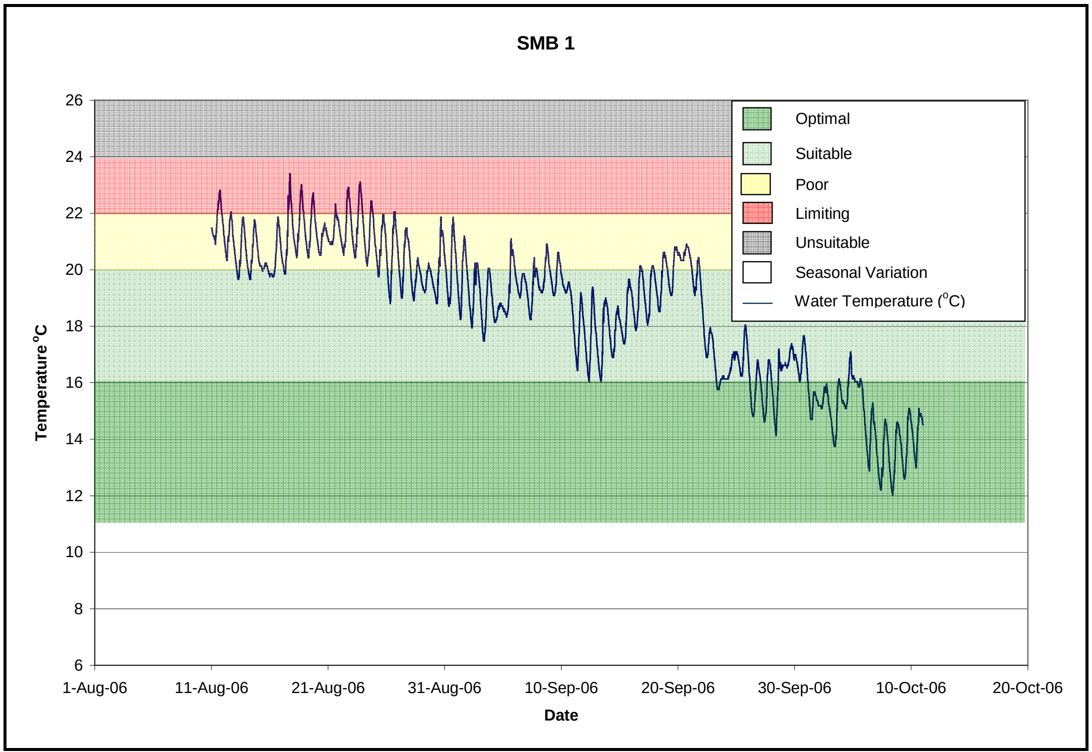


Figure 4.4. Temperature Profile at SMB 1, August 11th, 2006 – October 10th, 2006

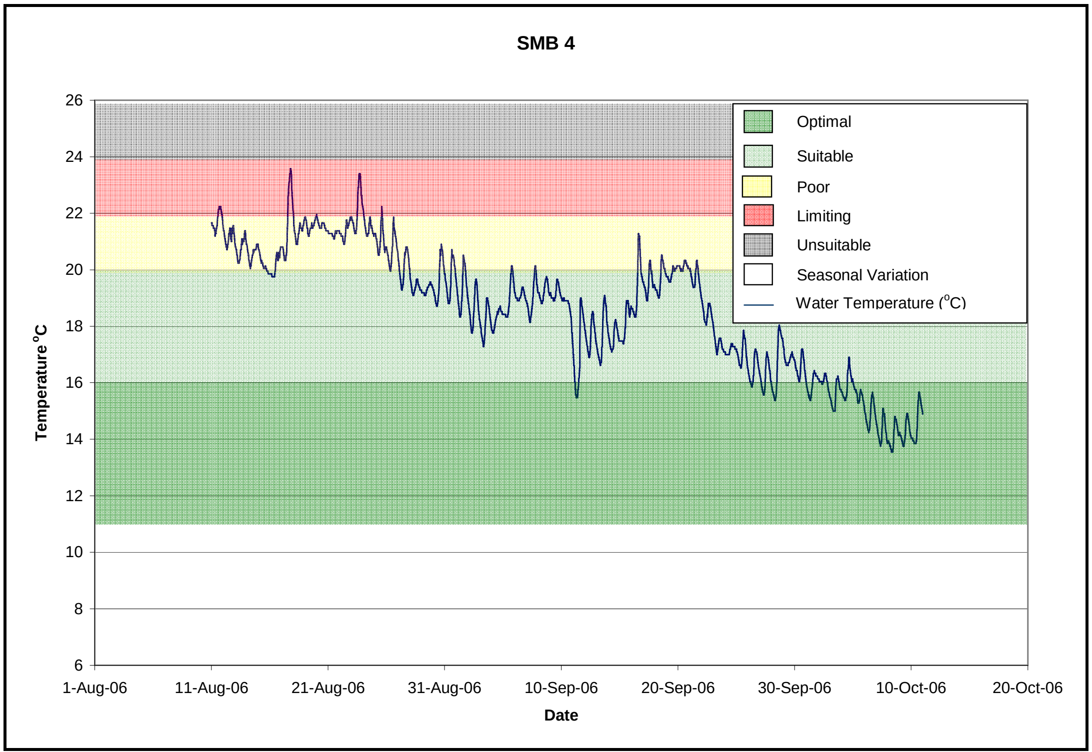


**Figure 4.5. Temperature Profile at SMB 4, August 11th, 2006 – October 10th, 2006**

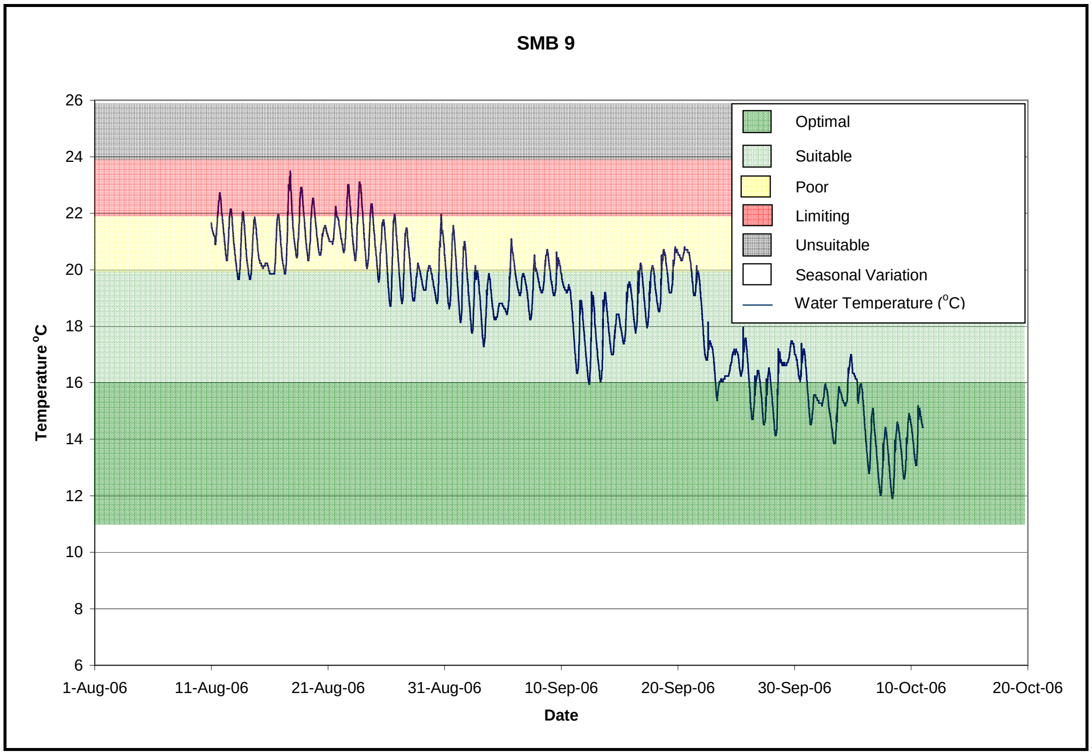


**Figure 4.6. Temperature Profile at SMB 9, August 11th, 2006 – October 10th, 2006**

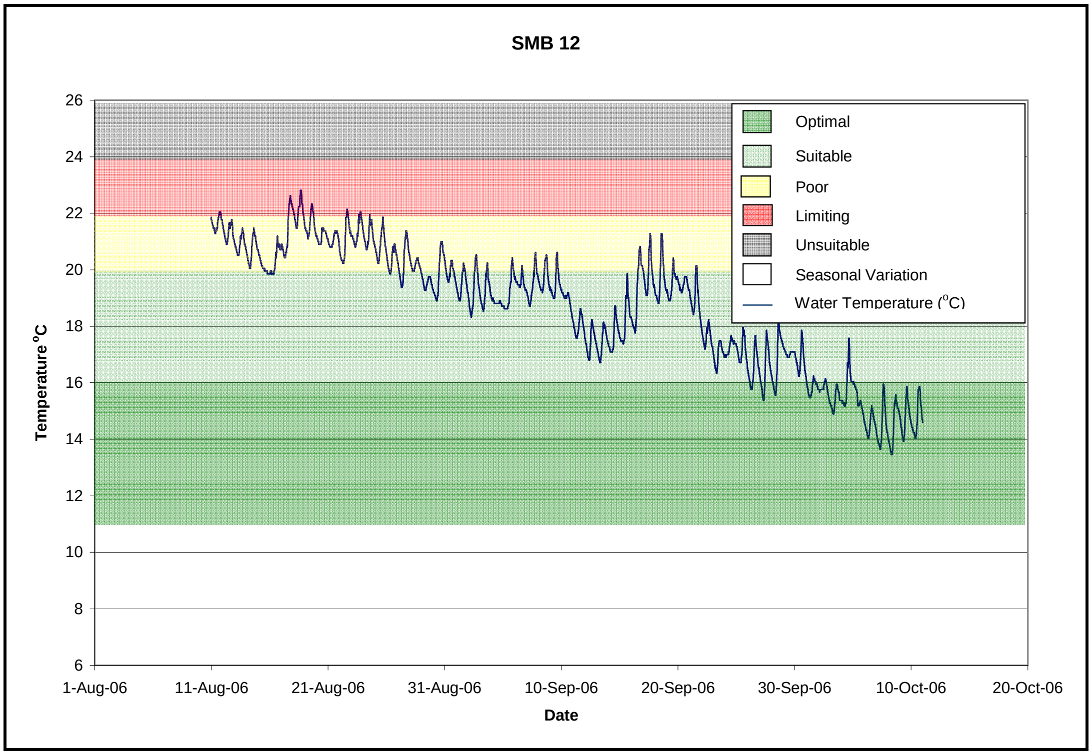


**Figure 4.7. Temperature Profile at SMB 12, August 11th, 2006 – October 10th, 2006**

Monitoring Location SMB 13 (**Figure 2.2**) is unique in that temperature data collected falls in between the 2 trends identified above. Although it's maximum summer temperature of 23.1 °C (**Table 4.1**) is comparable to that of locations SMB 1, SMB 4, SMB 9, and SMB 12, temperatures at this location decrease more rapidly, and therefore fall within the poor/limiting category 17.4% of the study period. Temperatures fall within the suitable range 48.3% of the time and exist in the optimum range 34.3 % of the study period. (**Table 4.1, Figure 4.8**). August mean temperature at this location has been calculated to be 19.78 °C receiving a suitability index score of 0.68 (**Table 4.2**). September mean temperature at SMB 13 was recorded as being 16.47 °C with a suitability index score of 0.97, and similar to all other monitoring locations, October mean temperature falls within the optimal range receiving a perfect suitability index score (**Table 4.2**).

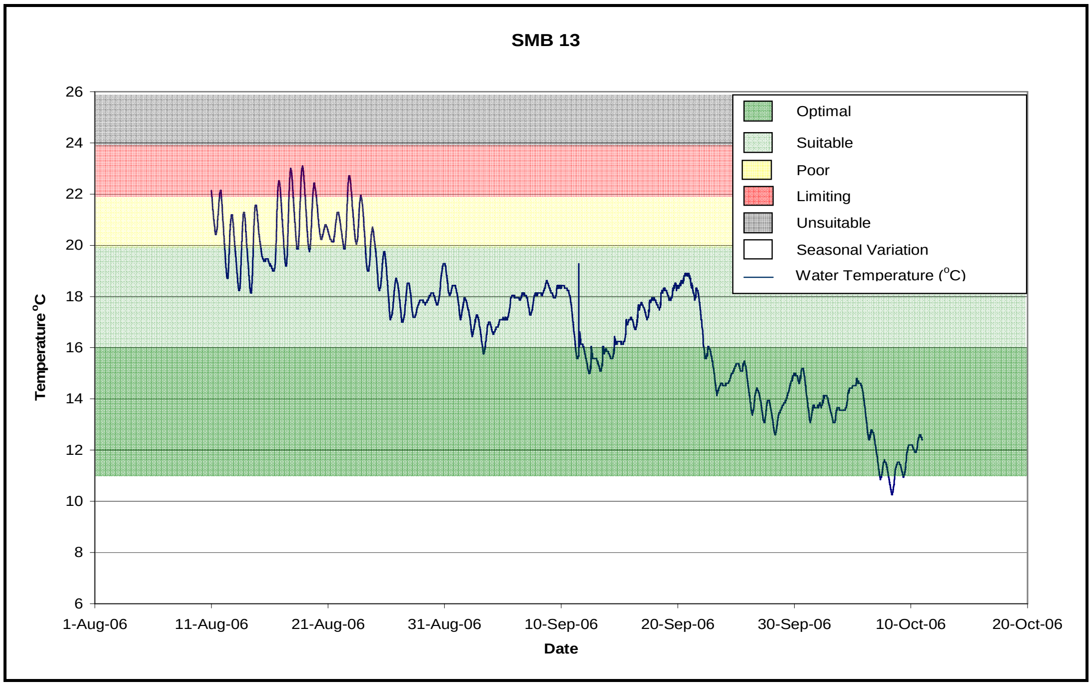


**Figure 4.8. Temperature Profile at SMB 13, August 11th, 2006 – October 10th, 2006**

It is important to note that throughout the entire study period, none of the monitoring locations experienced temperatures in the unsuitable range (≥24 °C). However, it is important to emphasize that (1) Onset data loggers were deployed in the field on August 11th, 2006 and may have missed absolute maximum summer temperatures (as will become apparent in the following section), and (2) as indicated previously, trout populations are more subject to disease where temperatures exceed 20 ° C for prolonged periods of time, as experienced in locations SMB 1, SMB 4, SMB 9, SMB 12, and SMB 13 (**Figures 4.4 4.5, 4.6, 4.7, and 4.8**).

### 4.3 YSI Temperature

As described in the previous chapter, temperature, dissolved oxygen, and pH readings were taken and recorded at 13 locations using a calibrated YSI 556 MPS each time the study area was visited. It is important to take this into account because the time frame differs from the previous section, and the intervals between data collection is seemingly incomparable. Therefore, this section will briefly discuss YSI temperature readings from all 13 monitoring locations and will focus primarily on maximum summer temperature.

The YSI 556 MPS identified 3 monitoring locations with a maximum summer temperature $\geq$ 24.0 $^{o}$C, and therefore falling within the unsuitable range receiving a suitability index score of 0.0. A maximum summer temperature of 24.3 $^{o}$C was recorded on July 20th, 2006 at SMB 1 (**Figure 2.2; Appendix A** Site 1), and on August 1st, 2006 temperature remained over 24.0 $^{o}$C (**Appendix A**, Site 1). SMB 2 (**Figure 2.2**) had a maximum summer temperature of 24.08 $^{o}$C on July 20th, 2006 (**Appendix A**, Site 2). A temperature of 24.92 $^{o}$C was recorded on July 20th, 2006 (**Appendix A**, Site 8) at SMB 8 (**Figure 2.2**), and the maximum summer temperature was recorded as being 27.13 $^{o}$C on

August 1st, 2006 (**Appendix A**, Site 8) (highest value recorded at any of the monitoring locations).

Temperature readings taken at SMB 14 (**Figure 2.2**) all fell within the optimal range therefore receiving suitability index scores of 1.0 (**Appendix A**, Site 14). Water temperatures at SMB 5 (**Figure 2.2**) ranged from 14.85 °C on September 11th, 2006 to 21.20 °C on August 1st, 2006 generating suitability index scores of 1.0 and 0.5 respectively (**Appendix A**, Site 5). SMB 10 (**Figure 2.2**) water temperatures ranged from 13.7 °C June 21st, 2006 to 22.36 °C on August 1st, 2006 receiving suitability index scores of 1.0 and 0.32 respectively (**Appendix A**, Site 10).

With the exception of the observations discussed above, the results of the YSI temperature component of the study are comparable to those recorded by the Onset data loggers. Readings taken in June, July, and early August 2006, indicate that in some cases maximum summer temperature may have occurred prior to deployment of the Onset Hobo data loggers. However, in these instances, variations appear to be insignificant.

### 4.4 pH

The results of the pH data collected by the YSI 556 MPS unit indicate significant temporal and spatial variation between monitoring locations. Although temporal trends are not as clear due to processes operating outside the scope of this research, there is an evident relationship between pH and the presence of drumlins cored by Lawrencetown till in the area.

Recorded pH values ranged from a low of 3.85 at SMB 7 on August 10th, 2006 (**Table 4.3, Figure 2.2, Appendix A**, Site 7) to a high of 6.86 at SMB 14 on August 21st, 2006 (**Table 4.3, Figure 2.2, Appendix A**, Site 13). Mean pH between monitoring locations ranged from 4.48 at SMB 7 to 6.26 at SMB 14 (**Table 4.3**).

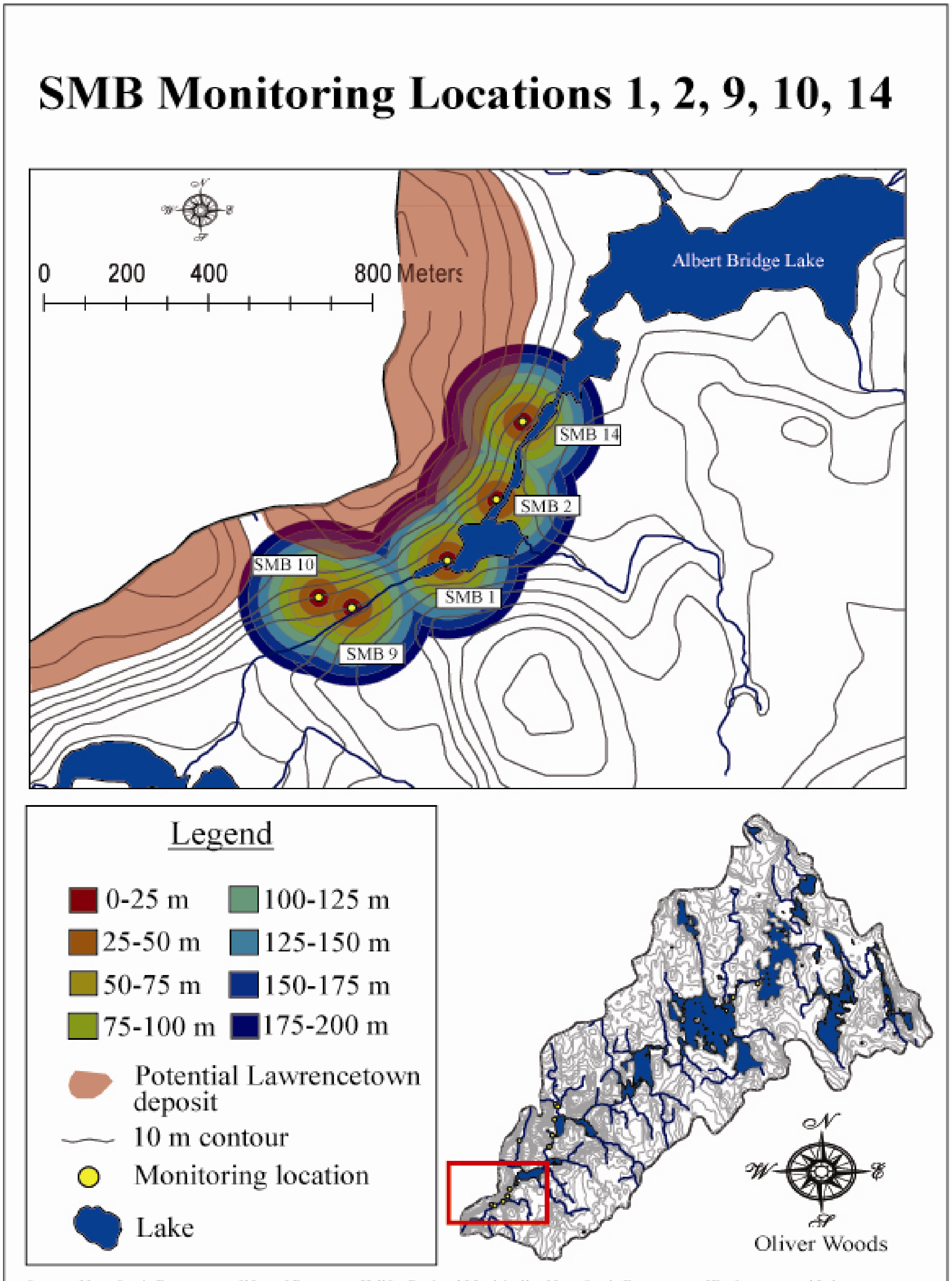
| | **Mean pH** | **S.I. Score** | **Range** |
|---|---|---|---|
| **SMB 1** | 4.96 | 0.41 | 4.62-5.29 |
| **SMB 2** | 4.95 | 0.41 | 4.68-5.22 |
| **SMB 3** | 5.48 | 0.62 | 5.15-5.82 |
| **SMB 4** | 4.97 | 0.41 | 4.62-5.25 |
| **SMB 5** | 4.92 | 0.40 | 4.67-5.14 |
| **SMB 6** | 5.46 | 0.62 | 4.78-6.52 |
| **SMB 7** | 4.48 | 0.19 | 3.85-5.37 |
| **SMB 8** | 5.12 | 0.47 | 4.79-5.72 |
| **SMB 9** | 4.76 | 0.31 | 4.35-5.24 |
| **SMB 10** | 6.13 | 0.83 | 5.84-6.51 |
| **SMB 12** | 5.52 | 0.63 | 4.86- 5.83 |
| **SMB 13** | 5.18 | 0.50 | 4.82-5.67 |
| **SMB 14** | 6.26 | 0.88 | 5.70-6.86 |

**Table 4.3. Summarized pH Data (YSI)**

Monitoring sites SMB 14 and SMB 10 (**Figure 4.9**) have mean pH values of 6.26 and 6.13 respectively, representing most suitable values in the study area (**Table 4.3**). Suitability index scores were calculated to be 0.88 for SMB 14 and 0.83 for SMB 10 (**Table 4.3**). As indicated in chapter 3, these sites were not chosen as areas for potential restoration, instead they were included to identify the potential relationship between pH and proximity to Lawrencetown deposits. SMB 3 and SMB 6 (**Figure 4.10**) had mean pH values of 5.48 and 5.46 respectively, both receiving suitability index scores of 0.62 (**Table 4.3**). Similar to locations SMB 10 and SMB 14, these sites were included to identify possible relationships between pH and proximity to Lawrencetown deposits; however they can also be included as potential restoration sites due to their location in small tributaries (**Appendix A**).

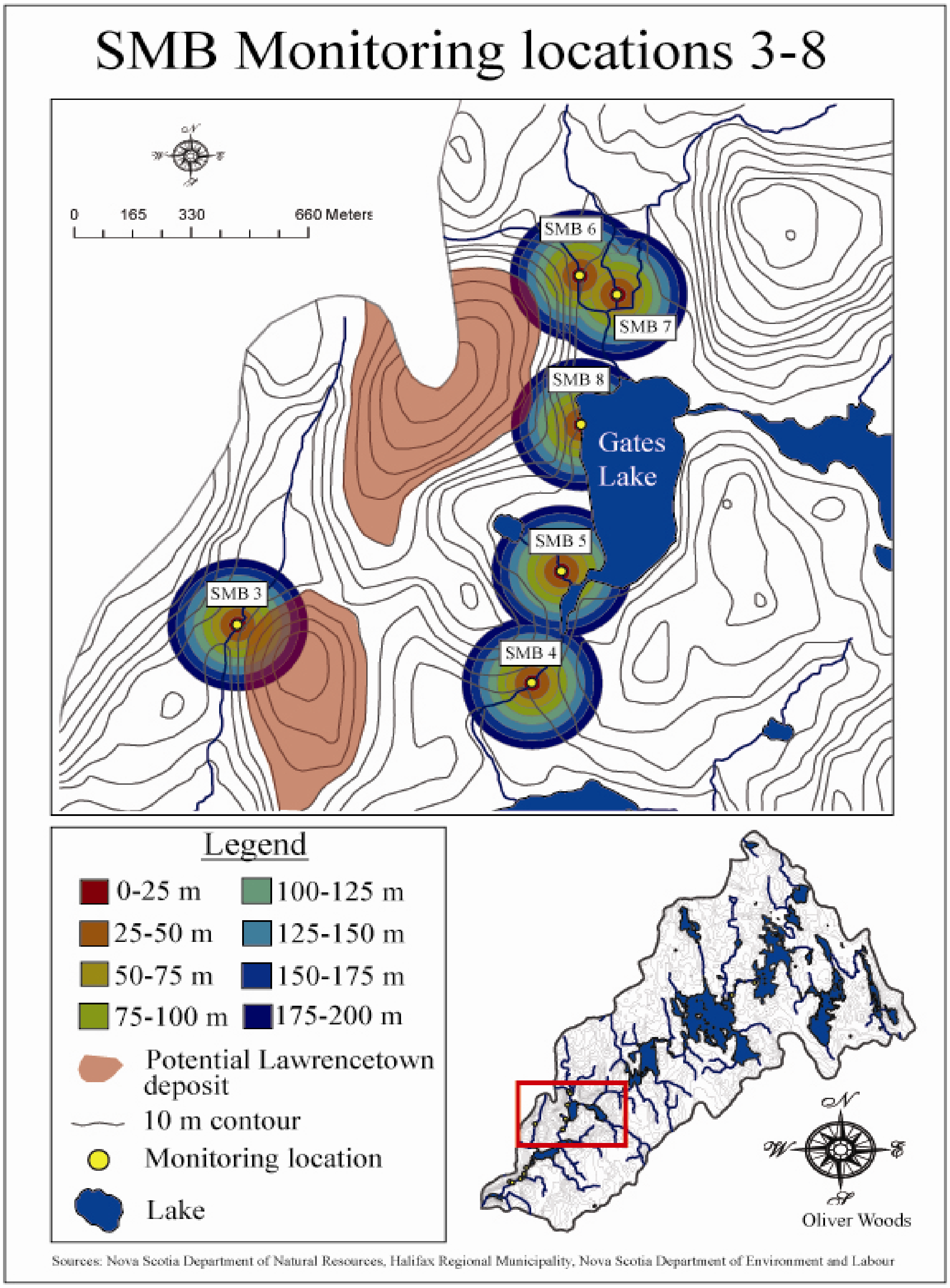
Although not located close to Lawrencetown deposits, and existing in the upper watershed often characterized by less favorable water quality, SMB 12 and SMB 13 (**Figure 4.11**) were found to have mean pH values of 5.52 and 5.18 (**Table 4.3**). A suitability index score of 0.63 was generated for SMB 12 (**Table 4.3**) while SMB 13 received an index score of 0.5 (**Table 4.3**). The mean pH values at these locations are unique because both locations exist within the main system and have pH values which are more favorable compared to other locations with common attributes, therefore not following the overall observed trend (discussed in chapter 5).

SMB 8 (**Figure 4.10**), located in Gates Lake, experienced a mean pH of 5.12 (**Table 4.3**) receiving a suitability index score of 0.47. SMB 5 (**Figure 4.10**) had a mean pH value of 4.92 and a corresponding index score of 0.40 (**Table 4.3**). Although this site is located in a small tributary and is in close proximity to drumlins cored by Lawrencetown till, the pH value is lower than could be expected. This may be influenced by the nearby peat bog located just upstream. It is important to note that all locations discussed above (with the exception of SMB 12 and SMB 13), are not located on the Wooden's River.



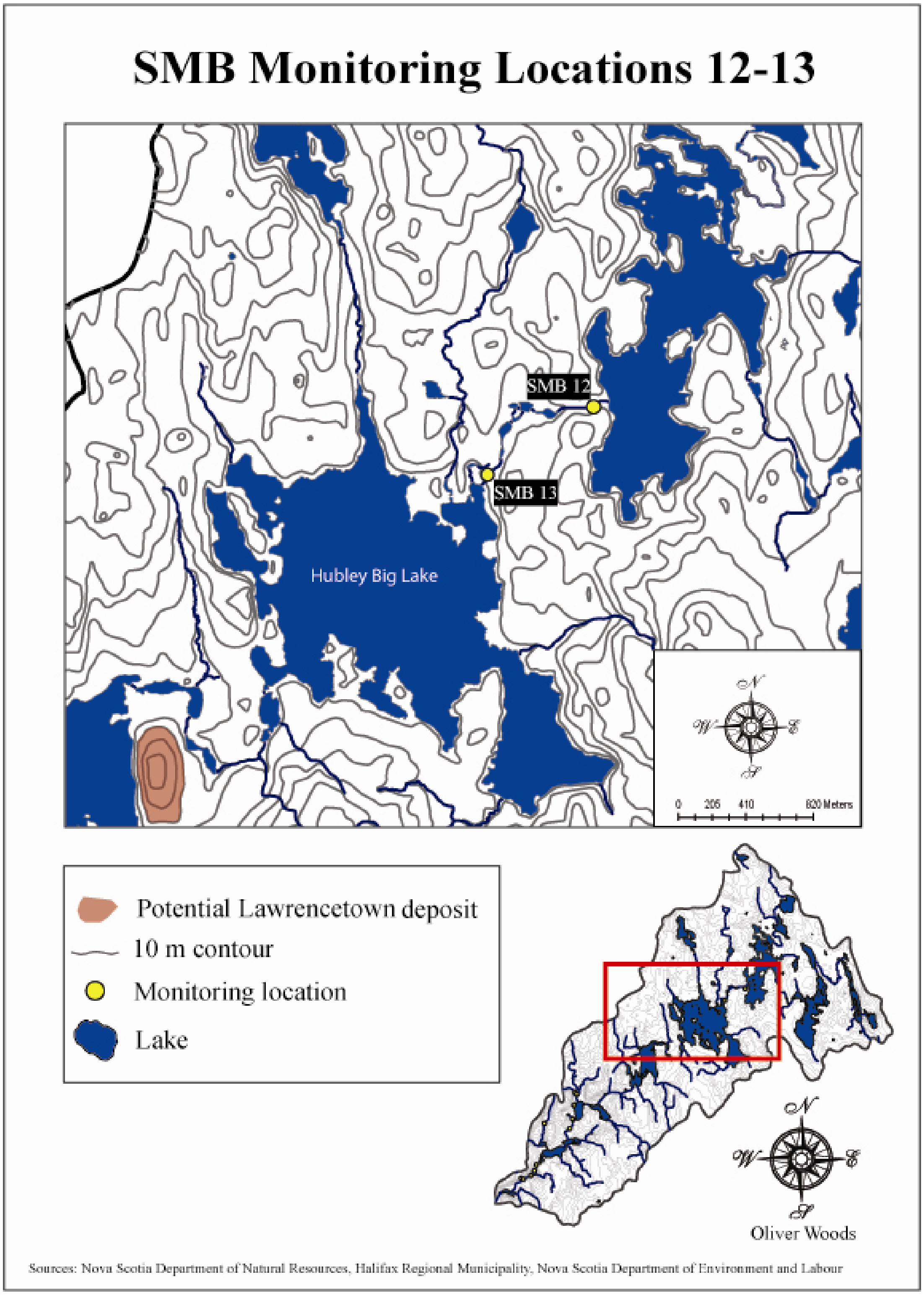
Sources: Nova Scotia Department of Natural Resources, Halifax Regional Municipality, Nova Scotia Department of Environment and Labour

Figure 4.9 Drumlins Cored by Lawrencetown Till in Lowermost Watershed (South East of Albert Bridge Lake)



Sources: Nova Scotia Department of Natural Resources, Halifax Regional Municipality, Nova Scotia Department of Environment and Labour

**Figure 4.10 Drumlins Cored by Lawrencetown Till in Lower Watershed (South East of Gates Lake)**



Sources: Nova Scotia Department of Natural Resources, Halifax Regional Municipality, Nova Scotia Department of Environment and Labour

**Figure 4.11 Drumlin Cored by Lawrencetown Till in Upper Watershed (South of Hubley Big Lake)**

The pH results from the 5 remaining monitoring sites will be discussed collectively; as all locations fall within the Wooden's River, and share common attributes. Mean pH values at locations SMB 1, SMB2, SMB 4, SMB 7, and SMB 9 (**Figure 4.10, 4.11**) range from 4.48 to 4.96 (**Table 4.3**). Suitability index scores at these sites are among the least favorable in the study area ranging from 0.19 at SMB 7 to 0.41 at locations SMB 1, SBM 2 and SMB 4 (**Table 4.3**). Although all sites fall within close proximity to Lawrencetown Deposits, mean pH values are the lowest values in the study area. The reasoning behind this will be discussed in detail in chapter 5.

### 4.5 Dissolved Oxygen (D.O.)

Dissolved oxygen (D.O.) concentrations in the study area can be classified as good to excellent with few exceptions. This is significant considering temperatures in the study area were relatively high, indicating a probable decrease in D.O. saturation. Increased temperatures do however increase D.O. requirements for trout populations, as seen in the dissolved oxygen suitability graph (**Appendix B**).

With the exception of SMB 3 SMB 5, SMB 10 and SMB 13, dissolved oxygen concentrations and associated suitability index scores ranged from 6.29 mg/L with a S.I. score of 0.44 at SMB 12 to 10.94 mg/L with an S.I. score of 1.00 at SMB 14 (**Appendix A**). Poor S.I. scores at locations SMB 5, SMB 10, and SMB 13 were a result of dramatically decreased flows (**Appendix A**). A relatively poor suitability index score of 0.38 was recorded on July 20th 2006 at SMB 3, likely due to the transition in dissolved oxygen suitability occurring at 15 $^{o}$ C (see temperature/D.O. relationship discussed in section 1.2 and suitability graph in **Appendix B**).

Apart from the exceptions discussed above, D.O. concentrations in the study area appear suitable to maintain healthy trout populations. In most locations, suitability index scores neared perfect following maximum summer temperature.

## 4.6 Summary

The large amount of data collected has been summarized in the previous sections, indicating significant spatial and temporal variation between and amongst variables. It is apparent that on the whole, pH, D.O. and temperature values differ greatly between monitoring sites. Only few locations exist where all parameters fall within a suitable range in which trout populations thrive. Furthermore, these locations appear to exist in small tributaries which would not support large numbers of juvenile or adult trout.

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The next chapter will discuss in more detail the results presented above, and will explore restoration possibilities in the study area.

# Chapter 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Introduction

The results from the previous chapter are discussed below in accordance with the information provided in chapters 1-3. Conclusions on aquatic habitat suitability at the monitored locations, the effects of the Lawrencetown deposits on local water quality, and the effectiveness of LEK are provided. Moreover, several recommendations have been proposed, highlighting potential restoration areas in the Wooden's River Watershed based on the findings of this research. Finally, recommendations for further studies are included which will help to explain the complexities of this watershed system which exist outside the scope of this thesis.

## 5.2 Temperature

The results presented in the previous chapter indicate significant spatial and temporal variation between monitoring sites in terms of recorded temperature.

Because the purpose of this research was to prioritize restoration initiatives, and therefore highlight areas with the most suitable balance between water quality variables, any location in the main river which experienced temperatures which exceeded 20 $^{o}$C for prolonged periods of time was considered unfeasible for restoration purposes. The heavy bolder substrate and the many connected lakes and still-waters which exist throughout the study area, would make restoring the temperature variable extremely difficult.

Unfortunately, the temperature data collected by both the Onset data loggers and the YSI unit indicate that locations SMB 1, SMB 2, SMB 4, SMB 5, SMB 8, SMB 9, SMB 10, SMB 12, and SMB13 (**Appendix A**) fall within this category. This proves to be a significant finding because these monitoring locations all exist within the main Wooden's river and connecting lakes. Furthermore, it was apparent that no monitoring locations exist in the main river with suitable summer temperatures. This is expected to be a result of the relatively shallow water depth, the presence of multiple lakes and/or still-waters connecting the system which act as 'heat sinks' and finally, the low velocity of the main river at many of the locations.

The remaining 4 monitoring locations seen in **Appendix A** and **Table 4.1** (SMB 3, SMB 6, SMB 7, and SMB 14) are characterized by optimal temperatures throughout the entire study period. With the exception of SMB 14 which was included primarily to test the relationship between pH and the Lawrencetown deposits and was not intended as a location for potential restoration, the remaining monitoring locations exist within small ground water fed tributaries which eventually enter the Wooden's River. Although these small tributaries are not expected to support large numbers of juvenile or adult trout, they are considered important here in terms of population dynamics as they are likely the source of cold water refuge areas in times of maximum summer temperature and are expected to be preferred spawning habitat.

In summary, the results indicate that the temperature variable appears to be a significant limiting factor in terms of identifying areas for potential restoration.

Moreover, because Brook trout are known to move throughout the system to find preferred temperatures (< 20 $^{o}$C in summer) (Abraham, 2007), the cold ground water fed tributaries which have been identified likely play a much larger and complex role than would have been expected. In terms of the temperature variable alone, sites SMB 3, SMB 6, and SMB 7 appear to be the most suitable locations for future habitat restoration.

## 5.3 pH

The results of the pH data collected over the study period show significant spatial and temporal variation. As will be further discussed in this section, there appears to be a significant relationship between pH and the presence of the Lawrencetown Deposits.

As indicated in chapter 4, SMB 10 and SMB 14 had the highest mean pH values out of all monitoring locations (**Appendix A**). This proved to be significant because these two locations were chosen strictly on the basis of identifying the buffering capacity of the Lawrencetown deposits. With this being said, it must be understood that these locations do not have the physical characteristics capable of supporting Brook trout in any stage of their life cycle and therefore can not be considered as areas for potential restoration.

SMB 3 and SMB 6 (**Appendix A**) were also included to identify possible relationships between pH and the presence of Lawrencetown deposits; however they are also potential restoration sites due to their location in small tributaries. pH recorded at these locations was good relative to other monitoring locations, once again indicating the potential buffering capacity of the drumlins cored by Lawrencetown till. Before discussing the remaining monitoring locations, it is important to take into account that the four sites discussed above are the only sites existing outside of the Wooden's River which are in close proximity to, and experience significant runoff and ground water input from, the Lawrencetown deposits.

Monitoring locations SMB 1, SMB 2, SMB 4, SMB 5, and SMB 9, all located within the main Wooden's River, had relatively poor pH readings throughout the entire study period regardless of Lawrencetown deposits in the area (**Appendix A**). This proved to be significant because although these sites potentially receive runoff and groundwater input from the deposits in many cases, the deposits capacity to buffer larger bodies of water appears to be minimal.

Site SMB 7 experienced both the lowest recorded pH value and the lowest mean pH value out of all monitoring locations in the study area (**Appendix A**). The first YSI reading taken on June 21st, appeared to fit the overall observed trend, however on or around July 20th, the pH significantly dropped. Readings taken on August 1st and August 10th remained significantly low (reaching a minimum value of 3.85), however by August 21st, the pH value was back within the tolerable range for the species. This event was an anomaly within the study area, and one which was not well understood. Because the temperature and D.O. variables appear to be optimal at this site, it is considered to be an area requiring further studies and/or future restoration. This location is thought to play an important role during the time of maximum summer temperature (acting as a cold water refuge area) however the dramatic fluctuations in pH are concerning.

Not located in the vicinity of the Lawrencetown deposits, and located within the main river, both SBM 12 and SMB 13 experienced moderate to good pH during the entire study period (**Appendix A; Figure 4.11**). This could be a result of nutrient loading from the surrounding subdivisions however further studies would be necessary to confirm this. Finally, site SMB 8 (**Appendix A**) which exists on the edge of Gates Lake, experienced moderate to good pH (relative to the watershed). This is interesting because as previously stated, the Lawrencetown deposits capacity to buffer larger bodies of water appears to be minimal. However, it was indicated on a field trip with Lawrence Abraham (2007) that ~ 5-7 meters from where the YSI reading was taken, there is a large groundwater upwelling. This is significant because Gates Lake exists at the bottom of a drumlin cored by Lawrencetown till, and it is likely that the groundwater upwelling is influenced by the drumlin and therefore influences the pH in the waters in close proximity to this upwelling. Once again, further studies would be necessary to confirm this idea however this anomaly would not be understood without LEK.

In summary, it appears that pH is influenced by the presence of drumlins cored by Lawrencetown till only in the small tributaries which experience significant runoff and/or ground water input from the deposits. It appears that as the quantity of water increases, the effect of the deposit is decreased, indicating the deposits capacity to buffer larger bodies of water is minimal. Although pH values recorded over the study period do not fall within the optimal range of the target species, they do not appear to be a significant limiting factor as previously seen with the temperature variable.

### 5.4 Dissolved Oxygen

As stated in Chapter 4, the results of the Dissolved Oxygen (D.O.) portion of the study indicate concentrations are good to excellent with only few exceptions. This section will discuss the circumstances under which poor D.O. readings were recorded.

Locations SMB 5, SMB 10, and SMB 13 experienced poor D.O. values directly resulting from dramatically decreased flows (Appendix A). Because these locations only appear to exist as seasonal streams, they can not be considered as areas for potential restoration. Finally, the results indicate that D.O. suitability was poor at SMB 3 around the time of maximum summer temperature (Appendix A). Although the generated suitability index score was low on this occasion (S.I. = 0.38), the transition in dissolved oxygen suitability occurring at 15 $^{o}$C must be taken into consideration. This is a loosely defined threshold and if temperature would have been 0.34 $^{o}$C lower (therefore existing below 15 $^{o}$C), the associated index score would have been 0.9 (Appendix B). Therefore, it is suggested that the relatively poor dissolved oxygen S.I. score assigned at SMB 3 is not significant, and should not be considered a limiting factor.

In summary the D.O. variable used in this study, and the generated S.I. scores, indicate this water quality parameter exists in the suitable to optimal range throughout the study area with the exceptions discussed above.

## 5.5 Conclusions and Recommendations

The model chosen to represent habitat suitability for the purpose of prioritizing restoration initiatives in the Wooden's River watershed has proven to be effective. Because the water quality parameters could be directly compared through generated suitability index (S.I.) scores, it was possible to identify areas with the most suitable balance between the water quality variables studied.

For reasons stated above, 10 of the 13 monitoring locations have been excluded as potential restoration sites in the study area. According to the generated suitability index scores, the three sites remaining, SMB 3, SMB 6, and SMB 7 (**Appendix A, Figure 2.2, Figure 4.10**), appear to have the most suitable balance between water quality variables in terms of aquatic habitat suitability. Furthermore, where individual variables are not favorable as seen with the pH parameter at SMB 7, restoration could be feasibly undertaken through liming or similar approaches.

Although water quality generally appears good at the three locations identified above, they all exist in areas that may be vulnerable to disturbance and/or human impact. For example, both SMB 6 and SMB 7 exist close to frequently used dirt roads and are therefore susceptible to sediment loading and or contamination. SMB 3 is located in an area which has experienced significant forestry practices in recent years and was not properly restored following these events. Therefore in these areas, a physical habitat assessment is necessary to identify areas of improvement and to ensure that the ecosystem health is maintained at these locations (which are expected to be the source of summer refuge areas and or spawning grounds).

The use of topographical, geological, and hydrological maps along with LEK of the watershed has proven extremely effective in identifying areas for potential restoration. In fact, all three proposed areas for further study or possible restoration were identified by these sources of information. Furthermore, the results presented in chapter 4 and summarized above, seem to agree with LEK of Brook trout movement in times of maximum summer temperature, therefore highlighting the importance of incorporating LEK into the framework.

The methodologies used in this research have not only helped to effectively prioritize areas for aquatic restoration, they have also helped to uncover the probable correlation between Lawrencetown deposits and improved local water quality. Most importantly, the methodologies used here have helped to bridge the gap in the literature where LEK, mapping technologies, fish habitat models and CBM are collectively incorporated to assess aquatic habitat quality and quantity and to identify sensitive areas requiring added protection and/or restoration. This is expected to benefit anyone wishing to adopt some or all of the methodologies as they have proven to effectively narrow the study area, focus the research, identify areas with apparent monitoring gaps and save significant financial resources. Therefore, community-groups choosing to adopt some or all of the discussed methods will inevitably benefit, and most importantly, resources will be utilized in an efficient and meaningful manner.

Because of the complexities of the Wooden's River watershed system, and the dynamic processes operating outside of the scope of this thesis, several future recommendations are proposed below.

**1.** It is recommended that a physical habitat assessment and especially riparian zone studies be conducted at all of the monitoring locations in this study. Physical habitat could be enhanced at many of the monitoring sites which may help to improve water quality variables such as temperature or parameters existing outside the scope of this research.

**2.** It is recommended that the many lakes connecting the system be studied in detail. Determining which lakes have an active thermocline in times of maximum summer temperature is necessary to fully understanding the movement of the target species. Furthermore, determining which lakes stratify will allow further conclusions to be drawn on the systems capacity to support large populations and will help to identify areas in the watershed which play an important role during maximum summer temperatures.

**3.** It is suggested that equipment be put back in the field to obtain water quality data over the entire summer period. Specifically, the deployment of a hydrolab would be beneficial to obtain a larger data set and assess fluctuations of pH and D.O. which were somewhat limited in this study. The deployment of a hydrolab would also help to determine the state of other water quality variables existing outside the scope of this thesis.

**4.** Finally, as stated throughout this thesis, the methodologies used were designed to benefit the environmental monitoring community. Therefore, it is recommended that one or more community-based groups apply the methodologies used in this research in another watershed to test effectiveness.

# APPENDIX

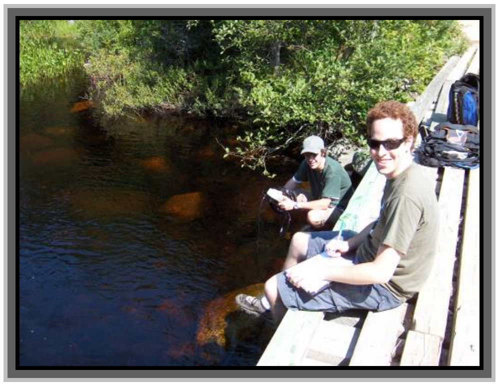
## A. SMB Monitoring Locations 1-14: coordinates, site descriptions, and photographs

# SMB 1

## Datum: NAD/1983; Map Projection: UTM Zone 20 N
## Y Proj/X Proj: 4939105/ 428350
## Lat/Long: 44.601727/-63.902847

| Date | Temp.(°C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | 18.30 | 0.84 | 5.00 | 0.42 | 7.56 | 0.81 |
| **July 20th** | 24.30 | 0.00 | 5.00 | 0.42 | 7.04 | 0.69 |
| **Aug. 1st** | 24.27 | 0.00 | 4.78 | 0.34 | 7.18 | 0.71 |
| **Aug. 10th** | 23.09 | 0.19 | 4.62 | 0.23 | 8.72 | 0.98 |
| **Aug. 21st** | 22.73 | 0.22 | 5.07 | 0.42 | 8.04 | 0.91 |
| **Sept.11th** | 19.44 | 0.73 | 5.29 | 0.46 | 8.82 | 1.00 |

**Site Description:** Little canopy cover, slow flowing open water just downstream from Old Mill Pond, YSI reading taken from off bridge. Hobo x2.




# SMB 2

## Datum: NAD/1983; Map Projection: UTM Zone 20 N
## Y Proj/X Proj: 49392604/ 428475
## Lat/Long: 44.603132/ -63.901300

| **Date** | **Temp.(°C)** | **SI Score** | **pH** | **SI Score** | **D.O. (mg/L)** | **SI Score** |
|---|---|---|---|---|---|---|
| **June 21st** | N/A | N/A | N/A | N/A | N/A | N/A |
| **July 20th** | 24.08 | 0.00 | 4.94 | 0.41 | 7.04 | 0.69 |
| **Aug. 1st** | 23.75 | 0.05 | 4.68 | 0.26 | 7.03 | 0.69 |
| **Aug. 10th** | 22.69 | 0.28 | 4.80 | 0.38 | 8.93 | 1.00 |
| **Aug. 21st** | 21.74 | 0.43 | 5.11 | 0.43 | 7.29 | 0.72 |
| **Sept.11th** | 19.40 | 0.72 | 5.22 | 0.46 | 8.86 | 0.99 |

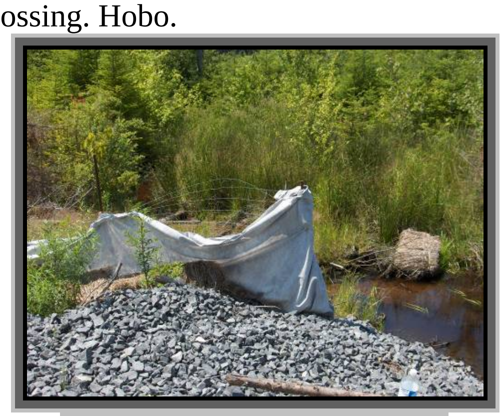
**Site Description:** YSI reading taken just upstream from Old Mill Pond, canopy cover roughly 40 %, medium flowing with some small rapids.

# SMB 3

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4940855/ 428833**
**Lat/Long: 44.617525/ -63.897009**

| Date | Temp.(°C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | 14.10 | 1.00 | 5.15 | 0.46 | 6.43 | 0.96 |
| **July 20th** | 15.33 | 1.00 | 5.26 | 0.50 | 5.99 | 0.38 |
| **Aug. 1st** | 15.92 | 1.00 | 5.26 | 0.50 | 6.94 | 0.68 |
| **Aug. 10th** | 14.89 | 1.00 | 5.68 | 0.68 | 8.20 | 1.00 |
| **Aug. 21st** | 15.80 | 1.00 | 5.72 | 0.69 | 8.06 | 0.91 |
| **Sept.11th** | 13.02 | 1.00 | 5.82 | 0.77 | 9.88 | 1.00 |

**Site Description:** stream intersected by logging road eventually entering Brines Little Lake then Albert Bridge Lake; located between 2 Lawrencetown deposits. Area recently clear cut; YSI reading taken from upside of crossing. Hobo.

## SMB 4

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4940663/ 429666**
**Lat/Long: 44.615886/ -63.886484**

| Date | Temp.(°C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | 18.50 | 0.82 | 5.05 | 0.42 | N/A | N/A |
| **July 20th** | 23.40 | 0.15 | 5.04 | 0.42 | 7.13 | 0.70 |
| **Aug. 1st** | 23.27 | 0.16 | 4.79 | 0.30 | 7.16 | 0.70 |
| **Aug. 10th** | 21.27 | 0.49 | 4.62 | 0.22 | 8.16 | 0.91 |
| **Aug. 21st** | 21.13 | 0.50 | 5.05 | 0.42 | 7.26 | 0.74 |
| **Sept 11th** | 18.84 | 0.79 | 5.25 | 0.52 | 8.11 | 0.91 |

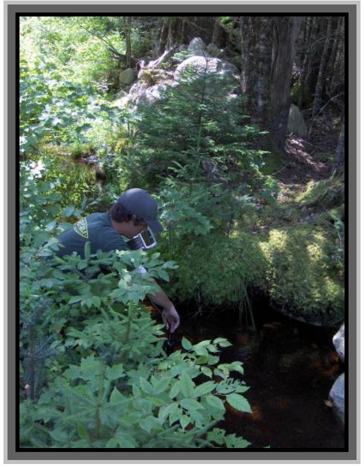
**Site Description:** Located on Wooden's River downstream of Gates Lake, mature forest, 90 % canopy cover (well shaded), large granite boulders. Hobo.

## SMB 5

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4940992/ 429758**
**Lat/Long: 44.618850/ -63.885361**

| Date | Temp.(°C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | 16.40 | 0.97 | 4.94 | 0.39 | 2.74 | 0.00 |
| **July 20th** | 20.35 | 0.62 | 4.99 | 0.41 | 2.29 | 0.00 |
| **Aug. 1st** | 21.20 | 0.50 | 4.81 | 0.38 | 1.56 | 0.00 |
| **Aug. 10th** | 19.43 | 0.71 | 4.67 | 0.23 | 2.31 | 0.00 |
| **Aug. 21st** | 19.38 | 0.71 | 4.95 | 0.40 | 1.42 | 0.00 |
| **Sept 11th** | 14.93 | 1.00 | 5.14 | 0.44 | 3.04 | 0.00 |

**Site Description:** Small brook running out of peat bog, runs through ditch and spills into road in several places; slowed down to a trickle by Aug. 1st.

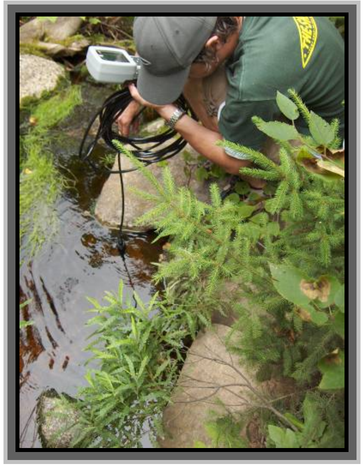


# SMB 6

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4941888/ 429867**
**Lat/Long: 44.626931/ -63.884119**

| Date | Temp.(°C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | 12.30 | 1.00 | 4.85 | 0.38 | 9.98 | 1.00 |
| **July 20th** | 14.10 | 1.00 | 5.10 | 0.42 | 9.73 | 1.00 |
| **Aug. 1st** | 15.14 | 1.00 | 4.78 | 0.29 | 9.51 | 1.00 |
| **Aug. 10th** | 14.67 | 1.00 | 5.09 | 0.42 | 10.38 | 1.00 |
| **Aug. 21st** | 14.67 | 1.00 | 6.44 | 0.92 | 9.38 | 1.00 |
| **Sept 11th** | 11.67 | 1.00 | 6.52 | 0.95 | 10.41 | 1.00 |

**Site Description:** small brook running under road; several small trout were observed; YSI reading taken from upper side of culvert. Hobo.



# SMB 7

## Datum: NAD/1983; Map Projection: UTM Zone 20 N

## Y Proj/X Proj: 4941820/ 429923

## Lat/Long: 44.626320/ -63.883402

| Date | Temp.($^o$C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | 13.30 | 1.00 | 4.73 | 0.28 | 9.76 | 1.00 |
| **July 20th** | 15.74 | 1.00 | 4.04 | 0.01 | 9.08 | 1.00 |
| **Aug. 1st** | 16.47 | 0.97 | 4.07 | 0.02 | 9.04 | 1.00 |
| **Aug. 10th** | 15.75 | 1.00 | 3.85 | 0.00 | 10.26 | 1.00 |
| **Aug. 21st** | 15.53 | 1.00 | 4.83 | 0.33 | 8.83 | 1.00 |
| **Sept 11th** | 12.28 | 1.00 | 5.37 | 0.71 | 10.24 | 1.00 |

**Site Description:** YSI reading taken off small bridge in tributary eventually entering Gates Lake, less dense younger forest, 50 % canopy cover, medium granite boulders. Hobo.

# SMB 8

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4941446/ 429823**
**Lat/Long: 44.622947/ -63.884608**

| Date | Temp.($^{o}$C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | 18.10 | 0.86 | 5.07 | 0.42 | 9.26 | 1.00 |
| **July 20th** | 24.92 | 0.00 | 5.03 | 0.41 | 7.20 | 0.72 |
| **Aug. 1st** | 27.13 | 0.00 | 4.96 | 0.40 | 6.94 | 0.68 |
| **Aug. 10th** | 23.03 | 0.19 | 4.79 | 0.27 | 8.84 | 1.00 |
| **Aug. 21st** | 21.61 | 0.42 | 5.14 | 0.45 | 8.29 | 0.92 |
| **Sept 11th** | 18.91 | 0.78 | 5.72 | 0.70 | 9.75 | 1.00 |

**Site Description:** YSI reading taken on edge of Gates lake just under Lawrencetown deposit.

## SMB 9

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4938989/ 428112**
**Lat/Long: 44.600658/ -63.905835**

| Date | Temp.(°C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | N/A | N/A | N/A | N/A | N/A | N/A |
| **July 20th** | 23.98 | 0.03 | 4.80 | 0.38 | 7.65 | 0.83 |
| **Aug. 1st** | 23.38 | 0.15 | 4.35 | 0.10 | 7.50 | 0.81 |
| **Aug. 10th** | 22.19 | 0.33 | 4.41 | 0.13 | 8.62 | 0.97 |
| **Aug. 21st** | 22.17 | 0.33 | 4.98 | 0.41 | 8.00 | 0.91 |
| **Sept 11th** | 18.71 | 0.80 | 5.24 | 0.51 | 8.67 | 0.98 |

**Site Description:** Wooden's River just downstream of Old Mill Pond, large granite boulders, good deep fishing hole just downstream, dense canopy, well shaded. Hobo.

## SMB 10

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4939017/ 428030**
**Lat/Long: 44.600903/ -63.90687**

| Date | Temp.(°C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | 13.70 | 1.00 | 5.99 | 0.80 | 8.39 | 1.00 |
| **July 20th** | 20.55 | 0.60 | 6.51 | 0.94 | 7.75 | 0.88 |
| **Aug. 1st** | 22.36 | 0.32 | 5.84 | 0.78 | 7.50 | 0.81 |
| **Aug. 10th** | 19.96 | 0.67 | 6.08 | 0.81 | 6.75 | 0.63 |
| **Aug. 21st** | 19.76 | 0.70 | 6.14 | 0.82 | 5.78 | 0.30 |
| **Sept 11th** | 15.27 | 1.00 | 6.20 | 0.83 | 8.17 | 1.00 |

**Site Description:** Ditch just off road when entering Wooden's road; by Aug 1st it had almost stopped flowing. Lawrencetown till present.

## SMB 12

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4945276/ 435558**
**Lat/Long: 44.657957/ -63.812808**

| Date | Temp.(°C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | N/A | N/A | N/A | N/A | N/A | N/A |
| **July 20th** | 23.22 | 0.16 | 5.83 | 0.78 | 6.29 | 0.44 |
| **Aug. 1st** | 23.63 | 0.09 | 5.63 | 0.68 | 7.59 | 0.82 |
| **Aug. 10th** | 21.26 | 0.48 | 4.86 | 0.40 | 8.41 | 0.96 |
| **Aug. 21st** | 21.15 | 0.49 | 5.69 | 0.69 | 7.83 | 0.89 |
| **Sept 11th** | 18.20 | 0.84 | 5.59 | 0.67 | 8.56 | 0.98 |

**Site Description:** Granite Cove Drive located upstream of Hubley big lake and downstream of Five Island Lake; YSI reading taken at elbow of stream before culvert; mixed forest. Hobo.




## SMB 13

**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4944886/ 434872**
**Lat/Long: 44.654384/ -63.821404**

| Date | Temp.($^{o}$C) | SI Score | pH | SI Score | D.O. (mg/L) | SI Score |
|---|---|---|---|---|---|---|
| **June 21st** | N/A | N/A | N/A | N/A | N/A | N/A |
| **July 20th** | 24.37 | 0.00 | 5.67 | 0.68 | 6.57 | 0.60 |
| **Aug. 1st** | 21.87 | 0.40 | 5.27 | 0.50 | 6.33 | 0.44 |
| **Aug. 10th** | 20.11 | 0.65 | 4.82 | 0.38 | 7.56 | 0.81 |
| **Aug. 21st** | 21.10 | 0.65 | 5.26 | 0.49 | 5.80 | 0.23 |
| **Sept 11th** | 15.82 | 1.00 | 4.90 | 0.40 | 4.64 | 0.00 |

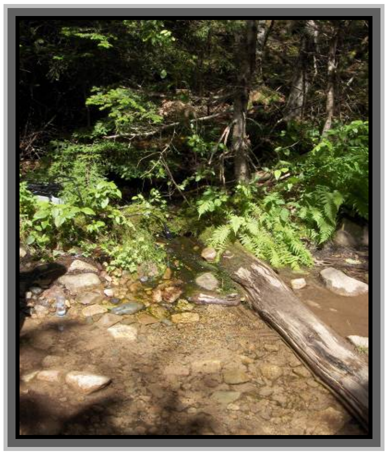
**Site Description:** YSI reading taken just on headwater side of culvert/bridge on Oak Ridge Road located upstream of Hubley big lake and downstream of Five Island Lake. River slow flowing; 90 % canopy cover. Hobo.

## SMB 14

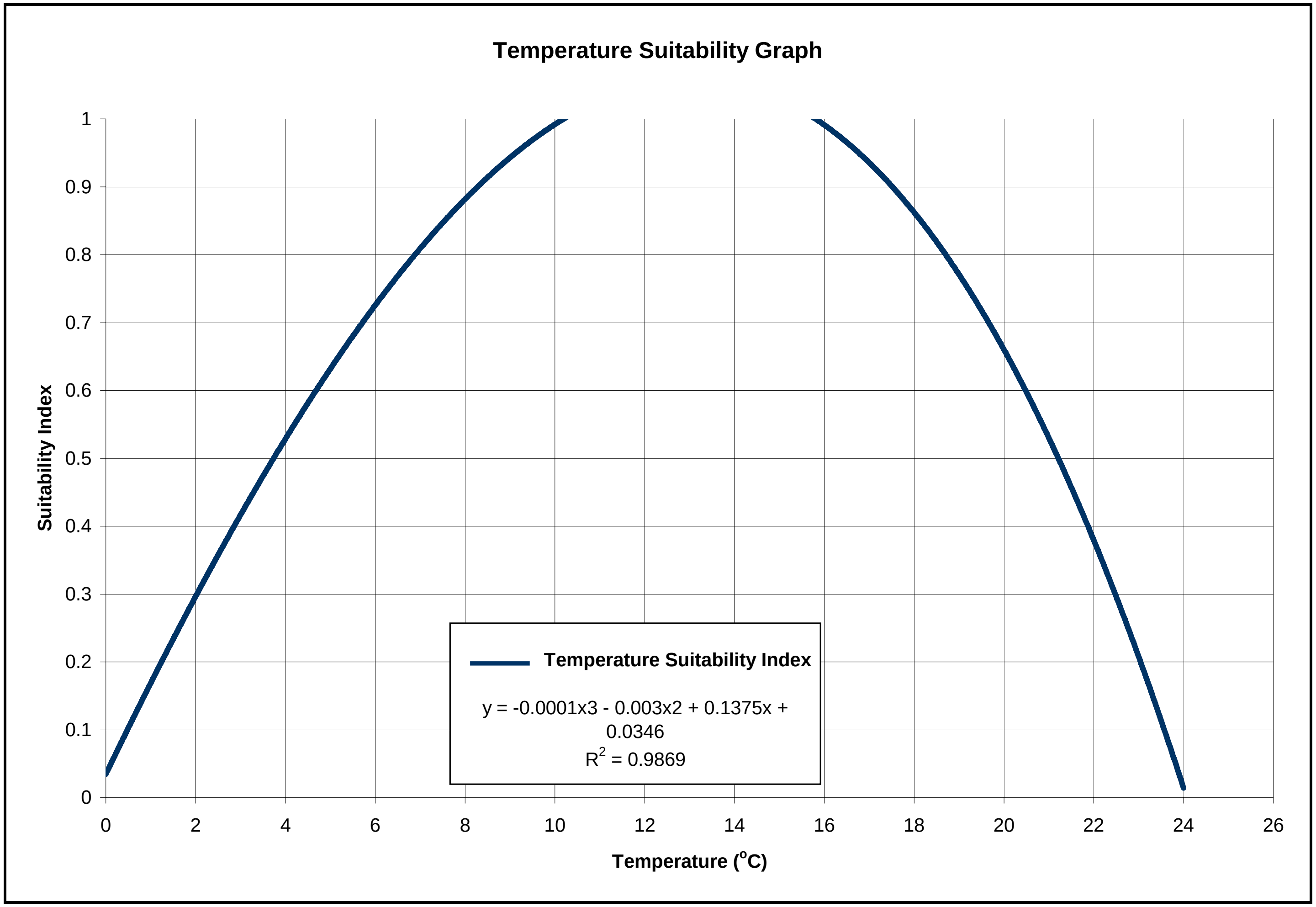
**Datum: NAD/1983; Map Projection: UTM Zone 20 N**
**Y Proj/X Proj: 4939458/ 428543**
**Lat/Long: 44.604925/ -63.900465**

| **Date** | **Temp.(°C)** | **SI Score** | **pH** | **SI Score** | **D.O. (mg/L)** | **SI Score** |
|---|---|---|---|---|---|---|
| **June 21st** | N/A | N/A | N/A | N/A | N/A | N/A |
| **July 20th** | N/A | N/A | N/A | N/A | N/A | N/A |
| **Aug. 1st** | 12.77 | 1.00 | 5.70 | 0.70 | 10.21 | 1.00 |
| **Aug. 10th** | 12.74 | 1.00 | 6.31 | 0.89 | 10.94 | 1.00 |
| **Aug. 21st** | 12.37 | 1.00 | 6.86 | 1.00 | 9.40 | 1.00 |
| **Sept 11th** | 11.62 | 1.00 | 6.18 | 0.84 | 9.71 | 1.00 |

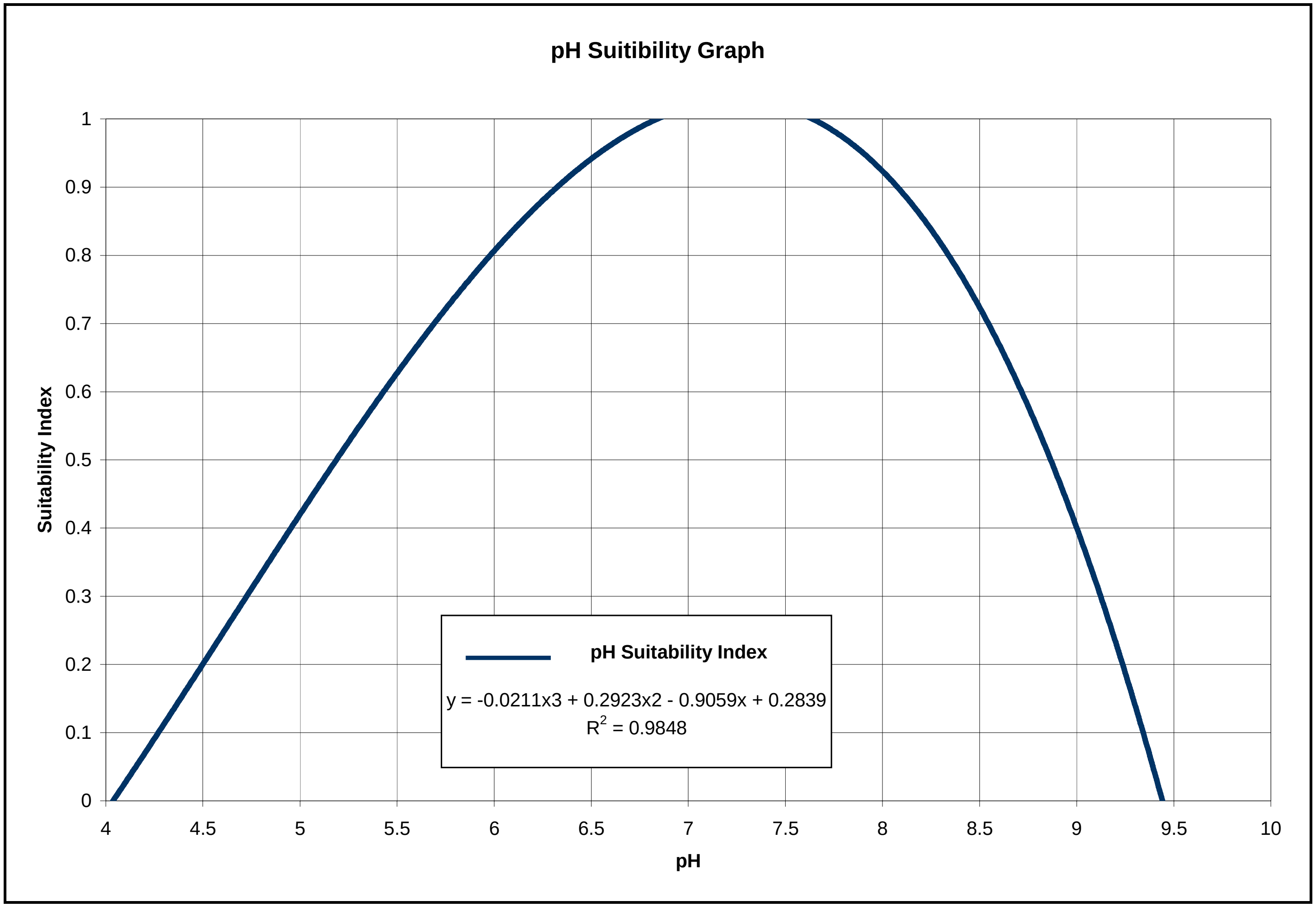
**Site Description:** 200 meters from SMB 2, small cold water source running from drumlin which cuts across road and into river. YSI reading taken on drumlin side of road.



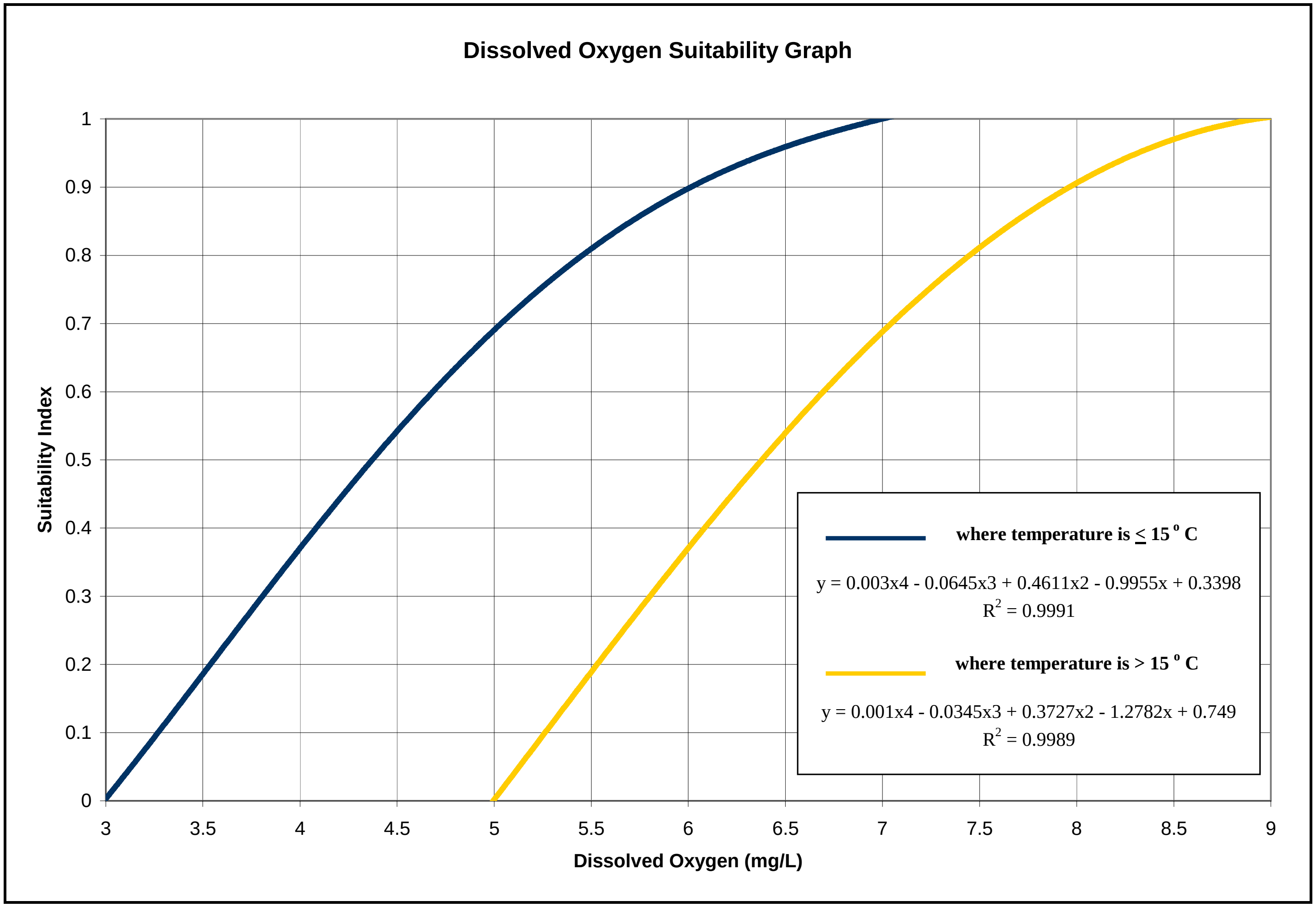
## B. Suitability Index Graphs



**Temperature Suitability Index Graph**



**pH Suitability Index Graph**



**Dissolved Oxygen Suitability Index Graph.**

## C. List of Maps.

Nova Scotia Department of Natural Resources
Minerals and Energy Branch
Map ME 2000-1
Geological Map of the Province of
Nova Scotia
Compiled by: J.D. Keppie (2000)
Scale: 1:500,000

Nova Scotia Department of Natural Resources
Map 81-1, Sheet 4
Pleistocene Geology and Till Geochemistry
Central Nova Scotia
Compiled by: Stea, R.R. and Fowler, J.H. (1980)
Scale: 1:100,000

Nova Scotia Department of Natural Resources
Mines and Energy Branche
Map 92-3
Surficial geology of the Province of
Nova Scotia
Compiled by: R.R. Stea, H. Conely, and Y. Brown (1992)
Scale: 1:500,000

Service Nova Scotia and Municipal Relations
Nova Scotia Topographic Database
Coastal Series
11D/12 Halifax, Nova Scotia
50 445000 63500 edition A05
Scale: 1: 50,000
UTM Zone 20 N based on NAD83.

Service Nova Scotia and Municipal Relations
Nova Scotia Topographic Database
Coastal Series
21A/09 Chester, Nova Scotia
50 445000 64000 edition F02
Scale: 1:50,000
UTM Zone 20 N based on NAD83.

Service Nova Scotia and Municipal Relations
Nova Scotia Topographic Database
Resource Series
21A/16 Windsor, Nova Scotia
50 447500 64000 edition J03
Scale: 1:50,000
UTM Zone 20 N based on NAD83.

Service Nova Scotia and Municipal Relations
Nova Scotia Topographic Database
Resource Series
11D/13 Mount Uniacke, Nova Scotia
50 447500 63500 edition B04
Scale: 1:50,000
UTM Zone 20 N based on NAD83.

Nova Scotia Department of Natural Resources
Surveys and Mapping Branch
Nova Scotia Department of Environment and Labour
Nova Scotia Watershed Areas
Maps:
**11D/12 Halifax, Nova Scotia**
**11D/13 Mount Uniacke, Nova Scotia**
**21A/09 Chester, Nova Scotia**
**21A/16 Windsor, Nova Scotia**
Scale: 1:50,000

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