Chapter 3

VULNERABLE AREAS INVENTORY

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3 Vulnerable Areas

Recent drinking water-related public health outbreaks in North America (e.g., Walkerton, North Battleford, and Milwaukee) have prompted public agencies to advance a more comprehensive approach to safeguarding drinking water. In Ontario, this “multi-barrier” approach involves a more complete understanding of activities that occur within the drinking water intake area (source protection planning), professional training for water treatment plant managers and improved water treatment plants, water distribution systems and programs for monitoring drinking water. The first step among these approaches is to protect our surface and groundwater from contamination and overuse through source protection planning (Conservation Ontario 2005).

Understanding vulnerable areas is a critical step in the development of a source water protection plan. Vulnerable areas can be defined as those areas where the potential impacts of human activity on the land surface are more likely to cause impacts on available sources of drinking water, in terms of both water quantity and water quality.

For the purposes of developing source water protection plans for Ausable Bayfield and Maitland Valley watersheds, the first step in identifying these areas is developing an inventory of these vulnerable areas, necessarily at a regional scale. Numerous studies have been completed in recent years that developed methodologies for and identified vulnerable areas. The intention of this chapter is to summarize this readily available information.

Vulnerable areas are unique to the source of drinking water for which they were developed, such that an area may be vulnerable with respect to one source, but not be considered to be vulnerable with respect to another. In addition, the activities that may impact one source may not be considered a threat to another. As a result of this relationship, it is appropriate to discuss vulnerable areas according to the sources for which they were developed, and this chapter is structured as such. This fact is also important for consideration during the development of the Source Protection Plans, as each source will require unique strategies in order to mitigate the threats in the vulnerable areas.

3.1 Vulnerable Areas to Groundwater Resources

Groundwater is overwhelmingly the most utilized source of drinking water throughout the Ausable Bayfield Maitland Source Protection Source Protection Region (the “study area”). It is estimated that over 85% of the population of the study area rely on groundwater for their personal supplies, including both municipal and private wells (see Table 3-1). Protecting groundwater resources will be a key element of all source protection plans in the study area.

Groundwater resources in the study area have been divided into two major groupings of aquifers, namely bedrock and overburden aquifers. Bedrock aquifers are the most reliable, from both a water quality and quantity perspective, and readily available as they underlie the whole of the study area. These bedrock aquifers are considered to be relative secure aquifers, as they are protected by thick sequences of unconsolidated glacial material. Bedrock aquifers are also less susceptible to water quantity issues due to the large volume of water that flows through the system. Overburden aquifers are sporadically dispersed, as they are associated with coarse grained glacial or glaciolacustrine deposits. Overburden aquifers are highly variable in their quality and quantity, and are more susceptible to both contaminations from anthropogenic activity and drought conditions.

There are a number of different approaches that have been applied in order to identify the vulnerable areas for (both bedrock and overburden) aquifers in the study area. These are generally developed from the geology of the area, and reflect a general rule that coarser grained materials allow for faster movement (i.e. they have higher hydraulic conductivities) of water, as both groundwater flow within aquifers and infiltrating water from the ground surface to the water table. Faster travel times for infiltration and groundwater flow allow contaminants in water less opportunity for attenuation and dilution. Aquifers with higher hydraulic conductivities allow water to be discharged at higher rates, making them more susceptible to changes in recharge rates.

3.1.1 Well Head Protection Areas (WHPA)

Well Head Protection Areas (WHPA) were generated for the study area as part of the MOE Groundwater studies completed for Lambton, Huron, Bruce, Huron and Perth Counties (2003) and for Wellington County (2005). A WHPA is the two-dimensional projection onto the ground surface of the three-dimensional volume of groundwater that is pumped from a well field. WHPAs themselves are composed of a number of Well Head Capture Zones (WHCZ) that reflect the time required for water to move to the well from different areas of the aquifer. These Time-Of-Travel (TOT) WHCZ's were applied for all municipal groundwater supplies within the study area as part of the MOE Groundwater studies.

TOT capture zones that were calculated for municipal supplies that had WHPAs delineated for them are listed in Table 3-1.

Table 3-1: Wellhead Protection Areas (WHPA for SWP Area)

Municipality	Well	Population	WHPA Size	100m	50 day	2 year	5 year	10 year	25 year	SWAT
ACW	Century Heights	200	3 km^2		√	√		√	√	No
	Huron Sands (Seasonal System)	120	2.1 km^2		√	√		√	√	No
	Benmiller	75	5 km^2		√	√				No
Central Huron	Van de Wetering	45	2 km^2		√	√		√	√	No
	Dundass	20			√	√		√	√	
	S.A.M.	36	4.2 km^2		√	√		√	√	No
	McClinchey	39	3 km^2		√	√		√	√	No
	Clinton 1,2 & 3	3117	18 km^2		√	√		√	√	No
	Auburn	272	1.7 km^2		√	√		√	√	No
	Kelley	43	2.4 km^2		√	√		√	√	No
North Huron	Blyth 1 & 2	987	2.2 km^2		√	√		√	√	Yes
	Wingham Well 3 & 4	2885	5 km^2		√	√		√	√	Yes
Huron East	Brussels 1 (Turnberry St.)	1277	3.6 km^2		√	√		√	√	Yes
	Brussels 2 (Church St.)	1277	2 km^2		√	√		√	√	Yes
	Brucefield	175	2.6 km^2		√	√		√	√	No
North Perth	Listowel 1, 4, & 5	7000	2.4 km^2		√	√		√	√	No
	Listowel 6	42	0.7 km^2		√	√		√	√	No
	Atwood (Smith)		2.2 km^2		√	√		√	√	No
	Atwood (Bowman Court)	260	2.5 km^2		√	√		√	√	No
	Gowanstown	105	0.5 km^2		√	√		√	√	No
Minto	Clifford 1, 2, 3, & 4	835	2.6 km^2		100 day		√	√	√	No
	Harriston	1985	14 km^2		100 day		√	√	√	No
	Palmerston	2450	12.9 km^2		100 day		√	√	√	No
Morris Turnberry	Belgrave (Jane & McCrae)	383	4 km^2		√	√		√	√	No
Bluewater	Zurich 1 & 3	900	6.9 km^2		√	√		√	√	No
	Hensall 1, 2 & 4	1100	3.5 km^2		√	√		√	√	No
	Harbour Lights	100	4.5 km^2		√	√		√	√	No
	Carriage Lane	100	0.35 km^2		√	√		√	√	No
Warwick	Arkona				√	√		√	√	No
Huron-Kinloss	Lucknow				√	√		√	√	No
	Whitechurch				√	√		√	√	No
South Huron	Exeter					√	√	√		No

Methodology

Delineation of wellhead protection areas (WHPAs) is accomplished through the application of numerical groundwater models. The physical relationships governing the movement of groundwater can be incorporated into numerical models to simulate the existing groundwater flow system. Once calibrated, this model can be used to determine the pathways of groundwater in the aquifer and to calculate the travel time between any two points along those pathlines. TOT capture zones for pumping wells are calculated by releasing many particles originating in a circle around the well, and running the model in reverse. These capture zone results from the basis for delineating WHPAs for the municipal well.

Limitations of WHPA Modeling Results

WHPAs produced from numerical models incorporate a number of assumptions, input parameters, and boundary conditions. Each model is a representation of the understanding of the area surrounding the municipal well, and in all cases this representation has been simplified to facilitate model development. The WHPA modeling results represent a best estimate of the actual WHPAs and provide excellent guidance regarding the specific water source for each well.

As additional information becomes available the numerical models will be revised and WHPAs re-evaluated. Furthermore, water taking will be different in the future, as communities grow and additional groundwater wells are developed.

One important limitation is that the capture zones are projected to ground surface, and does not reflect the time required for water to travel from ground surface to the aquifer. This is particularly true when the wells that are being evaluated pump water from a deep aquifer that is overlain with fine-grained sediments (silts and clays).

Results

WC Map 3-1 shows, at a regional scale, the TOT capture zones that were produced as part of the MOE groundwater studies. The size and shape of WHPAs are largely a function of the amount of water being pumped, the permeability of the aquifer from which it is being pumped, and the overall regional gradient. Large WHPAs occur in areas where there are high gradients, high permeabilities and large volumes being pumped.

Of particular importance to this study are those WHPAs in which the aquifer is considered to be susceptible to impact from surface water, or the well is considered to be Groundwater Under the Direct Influence of surface waters (GUDI wells). These WHPAs reflect a high probability of impact on the aquifer via surface activities and will necessitate a different approach to mitigating potential impacts than those WHPAs that are not susceptible or GUDI.

3.1.1.1 Surface to Well Advection Time (SWAT) Well Head Protection Areas

In order to address some of the limitations of the original TOT WHPAs developed, during the MOE sponsored groundwater studies, a number of pilot projects were undertaken in the area to develop Surface to Well Advection Time (SWAT) capture zones for a select group of municipal wells. SWAT incorporates the time it takes for water to infiltrate through the unsaturated zone to the water table, as well as the TOT from that point to the actual well.

Methodology
In order to determine the travel times through the unsaturated zone an advection time calculation was done using estimated average porosities and saturation values. This advection time estimates, based on the understanding of the local geology, the time required for any given water particle to travel from the ground surface to the top of an aquifer. Once the advection time is calculated it was added to the previously defined TOT capture zones to determine the total SWAT.

Results
Municipal wells, for which WHPAs have been delineated, at the time of writing this report, are listed in Table 3-1. This table outlines the capture zones which have been defined, and the methodology used in developing the WHPA. Those wells that have a SWAT WHPA have necessarily already had a TOT WHPA calculated for them.

The use of the SWAT information allows for greater understanding of the influence of activities on the ground surface on the actual wells in these areas. Those wells with significant potential impact, based on this SWAT modeling, will likely require different planning and implementation tools in order to accomplish the goal of protecting the long term sustainability of the well.

As part of the ongoing Municipal Technical studies, SWAT WHPAs are being delineated for all large municipal wells in the study area.

3.1.2 Intrinsic Susceptibility Index and Aquifer Vulnerability Index

Intrinsic Susceptibility Index (ISI), along with the earlier Aquifer Vulnerability Index (AVI), is a calculated value that estimates the susceptibility of a groundwater resource to contamination. The susceptibility of an aquifer to contamination is a function of the susceptibility of its recharge area to the infiltration of contaminants, which can be evaluated using ISI.

ISI mapping is available for the entire study area from a number of county groundwater studies, including: Huron County (2003); Perth County (2003); Grey and Bruce Counties (2003); Lambton County (2003); Middlesex and Elgin Counties (2003); and Wellington County (2005). These studies were undertaken with funding from the Ontario Ministry of the Environment and as such were expected to utilize a standardized methodology for determining ISI. However, minor modifications to the ISI calculation were encountered, and as a result an Edge-Matching project was undertaken to rectify these issues.

Methodology
As part of the Edge-matching study, ISI Mapping was redeveloped using a common methodology. Map development begins with assigning an ISI value for each well within the Water Well Information System (WWIS) for the study area. This is accomplished by summing the product of the thickness of each unit (b) in the well log and a corresponding K-factor (see Appendix A), as represented in the equation below. The thickness (a.k.a. depth) for which ISI was calculated at each well is calculated from the ground surface to the water table for the unconfined aquifer, and from the ground surface to the top of any confined aquifer.

$$ISI = \sum i1 \;\; bi \bullet KFi$$

where:

- i = the number of geologic units recorded in the water well record (borehole)
- b = the thickness of each geologic unit recorded in the water well record.
- K_F = the Representative K-Factor as outlined in the MOE Terms of Reference:

After assigning individual wells ISI values, the mapping was developed by interpolating these values between wells. These interpolated areas were then subdivided and classified following the Technical Terms of Reference into one of 3 susceptibility groupings: low (ISI > 80), medium (30 ≤ ISI ≤ 80) and high (ISI < 30) (MOE 2001).

In areas of thin overburden it was recognized that the vulnerability to the underlying aquifers was increased due to the highly fractured nature of the bedrock. In order to accommodate these concerns, polygons representing overburden thickness of less than 6.0 meters were assigned an ISI value of 20 (high susceptibility). In some areas with documented karst development, polygons representing the identified karst areas within the study area were overlain and assigned an ISI value of 20 (high susceptibility). Where modifications to the original ISI mapping were made, the ISI map was re-interpolated to provide a final ISI map.

ISI mapping for the entire study area are shown in WC Map 3-2 accompanying this report. Areas with high susceptibility tend to be those that have very shallow overburden deposits. Areas with known sinkhole development also show high susceptibility. It is important to note that for the study area groundwater resources tend to be relatively well protected from surface activities.

Limitations of ISI mapping

It is important to understand the limitations of the produced ISI mapping when developing a Source Water Protection Plan. Although ISI mapping is a well-documented and accepted methodology in Ontario for assessing aquifer vulnerability, it does have a number of limitations, including:

1. ISI mapping is intended to be viewed and interpreted at a regional scale and is not intended to be interpreted at a property or site-specific scale
2. The primary source of data for calculating ISI is the Well Water Information System (WWIS), which is known to have several deficiencies in both the lack of records for existing wells, and more importantly, in the location of the existing records.
3. ISI does not take into account hydrogeological characteristics of aquifers which may make them more or less susceptible
4. ISI is interpolated between known data points and does not take into account geological features/boundaries that may be the cause of significant differences between the points.
5. ISI cannot account for the condition of existing wells, which may represent a more important pathway for the contamination of aquifers than infiltration of meteoric water.

These limitations in mind, ISI is still a useful tool in evaluating the overall susceptibility of a given aquifer at a regional scale. However, it is most important to note that ISI should never be substituted for comprehensive site-specific investigation, and a qualified geoscientist should determine the accuracy of the index at a property scale.

3.1.3 MOE Groundwater Susceptibility Mapping

Initial attempts at defining the hydrogeologic environments susceptible to contamination were carried out by the Ontario Ministry of Environment (MOE 1985a). Broad scale mapping was created that separated the province into distinct hydrogeologic environments. These environments were subsequently evaluated for their susceptibility to contamination, based on:

1. The permeability of the materials commonly found at the ground surface;
2. Groundwater movement in the materials;
3. The presence of major shallow aquifers; and
4. The use of groundwater in the area.

These regions were developed primarily upon the existing quaternary geologic and physiographic mapping for the province. Based on this broad scale mapping effort the study area is dominated by ‘highly variable’ susceptibility, with areas of high susceptibility associated with the former Lakes Nippising-Algonquin shoreline deposits, and kame deposits within the Wawanosh and Wyoming moraines. The broad region defined as the ‘Huron Slope’ (Chapman and Putnam 1984) was considered to be low susceptibility, primarily as a function of the fine grained sediments and soils in this area.

A further refined version of this mapping was created for a portion of the study area (MOE 1985b). This map used an identical methodology and divided the area in the vicinity of Seaforth into hydrogeologic environments. These were based primarily on the physiography of the area. As part of this mapping, areas of moraine (including kames), glacial outwash and glaciolacustrine shoreline deposits were identified as highly susceptible to contamination, as well as areas with exposed bedrock.

These mapping sets are considered a good reference point for understanding the susceptibility of groundwater resources for the area. However, these maps are focused primarily on the surficial geology of the area and do not address the vulnerability of the important bedrock aquifer system.

3.1.4 Shallow Susceptibility Index Mapping (SSI)

During the "Improvind Access to Water Resource Information in Agricultural Watersheds" phase II pilot study (also referred to as My Land, Our Water - MYLOW study) completed by the Maitland Valley and Saugeen Valley Conservation Authorities, it was recognized that ISI and MOE Susceptibility mapping were insufficient for those areas. In fact, due to local shallow groundwater conditions and a large Old Order Mennonite population serviced by shallow wells it was determined that the ISI layer underestimated the vulnerability of this region. This was primarily due to a lack of data points, attributed to underreporting of shallow bored and dug wells and the subsequent lack of inclusion in the MOE water well database (WWIS).

In order to address these concerns, and acknowledging the limited well information, another vulnerability layer was developed to give landowners an alternative to ISI. The Surficial Susceptibility Index (SSI) is a semi-quantitative method for estimating the security of potential shallow aquifer based on the permeability of the soils and the first subsoil layer (Quaternary geology) – the higher the permeability, the higher the susceptibility.

Methodology

The susceptibility of these shallow aquifers can be estimated by overlay of the permeability of the soils and the quaternary geology in a GIS environment. In order to do this, the soils layer and quaternary geology layer were overlain and simplified values given to each type of soil and geological unit. The combination of different soils and subsoil types were given values based on their estimated rate of infiltration in order to approximate the susceptibility of a given area.

Soil permeability values were derived from the hydrologic soil classification groupings, where "A" soils are the most permeable and "D" the least. Soils with more than one association were grouped according to the best fit with known data. Geological materials were similarly grouped in just two groupings, low permeability and high permeability, based on existing quaternary geological mapping and the materials associated with each type of deposit. These groupings, for both soils and quaternary geology, are highly simplified, but allow for not only a comparison of the relative susceptibility of each area, but also as a predictor for where shallow overburden aquifers may be encountered. The matrix for determining the SSI is shown below in Table 3-2.

Table 3-2: Matrix for determining Shallow Groundwater Susceptibility values based on hydrologic soil grouping and permeability of quaternary geology

	Soils		
Geology	D	B/C	A
Low permeability	1	3	5
High permeability	2	4	6

In SSI, values from 1 to 3 are considered low susceptibility, 4 and 5 considered moderately susceptible and 6 is considered highly susceptible to contamination. Refer to Appendix B for the classification of soil and geology units.

Limitations of SSI

SSI is developed primarily as a predictive tool and is based on both the soils mapping and quaternary geology mapping, as well as broad scale geological interpretation. As a result, the final product has incorporated a number of potential errors, and should be viewed as such. It is important to note that no field verification of this methodology has been undertaken.

Results

SSI is presently available for the Maitland Valley portion of the study area only. The results of the SSI for this region are weighted heavily by the quaternary geology. This is partially a product of the genetic association of soils with the underlying quaternary geology. SSI mapping is shown in WC Map 3-3. SSI does highlight areas that are not identified by existing ISI mapping and is considered a useful tool for defining where ISI needs to be refined or more investigative work completed.

3.1.5 Localized Vulnerability Issues (outside WHPAs)

3.1.5.1 Recharge/Discharge Areas

Areas where groundwater interacts with the ground surface are critical to develop our understanding of both groundwater and surface water systems. These areas are also extremely sensitive, as they allow interactions between relatively good quality, un-impacted groundwater with commonly impacted surface waters. Areas that allow this interaction are commonly separated into 'discharge areas' where groundwater is being outlet into surface water bodies, and 'recharge areas' where surface water is infiltrating into groundwater bodies.

Discharge Areas

Discharge areas are important sources of water for surface water bodies. High quality and consistent quantities of water being discharged into streams and lakes from aquifers provide essential water for the natural function of those streams and lakes. Estimating areas of discharge can be accomplished by comparing the known water table surface with the ground surface. Where that water table surface is higher than the ground surface, one could reasonably expect to find groundwater discharging onto the ground surface or into streams and lakes. Realistically, the geology and soils of the area may preclude the discharge of water due to its fine texture and resultant low permeabilities. As a result, it is often difficult to predict where discharge is occurring without considering the geology and soil structure of the ground surface in a given area.

The most reliable method for delineating discharge areas is through the aquatic ecology of the streams and rivers themselves. Streams, drains and lakes throughout the study area have had their aquatic habitat intensively studied and classified. The results have been used to categorize the watercourses (and even specific reaches of individual watercourses) into cold and warm water fisheries habitat.

In order to create a map of predicted discharge areas from overburden aquifers, the water table elevation layer was intersected with the ground surface layer in a GIS environment. If geological and soil conditions permit, discharge areas can be predicted in regions where the water table surface is above the ground surface.

WC Map 3-4 shows the distribution of these discharge areas and cold and warm water streams throughout the study area. Of interest is the association of cold water streams with coarser grained quaternary deposits, including those associated with moraines, glacial outwash and contact deposits, as well as glaciolacustrine shoreline deposits. These coldwater streams then represent discharge from overburden aquifers, rather than the deeper bedrock aquifers.

The relatively small percentage of the study area where discharge from overburden aquifers is predicted is noted. This corresponds well with known cold-water subwatersheds, and wetlands (e.g. Nine Mile River upstream of Lucknow and Hay Swamp). The southern portion of the study area has a proliferation of discharge areas, which may reflect a more refined water table elevation layer in that area, largely due to the increased number of overburden wells available to develop that information.

Recharge Areas

Recharge areas are those areas from which aquifers are being replenished by surface waters. These areas are inherently vulnerable as they allow generally poorer quality surface water access to otherwise well-protected groundwater resources. It is important to recognize that recharge is essential for maintaining water levels within a given aquifer, as it is the only input of water. Recharge is happening throughout the region, as a given portion of rainfall is infiltrated through the soil surface. Outlining a recharge area, therefore, is largely a subjective exercise aimed at identifying those areas where the recharge rates are considered to be high.

Understanding recharge in the study area is a complex exercise, as there exists numerous aquifers, all of which have their own recharge areas and discharge areas. For overburden aquifers, which are for the most part unconfined, recharge is happening *in situ*. That is, meteoric water (precipitation) is infiltrating through the soil and near-surface quaternary sediment and eventually reaching the water table, effectively recharging those aquifers. The location of these recharge areas can thus be delineated by the existing distribution of these quaternary materials (see, for example, MOE Susceptibility mapping from 1985).

The more difficult task is in defining recharge areas for confined aquifers in the study area, particularly the deep bedrock aquifer system. Bedrock aquifers are exposed only in a very small area throughout the study area, and as a result, infiltrating surface water must pass through intermediate overburden aquifers before ultimately recharging the bedrock aquifer (an exception to this is sinkholes, which are discussed below in section 3.1.5.2). Effectively, recharge to the deeper bedrock aquifer is from overlying overburden aquifers, rather than meteoric water.

With this fact in mind, an experimental procedure was developed in order to try to identify those areas, where:

1. The geology allows for high rates of groundwater flow; and
2. The hydraulic conditions exist that allow for this flow to occur.

In order to accomplish the first, the concept of geological "windows" was developed. Geological windows are areas where the grain-size of the materials is considered coarse enough to allow for rapid movement, or flow, of groundwater – sands and gravels. In order to determine where these "windows" exist, GIS data layers created as part of the MOE Groundwater studies were manipulated.

Rather than try and identify those areas with thick sequences of sand and/or gravel overlying the bedrock, a negative reasoning approach was utilized, as it is easier to identify areas with no significant silt or clay layer. The approach is listed below:

1. Ground Surface (m.a.s.l.) – Bedrock surface (m.a.s.l.) = Overburden thickness (m)
2. Overburden thickness (m) – Sand & Gravel thickness (m) = thickness of silt and clay (m)
3. Where Thickness of silt and clay < 1m = geological "windows"

This was done by subtracting the bedrock surface elevation (in metres above sea level – m.a.s.l.) from the ground surface elevation, which gives an estimate of the thickness of the overburden in any given location. From there, the thickness of sand and gravel, calculated in the MOE Groundwater studies, could be subtracted from the overburden thickness. The resultant overburden thickness should be composed of either silt or clay. For the purposes of this procedure, we considered anything less than 1m thickness of silt and clay to be insignificant (note that due to interpolation errors for all the data layers, there were some negative values which are theoretically impossible). WC Map 3-5 was created which outlines these geological "windows" in the overburden.

Having mapped where the geology is favourable for rapid groundwater movement, the second stipulation must be satisfied in order to delineate recharge areas that have hydraulic conditions that allow for recharge to occur. The first hydraulic condition is to allow for rapid infiltration of meteoric water and is generally satisfied by the geological "windows" procedure described above. Areas with no significant clay or silt layer are expected to have high infiltration rates.

The second condition that must be satisfied is that water pressure in the shallow aquifers must be greater than the bedrock aquifers – where a downward gradient exists. This pressure manifests itself in the elevation of the water table and potentiometric surfaces, respectively. The pressure was calculated by subtracting the potentiometric surface (in m.a.s.l.) from the water table surface (in m.a.s.l.). Where this value is negative (i.e. the potentiometric surface is higher than the water table) it is assumed that water is being discharged from the higher pressure bedrock aquifer into the overburden aquifer. Where this value is positive (i.e. the water table surface is higher than the potentiometric surface) it is assumed that water is being recharged into the bedrock aquifer from the overburden aquifer. This exercise was intended to delineate where water may have 'quick' access to the bedrock aquifer from the surface.

In order to define our recharge areas, the areas where recharge is expected to occur to the bedrock aquifer from the overburden aquifer were intersected with the geological windows, creating areas where recharge to the bedrock aquifers is expected. Conversely, areas where discharge is expected were intersected with the geological windows in order to determine where significant discharge from the bedrock aquifer to the overburden may be occurring. These areas are shown in WC Map 3-6. Recharge and discharge occurs throughout the entire area, but the map highlights the most important areas of interaction. The bedrock aquifer is considered very well protected where no constructed pathways are available; the Source Protection Region has very thick overburden.

It is important to address the limitations of this procedure in order to understand the reliability of the information presented. Firstly, the data sources that are being utilized to develop this information are interpolated layers from regional scale studies and may not be accurate at a smaller scale. Accordingly, this information should be viewed from a regional perspective and should never replace good quality site-specific geological interpretation. Secondly, the primary data source for these layers is the WWIS, for which locations and particularly elevations are suspect, once again highlighting the regional scale at which this information should be viewed. The third and most salient limitation is in understanding that this procedure completely ignores any horizontal flow of groundwater in the overburden aquifers. In fact, recharge through the geological windows may originate from distal areas and flow through the overburden aquifer a significant distance (and time) before recharging the bedrock aquifer. The fourth and final limitation is that this is a non-quantitative, conceptual geological method for where recharge is occurring. Three-Dimensional groundwater modeling may provide more accurate and hydrogeologically significant recharge areas.

3.1.5.2 Karst Aquifers and Sinkholes

Karst is a term originally developed to describe the typical topography that develops in areas where significant dissolution of the bedrock has occurred. It has since been applied to any dissolution feature found in bedrock, and includes caves, solution-enhanced fracturing and sinkholes. Karst features have been identified due to the carbonate composition of the Paleozoic rocks underlying the study area.

Karst features within an aquifer allow for rapid transport of water both within and between aquifers. This, by default, makes those aquifers with karst features more susceptible to contamination and less likely to have the capacity to mitigate any impact. In the study area, the most dramatic karst features are found in the form of sinkholes. Sinkholes can loosely be defined as areas where surface waters are directly accessing the bedrock aquifers and are recognized by semi-circular depressions. These depressions are commonly situated in low areas, and as such surface drainage is directed towards them. The situation has been further exacerbated by the use of sinkholes as outlets to municipal drains, which occurred post European settlement of the area.

In order to investigate the potential impacts of sinkholes on local water supplie,s the Ausable Bayfield Conservation Authority has carried out two studies. The first study focused on a well known area of sinkholes concentrated along the boundary between the Municipalities of Huron east and West Perth, near Staffa. Sinkholes were located and information was collected and stored in a common database.

The second phase of the project extended the scope of the project to include all sinkholes within the study area. Sinkholes were identified and mapped, and information stored in a common database for further analysis. In addition, two boreholes were drilled in attempt to outline the geological characteristics and environments that favour development of sinkholes.

With respect to understanding vulnerable areas associated with sinkholes, the primary concern must be with the areas of the ground surface that drain into the sinkholes. These areas contribute water to surface water bodies that are in turn drained into a sinkhole, which allows for rapid infiltration into the bedrock aquifer and circumventing the process of infiltration through overburden materials. In addition, aquifers in which sinkholes have been identified are more likely to have additional karst-like properties, such as high permeabilities and enhanced fracture flow within them.

Sinkholes identified in the database have been plotted and the areas which drain into them in WC Map 3-7. These areas will require special consideration during the development of a source protection plan.

3.1.5.3 Village Well Fields

Village well fields are areas that will require special attention in the development of a Source Protection Plan. Village well field are those areas/villages that have no municipally operated water system, and rather rely on numerous private/shared systems, owned and operated by the landowners. There exists significant debate over the number of wells/homes required to delineate a settlement as a village well field, or whether regard should be had for density of wells/homes within the settlement. It is often difficult to define the boundary of an unorganized settlement. No definitive guidance has been established for the categorization of a settlement as a village well field.

These areas are of particular concern, largely because of the concentrated population, all utilizing on-site septic disposal systems. Private well head practices also tend to be less rigorous than that of municipal systems and poorly situated, improperly constructed wells present a dense distribution of potential pathways for the contamination of the aquifer. Once contaminated, nearby wells are likely to be contaminated without significant dilution due to the high density of homes in these areas. In essence, village well fields are of concern due to the fact that there exists significant threats, multiple potential pathways and a high population of receptors (i.e. water users) within a restricted area. These effects are further exacerbated by the fact that these areas have sporadic to non-existent treatment for potable water supplies. In effect, there are no "barriers" for drinking water protection in these areas.

No comprehensive mapping of these areas has been made available for the development of a source protection plan at this time. A list of significant communities that lack any municipal system is provided in Appendix C, and was developed by canvassing municipal and conservation authority staff. However, there also does not exist a standardized or recommended methodology for evaluating the potential vulnerability within village well fields. This should be considered a significant data gap that needs to be addressed prior to development of a source water protection plan.

3.2 Surface Water Vulnerability

Delineating areas that are susceptible from surface water bodies is a more complicated task than for groundwater. In general, the natural susceptibility of a given watercourse is defined by the soils, slope, and precipitation patterns of its drainage area. The other major factor contributing to the susceptibility of a given watercourse is the land use and land management practices within its drainage area. Although soil, slope, and precipitation data are readily available, susceptibility cannot be accurately defined without considering land use and land management. These data are often outdated and in constant flux, as land management practices vary seasonally, and between landowners.

Overall, three approaches for determining the susceptibility of a water course have been utilized, including: the use of the Universal Soil Loss Equation (USLE) and Modified USLE (MUSLE) developed for and utilized by the US Department of Agriculture (Wishmeier and Smith 1978); the time-of-travel (TOT) approach, whereby a given period of time for water running off the ground takes to join a receiving watercourse is evaluated, and; the use of standard runoff hydrograph approaches to hydrologically model the drainage area. Of these approaches, the hydrologic modeling approach is the most fruitful and accurate.

In the study area, very little data exists for surface water vulnerability, with the exception of the Run-off index created as part of the phase II pilot study completed by the Maitland Valley and Saugeen Valley Conservation Authorities, and flood plain mapping created for emergency management.

3.2.1 Surface Water Vulnerability – Runoff Index

A Runoff Index (RI) was created as part of the phase II pilot study completed by the Maitland Valley and Saugeen Valley Conservation Authorities. The goal for development of this index was to provide a guide for landowners about the risk of runoff from their property, where a higher risk for runoff has a greater potential for contaminating surface water with sediment, nutrients and/or bacteria. The chosen methodology was designed for and is more suited to an agricultural watershed.

Methodology

The RI includes a variant of the Time of Travel approach, incorporates actual runoff hydrographs in the calculation. A modified unit hydrograph approach was used to calculate the runoff proportion. The main modification is that the runoff proportion is calculated from the soil and slope characteristics for each pixel in the watershed versus an area weighted single value for an entire catchment (i.e. using a lumped approach). The major variables for the calculation were:

1) The curve number (CN) for each pixel was assigned based on the soil hydrologic group and percent slope. The initial CN value range was based on a row crop scenario. This will overestimate runoff of permanent pasture and hay and grain systems. See table Appendix D for a listing of soil types and hydrologic soil groups. In selecting the CN value, the higher end of the range was selected since the watershed condition was assumed to be saturated, or condition III. This is to simulate the times of the year when soil is more likely to be bare and wet (i.e. spring). This will again lead to an overestimate of the amount of runoff that would occur when the soil is drier.
2) Deep percolation (FC) was determined by soil type. See Appendix D for a listing of soil types and FC values.

Based on water quality information in response to rainfall, and based on rainfall patterns, an Atmospheric Environment Service (AES) 50 mm, 8 hour storm with 30% distribution was selected.

An important consideration is that the estimated runoff is conservative and is based on a worst case (i.e. highest potential runoff) scenario. For defining levels of runoff potential, the following categories are used, based on the percentage of the rainfall (50mm) that would run off from the 8 hour storm:

Low – 0- 15% of the rainfall amount ran off
Medium – more than 15% to 30% of the rainfall amount ran off
High – greater than 30% of the rainfall amount ran off

Limitations

These estimates are for each pixel in the watershed and do not take into account runoff water derived from upslope areas. Also, this methodology does not indicate areas that are contaminating surface water since no transport function is included. A steep slope may produce runoff, but if it infiltrates on more level ground before reaching a watercourse it may have no impact on water quality.

Results

WC Map 3-8 shows the RI calculated for the Maitland valley portion of the Study Area. The maps highlight areas of high slopes and/or finer grained soils, corresponding to subwatersheds considered to be dependant on precipitation for flows, versus those which are dependant on groundwater discharge. This methodology is valuable for identifying areas at a broad scale where erosion and subsequent loss of soil may be an issue from an agricultural perspective, however, it does not differentiate between areas closer or further from a given water course.

3.2.2 Modified RI

The RI developed as part of the phase II pilot study completed by the Maitland Valley and Saugeen Valley Conservation Authorities was modified for the middle Maitland watershed in order to accommodate for distance from the watercourse. This was accomplished by overlying the RI layer and a series of buffers around watercourses in a GIS environment. Table 3-3, below is the matrix used to define these areas.

Table 3-3: Matrix for identifying vulnerable areas for the modified RI

Runoff Risk Rating	100 m	250 m	500 m
Low	6	7	7
Moderate	3	4	5
High	1	2	3

By accommodating distance to watercourses, the impact of given activities in specific areas can be more easily related to water quality in the watershed. WC Map 3-9 shows the mapping developed for the middle Maitland watershed.

3.2.3 Flood Plain Mapping

In general, those areas located closest to a watercourse are thought to contribute more to the water quality of the watercourse as a whole. In particular, those areas which are periodically flooded can be considered vulnerable areas, not only for the potential damage caused by flooding, but also due to the potential water quality impacts from flood waters over the lands themselves.

Flood plain mapping has been created for most major branches of the Ausable, Bayfield and Maitland Rivers for the purpose of emergency management and the development of zoning by-laws. These maps are created from hydraulic models that simulate water levels during flood events of varying magnitude. It has not been established what magnitude flood event, typically measured as a probability of occurrence within a given time period (i.e. a 1 in 5 year flood is less magnitude than a 1 in 100 year flood), should be considered to define a vulnerable area. Nor is it well understood what impacts a discrete flooding event has on the long term water quality of a watercourse.

No comprehensive mapping exists for flood plains at this point. However, flood plains, typically the regional (1 in 350 years) or 1 in a 100 year floods, have been incorporated into zoning by-laws where they exist. As a result, very few new structures have been permitted within flood plains.

As part of source protection planning, floodplains could be considered and policies within them revisited in order to protect surface water bodies.

3.3 Surface Water Intakes in the Nearshore of the Great lakes

The Great Lakes region is home to 37 million Canadians and Americans, and more than 40 million people rely on the Great Lakes drainage basin for their drinking water. The Great Lakes are the source of drinking water for approximately 75 per cent of Ontario's population. Water from the Great Lakes also drives the region's economy. Every day, 56 billion gallons of water provide for municipal, agricultural and industrial uses. More than 250 million tons of cargo, primarily iron ore, coal and grain, are shipped on the Great Lakes annually. The shipping industry alone brings $3 billion to the region each year and provides 60,000 American and Canadian jobs. The Great Lakes region also provides for nearly 30 per cent of American and Canadian agricultural production. One-third of the land within the Great Lakes drainage area is used for agriculture, primarily for corn and soybean production and for livestock (International

Joint Commission 2004). The multiple-use nature of the water in this unique ecosystem means that a more complete understanding of activities that occur within the Great Lakes drinking water intake area may be a complex undertaking.

There are three main types of drinking water intakes from the surface water of the Great Lakes. Water intakes may (1) extend into the lake (offshore), (2) be located within the nearshore lake environment, or (3) be within a connecting channel. Various considerations should be made for the water intakes at the different locations. The primary intent of this section is to review potential factors that may affect water quality for Great Lake nearshore intakes. A secondary component of the paper is to identify protection options for drinking water intakes within nearshore environments of the Great Lakes. This review is intended to provide a general overview of factors influencing nearshore water quality and potential protection options; a more comprehensive discussion of these issues can be found in the citations listed in the reference section of this report. Further, this discussion will focus on specifics of the southeast shore of Lake Huron.

3.3.1 Nearshore Water Quality

The nearshore is recognized as the interface between the land and the open lake. Edsall and Charlton (1997) defined the various components of the Great Lakes ecosystem and suggested that the nearshore waters occupy a band of varying width around the perimeter of each lake between the land and the deeper offshore waters of the lake. This band is thought to be approximately 5 to 10 km from shore (Howell 2005, pers. comm.). The band is narrowest where the slope of the lake bed is steep and continuous. More specifically, Edsall and Charlton (1997) defined the nearshore waters as the area that begins at the shoreline, or the lakeward edge of the coastal wetlands, and extend offshore to the deepest lakebed depth contour, where the thermocline typically intersects with the lake bed in late summer or early fall.

In the Great Lakes, offshore chlorophyll and total phosphorus (TP) concentrations have met or exceeded target concentrations set by international agreement. The 1972 Great Lakes Water Quality Agreement has resulted in reduced phosphorus loadings to the Lakes. For example, in Lake Erie, TP from tributaries, municipal and industrial sources and connecting channels declined from a high in 1968 of 27,944 tonnes to 12,349 tonnes in 1982 (Fraser 1987). Yet, deterioration of nearshore conditions as indicated by the resurgence of *Cladophora* in the 1990s (Hiriart-Baer 2003), and recent postings (i.e., advisories or closures) of Great Lake beaches (Howell et al. 2005) have suggested that the nearshore Great Lake environment is not comparable to the more oligotrophic offshore conditions.

In the nearshore zone of the Great Lakes, the principal sources of nutrients are multiple and complicated with respect to timing and location. Edsall and Charlton (1997) listed combined sewer overflows (CSO), sewage treatment plant effluents and tributaries draining agricultural and rural areas as primary nutrient sources. Fraser (1987) acknowledged that control measures aimed at non-point sources of phosphorus would be required to further reduce TP loadings.

The nearshore lake environment is a primary concern for the public as it is this area that the public is most likely to observe and use. Drinking water intakes from the nearshore of the Great Lakes serve 75 to 80 per cent of Ontarians. Assessment of the potential threats and risks to these drinking water sources will be included in the upcoming efforts under source water protection.

3.3.1.1 Factors affecting nearshore water intake zones

Characteristics of the nearshore zone that potentially influence intake water quality include:

- local current patterns;
    - thermal regime (thermal bars, upwelling/downwelling);
    - prevailing wind (direction and velocity);
    - long term and shorter term seasonal weather patterns (periods of precipitation, storm events);
    - local bathymetry (i.e., proximity to a shallow bay may mean that bottom sediments are re-suspended into the intake water column);
- tributary characteristics (i.e., proximity, tributary discharge, water quality of tributary, watershed activities);
- other local influences (shipping routes and activities, recreational use and shoreline modifications);
- sediment and substrate characterization in the local lakebed (benthic nepheloid layer);
- biology and
- atmospheric deposition (Ontario Ministry of the Environment 2006).

3.3.1.1.1 Water Movement

There are many processes that result in water movement in the Great Lakes. Offshore currents are influenced by the morphometry of the lake basin, the lake's stratification structure and exposure to wind (Wetzal 1983). Beeton and Saylor (1995) suggested the primary factors influencing Lake Huron water movement include hydraulic currents and currents from wind and spatial gradients in water density due mainly to temperature differences. Hydraulic discharge results from lake inflows and outflows. In Lake Huron, for example, hydraulic currents are created by inflows from the St. Mary's River from Lake Superior and the Straits of Mackinac from Lake Michigan, and the outflow from St. Clair River.

Wind-driven transport is a dominant feature of circulation in the lakes. Waves are generated by the wind blowing over the lake. Prevailing winds along the southeast shore of Lake Huron are from the west and northwest with the most severe storms from the north and northwest (Reinders and Associates 1989). The magnitude of the waves is dependent upon wind speed, the duration of the wind, and the fetch (distance over which the wind blows). Wind can also result in oscillations at the lake surface and internally deep with the basin. Strong winds may also displace more water at one end of the lake than at the other. After the cessation of the wind, the tilted water flows back and overshoots equilibrium. The resulting rocking of the entire water mass is termed seiches (Wetzal 1983). Potential for seiche conditions is inversely related to lake depth. Because of Lake Huron's great depth, storm surges are usually small in magnitude (Beeton and Saylor 1995).

Horizontal pressure differences caused by wave motions and long-lasting spatial variations in thermocline depths also cause currents. A thermocline results when stratification occurs in dimictic lakes (i.e., lakes that mix twice a year). The water column in dimictic lakes mixes completely in the spring and the fall. In the summer months, the upper, surface waters become warmer and less dense than deeper waters (water is most dense at 4 °C). Density differences in the water cause increased resistance to mixing of the waterbody and the water column becomes thermally stratified. The thermocline is that layer of water where there is maximum rate of water temperature change with depth. Accumulations of dense or light waters produce pressure gradients that result in water movement from high to low pressure.

In Lake Huron, Howell et al. (2005) summarized offshore circulation patterns of the central basin, west of the Bruce Peninsula as characterized by a cyclonic gyre. In seasons of stratification (summer and winter) currents move southward on the west coast and turn northward on the east coast.

Nearshore currents are complicated by local winds, lake bathymetry and geographic features of the shoreline (Howell et al. 2005). As waves travel from offshore to the nearshore, the wave shape changes; the height of the waves is determined by the nearshore bathymetry (i.e., the depths of water close to the shoreline) (Reinders and Associates 1989). The Lake Huron Centre for Coastal Conservation (2004) noted that studies conducted by the Ontario Ministry of the Environment in 1984 found that sediment resuspension (and associated increase in pathogen concentration) was linked to the slope geometry of the nearshore ramp. Gradual foreshore slopes at Ipperwash and Sauble Beach result in waves breaking further offshore. However, the fine sand conditions that are also related in part to the coastal features supported a higher concentration of bacteria than the coarse sand at Grand Bend or Goderich.

Table 3-4: Nearshore slope and sediment characteristics of beaches along the southeast shore of Lake Huron (taken from Lake Huron Centre for Coastal Conservation 2004)

	Ipperwash	Grand Bend	Goderich	Sauble
Slope (%)	3	30	40	3
Substrate	fine sand	coarse sand	coarse sand	fine sand

Water temperature differences can also be established between nearshore and offshore areas. Seasonal stratification in the Great Lakes is influenced by the formation of thermal bars. Warm thermal bars occur in the spring, when nearshore shallow waters warm faster and are separated from cooler offshore waters. Cold thermal bars may occur in the fall, when nearshore waters cool faster than warmer offshore waters. Water column mixing, due to wind, is more common in the fall and may result in fewer cold thermal bars at this time of year. Thermal bars along nearshore areas create a sharp density front which can reduce the mixing with offshore waters, trapping nutrients and suspended solids from the nearshore area. Meteorological conditions such as air temperature and wind mixing affect the rate at which thermal bars progress offshore to the midlake (Edsall and Charlton 1997). Thus, the timing and the duration of the thermal bars in the spring and the fall may influence nearshore water quality (Howell et al. 2005).

Movement of water and the constituents suspended in the water column ensures that water quality conditions of the nearshore are variable and may be unpredictable.

3.3.1.1.2 Tributary effects

Although there is a seemingly obvious connection between conditions in the tributaries and conditions in the nearshore, only infrequent attempts have been made to directly relate nearshore water quality to tributary water quality and discharge volume (Howell et al. 2005). For example, Edsall and Charlton (1997) suggest that the suspended material in the Great Lakes was more a function of shoreline erosion rather than tributary input. Edsall and Charlton (1997) also cited a lack of information regarding pesticide loadings and did not mention nutrient contributions from tributaries. Although not in specific reference to the Great Lakes, general sources of nutrients to water bodies include municipal and industrial wastewater discharge, agricultural fertilizer use, aquaculture operations, forestry practices and atmospheric deposition (Chambers et al. 2001). Literature that relates nearshore nutrient enriched conditions in the Great Lakes specifically to local tributaries is limited.

The following section will focus on an example in the southeast shore of Lake Huron to illustrate potential effects of a tributary on nearshore water quality conditions

3.3.1.2 Lake Huron Case Example

In 1977, the Upper Lake Reference Group, the Ontario Ministry of the Environment and Environment Canada concluded that the water quality of Lake Huron was excellent except in localized nearshore areas (*in* Jackson et al. 1985). Areas near the outlet of the Saugeen River, Maitland River and Parkhill River (mistakenly referred to as the Ausable River) showed signs of eutrophication and further investigation of these areas was conducted in 1980. In 1985, Jackson et al. (1985) concluded that nutrient entrapment from tributary and municipal (sewage treatment plant) loadings, storm-induced sediment resuspension, and increased shoreline erosion accounted for the mesotrophic conditions in the nearshore enriched zones.

A more current review of the water quality data from two water supply intakes from southeastern Lake Huron between 1976 and 2004, may in part contribute to the discussion about the potential impacts of tertiary tributaries to nearshore water quality conditions. Beginning in 1976, indicators of water quality have been collected twice a month year-round at the intake of municipal water treatment plants. Although, trends in total phosphorus (TP) concentrations for 18 municipal water treatment plants in the Great Lakes were recently evaluated (Nicholls 2001), this information has not been reported to water managers in a form that highlights the nearshore Lake Huron conditions. WC Map 3-1 depicts the two drinking water intakes in the Source Protection Region: the Lake Huron Primary Water Supply System (Port Blake) and the Goderich Water Treatment Plant.

Water quality data from the Goderich and Port Blake (north of Grand Bend) facilities were examined with an exploratory procedure, LOWESS (locally weighted regression), to detect potential time series trends (SYSTAT version 11, 2004). Difference in concentrations for two variables (TP and nitrate) between the two locations was determined with non-parametric Mann-Whitney U Tests (SYSTAT version 11, 2004).

Graphs of the water quality data appear as box and whisker plots. The box length shows the central 50 per cent of the values from the 25th percentile to the 75th percentile. The median is indicated as the central line within the box. The whiskers and asterisks denote 1.5 and 3 times, respectively, the absolute values between the 25th percentile and the 75th percentiles. The empty circles represent values that are beyond 3 times the absolute values between the 25th percentile and the 75th percentile.

Overall, the concentrations of the nutrients, TP and nitrate, were greater at the Goderich water intake facility compared to the Port Blake intake facility (Table 3-5, Figures 2 and 3). Further, trends in TP and nitrate over approximately the last 30 years appeared to be similar at the two facilities. Exploratory analyses suggest a decrease in TP concentrations since the 1970s and potentially increasing nitrate concentrations at both locations since 1976.

Table 3-5: Summary of water quality from the water intake plant in Goderich and Port Blake in Lake Huron (1976 to 2004)

Facility	Total Phosphorus (mg/L) PWQO = 0.02 mg/L	Nitrate (mg/L) CWQG = 2.93 mg/L
Goderich		
n	1384	1388
median	0.018	0.58
range	0.00 – 0.380	0.00 – 6.36
90th percentile	0.065	1.80
Port Blake		
n	1104	1105
median	0.012	0.34
range	0.00 – 0.16	0.00 – 3.70
90th percentile	0.03	0.67

(PWQO – Provincial Water Quality Objective and CWQG – Canadian Water Quality Guideline)

Phosphorus

Total phosphorus includes dissolved phosphorus and forms bound to organic and inorganic material in water. In many aquatic systems phosphorus is the nutrient limiting primary production (i.e., plant growth). When phosphorus is added the first response may be increased productivity, and although this may be an aesthetic concern, increased productivity is beneficial to aquatic life. However, beyond a certain point detrimental effects become apparent due to eutrophication from nutrient over-enrichment.

The median TP concentration at the Goderich water intake facility (median = 0.018 mg/L) over the past 28 years is similar to the Provincial Water Quality Objective for TP (PWQO = 0.02 mg/L). The provincial objective was established to prevent eutrophication in lentic systems. The median TP concentration at the Port Blake intake facility between 1976 and 2004 was significantly lower than the objective (median = 0.012 mg/L; Mann-Whitney U statistic 988358.5; $p < 0.001$). However, concentrations of TP at the Port Blake intake facility were in the range of concentrations that would be considered to contribute to nearshore nutrient enrichment conditions (i.e., the 90th percentile = 0.03 mg/L) (Figure 2).

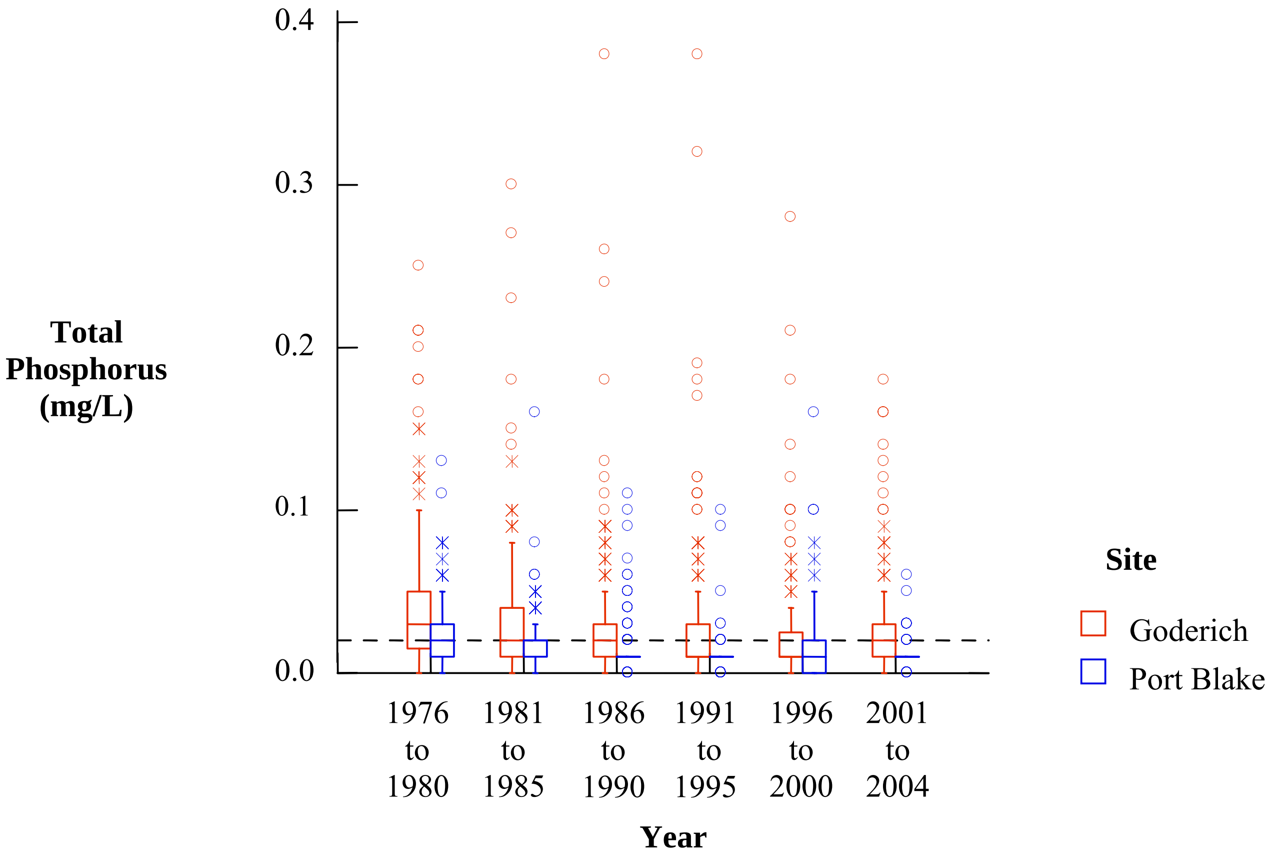

Figure 3-1:Total phosphorous concentrations (mg/L) at Goderich and Port Blake water intake facilities (1976 to 2004)
The Provincial Water Quality Objective to prevent eutrophication in lakes (0.02 mg/L) is indicated with a dashed line.

Nitrate
Nitrate is the primary source of nitrogen for aquatic plants. All forms of inorganic nitrogen (nitrite and ammonia) have the potential to undergo nitrification to nitrate. In well-oxygenated systems, increasing concentrations of inorganic nitrogen increase the risk of algae blooms and eutrophication.

The Canadian Council of the Ministers of the Environment (2002) suggested that nitrate concentrations above 0.9 mg/L were generally associated with eutrophic conditions (i.e., algae and macrophyte blooms, shortened food chains and changes in the aquatic community). Between 1976 and 2004, the median nitrate concentration at the Goderich water intake facility was 0.58 mg/L. Overall, these concentrations were in the range of concentrations that would be considered to contribute to nearshore nutrient enrichment conditions (i.e., the 90th percentile = 1.80 mg/L) (Figure 3).

Nitrate concentrations at the Goderich station rarely exceeded the water quality objective of 2.93 mg/L (the draft Canadian Water Quality Guideline for the protection of aquatic life from direct toxic effects; CCME 2002) and never exceeded the drinking water guideline of 10 mg/L (CCME 1978). Nitrate concentrations at the Port Blake facility (median = 0.34 mg/L) were significantly lower than at the Goderich facility (Mann-Whitney U Test Statistic 11933230; $p < 0.001$), between 1976 and 2004.

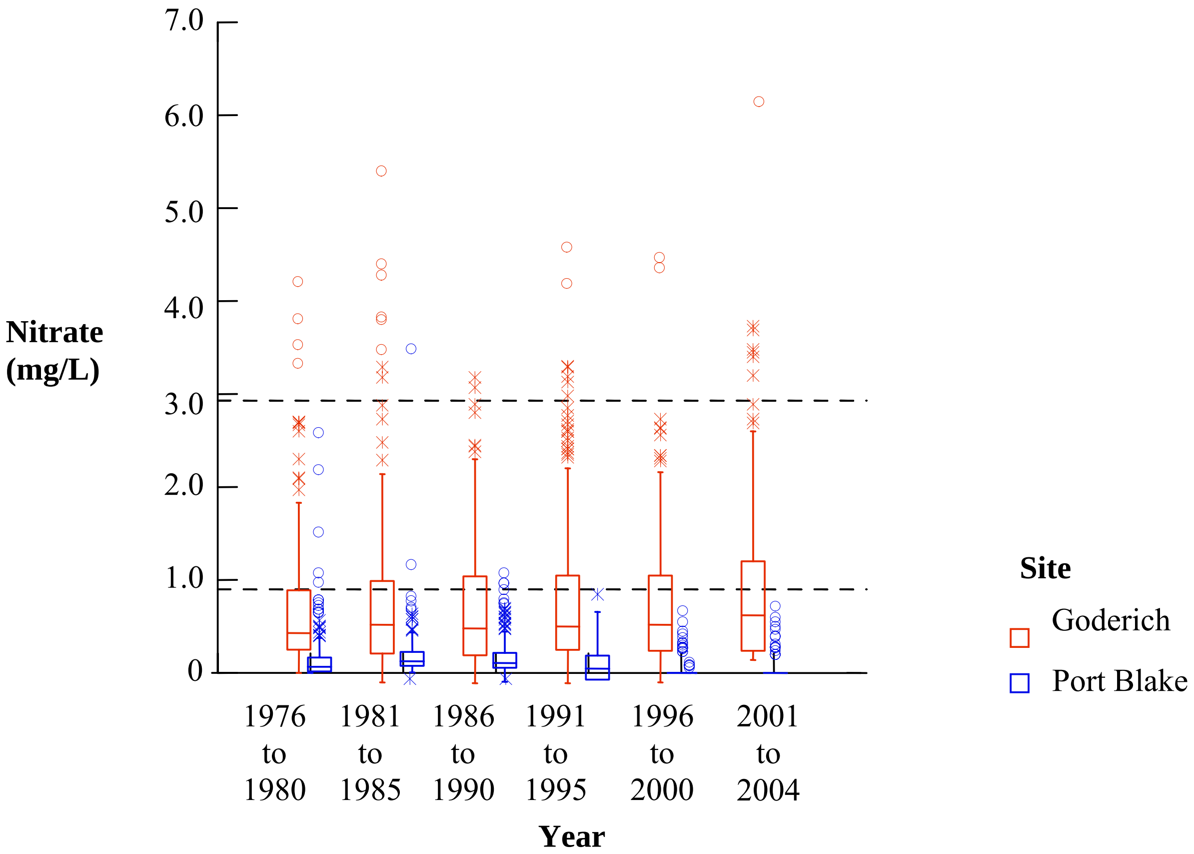

Figure 3-2: Nitrate concentrations (mg/L) at Goderich and Port Blake water intake facilities (1976 to 2004)
The Canadian Council for Ministers of the Environment (CCME) standard to prevent eutrophication (0.9 mg/L) and the CCME draft guideline for the protection of aquatic life (2.93 mg/L) are indicated with dashed lines.

Results
The concentrations of the nutrients (TP and nitrate) at the Goderich facility were in the range of contributing to eutrophic conditions in the nearshore zone of Lake Huron, and were significantly greater than the concentrations at the Port Blake facility. Although both intakes are located in the nearshore environment of Lake Huron, the Goderich facility is directly within the zone of influence of a tertiary tributary, the Maitland River. The data presented in this analysis suggests that the Maitland River is contributing to the nutrient-enriched conditions of the nearshore environment of Lake Huron.

Further, Steele et al. (2006) also indicated that there are potentially higher concentrations of nutrients in the Ausable, Bayfield and Parkhill rivers compared to the Maitland River. There are no water intake plants within the zone of influence for these rivers. Thus, there are no long-term data to illustrate the potential impacts these tributaries may have on the nearshore of Lake Huron. However, Jackson et al. (1985) indicated that lake water quality was moderately enriched at Grand Bend, near the outlet of the Parkhill Creek, the Maitland River in Goderich and the Saugeen River in Southampton. It is therefore reasonable to suggest that the tributaries of the southeast shore of Lake Huron are contributing, and have been contributing to the enriched conditions in the nearshore.

Currently there are attempts to document the volume and the quality of the discharge from selected Lake Huron tributaries (Howell et al. 2005). In Lake Huron, determining the volume of the discharge may influence the size of the mixing zone, while identifying the concentration of the pollutant will help to determine the contaminant load (Howell et al. 2005). Understanding these important factors will help to determine the potential nutrient enrichment impacts of tertiary tributaries upon the nearshore.

3.3.1.3 Other Local Influences

One consideration that may be beyond the scope of an intake zone assessment is the potential impact of a major chemical spill in the Great Lakes. In 2004, the International Joint Commission expressed concern about the increase in major spills in the connecting channel from Lake Huron to Lake Erie between 2002 and 2004. For example, in April 2002, a large oil spill (estimated at 378,500-1,000,000 litres) occurred in the Rouge River. In August 2003, a major regional power blackout led to several overflows from wastewater treatment plants and an unacceptable delay in reporting of a vinyl chloride spill in Sarnia. In February 2004, a discharge of methyl ethyl ketone and methyl isobutyl ketone was discharged into the St. Clair River. Water treatment plant operators downstream are concerned about the frequency with which they have been closing their water intakes due to these spills (International Joint Commission 2004).

Other shoreline considerations for nearshore environments described more completely by Edsall and Charleton (1997) are the potential effects of combined sewer outfalls (CSOs), wildlife and other industrial activities.

3.3.1.3.1 Sediment Characteristics

Sediment and substrate characterization in the local lakebed will also affect the variability in nearshore water quality conditions. Sediment plays a major role in the transport of P in aquatic systems (Stone and English 1993). The availability of P for lake algae depends on the species of P attached to the fine-grained material (Stone and English 1993) and the patterns of sediment transport (particularly deposition, and re-suspension rates) (Howell et al. 2005). The factors that determine deposition and re-suspension rates are also variable and dependent on particle size and density, water temperature, total suspended material (Rosa 1985) and nearshore wave energy (mediated by bathymetry and geographic features) (Howell et al. 2005).

3.3.1.3.2 Biology

Hecky et al. (2004) have suggested that conditions of nutrient enrichment in the nearshore may be exacerbated by an introduced dressenid mussels. Zebra mussels (*Dreissena polymorpha*) are an exotic and invasive mussel species that were first noticed in 1988 in Lake St. Clair. Hecky et al. (2004) summarized the current supposition that these benthic organisms are sequestering nutrients that had previously been transported offshore. An important source of nutrients to the nearshore Great Lake environment is non-point sources (Fraser 1987). Stone and English (1993) found that most of the non-point phosphorus is fine-grained particulate material. Prior to dreissenid colonization the fine-grained material was thought to have been transported offshore. The filtering and potential retention of this material by the zebra mussels is currently thought to be contributing to nutrient enriched conditions of the nearshore.

3.3.1.3.3 Atmospheric Deposition

When pollutants, both natural and anthropogenic, are released into the atmosphere, they can eventually return, or be deposited back to the land or water. This process occurs through wet deposition, dry deposition and air-water gas exchange, and can contribute significant pollution loadings to the Great Lakes. Such compounds include, but are not limited to sulphur, nitrogen and mercury compounds, other heavy metals, anthropogenic pesticides and industrial by-products (US EPA 2001). Nitrogen compounds are of concern because of the eutrophication that occurs with excessive nitrogen loading. Burning of fossil fuels and agricultural activities (i.e., fertilizer application, feedlots, waste lagoons) are the main anthropogenic sources of nitrogen, while forest fires and microbial activity contribute to the natural sources of nitrogen (US EPA 2001). Unfortunately atmospheric deposition is not a localized problem and contaminants can travel and be deposited extensive distances from their source.

The Integrated Atmospheric Deposition Network (IADN) is a joint program (US and Canada) formed to assess the impact of atmospheric deposition. Estimates on pollutant loadings to the Great Lakes are made every two years (Blumberg et al. 2000).

3.3.1.3.4 Summary of Factors Influencing Nearshore Water Quality Conditions

In a recent review of Lake Huron's nearshore water quality information, Howell et al. (2005) summarized the microbiological studies that had been conducted in 1984 and 1985 by the Ministry of the Environment (Palmateer and Huber 1984 *in* Howell et al. 2005). Bacteria concentrations tended to be higher in beach water samples on days when the lakes were considered "rough" and a number of factors were examined to determine what contributed to "rough" water conditions (Table 3 – from Howell et al. 2005). The specific scenarios that contribute to roughness and enhanced bacterial concentrations were documented to be numerous. These factors, when combined with the broad lake dynamics (as discussed above - thermal gradients, wind direction, speed and duration and tributary runoff) ensure that nearshore water quality conditions tend to be variable and difficult to predict.

Table 3-6: A summary of the factors that effect bacteria concentrations along the south-east shore of Lake Huron (taken directly from Howell et al. 2005)

Factor	Effect on Bacteria	Remarks
rainfall events	increased concentrations in some instances but not all	some locations may have too many confounding inputs to respond to rainfall alone (e.g., Goderich)
lake roughness / wave height	increased concentrations due to sediment resuspension	measurements somewhat empirical and not quantitative
hours of sunlight	decreased concentrations	ND
swimmer density	some increase concentrations	ND
number of seagulls	no correlation	ND
plumes from major rivers	increased concentrations when wind directed plume towards the beach	related to wind direction
wind direction	south-westerly winds increased concentrations	influenced lake roughness, wave height and river plume direction
storm sewers	little effect except in unique circumstances	sewage inputs discovered and remedial action taken to reduce bacterial counts
sewage treatment plant (Goderich)	difficult to assess	beaches at Goderich had potential inputs from too many sources
sewage bypass events	only one event recorded – not significant to data collected during study period	
boats and marinas	no significant contribution	
agricultural watercourses	highest Bacterial concentrations within creeks, high levels at drainage points,	some evidence that contamination at beaches coming from these drains
sediment resuspension	higher concentrations with greater turbidity	anecdotal as data isn't presented in this manner. Factors and events that cause sediment resuspension also result in increased bacterial levels.
human fecal input	localized situations (Duffus Creek and Walkers Drain)	evidence came from investigation of a variety of factors
agricultural input	localized situations and some microbial source tracking evidence and investigative observation	human fecal input not excluded Some bias due to locations chosen for source tracking studies

ND: Not discussed in detail in these reports

3.3.2 Intake Protection Zone

It is well understood that the assessment of intakes that extend into the Great Lakes presents a difficult scoping exercise. The United States Environmental Protection Agency (US EPA) has devised a protocol that would help to characterize the susceptibility of the intake area with respect to local conditions (Brogren and Sweat 2000). In 1999, a working group from the US EPA Region V (six western Great Lake states) was formed to provide guidance on assessments for drinking water from the Great Lakes. The working group consisted of representatives from the Great Lake states, water utilities with intakes on the Great Lakes, US EPA - Region V representatives and other interested parties. In 2000, the working group recommended an assessment protocol for Great Lake sources.

The preliminary assessment involves an initial survey of local water impacts:

i) review intake location studies,

ii) interview senior operators at the treatment plant to understand raw water quality fluctuations, and

iii) analyse water quality records (particularly bacteriological concentrations, alkalinity and turbidity).

The next step is to determine the Critical Assessment Zone (CAZ). Two factors are assumed to determine the sensitivity of the intake; length of the intake pipe and water depth of the intake structure. Shallower, nearshore intakes are considered more sensitive to shoreline influences than offshore, deep intakes.

If the assessment indicates that intake is not impacted by potential shoreline contaminants, the assessment should reference general Great Lakes water quality (Michigan Department of Environmental Quality 1999). This critical zone assessment, based on linear distance, has the potential to overlook the consequences of local currents moving contaminants to within the intake zone. The preliminary assessment requirements to analyse local water quality conditions should help to ensure that offshore, typically more oligotrophic conditions, are not used for analyses in inappropriate situations in the US.

In Ontario, the draft guidance for the analysis of surface water vulnerability (Ministry of the Environment 2006) suggests as a first step the need to characterize intake information such as:

- technical characteristics related to the intake (i.e, depth of crib and length of intake pipe);
- discussions with the water treatment plant operators about response times to shutting down the plant;
- review of existing engineering reports with information regarding the hydrodynamic and hydrological conditions;
- bathymetry of the lake bed near the intake;
- limnology (e.g., lake thermal structure) in the intake area;
- local and regional current/flow and drift patterns and vectors;
- prevailing wind direction and intensity;
- long term and seasonal weather patters as they influence wave generation, magnitude and direction;
- a raw water quality (i.e., bacterial concentrations, taste and odour compounds, suspended solids) profile;
- local watershed influences;
- local and regional shipping routes and patterns;
- local recreational uses;
- historical shoreline and substrate trends;
- historical land uses; and
- shoreline modifications.

The purpose of delineating zones around the Great Lakes intakes is to protect them from immediate contaminants that might enter from nearby areas or known sources. In Ontario, two zones have initially been proposed. The first zone (Intake Protection Zone 1 - IPZ-1) is a 1 km radius around the intake crib. The second zone (IPZ-2) is proposed to account for the influence of shore watercourses. This zone has been determined by 1) water plant shut down response time and 2) average maximum water velocity. The influence of variable or fluctuating currents should be considered under the IPZ-2 determination.

In both the US and Ontario initial water assessments, the survey of conditions at the intake (and within 1 km radius or the local plant response time) is critical to determining risk to these sources of drinking water. Although the zones are necessary for risk management decisions, it is important to understand that the complex and interacting factors (as discussed above - thermal gradients, wind direction, speed and duration and tributary runoff) ensure that nearshore water quality conditions tend to be variable and difficult to predict. For example, along the south east shore of Lake Huron there will be the direct contributions that the Maitland River has on the Goderich intake facility and this will be important to categorize from a risk management perspective. However, due to the complex environment of the nearshore, nutrients and contaminants from tributaries outside of the intake protection zone or the critical assessment zone may also potentially influence intakes.

3.3.2.1 Conclusions for Great Lakes Intake Protection Zones

The Great Lakes are the source of drinking water for approximately 75 per cent of Ontario's population. Many of the drinking water intakes occur in the nearshore of the Great Lakes. Nearshore water quality is considered nutrient enriched compared to offshore waters which have a more oligotrophic condition. As reviewed in the preceding discussion there are many factors that contribute to nutrient enriched conditions of the nearshore. Although there is a seemingly obvious connection between conditions in the tributaries and conditions in the nearshore, more recognition of tributaries as conduits of non-point source pollutants, particularly nitrogen and phosphorus, may be required to address nearshore water quality issues.

The source protection planning process provides water managers with a choice to continue to treat nearshore diminished water quality symptoms (beach closures, aesthetic problems with algal blooms, drinking water intakes, problems with fisheries), or begin to identify and manage the source of the contamination. When faced with a particularly damaging ecosystem impact, policy responses tend to focus on treating particular symptoms, with little emphasis on focused on preventing the integrated sources of stress that cause these symptoms. Worte (2005) outlined how the water management sector in Ontario evolved with an issue based infrastructure in response to crisis situations. In Ontario, there are seven pieces of federal legislation and 15 pieces of provincial legislation that have jurisdiction over water issues. The different legislative requirements involve many agencies with conflicting objectives and policies and the potential to duplicate efforts. This approach is regarded as costly and may not be considered effective in ensuring good water quality in the nearshore lake environment.

The Watershed Based Source Protection Implementation Committee (2004) recommended that source water protection principles, strategies, and policies should be incorporated into existing Great Lakes programs and resulting agreements so that they are protected and improved as sources of drinking water. The source protection planning process provides such an opportunity, and has the ability to identify and remediate pollution issues most directly, or most likely to impact nearshore waters. In order to do so the source protection planning process needs to embrace an ecosystem-based management approach. Ecosystem Management is an integrative, interdisciplinary, adaptive, and collaborative approach to policymaking, planning, and management. It is grounded in the best scientific information available and recognizes uncertainties and the understanding that human activity and ecosystems are inextricably linked.

The goal of ecosystem management is to sustain and/or restore ecosystem integrity and biological diversity at all spatial and temporal scales through scientific understanding and collaborative decision-making (Randolph 2003). Watershed based approaches to land use management offer the best opportunity to minimize negative impacts associated with non-point sources of nitrogen and phosphorus (Carpenter and Lathrop 1999).

Globally, one of the greatest environmental threats to human populations remains access to safe water and sanitation (World Health Organization 2006). The amount of fresh water on earth is very small in comparison to the water of the oceans. The Laurentian Great Lakes of North America - Lakes Superior, Huron, Michigan, Ontario and Erie - constitute the largest mass of fresh water on earth with a volume of liquid 24,620 km^3, or 20 % of the world's freshwater (Wetzal 1983). The immensity of this resource is matched by the paramount responsibility water managers in the Great Lakes basin have to improve nearshore conditions in these Lakes to ensure the continued access to safe and usable water.

3.4 Potential Future Sources of Drinking Water

Possible future source of drinking water is an issue that will be address in the Municipal Long Term Water Supply Strategies. Historically, there have been no issues related to water quantity as there is not much growth in the region. There may be occasions such as the development of the Greenfield Ethanol plant in Hensall where water quantity is insufficient. The abundance of groundwater and proximity to Lake Huron provide sources of drinking water for such cases. Water quality remains a greater factor in discussing future sources of drinking water.

3.5 Conclusions

Vulnerable areas have been defined using several different methodologies for both surface and groundwater resources. It is important in the development of the source protection plan for the study area to not only delineate these areas as accurately as possible, but also to understand the methodologies used to derive them. These methodologies are necessarily limited by the data available in developing them, as well as the scale at which they were developed. It is essential, therefore, to consider these limitations during development of the plan.

3.6 Data and Knowledge Gaps

Well Head Protection Areas

WHPAs are produced from models that incorporate a number of assumptions, parameters and boundary conditions. As more information becomes available, these models will be revised and WHPAs will be re-evaluated. In addition, models will only reflect current conditions, and will have to be revisited when additional development takes place and communities grow. As of the production of this document, municipal studies are still underway that delineate SWAT WHPAs for all large municipal wells in the study area. This information is currently a data gap but will be filled in the near future.

Intrinsic and Shallow Susceptibility Index Mapping

ISI mapping is intended for use at a regional scale; information for this mapping derives from the Well Water Information System (WWIS) which has a lack of information both for records of existing wells, but the location of known records. As well, it does not take into consideration the conditions of a well, which can play a role as a potential contamination pathway for an aquifer. ISI cannot be used locally and should not be substituted for a site-specific investigation performed by a professional. SSI can be a useful tool for defining where ISI needs to be refined, but SSI itself needs field verification.

Recharge/Discharge Areas

Like ISI, the procedure used to calculate recharge areas of bedrock aquifers also uses WWIS as a source for locations and elevations, and the information may be suspect. The procedure also ignores any horizontal flow of groundwater in overburden aquifers and it is a non-quantitative, conceptual geological method. Three-dimensional groundwater modelling may provide more accurate and hydrogeologically significant recharge areas.

Village field wells

Village field wells are an important category of vulnerable areas, but information on their location and records have not been released due to privacy issues. These areas are of particular concern due to the concentration of population in a village which use private on-site septic disposal systems and the fact that they create multiple pathways for potential contamination of an aquifer. Appendix D lists communities without a municipal system. At the current time, there is no way to assess the vulnerability of village field wells; this data and knowledge gap is significant and needs to be addressed before the construction of a source protection plan.

Surface Water Vulnerability-Runoff Index

Estimates of surface water runoff do not take into account runoff from upslope areas. A modified Runoff-Index has only been calculated for the Middle Maitland subwatershed, and this information would be useful to other areas of the SPR as it differentiates areas on their distance to a watercourse. Tile drainage cannot be taken into account because there is no reliable mapping available and because there is not a systematic and defensible method that currently exists.

Nearshore Water Quality

Literature relating to the effect of local tributaries on the water quality of the nearshore of the Great Lakes is limited; however the water quality data comparing Port Blake to Goderich indicates that the plume from the Maitland River affects the area around the intake at Goderich. There are currently attempts to document the effect of select tertiary tributaries of the nearshore (Howell et al. 2005) and this will help to understand the potential for nutrient enrichment of the nearshore by tributaries. The nearshore presents an environment which is difficult to predict – there are a number of factors that influence nearshore water quality including thermal gradients, wind direction, speed, duration and tributary runoff. These factors must be understood to determine how tributaries impact intake protection zones and to address water quality issues.

Table 3-7: Data Gap Reporting for the Vulnerable Areas Chapter of the Ausable Bayfield and Maitland Valley Watershed Characterization

WC Deliverable	Data Set Name	Data Gap Problem	Comment
WC WC Map 19 Vulnerable aquifers as defined in groundwater studies.		Does not exist	Need help from consultant.
WC WC Map 20 Identify potential future drinking water sources.		Does not exist	Need input from municipalities regarding MLTWSS.

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Appendix A: Generic Representative Permeability (K-factor)

Geomaterial	Representative K-Factor (dimensionless)	K-Value (m/s) @75% range	Highest K-Value (m/s)
Gravel Weathered dolomite/limestone Karst Permeable basalt	1	1.00E-01 1.00E-06 1.00E-03 1.00E-03	0.1
Sand	2	1.00E-2	1.00E-2
Peat (organics) Silty sand Weathered clay (<5m below surface) Shrinking/fractured & aggregated clay Fractured igneous & metamorphic rock Weathered shale	3	1.00E-3 1.00E-4 1.00E-4** 1.00E-4** 1.00E-5 1.00E-5***	1.00E-3
Silt Loess Limestone/dolomite	4	1.00E-6 1.00E-6 1.00E-6	1.00E-6
Weathered/fractured till Diamicton (sandy, silty) Diamicton (silty, clayey) Sandstone	5	1.00E-7 1.00E-7*** 1.00E-8*** 1.00E-7	1.00E-7
Clay till Clay (unweathered marine)	8	1.00E-9*** 1.00E-10	1.00E-9
Unfractured igneous & metamorphic rock	9	1.00E-13	1.00E-13

From Schedule C of the MOE Terms of Reference, November 2001.

Appendix B: Soil and Geology Values for SSI

The classes for estimating the permeability of the Quaternary Geology Units for the Maitland Valley CA watershed are listed below. Relative classifications were developed specifically for this project and may not be suitable for use in other applications or analysis.

Permeability Rating for SSI	Standard Code Unit Name from ABCA, MVCA and UTRCA Quaternary Geology Digitizing Project
Low	Catfish Creek Till: stony, clayey silt to silty sand matrix
Low	Cultural features: fill; man-made deposits
Low	Dunkeld Till (Huron-Georgian Bay lobe): silt matrix
Low	Elma Till (Huron-Georgian Bay lobe): stony, silt to sandy silt matrix
Low	Glaciolacustrine Deep Water deposits: clay, silt, silty and very fine sand;
Low	Maryhill Till (Erie lobe): clay matrix
Low	Modern Fluvial deposits: clay, silt, sand, gravel, muck; alluvial and stream deposits, deposited on modern flood plains
Low	Mornington Till (Huron-Georgian Bay lobe): silty clay matrix
Low	Organic deposits: muck, peat, marl; bog and swamp deposits
Low	Port Stanley Till (Erie lobe): silty clay to sandy silt matrix
Low	Rannoch Till (Huron lobe): silty clay to sandy silt matrix
Low	St. Joseph Till (Huron lobe): silt to silty clay matrix
Low	Stratford Till (Huron-Georgian Bay lobe): sandy silt matrix
Low	Tavistock Till (Huron-Georgian Bay lobe): silty clay to sandy silt matrix
Low	Wartburg Till (Huron-Georgian Bay lobe): clay matrix
Low	Wildwood Silts (Huron lobe): silt; lacustrine deposits
High	Bass Island Formation: dolostone
High	Bedrock: Undifferentiated
High	Bois Blanc Formation: limestone with chert
High	Detroit River Group: limestone, dolostone
High	Dundee Formation: limestone
High	Eolian deposits: fine sand, silt; dunes and sand plains
High	Eolian deposits: fine to medium sand; dunes and sand plains
High	Fluvial deposits: gravel, sand, silt; alluvial deposits
High	Glaciofluvial Ice-contact deposits: gravel; esker, kame, end moraine, ice-marginal delta and subaqueous fan deposits
High	Glaciofluvial Ice-contact deposits: sand, silt; esker, kame, end moraine, ice-marginal delta and subaqueous fan deposits
High	Glaciofluvial Ice-contact deposits: undifferentiated sand, gravel, silt and till; esker, kame, end moraine, ice-marginal delta and subaqueous fan deposits
High	Glaciofluvial Outwash deposits: gravel, gravelly sand; proglacial river and deltaic deposits
High	Glaciofluvial Outwash deposits: sand; proglacial river and deltaic deposits
High	Glaciolacustrine Beach and Shoreline deposits: coarse sand, gravel; beach, bar, deltaic, shallow water and nearshore deposits
High	Glaciolacustrine Shallow Water deposits: fine to medium sand; deltaic and nearshore deposits
High	Hamilton Group: shale, limestone

High	Lacustrine Shoreline deposits: sand, gravel; nearshore and beach deposits
High	Older Fluvial deposits: sand, gravel; alluvial deposits
High	Salina Formation: shale, dolostone, evaporites

Primary Material attribute of the quaternary Geology mapping and the corresponding SSI rating

Permeability Rating for SSI	**Primary Material Attribute Provincial Quaternary Geology Layer from OGDE**
Low	Clay, silt
Low	Clay, silt, sand, gravel
Low	Diamicton
Low	Organic Deposits
High	Gravel
High	Paleozoic Bedrock
High	Sand
High	Sand, Gravel
High	Silt, sand
High	Silt, Sand, Gravel

Appendix C: Potential Village Well Fields

The following is a list of communities with no municipal water treatment facilities, compiled by Municipal and Conservation Authority Staff, organized by Municipality.

Municipality	Community
North Wellington	Kenilworth
Minto	Teviotdale
Howick	Fordwich Gorrie Wroxeter Lakelet
North Perth	Monkton Kurtzville Atwood* Trowbridge Newry
Huron East	Ethel Cranbrook Egmondville Walton Winthrop
Morris and Turnberry	Lowertown Wingham Bluevale
North Huron	Auburn**
Ashfield-Colborne-Wawanosh	St. Helen’s Auburn** Nile Port Albert Lakeshore wells*** Fernhurst Glen/Bishop’s Subdivision Kingsbridge
Central Huron	Holmesville Londesborough Lakeshore wells***
Bluewater	Varna Kippen Bayfield*
West Perth	Dublin St. Columban Staffa Cromarty
South Huron	Kirkton
Huron Kinloss	Holyrood

*Portion of the village is serviced by municipal wells,
** Shared area between ACW, North Huron and Central Huron (1 municipal well in central Huron),
***many wells spread along entire shoreline.

Appendix D: Soil Values for Runoff Index

The values for the runoff index for soil hydrologic characteristics are listed below.
Values were used for this project that may not be suitable for other applications or analysis

Basin Runoff Forecast Unit Calibration of the Saugeen and Maitland Watersheds by Jack MacPherson 1978-1982.

		County	**Class**	**A Horizon (cm)**	**S %**	**Fc mm/hr**
Berrien Sandy Loam	Bes	Bruce	B-A	22.86	31.0	7.0
		Grey				
		Wellington				
	Bes	Huron	B-A	25.40	30.9	7.4
Bookton Sandy Loam	Bos	Bruce	B-A	20.32	31.0	7.0
		Grey				
		Wellington				
	Bos	Huron	B-A	12.70	30.9	7.0
Bottom Land	BL	Bruce	B	30.48	31.3	6.1
	BL	Grey	B	30.48	31.3	6.1
	BL	Wellington	B	30.48	31.3	6.1
Brady Sandy Loam	Bsl	Bruce	B-A	33.02	31.0	7.5
	Bsl	Grey	B-A	30.48	31.0	7.0
	Bs	Wellington	B-A	20.32	31.0	7.6
	Brs	Huron	A-B	20.30	33.0	8.9
Breypen	Bp	Bruce	B-D	2.54	26.0	3.0
	Bp	Grey	B-D		26.0	3.0
		Wellington				
Bridgman Sand	Bis	Bruce	B	15.24	24.4	6.3
		Grey				
		Wellington				
Brighton Sand		Bruce				
	Brs	Grey	B	30.48	32.3	6.8
		Wellington				
Brisbane Loam	Brl	Bruce	B	25.40	30.0	5.0
	Brl	Grey	B	25.40	30.0	6.0
	Bl	Wellington	B	17.78	30.0	6.0
	Brl	Huron	B	27.90	30.0	5.8
Brookston Clay Loam	Bc	Perth	B-C	17.78	25.7	3.5
	Bc	Bruce	B-C	17.78	25.7	3.5
	Bc	Grey	B-C	17.78	25.7	3.5
	Bnc	Wellington	B-C	15.24	25.7	3.8
	Bc	Huron	B-C	20.30	25.7	3.9
Brookston Loam		Bruce				
		Grey				
	Bnl	Wellington	B	15.24	30.0	7.6
Brookston Silt Loam	Bs	Perth	B	17.78	31.3	3.8

	Bs	Bruce	B	17.78	31.3	3.8
		Grey				
	Bns	Wellington	B-C	15.24	25.7	3.8
	Bs	Huron	B	20.30	31.3	4.0
Brookston Silty Clay Loam	Bsc	Huron	C-B	20.30	23.3	3.8
Burford Loam	Bg	Perth	B	48.30	30.0	4.0
	Bg	Bruce	B	40.64	30.0	6.1
	Bg	Grey	B	25.40	30.0	5.5
	Bg	Wellington	B	30.48	30.0	5.0
	Bg	Huron	B	40.60	30.0	5.9
Chesley Clay Loam	Cc	Bruce	B-C	12.70	25.7	3.5
		Grey				
		Wellington				
Chesley Silt Loam	Cs	Bruce	B	12.70	31.3	4.5
		Grey				
		Wellington				
Chesley Silty Clay Loam	Csc	Bruce	C-B	12.70	23.3	3.5
	Csc	Grey	C-B	12.70	23.3	3.5
		Wellington				
Colwood Silt Loam		Bruce				
		Grey				
	Cos	Wellington	A-B	15.24	36.3	8.4
Donnybrook Sandy Loam	Dsl	Perth	B-A	58.40	31.0	7.0
	Dos	Bruce	B-A	43.18	31.0	7.6
	Dos	Grey	B-A	40.64	31.0	7.6
	Db	Wellington	B-A	25.40	31.0	7.0
	Dos	Huron	B-A	61.00	31.0	7.6
Dumfries Loam	Dl	Bruce	B	35.56	30.0	5.8
		Grey				
	Dl	Wellington	B	30.48	30.0	4.0
	Dl	Huron	B	27.90	30.0	6.0
Dumfries Sandy Loam	Ds	Huron	B-A	27.90	30.9	7.6
Dumfries-Hillsburgh		Bruce				
		Grey				
	Dl-Hif	Wellington	B	35.56	30.0	7.6
Eastport Gravel	Eg	Bruce	B	91.44	24.4	6.4
		Grey				
		Wellington				
Eastport Sand	Es	Bruce	B	15.24	24.4	6.3
		Grey				
		Wellington				
Elderslie Clay Loam	Ecl	Bruce	B-C	17.78	25.7	3.5
		Grey				
		Wellington				

Elderslie Silt Loam	Esl	Bruce	B	17.78	31.3	4.5
		Grey				
		Wellington				
Elderslie Silty Clay Loam	Esc	Bruce	C-B	17.78	23.3	3.5
	Esc	Grey	C-B	10.16	23.3	3.5
		Wellington				
	Psc	Huron	C-B	20.30	23.3	3.9
Farmington Loam		Bruce				
	Fl	Grey	B-A	12.70	30.9	6.1
	Fl	Wellington	B-A	12.70	30.9	6.1
Fox Sandy Loam	Fsl	Bruce	B-A	66.04	31.0	7.6
	Fsl	Grey	B-A	58.42	31.0	7.6
	Fs	Wellington	B-A	60.96	31.0	7.6
	Fs	Huron	A	56.00	32.7	8.9
Gilford Loam	Gil	Perth	B	17.80	30.0	6.1
	Gil	Bruce	B	15.24	30.0	6.1
	Gil	Grey	B	15.24	30.0	6.1
	Gil	Wellington	B	20.32	30.0	6.1
	Gil	Huron	B	17.80	30.0	6.1
Granby Sand	Gs	Bruce	B	17.78	32.3	6.9
	Gs	Grey	B	20.32	32.0	6.9
	Gs	Wellington	B-A	17.78	31.0	7.6
Granby Sandy Loam	Gsl	Bruce	B-A	17.78	31.0	7.5
		Grey				
	Grs	Wellington	B-A	17.78	31.0	7.5
	Gs	Huron	B-A	20.30	30.9	7.6
Guelph Loam	Gl	Perth	B	33.60	30.0	4.0
Guerin Loam	Gul	Huron	B	22.90	30.0	6.1
Harkaway Loam	Hal	Bruce	B	12.70	30.0	6.0
	Hal	Grey	B	10.16	30.0	6.0
Harkaway Silt Loam	Has	Bruce	B	12.70	31.3	6.1
	Has	Grey	B	10.16	31.3	6.1
		Wellington				
Harriston Loam	Hl	Bruce	B	45.72	30.0	5.8
	Hl	Grey	B	45.72	30.0	5.8
	Hl	Wellington	B	48.26	30.0	5.8
	Hl	Huron	B	48.30	30.0	5.0
Harriston Silt Loam	Hsi	Perth	B	50.80	31.3	4.0
	Hs	Bruce	B	50.80	31.3	5.8
	Hs	Grey	B	45.72	31.3	5.5
	Hs	Wellington	B	48.26	31.3	6.1
	Hs	Huron	B	48.30	31.3	5.0
Huron Clay Loam	Huc	Perth	B-C	25.40	25.7	3.5
	Huc	Bruce	B-C	27.94	25.7	3.5
		Grey				
	Huc	Wellington	B-C	43.18	25.7	3.8

	Huc	Huron	B-C	25.40	25.7	3.5
Huron Loam	Hul	Bruce	B-C	27.94	25.7	3.8
		Grey				
	Hul	Wellington	B-C	43.18	25.7	3.8
Huron Silt Loam	Hus	Perth	B	25.40	31.3	3.3
	Hus	Bruce	B	27.94	31.3	4.5
		Grey				
	Hus	Wellington	B	43.18	31.3	4.0
	Hus	Huron	B	25.40	31.3	3.5
Killean Loam	Kl	Bruce	B	30.48	30.0	6.5
		Grey				
		Wellington				
Lily Loam		Bruce				
	Lyl	Grey	B	15.24	30.0	5.8
	Lyl	Wellington	B-A	17.78	31.0	7.6
Listowel Loam	Ll	Bruce	B	30.48	30.0	5.0
	Ll	Grey	B	25.40	30.0	5.0
	Ll	Wellington	B	30.48	30.0	6.0
	Ll	Huron	B	33.00	30.0	6.0
Listowel Silt Loam	Lsi	Perth	B	35.60	31.3	4.5
	Ls	Bruce	B	30.48	31.3	4.5
	Ls	Grey	B	25.40	31.3	4.5
	Lis	Wellington	B	30.48	31.3	6.1
	Ls	Huron	B	17.80	31.3	6.1
London Loam	Li	Perth	B	22.90	30.0	4.0
Lyons Loam	Lyl	Huron	B-A	20.30	30.0	7.6
Muck	M	Bruce	D	0.00	27.0	3.5
	M	Grey	D	0.00	27.0	3.5
	M	Wellington	D	0.00	27.0	3.5
	M	Huron	D	0.00	27.0	3.5
Osprey Loam	Ol	Bruce	B	7.62	30.0	5.2
	Ol	Grey	B	5.08	30.0	5.0
		Wellington				
Parkhill Loam	Pl	Perth	B	15.24	30.0	5.8
	Pal	Bruce	B	15.24	30.0	5.8
	Pal	Grey	B	15.24	30.0	5.0
	Pal	Wellington	B	17.78	30.0	5.8
	Pal	Huron	B	17.80	30.0	5.8
Parkhill Silt Loam	Pas	Bruce	B	17.78	30.0	5.8
	Pas	Grey	B	15.24	31.3	6.0
	Pas	Wellington	B	17.78	31.3	6.0
	Pas	Huron	B	17.80	31.3	6.1
Peat	P	Bruce	D	0.00	27.0	3.8
	P	Grey	D	0.00	27.0	3.8
	P	Wellington	D	0.00	27.0	3.8
Perth Clay Loam	Pc	Perth	B-C	25.40	25.7	3.5
	Pc	Bruce	B-C	33.02	25.7	3.5

		Grey				
	Pc	Wellington	B-C	17.78	25.7	3.8
	Pc	Huron	B-C	20.30	25.7	3.8
Perth Loam		Bruce				
		Grey				
	Pl	Wellington	B-C	17.78	25.7	3.8
Perth Silt Loam	Ps	Perth	B	25.40	31.3	3.3
	Ps	Bruce	B	33.02	31.3	4.0
		Grey				
	Ps	Wellington	B	17.78	31.3	4.5
	Ps	Huron	B	20.30	31.3	3.9
Perth Silty Clay Loam	Psc	Huron	C-B	20.30	23.3	3.9
Pike Lake Loam		Bruce				
	PLl	Grey	B-A	27.94	31.0	7.5
		Wellington				
Plainfield Sand	Pls	Bruce	B-A	7.62+	31.0	7.6
		Grey				
		Wellington				
Sargent Loam	Sg	Bruce	B	7.62	30.0	5.0
	Sg	Grey	B	7.62	30.0	4.5
		Wellington				
Saugeen Clay Loam	Sc	Bruce	B-C	17.78	25.7	3.5
		Grey				
		Wellington				
Saugeen Silt Loam	Ss	Bruce	B	10.16	31.3	4.2
		Grey				
		Waterloo				
Saugeen Silty Clay Loam	Ssc	Bruce	C-B	17.78	23.3	3.5
	Ssc	Grey	C-B	15.24	23.3	3.8
		Wellington				
Sullivan Sand	Sus	Bruce	B	7.62	32.3	6.9
	Sus	Grey	B	7.62	32.3	6.9
		Wellington				
Tecumseth Sand		Bruce				
	Ts	Grey	B	20.32	32.3	6.9
		Wellington				
Teeswater Silt Loam	Tes	Bruce	B	48.26	31.3	4.2
		Grey				
	Tes	Wellington	B	60.96	31.3	4.2
	Tes	Huron	B	45.70	31.3	5.5
Toledo Clay Loam	Tc	Bruce	B-C	15.24	25.7	3.5
	Tc	Grey	B-C	15.24	25.7	3.4
	Tc	Wellington	B-C	15.24	25.7	3.5
	Tc	Huron	B-C	17.80	25.7	3.8
Toledo Silt Loam	Ts	Bruce	B	15.24	31.3	3.0
		Grey				

		Wellington				
	Ts	Huron	B	17.80	31.3	5.5
Vincent Silty Clay Loam	Vsc	Bruce	C-B	7.62	23.3	3.8
	Vsc	Grey	C-B	10.16	23.3	3.5
		Wellington				
Waterloo Sandy Loam	Wsl	Perth	B-A	40.60	31.0	7.0
	Wsl	Bruce	B-A	43.18	31.0	7.0
	Wsl	Grey	B-A	35.56	31.0	7.0
		Wellington				
Wauseon Sandy Loam	Was	Bruce	B-A	20.32	31.0	4.5
		Grey				
		Wellington				
	Was	Huron	B-A	22.90	30.9	7.2
Wiarton Loam	Wl	Bruce	B	15.24	30.0	5.8
		Grey				
		Wellington				
Wiarton Silt Loam	Ws	Bruce	B	15.24	31.3	5.9
	Ws	Grey	B	17.78	31.3	5.9
		Wellington				

Appendix E: Catalogue of WC Maps in the Accompanying Map Book

WC Map 3-1: Well Head Protection Areas and Water Systems

WC Map 3-2: Intrinsic Susceptibility Mapping

WC Map 3-3: Surficial Susceptibility Index

WC Map 3-4: Discharge from Overburden Aquifer

WC Map 3-5: Geologic Windows

WC Map 3-6: Recharge and Discharge Bedrock Aquifer

WC Map 3-7: Sinkhole and Sinkhole Drainage Area

WC Map 3-8: Runoff Index

WC Map 3-9: Modified Runoff Index