Credit Valley Conservation

March 2014

Shaws Creek Subwatershed Study - Subwatershed 17
Phase I Characterization Report

CVC
CREDIT VALLEY CONSERVATION

Credit Valley Conservation
Shaws Creek Subwatershed Study
Subwatershed 17

Phase I
Characterization Report

Credit Valley Conservation
1255 Old Derry Road
Mississauga ON L5N 6R4

November 2012

ISSN ####-####

To be cited as:
Credit Valley Conservation. 2009. Credit Valley Conservation Technical Report Series Guidelines. vi+ 15 p.

Table of Contents

List of Figures

List of Tables

Appendices

1. Introduction

1.1 STUDY PURPOSE

This study covers the environmental and water related issues within the Shaws Creek Subwatershed, also reffered to as Subwatershed 17. Specifically, an analysis of the groundwater and surface water hydrology, water quality, stream geomorphology, and aquatic and terrestrial ecology were undertaken. The goal of these analyses was to achieve a thorough understanding of how the subwatershed functions, and how land use changes will impact upon it. This study is intended to be used as one component of a land use management strategy that may be developed by the municipal partners in an effort to balance economic, social and environmental needs within the communities.

Figure 1.4.3 shows the location of the Shaws Creek Subwatershed in relation to the entire Credit River watershed. Figure 1.4.4 shows a more detailed map of the subwatershed and its major roads and towns.

1.2 STUDY PROCESS

In January 1992, Credit Valley Conservation (CVC) in concert with all member municipalities and the Ministries of Natural Resources (MNR) and Environment and Energy (MOEE), completed a watershed management plan titled *Credit River Water Management Strategy* (CRWMS), Phases I and II. These studies evaluated the present and future state of the Credit River Watershed with respect to its overall health (e.g., flooding, erosion, base flows, surface and groundwater quality and quantity and the natural environment). The results for the future scenario indicated that with the ever increasing pressures for development and resource use, the impacts to the subwatershed, if not managed properly, will be irreparable. The study recommended that the entire Credit River Watershed be subdivided into 20 subwatersheds and that plans be prepared in order to properly manage the health of the watershed.

The Water Management Strategy was updated in 2007 (Credit River Water Management Strategy Update, 2007). As part of this process, alternatives for future watershed conditions were evaluated and targets were set for watershed-wide parameters. The long-term health of the residents depends on the health of the Credit River watershed because our communities and economies are supported by fuctions provided by the watershed. There is a direct link between public well-being and the health of the watershed, which provides us with much of value including clean drinking water, connected habitats to support wildlife, natural flowing rivers and streams, and a variety of recreational spaces and places for people. The health of the Credit River is already at risk due to urbanization in the lower watershed, where there are more impervious surfaces which result in poor to fair water quality, poor baseflows and degraded fish habitat. Current planning and development practices are not sustainable in the long-term and we need to become proactive for the future. We can continue growing if we change our planning and water management practices, such as taking a more aggressive approach to stormwater management and stream restoration in developing areas. The 2006 Credit River Water Management Strategy Update (CRMWSU) developed a set of 8 Guiding Principles or conditions that must be met in the strategy. These principles were also adopted for the Headwaters Subwatershed Study. The guiding principles are:

1. Recognize that the responsibility for the health of water and natural resources is shared by everyone. Successful water management within the Credit River watershed can only be achieved through active and sustained partnerships with all levels of government, agencies, groups and individuals.
2. Apply a long-term approach to ensure a sustainable and environmentally healthy river for current and future generations.
3. Maintain a watershed scale perspective and consider the implications of our cumulative actions, as well as external factors, on the watershed as a whole.
4. Protect, enhance and restore natural systems as a priority within the urban environment and throughout the watershed.
5. Take a preventative, proactive and integrative approach based on the principles of adaptive management. Where there is uncertainty, risk or irreversibility, use caution and err on the side of protecting the environment.
6. Pursue reasonable, practical approaches to water and natural resources management based on sound science, creativity and innovation for effective solutions.

7. Recognize that healthy communities require a sustainable balance between economic, social, natural and human uses in the watershed.
8. Promote ecologically sustainable lifestyles and behaviours through sustainable urban design approaches.

To meet the guiding principals, CVC and its partners have undertaken subwateshed studies of nearly all 20 subwatersheds in order to refine targets at the smaller scale and improve local conditions.

1.3 STUDY APPROACH

The concept of subwatershed planning has become an accepted method for dealing with environmental concerns over broad areas of land. The subwatershed plan integrates the functions of resource management and the land use planning process. A subwatershed plan does not set out ideal land uses, but it does make valuable contributions to the land use decision making process by developing a detailed understanding of the subwatershed ecosystem and making recommendations regarding the management of the ecosystem, in light of alternative land use patterns. Information derived from the subwatershed plan will be incorporated into planning documents as the basis for environmentally sound land use designations and development policies.

The Shaws Creek Subwatershed Study addresses environmental and water related issues within the Shaws Creek Subwatershed (see Figure 1.4.3 and Figure 1.4.4). This study is intended to be one component of a land use management strategy that compliments work being done by the municipalities.

The first step in the study was to conduct a scoping exercise to assess the available data and information, including an examination of historical conditions. This exercise resulted in the preparation of a Background Report that documents existing Subwatershed information and identified gaps in the data (CVC et al. 2001b).

The next step in the Study process was to conduct field work to fill in the data gaps to help characterize the Subwatershed. This field work was completed in the summer and fall of 2005. This document summarizes the findings of the field work, and completes Phase I of the subwatershed study: Subwatershed Characterization. This report establishes the features, functions and linkages of the Shaws Creek Subwatershed.

Phase II will predict the effect of different development scenarios on the existing conditions identified in Phase I. It will focus primarily on assessing impacts from land use changes. This phase will answer questions such as: What are the potential stressors? How will impacts be evaluated? What are the potential impacts from the stressors? and What are the alternate solutions? The study components identified in Phase I will continue to be investigated and various simulation models and field data will be assimilated. The end product will be a report documenting impacts, management measures, alternative solutions, their evaluation and development of a management strategy.

The third phase of the study will focus on the implementation of the Recommended Plan, will identify roles and responsibilities of the various stakeholders, and will identify long-term monitoring goals. Phase III will document the benefits and drawbacks of selected solutions. A preferred solution will be established which specifies the criteria for selection of management measures as part of the overall strategy. This phase will also indicate with whom the responsibility lies for addressing various recommendations, and what is required to achieve the established goals.

This report covers the Phase I Characterization component of the subwatershed study. Subsequent phases are provided under a separate cover.

1.4 ADAPTIVE ENVIRONMENTAL MANAGEMENT (AEM)

AEM can be defined as *an approach to environmental management aimed at improving understanding of the ecosystems being managed, the institutions charged with their management, and the coupling of the two* (Gunderson et. al. 1995:506).

displays the AEM approach.

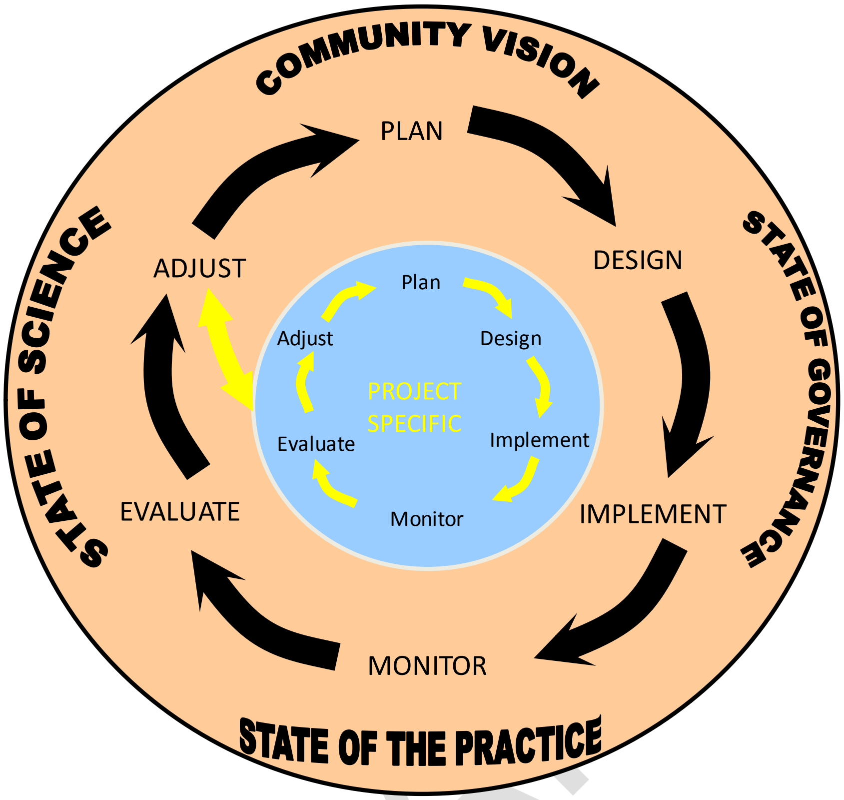


Figure 1.4.1 Adaptive Environmental Management Approach

AEM is used as a management tool where the results cannot be predicted with sufficient certainty. Unlike more traditional projects that involve municipal infrastructure or engineering projects, such as dam construction, watershed management has a large element of uncertainty associated with it.

In infrastructure projects for example, tools for predicting the behaviour of different designs are available from a wide background of theory, research, post construction monitoring, codes of practice, design safety factors and professional education and licensing.

Flood flow forecasting, delineation of flood plains, and development of design flows for dam structures are an example of managing with Mother Nature. There is a significant element of uncertainty associated with the science, but an area of professional practice has developed which is adequate for addressing the management problems at hand. One managerial tool that can be used is watershed planning.

Management of watersheds and subwatersheds, including analysis of the present state, prediction of future changes, and prediction of the utility of a proposed design, is much more uncertain than the hydrological areas of practice such as flood - flow management. These uncertainties, the long time frames of response of stream channels (up to 50 - 100 years) and groundwater aquifers (10 - 30 years) to a set of alterations caused by humans, and other influencing factors, require a different approach to management.

Subwatersheds, their design and management share key attributes of many other environmental management initiatives. They include:

Integration - It is necessary in the design process to integrate the knowledge of several technical disciplines (e.g. hydrogeology, hydrology, terrestrial and aquatic ecology) and there is continuing uncertainty about precisely what is needed, for example to meet habitat objectives, and how to best design and implement natural channel projects.

Implementation - Like much of today's environmental management, the design and implementation of watershed plans is somewhat of an art growing into a science.

Time Lag - There is a long response time associated with past impacts such as land use change, meaning that there is significant uncertainty about assumptions on whether the stream's geomorphology is at a stable state with respect to the hydrological regime of the channel and flood plain. demonstrates the time lag of the physical processes of a subwatershed due to a change in land use.

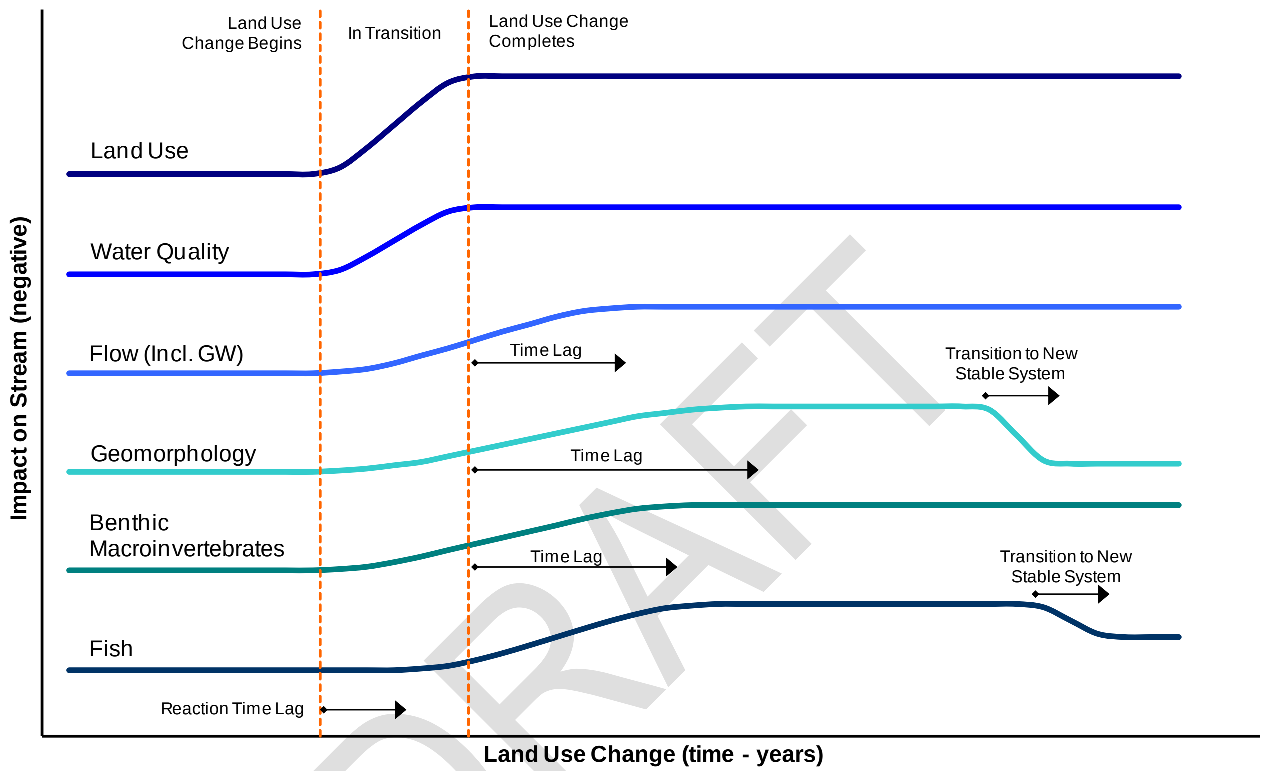


Figure 1.4.2 Impact of Land Use on Physical Processes/Conditions

Future Work - It is anticipated that future maintenance and intervention will be needed, but the timing and type of intervention cannot be estimated with certainty.

The critical need for integration of different technical disciplines together with the need to explicitly account for the uncertainty involved and to learn from our experience so that we can improve watershed plans are the conditions that led to the development in the early 1970's of the Adaptive Environmental Management (AEM) approach.

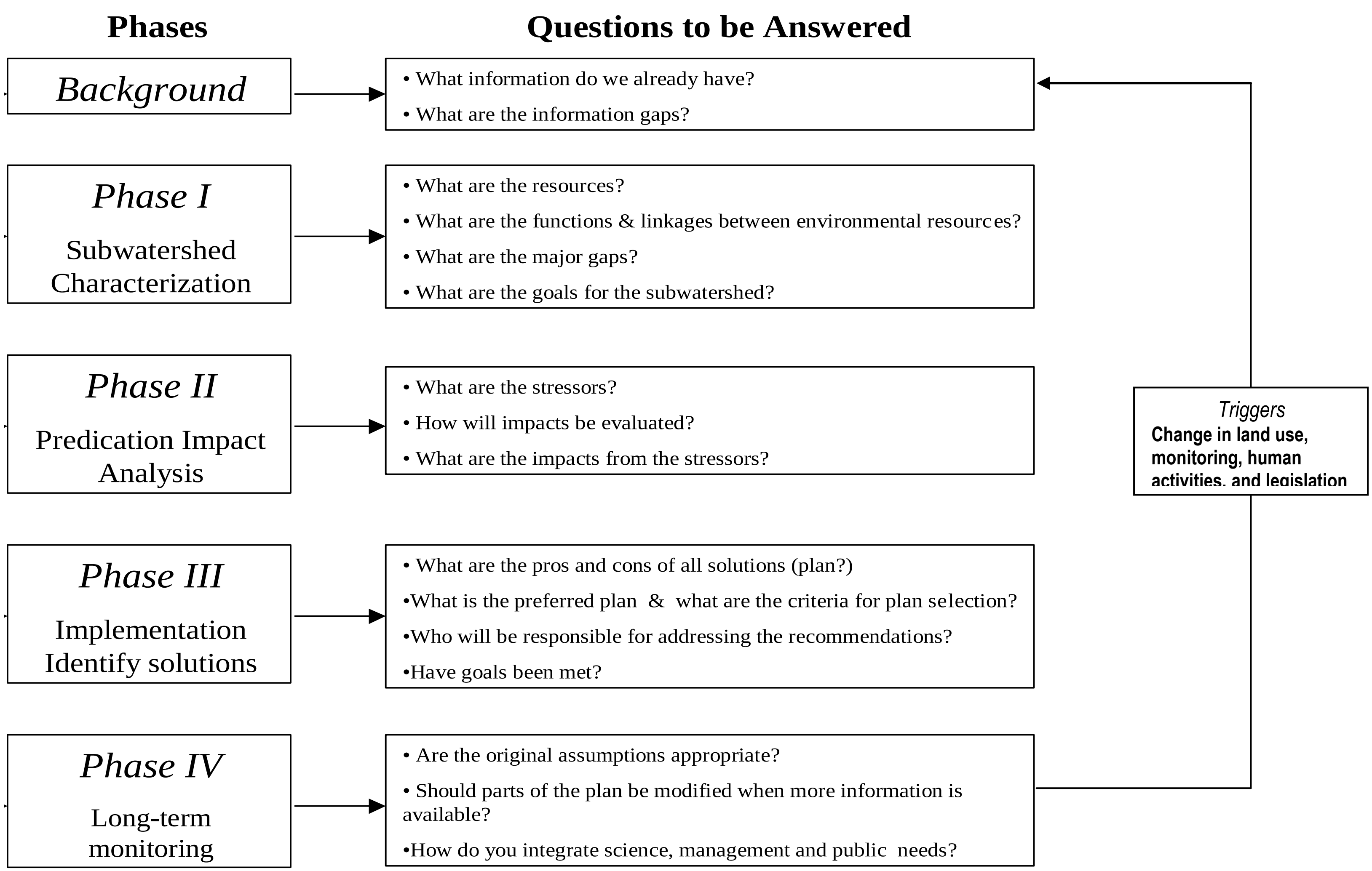


Figure 2.4. 1 Subwatershed Study Process

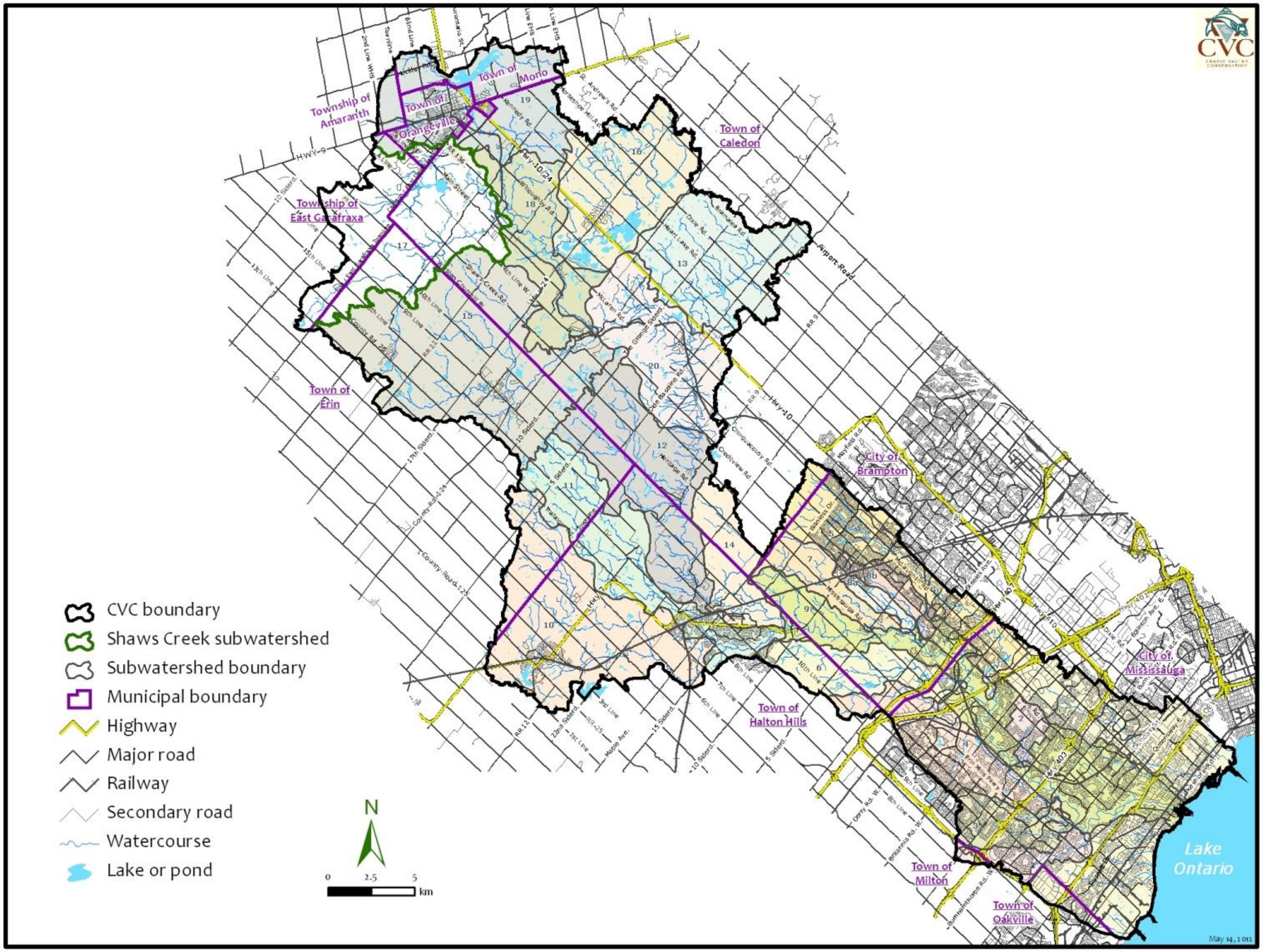


Figure 1.4.3 Shaws Creek Subwatershed in relation to the Credit River Watershed

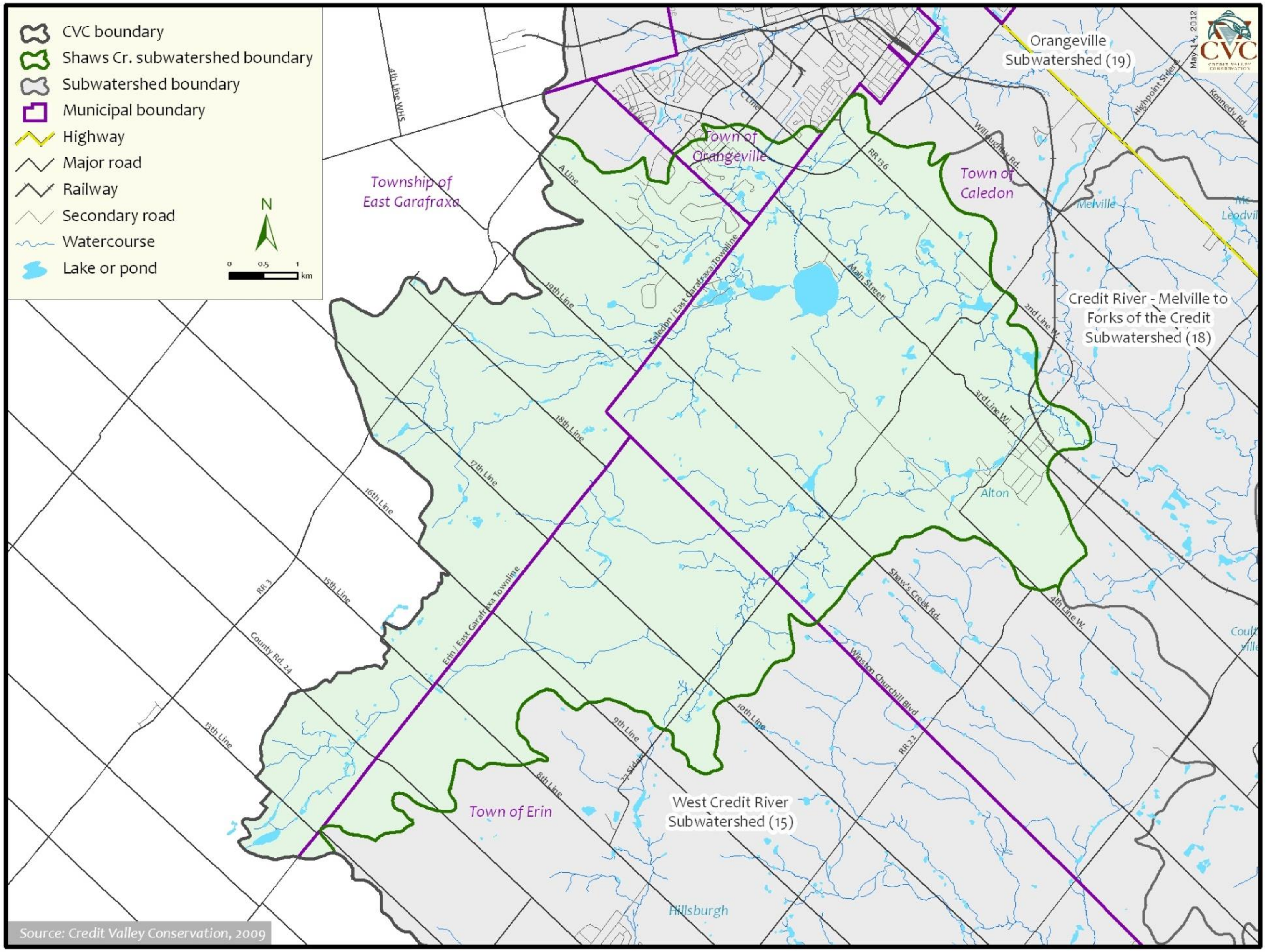


Figure 1.4.4 Shaws Creek Subwatershed

1.5 REPORT CONTENT

This Characterization report describes the form, function, and linkages of the various components of the natural environment, and identifies the issues that affect future land use. The content of this report has been organized as follows:

Chapter 1 provides a brief description to the subwatershed study process.

Chapter 2 is a background summary of the physical, social and economic characteristics of the study area.

Chapter 3 describes the communication initiatives planned and completed to involve the public in the development of the subwatershed study.

Chapter 4 is a detailed characterization of the subwatershed from each of the technical disciplines involved in the study: hydrology, hydrogeology, hydraulics, terrestrial, aquatics, stream morphology, water quality, and benthics.

Chapter 5 is an analysis of the individual technical disciplines and their inherent linkages with one another.

Chapter 6 includes the vision and goals for the Shaws Creek subwatershed, and will guide management of the environmental features of the area. This was developed with input from the focus group, and Technical Committee.

2. Background

2.1 STUDY AREA

The Shaws Creek Subwatershed is a large headwater area of the Credit River system, located in the far upper reaches of the watershed (see **Figure 1.4.3** and **Figure 1.4.4**). The area is characteristic of a headwater area, with undulating and hummocky terrain. The area contains several significant wetland features and several coldwater reaches of creek, supporting habitat and spawning of sensitive fish species such as rainbow and brook trout.

Shaws Creek is a tributary of the Credit River that joins it near the Village of Alton, of the Town of Caledon in the Credit River at the Alton Wetland Complex. The area contains two other significant wetland areas: the Caledon Lake Wetland Complex and the Alton-Hillsburgh Wetland Complex (see

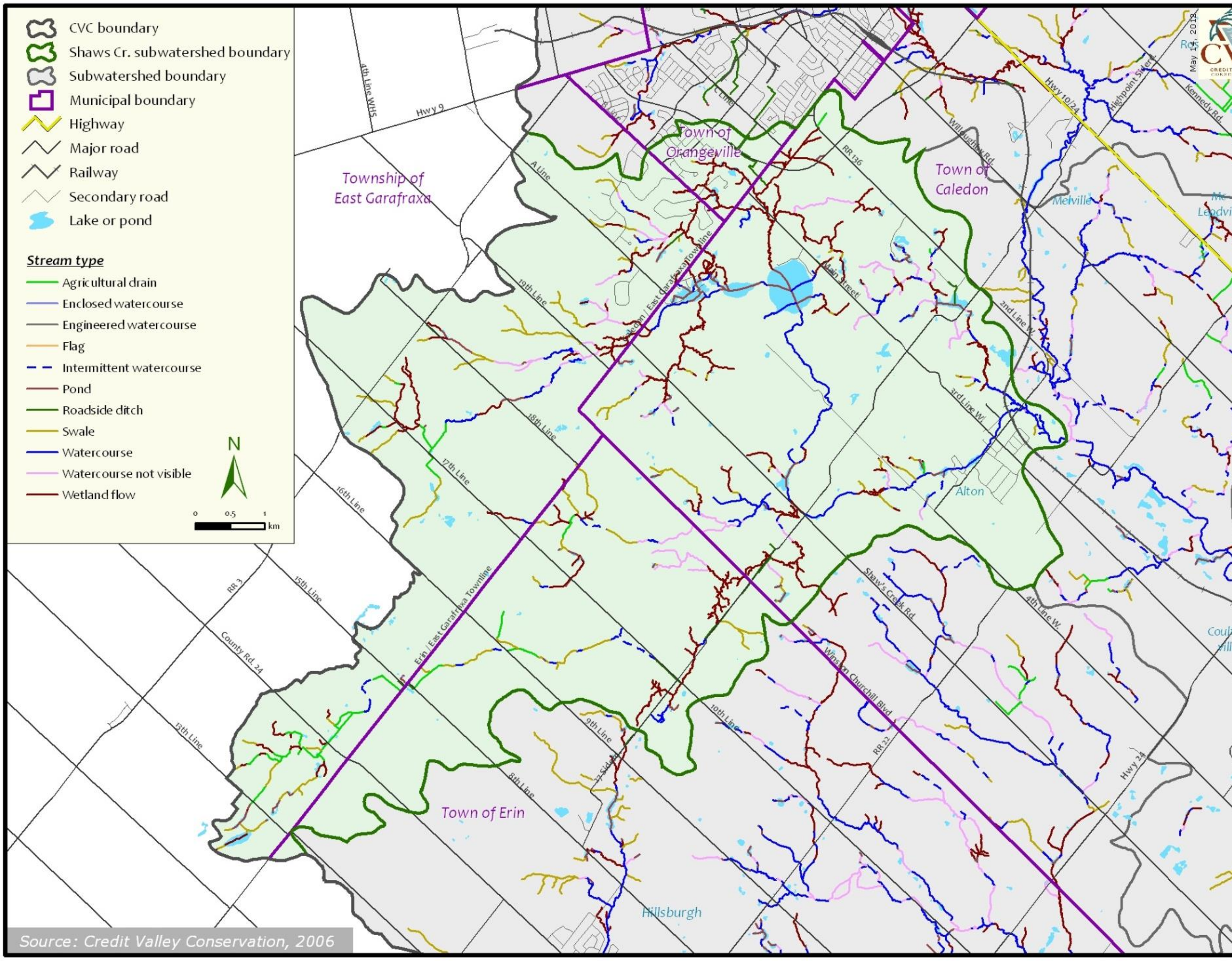


Figure 2.1.1). These two areas also support Areas of Natural and Scientific Interest (ANSI) and Environmentally Significant Areas (ESA), containing the two largest ESAs in the Credit River Watershed (Caledon Lake and Alton Swamp Complex). The Alton Swamp Complex provides large quantities of groundwater to Shaws Creek, and also serves as the headwaters of the West Credit River.

The majority of the subwatershed lies on the Amabel and Guelph bedrock formations, which are similar in composition and consist of a crystalline dolostone with widespread secondary porosity features such as fractures and cavities that yield large quantities of groundwater. The surficial geology is variable, but generally dominated by large deposits of coarse grained deposits, dominated by the Orangeville Moraine. The nature of this surficial geology has made this area attractive to aggregate extraction ventures, and as such there is increased pressure to develop this industry further.

Over 40% of the total land area in the subwatershed is used for agriculture (see **Figure 2.1.2**). In areas of agriculture, vegetation and forests are limited, with little riparian buffer around the various tributaries to Shaws Creek. In many places the tributaries consist of swales, agricultural drains and intermittent streams. The lack of riparian cover has left many of these surface water features vulnerable to erosion and high stream temperatures, and capable of providing only sparse habitat for aquatic biota (see

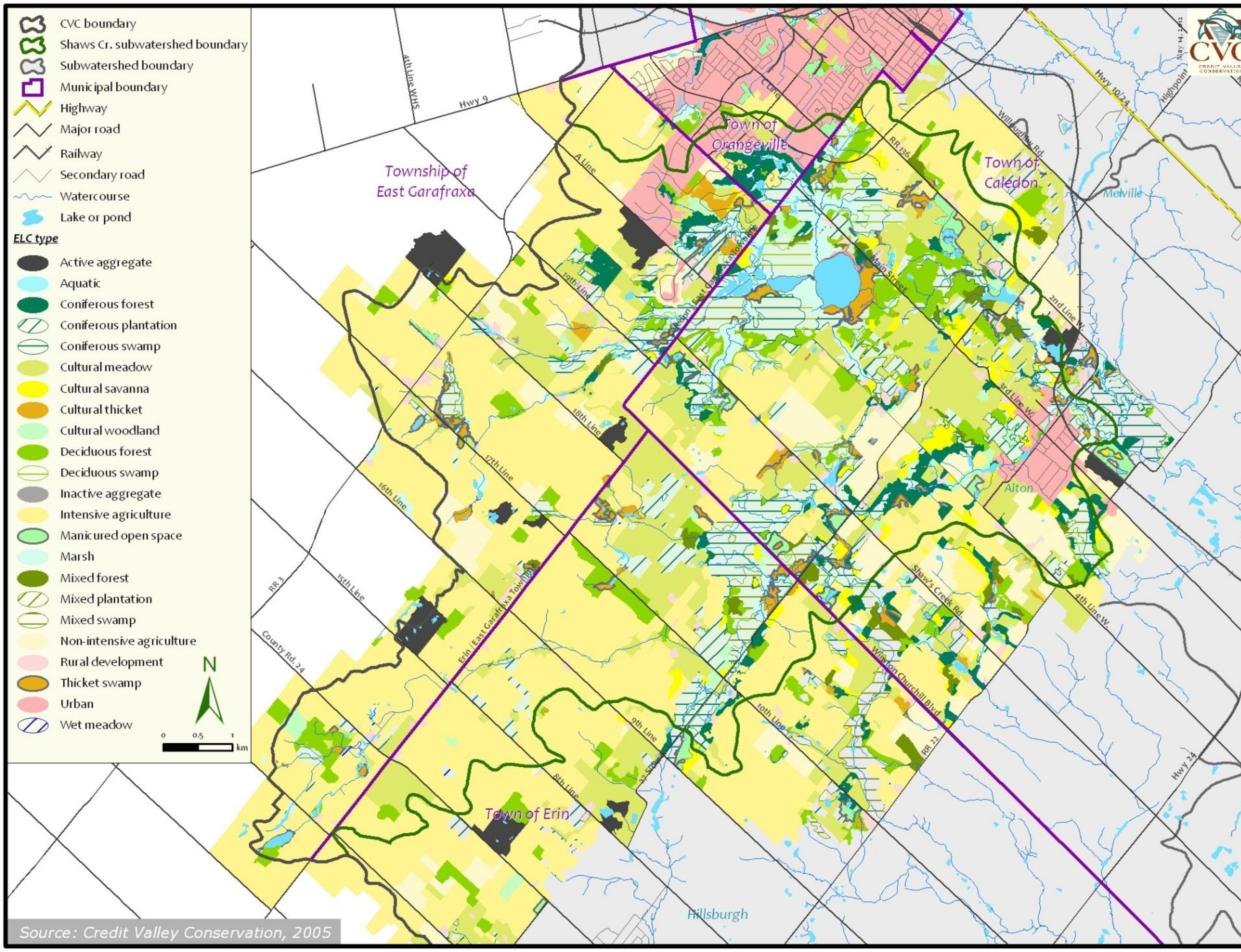


Figure 2.3.1).

For the most part the basin consists of a rugged relief with marshy conditions existing along the watercourse in the low lying areas. The catchment area for Shaw’s Creek is bounded by the Credit River Watershed to the East and the Grand River Watershed to the west.

Shaws Creek is the main watercourse through Subwatershed 17. Watersheds South of Shaws Creek include Caledon Creek, the East Credit River and the West Credit River. Outflows from Shaw's enter the Credit River downstream of Alton near rural road RR 136.

The basin is irregular in shape with the Town of Orangville and Alton being the only areas of existing major development within its catchment. Caledon Lake located in the northern part of the basin controls the drainage characteristics of the upper basin as well as providing the area with some recreational benefits.

The area drained by the Shaws Creek watershed is 77.8 km^2. This represents 14% percent of the Upper Credit River watershed above Norval, and 9% percent of the Credit River watershed discharging to Lake Ontario. The main branch of Shaws Creek is approximately 16 km in length, with an average channel slope of 0.8 %.

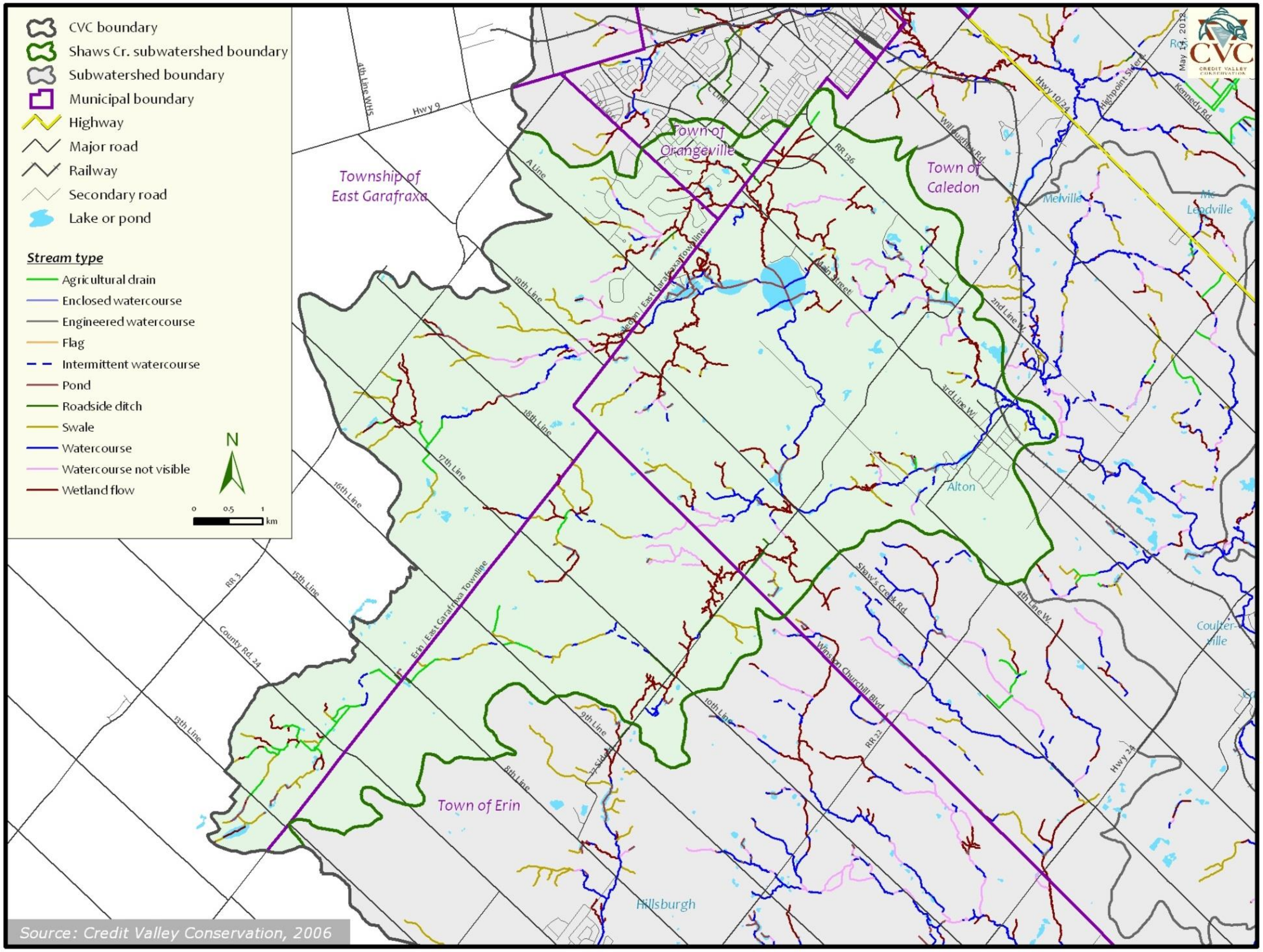


Figure 2.1.1 Aquatic System: Watercourses, Lakes and Ponds

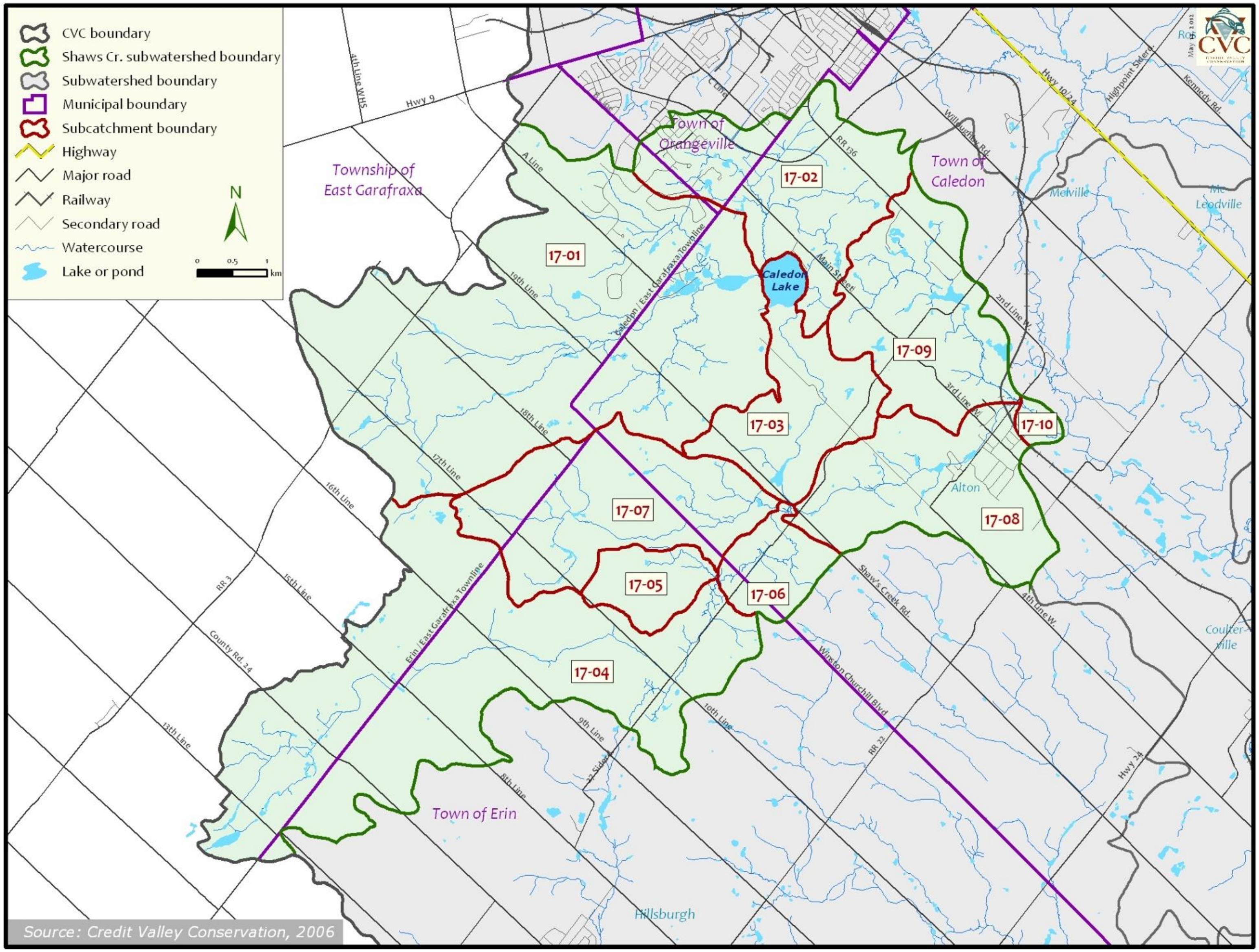


Figure 2.1.2 Subcatchments

2.2 LAND USE

The Shaws Creek Subwatershed is one of the several subwatersheds that make up the vast headwater areas of the Credit River (see **Figure 1.4.3**). It is also the fourth largest of the Credit River's twenty subwatersheds, with a total area of 72 sq. km. There are two small areas of urban settlement in the area: the Village of Alton at the eastern border of the subwatershed where Shaws Creek meets the Credit River; and a small part of the Town of Orangeville along the northern border (see **Figure 2.1.2**). There is also a concentration of development around the shores of Caledon Lake which is more cottage-like in nature. Of the development areas, Orangeville has experienced the highest growth rate. East Garafraxa is going to undergo future development with three residential subdivisions being planning and constructed in the area. One subdivision is currently under construction and is due to have 25 residential lots, approximately one acre in size, which was approved by CVC in 2013. Construction is currently underway and it is expected to be complete within five years. Adjacent to that subdivision is planning for another residential subdivision with approximately 19 lots less than one acre in size, but permits have not been issued yet and it is still in the early stages of planning. No formal submissions have been made for the third development site, which is supposed to be residential and approximately 10 to 15 acres in total.

The western portion of the subwatershed, located in the Town of Erin and Township of East Garafraxa, is dominated by intensive agriculture with isolated woodlots and rural settlement, and little riparian features along the Shaws Creek tributaries.

The south-central portion of the subwatershed, straddling the border between the Towns of Erin and Caledon, contains an area of forest (coniferous, deciduous and mixed) and wetland, comprising the Alton-Hillsburgh Wetland

Complex. Agricultural areas ring this wetland feature (see

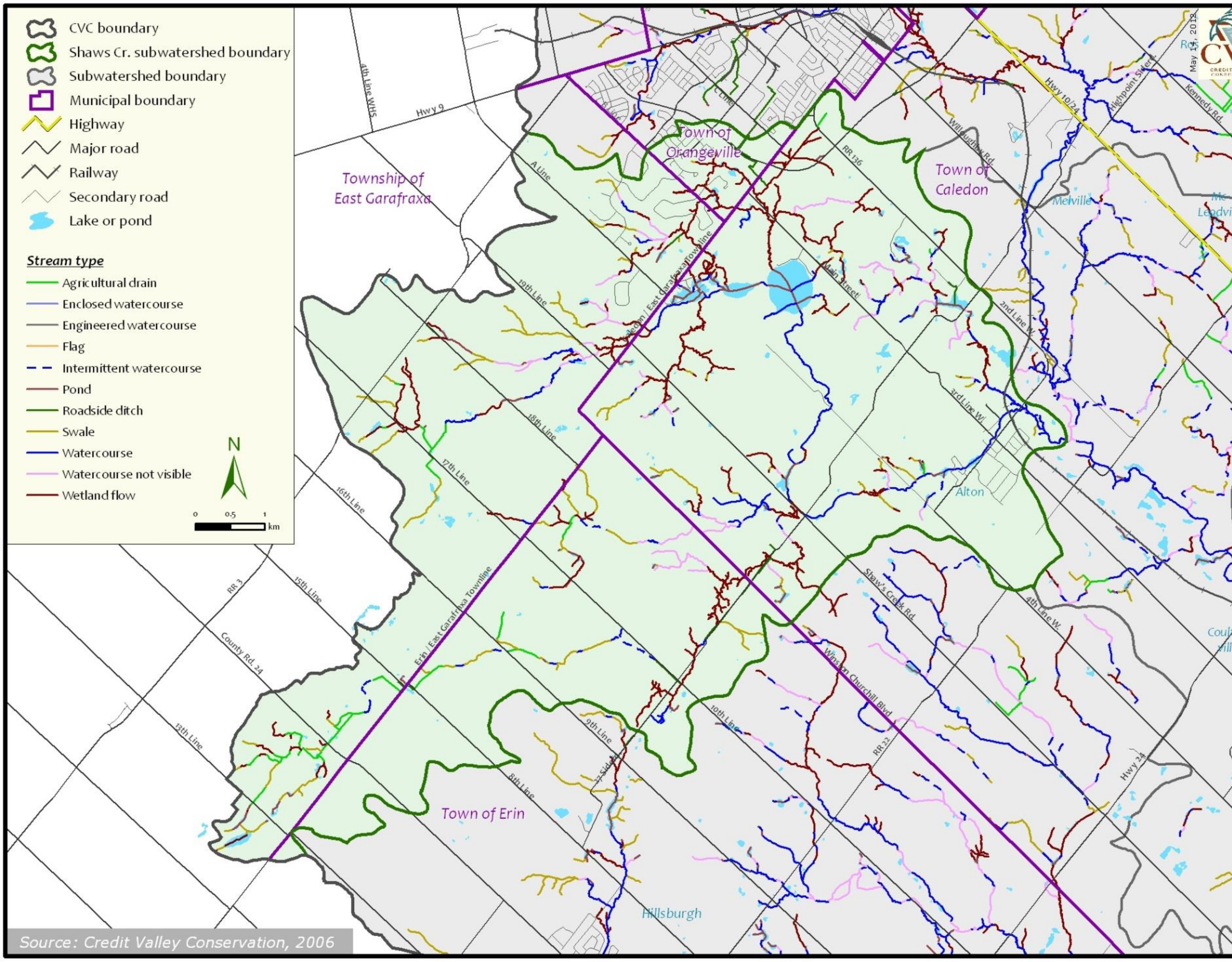


Figure 2.1.1).

The north-central portion of the subwatershed, shared among the Township of East Garafraxa, the Town of Orangeville and the Town of Caledon, is characterized by the Caledon Lake and its surrounding wetlands, comprising the Caledon Lake Wetland Complex. A mix of coniferous and deciduous forest covers the area among the marshes, with agriculture on the outskirts. Urban development from Orangeville dominates the northern border of this area.

The eastern portion of the subwatershed, contained wholly in the Town of Caledon, is characterized by the Village of Alton and surrounding forest, meadow and wetlands. It is here that Shaws Creek joins the Credit River in a vast tract of forest called the Alton Grange, contained just outside of the subwatershed in Subwatershed 18. The eastern area also contains portions of the Credit River at Alton Wetland Complex and the Coulterville Wetland Complex.

Table 2.2.1 displays the land use coverage for the Shaws Creek Subwatershed. Overall, the subwatershed is dominated by agricultural and natural areas, with 91.5% of the total area between them. A growing land use demand is that of aggregate extraction (currently at 1.2% of total area), with several gravel pits and quarries already in existence and pressure to develop more.

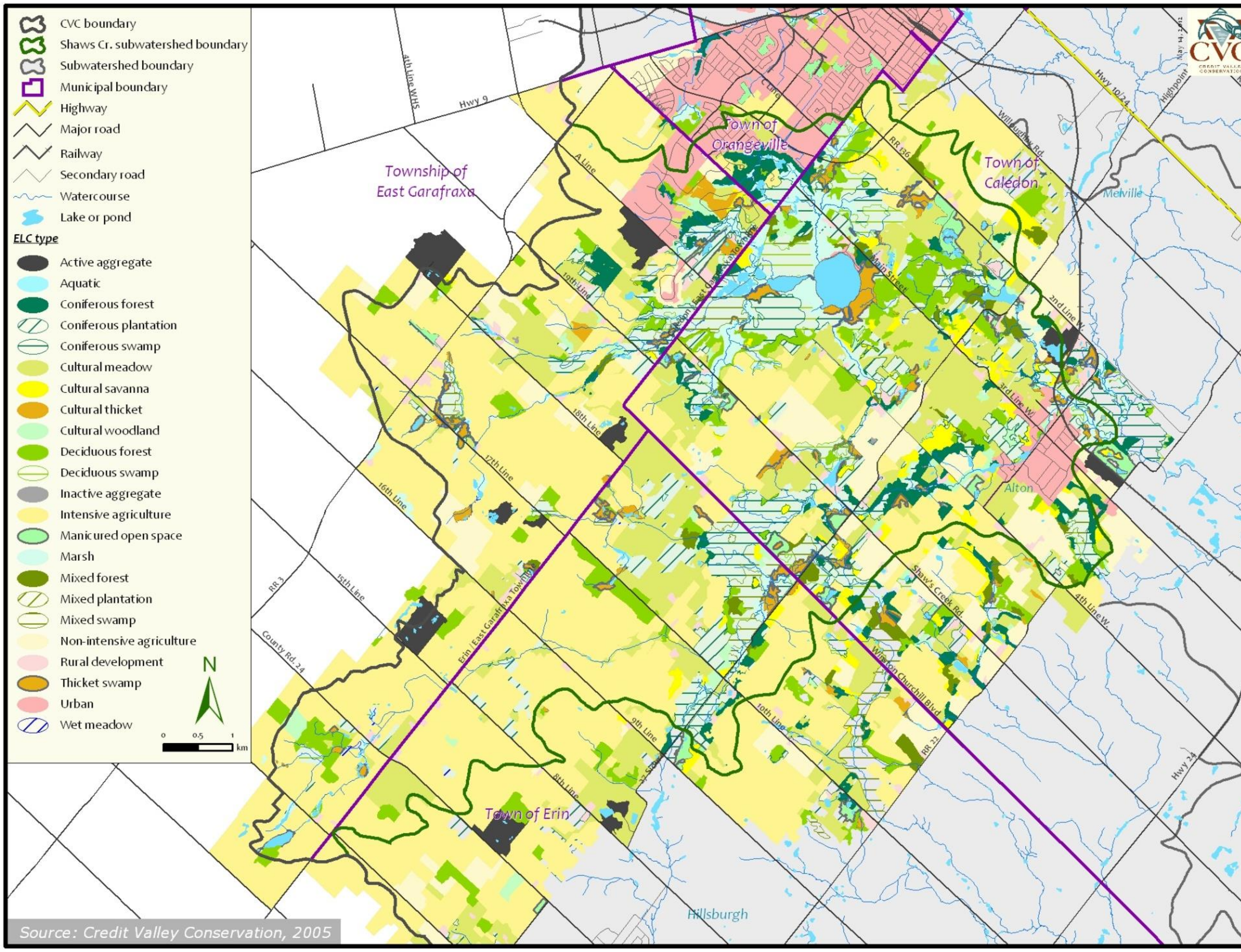


Figure 2.3.1 displays the existing land uses and simplified Ecological Land Classification.

Table 2.2.1 Existing Land Use and Natural Area in the Shaws Creek Subwatershed

Land Use	Percentage of Subwatershed Area
Urban	6.2%
Agriculture (Active/Inactive)	43.6%
Wet Meadow	1.1%
Aggregate	1.2%
Natural	47.9%

2.3 CLIMATE

The climate of Southern Ontario is characterized as having warm summers, mild winters, a long growing season, and usually reliable precipitation. The climate within Southern Ontario differs somewhat from one location to the other and from one year to the next. Spatial variations are caused by the topography and varying exposure to the prevailing winds in relation to the Great Lakes.

According to Brown et al. (1974), the Credit River watershed is located within four climatic regions: the Huron Slopes, South Slopes, Simcoe and Kawartha Lakes, and Lake Ontario Shore. Figures showing the long-term monthly precipitation and air temperature for selected climate stations within and surrounding the watershed are given in several texts (Brown et al., 1974; Hare, 1979; MNR, 1984). These figures show the typical variability in rain and snowfall amounts and spatial variations in mean annual precipitation, snowfall and air temperature.

The mean annual precipitation in the Credit River Subwatershed 17 (Shaw's Creek) is about 892 mm, of which 18% appears as snowfall (or 160 cm in depth). The greatest precipitation amounts occur in the northern part of the subwatershed due to influences from lake effect precipitation originating from Lake Huron and Georgian Bay. Total precipitation is distributed such that June, August, September and November are the wettest months, and January and February are the driest months. The lowest total precipitation (50 mm) occurs in February, whereas the highest precipitation amount occurs in August (96 mm). For the Alton Village area, the greatest 24 hour rainfall total of 84 mm occurred in August 1968. The greatest 24 hour snowfall of 27 cm occurred in February 1986. On average there are 107 days with measurable rainfall annually, and another 47 days with snowfall. Frozen ground conditions are persistent between mid-November to late March, yielding high runoff potential for all soil types.

The mean annual evapotranspiration in the watershed is about 540 mm as deduced from isoheytal maps for southern Ontario (Brown et al., 1974; OMNR, 1984), which has been verified from water balance analyses using observed streamflow data by Singer et al. (1994). The area has an annual frost-free period of 148 days, with a growing period of about 202 days. The mean annual air temperature is 6.0 °C, where the mean daily temperature in January is about -8°C and 19.1 °C in July.

Although August and September tend to be the wettest months, the annual maximum streamflows usually occur in the March to April period resulting from snowmelt or rainfall on frozen ground.

Although the precipitation is generally distributed throughout the years, during the summer period there is a net deficit in the amount of precipitation that falls and is lost through evapotranspiration. The potential evapotranspiration amounts (e.g. lake evaporation) are higher than the total precipitation input for May through August.

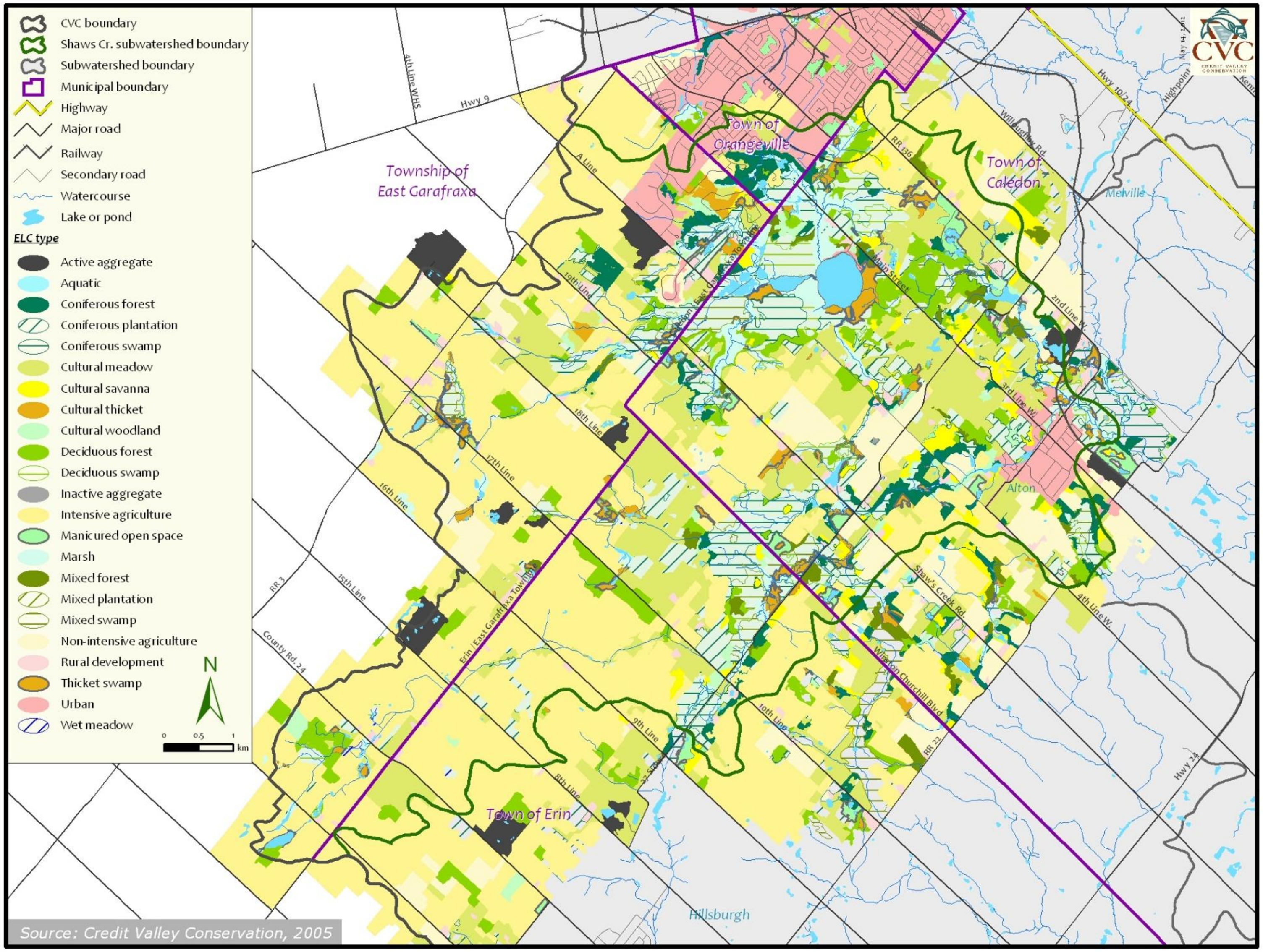


Figure 2.3.1 Existing Land Use and Simplified ELC

3. Study Team

In January 1992, Credit Valley Conservation (CVC) in concert with all member municipalities and the Ministries of Natural Resources (MNR) and Environment and Energy (MOEE), completed a watershed management plan titled Credit River Water Management Strategy (CRWMS), Phases I and II (Triton Services 1992, Beak et al. 1992). These studies evaluated the present and future state of the Credit River Watershed with respect to its overall health (e.g. natural environment). The results for the future scenario indicated that with the ever-increasing pressures for development and resource use, the impacts to the watershed, if not managed properly, will be irreparable. The study recommended that the entire Credit River Watershed be subdivided into 20 subwatersheds and that plans be prepared in order to properly manage the health of the watershed.

The concept of subwatershed planning has become an accepted method for dealing with environmental concerns over broad areas of land. The subwatershed plan integrates the functions of resource management and the land use planning process. A subwatershed plan does not set out ideal land uses, but it does make valuable contributions to the land use decision-making process by developing a detailed understanding of the subwatershed ecosystem and making recommendations regarding the management of the ecosystem, in light of alternative land use patterns. Information derived from the subwatershed plan will be incorporated into planning documents as the basis for environmentally sound land use designations and development policies.

3.1 THE FOCUS GROUP

The Focus Group was established to act as a voice for local stakeholders and to act as a mechanism for them to provide advice as the Subwatershed study unfolds. The membership of the Focus Group includes private land owners, representatives of local and regional non-governmental organizations and clubs, local councillors, and concerned citizens from the Subwatershed. The Focus Group has provided advice to the study team, identified key issues and suggested how best to communicate the plan to the local public. During the course of the study, the Focus Group will also have opportunities to review the draft reports and provide comments.

The first Focus Group meeting was held on May 19th, 2005. This meeting introduced the Subwatershed planning process, presented an overview of the study area and discussion among the group resulted in an issues list.

3.1.1 Issues Identification

The following issues were identified as potential concerns for the community at the initial Focus Group meeting held May 19, 2005. Concerns of the Technical Committee have also been included. Related items have been placed under specific headings for ease of reference but they may, in fact, relate to more than one heading.

Dams

- Political/environmental pressure to remove dams
- Historical significance of Alton Dam and impact of retrofits/removals on Village of Alton
- Many of the dams may be in poor shape, but privately owned
- Temperature impacts of dams on downstream reaches

Water Quality

- Impacts of urbanization (siltation) on Caledon Lake wetland
- Spreading sewage sludge on land
- Amount of road salt, de-icers, sands used during winter
- Golf courses – spraying pesticides and herbicides
- Increasing water temperatures due to lack of riparian cover, dams/ponds
- Pollution from runoff from agriculture, development, septic systems

Water Quantity

- Golf courses – water taking
- Subwatershed are headwaters – need to maintain baseflow
- Water Bottling – in the future?
- Old abandoned wells – sealed?

- Current wells that are below standards (wellhead protection)

Aggregate Development
- Lack of control over pit rehabilitation
- Concern over use of closed pits for development instead of being restored or reforesting

Vegetation
- Removal of trees/woodlands/vegetation
- Tree diseases and infections that threaten forest

Fish
- Lots of non-native fish in Subwatershed (i.e. perch, smallmouth bass, rainbow trout, rock bass, pumpkinseed)

Other
- Soil erosion downstream of Caledon Lake
- Haven't set enough land aside for future parks
- Education needed on Subwatershed
- Illegal garbage dumping – need plan for public education & outreach
- Need to consider relationships outside of Shaws Creek (including watershed & municipalities)
- Need to consider Greenbelt legislation and Moraine
- Invite local councillors to champion the plan – invite to meeting & Caledon Environmental Advisory Committee (CEAC)
- Winter time use (snowmobiling) – trails
- Need expert science to back up the plan
- West Nile virus

Questions the group would like to have answered:
- How many abandoned pits are there in the Subwatershed?
- Status of the aggregate development in the Subwatershed? What are the rehabilitation plans?
- What the effects of these pits on the water? Drainage
- Who is responsible for the mill pond in Alton?
- What kinds of crops are being planted? Genetically Modified Organisms (GMO)? Pesticides to support?
- What is long-term water quality?
- What is long-term wildlife habitat?

3.1.2 Involving the Public

Bus Tour

On September 19, 2005, a bus tour for the focus group, Technical and Steering Committees was completed to provide the opportunity to discuss issues, concerns and to network amongst the groups. Technical Committee members provided a running commentary on the natural features along the tour route and issues and questions were discussed throughout the tour.

Public Meetings

CVC presented information related to the Shaws Creek Watershed Study at the Public Workshop for the Alton Settlement & Servicing Master Plan. This gave the public an opportunity to comment on the Subwatershed study as it relates to the preparation of the Environmental Management Plan for Alton.

Education & Outreach

On June 15, 2005, CVC made a visit to the Alton Public School as part of the education and outreach portion of the Shaws Creek Subwatershed Study. A short presentation to 130 students and teachers from Kindergarten to Grade 6 focused on what a watershed is and why we need to care for it. We then asked the students to give us their perspective on their hopes for the future of Shaws Creek through an assignment in drawing or writing.

On July 13, 2005, CVC made a similar presentation to the residents of the Pinnacleview Retirement Community in Alton.

3.2 LANDOWNER CONTACT

A total of 115 landowners were contacted in the Shaws Creek Subwatershed for access to their lands for the purposes of collecting data for the Subwatershed study. The majority of the landowners were initially contacted by letter in April 2005. Other landowners were contacted through personal contact at their properties. After approval from landowners was gained, a total of 43 sites were accessed. In order to ensure good rapport with the landowners and to encourage information exchange between landowners and CVC, the landowners were offered the opportunity to join the crews during their site investigations. Many landowners requested that any information of interest collected on their property be forwarded to them. To this end, a data package including results of the work conducted on the sites will be forwarded to landowners at the completion of the study.

3.3 STEERING COMMITTEE

The steering committee operates as a coordingating and information exchange committee to help establish and recommend strategic direction and priorities needed to meet project goals. The steering committee includes Dufferin County, Wellington County, Region of Peel, Township of East Garafraxa, Township of Amaranth, Town of Erin, Town of Caledon, Town of Orangeville, MNR, MOE, and OMAFRA.

3.4 TECHNICAL COMMITTEE

The technical committee is comprised of representatives from consulting firms and CVC staff who have expertise in the technical components of the study including:

- Hydrology
- Hydraulics
- Hydrogeology
- Water quality
- Fluvial geomorphology
- Terrestrial
- Planning
- Aquatics

4. Study Components

4.1 INTRODUCTION

This Chapter describes the features of Subwatershed 17 in terms of their form, function and linkage and where possible identifies trends and indicators (early warning signs) of irreversible or non-sustainable changes. In addition, examples of positive or sustainable changes are highlighted where they occur in relation to historic conditions.

The **form** of a feature is its biophysical characteristics – the size, shape, dominant vegetation type/age/health, species composition (diversity, abundance, rarity, special significance), uniqueness or representativeness and spatial distribution.

The **function** of a feature is its role as part of a larger system. These roles can include

- habitats for plants, fish, birds, other animals;
- being part of the hydrologic cycle (e.g., groundwater recharge, aquifer/ surface water supply, and the drainage network);
- forming part of the food web/chain (e.g., as a predator, prey, primary producer, or decomposer);
- acting as buffers between competing/conflicting uses (such as old fields, parklands, rights-of-way, and forest edges;)
- contributing to biosphere functions (such as creating microclimates, contributing to biomass/nutrients/air quality or adding biodiversity); and
- adding quality of life to human experiences though economics (maple syrup, wood products, and property values), nature appreciation or passive recreation.

The **linkage** of a feature is its connections to or between other features: as migration corridors for fish and wildlife, as an attenuator of surface water runoff quantity/quality to streams; as a recharge or discharge area linking surface water runoff to groundwater storage areas to stream spawning areas.

For example, a hardwood forest, a recharge area (area where soils such as sandy loams promote infiltration of rainfall into the groundwater system), a coldwater stream and a brook trout population are considered features. One of the functions of a hardwood forest is to help reduce the amount of rainfall running off the land surface, which thereby improves the quality and amount of water recharging the groundwater system. The link between the hardwood forest and groundwater feature is that the groundwater feature in turn holds water within the soils for forest vegetation uptake as well as provides a constant source of cold, clean baseflow to the stream. This cold water, which upwells through the streambed provides spawning habitats for brook trout and prevents the stream temperature from becoming too warm for these fish. The replacement of forest with agricultural row crops or urban development causes rainfall to run off the land rather than percolating into the ground. This reduces the supply of water to the groundwater system, lowering the water table and reducing or eliminating the supply of cold, clear, upwelling baseflow to the stream. At the same time, the amount of warm, runoff water to the stream increases, causing rapidly increasing water temperatures. As a consequence, brook trout habitat is lost and these fish disappear from this part of the stream.

The changes illustrated by the example above are not necessarily negative or irreversible. Changes occur naturally and affect the features in a watershed. All ecosystems, because of their complexity, are resilient or have the ability to resist or recover from a certain amount of change whether natural or human. While it may be difficult to predict whether a change will negatively affect a watershed ecosystem, it is often quite feasible to identify indicators or early warning signs that a watershed is beginning to undergo permanent change and whether that change is positive or negative based on the features in the watershed considered most valuable or desirable.

Changes resulting from human activity that remain within the watershed's natural resiliency or capacity to resist or reverse change are often called sustainable development. Activities causing a permanent or irreversible change in a watershed are examples of non-sustainable development.

The investigations were carried out in a manner that would facilitate the integration of the components or disciplines to provide on understanding of the interrelationship between these components. This integration and the overall characterization is outlined in Section 5 of this report. This section discusses the individual analyses data collection and modelling carried out in each area of investigation.

4.2 HYDROGEOLOGY

Understanding the hydrogeological setting of a subwatershed plays an important role in understanding the linkages between groundwater and surface water features within that subwatershed. It is important to understand the role of groundwater when developing a water balance or water budget for a subwatershed. Knowledge of the subsurface geology of a subwatershed, in conjunction with the ground surface topography, are the most important elements in determining the groundwater flow system within a subwatershed and the surrounding subwatersheds. The surficial geology plays a dominant role in determining the amount of precipitation that will infiltrate into the ground and recharge the water table. Fine grained surficial sediments such as silts and clays are less permeable, and therefore water will infiltrate more slowly and tend to run off more than with coarse-grained sediments such as sand and gravel. Topographical relief also plays a role in determining whether infiltrated water moves laterally and seeps out, discharges as baseflow into a local stream valley, or moves through the deep aquifer system to a larger river or lake.

The prime objectives of the hydrogeological assessment of this phase of the study are to:

- characterize the geological conditions within the subwatershed;
- characterize the hydrogeological conditions within the subwatershed; and
- identify the linkages between subwatershed hydrogeology and hydrology.

4.2.1 Geologic Setting

4.2.1.1 Overview of Geological Setting

Subwatershed 17, the Shaws Creek Subwatershed, comprises portions of three distinct physiographic regions (Chapman and Putnam, 1984): Guelph Drumlin Fields, Hillsburgh Sandhills and the Dundalk Till Plain. Each of these physiographic regions was formed within a distinct depositional environment and therefore each has a distinct geological character. The geology of the subwatershed therefore, varies from one physiographic region to another. Understanding the nature and depositional history of the bedrock and overburden sediments within the study area provides valuable information about potential aquifers and aquitards and their continuity through the subsurface.

4.2.1.2 Surface Topography

Surficial topographic relief in the Shaws Creek Subwatershed is highly variable and is the direct result of glacial deposition (Orangeville Moraine, till plains), and erosion (river valleys) during the Quaternary Period (two million years ago to present).

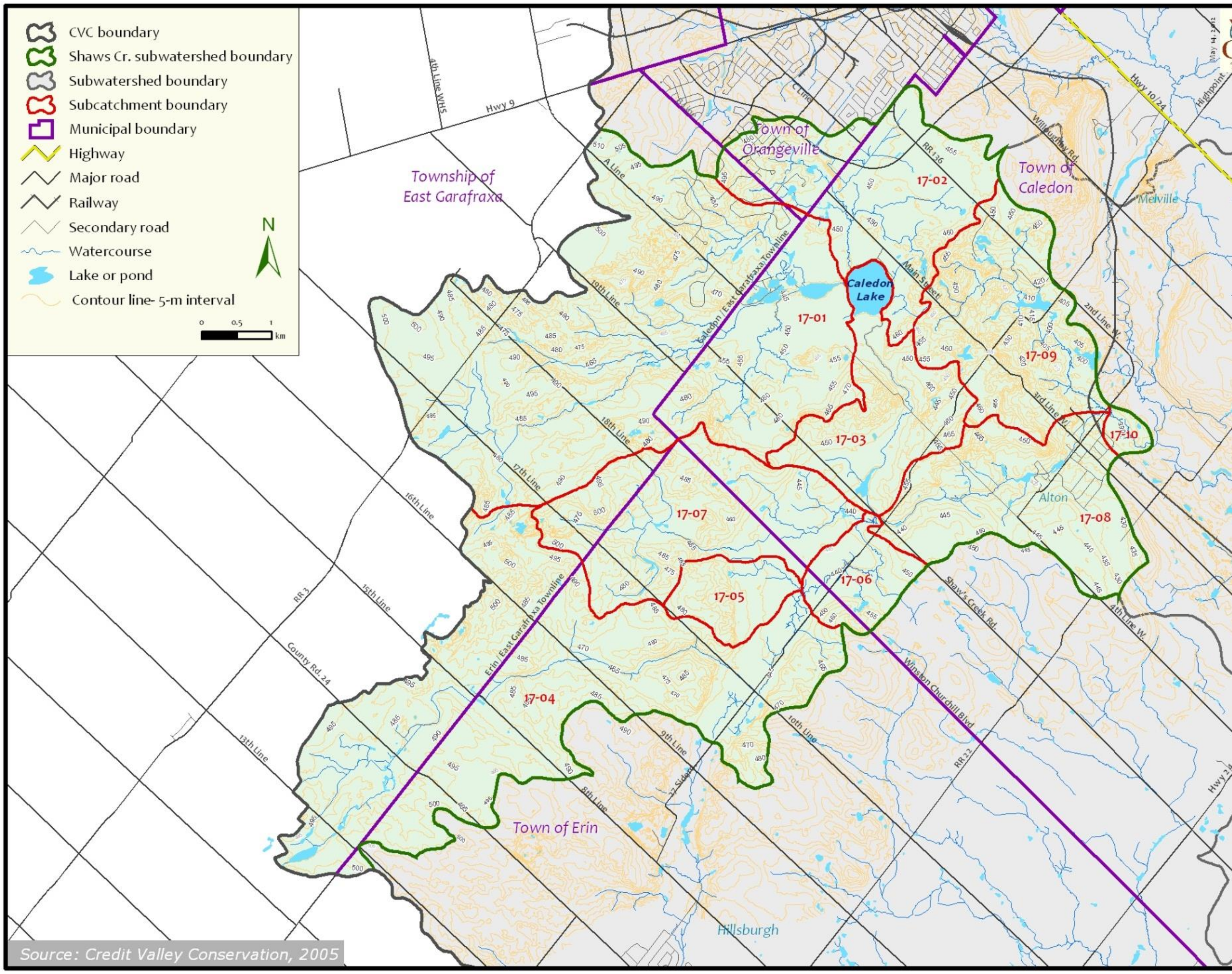


Figure **4.2.1** is a map of the ground surface elevation generated using the Digital Elevation Model (DEM) provided by the Ministry of Natural Resources. According to the DEM, the highest elevation in the subwatershed (512 m amsl) is recorded west of Orangeville near the intersection of A Line and the Orangeville-Fergus Road. This area is part of the northeast-southwest trending Orangeville Moraine. The lowest elevation in the watershed (395 m amsl) is found within the Village of Alton. In general the ground surface topography is highest in the western portions of the subwatershed and slopes towards the Credit River located just east of the Subwatershed.

4.2.1.3 Physiography

As stated above, Subwatershed 17 comprises portions of three physiographic regions: Guelph Drumlin Fields, Hillsburgh Sandhills and the Dundalk Till Plain. The characteristics of each of these regions are as follows:

Guelph Drumlin Field

The Guelph Drumlin Field exists only in the far eastern reaches of the subwatershed near Acton (Figure 4.2.2). This physiographic region lies between the Paris Moraine to the east, the Singhampton Moraine to the north, and the Orangeville Moraine to the west (Singer et al., 1994). The region has been described as a series of elongated streamlined hills that rise modestly above the surrounding till plain on the northern reaches of the Paris Moraine.

The core of the drumlins is interpreted to consist of Port Stanley Till, a relatively coarse sandy till (Karrow, 1987). The drumlins are interpreted to be separated from one another by numerous interconnected meltwater channels. These meltwater channels are frequently coarse-grained and can play a significant role in the local shallow groundwater flow regime.

Hillsburgh Sandhills

The physiographic region known as the Hillsburgh Sandhills covers the vast majority of the study area (Figure 4.2.2). This area extends from Hillsburgh in the south to Orangeville in the north and this prominent topographic feature is more commonly known as the Orangeville Moraine (Cowan, 1976). The moraine is composed primarily of coarse-grained sandy material that has been extensively dissected by fluvial erosion. The outstanding physiographic features of this region include the rough topography and the extensive low lying swampy Hillsburgh Meltwater Channel that runs from Orangeville to Hillsburgh (Chapman and Putnam, 1984). Topography on the moraine ranges from 440 to 500 m amsl, with local relief of up to 30 m
(

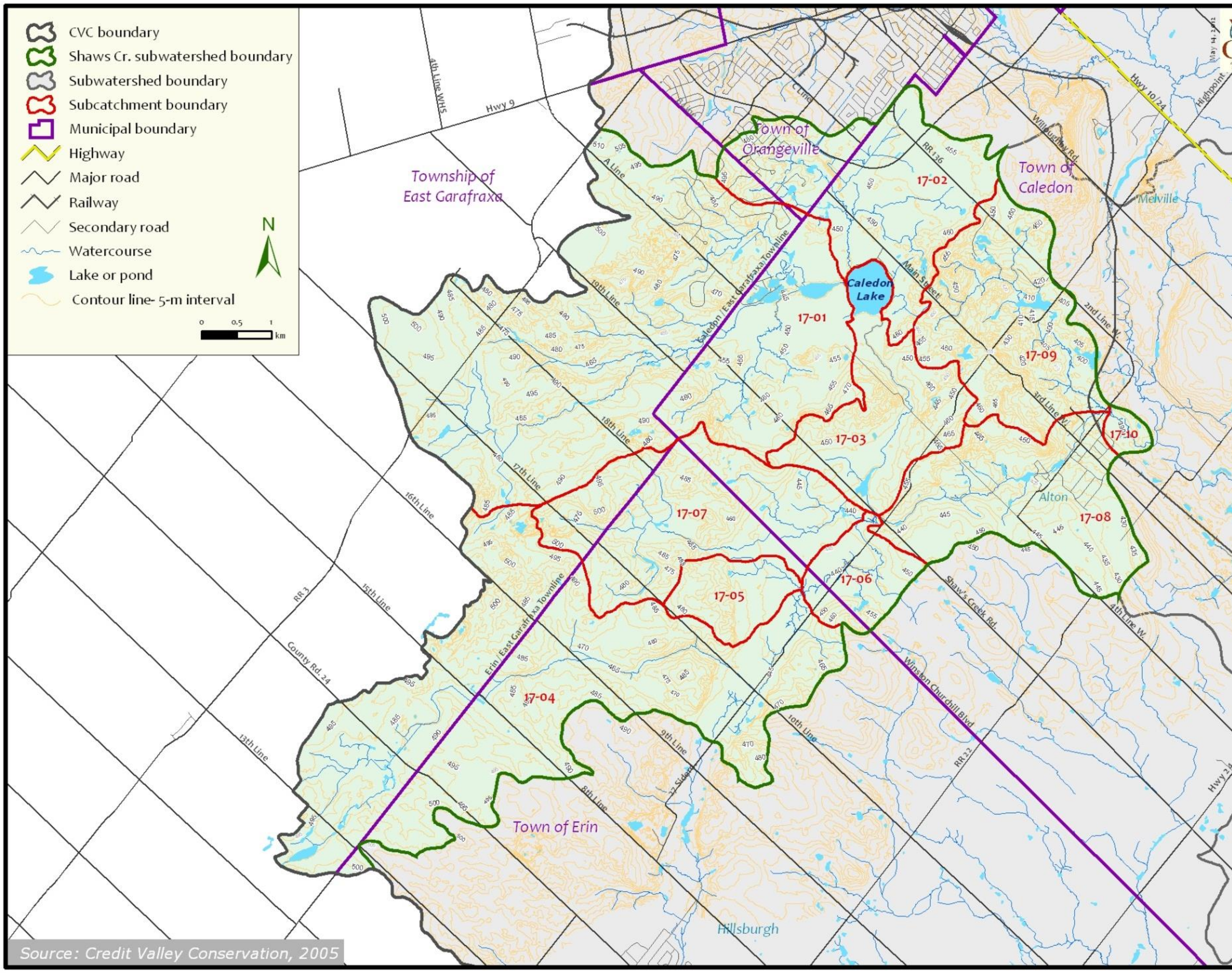


Figure **4.2.1**).

Dundalk Till Plain

The westernmost portions of Subwatershed 17 are represented by a physiographic region that Chapman and Putnam (1984) referred to as the Dundalk Till Plain. This till plain is characterized as gently undulating and poorly drained due to the preponderance of fine-grained silt and clay tills.

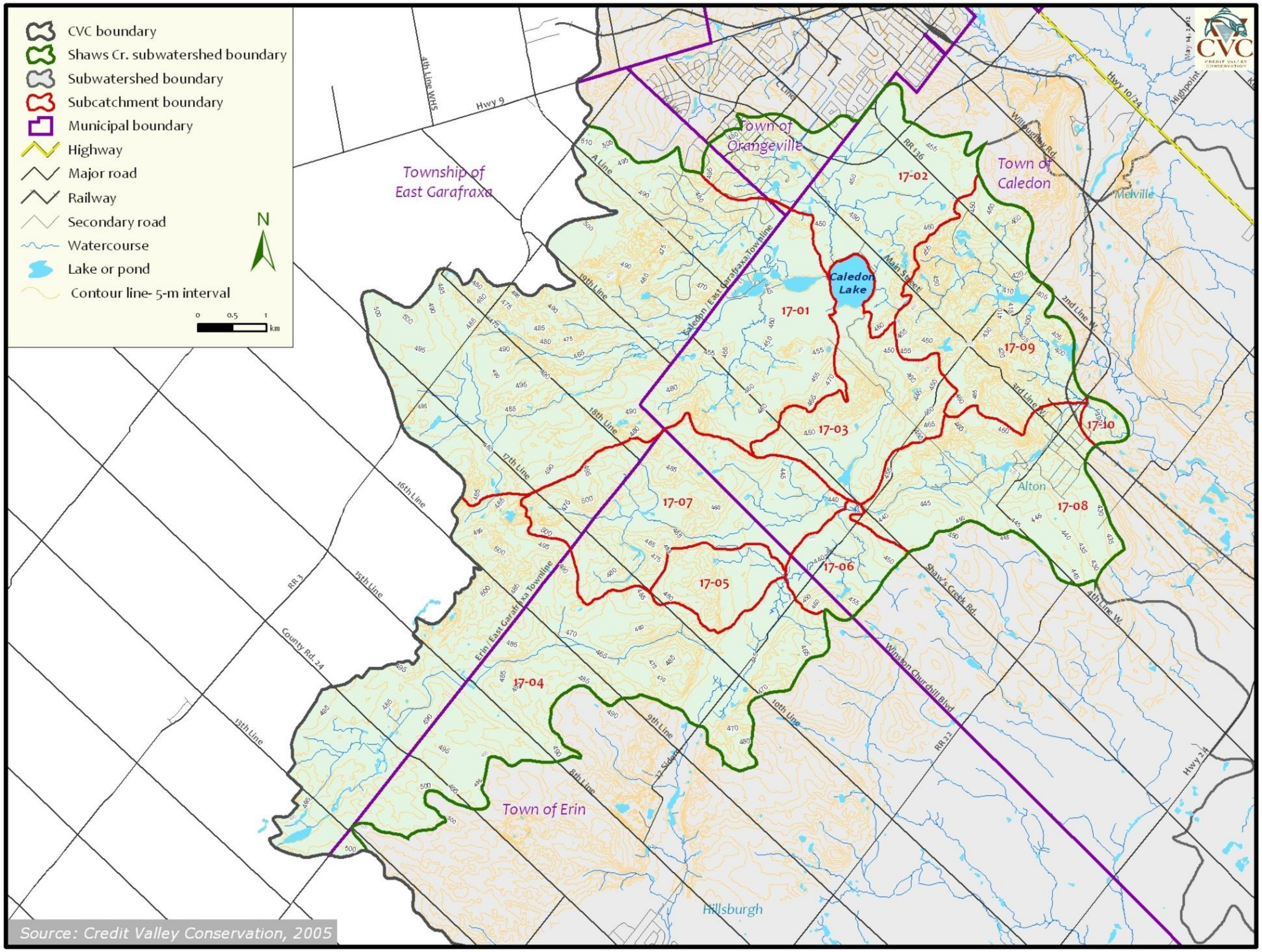


Figure 4.2.1 Ground Surface Elevation

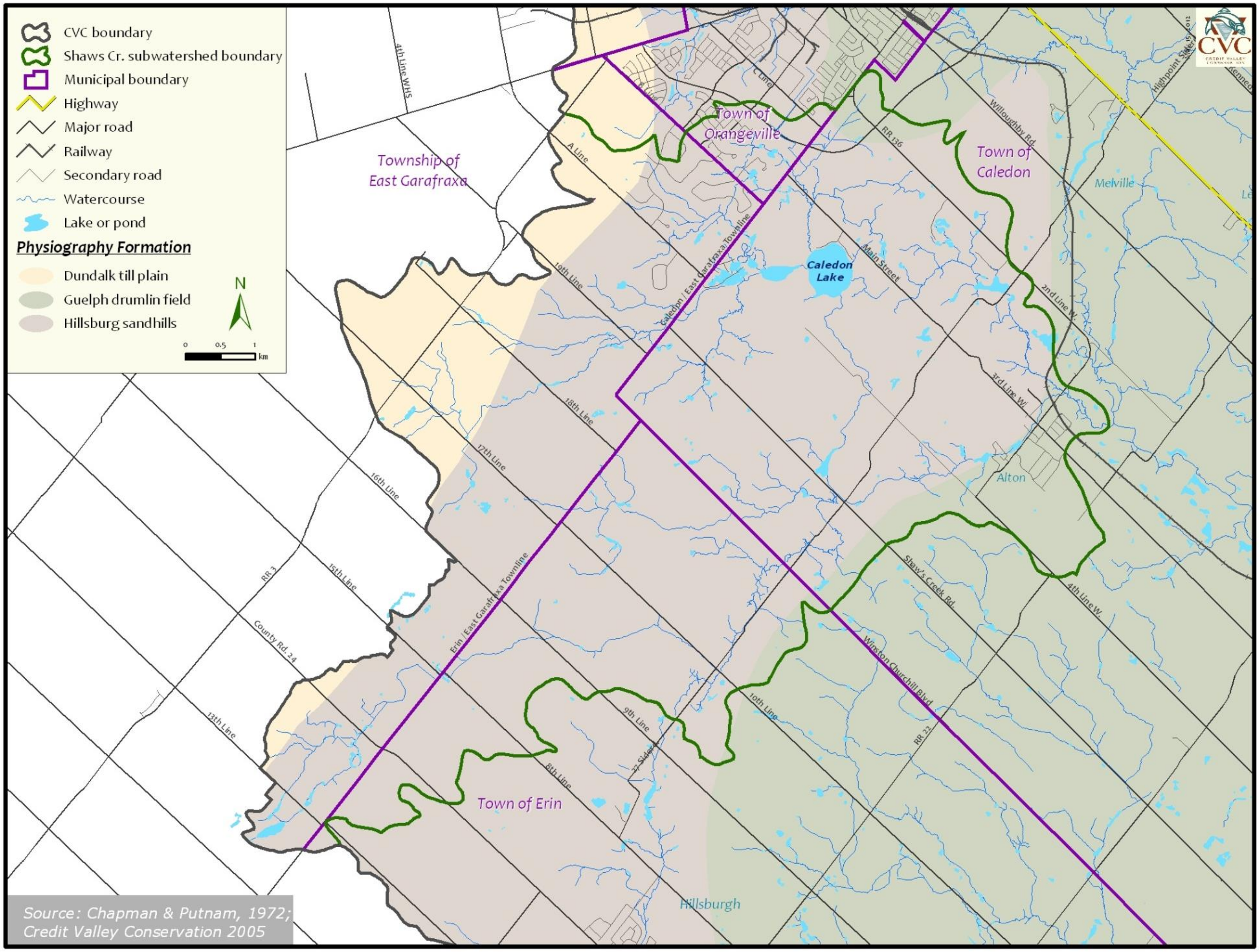


Figure 4.2.2 Physiography

4.2.1.4 Surficial Geology

The surface deposits covering the Shaws Creek catchment area owe their origin to the action of ice and water. The glacial drift deposited by the melting ice of the Wisconsin Glaciation blankets the entire area. The variations in the texture and drainage characteristics of these unconsolidated surface deposits are a result of the differences in the nature of their deposits. The surface deposits occurring in the Shaws Creek catchment area can be classified according to the following divisions; glacial till, glacio-fluvial and lacustrine.

The surface geology of the basin includes areas of fine, sandy loam of the Hillsburgh Series, poor to well sorted sandy outwash till of the Pontypool and Caledon Series and medium textured till loam of the Harriston Series.

The impoundment of water in the low lying areas of the basin has resulted in swampy conditions and the accumulation of organic materials. These organic deposits are scattered throughout the basin.

The Shaws Creek catchment area is underlain by sedimentary strata of the Silurian age. The formations of this age include the Guelph and Lockport shales.

The relief of the basin consists of typical land form features associated with the continental glaciation. Most of the basin consists of a continuous rugged relief with marshy areas within the floodplains. A land form characteristic of the glaciation found in this area is the elongated hills known as drumlins.

Figure 4.2.3 illustrates the surficial geology of the study area. This map was reproduced without modifications from an Ontario Division of Mines Map (P.2326), which details the Quaternary geology of the Orangeville area (Cowan, 1976). This map was created at a 1:50,000 scale, and therefore, some variations from the soil types presented are anticipated on a local scale. Nevertheless, the mapping is useful in illustrating the overall surficial geology of the study area.

The surficial geology of the study area is characterized by four significant geological features:

1. Orangeville Moraine
2. Tavistock Till Plain
3. Port Stanley Till Plain
4. Hillsburgh Meltwater Channel

The following is a brief geological description of each of these deposits from a groundwater perspective:

Orangeville Moraine

The most prominent topographic feature in the subwatershed is the Orangeville Moraine. The Orangeville Moraine was formed between three opposing ice lobes during the last advance of the Laurentide Ice Sheet during the Late Wisconsinan glacial stade. One ice lobe advanced south-eastward from Georgian Bay into the area, another advanced south-westward from Lake Simcoe and a third advanced northward out of the Lake Ontario basin (Chapman and Putnam, 1984). These three lobes coalesced in the Orangeville area leaving behind the coarse-grained glaciofluvial sediments that make up the Orangeville Moraine. The moraine is a south-westerly trending band of stratified drift, comprised primarily of sand and gravel, with some finer grained material (generally silt) as well (Cowan, 1976). The north-eastern extent of the Orangeville Moraine is comprised of two lobes on either side of the Town of Orangeville that merge forming a single band southeast of Orangeville. The location of the Orangeville Moraine is identifiable by the thick and laterally extensive deposits of ice-contact stratified drift (sand and gravel) outlined on Figure 4.2.3. The Orangeville Moraine is generally a flat to hummocky topographic feature that has been dissected by fluvial erosion. As noted above, local topographic relief on the moraine is up to 30 m above the surrounding landscape.

Tavistock Till Plain

The Tavistock Till Plain occurs on the western and northern edges of the Shaws Creek Subwatershed, primarily west of the Orangeville Moraine. It was deposited when the Georgian Bay ice lobe advanced from the north overriding the western portion of the Orangeville Moraine in the townships of East Garafraxa and Amaranth (Singer et al, 1994). The Tavistock Till ranges in thickness from less than 1 m to over 10 m (Chapman and Putnam, 1984), and within the subwatershed is described as a brown to dark yellowish brown, silt or clayey silt till (Cowan, 1976).

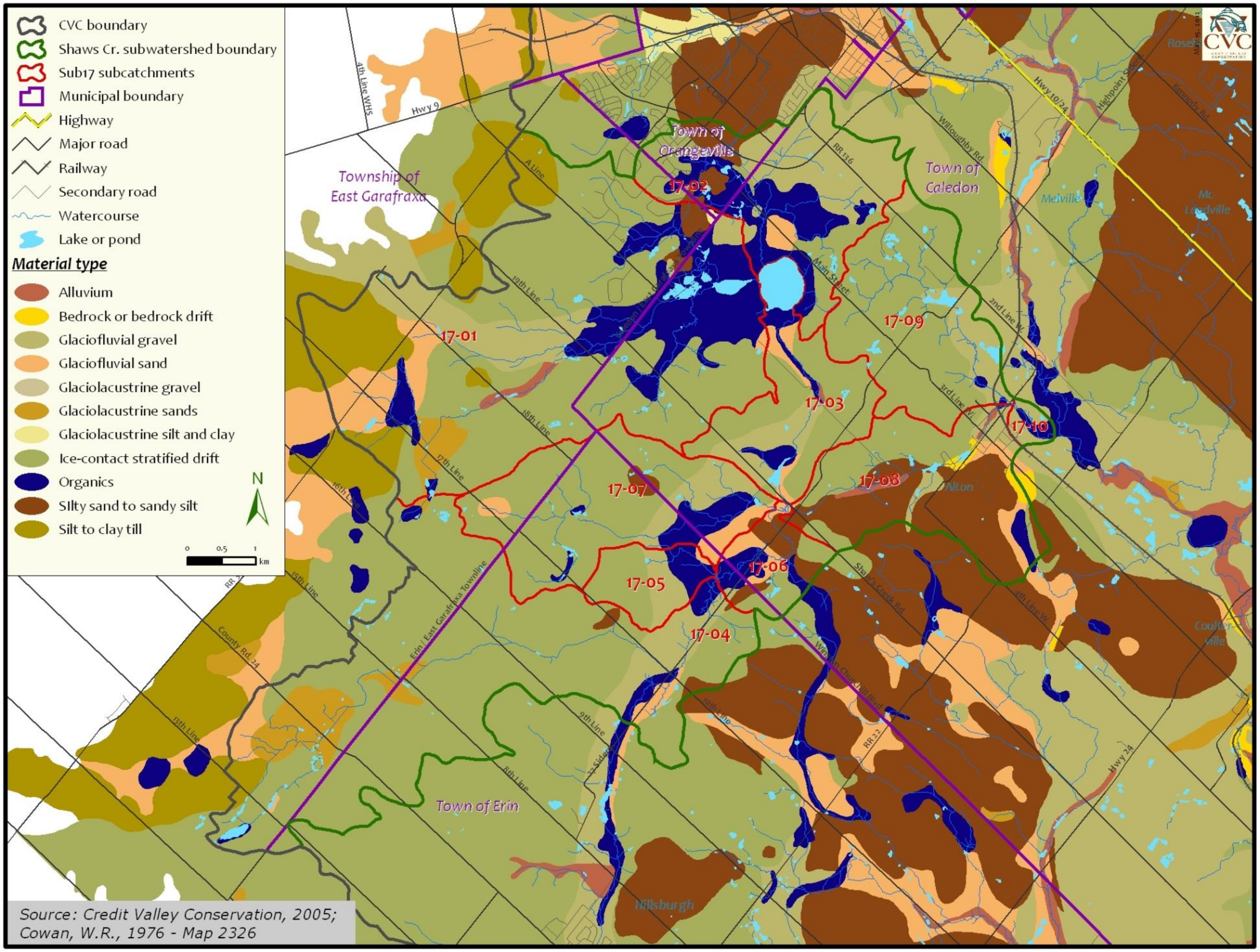


Figure 4.2.3 Surficial Geology

Port Stanley Till Plain

The Port Stanley Till Plain is found in the south-eastern portion of the subwatershed, south of the Orangeville Moraine, and east of the study area. The Port Stanley Till was deposited by a north-westward advance of the Lake Ontario ice lobe and typically occurs in the Guelph Drumlin Field as sandy silt till with occasional stones or boulders. The thickness of the till ranges from 1 m to 15 m (Chapman and Putnam, 1984), and is mapped (Figure 4.2.3) as brown to light yellowish-brown stony to bouldery silty sand to sandy silt till (Singer et al., 1994).

Hillsburgh Meltwater Channel

The Hillsburgh Meltwater Channel, (Figure 4.2.3) is a glaciofluvial gravel deposit trending north-south from south of Caledon Lake to the Town of Hillsburgh on the eastern limb of the Orangeville Moraine. The Hillsburgh Channel is comprised of approximately 7 m of gravel or gravelly sand, and is often overlain by finer grained deposits that limit infiltration to the deeper sediments (Chapman and Putnam, 1984; Singer et al., 1994).

Other Surficial Geology Deposits

Other glaciofluvial deposits in and near the subwatershed are outwash deposits comprised primarily of sand with some gravel. These deposits are found near the western boundary of the study area and also along the path of the Hillsburgh Meltwater Channel (Figure 4.2.3). Glaciolacustrine deposits in the subwatershed are generally comprised of fine to very fine sands, and are mapped in the western portion of the subwatershed.

Non-glacial deposits in the subwatershed include more recent alluvium, bog, and swamp deposits. Alluvium deposits occur along much of Shaws Creek and its tributaries, and are comprised of materials ranging from silt and organic material to sand and gravel deposits. The bog and swamp deposits typically occur near Caledon Lake and in the low, poorly drained meltwater channel that trends from near Caledon Lake towards Hillsburgh.

4.2.1.5 Bedrock Geology

The uppermost bedrock surface underlying the Shaws Creek Subwatershed is illustrated in Figure 4.2.4. The map was produced from a Ministry of Northern Development and Mines bedrock geology map, created at a scale of 1:1,000,000 (Ontario Geological Survey, 1988).

The bedrock units in the Credit River Watershed consist of Palaeozoic sedimentary rocks, composed of limestone, dolostone, sandstone and shale sequences that overlie Precambrian basement rocks. The Paleozoic sedimentary bedrock units dip regionally at 0.2° to the southwest towards the centre of the Michigan Basin. Bedrock outcrops are rare within the subwatershed area as thick glacial deposits overlie these units. Within Subwatershed 17, bedrock is exposed along Shaws Creek just outside the Village of Alton.

There are three bedrock formations that subcrop beneath the subwatershed: the Manitoulin, Amabel, and Guelph Formations. Each of these bedrock formations is described in detail below.

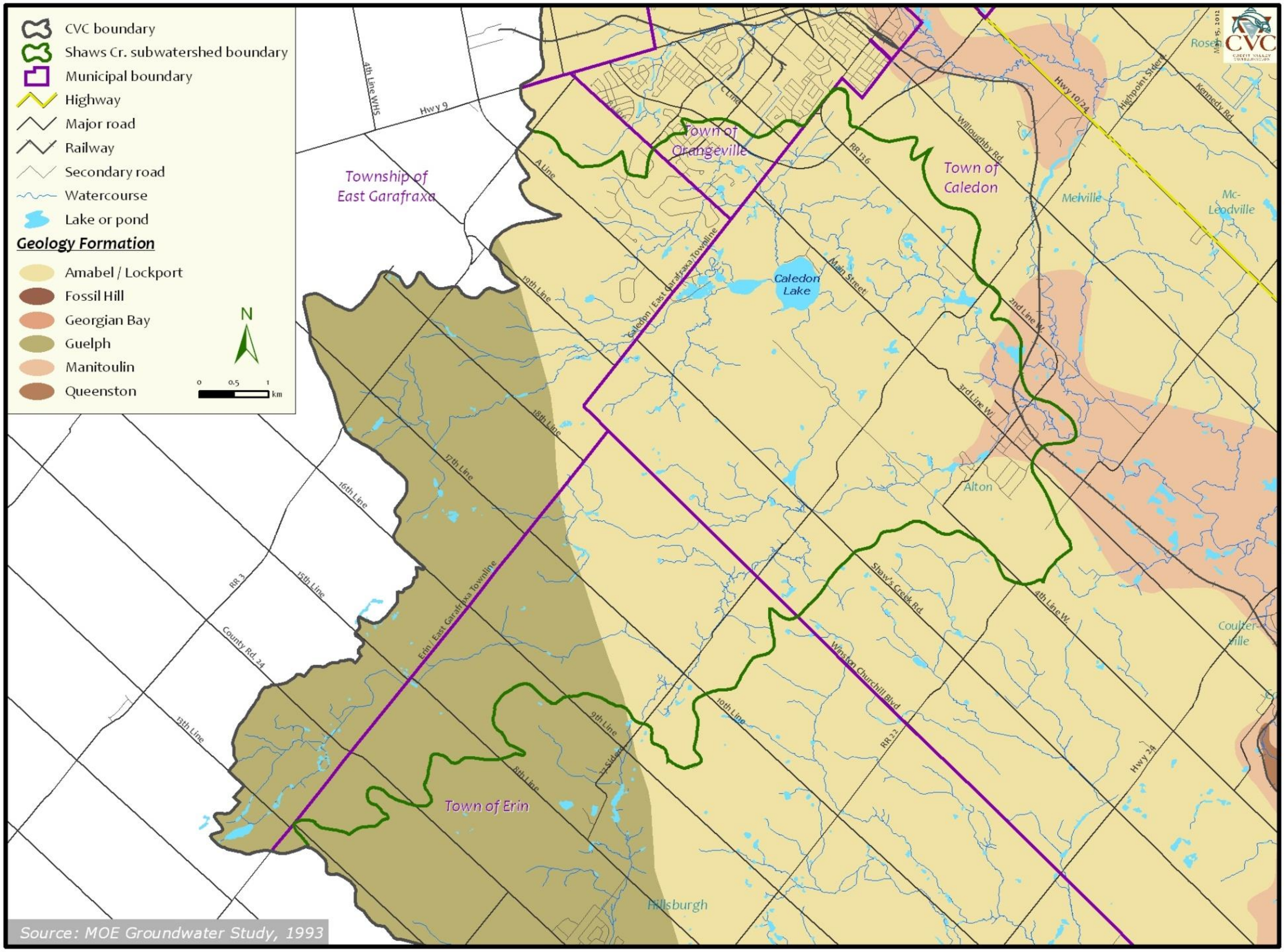


Figure 4.2.4 Bedrock Geology

Manitoulin Formation
The Manitoulin Formation underlies only a small portion of subwatershed beneath the Village of Alton (Figure 4.2.4). This unit has been described as a grey, dense, weathered dolostone with abundant fossils. The Manitoulin Formation ranges in thickness from 5 to 7 m (Cowan, 1976).

Amabel Formation
The Amabel Formation overlies the Manitoulin Formation and is the uppermost bedrock unit beneath the central portion of the Shaws Creek Subwatershed (Figure 4.2.4). The Amabel Formation is described as a highly fossiliferous, grey crystalline dolostone with abundant reefal structures (Cowan, 1976). The unit is capable of yielding large quantities of groundwater due to secondary porosity features such as fractures and dissolution cavities (Singer et al, 2003). The Amabel Formation varies in thickness from a few meters to over 30 m (Singer et al., 1994). The Amabel Formation is a very significant local and regional aquifer, and its hydrogeologic properties are described in further detail below.

Guelph Formation
The Guelph Formation overlies the Amabel Formation and underlies the western portion of Subwatershed 17 (Figure 4.2.4). The Guelph Formation is described as a fossiliferous, cream to brown crystalline dolostone, and it is also capable of yielding large quantities of groundwater in some areas due to secondary porosity features such as fractures and cavities (Cowan, 1976; Singer et al, 2003). As the Guelph and Amabel Formations have similar geologic and hydrogeological properties these units are frequently considered as a single hydrostratigraphic unit (Singer et al., 1994).

4.2.1.6 Overburden Thickness
Figure 4.2.5 illustrates the overburden thickness, or depth to bedrock within the Shaws Creek Subwatershed. This map was created by subtracting the ground surface elevation from the top of bedrock elevation recorded at wells within the study area as contained in the MOE Water Well Information System (WWIS). The resulting overburden thickness was then interpolated and contoured across the study area.

Overburden thickness in the study area varies from negligible thickness, where bedrock is exposed, to areas that contain over 70 m of unconsolidated sediments. The bedrock outcrops in only a few areas of the subwatershed including a portion of Shaws Creek in the Village of Alton. Overburden thickness reaches its maximum in the western reaches of the subwatershed and is associated with the crest of the Orangeville Moraine (Figure 4.2.3). Overburden is relatively thin (10 m to 20 m thick) along the Hillsburgh Meltwater Channel along Sideroad 27, and in areas within the Village of Alton. Figure 4.2.5 also illustrates the presence of numerous fluvial channels that have locally eroded the Orangeville Moraine.

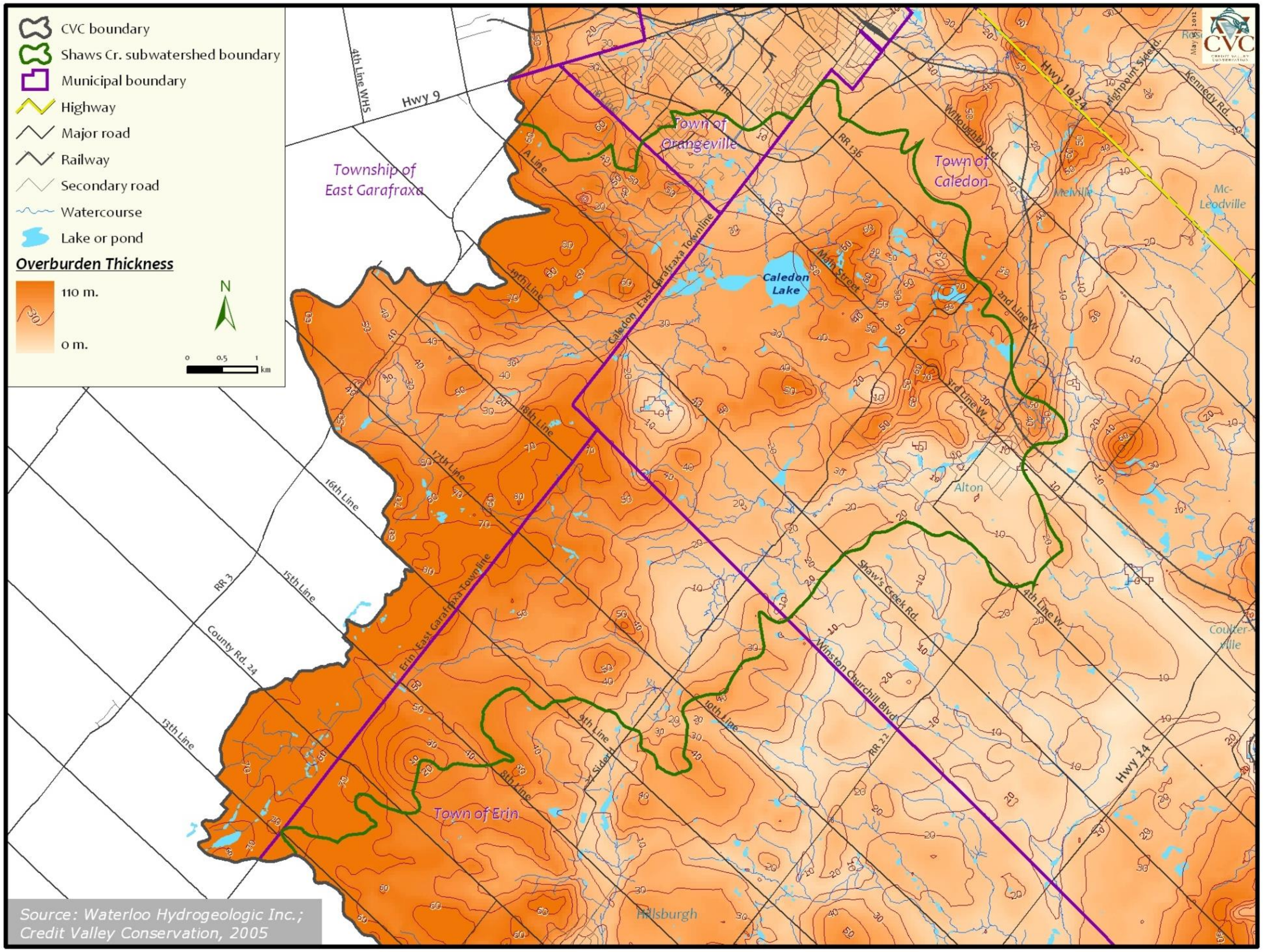


Figure 4.2.5 Overburden Thickness

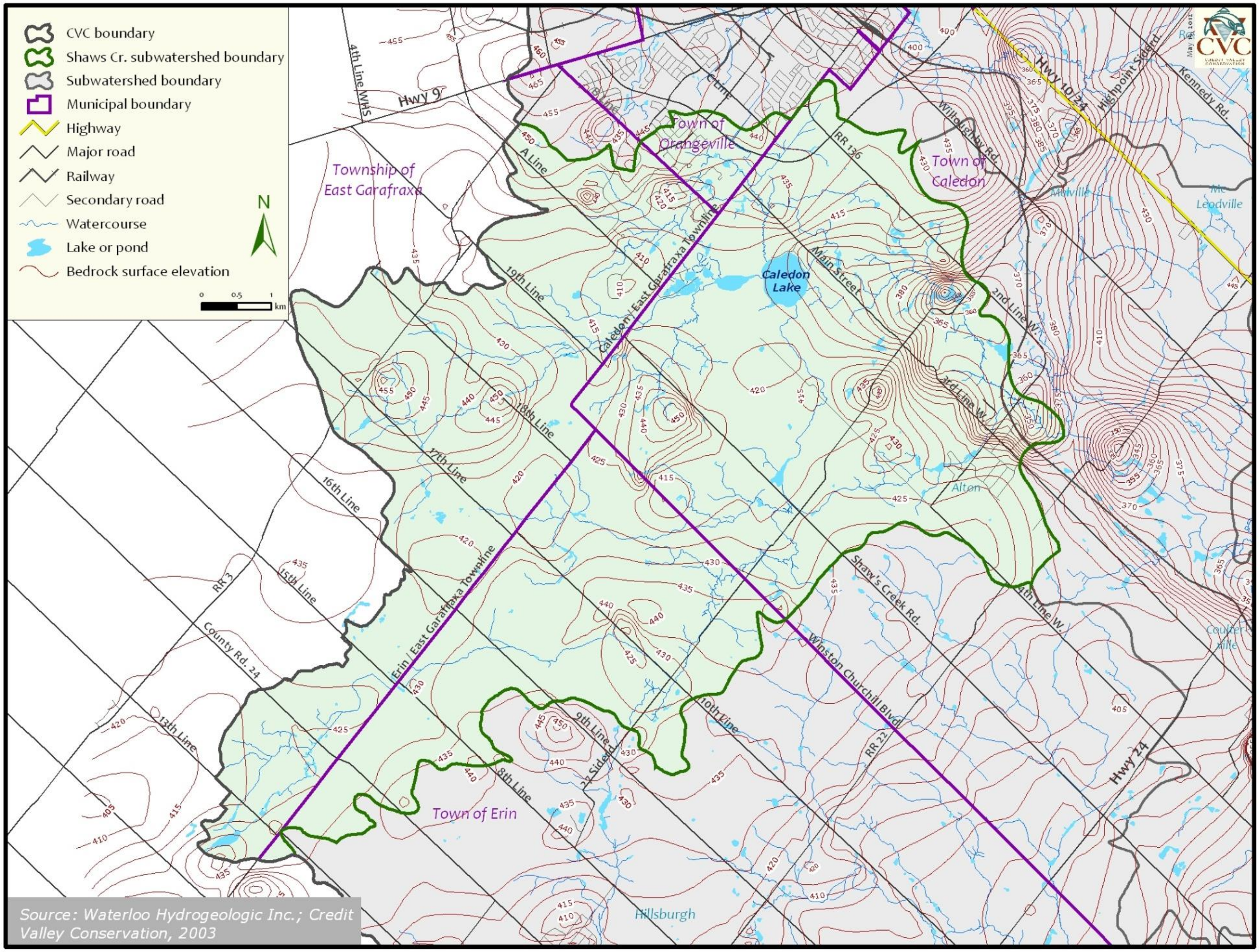


Figure 4.2.6 Bedrock Topography

4.2.1.7 Bedrock Topography

The topography of the bedrock surface beneath the Shaws Creek Subwatershed is similar to the present day surficial topography (Figure 4.2.5). In general, the bedrock surface forms a plateau which slopes in a south-easterly direction towards the crest of the Niagara Escarpment. The Ministry of the Environment Water Well Information System (MOE WWIS) was used to improve this general interpretation of the bedrock topography. The top of bedrock, recorded in the WWIS at individual wells, was interpolated across the study area to produce the bedrock topography map (**Figure 4.3.6.** The bedrock topography ranges in elevation from a high of approximately 455 m amsl in the north-western portion of the subwatershed, to a low of approximately 340 m amsl at the eastern boundary of the subwatershed near Alton. **Figure 4.3.6** also illustrates the irregular nature of the bedrock surface beneath the Shaws Creek area. There is an area in the central portion of the subwatershed where the bedrock surface appears to rise roughly 35 m above the surrounding bedrock, however, it is not known if this is the result of a few unreliable water well records, or if it is a true representation of the bedrock surface. Aside from this potentially anomalous area of the subwatershed, the bedrock in general slopes from the northwest to the southeast.

Figure 4.3.6 illustrates the presence of a bedrock depression along the far eastern reaches of the subwatershed and areas just east of the subwatershed boundary west of Second Line West and 27 Sideroad. The bedrock surface in this area is reported to be at an elevation of 340 to 360 m amsl, in contrast to the surrounding area, which reports elevations ranging from approximately 420 to 455 m amsl. This bedrock depression is somewhat linear in nature and is interpreted to be a valley eroded into the bedrock millions of years ago when a river running through this area carved a valley into the exposed bedrock. This valley was subsequently infilled with fine and coarse grained sediments leaving the area without any indicators on the ground surface of what lies beneath. There are few reliable records of boreholes that intersect buried bedrock valleys such as this one, and geologists can only speculate on their general extent and location. Singer et al. 1994 and Singer et al. 2003 identified a channel running from the north-eastern limb of the Orangeville Moraine to Alton. They interpret this channel to contain variable sediments including clean stratified gravel up to 15 m in thickness (Singer et al, 2003).

4.2.1.8 Detailed Geological Assessment

The subsurface geology and hydrogeology of Subwatershed 17 were examined by developing over 10 cross-sections. The locations of these cross-sections are illustrated on **Figure 4.2.7**, with five representative cross-sections illustrated on **Figure 4.2.8** to **Figure 4.2.12**.

There are 388 water wells with records that lie within Subwatershed 17 and a number of these records were used to create and interpret the 10 cross-sections within the subwatershed. In general, cross-sections that run southwest-northeast were spaced 1 km to 1.5 km apart, and cross-sections that run northwest-southeast were spaced 1.5 km to 1.75 km apart. The spacing of the cross-sections was largely influenced by the rural road network, and the location of private water wells along those rural roads. Four main hydrostratigraphic units were identified on the cross-sections. From ground surface to bedrock, these units are:

- upper sand and gravel aquifer (associated with the Orangeville Moraine);
- clay till aquitard (Port Stanley and Tavistock Till);
- a lower basal sand and gravel aquifer; and
- Guelph/ Amabel/ Manitoulin Formation bedrock.

The general descriptions provided in the MOE WWIS, based often on rotary drilling (which provides limited stratigraphic information), has prevented further subdivision of regional hydrostratigraphic units. Localized aquifers and aquitards are likely to exist, but have not been captured on these regional cross-sections. It is expected that ongoing studies undertaken as part of CVC's Source Water Protection efforts, such as aquifer vulnerability assessments, will lead to further refinements of the geology in this area.

Cross-section A-A'

Cross-section A-A' (**Figure 4.2.8**) is approximately 8 km in length and extends in a southwest to northeast direction, into the southwest corner of the Town of Orangeville. Overburden thickness varies greatly along the cross-section from roughly 25 m near Orangeville, to over 70 m in the central portion of the cross-section near the crest of the Orangeville Moraine. The Moraine forms a significant topographic high across much of the north-western portion of

Subwatershed 17. Cross-section A-A' illustrates the high topographic elevations of the moraine with the top of well casings lying at elevations ranging from 455 to 485 m amsl.

As illustrated on this cross-section, a thick (up to 30 m) layer of surficial sand and gravel associated with the moraine (ice contact stratified drift) lies just below ground surface. Beneath the surficial sand and gravel unit lies a thick layer of till with significant clay content interpreted to be either Tavistock Till or Port Stanley Till. This unit varies in thickness from 0 m (Well 1705288 in Orangeville) to 60 m west of the Subwatershed 17 (well 1705393) and commonly overlies the limestone/ dolostone bedrock. In a few boreholes (wells 1705455 and 1704869), a lower sand and gravel overburden aquifer lies between two till sheets and is interpreted to represent localized outwash sand and gravel deposits.

Cross-section B-B'

This cross-section (**Figure 4.2.9**) runs southwest to northeast through the central portion of the Shaws Creek Subwatershed. The cross-section is approximately 11 km in length, and extends through the centre of Caledon Lake. The stratigraphy of this cross-section is very similar to that of cross-section A-A' in that there is a thick layer of glaciofluvial sands, and ice contact stratified drift (sands and gravels) associated with the Orangeville Moraine, overlying fine-grained clay till and dolostone bedrock. Well 4900983, the far north-eastern well on the cross-section, contains a very thick sequence of sand and gravel from surface to bedrock. This thick accumulation is interpreted to be related to the buried bedrock valley or the subsurface outwash deposits discussed above.

Cross-section C-C'

Cross-section C-C' (**Figure 4.2.10**) runs southwest to northeast through the eastern reaches of the subwatershed near the Village of Alton. The ground surface topography along this cross-section varies from 480 m amsl in the west to 390 m amsl in the east near Alton. This 90 m difference in elevation is attributed mainly to the presence of the Orangeville Moraine in the west. The thickness of sand and gravel decreases from the west to the east, and only a thin veneer of sand blankets the surface in the Alton area.

The bedrock surface on this cross-section also varies dramatically from west to east along this cross-section. Most notable is the drop in bedrock elevation in the far eastern portion of the cross-section between boreholes 4906307 (top of bedrock at 360 m amsl) and 4903140 (top of bedrock of approximately 400 m amsl). This 40 m change in bedrock elevation is interpreted to be associated with the buried bedrock valley that runs from Orangeville to Alton.

Cross-section D-D'

This cross-section (**Figure 4.2.11**) runs perpendicular to the three cross-sections discussed above. It is roughly 14 km in length and extends in a northwest to southeast direction through the Shaws Creek Subwatershed. Most notable on this cross-section is the variable ground surface topography. Ground surface elevations vary from approximately 495 m amsl (well 1702966) on the Orangeville Moraine, to 420 m amsl (Borehole 4905134) at Shaws Creek south of Alton. There is an outcrop of bedrock in Alton where the Shaws Creek has eroded the overburden The low lying topography surrounding Caledon Lake associated with the Hillsburgh Meltwater Channel is also illustrated in boreholes 4900985 and 4905473 on this cross-section.

The thickness of individual overburden units varies from one borehole to the next; however, the general stratigraphy remains the same, with an upper sand and gravel aquifer overlying a clay till aquitard, and a lower basal aquifer overlying dolostone bedrock.

Cross-Section E-E'

Cross-Section E-E' (**Figure 4.2.12**) runs parallel to D-D', and extends roughly 12 km in length through the central portion of the Shaws Creek Subwatershed. Similar to the other cross-sections discussed above, the stratigraphy encountered consists of thick deposits of sand and gravel associated with the Orangeville Moraine, underlain by clay tills. The basal sand unit lying atop bedrock is absent in this area, however, it appears that this unit is fairly localized and discontinuous across the subwatershed.

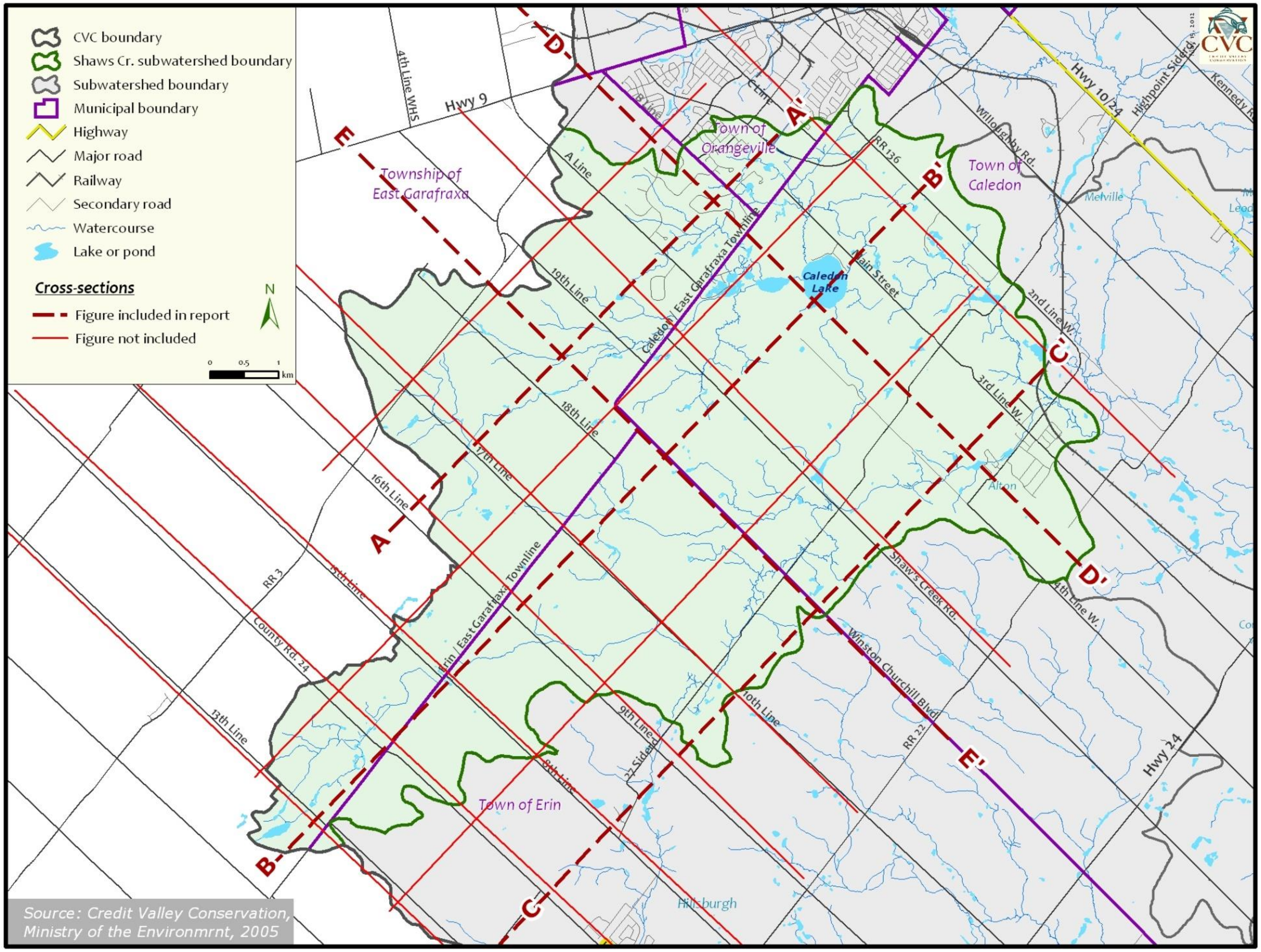


Figure 4.2.7 Cross-Section Locations

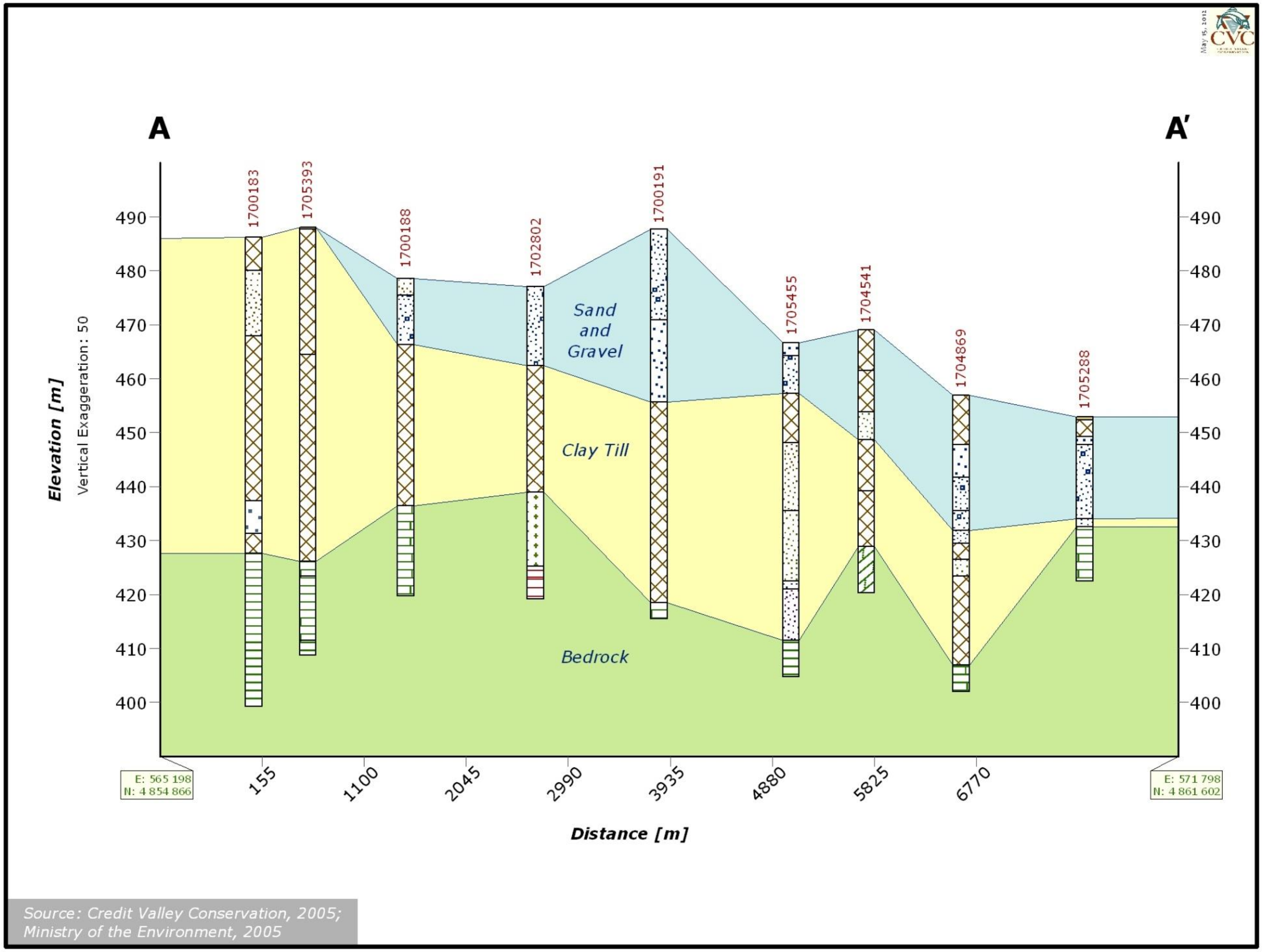


Figure 4.2.8 Cross-Section A-A'

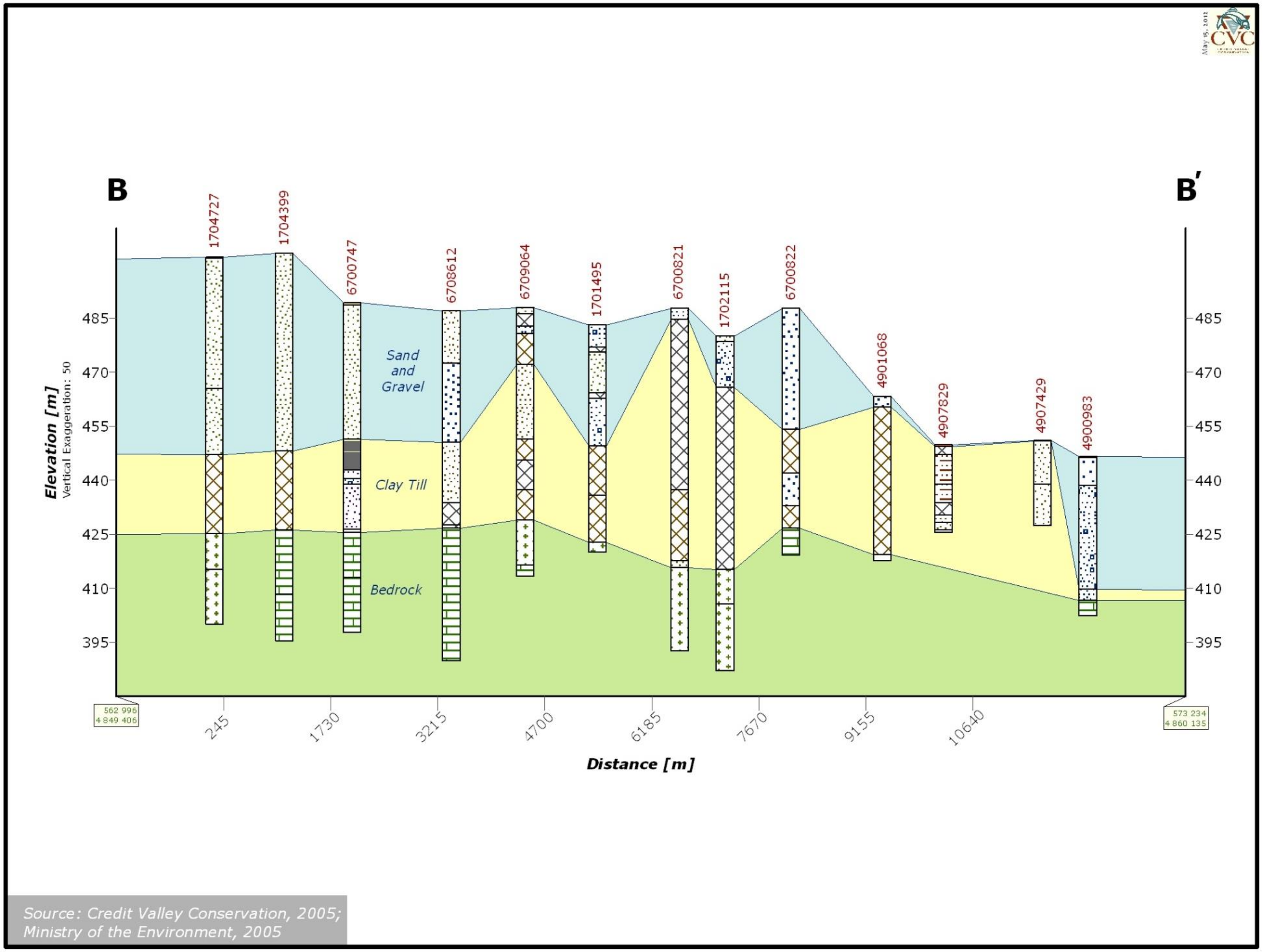


Figure 4.2.9 Cross-Section B-B'

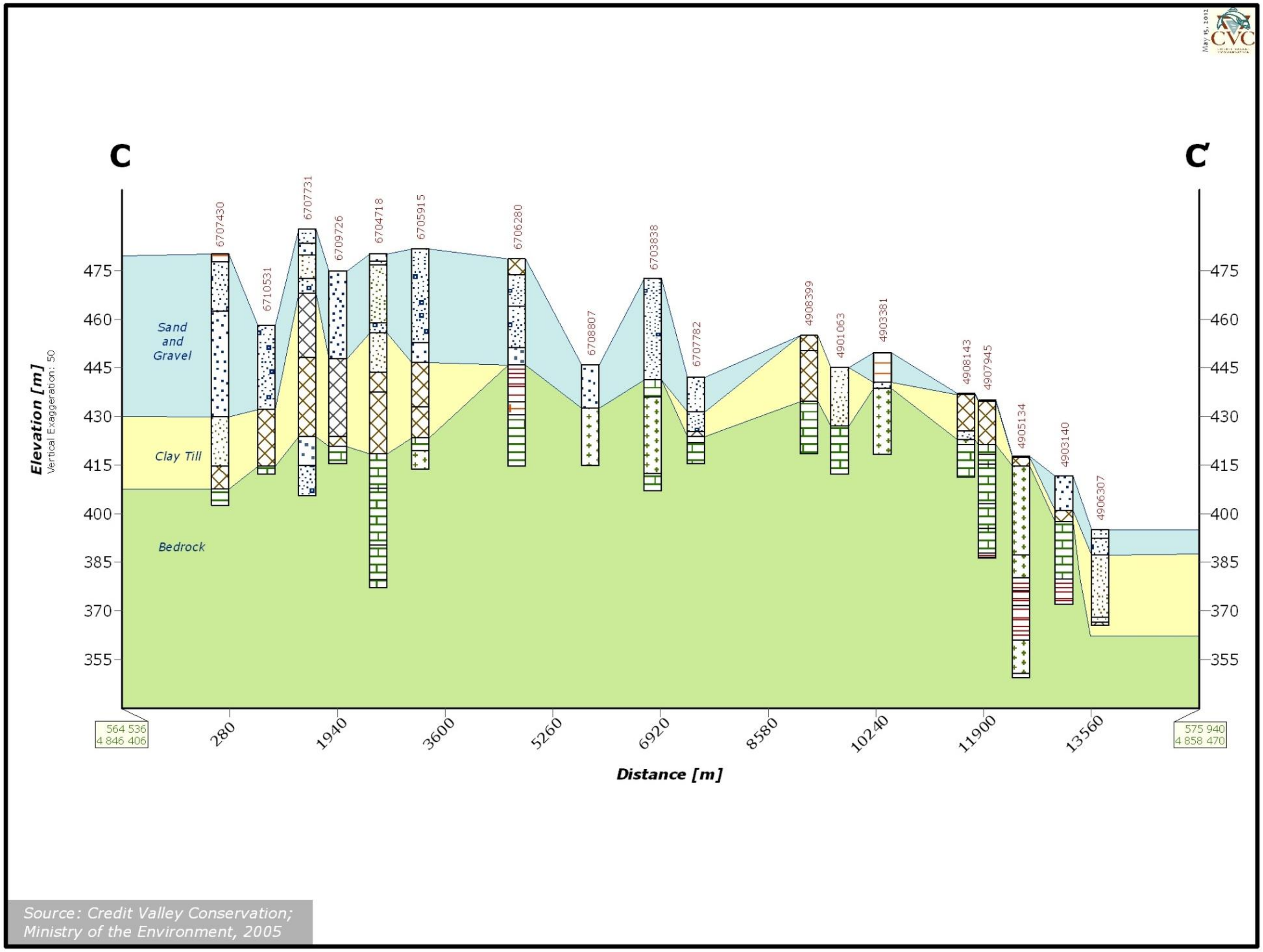


Figure 4.2.10 Cross-Section C-C'

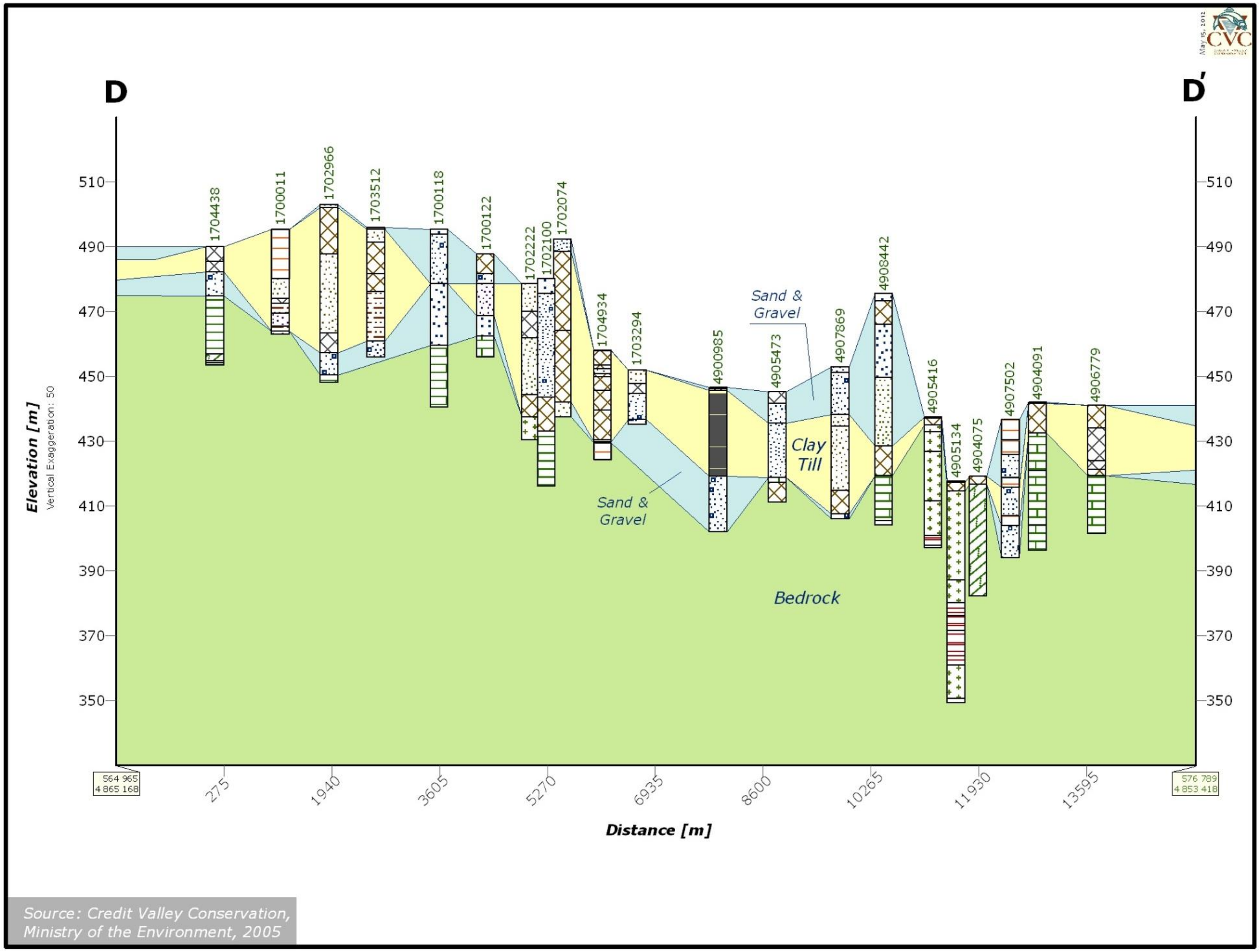


Figure 4.2.11 Cross-Section D-D'

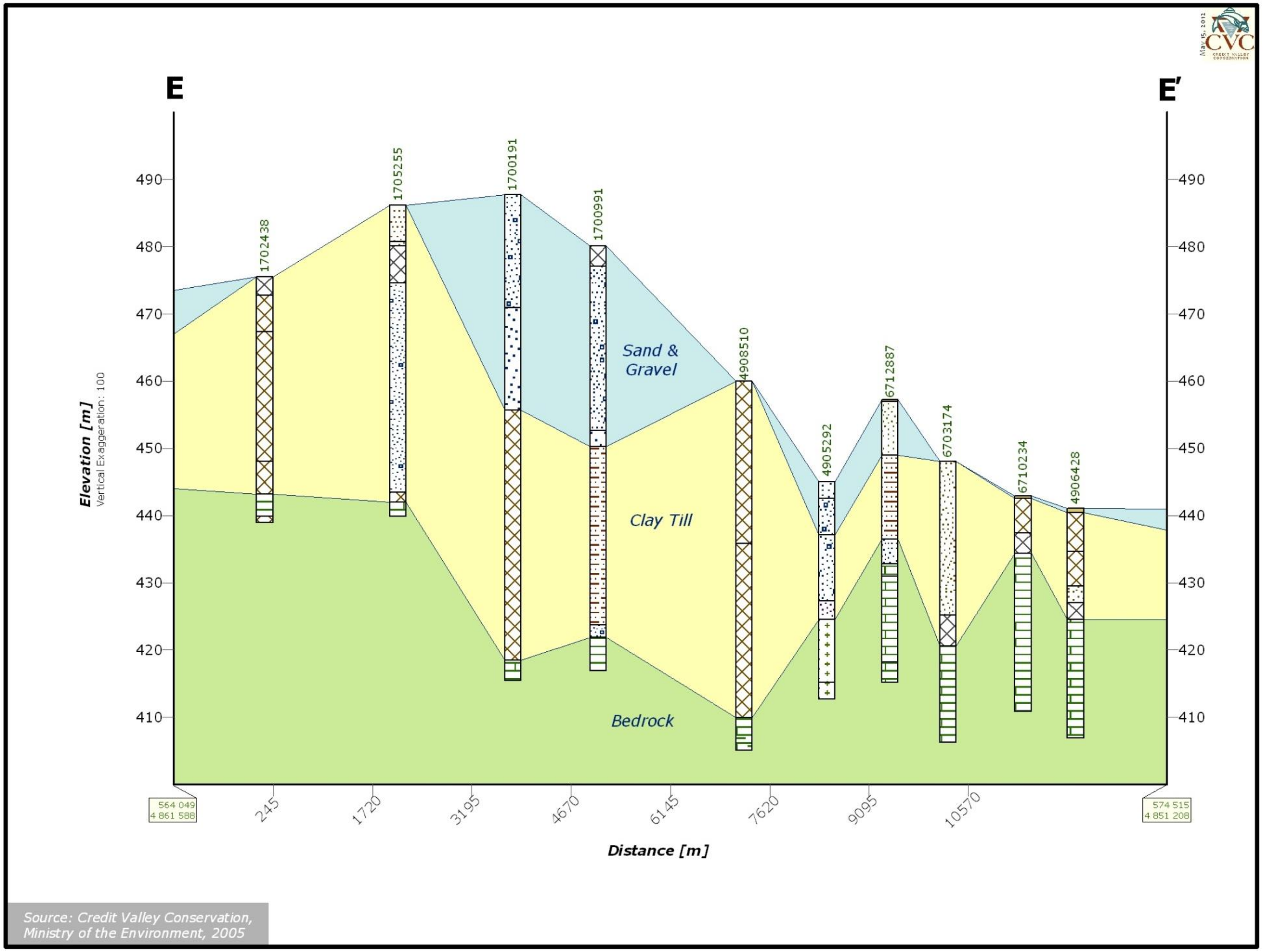


Figure 4.2.12 Cross-Section E-E’

4.2.2 Groundwater Flow System

4.2.2.1 Overview of Groundwater Flow

Information regarding the groundwater flow system in the study area for this stage of the subwatershed study was obtained from data contained in the MOE WWIS. Additional information regarding regional groundwater flow in the area was available in a report entitled *Groundwater Resources of the Credit River Watershed* (Singer et al., 1994), and from field investigations conducted as part of this study to supplement the existing data.

Overburden groundwater levels are presented in **Figure 4.6.13**, and were created for the *Interim Watershed Characterization Report for the Credit River Watershed* (CVC, February 2007) using the water levels for those wells screened in the overburden, as described in the WWIS and YPDT databases (CVC is one of several members of the Conservation Authorities Moraine Coalition (CAMC), who have teamed up with the municipalities of York, Peel, Durham, Toronto (YPDT) to undertake several technical studies, including the development of the 'YPDT database' that stores geologic and hydrogeologic information from the study partners, built on the structure of the MOE water well information system). This Figure shows that in general, groundwater flow follows ground surface topography (

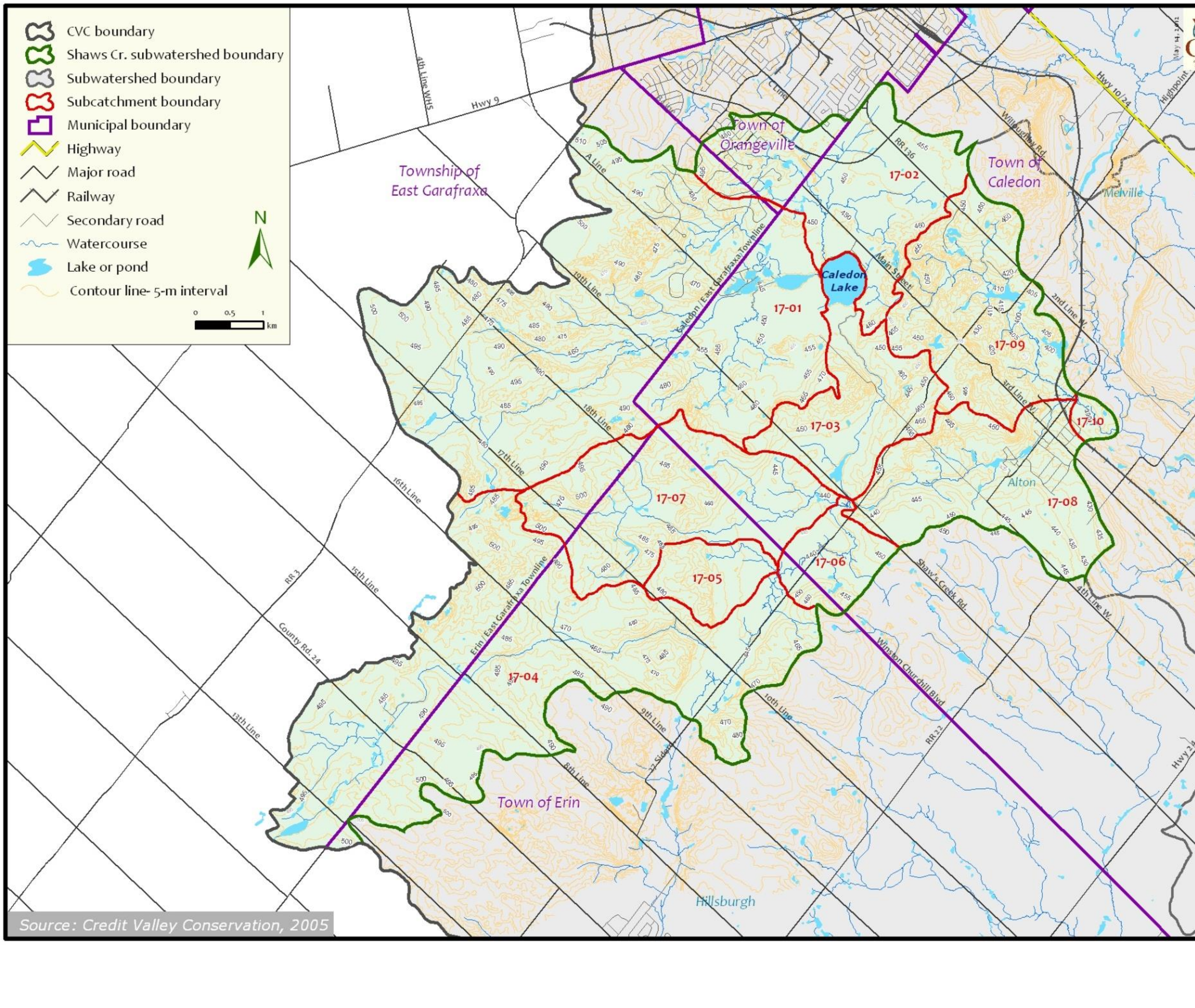


Figure 4.2.1) and that the highest groundwater elevations coincide with the coarse-grained deposits of the Orangeville Moraine. The highest groundwater elevation within the Shaws Creek Subwatershed is approximately 470 m amsl, where the corresponding ground surface elevation is approximately 490 m amsl. Groundwater flows away from these areas, generally following the topographical slope. The overburden groundwater flow system will be further analyzed through the groundwater modelling efforts in support of Phases 2 and 3 of the Shaws Creek Subwatershed Study.

The predominant direction of groundwater flow is from north to south, and localized flow in the eastern portions of the subwatershed is towards the Credit River. This includes the occurrence of flatter horizontal hydraulic gradients in the middle of the subwatershed, the steeper horizontal hydraulic gradients towards the buried bedrock valley (infilled with glaciofluvial outwash deposits), and the Credit River located just east of the subwatershed boundary.

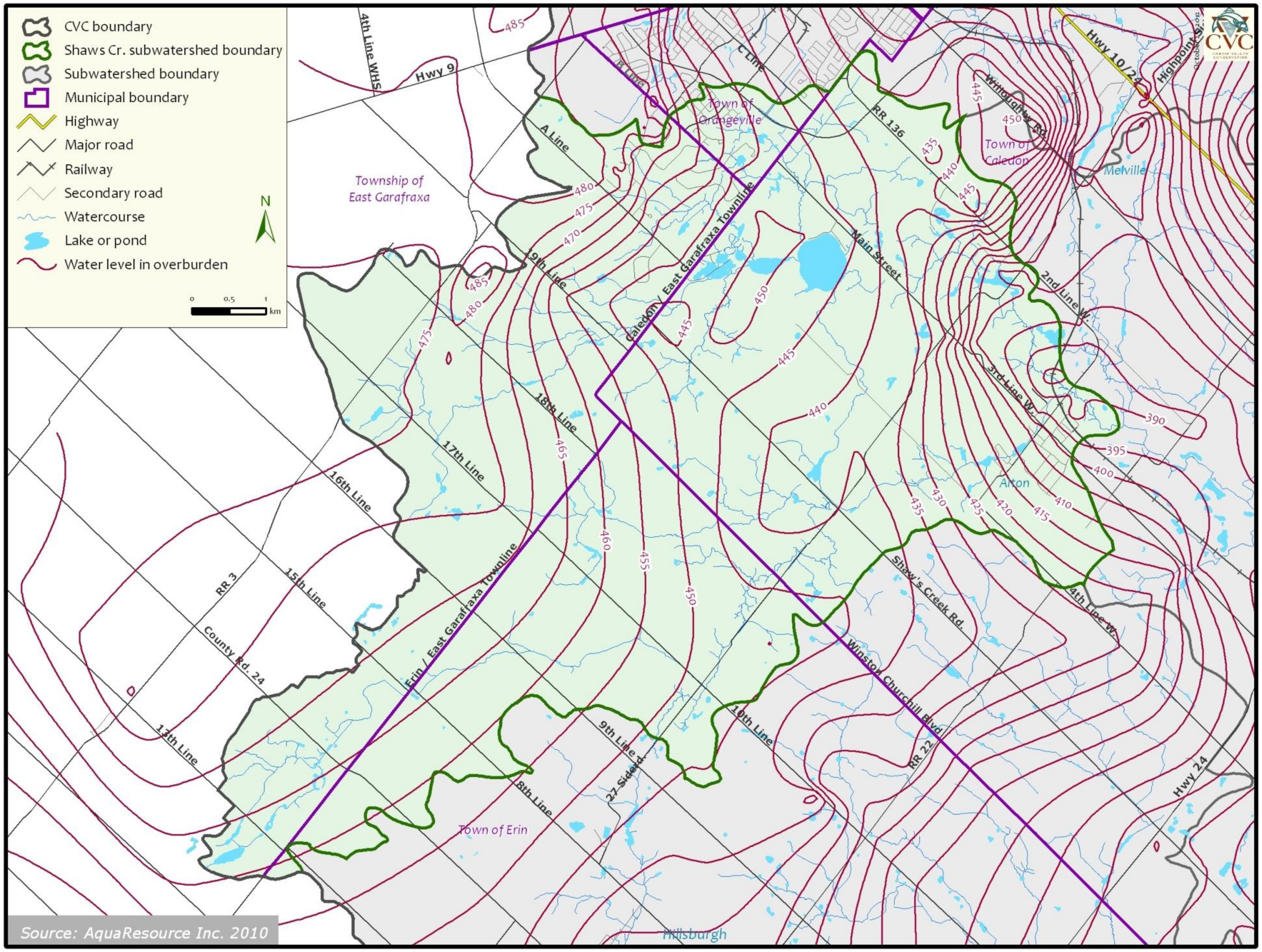


Figure 4.2.13 Overburden Groundwater Levels

4.2.2.2 Bedrock Water Levels

Figure 4.2.14 presents the piezometric head contours within the bedrock aquifers. This map was created by interpolating the water levels recorded at individual wells screened within the bedrock that were completed at a depth greater than 50 m below ground surface, as reported in the MOE WWIS. Given the thickness of the overburden across this area (**Figure 4.2.5**), the majority of the bedrock wells within the study area are at least 50 m deep. However, there are areas in the eastern portion of the subwatershed near Alton where the bedrock surface is close to ground surface and the water levels are more indicative of the shallow unconfined watertable than the deep confined bedrock aquifer. Therefore, wells completed in bedrock to a depth less than 50 m were excluded from this analysis.

In general, groundwater flow in the bedrock aquifers (Guelph and Amabel Formations) is from the west near the crest of the Orangeville Moraine, to the east towards the deep buried bedrock valley (). In the bedrock, horizontal hydraulic gradients are steepest at the eastern boundary of the subwatershed where groundwater flows towards the interpreted buried bedrock valley lying just east of Alton, and shallowest in the central portion of the subwatershed where the ground surface topography is more subdued. The highest bedrock water levels (475 to 489 m amsl) coincide with areas where the overburden water levels are also high, including near the intersection of Regional Road 3 (RR3) and 17th Line. The lowest water levels (390 to 395 m amsl) coincide with the buried bedrock valley complex along the eastern reaches of the subwatershed.

4.2.2.3 Groundwater Flow

The regional groundwater flow system was interpreted utilizing the following information:

- overburden and bedrock water level contours;
- topographical relief;
- geological units;
- surface water flow data; and
- site-specific data, where available.

A review of the geological cross-sections (**Figure 4.2.8 to Figure 4.2.12**) provides some insight into how groundwater is expected to flow in the subsurface. The bulk of the groundwater flow into the subwatershed occurs in the western portion of the subwatershed, where groundwater flows in from the Grand River Watershed. The groundwater flow divide between the Credit River and the Grand River Watersheds likely occurs a few kilometres west of the watershed boundary. There is very little water flowing into Subwatershed 17 from Subwatershed 19, as the bulk of the groundwater flow in this area is oriented along the subwatershed boundary from west to east (i.e. a no flow boundary). Groundwater flows out of Subwatershed 17 primarily into Subwatershed 18 towards the deep buried bedrock valley, and to Subwatershed 15 following ground surface and bedrock topography.

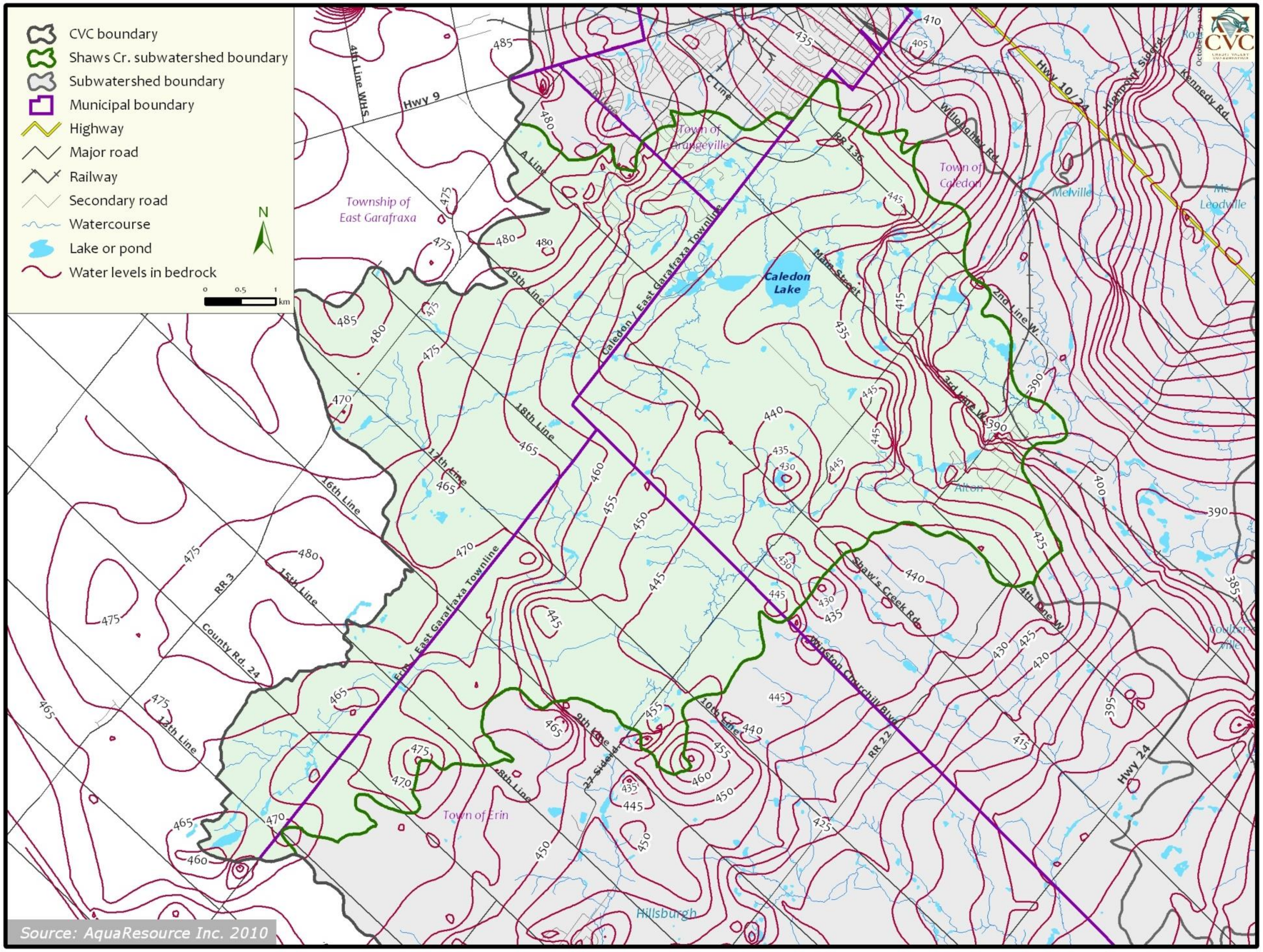


Figure 4.2.14 Bedrock Groundwater Levels

Groundwater flow in Subwatershed 17 is away from the topographical highs associated with the Orangeville Moraine towards the West Credit Subwatershed (Subwatershed 15) to the southeast, or to the Credit River Subwatershed (Subwatershed 18) into the buried bedrock valley. The vertical hydraulic gradients are interpreted to be variable throughout the subwatershed study area and are in the central portion of the subwatershed near Caledon Lake. The vertical gradients are predominately downward, and this is confirmed by the baseflow measurements across this section of the subwatershed which indicate no increases in baseflow from groundwater discharge. Groundwater is inferred to infiltrate slowly through the organic rich surficial soils and clay till surrounding Caledon Lake (see Cross-section D-D', boreholes 1703294 and 4900985). Recharge in this area is interpreted to be low, and the many wetlands in the area are a result of the relatively poor drainage.

Within the Guelph and Amabel Formations, groundwater is interpreted to generally flow horizontally to the southeast towards the crest of the Niagara Escarpment. Significant further downward migration of flow is inhibited by the lower permeability Cabot Head shale unit that underlies the Amabel Formation and acts as a lower confining layer. Horizontal flow in the bedrock is also towards the north-south trending buried bedrock valley that runs from Orangeville through Alton to Cataract.

Available baseflow data collected by CVC in the summer of 2005 suggest that there is abundant groundwater discharge to many of the Shaws Creek tributaries, as will be discussed in the following section.

4.2.2.4 Assessment of Recharge and Discharge Areas

A major part of the hydrogeological component of this subwatershed study is the identification of the existing regional and local groundwater discharge conditions. Groundwater discharge to streams maintains baseflow, which is critical to aquatic habitats for the following reasons:

1. Groundwater discharge maintains volumetric baseflow in channels during times when there is no precipitation runoff or snowmelt. A sufficient volume of baseflow within Shaws Creek and its tributaries is critical to maintaining a minimum depth of water necessary for aquatic habitat and to provide thermal refuge by moderating stream temperatures during the summer and winter; and
2. Areas of direct discharge, or upwellings, through the streambed, are critical to maintaining fish spawning areas because the upwellings typically consist of oxygen-rich water at constant cool temperatures, which represents optimal conditions for spawning in cold-water fisheries.

All water that discharges to streams as baseflow originated at some point upgradient of the stream as groundwater recharge, which could occur either inside the immediate subcatchment area or outside of the subcatchment area. Any area that is not a discharge area is a recharge area, and this generally comprises all lands outside of the fairly focussed discharge zones in stream valleys or shoreline environments. However, certain environments contribute a higher rate of recharge than others due to several factors typically related to surficial geology and / or topography. For example, areas that have relatively permeable soils at ground surface, such as sand or gravel, have a tendency to promote infiltration rather than runoff. In contrast, relatively impermeable soils, such as silt and clay, promote runoff. Therefore, areas of high recharge are equally important to aquatic habitat as areas of groundwater discharge because if recharge in these areas were reduced due to land use change, climate change or other influences, baseflow and/or upwellings in the discharge zones would also be reduced.

The subwatershed-scale assessment of the major recharge and discharge areas was developed from the compiled information related to groundwater flow, topography and stratigraphy. With respect to baseflow, there is a CVC low flow stream gauge located on Shaws Creek near the downstream end of the subwatershed. Stream flow data have been collected from this gauge station since September 2001. Singer et al., (1994) also completed a baseflow analysis of data collected from 1987 to 1990 at a stream gauging station located near the downstream end of Shaws Creek. The baseflow analysis by Singer (1994) indicated that the mean annual baseflow for the subwatershed was 233 mm (equivalent to a mean flow rate of 0.532 m^3/sec). This baseflow is in agreement with the average baseflow rates recorded by the low flow gauge station installed in 2001, and with the spot baseflow measurements collected during the course of this study (as discussed further below). It should also be noted that the mean baseflow reported by Singer (1994) for the Shaws Creek Subwatershed was among the highest for the Credit River Watershed.

In order to understand discharge and baseflow variations within the subwatershed, a more detailed assessment of baseflow on a subcatchment scale was carried out. This assessment was completed by the complimentary methods outlined below.

1. The overburden and bedrock groundwater contour maps (**Figure 4.2.13 and Figure 4.2.14**) produced from water level data provided in the MOE WWIS were used to identify areas where groundwater may flow out of a subcatchment or the subwatershed and as a result, would not contribute to baseflow in a particular subcatchment area. For example, if some of the recharge that occurred in a particular subcatchment flowed out of the subcatchment as groundwater flow rather than discharging to stream sections locally within that subcatchment, groundwater contour maps would be useful in identifying where this outflow occurred and in accounting for the lower baseflow rates observed in the subcatchment.

2. A subcatchment scale baseflow assessment was completed in order to determine the overall contribution of baseflow in each of the identified subcatchments in the study area. An increase in baseflow between the upstream and downstream ends of a subcatchment indicates that groundwater discharge to streams is occurring within the subcatchment. The change in baseflow within a subcatchment is an indication of the amount of groundwater discharge or recharge that is occurring within the subcatchment. Subwatershed 17 was divided into 12 subcatchments (17-01 to 17-12). Individual subcatchments were assessed for contributions to baseflow by collecting spot stream flow measurements. Spot stream flow measurements were taken following a sustained period with very minimal or no precipitation (approximately three to five days) and therefore provide a reasonably accurate estimation of the rate and volume of groundwater discharge to the stream (i.e. baseflow). The spot flow rates measured by CVC on four occasions between June 6 and August 8, 2005 are presented in **Table 4.2.1. Figure 4.2.15** illustrates the 20 locations where spot flow measurements were obtained.

1. For this analysis, the data were interpreted by looking at the contribution to baseflow per unit area (in units of litres per second per hectare [L/sec/ha]) for each subcatchment. This was done by subtracting the measured flow at the station(s) nearest to the upstream end of the subcatchment from that at the station(s) nearest to the downstream end, and dividing this amount by the area of the subcatchment. This amount represents the individual baseflow contribution for each subcatchment area. These calculations are presented in **Table 4.2.2**, and

2.

3.

Table 4.2.3 provides a summary of the results.

To put flow rates into perspective, for the purpose of the following discussion, the average annual baseflow rate of 233 mm (based on Singer, 1994) is equivalent to a flow rate of 0.074 L/sec/ha. Therefore, subcatchments with baseflow contributions greater than this value are subcatchments where baseflow values are above average for the subwatershed, and would indicate areas of higher groundwater discharge.

3. Similar to the analysis completed above, a semi-quantitative subcatchment-scale assessment of recharge potential was also completed for each of the 12 subcatchments. This involved an assessment of the permeability of the surficial geologic deposits in each subcatchment area and the assignment of an infiltration rate to each geologic deposit. Based on the area of each unit, a total volume of infiltration was calculated. A potential baseflow rate was estimated based on the calculation of infiltration, with the assumption that all water that infiltrates within a subcatchment also discharges to streams within the subcatchment area. This calculated value was then compared to the spot flow data measured in the field. This exercise provided a very general indication of whether baseflow gains or losses within a subcatchment area reflect the recharge potential in the

subcatchment. The surficial geologic deposits were divided into three general categories (i.e. low, medium, and high) based on the expected rate of groundwater infiltration. For this exercise, sand or gravel deposits (e.g., outwash deposits) were assigned a high infiltration rate (0.3 – 0.4 m/yr), dolostone bedrock and sandy silt to silty sand till deposits (e.g., Amabel Formation, Port Stanley Till) were assigned a medium infiltration rate (0.1 - 0.2 m/yr), and clay silt till deposits (e.g., Tavistock Till) were assigned a low infiltration rate (0 - 0.05 m/yr).

4. The measured baseflow rates moving downstream in the subwatershed were calculated in a cumulative fashion in order to identify specific stream reaches that are gaining baseflow (receiving groundwater discharge) or losing baseflow (recharging groundwater). If the baseflow amount increased along a stream section (with no other identified stream inputs), the stream was interpreted to be a gaining stream. Alternatively, if baseflow rates decreased moving downstream, losing conditions were interpreted to exist. Areas with no baseflow were interpreted to be losing streams or represent areas of recharge because the water table was beneath the ground surface.

Table 4.2.1 Summary of Spot Flow Measurements

	Stream Flow (m^3/sec)			
Location ID	**06-Jun-05**	**20-Jun-05**	**11-Jul-05**	**08-Aug-05**
Station 1	0.4335	0.4796	0.3305	0.3219
Station 2	0.0221	0.0249	0.0135	0.0113
Station 3	0.0101	0.0135	0.0019	0.0028
Station 4	0.0261	0.0106	0.0054	0.0084
Station 5	No data collected due to poor conditions for stream flow measurement			
Station 6	0.2685	0.2858	0.1998	0.1963
Station 7	0.0345	0.0443	0.0267	0.0300
Station 8	0.2601	0.2701	0.1892	0.1910
Station 9	0.3038	0.2714	0.2414	0.1985
Station 10	0.0688	0.0668	0.0530	0.0499
Station 11	0.3822	0.4053	0.2960	0.2908
Station 12	0.0772	0.0775	0.0486	0.0464
Station 13	No data collected due to poor conditions for stream flow measurement			
Station 14	0.0602	0.0468	0.0313	0.0375
Station 15	No data collected due to poor conditions for stream flow measurement			
Station 16a	0.1302	0.1340	0.1230	0.1182
Station 16b	0.1673	0.1741	0.1496	0.0989
Station 17	0.4706	0.4739	0.3178	0.3063
Station 18	0.4173	0.4620	0.2937	0.3468
Station 19	0.0803	0.0774	0.0530	0.0424
Station 20	0.0731	0.0734	0.0496	0.0455
Station 21	0.0651	0.0716	0.0536	0.0422
Station 22	0.0116	0.0117	0.0076	0.0056

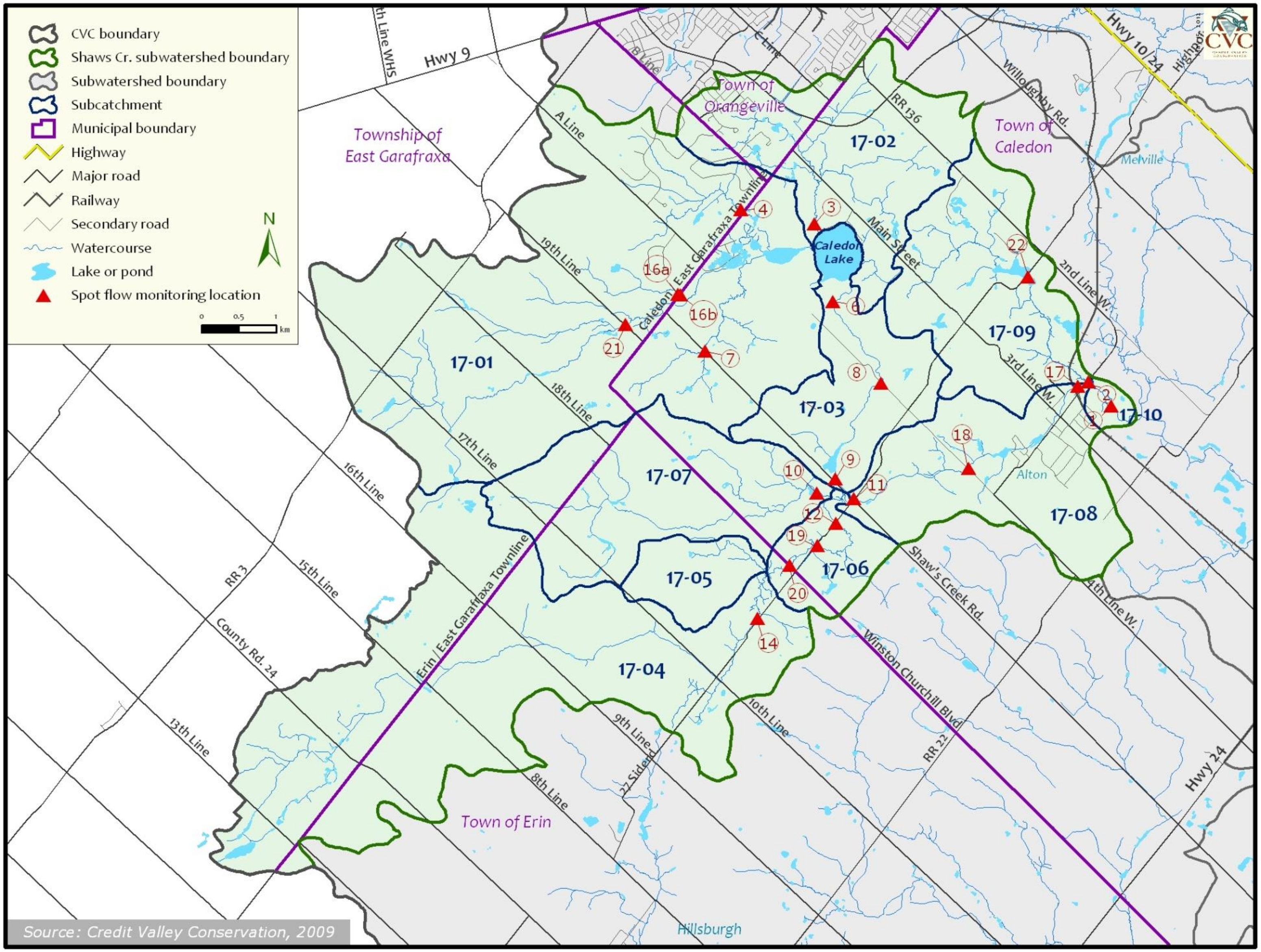


Figure 4.2.15 Spot Flow Monitoring Locations

Table 4.2.2 Subcatchment Baseflow Calculation Summary

Sub-catchment No.	Baseflow Calculation	Observed Baseflow (m3/sec) June 6, 2005	June 20, 2005	July 11, 2005	August 8, 2005
17-01	=Station 6 - Station 3	0.2585	0.2723	0.1979	0.1934
17-02	=Station 3	0.0101	0.0135	0.0019	0.0028
17-03	=Station 9 - Station 6	0.0353	-0.0144	0.0417	0.0023
17-04	=Station 14	0.0602	0.0468	0.0313	0.0375
17-05	=Station B - Station 14	0.0129	0.0265	0.0182	0.0080
17-06	=Station 12 - Station B	0.0041	0.0042	-0.0010	0.0009
17-07	=Station 10	0.0688	0.0668	0.0530	0.0499
17-08	=Station 11 - Station 10 - Station 9 - Station 12	-0.0676	-0.0104	-0.0469	-0.0040
17-09	=Station 18 - Station 11	0.0351	0.0567	-0.0023	0.0561
17-10	=Station 17 - Station 18	0.0533	0.0119	0.0241	-0.0405
17-11	=Station 2	0.0221	0.0249	0.0135	0.0113
17-12	=Station 1 - Station 2 - Station 17	-0.0593	-0.0192	-0.0007	0.0042

Table 4.2.3 Baseflow Summary

Sub-catchment No.	Sub-catchment Area (ha)	Average Infiltration Rate (m/yr)	Potential Baseflow (m3/sec)	Potential Baseflow (L/sec/ha)	Observed June 6, 2005 (m3/sec)	(L/sec/ha)	June 20, 2005 (m3/sec)	(L/sec/ha)
17-01	2,145	0.21 - 0.29	0.14 - 0.20	0.066 - 0.093	0.2585	0.120	0.2723	0.127
17-02	658	0.19 - 0.28	0.04 - 0.06	0.062 - 0.088	0.0101	0.015	0.0135	0.021
17-03	429	0.25 - 0.34	0.03 - 0.05	0.078 - 0.107	0.0353	0.082	-0.0144	-0.034
17-04	1,752	0.29 - 0.38	0.16 - 0.21	0.090 - 0.121	0.0602	0.034	0.0468	0.027
17-05	160	0.24 - 0.33	0.01 - 0.02	0.076 - 0.105	0.0129	0.080	0.0265	0.166
17-06	170	0.17 - 0.26	0.009 - 0.014	0.054 - 0.082	0.0041	0.024	0.0042	0.025
17-07	676	0.27 - 0.36	0.057 - 0.078	0.085 - 0.115	0.0688	0.102	0.0668	0.099
17-08	5	0.27 - 0.37	0.0004 - 0.0005	0.087 - 0.119	-0.0676	-14.904	-0.0104	-2.301
17-09	177	0.19 - 0.29	0.0106 - 0.0162	0.060 - 0.092	0.0351	0.199	0.0567	0.321
17-10	409	0.18 - 0.28	0.0231 - 0.0359	0.056 - 0.088	0.0533	0.130	0.0119	0.029
17-11	588	0.30 - 0.40	0.0556 - 0.0742	0.095 - 0.126	0.0221	0.038	0.0249	0.042
17-12	34	0.20 - 0.28	0.0022 - 0.0031	0.064 - 0.090	-0.0593	-1.728	-0.0192	-0.559

Recharge and Discharge Conditions

All of the subcatchment areas in the Shaws Creek Subwatershed had flow throughout the field season. This observation is reflective of the medium to high infiltration rates that occur in the subwatershed due to the generally coarse grained soils of the dominant surficial geologic deposits (e.g., stratified drift and glaciofluvial sand and gravel deposits). The generally high infiltration rates account for large amounts of groundwater recharge that ultimately results in large amounts of groundwater discharge to the tributaries in the subwatershed, thus accounting for the perennial flow in most tributaries in the subwatershed. However, it should be noted that the measured baseflow in the subwatershed (0.27 to 0.40 m^3/sec) was only equal to approximately half of the estimated groundwater recharge across the subwatershed (0.54 to 0.75 m^3/sec - see

Table 4.2.3). Some of this apparent discrepancy may be accounted for by the timing of the baseflow measurements. Flows were measured between the months of June and August, and would not be reflective of the highest baseflow rates, which would be expected during the spring when groundwater levels are generally highest. Therefore, despite the significant amounts of groundwater discharge appearing as baseflow in the subwatershed, most of the subwatershed acts as an area of groundwater recharge, with a significant portion of the groundwater recharge flowing to adjacent subwatersheds (primarily Subwatersheds 15 and 18, as described in previous sections) as part of the deeper overburden and bedrock groundwater flow systems.

As previously indicated, the predominant geologic deposit in the subwatershed is the Orangeville Moraine, which is composed of moderately to highly permeable stratified drift deposits, which encourage groundwater recharge due to its hummocky topography. The many closed depressions associated with this type of topography limit runoff, and as a result, maximize infiltration. However, the stratified nature of the moraine deposits, where layers of lower permeability material occur between higher permeability layers, would also encourage the horizontal flow of groundwater after infiltration. These conditions would tend to enhance groundwater discharge where shallow horizontal flow encounters a sharp decrease in permeability (e.g., where moraine deposits contact lower permeability till or organic deposits) or where there is a sharp decrease in topographic elevation.

Surficial geologic deposits that are less permeable, and would therefore limit groundwater infiltration, are the organic deposits that occur primarily in the vicinity of Caledon Lake, along with the lower permeability till deposits that are mostly found in the upper reaches of the subwatershed and in the vicinity of the town of Alton. Areas covered with these lower permeability deposits would typically have lower groundwater recharge values, and would also tend to have lower discharge values.

Summary of Recharge and Discharge Areas

As discussed previously, the Shaws Creek Subwatershed is interpreted to be a significant groundwater recharge area for several reasons. The Orangeville Moraine, which covers the majority of the subwatershed is typically hummocky, which tends to encourage internal drainage and ponding rather than runoff. This topography, combined with the moderate to high permeability of the stratified drift deposits of the moraine, enhances recharge rather than runoff. The vertical hydraulic gradient in this area is interpreted to be generally downward and is thought to provide significant recharge to the underlying Amabel Formation. However, the stratified nature of the Orangeville Moraine, in which deposits of lower permeability are found interlayered with more permeable deposits, also encourages a horizontal component of groundwater flow and results in groundwater discharge along areas where there is a sudden decrease in topographic elevation.

Figure 4.2.16 presents the locations of the major groundwater recharge and discharge areas in the subwatershed. As previously described, the majority of the subwatershed is covered by high permeability overburden deposits, and therefore high recharge conditions are predominant. The areas indicated to be medium recharge areas are generally found in the vicinity of the Village of Alton and represent areas where silty sand to sandy silt till is found at ground surface. The areas of low recharge are areas where organic deposits or silt to clay till are found at the surface. These lower permeability deposits discourage infiltration and encourage runoff.

The areas of significant groundwater discharge were determined from the baseflow measurements collected throughout the subwatershed, and inferred from the results of the cool and cold water aquatic community identification presented in the Aquatics discussion (Section 4.8). Due to the distribution and density of the flow monitoring stations used in this study, **Figure 4.2.16** should be viewed only as a general indicator of where significant groundwater discharge occurs in the subwatershed. A more intensive baseflow monitoring program would be required to conclusively identify all of the significant groundwater discharge locations. Such a monitoring program would be more appropriate for a subcatchment-scale study.

Baseflow was consistently observed to decrease (i.e., surface water is contributing to groundwater recharge) through subcatchments 17-08 and 17-12, and in the upper half of subcatchment 17-03. The observed baseflow decrease through subcatchment 17-08 is suspect due to the relatively small size of the catchment area and the large number of monitoring locations used to calculate flow at this location (as shown in **Table 4.2.2**). The cumulative potential errors from the measurements may be significantly magnified by the smaller subcatchment area. Baseflow was consistently observed to decrease through the upper half of subcatchment 17-03, from Caledon Lake to the crossing of Fourth Line. This reach of the tributary is underlain by fine grained organic deposits and the topography is generally flat as well. These conditions are not conducive to groundwater discharge, and the loss of baseflow is likely due to the watertable sitting below the streambed, thus encouraging the loss of baseflow to groundwater infiltration. Spot flow measurements indicate baseflow gains (i.e., groundwater discharge) along the lower portion of this subcatchment, but the measured flows may have been affected by the discharge from the online pond located near the downstream end of the subcatchment (just upstream of the low flow monitoring location at the end of the subcatchment).

In subcatchment 17-12 generally low permeability materials underlie the flat topography of Shaws Creek (**Figure 4.2.3**) with flat topography, which are the likely contributing factors to decreasing baseflow in this reach. It should be noted, however, that a 2003 study in this area by Groundwater Science (Groundwater Science, November 2003) indicated that while baseflow was observed to decrease between the area of Queen Street in Alton and the location of Monitoring Location No. 1 (**Figure 4.2.16**), gaining conditions were observed between Monitoring Location No. 1 and the confluence with the Credit River. In addition, the spawning and habitat surveys completed in support of the Aquatics component of this study (**Section 4.6.4.7**) identified this area as supportive of cold water species, which would also suggest groundwater discharge to this reach of Shaws Creek.

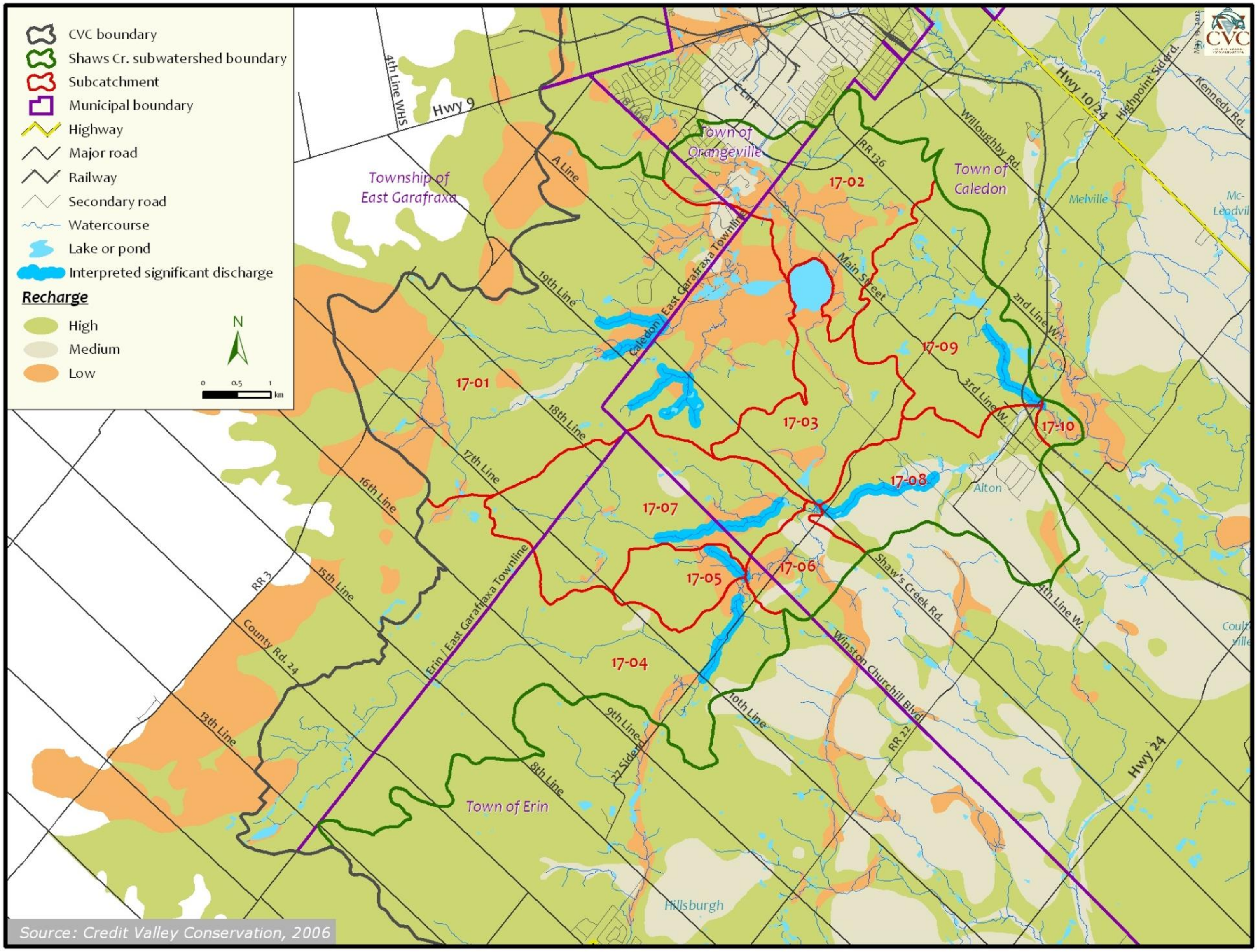


Figure 4.2.16 Interpreted Recharge and Discharge Areas

The subcatchments with the most significant contributions to baseflow were 17-01, 17-04, 17-05, 17-07, 17-09, and 17-11. The baseflow contributions from subcatchments 17-04 and 17-11 were due to the relatively large area of those subcatchments. However, by far the largest contribution was observed to come from subcatchment 17-01, which comprises approximately 30% of the subwatershed area but contributes approximately half of the measured baseflow. This significant contribution to baseflow is attributed to the large portion of the subcatchment where high recharge occurs due to the hummocky topography and coarse grained sediments of the Orangeville Moraine, and to the contact between the moraine deposits and the fine grained organic deposits above Caledon Lake.

While subcatchments 17-05 and 17-07 do not contribute as much baseflow as 17-01, a review of

Table 4.2.3 indicates that they do contribute more baseflow than expected (indicated by the “potential baseflow” rate). The larger than expected volume of baseflow in these subcatchments is attributed to horizontal groundwater flow into 17-05 and 17-07 from adjacent subcatchments (**Figure 4.2.13**), and to the sharp drop in topography and the contact between the coarse grained moraine / outwash deposits and the low permeability organic deposits in the vicinity of the tributary that flows through these subcatchments.

Spot flow data also indicates that subcatchment 17-09 contributes an above average amount of baseflow (on a per hectare basis). This observed high baseflow contribution is attributed to the decrease in topography from north to south, and the contact between higher permeability deposits (stratified drift) and the lower permeability deposits (silty sand / sandy silt till).

4.2.3 Groundwater Balance

4.2.3.1 Overview of Regional Groundwater Balance

The hydrologic cycle describes the continuous movement of water above, on, and below the earth’s surface and this links the subwatershed ecosystem together. The movement of water within the hydrologic cycle can be described through a water balance or water budget. Various components of the water balance are presented in . From a hydrogeological perspective, the key components of the water budget on a regional scale are:

- recharge;
- contribution to baseflow within the subwatershed;
- deeper groundwater flow to or from other subwatersheds; and
- groundwater takings.

4.2.3.2 Preliminary Water Balance Results

In general, the components of the water balance are difficult to measure, which makes an accurate quantitative water balance difficult to develop. There is data available as well as some general assumptions that allow for a reasonable preliminary water balance to be developed on a subwatershed scale. Based on the baseflow analysis completed by Singer (1994), the annual average baseflow for the Shaws Creek Subwatershed was estimated to be equivalent to 233 mm.

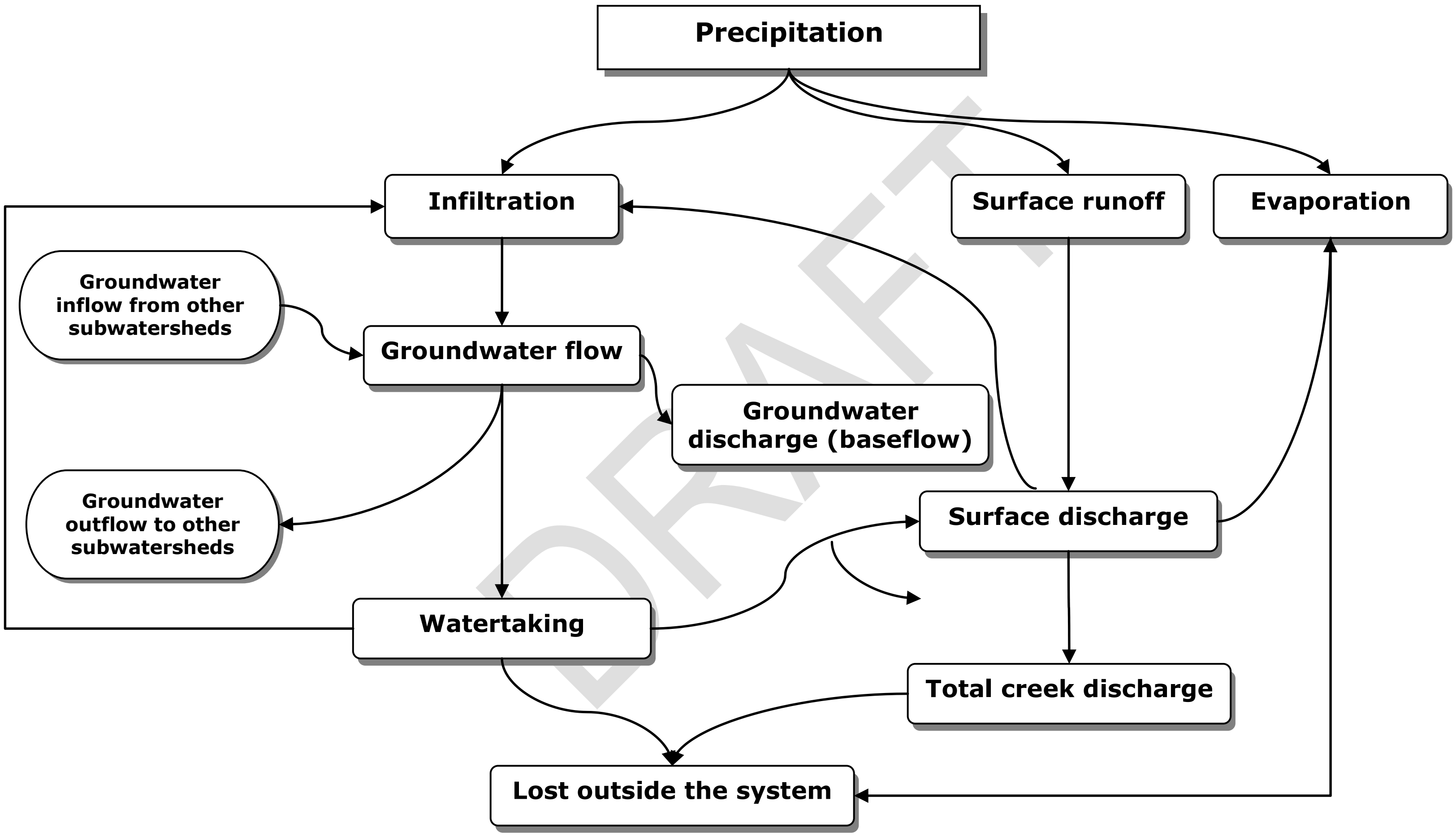


Figure 4.2.17 Water Balance Components

This value will be used in the water balance assessment below. Numerical modelling of the subwatershed is anticipated to be completed in the next phase of the Shaws Creek Subwatershed Study, and a more detailed and accurate quantitative water balance will be completed as part of that exercise.

The preliminary assessment of the water budget was completed by itemizing all the known water inputs and outputs and then doing a simple "spreadsheet" analysis to determine whether there were significant gains or losses to the subwatershed.
Table 4.2.4 and the following section present the results of this analysis which, as stated, should be considered preliminary and representative of average conditions.

Groundwater Inputs:

- Recharge - The average recharge rate across the subwatershed is estimated to be between 0.24 and 0.33 m/yr, based on the surficial geology, which translates to a total annual recharge rate of 17,289,600 m3/yr to 23,773,200 m3/yr. This range is considered representative of the long-term average and does not take into consideration short-term variations in precipitation.
- Groundwater Inflow from Neighbouring Watersheds– As described earlier in this section, there is little groundwater inflow into the Shaws Creek Subwatershed from Subwatershed 19. Therefore, groundwater inflow from neighbouring Credit River subwatersheds was not considered in this analysis. Flow from the Grand River Watershed is believed to be a significant groundwater input; however, this component will not be considered in this semi-quantitative analysis but will be included in the more detailed water budget expected for the Phase 2 study.

Therefore, the total potential groundwater input for the Shaws Creek Subwatershed, as considered in this analysis, is expected to range from 17,289,600 m^3/yr to 23,773,200 m^3/yr.

Groundwater Outputs:

- Shaws Creek Baseflow – Singer's (1994) estimate of average baseflow at the downstream end of the Shaws Creek Subwatershed is equal to 0.233 m/yr, which is equal to a discharge of 16,777,152 m3/yr. This value is higher than the average of the spot flow measurements collected at the bottom of the subwatershed (12,342,402 m3/yr); however, since the spot flow measurements were collected during the summer months, it would be expected that the annual average would be significantly higher.
- Municipal Pumping – Details regarding the municipal pumping wells are provided in the following section. The available average daily flow rate data for these wells were used for the groundwater balance assessment. This corresponds to an average yearly flow rate of approximately 800,000 m3/yr. Due to the lack of detailed information about the actual (versus permitted) rates of water taking for the non-municipal PTTWs in the subwatershed, they were not included in this analysis.
- Groundwater Outflow – This value was not known nor easily approximated at this point, however, the net groundwater flux for the subwatershed is estimated below based on the results of the water balance results.

Assuming that over the long term there is no change in groundwater storage, all of the inputs to the hydrologic cycle should equal the outputs. Therefore, the known outputs are subtracted from the known inputs and the difference will represent either a net input of groundwater into the subwatershed or a net output of groundwater. On this basis, applying the "maximum" recharge value across the subwatershed indicates a net outflow of groundwater to Subwatersheds 15 and 18. Applying the "minimum" recharge value across the subwatershed results in a negative water balance, which indicates that more groundwater flows into the subwatershed (from the Grand River Watershed) than flows out to other subwatersheds. Based on the information in
Table 4.2.4, it appears that if an average or median recharge value is applied then the result is a positive water balance, which indicates net groundwater outflow to adjacent Subwatersheds 15 and 18.

The water balance completed to date is useful only in illustrating general trends. As part of the numerical modelling exercise expected to be completed as part of the Phase 2 component of this study, a detailed quantitative water balance will be completed.

Table 4.2.4 Summary of Preliminary Water Balance

Water Balance Component	Flux (m3/year) minimum	maximum
Inputs		
Recharge	17,289,600	23,773,200
Outputs		
Stream Flow	16,777,152	16,777,152
Municipal Water Takings (total)	798,912	798,912
Balance:	**-286,464**	**6,197,136**

Note: A negative value for water balance would suggest that more water flows into the Subwatershed than out of the Subwatershed, while a positive water balance would indicate that more water flows out of the Subwatershed than flows in.

4.2.4 Water Supply

4.2.4.1 Delineation of Major Aquifers

In terms of groundwater supply, the bedrock acts as a regionally significant aquifer within the subwatershed. The Amabel Formation comprises an extensive and very transmissive to moderately transmissive bedrock aquifer. The Amabel Formation consists of numerous reefal structures of moderate to high primary porosity. In addition, this unit is frequently fractured and karstic, which results in an increase in the overall permeability. **Figure 4.2.4** shows the uppermost bedrock surface beneath the Shaws Creek Subwatershed. Other important productive bedrock formations that subcrop beneath the subwatershed include the Manitoulin and Guelph Formations.

In addition to the bedrock aquifer, there are also localized overburden aquifers that are able to transmit water for domestic water supply. These overburden aquifers include coarse-grained sand and gravel deposits associated with the Orangeville Moraine, and in some portions of the subwatershed, deep sand and gravel aquifers that overlie bedrock also act as productive water supply aquifers (See Cross-section D-D’; **Figure 4.2.11**).

4.2.4.2 Overview of Existing Water Supply

All water used for drinking water purposes is obtained from groundwater within the subwatershed. Water is obtained from individual private wells, private communal systems, or municipal systems. All of the groundwater taking for municipal use is used within the Alton and Orangeville areas. In addition to groundwater takings for drinking water purposes, there may be groundwater takings for other uses such as golf courses, plant nurseries, aggregate washing and agriculture. As previously indicated, any location where the total volume of water obtained from either a surface or groundwater source exceeds 50,000 L/day must have a Permit to Take Water (PTTW) issued by the MOE.

The Alton water supply system supplies drinking water to Alton from four wells. These wells include Alton Wells 1, 2, 3 and 4. Alton Well 3 is the primary supply well for the Village, while Alton Well 4 acts as a backup, and Wells 1 and 2 are used only in case of emergency. Alton Wells 1 and 2 are located next to each other at Station Street to the south east side of Alton Village. Wells 3 and 4 have a combined permitted pumping capacity of 1,046 m^3/day. However, as of 2006 the average rate of water taking from Wells 3 and 4 was only 211 m^3/day. The locations of these municipal wells are illustrated on **Figure 4.2.18**.

The Town of Orangeville also manages two wells within the Shaws Creek Subwatershed, Wells 6 and 11 **-** in addition to ten wells located in Subwatershed 19. The well locations are shown on **Figure 4.2.18**. Orangeville Well 6 is completed in bedrock and is cased from ground surface to a depth of 24.5 m below ground surface (bgs) and an open hole from 25 to 55 m bgs. The permitted rate for is 3,600 m^3/day, however the Town of Orangeville reported an average taking of 1,578 m^3/day based on actual water usage in 2005. Orangeville Well 11 has a permitted rate of 1,309 m^3/day, however actual average water use in 2005 was 711 m^3/day.

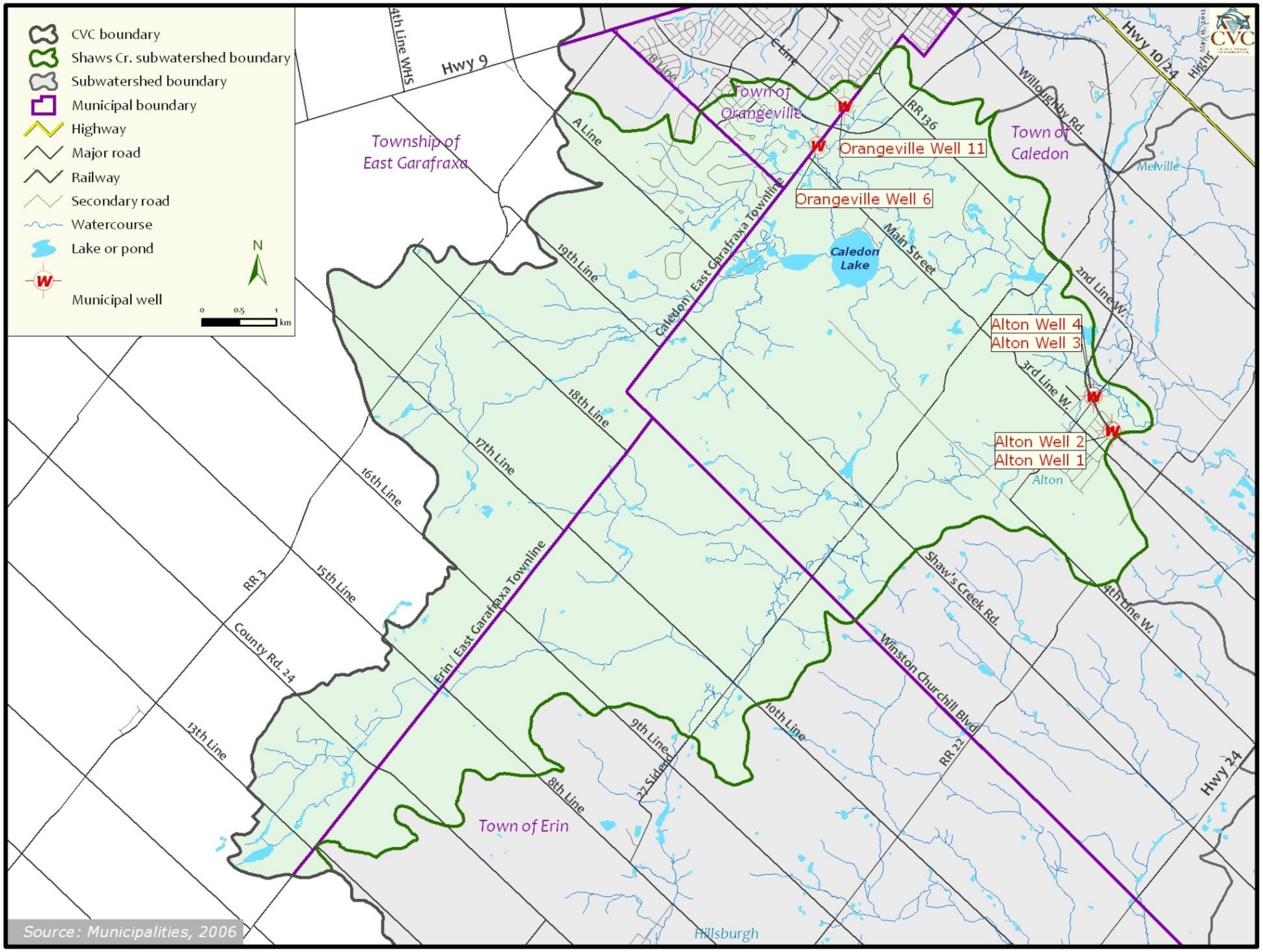


Figure 4.2.18 Municipal Well Locations

Preliminary information provided to CVC from the MOE regarding other PTTWs in the Shaws Creek Subwatershed indicates that there are five other registered water takers. The details on the permitted water takings are as follows:

- One permit (88-P-2020) to take surface water west of Winston Churchill near the Erin/ East Garafraxa Townline. This permit was granted to dam a surface water feature to hold water and create wildlife habitat.
- One permit (73-P-0480) for two wells in the subwatershed for agricultural irrigation (fruit and vegetable crops). The maximum taking per day is 1,209,000 L/ day or 840 L/min for one well and 3,240,000 L/day or 2,250 L/min for the other.
- Two of the three permits for industrial water takings have been granted to one company (maximum takings are 5.94 million L/day or 4,125 L/min under one permit and 4.00 million L/day or 2,778 L/min under the second permit.
- The third industrial permit allows a maximum taking of 0.98 million L/day or 682 L/min.

There are 438 domestic wells within the subwatershed that service residences outside of the urban areas of Orangeville and Alton. Records in the vicinity of Alton indicate the majority of wells were drilled to bedrock and overburden wells were typically shallow (i.e., less than 15 m). Domestic wells are dug (excavated), bored or drilled. Licensed water well drillers are required, by law, to submit a water well record to the MOE after the completion of a well. The water well record provides information regarding the depth of well, method of construction, as well as specific details regarding the observed geological and hydrogeological conditions. The MOE maintains a database which has proven to be an invaluable source of information for regional hydrogeological investigations, such as this one. The water well record database for the CVC watershed was updated in 2002: any records that were submitted after this time have not yet been included in the database. The database indicates that of the registered wells, 354 (81%) were completed in bedrock, and 84 (19%) were completed in the overburden.

In terms of groundwater supply, the regionally significant aquifers within the subwatershed include the Guelph and Amabel Formations, which are extensive and highly transmissive bedrock aquifers. These formations consist of numerous reefal structures of moderate to high primary porosity. In addition, this unit is frequently fractured and karstic, which results in an increase in the overall permeability. In addition to these significant aquifer systems, some private residential wells obtain their groundwater from the coarser grained deposits associated with the Orangeville Moraine and coarse-grained outwash deposits.

4.2.4.3 Preliminary Groundwater Quality Assessment

Groundwater sampling for the assessment of groundwater quality was not completed as part of this study. A preliminary assessment of groundwater quality was completed from a review of a number of previously published reports, most notably Singer et al. (1994; 2003). Groundwater chemistry in the area is largely controlled by the local geological setting. Groundwater in the Shaws Creek area is typically enriched in calcium, magnesium, and bicarbonate due to dissolution of the carbonate rich Guelph and Amabel bedrock formations (dolostone). Major ions that are typically encountered in groundwater samples include calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), sulphate (SO_4^{2-}) and chloride (Cl^{-}).

Groundwater quality will vary somewhat depending on the aquifer through which groundwater flows. As noted, the most regionally significant aquifer within the subwatershed is the Guelph/ Amabel Formation. In general, groundwater quality associated with the Guelph/ Amabel Formation is typically hard, with a resultant relatively high (alkaline) pH. The degree of mineralization varies depending upon the age of groundwater and the types of soluble minerals that occur along the groundwater flow path. According to Singer and others (1994), water quality sampling of the Amabel-Lockport- Guelph Formations indicated that groundwater samples had high total dissolved solids (TDS) and elevated iron concentrations, attributed to the mineralogical makeup of the bedrock and not anthropogenic sources. Previous watershed-wide research has shown that chloride concentrations are variable, and that some areas have elevated chloride concentrations attributed to road salting practices.
CVC maintains two monitoring wells, as part of the Provincial Groundwater Monitoring Network, in the northern reaches of the subwatershed on the west side of B Line near the Caledon/ East Garafraxa Townline. One of the wells is completed in bedrock, and the other in overburden sediments. Water quality was sampled in 2003 and 2005; however the wells were not accessible for sampling in 2004 due to construction activities in the vicinity. The water samples were tested for a general suite of water quality parameters, and in general, the water quality in these wells is good. The only parameter in exceedence of Provincial Standards is iron in the overburden well. The

Ontario Drinking Water Standards (ODWS) aesthetic objective for iron is 0.3 mg/L and the water sample yielded values of 0.63 and 0.46 mg/L in 2003 and 2005, respectively. Hardness was also above the ODWS; however, it is also an aesthetic objective rather than a health related concern.

Municipal well water quality results were provided to the CVC by the municipalities for the purpose of completing the Source Water Protection *Interim Watershed Characterization Report for the Credit River Watershed* (CVC, February 2007). The water quality data indicate that the Orangeville and Alton municipal wells currently in use in the Shaws Creek Subwatershed (Orangeville Wells 6 and 11 and Alton Wells 3 and 4) generally have good water quality, with the exception of a few water quality parameters, as described below.

Chloride and sodium, both of which are aesthetic parameters, have been detected in increasing concentrations in all four active municipal wells in recent years, although concentrations at Alton Wells 3 and 4 in 2005 were below concentrations measured in 2004. Potential sources of sodium and chloride in groundwater are road salting and private septic systems.

While nitrate concentrations at Orangeville Wells 6 and 11 have been quite low, there have been elevated concentrations of nitrate reported for Alton's municipal wells. Alton Wells 1 and 2 are no longer in use due to elevated nitrate concentrations near the ODWS of 10 mg/L. The source for the elevated nitrate concentrations is suspected to be private septic systems in the Village of Alton, which overlie the capture zone for Wells 1 and 2. Wells 3 and 4 have nitrate concentrations significantly less than the ODWS of 10 mg/L, with 2005 concentrations reported to be 3.6 mg/L and 2.7 mg/L, respectively. It should be noted that the capture zones for Wells 3 and 4 do not extend below the main Village of Alton.

4.2.4.4 Aquifer Susceptibility Assessment

This section reviews the mapping of the susceptibility to surficial contamination of the uppermost aquifer in Subwatershed 17. In general, maps of groundwater intrinsic susceptibility are produced to identify areas where groundwater is interpreted to be more vulnerable to contamination from sources near ground surface. Aquifer susceptibility is a relative measure of the physical properties of the material that overlie an aquifer, and how well those overlying materials are able to protect the aquifer from contamination if a contaminant was released at, or just below ground surface.

The analysis presented below identifies areas that are more vulnerable to contamination than others, based solely on the geologic protection overlying the bedrock aquifer. This type of analysis does not account for the specific vulnerability or actual risk that a contaminant could enter the aquifer. That aspect of vulnerability is addressed through the identification of potential threats to groundwater, or the presence of potential contaminant sources, as described later in this section.

Numerous methods have been developed for mapping intrinsic susceptibility of an aquifer across the Credit Valley Watershed. Specifically, in the Silver Creek (Subwatershed 11) and East Credit (Subwatershed 13) subwatershed studies, the susceptibility of the bedrock aquifer was assessed using the Aquifer Vulnerability Index (AVI) method of Van Stempvoort and others (1992). Since these studies were completed, the MOE developed a comparable Intrinsic Susceptibility Index (ISI) method to be used to map the susceptibility of a given region.
The groundwater susceptibility for the Shaws Creek area was evaluated using the ISI, which is a calculated value that estimates the susceptibility of the groundwater resource to contamination at a given point, and is determined for each well in the subwatershed that is included in the MOE WWIS database.

The following process was used to determine the ISI of the Shaws Creek Subwatershed area. The geology of each well was evaluated to determine the "uppermost significant aquifer", defined as a unit of aquifer material (sand and/or gravel) having a thickness greater than, or equal to, 5 m, and is at least partially saturated. To determine the saturation, the water table map (**Figure 4.2.13**) and the bedrock equipotential map (**Figure 4.2.14**) were consulted. The ISI value at each well was calculated by summing the product of the thickness of each unit and the K-factor that represents its geology over this depth. A K-factor (MOE, 2001) is assigned for each type of overburden or bedrock material and its value is inversely proportional to the permeability of the material (e.g. sand has a low K factor of 2, while clay has a K factor of 6). The ISI value at each individual well was then interpolated across the study area to produce a map that illustrates the susceptibility of the uppermost significant aquifer across the subwatershed (Error!

Reference source not found.). Following the guidelines laid out in the MOE Technical Terms of Reference (2001), the ISI value at each well was classified into one of three groupings; high (<30), medium (30 to 80), or low (>80) susceptibility.

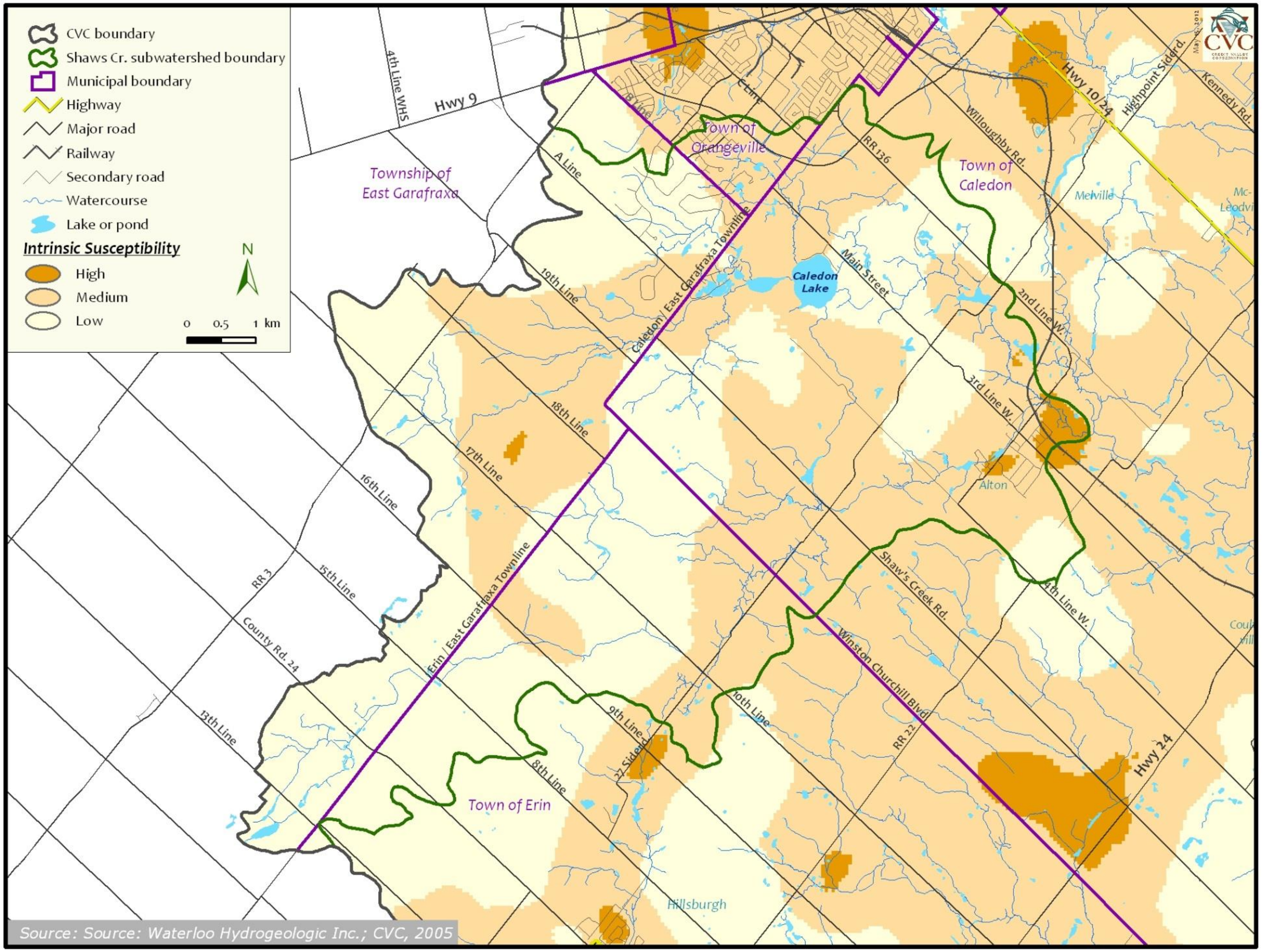


Figure 4.2.19 Groundwater Intrinsic Susceptibility

A number of factors may influence the susceptibility or vulnerability of an aquifer to contamination from surficial sources. In general:

1. Areas of high recharge are generally more susceptible to groundwater contamination than areas where recharge is restricted;
2. Unconfined aquifers having little overlying fine-grained material are more susceptible to contamination than confined aquifers with appreciable thicknesses of fine grained sediment. Similarly, fractured bedrock is also highly susceptible to contamination because of the high groundwater flow velocities associated with fractured rock, which translates to a decreased potential for attenuation of contaminants;
3. Deeper aquifers confined by a low permeability layer of overburden or bedrock will be better protected, and in turn have a low susceptibility to contamination; and
4. The position and condition of water wells can also impact aquifer susceptibility. Wells can provide a direct pathway from the land surface to an aquifer if they are not properly constructed or maintained. In addition, wells that intersect more than one aquifer increase the chance of cross contamination between aquifers.

Results of the Intrinsic Susceptibility Mapping

The high and medium ISI values are the most important classes to consider. Interpretation of the susceptibility of the uppermost significant aquifer identifies a number of different trends. Firstly, there are very few areas within the subwatershed that have been designated as highly susceptible to surficial contamination (shaded dark orange on Error! Reference source not found.). One such area lies between 17th Line and 18th Line, just north of the Erin/ East Garafraxa Townline. This area is denoted as highly susceptible as the water levels in this area are close to ground surface, and there is a thick layer of sand and gravel close to ground surface. In this case, the high susceptibility rating refers to the coarse-grained overburden unit at surface, and not the deep confined bedrock aquifer below. In addition to this area, areas of high susceptibility are also found in the eastern reaches of the subwatershed near Alton, where the bedrock aquifer is exposed at ground surface or is covered by only a thin veneer of overburden sediment.

There are areas of moderate susceptibility found just west of the Erin/ East Garafraxa Townline that are associated with the coarse-grained sediments of the Orangeville Moraine. Here, moderate susceptibility refers to the uppermost overburden aquifer, and not to the deep bedrock aquifer. Another area of moderate susceptibility is the area south of Caledon Lake, covering much of the south-western portion of the subwatershed, including the Village of Alton. The susceptibility in this area is higher than the surrounding areas due to the thin overburden confining layer that overlies the bedrock aquifer.

Limitations of the Aquifer Susceptibility Assessment

The ISI groupings are based on typical values used in Wellhead Protection studies across Ontario; however, the user of this map is cautioned to keep the following limitations in mind:

5. The process does not take land use, slope, or the presence of hummocky topography into consideration.
6. The vulnerability or susceptibility analysis does not consider possible conduits such as improperly constructed or abandoned wells/boreholes. These features can compromise the existing geologic protection above the aquifer and can lead to rapid contamination of an aquifer.
7. The ISI is evaluated at individual water wells and values are interpolated between wells. Hence, the map is more reliable in areas where there are several wells and has a lower reliability in areas where wells are sparse.
8. The ISI map is based on the geological information recorded on the MOE WWIS and this information has varying levels of reliability.

Given the limitations, it is recommended that the susceptibility map be used as a guidance tool only. More detailed assessments of groundwater vulnerability and potential drinking water threats will be completed as part of CVC and the municipalities' Source Water Protection initiatives, which will be summarized in the ongoing Source Water Protection Assessment Report for CVC's jurisdiction.

4.2.4.5 Potential Groundwater Impacts

Surface and groundwater contamination may occur from two different types of sources: point and non-point sources, with the two terms generally describing the localization of the contaminant. Point source contaminants are typically smaller in scale, such as a single leaky underground fuel storage tank. These types of contaminants are generally concentrated in industrial and commercial areas and within urban settings. In contrast, non-point sources occur at a larger scale and are more diffuse than point source contaminants. Non-point sources primarily relate to land use practices such as pesticide or fertilizer spreading, or road salting.

4.2.4.6 Point Sources

Information on potential point source contaminants for the Shaws Creek Subwatershed, and a 500 m buffer area around the subwatershed was compiled and summarized for CVC by Eco Log Environmental Risk Information Services Ltd. (ERIS) of Toronto, Ontario. A copy of the ERIS report is provided in Appendix A.

The presence and location of various potential point sources of contamination were assessed using the following databases and sources of information:

- Anderson's Waste Disposal Sites;
- Ontario Regulation 347 Waste Generators Summary;
- Ontario Regulation 347 Waste Receivers Summary;
- Ontario Retail Fuel Storage Tanks Summary;
- Private Fuel Storage Tanks Summary;
- Ontario Inventory of Poly-Chlorinated Biphenyl (PCB) Storage Sites;
- Waste Disposal Site Inventory – MOE CA Inventory and MOE 1991 Historical Approval Inventory; and
- Occurrence Reporting Information System.

A summary of the databases utilized for this search is as follows. This information should only be used as a general description of potential impacts within the subwatershed. A more detailed assessment of groundwater threats will be completed as part of CVC's Source Water Protection studies.

- **Anderson's Waste Disposal Sites** - Information on these sites was collected through examination of historical documents and aims to characterize the likely position of former waste disposal sites from 1860 to present. This database revised and corrected locations identified in the MOE Waste Disposal Inventory. The database also includes the locations of auto wreckers and scrap yards that have been obtained from documentary sources.
- **Ontario Regulation 347 Waste Generators Summary** - Regulation 347 of the Ontario Environmental Protection Act (EPA) defines a waste generation site as any site involved in the production, collection, handling and / or storage of regulated wastes. According to the regulation, a generator is required to register the waste generation site and each waste produced, handled or stored at the site. This summary covers the period from 1986 to 2000. Companies that generated wastes prior to 1986 may not be included in the summary.
- **Ontario Regulation 347 Waste Receivers Summary** - The EPA also regulates the disposal of regulated waste through operating waste management systems or waste disposal sites. A waste receiving site is defined as any site or facility to which a waste carrier transfers waste. This summary spans the years from 1986 to 2000. Waste receivers that existed prior to 1986 may not be included in the summary.
- **Ontario Retail Fuel Storage Tanks Summary** - The Fuel Safety Branch of the Ministry of Consumer and Commercial Relations maintained a database of all licensed retail fuel outlets from 1989 to 1999. This database includes an inventory of retail fuel outlet locations that have gasoline, oil, waste oil, natural gas and / or propane storage tanks on their property.
- **Ontario Inventory of PCB Storage Sites** - The MOE maintains an inventory of PCB storage sites within Ontario. All PCB storage equipment and PCB waste require registration under the Ontario EPA. This database contains information on waste quantities, major and minor sites storing liquid or solid waste and a waste storage inventory.
- **Private Fuel Storage Tanks Summary** - The Fuel Safety Branch of the Ministry of Consumer and Commercial Relations maintained a database of all registered private fuel storage tanks from 1989 to 1996.
- **Waste Disposal Site Inventory** - The MOE maintains an inventory of known, active, inactive and closed disposal sites in Ontario.

- **Occurrence Reporting Information System** - The MOE maintains an inventory of sources, effects/ actions, and approximate locations of spills and their occurrences across Ontario.

The results of a review of this information are provided in the following subsections.

Anderson's Waste Disposal Sites
The database indicates that there are six unique waste disposal sites (including auto wreckers and scrap yards) within the Subwatershed 17 area. These locations include two auto junkyards and four dump sites, all located just west of Orangeville, south of Highway 9.

Ontario Regulation 347 Waste Generators Summary
According to the database search, there are approximately 38 waste generators in the study area. All of these, with the exception of an electric motor repair shop in Alton, are located within the urban area of southwest Orangeville just outside the subwatershed boundary.

Ontario Regulation 347 Waste Receivers Summary
There are only five registered waste receivers within the study area.

Ontario Inventory of PCB Storage Sites
There are two locations within the study area that are registered for the storage of PCB waste. Both of these locations are within Orangeville's urban area.

Ontario Retail Fuel Storage Tanks Summary
There are 17 Ontario retail fuel storage tanks identified in the study area. All of these correspond to service stations with gasoline, propane, motor oil, and/or fuel oil and are located throughout the subwatershed. The locations of these are illustrated in the Eco Log report in Appendix A.

Private Fuel Storage Tanks Summary
There were four facilities noted in the Eco Log report as containing private fuel storage tanks. All of these facilities were located in Orangeville.

Waste Disposal Site Inventory
Three waste disposal sites were noted in the study area, all of which are listed at being closed. The locations of these are illustrated in the Eco Log report in Appendix A.

Occurrence Reporting Information System
Nine spills of various chemicals were reported within Subwatershed 17. The materials spilled ranged from gasoline to muriatic acid and were spilled in various quantities. Details on the reported spills can be found in Appendix A. The reported spills were recorded across the subwatershed including areas of Orangeville, Alton, and along country roads.

4.2.4.7 Non-Point Sources
Information regarding potential non-point sources of contamination to groundwater quality in the study area was limited. In general, based on the land use in the area, potential non-point sources of impact were interpreted to be largely related to nutrient loadings (especially nitrate) associated with agricultural practices and septic systems, and elevated chlorides associated with road salting.

As noted on Error! Reference source not found., there are areas of moderate aquifer susceptibility in the subwatershed associated with the coarse-grained sediments of the Orangeville Moraine, as well as in the area south of Caledon Lake, covering much of the south-western portion of the subwatershed, including the Village of Alton. The susceptibility in this area is higher than the surrounding areas due to the thin overburden confining layer that overlies the bedrock aquifer. Therefore these aquifers could potentially be impacted by the non-point sources described above.

This information should only be used as a general description of potential impacts within the subwatershed. A more detailed assessment of groundwater threats will be completed as part of CVC's Source Water Protection studies.

4.2.5 Characterization of Hydrogeological Conditions

Groundwater flow and interaction with surface water in the Shaws Creek Subwatershed is controlled by the geologic setting of the subwatershed. The subwatershed comprises portions of three distinct physiographic regions (Chapman and Putnam, 1984): Guelph Drumlin Fields, Hillsburgh Sandhills and the Dundalk Till Plain and the geology varies from one physiographic region to another.

The surficial geology of the study area is characterized by four significant geological features:

- Orangeville Moraine;
- Tavistock Till Plain;
- Port Stanley Till Plain; and
- Hillsburgh Meltwater Channel.

Four main hydrostratigraphic units were identified on the cross-sections. From ground surface to bedrock, these units are:

- upper sand and gravel aquifer (associated with the Orangeville Moraine);
- clay till aquitard (Port Stanley and Tavistock Till);
- a lower basal sand and gravel aquifer; and
- Guelph/ Amabel/ Manitoulin Formation bedrock.

The most prominent topographic feature in the subwatershed is the Orangeville Moraine, which represents the highest topographic elevation in the subwatershed. This feature is composed of moderately to highly permeable stratified drift deposits and encourages groundwater recharge due to its hummocky topography. These conditions would tend to enhance groundwater discharge where shallow horizontal flow encounters a sharp decrease in permeability (e.g., where moraine deposits contact lower permeability till or organic deposits) or where there is a sharp decrease in topographic elevation.

The Amabel Formation is the most significant bedrock aquifer in the Shaws Creek Subwatershed, and is described as a highly fossiliferous, grey crystalline dolostone with abundant reefal structures (Cowan, 1976). The unit is capable of yielding large quantities of groundwater due to secondary porosity features such as fractures and dissolution cavities (Singer et al, 2003). The Amabel Formation varies in thickness from a few metres to over 30 m (Singer et al., 1994).

The bulk of the groundwater flow into the subwatershed occurs in the western portion of the subwatershed where groundwater flows from the Grand River Watershed. The groundwater flow divide between the Credit River and the Grand River Watersheds is thought to occur a few kilometres west of the watershed boundary. There is very little water flowing into Subwatershed 17 from Subwatershed 19, as the bulk of the groundwater flow in this area is oriented along the subwatershed boundary from west to east (i.e., a no flow boundary). Groundwater flows out of Subwatershed 17 primarily into Subwatershed 18 towards the deep buried bedrock valley, and to Subwatershed 15 following ground surface and bedrock topography.

The predominant direction of groundwater flow in the overburden deposits is from north to south, and localized flow in the eastern portions of the subwatershed is towards the Credit River. This includes the occurrence of flatter horizontal hydraulic gradients in the middle of the subwatershed, and steeper horizontal hydraulic gradients towards the buried bedrock valley (infilled with glaciofluvial outwash deposits) and the Credit River located just east of the subwatershed boundary.

In general, groundwater flow in the bedrock aquifers (Guelph and Amabel Formations) is from the west near the crest of the Orangeville Moraine to the east towards the deep buried bedrock valley. Bedrock groundwater horizontal hydraulic gradients are steepest at the eastern boundary of the subwatershed where groundwater flows towards the interpreted buried bedrock valley lying just east of Alton, and are shallowest in the central portion of the subwatershed where the ground surface topography is more subdued.

The baseflow analysis by Singer (1994) indicated that the mean annual baseflow for the subwatershed was 233 mm (equivalent to a mean flow rate of 0.532 m^3/sec), which is among the highest for the Credit River Watershed. All of the subcatchment areas in the Shaws Creek Subwatershed had flows throughout the field season. This observation is reflective of the medium to high infiltration that occurs in the subwatershed due to the generally coarse grained soils of the dominant surficial geologic deposits (e.g., stratified drift and glaciofluvial sand and gravel deposits). The generally high infiltration rates account for large amounts of groundwater recharge that ultimately result in large amounts of groundwater discharge to tributaries.

The subcatchment with the most significant contributions to baseflow was 17-01, which comprises approximately 30% of the area of the subwatershed but contributes approximately half of the measured baseflow. This large contribution to baseflow is attributed to the large portion of the subcatchment where high recharge occurs due to the hummocky topography and coarse grained sediments of the Orangeville Moraine, and to the contact between the moraine deposits and the fine grained organic deposits above Caledon Lake where spot flow measurements indicated significant increases in baseflow.

Groundwater chemistry in the area is largely controlled by the local geological setting. Groundwater in the Shaws Creek area is typically enriched in calcium, magnesium, and bicarbonate due to dissolution of the carbonate rich Guelph and Amabel bedrock formations (dolostone). Major ions that are typically encountered in groundwater samples include calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), sulphate (SO_4^{2-}), and chloride (Cl^{-}).

In general, very few areas within the subwatershed have been designated as being highly susceptible to surficial contamination. Theses areas are generally where there is a high water table, and a thick layer of sand and gravel close to ground surface, or in the eastern reaches of the subwatershed near Alton where the bedrock aquifer is exposed at ground surface, or is covered by only a thin veneer of overburden sediment (see **Figure 4.2.5**).

There are more areas of moderate susceptibility to surficial contamination in the subwatershed, and these are generally associated with the coarse-grained sediments of the Orangeville Moraine. The moderate susceptibility refers to the uppermost overburden aquifer, and not to the deep bedrock aquifer.

4.3 HYDROLOGY AND HYDRAULICS

The **water cycle**, also known as the **hydrologic cycle**, describes the continuous movement of water on, above, and below the surface of the earth. Since the water cycle is truly a "cycle," there is no beginning or end. Water can change states among liquid, vapor and ice at various places in the water cycle. Although the balance of water on earth remains fairly constant over time, individual water molecules can come and go.

Hydraulics is the science concerned primarily with the mechanical properties of liquids. Hydraulic topics cover concepts such as pipe flow, dam design, flow measurement, river channel behavior and erosion.

Both hydrology and hydraulics involve the interaction of water with the physical and biological environment including how water influences human activity.

For subwatershed studies hydrology and hydraulics look at the characteristics of flow along the watercourse (channel and flood plain), and the environmental impacts that result from development changes. Hydrologic characteristics include precipitation, evaporation, recharge rates, runoff volume/rates, and infiltration volumes/rates. Hydraulic characteristics include water levels flood plain and channel storage, flow capacities, flow velocities, flow depths and flow widths.

Hydrologic and hydraulic characteristics are influenced by runoff volumes and rates, topography, vegetation, erosion, and by land use (including urban and rural development). Development includes watercourse crossings, floodplain uses, storage facilities (i.e., dams), and channels, etc. Crossings (road/rail), and flood plain uses can have a significant impact on flow rates, flow velocities and water levels.

The Hydrologic Cycle (Figure 4.3.1) describes the continuous movement of water in and near the surface of the Earth. The elements of the Hydrologic Cycle are as follows:

- **Precipitation:** water in the form of rainfall or snowfall which reaches the Earth's surface;
- **Evapotranspiration:** water that leaves the Earth's surface and returns to the atmosphere by evaporation and transpiration mechanisms;
- **Groundwater Recharge:** water from rainfall or snowmelt that infiltrates the Earth's surface and enters the groundwater or subsurface flow regime;
- **Surface Runoff:** water that does not infiltrate the Earth's surface and remains in the surface water regime as surface detention storage, surface runoff or interflow; and
- **Groundwater Discharge:** water that flows from the subsurface (i.e., groundwater) regime to the surface water regime (lakes and rivers).

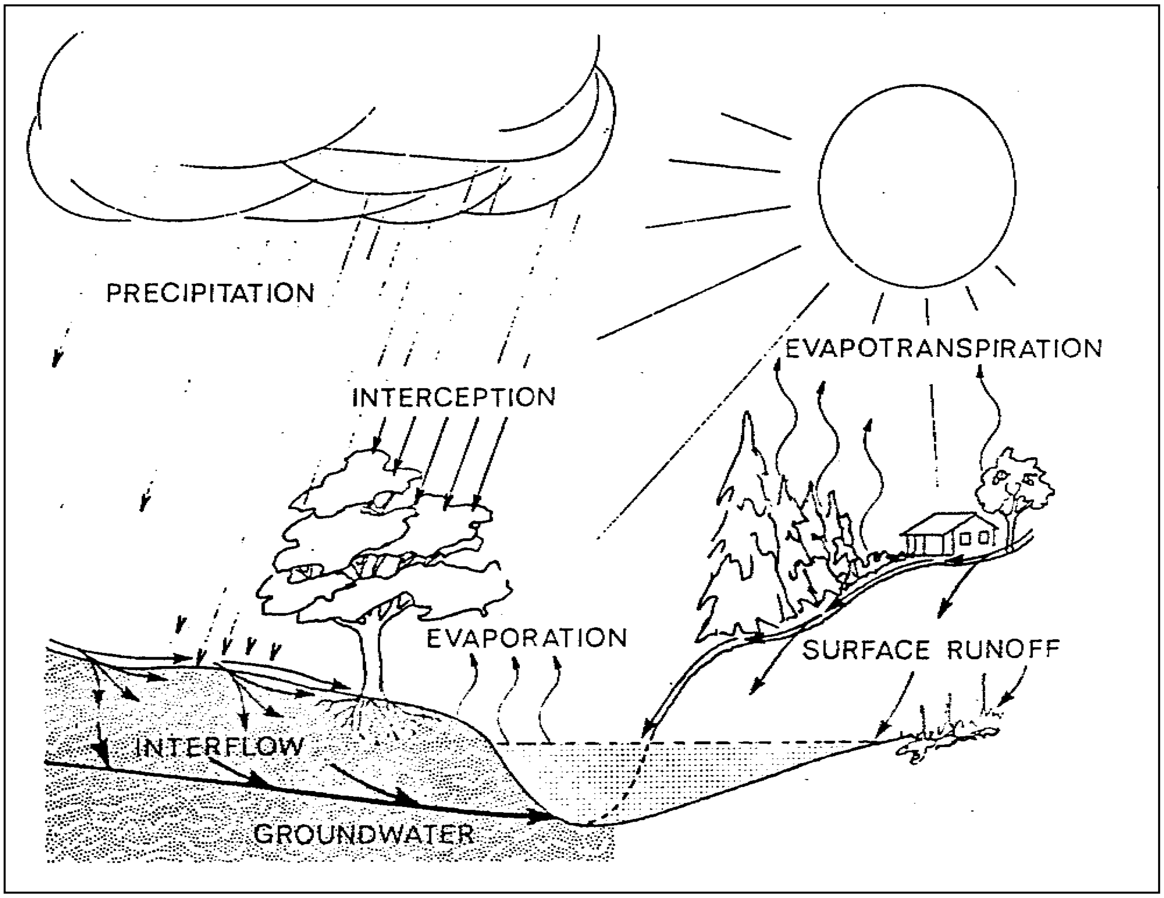


Figure 4.3.1 Hydrologic Cycle

4.3.1 General Description of the Subwatershed

Shaws Creek is located within the Orangeville moraine above the Niagara Escarpment. The porous soils and swampy valley lands, along with the closed drainage systems associated with the Orangeville moraine are the dominant factors influencing the streamflow response of Shaws Creek. The main branch of Shaws Creek follows a well-defined channel. The impoundment of water in the low lying areas of the basin has resulted in swampy conditions and the accumulation of organic materials. These factors combine to yield a low runoff response with the subwatershed which is discussed throughout this report. The streambed profile for Shaw's Creek is illustrated in **Figure 4.3.1**.

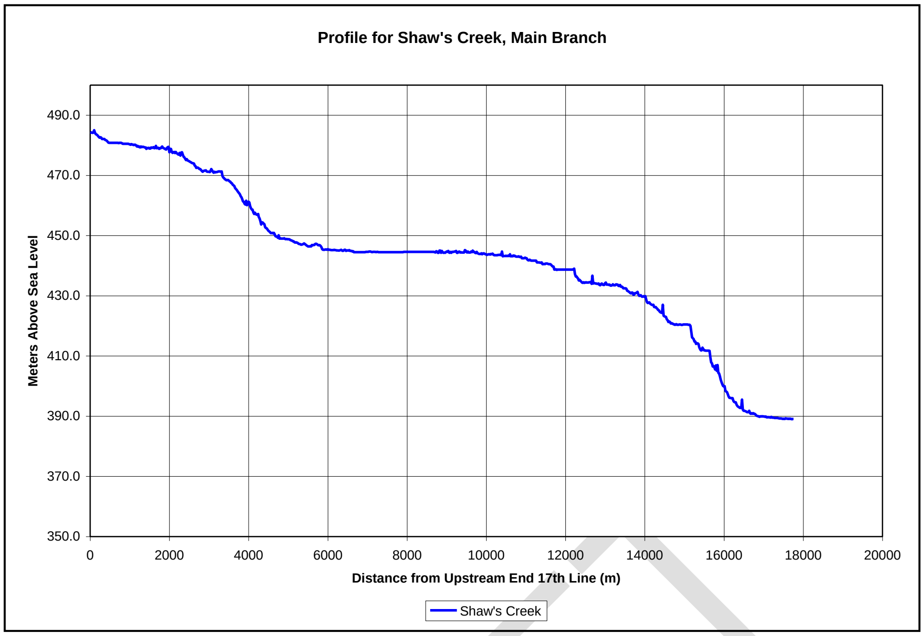


Figure 4.3.1 Streambed Profile for the Main Branch of Shaws Creek

Water in the creek is the result of precipitation that has fallen on the watershed over time. Water resulting from precipitation gains entry to the creek following three main paths: by directly falling on the creek surface, by running over the land surface to the creek (surface runoff) or by infiltrating into the ground and reappearing as groundwater discharge (springs or seeps) along the creek.
It is important to note that not all of the precipitation that on the watershed makes it to the creek. A portion of the precipitation that falls, returns to the atmosphere by evaporation from open water sources, or is used by plants through transpiration. A portion of the water infiltrates into the ground, and may leave the watershed and may discharge or is used by plants in an adjacent watershed.

The path water follows in a watershed will determine to a great extent how the watershed responds to precipitation. The local climate and physiography (surficial geology, topography and land use) are dominant factors that influence how water is delivered to the streams and rivers that form a watershed. Streamflow is the response to how water is delivered to the streams and creeks forming the drainage network of a watershed. Each of these factors needs to be considered when describing the surface water characteristics of a watershed. Details about the physiographic influences will be dealt with in Section 4.2 on hydrogeology.

4.3.2 Streamflow

Monitoring of streamflow was conducted in the Shaws Creek watershed between April 1983 and April 1991. Officially, Water Survey of Canada has called this gauge Credit *River at Alton Branch, Above Alton (02HB019)*, but in this report it will be referred to as the Alton Branch gauge (see **Figure 4.3.2**). This gauge measures 83% of the flow in the Shaws Creek system, an area comprising 59.50 km^2.

The presence and location of the Alton Branch gauge makes it possible to ascertain the contribution from the Shaws Creek to the total flow in the Credit River at the outlet of Shaws Creek. For example, gives the mean monthly flows in the Shaws Creek, showing the relative contribution from the upstream gauge on Shaws Creek. According to the graph the flows are highest during the spring freshet and late autumn and lowest during the summer months.

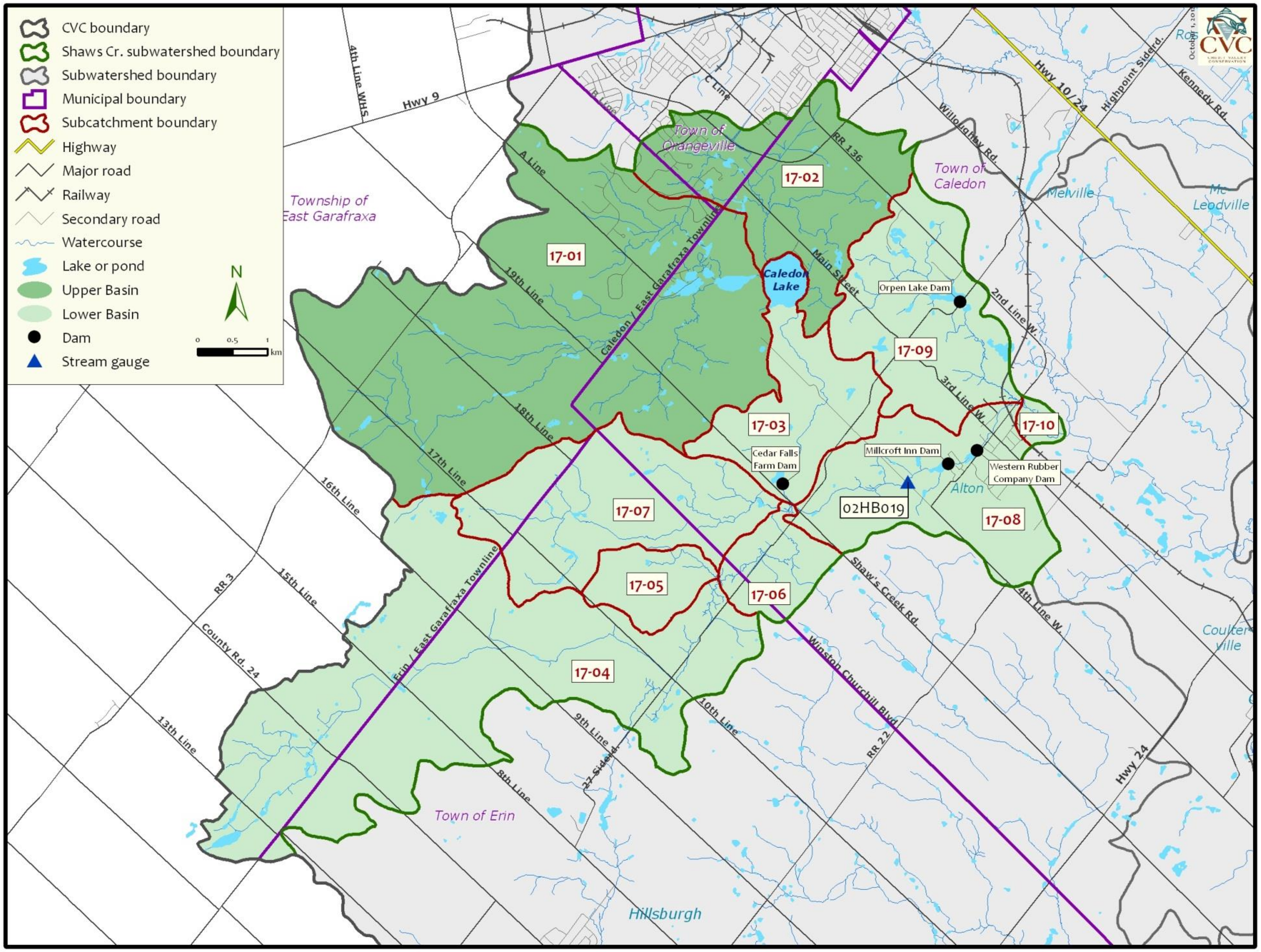


Figure 4.3.2 Streamflow Gauge, Dams and Hydrologic Basins in Shaws Creek Subwatershed

Flow characteristics for the areas above the Niagara Escarpment are very different from those below or downstream of the Escarpment (Chapman and Putnam, 1984; Singer et al., 1984), as illustrated by the hourly hydrograph plots obtained for two event periods, February 25 to April 15, 1986 and July 17 to July 25, 1986 at the Alton Branch gauge. Areas above the Niagara Escarpment are often dominated by hilly moraines, porous soils and swampy valley lands. As a result, these factors have a direct influence on the streamflow response. The dampened response from the rural areas in subwatershed 17 can be seen in the July 1986 plot. In addition, the base time for a typical snowmelt event (see

Figure 4.3.3 Monthly mean flows in Subwatershed 17
) is much longer than for a typical rainfall event (see
Figure 4.3.4 Observed hydrograph at Alton Branch station for Feb. 25 to May 6, 1986

). Furthermore, influences from Caledon Lake on downstream flow values can be seen in **Figure 4.2.5** in which the rising limb of the hydrograph is followed by a decreasing logarithmic limb, indicative of the streamflow response in a channel in which the flows are regulated by a large body of water such as a lake or pond.

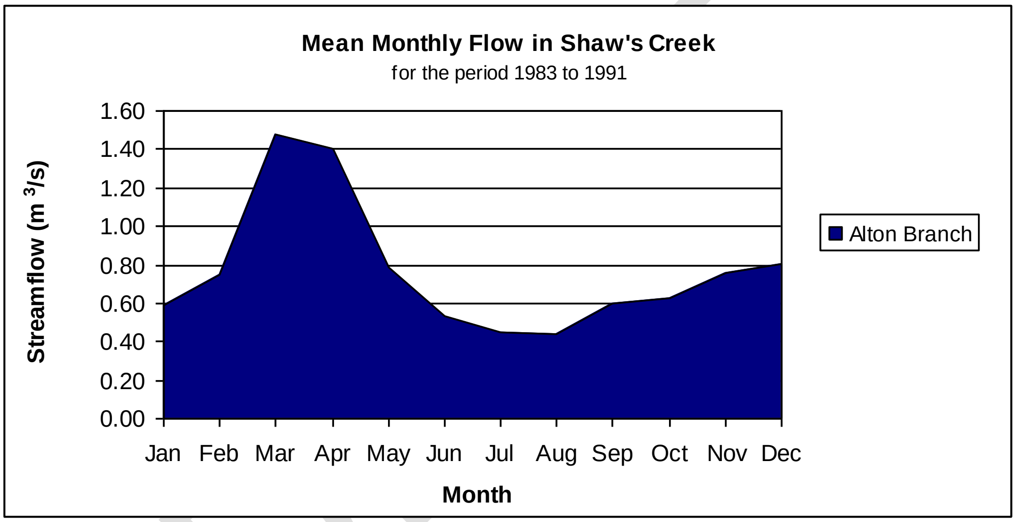


Figure 4.3.3 Monthly mean flows in Subwatershed 17

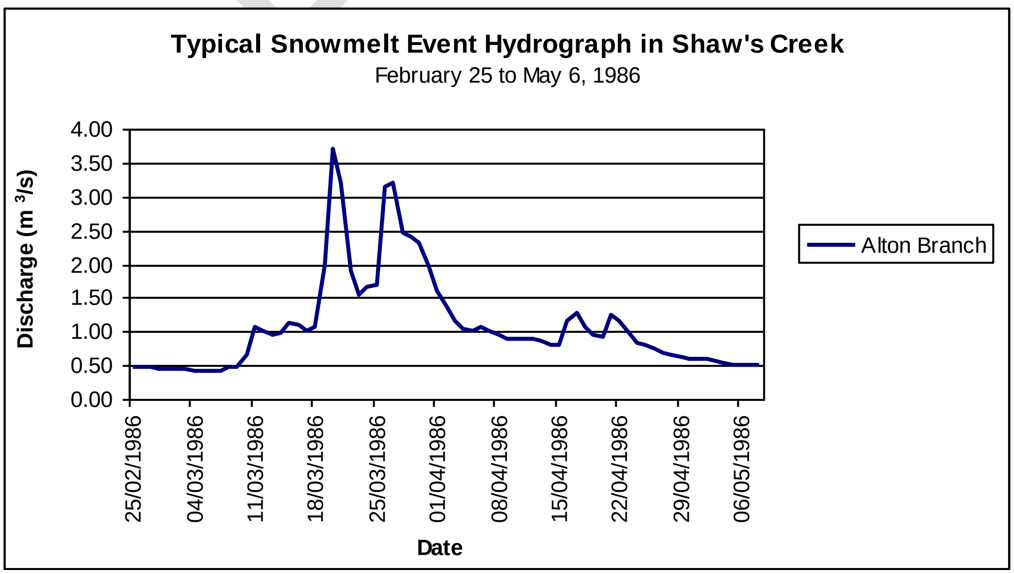


Figure 4.3.4 Observed hydrograph at Alton Branch station for Feb. 25 to May 6, 1986

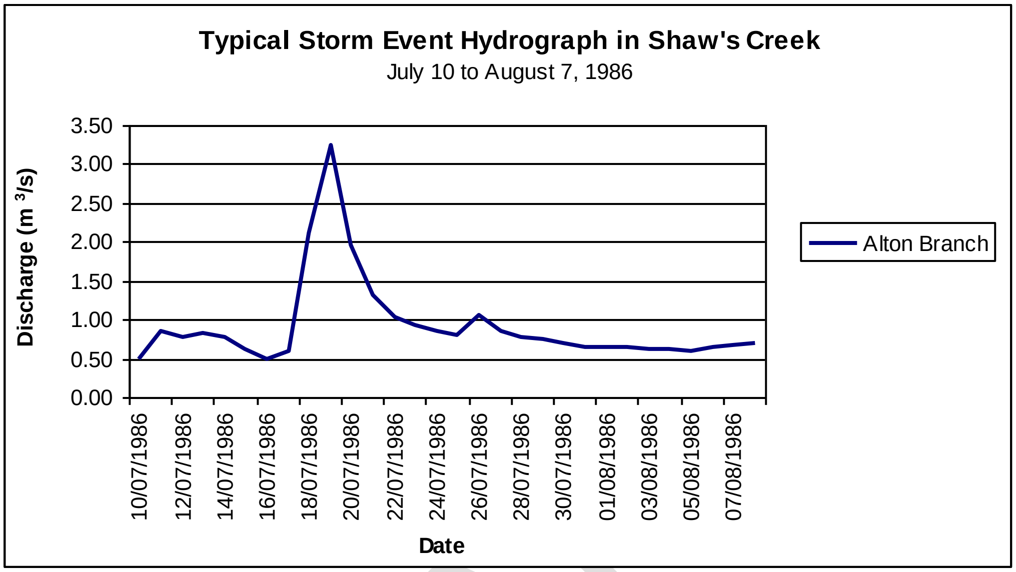


Figure 4.3.5 Observed hydrograph at Alton Branch station for July 10 to August 7, 1986

Further evidence for climate influences on the streamflow response of Shaws Creek can be seen in **Figure 4.2.6**, which gives the time-series of annual flows at the Alton Branch gauge for the period 1983 to 1991. Here we see lower peak flows during the drought of the late 1980's and higher peaks during the early 1990's. An examination of the time of occurrence of maximum flows indicated that within the period of record for the Alton Branch gauge (1983 to 1991) 90% of the annual maximum flows in Shaws Creek occurred during the 'spring freshet' in the months of March and April, when flood flows result from snowmelt or a combination of rain and snowmelt on frozen ground conditions. Flood flows in the late summer and early fall period are typically caused by tropical storm systems, a period when the infiltration capacity for most soils is reduced to 25 to 30% of their mid-summer values. During this time the runoff potential is at its highest without a snow pack. Recall that the highest 24 hour rainfall totals that has occurred in Shaws Creek was during the August to November period.

Figure 4.3.6 Time-series of annual maximum flows in Shaws Creek
gives the time-series annual minimum daily flows at the Alton branch gauge for the period 1983 to 1991. Generally, this plot shows some of the same climate variability that was evident in a similar plot for annual maximum flows. The highest minimum flow occurred in 1987 and the lowest minimum flows occurred in 1988 and 1989 during the drought of the late 80's, with recovery in baseflow in 1990. An examination of the time of occurrence of minimum low flows indicated that within the period of record for the Alton Branch gauge (1983 to 1991) 90% of the annual minimum flows in Shaws Creek occurred during the late summer and early autumn period (July to September).

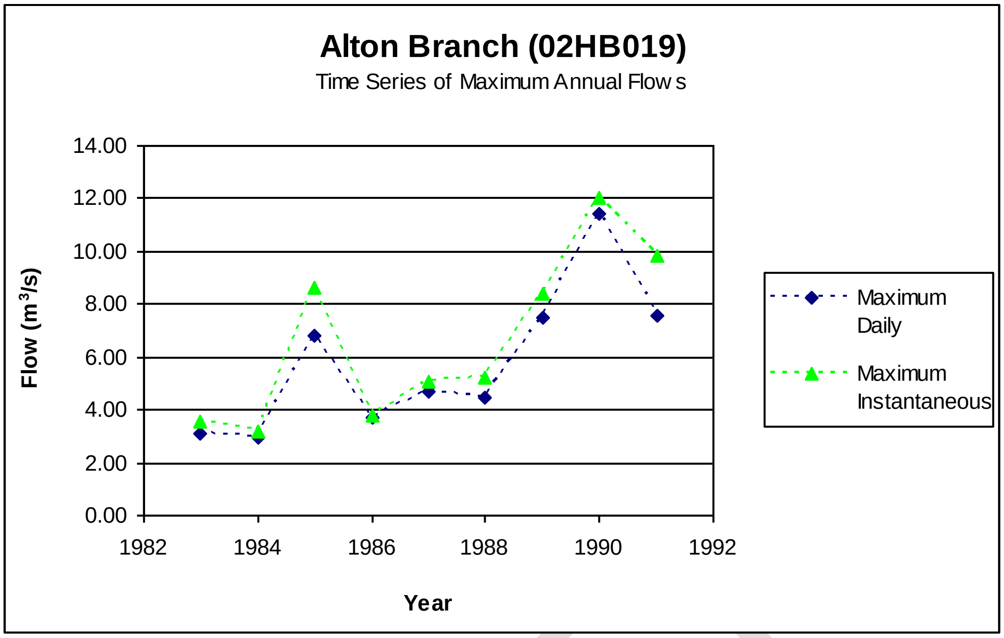


Figure 4.3.6 Time-series of annual maximum flows in Shaws Creek

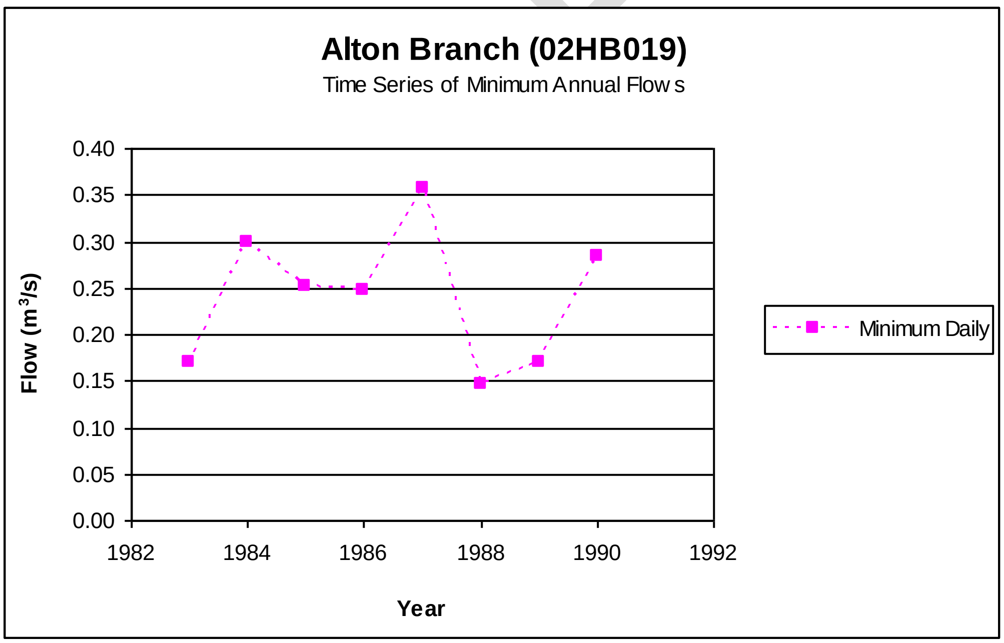


Figure 4.3.7 Time-series of minimum annual daily flows of Shaws Creek

A comparison of unit area low flows in Shaws Creek with other areas in the Credit River watershed is presented in

. The unit low flows for the Alton Branch station are higher due to greater recharge amounts attributed to soils with higher infiltration capacity, the closed drainage system associated with the Paris/Galt moraines and the presence of swampy valley lands. Furthermore, the Melville low flows are higher than the Cataract due to the presence of the Orangeville Moraine which is made up primarily of sands and gravels, resulting in higher recharge amounts.

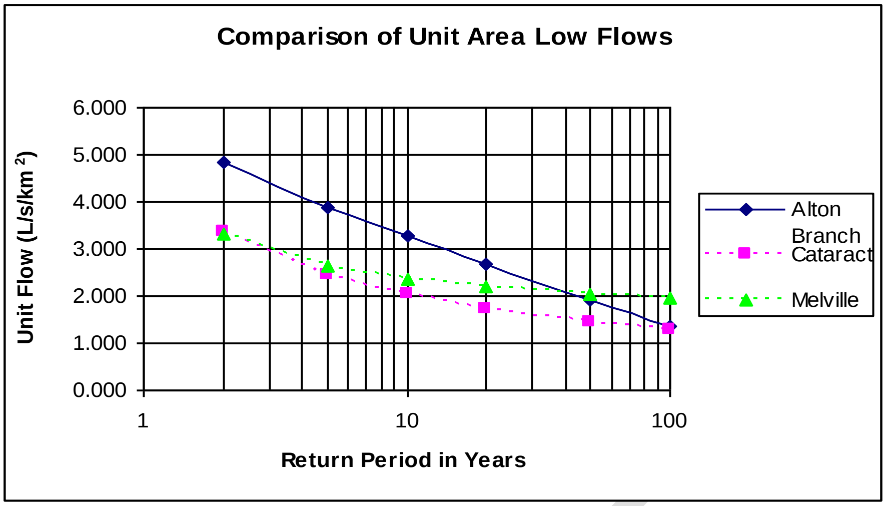


Figure 4.3.8 Comparison of unit area low flows in Shaws Creek with other areas

The low flow or dry weather flows can be characterized by examining the flow duration curves for the two gauges with the study area. **Figure 4.3.9** gives the 'all year' and 'summer only' (June to August) flow duration curves for the Alton Branch gauge. Flows with less than 10% duration represent the flood flow portion of the curve. The summer flow curve flattens out for durations greater than 60%. The summer flow curve and the 'all year' curve overlap for durations greater than 40%, indicating a high amount of recharge within the Shaws Creek basin. As suggested by Schroeter and Boyd (1998), the flow duration curves are highly correlated with the physiography of an area. In this regard, Subwatershed 17 is located above the Niagara Escarpment where more pervious soils dominate among wetland and depressional storage features associated with the Paris/Galt moraine. As a result, the flow duration curves for the Alton Branch gauge are indicative of the physiographic features of the subwatershed.

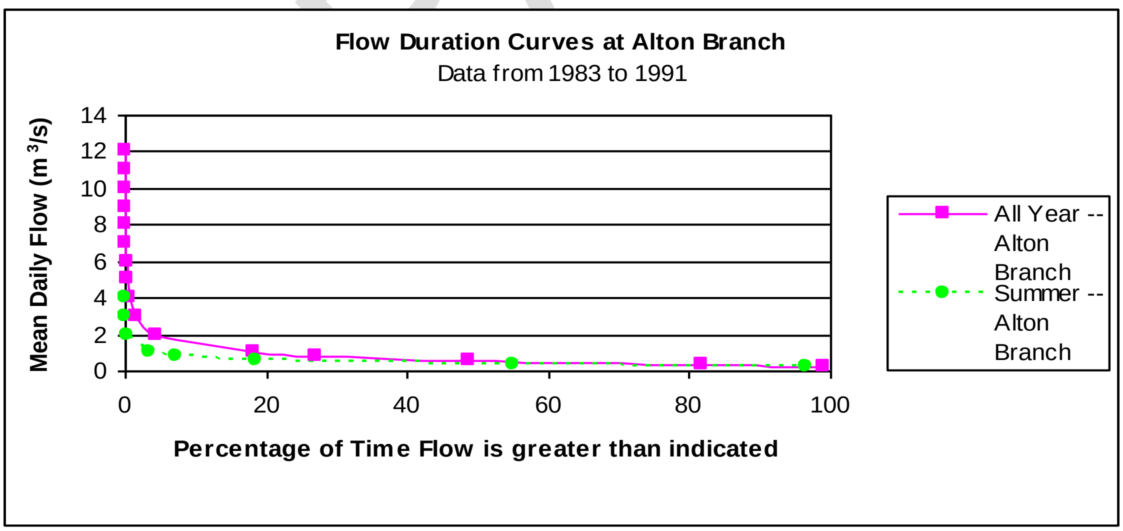


Figure 4.3.9 Flow duration curves for Shaws Creek

4.3.3 Watercourse Characteristics

Upon examination of several information sources (i.e. Pleistocene geology and soil maps, land cover information, streamflow data, streambed profiles and topographic maps), two 'sub-basins' or 'reaches' have been identified in the study area, where the surface water flow characteristics are generally uniform or consistent. These 'sub-basin' divisions have been chosen based upon information gathered from other studies during the background information review. With reference to the streambed profile given in **Figure 4.3.1** the two (2) sub-basins or reaches are outlined below (see **Figure 4.3.2**).

Upper Basin: This sub-basin drains all the areas upstream of Caledon Lake (north of Caledon/East Garafraxa Townline) to the watershed boundary. The total drainage area of this sub-basin is about 32 km^2, is about 11km in length and has a moderate bed slope of 0.8%. The drainage characteristics of the upper basin are controlled by Caledon Lake.

Lower Basin: This sub-basin drains all the areas downstream of Caledon Lake to it's confluence with the Credit River just downstream of the Village of Alton near RR 136. The lower basin drains 63% of the Shaws Creek watershed, an area comprising about 45 km^2. Its length is about 5 km and has a moderate grade of 0.86%. There are four tributaries within this sub basin. The impoundment of water in the low lying areas of the basin and in particularly the lower basin has resulted in swampy conditions and valley lands within the lower basin.

Specific characteristics found in Subwatershed 17 (Shaws Creek) impose a dominant influence of the flow response in this area. The dominant characteristics identified here include: the presence of large wetlands, well defined valleys, marshy areas within the floodplains and the prevalence of high infiltration soils above the Niagara Escarpment.

The hummocky topography associated with the Orangeville Moraine and large wetland areas above the Niagara Escarpment have resulted in large areas with either no surface drainage outlet or restricted outlets. These areas are referred to as closed drainage systems. Precipitation is retained in these areas, and either recharges the groundwater aquifers or evaporates.

The predominance of high infiltration soils, results in high recharge rates to groundwater aquifers, and reduced surface water runoff to flow within the watershed. This was confirmed through the streamflow analysis at the Alton Branch gauge for Shaws Creek, where it was determined that high flows were more likely to occur during the spring freshet, when frozen ground conditions contribute runoff for all soil types.

4.3.4 Watercourse Crossing Inventory

Hydraulic characteristics for Subwatershed 17 were determined through a review of topographic maps, and from a field inventory. The field inventory included characterizing watercourse crossings, and determining flood plain uses.

A watercourse crossing inventory was undertaken along Shaws Creek and its associated Tributaries, Tributary 1 (Subcatchment 17-09), Tributary 2 (Subcatchment 17-04), Tributary 4 (Subcatchment 17-07) and Tributary 5 (17-02):

- Identified the crossing shape, and the materials used to construct the crossing;
- Measured crossing dimensions including length, span and height; and
- Photographs of the crossing, and the watercourse upstream and downstream of the crossing.

The watercourse inventory is presented in as a separate document and the location of the road/rail crossings are shown in **Figure 4.3.10**. A summary of the crossings investigated is shown in

Table 4.3.1.

Table 4.3.1 Watercourse Crossing Summary

Crossing Label	Crossing Name	UTM Coordinate Northing	UTM Coordinate Easting	Top of Road Elevation m	1984 FDRP* Floodline Map No.
	Shaws Creek				
S-1	CP Railway	4856954	575010	396.46	4A
S-2	Main Street	4856587	574800	403.42	4A
S-3	Amelia Street	4856460	574714	407.49	4A
S-4	Walkway	4856356	574636	409.37	4A
S-5	Western Rubber Co. Dam	4856315	574600	413.43	4A
S-6	Credit Street	4856141	574357	414.91	4A
S-7	Walkway John Street	4856129	574222	419.04	4A
S-8	Millcroft Inn Dam	4856123	574176	420.99	4A
S-9	4th Line West	4856862	573585	429.02	4A
S-10	Highpoint Sideroad	4855686	572076	436.78	4A
S-11	Mississauga Road	4857240	572432	445.19	N/A
	Tributary 1				
ST1-1	CP Railway	4857438	574964	395.63	N/A
ST1-2	Highpoint Side Road	4858670	574377	404.77	N/A
ST1-3	RR 136	4859564	574008	393.22	N/A
	Tributary 2				
ST2-1	Shaws Creek Road	4855784	571957	435.92	N/A
ST2-2	Highpoint Sideroad	4855370	571810	439.52	N/A
ST2-3	Highpoint Sideroad	4855075	571551	440.92	N/A
ST2-4	Winston Churchill	4854784	571193	441.44	N/A
ST2-5	Highpoint Sideroad	4853576	570447	445.10	N/A
ST2-6	County Road 24	4852355	565121	487.13	N/A
	Tributary 4				
ST4-1	Winston Churchill Blvd.	4855459	570518	444.37	N/A
	Tributary 5				
ST5-1	Main Street	4859981	571626	449	N/A

** Floodline Mapping (1984, Kilborn)*

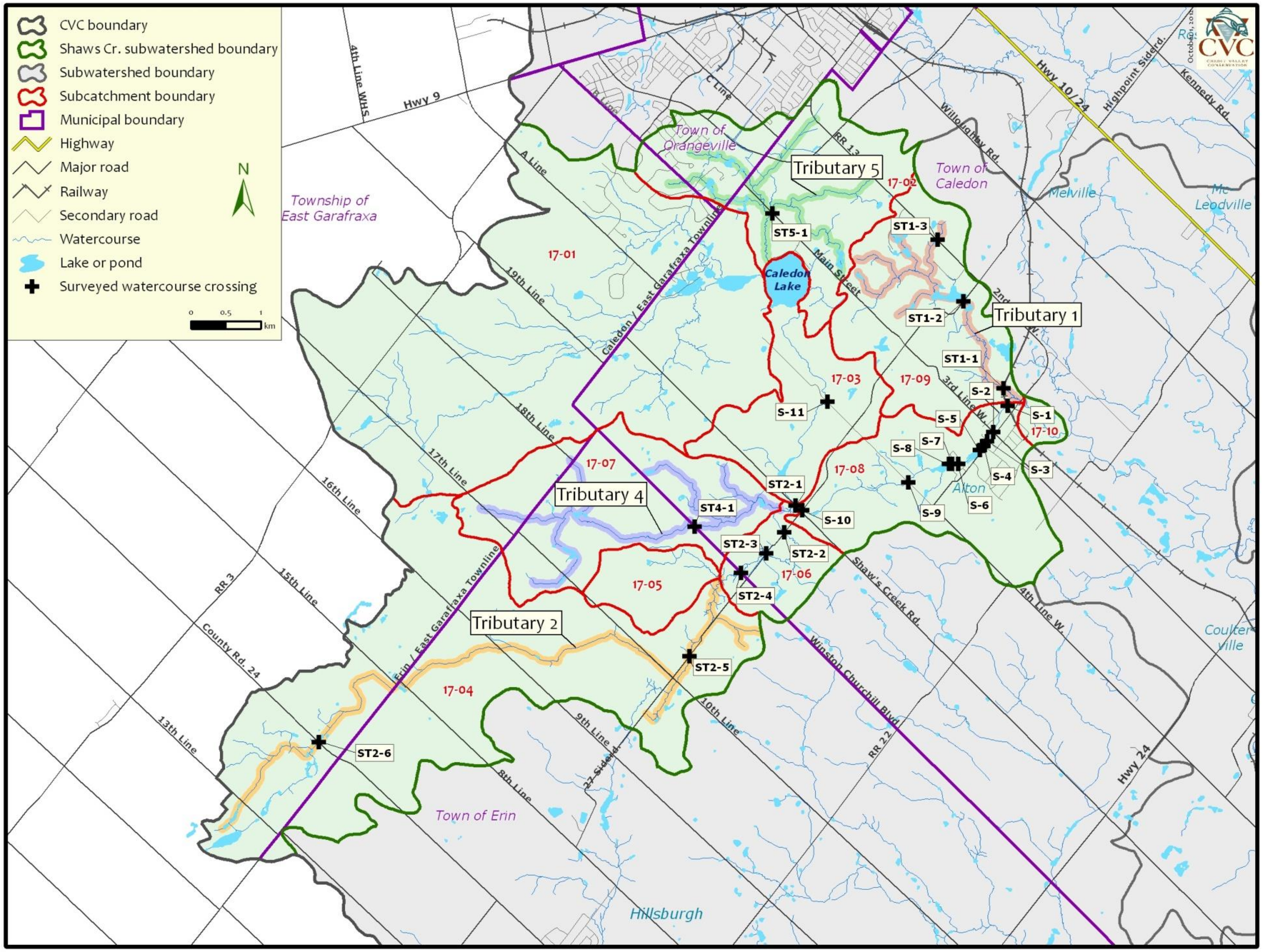


Figure 4.3.10 Crossing Locations

4.3.5 Floodplain Characteristics

The fourteen (14) flood plain mapping sheets produced by Kilborn Limited in 1984 (1984, Kilborn) extend from the confluence of Shaws Creek with the Credit River through to the northern part of Subwatershed 17, upstream of Cressview and Caledon Lakes. The following summarizes the conditions of the floodplain and watercourses within Subwatershed 17:

- The existing channel at the confluence with the Credit River is defined as natural, rising slightly through a well defined, broad, densely wooded valley. Typically the floodplain width along this reach according to the floodline mapping produced by Kilborn Limited is 300 m.
- Within the Village of Alton between the Canadian Pacific Railway and Main Street the existing channel is defined as having a moderate slope, traversing through a well defined, broad valley with dense wooded areas.
- Between Main Street and Victoria Street the channel than rises quickly through a moderately defined wooded valley. Downstream of Victoria Street is situated a control structure.
- Between Victoria Street and the Alton Mill Dam the existing channel rises moderately as it traverses through a well defined valley. Urban and industrial encroachment has taken place with bank stabilization schemes evident just downstream of Alton Mill access road and along that reach of channel from the access road to the dam.
- Upstream of the Alton Mill Dam to Millcroft Inn Dam the channel rises moderately as it traverses through the narrow, wooded and well defined valley.
- Between Fourth Line Road and Caledon Lake the existing channel is shallow with a moderate gradient as it meanders through a well defined, broad heavily wooded valley. For the most part the catchment area has remained in its natural state with little development having occurred.
- Between Caledon Lake and Seventh concession the natural channel has a shallow gradient with thick vegetation encroaching on the watercourse. The channel meanders through a densely wooded to marshy valley.
- Beyond Seventh Concession the existing channel rises sharply through a well defined but narrowing valley with light to dense vegetation covering the catchment area.
- For the tributary that confluences with the main channel at Highway 136 and extends to 25th Sideroad, the existing shallow, natural channel, meanders through a broad to narrow, well defined valley. The floodplain is densely wooded with some light patches. The area along the periphery of the basin is predominantly rural agricultural land.
- For the tributary that joins with the main channel between Fifth Line Road and extends to 7th Line Road, the existing channel is shallow, with thick vegetation encroaching on the watercourse. The channel meanders through a densely wooded to marshy valley. The catchment area is extremely wide with agricultural land located along the periphery of the wooded and marshy areas. Consideration should be given to maintaining this region as a recharge area for the watercourse.
- For the tributary that confluences with the main channel just upstream of Caledon Lake to Fifth Sideroad, the natural channel meanders through an extremely broad valley consisting of densely wooded to marshy regions. The channel is relatively flat with a shallow cross-section. Thick vegetation along its banks retards the flow during periods of peak runoff. Agricultural lands are located along the periphery of the basin.
- This relatively flat topography extends through Caldeon Lake, resulting in significant land coverage with flood events.

4.3.6 Potential Flood Damage Centres

The 1984 Credit River Flood Damage Reduction Study identified two (2) reaches along Shaws Creek with potential flood damages. The first reach is associated with the two (2) lakefront cottage developments on Shaws Creek. The Study Report identified that approximately 51 buildings located along Caledon Lake would be susceptible to damages under the Regulatory Flood. For the five (5) year flood approximately 15 buildings along Caledon Lake would be susceptible to flood damages. In addition, approximately fourteen (14) buildings are flood susceptible at the Regional flood along Cressview Lake. For the five (5) year flood approximately 6 buildings along Cressview Lake would be flood susceptible.

The second reach is located in Alton between the C.P.R. and the Millcroft Inn on the main branch of Shaws Creek. The reach was subdivided into five (5) subreaches. On the first subreach, upstream of the C.P.R. on the south bank, two (2) buildings (Meadowhouse Store, Barn) were identified as being flood prone. The Meadowhouse Store on Highway 136 exhibits Regional Flood damages only, whereas the Barn structure adjacent to the back suffers 5-10 Year flooding. On the second subreach the majority of floodprone residences within Alton fall along this north bank reach of Shaws Creek from downstream of Main Street to the Alton Mill. Four (4) of the eight (8) residences within this subreach on Amelia Street suffer 5-10 Year flooding. On the third subreach, the Alton Mill comprises the one floodprone building on the north bank of Shaws Creek in this reach. The existing building has been constructed immediately adjacent to the creek bank at the outlet of the southerly Mill pond. The south bank reach of Shaws Creek from Emeline Street to west of Agnes Street exhibits three (3) flood susceptible buildings along Queen Street, 2 of which are floodprone below Regional flood levels (10 Year flood). The south bank reach of Shaws Creek below the Millcroft Inn shows limited flood susceptibility. Three (3) buildings (2 Millcroft Inn buildings – Regional only, and the Old Mill building – 100 Year) are flood prone in this reach. The channel hydraulics adjacent to these flood susceptible buildings is characterized by rapidly varying flow over the two (2) weirs between the Mill ponds.

4.3.7 Dams

Four (4) dam structures have been identified within Subwatershed 17 (see **Figure 4.3.2**). Orpen Lake Dam, Alton Mill Dam (also referred to as the Western Rubber Company Dam), Millcroft Inn Dam and Cedar Falls Dam. Each of the dam structures is privately owned. The purpose of the dams was to provide electrical power during milling operations. The Orpen Lake Dam and the Cedar Falls Dam are both earthen gravity dams with concrete spillways and concrete headwalls. The Cedar Falls Dam is located along the main branch of Shaws Creek. On the downstream side of Ceaderfalls dam, approximately two residences are susceptiable to flooding starting at the 25-year event. The Alton Mill Dam and Millcroft Inn Dam are concrete dams and both are within the Village of Alton. The Orpen Lake Dam and Alton Mill Dam are controlled by flash boards; the Millcroft Inn Dam and Cedar Falls Dam are controlled by a concrete spillway. Drainage areas for the dam structures vary from as low as 330 ha (Orpen Lake Dam) to as high as 6450 ha (Alton Mill). The storage area behind each of the structures varies from 1.2 ha (Alton Mill Dam) to 4.8 ha (Orpen Lake Dam). The storage areas for the Millcroft Inn Dam and the Cedar Falls Dam are 1.5 ha and 3.3 ha respectively.

4.4 TERRESTRIAL

4.4.1 Terrestrial Communities

The terrestrial system of the Shaws Creek Subwatershed has been analyzed using Ecological Land Classification (ELC). Ecological Land Classification is a standardized hierarchal classification used for the description, inventory, and interpretation of ecological units. Ecological Land Classification provides resource managers with a “uniform and consistent way to identify, describe, name, map, manage and conserve important landscape patterns and communities” (Lee et al., 2001).

CVC has mapped the terrestrial system of the Shaws Creek Subwatershed using the *Ecological Land Classification for Southern Ontario* (Lee, H. et. al., 1998) and the *Credit Watershed Natural Heritage Project Detailed Methodology* (CVC, 1998). The Ecological Land Classification (ELC) was used to map and describe upland, wetland and aquatic systems to the community series level. The Natural Heritage Project (NHP) Methodology outlines the methods used to characterize the land use matrix of the watershed. Mapping of the study area was originally completed using 1996-spring aerial photography. The polygon boundaries drawn on the air photos were then transferred to1:10,000 Ontario Base Mapping and digitized into GIS (Geographic Information System ArcView 3.3). Mapping of the study area has been updated based on fieldwork as well as the 2002 digital ortho-rectified aerial photography.

4.4.1.1 Upland System

The upland system includes forests, plantations, and cultural (successional) communities. These communities were mapped to the Community Series level of the ELC (**Figure 4.4.1**). The Community Series is the finest level of the classification system that can be completed using aerial photography without fieldwork. The Community Series classifies upland communities as Deciduous, Mixed, or Coniferous Forest, Deciduous, Mixed or Coniferous Plantation, Cultural Woodland, Savannah, Thicket, or Meadow; or Open Beach/Bar. (For a detailed description of the community types please refer to the Terrestrial Appendix B) The Ecological Land Classification has been refined to the more detailed Vegetation Type level in areas where site level investigations have been carried out. Due to the scale of mapping contained within this report, however, these community types have not been illustrated.

Forests

Southern Ontario's forests are the dominant historic ecosystem of the region, and harbor much of the region's biological diversity, ranging in scale from genetic material to species and communities (Larson *et al.,* 1999). Forests provide numerous cultural, economic and social services. Forests sequester vast amounts of carbon, which would otherwise be released into the atmosphere and contribute to global warming. They also contribute to the water cycle when transpiration from a forest's trees moderate climate, and allow efficient absorption of subsequent precipitation, reducing both water flow-through rates and soil erosion. Forests also improve water quality, provide shade and lower water temperatures of any watercourses that pass through them. Finally, remnant forests in conservation areas across the region serve as centres of education, tourism and biological research.

At the time of European settlement, over 70% of southern Ontario was covered in upland forest communities (Larson *et al.,* 1999). In comparison, only 8.5% of the Shaws Creek Subwatershed is currently covered by natural forests, though this number increases to 13.6% when plantations are included (**Table 4.4.1**). **Figure 4.4.1** shows their distribution and classification.

Table 4.4.1 Forest Communities in the Shaws Creek Subwatershed

Forest Community Type	Area (ha)	Percentage of Subwatershed	Percentage of Forest Community
Coniferous Forest	186.13	2.63%	19.4%
Deciduous Forest	349.89	4.95%	36.4%
Mixed Forest	65.63	0.93%	6.8%
Coniferous Plantation	359.99	5.09%	37.4%
Deciduous Plantation	0.00	0.00%	0.0%
Mixed Plantation	0.00	0.00%	0.0%
Total	961.63	13.60%	100.0%

The Ministry of Natural Resources and Environment Canada recommend a minimum of 30% forest coverage in order to maintain forest interior species and area sensitive species (MNR 1997, Environment Canada et al., 2004). Credit Valley Conservation has adopted this recommendation. At present, the amount of forest coverage in the Shaws Creek Subwatershed falls short of this target. CVC therefore recommends not only the retention of current forested areas in the subwatershed, but restoration activities with a mandate to increase the amount of forested area.

Approximately half of the natural forests (i.e. terrestrial vegetation communities with at least 60% tree cover that are not the result of, or maintained by, cultural or anthropogenic-based disturbances) in the Shaws Creek Subwatershed are protected through provincial and regional designations (e.g. as Life Science Areas of Natural and Scientific Interest, Environmentally Significant Areas, Peel Greenlands & Caledon Environmentally Protected Areas). The remaining forests are scattered throughout the subwatershed, with limited connectivity along riparian corridors.

In addition to protecting current forest communities, the connectivity of habitat units needs to be improved. Connecting blocks of habitat is important for wildlife and plant species because they depend on corridors for travel between habitats and disbursal from one habitat to another. Where small gaps (i.e. a few hundred meters) exist between existing forest blocks in the Shaws Creek Subwatershed, it is recommended that restoration efforts focus on directly connecting these forest patches with each other and with other natural heritage communities (such as wetlands and riparian areas). Where larger gaps exist, it is recommended that restoration efforts focus on creating additional forest communities, thereby creating "stepping stone" habitats that various wildlife species can make use of. Areas where restoration efforts would be of particular benefit to the flora and fauna of the Shaws Creek Subwatershed include: along the riparian areas in subcatchment 17-04 (**Figure 2.1.2**) and subcatchment 17-01 between 17th Line and 18th Line (Lots 3 & 4, Concession 18, Town of East Garafraxa), as well as between upland communities between subcatchments 17-01 and 17-07 (Lots 28 and 29, Concession 6 WHS, Town of Caledon).

Cultural Communities
The cultural communities identified through ELC (**Figure 4.4.1**) can also be described as successional or old-field communities. These communities are no longer used for agriculture or other land use practices, but rather have been left to regenerate naturally. Generally speaking, vegetation in cultural communities is more abundant and diverse than that which is found on lands undergoing active human use. Cultural communities reflect the stages of natural succession from field (i.e. cultural meadow) to sparse forest (i.e. cultural woodland). They are important sources of food and shelter and often provide movement corridors for wildlife.

18% of the Shaws Creek Subwatershed is composed of cultural communities, and thus is in a stage of succession (**Table 4.4.2**). Cultural meadows are the predominant type of cultural community, reflecting a landscape that has recently experienced farm abandonment.

Table 4.4.2 Cultural Communities in the Shaws Creek Subwatershed

Cultural Community Type	Area (ha)	Percentage of Subwatershed	Percentage of Cultural Communities
Cultural meadow	1012.32	14.32	80.1
Cultural savanna	126.73	1.79	10.0
Cultural thicket	31.21	0.44	2.5
Cultural woodland	94.35	1.33	7.5
Total	1264.60	17.89	100.0

Cultural communities have traditionally been undervalued habitats, primarily because they are not seen as natural and because they are relatively abundant. However, they can provide important breeding and foraging habitat for many species of fauna, as well as suitable conditions for rare flora typical early successional stages (Davidson & Strobl, 1995). How and when animals use old-field habitats varies by species. It also varies seasonally and even within a single day. Some animals confine all of their activities to old-field ecosystems while others use cultural communities only a portion of the time. The features of cultural communities that provide suitable wildlife habitat include cover, amount of edge relative to the size of the old field, food source and suitability of breeding areas. Examples of species that depend on cultural communities include meadow voles *(Microtus pennsylvanicus*), red foxes (*Vulpes vulpes*), savannah sparrows (*Passerculus sandwichensis*), and swallows.

4.4.1.2 Existing Land Use
As has been mentioned in previous sections, the detailed methodology for the Credit Watershed Natural Heritage Project provided the basis for the mapping of existing land use in the Shaws Creek Subwatershed (**Figure 4.4.1**). This mapping was accomplished through air photo interpretation. Definitions of the existing land use classifications can be found in the Terrestrial Appendix B.

A large proportion of the land base in the Shaws Creek Subwatershed is being used for agricultural practices. Their distribution is illustrated in **Table 4.4.3**. While agricultural uses can include fields that are dominated by herbaceous vegetation and grasses (such as those used for pasture land and recently abandoned fields) the dominant type of agriculture in the subwatershed is of a more intensive nature consisting of cultivated fields, and row crops (e.g. corn and wheat).

Table 4.4.3 Existing Land Use in the Shaws Creek Subwatershed

Existing Land Use	Area (ha)	Percentage of Subwatershed	Percentage of Existing Land Use
Active aggregate	85.85	1.21	2.4
Inactive aggregate	1.79	0.03	0.0
Intensive agriculture	2664.63	37.69	73.6
Non-intensive agriculture	414.88	5.87	11.5
Manicured open space	67.52	0.96	1.9
Rural development	128.09	1.81	3.5
Urban and Roads	246.16	3.48	6.8
Wet meadow	10.99	0.16	0.3
Total	3619.90	51.20	100.0

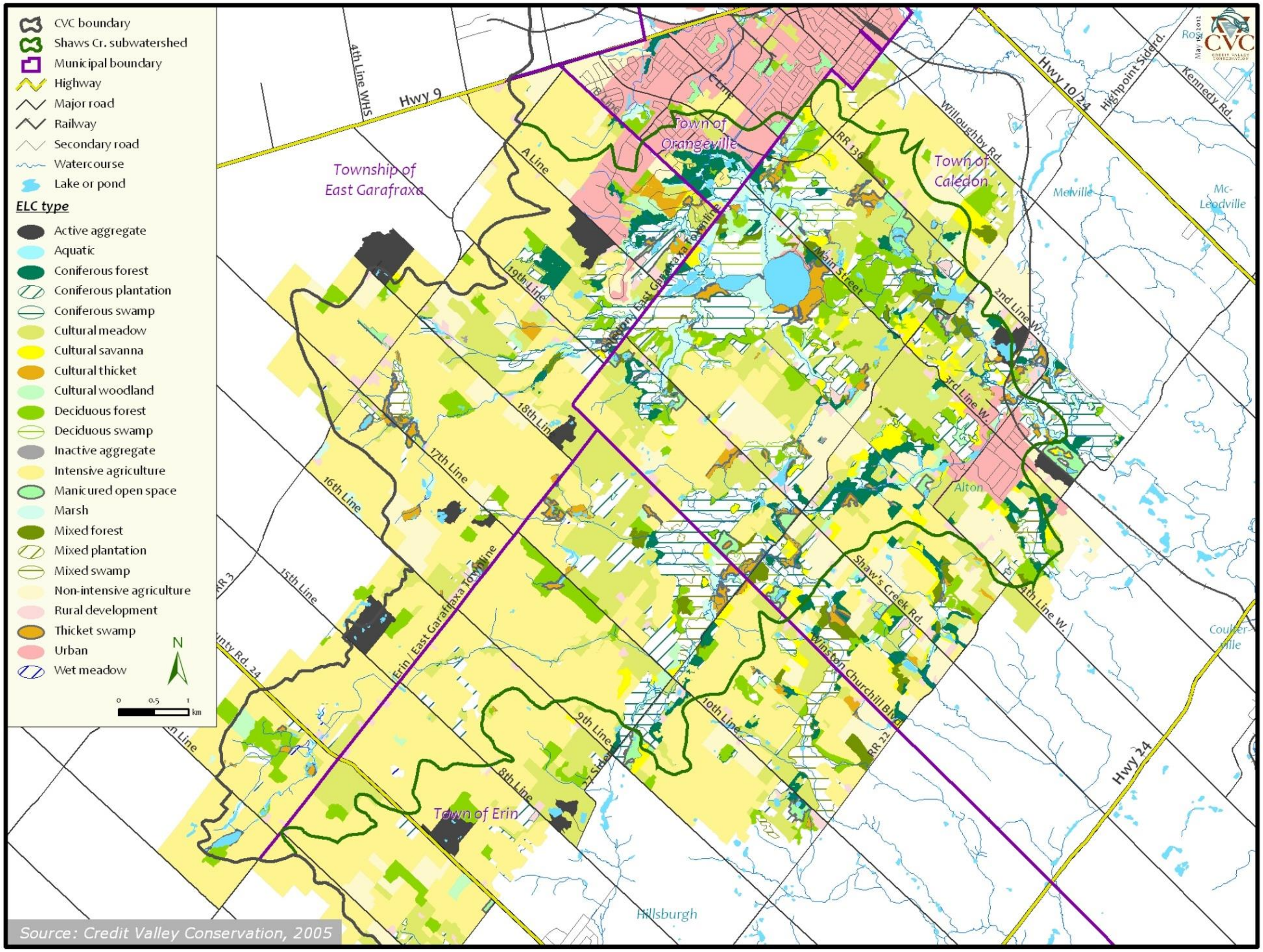


Figure 4.4.1 Ecological Land Classification and Simplified Land Use

4.4.2 Wetland Communities

Wetlands are areas of land that are saturated with water long enough to promote hydric soils or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity that are adapted to wet environments. This includes shallow waters that are generally less than 2 metres deep (Lee *et. al.,*1998). Wetland communities can include marshes, swamps, fens and bogs.

Swamps are classified to the Community Series level of the ELC as Deciduous, Mixed, Coniferous or Thicket Swamp (**Figure 4.4.2**). Marshes are not mapped according to the Community Class level because it is difficult to determine the differences between Meadow Marsh and Shallow Marsh from aerial photography. Marshes are therefore mapped to the Community Class level of ELC as Marsh. Fens and Bogs are also difficult to interpret from aerial photography, and thus are not mapped through the process of air photo interpretation. Instead, Fens and Bogs have been identified and mapped based on fieldwork, Ontario Wetland Evaluations, Environmental Impact Studies and other applicable research. (For detailed descriptions of community series classifications, please see Appendix B).

Wetlands perform many important functions. In terms of hydrology, wetlands play significant roles in attenuating peak flows, removing contaminants and nutrients, preventing erosion and recharging groundwater in certain geologic settings. The biological values of wetlands are usually assessed with respect to productivity (the number or amount of plants and animals sustained), biodiversity, system age, size and rarity. Wetlands provide critical habitat for fish, reptiles, amphibians, invertebrates, birds and mammals. Recreational values include nature appreciation, fishing, hunting, hiking, canoeing, bird watching and aesthetics.

4.4.2.1 The Wetland System

Wetlands make up approximately 16.4% of the Shaws Creek Subwatershed (**Table 4.4.4**). **Figure 4.4.1** shows their distribution and classification. Swamps are the dominant wetland type in the area (83%), though marshes are also present. There are three additional communities that aren't illustrated through the ELC mapping, but which are present in the subwatershed. Two significant fen communities were documented as a part of the Caledon Lake Wetland Evaluation. There is also a small opening in the vicinity of Caledon Lake in which a coniferous swamp exhibits bog features including a large accumulation of sphagnum. These wetland types are addressed under Section 4.3.6 Rare Communities.

Table 4.4.4 Wetland Communities in the Shaws Creek Subwatershed

Wetland Community Type	Area (ha)	Percentage of Subwatershed	Percentage of Wetland Cover
Coniferous Swamp	398.42	5.64	33.7
Deciduous Swamp	197.14	2.79	16.7
Mixed Swamp	162.72	2.30	13.8
Thicket Swamp	224.63	3.18	19.0
Marsh	200.40	2.83	16.9
Total	1183.30	16.4	100.0

Credit Valley Conservation and the Ontario Ministry of Natural Resources (OMNR) have conducted, or are in the process of conducting, formal evaluations on many of the wetlands in the Shaws Creek Subwatershed. Evaluated wetlands are classified under a standard methodology developed by the Ontario Ministry of Natural Resources and Environment Canada (*Wetland Evaluation System for Ontario - South of the Precambrian Shield*). This system identifies the wetlands that are considered to be "Provincially Significant."

According to the Provincial Policy Statement (MMAH, 2005) development and site alteration shall not be permitted in Provincially Significant Wetlands. In addition, lands adjacent to Provincially Significant Wetlands are protected from development and site alteration unless it can be demonstrated that there will be no negative impacts on the natural features or their ecological functions. Wetlands not identified as Provincially Significant Wetland often play important regional roles in terms of hydrology and biology. These wetlands can be protected as "Locally or Regionally Significant Wetlands" by the municipality. A brief description of Provincially Significant Wetlands (**Figure 4.4.2**) can be found below.

4.4.2.2 Provincially Significant Wetlands

Alton-Hillsburgh Wetland Complex

The Alton-Hillsburgh Wetland Complex is approximately 413 ha in size. It spans the boundary between the Shaws Creek and West Credit Subwatersheds, following the watercourse that runs between the towns of Hillsbugh and Alton. The complex is composed of swamp and marsh communities on predominantly organic and clay soils.

The Alton-Hillsburgh Wetland Complex is considered economically & socially significant for several reasons, including the fact that it contains large tracks of wooded areas, a variety of fur-bearing species, and is known to be used for hunting, fishing, and nature enjoyment/ecosystem study. Hydrologically, the wetland complex is significant because it serves an important role in flood attenuation, short-term water quality improvement, groundwater recharge and shoreline erosion control. Finally, the area provides a number of services to wildlife including acting as a feeding area for colonial waterbirds, providing habitat for waterfowl breeding & migration, acting as spawning and nursery habitat for fish communities, and is considered a locally significant area in terms of the protection it affords wildlife during the winter season.

Caledon Lake Wetland Complex

The Caledon Lake Wetland complex is approximately 589 ha in size. It is located in the northern portion of the Shaws Creek Subwatershed, encompassing the watercourses that drain into and out of Caledon Lake (along with the lake itself). The complex is composed of predominantly swamp (91%) and marsh (8%) communities on organic soils, though two small but significant fen communities have also been documented to occur.

Considered highly significant for its economic and social values, the Caledon Lake Wetland Complex scores 200/250 in the social component of the *Ontario Wetland Evaluation System*. It supports a number of species that are desirable for harvest including bullfrog (*Rana catesbeiana*), snapping turtle (*Chelydra serpentina*), muskrat (*Ondatra zibethicus*), raccoon (*Procyon lotor*), beaver (*Castor Canadensis*), mink (*Mustela vison*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), and wild rice (*Zizania sp.*). The complex also supports >200ha of wooded area, and a fishery that is used for commercial & recreational purposes. Finally, the Peel Board of Education owns property along Shaws Creek, and conducts educational programs at a staffed interpretation centre at that location.

The Caledon Lake Wetland Complex is also considered highly significant from a hydrologic standpoint (scoring 214 out of 250 possible points). It received the maximum score possible for its role in flood attenuation, as a long-term nutrient trap, and as a carbon sink. The complex also serves an important role in ground water recharge and wetland soil recharge potential.

Finally, the Caledon Lake Wetland Complex is highly valued for its biological diversity and special features. Sixty-eight communities have been documented in the wetland complex, including the previously mentioned rare fen communities. A provincially rare plant species has been documented to occur in the wetland complex, along with breeding habitat for waterfowl, overwintering habitat for wildlife, and nursery habitat for fish communities. The surrounding area is also biologically and physically rich, supporting row crops, pastureland, abandoned agricultural land, deciduous forest, mixed forest, deep river, fence rows & shelterbelts, hilly terrain and creek flood plain.

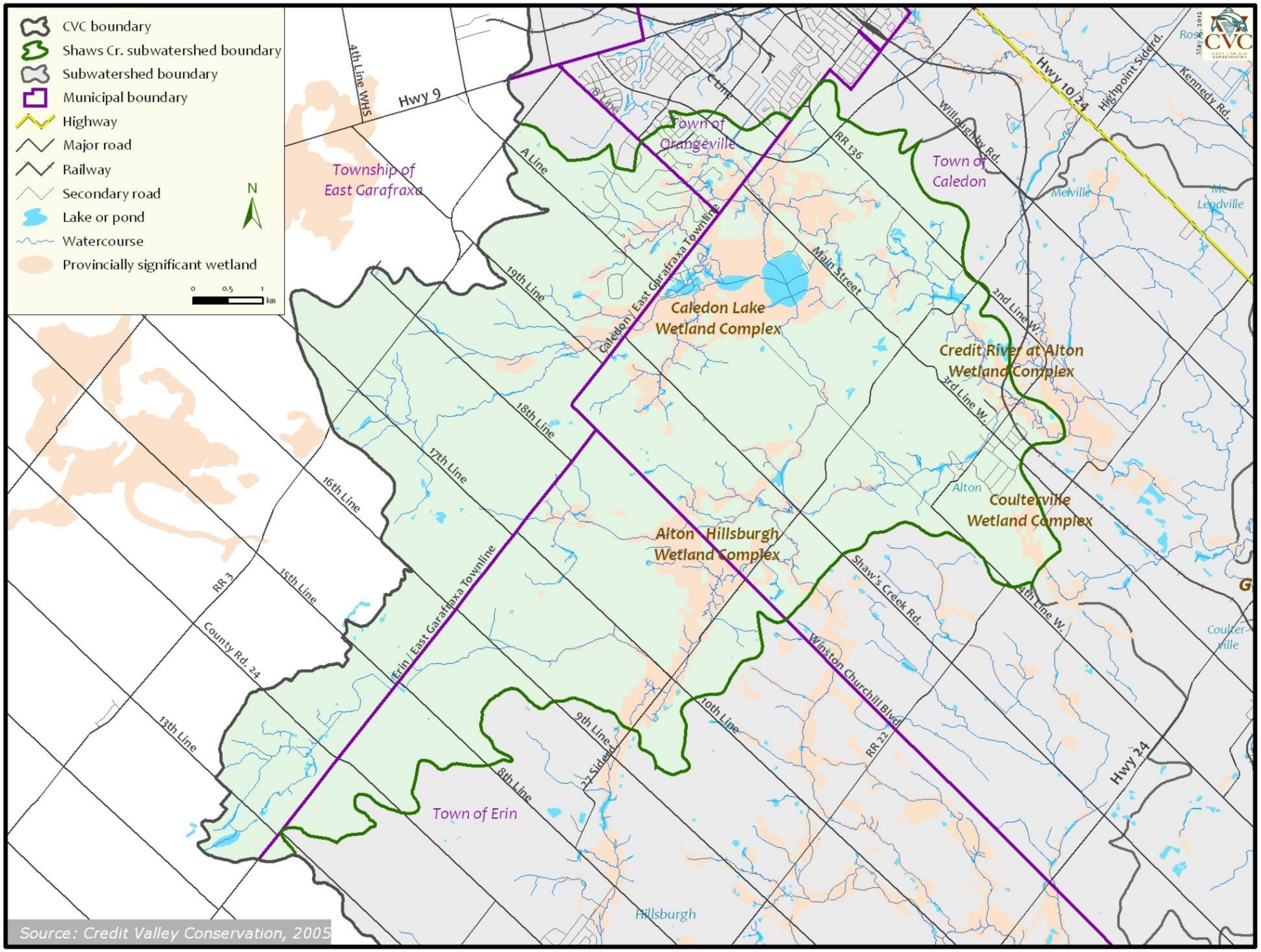


Figure 4.4.2 Evaluated Wetlands of the Shaws Creek Subwatershed

4.4.3 Aquatic Communities

The aquatic communities in the Shaws Creek Subwatershed Study area were identified through Ecological Land Classification mapping. As with the terrestrial and wetland systems, mapping of watercourses, lakes and ponds were originally done using 1:10,000 Ontario Base Mapping and were updated in 1999. These updates include previously unmapped lakes and ponds greater than 0.5 hectares in size, as well as sections of watercourses where there have been significant changes in the watercourse's size and location.

4.4.3.1 Aquatic System: Watercourses, Lakes and Ponds

In the spring of 2005, efforts were made to field verify the updated mapping of the Aquatic System of the Shaws Creek Subwatershed. Field verification involved Credit Valley Conservation staff members traveling roads and trails to confirm the presence and location of the mapped aquatic features. In addition, where CVC received landowner permission, CVC staff were able to note the location and status of aquatic features on private properties.

40.26 ha (or 0.57%) of the Shaws Creek Subwatershed is considered to be a part of the aquatic system. This system consists of natural waterways, modified waterways, lakes and ponds. *Natural Waterways* can be classified as: Watercourse, Intermittent Watercourse, Watercourse Not Visible, Wetland Flow, or Swale. *Modified Waterways* are classified as Engineered Watercourse, Agricultural Drain or Roadside Ditch. *Lake and Ponds* are classified as: Lakes, Ponds, On-line Ponds less than 0.5 hectare. (For a detailed description of this classification please refer to the Terrestrial Appendix B). For information on some of the faunal communities inhabiting the aquatic systems of the Shaws Creek Subwatershed, please refer to section 4.6 (Benthics) and section 4.7 (Aquatics & Fisheries).

4.4.3.2 The Riparian System

The riparian system includes those zones along a river that are flooded at least once every 20 years, and/or those zones that have high water tables, are connected to the stream channel and contain species of plants that can tolerate saturated roots for extended periods of time.

The quantity and quality of vegetation in the riparian zone is fundamentally connected to channel form and shape (geomorphology), aquatic habitat, water quality and temperature. Well-vegetated riparian stream banks help to control the form and shape of channels. Vegetated stream banks are fairly resistant to scouring. In such a system, streams are narrow, pools are deep, total sediment eroded into the channel system is low. In streams without extensive riparian vegetation, stream width increases, pools get shallower, and more material is eroded from banks. Streams with lush riparian vegetation - shrubs and grasses or trees and shrubs - have better pools and other habitats in them than streams with thinly grassed banks and active bank erosion.

The 1:10 000 scale mapping and 1:8,000 scale aerial photographs that were used for the ELC mapping exercise (and subsequent analysis) are not suitable for detailed mapping of riparian vegetation communities. As a result, these communities have not been classified specifically within the ELC mapping. They are captured, however, within the corridor mapping that is discussed under the Subwatershed Scale Corridors, refer to **Section 4.3.7.3**.

4.4.4 Area of Natural and Scientific Interest (ANSI)

ANSIs are areas of land and water containing natural landscapes or features which have been identified as having values relating to protection, natural heritage, scientific study, or education (MNR, 1984). Two kinds of ANSI are recognized by the province: Life Science and Earth Science. Life Science ANSIs are significant representative segments of Ontario's biodiversity and natural landscapes including specific types of forests, valleys and wetlands, their native plants and animals, and their supporting environments (MNR, 1999). Earth Science ANSIs consist of some of the most significant representative examples of bedrock, fossil and landform record of Ontario, and including some examples of ongoing geological processes (MNR, 1999).

ANSIs in the Shaws Creek Subwatershed were mapped based on information provided by the Ministry of Natural Resources (**Figure 4.4.3**). There are three Earth Science and two Life Science Areas of Natural and Scientific Interest located within the Shaws Creek Subwatershed Study Area. The Earth Science ANSIs are the Caledon Meltwater Channel (East), the Caledon Lakes Area and South of Orangeville (Melville Hill). The Life Science ANSIs are the Caledon Lake Forests and the Alton Branch Swamp. Unfortunately, not a great deal of information relating to the Earth Science ANSIs is available. As a result, only a summary of the two Life Science ANSIs appears below.

4.4.4.1 Caledon Lake Forests ANSI
(399.4 ha of the ANSI is contained within the Shaws Creek Subwatershed.)

Caledon Lake Forest is a Provincially Significant Life Science ANSI. It is situated on the Orangeville Moraine, and encompasses the northeastern portion of the Shaws Creek Subwatershed. Caledon Lake itself is positioned on a glacial spillway and is a shallow, marl-floored lake that appears to owe its existence to a mass of sandy drift dropped in the spillway just south of it. The area around Caledon Lake is a quaternary deposit of peat, muck & marl.

The Caledon Lake Forests ANSI contains an unusually high diversity of wetland types. Shrub thickets around the lakes are dominated by speckled alder (*Alnus incana*) and red-osier dogwood (*Cornus stolonifera*), though uncommon species such as shrubby cinquefoil (*Potentilla fruticosa)* and dwarf birch (*Betula pumila var. glandulifera) are also present.* As one progresses toward the center of the ANSI (away from the lakes), the vegetation changes to that of a coniferous swamp dominated by tree species such as tamarack, white cedar, balsam fir and black spruce. There is one small opening in the coniferous swamp which exhibits bog features including a large accumulation of sphagnum.

Deciduous and mixed swamp forests are more common in the northern portion of the ANSI. Deciduous forests cover the hills associated with the morainic topography on the periphery of the ANSI. There are several interesting plant associations in this area, including a thicket swamp of speckled alder, red-osier dogwood, dwarf birch and shrubby cinquefoil, a marsh dominated by wild rice (*Zizania aquatica*) and an open bog of dwarf birch, Labrador tea (*Ledum groenlandicum)* and sphagnum. All of these community types are uncommon in the region. Further, the Caledon Lake ANSI and its associated creeks provide habitat for one nationally (and provincially) rare plant species and numerous regionally rare plant & wildlife species. For additional details regarding the species and communities of the Caledon Lake Forest Area of Natural and Scientific Interest, please refer to the document J. Gould. 1988. A biological inventory & evaluation of the Caledon Lake Forests ANSI. OMNR, 46 pp., or contact the Natural Heritage Information Centre at the Ontario Ministry of Natural Resources office in Peterborough.

4.4.4.2 Alton Branch Swamp ANSI
(222.9 ha of the ANSI is contained within the Shaws Creek Subwatershed.)

The Alton Branch Swamp is a Provincially Significant Life Science ANSI. It is part of a swampy spillway valley stretching from Orangeville to Hillsburgh. This ANSI is a significant source area for the Credit River, in particular the Alton Branch.

The Alton Branch Swamp is extensive, and is composed of pure stands of cedar, a black spruce-balsam fir bog, cedar-tamarack-white birch and black birch lowlands, alder thickets and wet meadows. Numerous boreal (and therefore regionally rare) species are found in the Alton Branch Swamp ANSI.

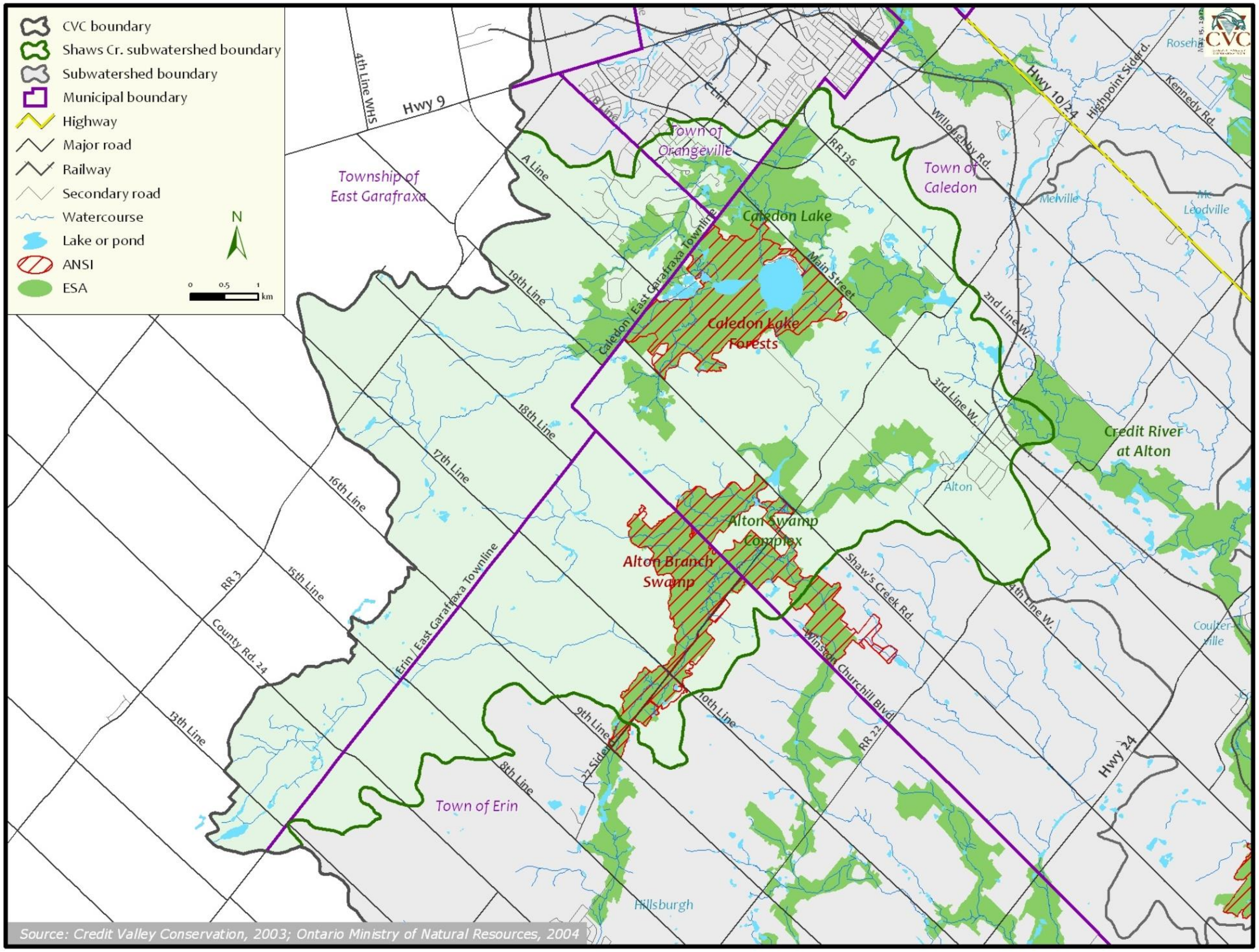


Figure 4.4.3 Life Science Areas of Natural and Scientific Interest (ANSI) and Environmentally Significant Areas (ESA) of the Shaws Creek Subwatershed

4.4.5 Environmentally Significant Areas

Because of concerns relating to the protection of significant natural areas in the Credit River Watershed, Credit Valley Conservation commissioned a study of Environmentally Significant Areas (ESAs) in 1977. To be considered an ESA, an area would have to meet one or more criteria that reflected its ecological importance within the watershed. In 1984, thirty-eight Environmentally Significant Areas were designated. At that time, CVC adopted a series of policies to aid in the protection of these features and their associated functions. The Town of Halton Hills, Wellington County and the Region of Halton also indicated a commitment to the protection of the designated ESAs. Moreover, the Region of Peel was one of the leaders in the identification, designation and protection of ESAs at a municipal level.

Three ESAs fall partially within the boundaries of the Shaws Creek Subwatershed. Their locations are illustrated in (**Figure 4.4.3**). A comprehensive summary of each of the ESAs can be found in Ecologistics Ltd. (1979). A brief synopsis of each ESA appears below.

4.4.5.1 Caledon Lake ESA

- 924.5 ha of the ESA is located within the Shaws Creek Subwatershed.

The Caledon Lake ESA is the largest Environmentally Significant Area in the Credit River watershed. It lies mainly within a large depression that is surrounded by sand, gravel and till deposits. Caledon Lake, Second Caledon Lake, and several man-made ponds (from marl mining) occupy part of the depression. The surrounding uplands of stratified drift are steeply sloping and hummocky, with many small depressions.

The Caledon Lake ESA is a diverse and extensive wooded area with a complex of wetland vegetation associations prevailing. A series of small streams and groundwater discharge from adjacent uplands maintain the water balance upon which the various associations depend. Deciduous swamps contain willow species (*Salix sp.*), white birch (*Betula papyrifera*) and alder shrubs (*Alnus sp.*) in the wetter areas, with trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*) in the drier areas. Open marshes, dominated by cattails (*Typha sp.*) and sedges (*Carex sp.*) are located along most of the streams, ponds and Caledon Lake itself. Calciphilic species occur in several locations, as do some species that are typically associated with northern acidic bogs. Finally, several old fields and upland wooded areas of sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*) & hemlock (*Tsuga canadensis*) occur in the fringe areas of the ESA.

4.4.5.2 Alton Branch Swamp ESA

- 496.4 ha of the ESA is located within the Shaws Creek Subwatershed

The Alton Branch Swamp ESA is the second largest ESA in the Credit River Watershed at 890 ha. Overlapping Subwatershed 15 (the West Credit) and the Shaws Creek Subwatershed, the ESA is the headwaters of both Shaws Creek and the West Credit River. It is situated in a glacial meltwater channel with organic soils covering the valley floor. Bordering the organic soils are deposits of poorly drained outwash sand and gravel with slopes of 0-5% along which loam soils have deposited. The edges of the meltwater channel are formed by relatively steep slopes, in places up to 25%. The ESA discharges significant quantities of groundwater to Shaws Creek, particularly via overburden aquifers.

The Alton Branch Swamp contains an extensive, undisturbed coniferous swamp comprised of several species associations. These include: pure stands of white cedar (*Thuja occidentalis*), a black spruce (*Picea mariana*) - balsam fir (*Abies balsamea*) sphagnum bog, and white cedar, tamarack (*Larix laricina*), white birch, black spruce mixtures. In addition, several alder thickets and meadows occur along stretches of Shaws Creek. The ground flora of the swamp and bog associations is quite diverse, and contains boreal species that become rare further south in the watershed. Numerous plant species that occur in the Alton Branch Swamp ESA are of phytogeographical interest in Ontario. In addition, the ESA supports a high diversity wildlife species, including brook trout (*Salvelinus fontinalis*),

4.4.5.3 Credit River at Alton ESA

- 29.6 ha of the ESA is located within the Shaws Creek Subwatershed

The Credit River at Alton ESA is confined mainly to the Credit River valley between Highway 24 and Alton, but includes the lower sections of Caledon Creek, Shaws Creek (Alton Branch) and two tributaries which enter the Credit from the east, one upstream of Caledon Creek and one upstream of Shaws Creek. The ESA is primarily a groundwater discharge area which releases water directly into the Credit River and helps to maintain water quality & base flow. In the north end of the ESA, mixed swamp is prevalent; the dominant species being black ash (*Fraxinus nigra*), white birch, balsam poplar, balsam fir, black spruce and trembling aspen. Some conifer plantations of red pine (*Pinus resinosa*), Scots pine (*Pinus sylvestris*), and white spruce (*Picea glauca*) have also been established

4.4.6 Rare Communities

The protection of rare species and communities has been, to many people, the single most important function of conservation (Margules and Usher, 1981). Some communities, such as bogs and fens are extremely rare, constituting only about 1% of the remaining wetlands in Southern Ontario (Riley and Mohr, 1994). Local agencies and municipalities have a level of responsibility to protect these, and other rare communities to the extent possible.

According to the Ontario Wetland Evaluation System – Southern Manual, 3rd Edition, fens are rare throughout most of Southern Ontario (Ontario Ministry of Natural Resources, 1994). Four fen communities were in initially identified as a part of the 1984 Ontario Wetland Evaluation of the Caledon Lake Complex. More recent visits to the wetland have indicated that only two of these communities are truly fens, with the other two being swamps with some fen characteristics. These communities are located north of the Caledon-East Garafraxa townline, between 18th Line and A Line. Their combined size is approximately 4 ha. These fen communities contain species such as white-cedar (*Thuja occidentalis*), tamarack (*Larix laricina*), Labrador tea (*Ledum groenlandicum*), grass of Parnassus (*Parnassia glauca*), round-leaved sundew (*Drosera rotundifolia*), thin-leaved cotton-grass (*Eriophorum viridi-carinatum*), skunk cabbage (*Symplocarpus foetidus*), as well as several sedge (*Carex*) and moss species (*Polytrichum sp.* and *Sphagnum sp.*).

Also identified within the Caledon Lake Wetland Complex is small opening (0.67 ha) within a coniferous swamp community that exhibits bog features. As was the case with fens, bogs are considered rare throughout Southern Ontario (Ontario Ministry of Natural Resources, 1994). This “bog” opening occurs along the road allowance south of Second Caledon Lake and provides habitat for at least six regionally rare plants (Kaiser, 2001). *Sphagnum fuscum* covers the ground surface in this community. Very few herbaceous species occur, though pitcher-plant (*Sarracenia purpurea*) and showy lady’s-slipper (*Cypripedium reginae*) are represented. Shrub species in the community include dwarf birch (*Betula pumila*), leather-leaf (*Chamaedaphne calyculata*), narrow-leaved meadowsweet (*Spiraea alba*), large cranberry (*Vaccinium macrocarpon*) and small cranberry (*Vaccinium oxycoccus*). In addition, a few pools of standing water contain common duckweed (*Lemna minor*). Soils are saturated organics and the microclimate is cooler than normal.

Other communities that were identified in the Caledon Lake Forests ANSI Report (Gould, 1987) as rare at a Site District scale, and that have been verified through field surveys conducted in 2004 and 2005, include the open aquatic communities found in Caledon Lake and Second Caledon Lake, the deep marsh (shallow aquatic) community formed along the edges of these two lakes, and a coniferous swamp community containing boreal species associations that is located to the south and west of Caledon Lake.

4.4.6.1 Subwatershed Rare Communities

Using the Ecological Land Classification Mapping it is possible to identify the community types that are uncommon within the Shaws Creek Subwatershed. On this basis, those community types that make up 5 percent or less of the natural area have been identified as rare in the subwatershed (**Figure 4.4.4**). Communities that meet this criterion include Bog (Trace), Fen (Trace), Aquatic (2.2%) and Mixed Forest (3.6%) (**Table 4.4.5**). These communities are designated as “special features” and are afforded consideration for protection.

Table 4.4.5 Rare Subwatershed Community Types

Natural Community Type	Area in Ha	Percentage of Natural Area
Aquatic	40.26	*2.21%*
Coniferous forest	186.13	10.20%
Coniferous swamp	398.42	21.83%
Deciduous forest	349.89	19.17%
Deciduous swamp	197.14	10.80%
Marsh	200.40	10.98%
Mixed forest	*65.63*	*3.60%*
Mixed swamp	162.72	8.91%
Thicket swamp	224.63	12.31%
Total*	1825.21	100.0%

**Note: Table does not include trace occurrences*

4.4.6.2 Communities with 3 or more Rare Species

The most comprehensive source of information on vascular plants in the Credit Watershed is The Vascular Plant Flora of the Region of Peel and the Credit River Watershed (Kaiser, 2001). This document identifies CVC/Peel Rare Species as species with 10 or fewer locations or distinct "plant stations" in the Credit River Watershed and/or the Region of Peel. A location or plant station is defined by an exclusion zone with a 1 km radius around each known location for a given species. Based on the fieldwork carried out by CVC staff as part of the Shaws Creek Subwatershed Study, communities with 3 or more CVC/Peel Rare Species have been identified (**Figure 4.4.4**). These communities are considered to be "Special Features" as part of the terrestrial analysis.

This review identified 57 vegetation communities with three or more species that are considered Rare in the Credit River Watershed. These communities are illustrated on **Figure 4.4.4**.

4.4.6.3 Forests Older than 125 Years

Old-growth forests have been defined in many ways. Generally, the term refers to communities that have been continuously forested since before European settlement, and/or that have a forest canopy that is dominated by trees of a certain age, which varies depending on the regional context and the forest types that can be found in a particular region. (In the Great Lakes region, northern hardwood and oak forests reach understorey reinitiation phase at approximately 120 years of age, and this age has been used as a cutoff for old-growth by the Old Growth Policy Advisory Committee).

Old-growth communities are complex, having a diversity of species, structures and functions that occur in different woodland types and site conditions. They represent unique opportunities to understand what pre-settlement forests were like, and thus can serve scientific, research and educational functions. They provide habitats for numerous rare plants and animals, and can act as reserves of genetic variation, preserving examples of life forms that may have value for the future because their genes enabled them to survive under severe conditions and to achieve longevity. Old-growth forests also provide many sources of wildlife habitat and facilitate the migration of species. Finally, these communities can provide economic and social benefits, including the provision of unique recreational and tourism opportunities, inspiration for art, photography and literature, and opportunities for cultural or spiritual reflection.

Before European settlement, most woodlands in southern Ontario were relatively mature; that is, replacement of canopy trees would have occurred mostly through gap regeneration (Frelich and Reich, 1996). Large-scale disturbances were relatively rare, so older-growth forests were fairly abundant. Currently, only 0.07% of the landbase south and east of the Canadian Shield is estimated to remain as old-growth production stands older than 120 years (FON, 2001).

Based on Forest Resource Inventory mapping of the Credit River Watershed, seven communities in the Shaws Creek Subwatershed were identified as being dominated by trees greater than 100 years in age. In addition, two communities were identified as having trees greater than 125 years in age. Landowner permission was granted to visit four of the nine communities that had been identified as “potential old growth” through the FRI mapping. Two of these communities, as well as two additional communities visited in the 2004 and 2005 field seasons, contained structural indicators of old growth. (Structural indicators of old growth include minimal anthropogenic disturbance, presence of slow colonizing species, large numbers of snags of large diameters, highly decomposed downed logs, a multi-layered canopy, soils showing pit and mound microrelief, an abundance of fungi, lichens, mosses and ferns, and individual trees that are very large and old). The remaining two communities were classified as mature forest, but were not noted to contain any physical indicators of old growth forests. These communities have been mapped in **Figure 4.4.4**.

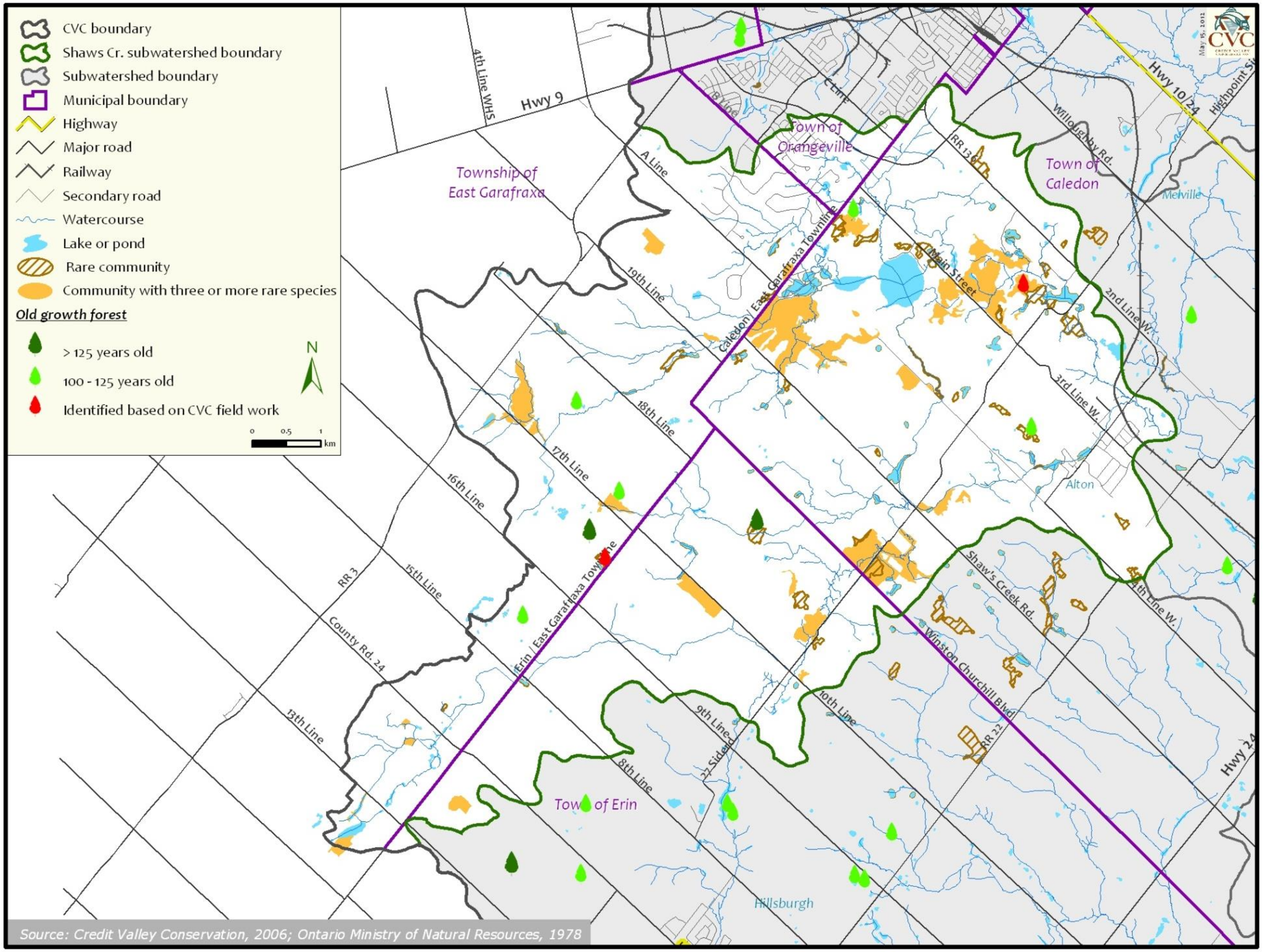


Figure 4.4.4 Rare Communities, Communities with Three or More Rare Species, and Forests Older Than 125 Years

4.4.7 Wildlife

Knowledge on specific wildlife species within the subwatershed has been gathered from several sources. A preliminary survey of the anurans of the Shaws Creek subwatershed was undertaken by Lorne Bennett and Robert Milne between April 26 and July 6, 2004 using *the Amphibian Road Call Count* protocols. The Amphibian Road Call Counts generally followed the procedures of the Wildlife Assessment Program and the Marsh Monitoring Program (Konze and McLaren, 1997; Weeber and Vallianatos, 2000). Bennett and Milne also conducted breeding bird surveys (following *Forest Bird Monitoring Protocol*) between June 4 and July 20, 2004 and between June 26 and July 20, 2005. In addition, the *Atlas of the Mammals of Ontario* (Dobbyn, 1994) was reviewed to obtain an overview of the mammal species in the area. This Atlas is based on a grid of 10 km x 10 km squares. The Shaws Creek Subwatershed mostly falls within two squares (17NU65 and 17NU75). Using the squares that cover the subwatershed, a list of species for the area was developed. In addition, wildlife lists from ANSI reports, ESA reports and wetland evaluations were been used to supplement the *Atlas* survey efforts.

4.4.7.1 Reptiles and Amphibians

The purpose of the Amphibian Road Call Count survey of the Shaws Creek Subwatershed was to document the presence and abundance of breeding anuran species in different vegetation communities. Based upon this fieldwork, 10 species of frog were identified through surveys conducted at 75 stops, adjacent to 17 communities, within the Shaws Creek Subwatershed (**Figure 4.4.5**). The most abundant species heard was the spring peeper (*Pseudacris crucifer*). This species is considered to be a generalist, and was heard calling at more than three-quarters of the survey points (**Error! Reference source not found.**). Green frogs (*Rana clamitans*) and grey treefrogs (*Hyla versicolor*) were also common. Conversely, bullfrogs (*Rana catesbeiana*), mink frogs (*Rana septenrionalis*) and pickerel frogs (*Rana palustris*) were only recorded at single sites.

Recent volunteer efforts have also identified two snake, two turtle, and three salamander species in the Shaws Creek Subwatershed (Scallen, 1998, 2002). These species were the eastern gartersnake (*Thamnophis sirtalis sirtalis*), the northern red-bellied snake (*Storeria occipitomaculata occipitomaculata*), the snapping turtle (*Chelydra serpentine*), the Midland painted turtle (*Chrysemys picta marginata*), the eastern red-backed salamander (*Plethodon cinereus*), the yellow-spotted salamander (*Ambystoma maculatum*) and the red-spotted newt (*Notophtlalmus viridescens viridescens*). Most of the herpetofaunal species found are considered to be common in the Credit River watershed, with the exception of both mink and pickerel frogs.

Mink frogs are considered to be a “northern species,” with the populations in the Shaws Creek Subwatershed likely constituting the most southern distribution for the species in the province. Pickerel frogs not only have very specialized habitat requirements (which limits their distribution), but also are difficult to detect in auditory surveys because their calls are quieter, and are also very similar to the call of the leopard frog (Rana pipiens). In addition, these species seem to be more sensitive to disturbance and thus prefer larger, well-vegetated, interior habitats, which are not likely to be captured through roadside surveys.

Table 4.4.6 Frog Species Abundance in the Shaws Creek Subwatershed based on Amphibian Road Count Surveys (Bennett and Milne, 2004)

Common Name	Scientific Name	Number of Locations Observed
Spring peeper	*Pseudacris crucifer*	68
Green frog	*Rana clamitans*	43
Grey treefrog	*Hyla versicolor*	32
Wood frog	*Rana sylvatica*	23
Northern leopard frog	*Rana pipiens*	20
American toad	*Bufo americanus*	13
Chorus frog	*Pseudacris triseriata*	3
Bullfrog	*Rana catesbeiana*	1
Mink frog	*Rana septenrionalis*	1
Pickerel frog	*Rana palustris*	1

The roadside frog survey completed by Bennett and Milne (2004) for the Shaws Creek Subwatershed on behalf of CVC focuses on species occurrences rather than community diversity. It is useful, however, to look at how species are affected by community type and connectivity. The Shaws Creek Subwatershed consists of a variety of natural and human-modified habitats. The Amphibian Road Call Count stops occurred most commonly at community types (or primary communities) that were mapped as pond (open aquatic) and thicket swamp. Other common primary community types included marsh, cultural meadow and coniferous plantation (**Table 4.4.7**).

Table 4.4.7 Distribution of Frog Species in each ELC Community Series or Ecosite in the Shaws Creek Subwatershed based on (Bennett and Milne, 2004)

ELC Community Series or Ecosite	Number of Occurrences as 1° Community Type	Number of Occurrences as 2° Community Type	Maximum Species Count at One Stop (1° Community)	Total Species Count per Primary Community
Pond	24	0	5	7
Thicket Swamp	18	5	6	8
Marsh	10	4	5	7
Cultural Meadow	5	19	5	6
Coniferous Plantation	4	6	2	3
Stream	3	0	2	4
Non-intensive Agriculture	2	5	2	3
Mixed Swamp	2	4	2	2
Deciduous Forest	2	2	2	3
Coniferous Swamp	1	8	3	3
Coniferous Forest	1	5	3	3
Deciduous Swamp	1	1	1	1
Cultural Woodland	1	1	2	2
Cultural Thicket	1	1	3	3
Intensive Agriculture	0	7	N/A	N/A
Cultural Savannah	0	5	N/A	N/A
Mixed Forest	0	1	N/A	N/A

Several permanent ponds are located within the subwatershed. Some of these ponds were surrounded by lawns and thus provide limited opportunity for use by amphibians. Other ponds were bordered by buffers of riparian vegetation and it was at these locations that a larger number of amphibians were heard calling. Some species, such as the green frog, are aquatic for their entire life cycle. They breed in swamps, marshes, river, pond and lake habitats, but will move through and forage in adjacent areas, including riparian habitats, shoreline habitats and vernal pools. Given that the three most common communities sampled through the Amphibian Road Call Count protocol were either aquatic or wetland in nature, and that a large number of riparian areas were adjacent to ponds, swamps and marshes, it is not surprising that green frogs were among the most common species encountered.

The second most common community in which frogs were heard calling was thicket swamp. Thicket swamps occur in 3.2% of the subwatershed, and are the third most common “non-anthropogenic-based” ELC community series mapped (**Table 4.4.2**). Thicket swamps are poplar habitats for several species of amphibians because they often contain standing water during the breeding season, have emergent vegetation that can be used for egg attachment sites, and contains shrubs in close proximity to the water that species like spring peepers and grey treefrogs will use as calling sites. This habitat was commonly connected to other habitat types (or secondary communities), and this “natural vegetation buffer” ensured a large area for movement around individual home ranges. Stops 6 and 58 had the greatest species diversity in the subwatershed, providing habitat for eight species of frog including the uncommon chorus frog and bullfrog.

The third most common community surveyed were roadside marshes. These marshes provided breeding habitat for between 1 and 5 species of frog. The greatest diversity occurred where the marsh was surrounded by Cultural Meadow (Stop 17) or Mixed Forest (Stop 69). The lowest diversity of frogs was recorded at a marsh surrounded by a Coniferous Plantation (Stop 73).

Amphibians require a variety of habitats throughout the year for breeding, feeding and hibernating. While the primary communities surveyed during the ARCC were the location of breeding activities, in many cases the secondary communities (**Table 4.4.7**) are required for feeding and overwintering activities. Fragmentation, the reducing of connectivity between habitats, has been linked to amphibian declines. Linkages between habitats in the Shaws Creek Subwatershed show various degrees of connectivity (Section 4.3.8). Of particular concern for amphibian and reptile species is fragmentation that is caused by roads.

Roads can pose a significant barrier for amphibian species moving and migrating to breeding ponds. They also can bisect overwintering and foraging habitat from breeding habitat in the cases of snakes and turtles. Turtle species are particularly slow-moving, and are often killed because they can’t cross the road quickly enough. In addition, the sandy and gravelly road surfaces present in much of the Shaws Creek Subwatershed make excellent nesting sites for some turtle species (e.g. snapping turtles) which can result in increased road mortality for both egg-laying females and the hatchlings themselves.

Shaws Creek Subwatershed contains one main east-west road (Erin-East Garafraxa Townline & Caledon-East Garafraxa Townline) and several north-south sideroads. The north-south roads with the most traffic include Highway 24 at the west end of the subwatershed, Winston Churchill Blvd in the centre, and the former Highway 136 at the east end of the subwatershed. In addition, Mississauga road has been paved for much of its length and may attract more traffic as a result. Pavement heats up during the day and often stays warm throughout the night, this heat attracts both frog and snake species, as they will use the heat from the road to speed up digestion.

While road mortality may be of minimal concern (low impact) to amphibian and reptile communities at present, it will be important to monitor these levels as the populations in surrounding areas (e.g. Orangeville) increase. Where possible, efforts to increase connectivity (amphibian tunnels?) should be made. In addition, a study to determine areas of particularly high road mortality (or the potential for it), are required.

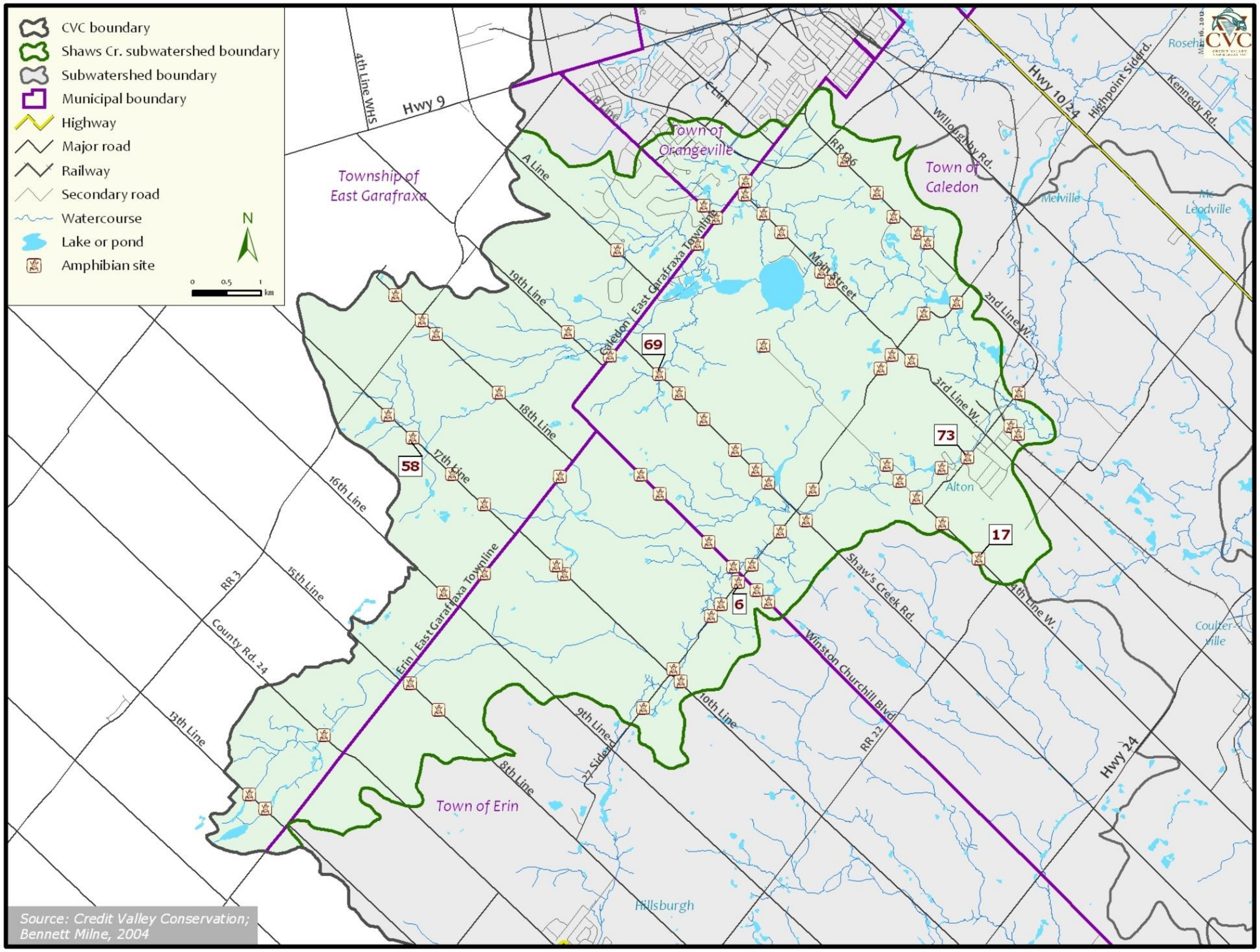


Figure 4.4.5 Amphibian Road Call Count Sites

4.4.7.2 Birds

The purpose of the breeding bird survey for the Shaws Creek Subwatershed was to document the presence and abundance of bird species in different vegetation communities (**Figure 4.4.6**). Particular attention was paid to species that were designated as "Species of Conservation Concern" by Credit Valley Conservation. Breeding bird surveys provide an inventory of the diversity of the species in the subwatershed as well as the importance of the region with respect to the distribution of the species that are considered rare, sensitive to disturbance, or are experiencing population declines throughout southern Ontario (Milne et al., 2002). The results of the breeding bird survey have been summarized from Milne and Bennett (2006).

Bird species presence and abundance were obtained from point count surveys of avian populations at 28 sites (properties) within 11 ELC community series types or ecosites. At these sites, 38 transects were established within designated habitats. In most cases each transect included four point counts, the exceptions occurring in cases where the survey line traversed several community types. The distribution of transects between community types was as follows: coniferous forest (1 transect), mixed forest (1), deciduous forest (6), coniferous plantation (3), marsh (4), coniferous swamp (4), deciduous swamp (3), mixed swamp (5), thicket swamp (4), cultural savanna (3), and cultural meadow (4).

84 species were observed within the community types and another 11 species such as common loon (*Gavia immer*) and turkey vulture (*Cathartes aura*), were observed in the subwatershed but not within a surveyed community type. The most abundant species included American robin (*Turdus migratorius*), American goldfinch (*Carduelis tristis*), American crow (*Corvus brachyrhynchos*), song sparrow (*Melospiza melodia*), and black-capped chickadee (*Poecile atricapillus*). These are generalist species that were found at almost all survey sites.

The high diversity of species (84) reflects the variation in community types sampled. The highest number of species within one community type was 44. This number was encountered in both Thicket Swamp and Mixed Swamp habitats. Most of the other community types were in the range of 30-40 species, with the human-influenced sites at the lower end including Cultural Savannah, Cultural Meadow and Plantations. The lowest richness scores were Coniferous and Mixed Forest but this may be the result of only having one representative sample of each type (**Table 4.4.8**)

Table 4.4.8 Breeding Bird Abundance in the Shaws Creek Subwatershed based on Forest Bird Monitoring Surveys conducted by Milne and Bennett (2006)

Community Type	Number of Surveys	Species Counts
Mixed Swamp	5	44
Thicket Swamp	4	44
Marsh	4	39
Coniferous Swamp	4	37
Deciduous Forest	6	35
Deciduous Swamp	3	32
Cultural Meadow	4	31
Cultural Savannah	3	31
Coniferous Plantation	3	30
Coniferous Forest	1	20
Mixed Forest	1	14

The results of the breeding bird surveys strengthen the findings of the amphibian roadside count surveys. Certain small wetland community types can be important sites for biodiversity. With respect to avian populations, it may be less important to maintain small pockets of swamp, and more important to create and/or maintain complexes of marsh, thicket and swamp to ensure species diversity.

Species abundance and diversity in deciduous forests were also relatively high but this likely relates to the position of these forests within a greater complex of forest and wetland communities. At CVC's Wilcox Property, for example, the vegetation cover is a mixture of deciduous forest, coniferous swamp, thicket swamp and cultural meadow. A number of species will move throughout these forested areas although their principal habitat is within the wetlands. Again this emphasizes the importance of maintaining landscape complexes not just specific habitats.

Species of Conservation Concern

Species of Conservation Concern (SCC) are species that Credit Valley Conservation has designated based on a set of criteria that included rarity, habitat specialists, and declining populations in Southern Ontario. Credit Valley Conservation has designated 110 avian “Species of Conservation Concern”. In total, 45 of these species were observed during the two years that breeding bird surveys were conducted for the Shaws Creek Subwatershed study.

Several species of conservation concern were found in relatively high numbers at a range of sites. These included common grackle (*Quiscalus quiscula*), white-throated sparrow (*Zonotrichia albicollis*) and ovenbird (*Seiurus aurocapillus*) that were observed in more than half of the survey plots. Many warbler species were also observed at numerous locations. As examples, Nashville warblers (*Vermivora ruficapilla*), black-throated green warblers (*Dendrioca virens*), and the black-and-white warblers (*Mniotilta varia*) were recorded in approximately half of the sites. About one-third of the SCC were recorded only once or twice.

When the SCC are considered with respect to the ELC community types there are several apparent patterns. The greatest number of species of conservation concern (16) was observed within a coniferous swamp. In fact, in all cases except one, the sites with greater than 10 species/site were in coniferous, mixed or thicket swamps. The survey sites for these records were situated in large tracts of relatively undisturbed habitat cover. The sites with the highest number of SCC species were both CVC properties (Caledon Lake Forest and Wilcox Properties). In comparison sites with less than 5 species were found across a variety of community types but were typically in small patches in highly fragmented landscapes. In particular, these sites included small cultural meadows and isolated upland deciduous woodlots.

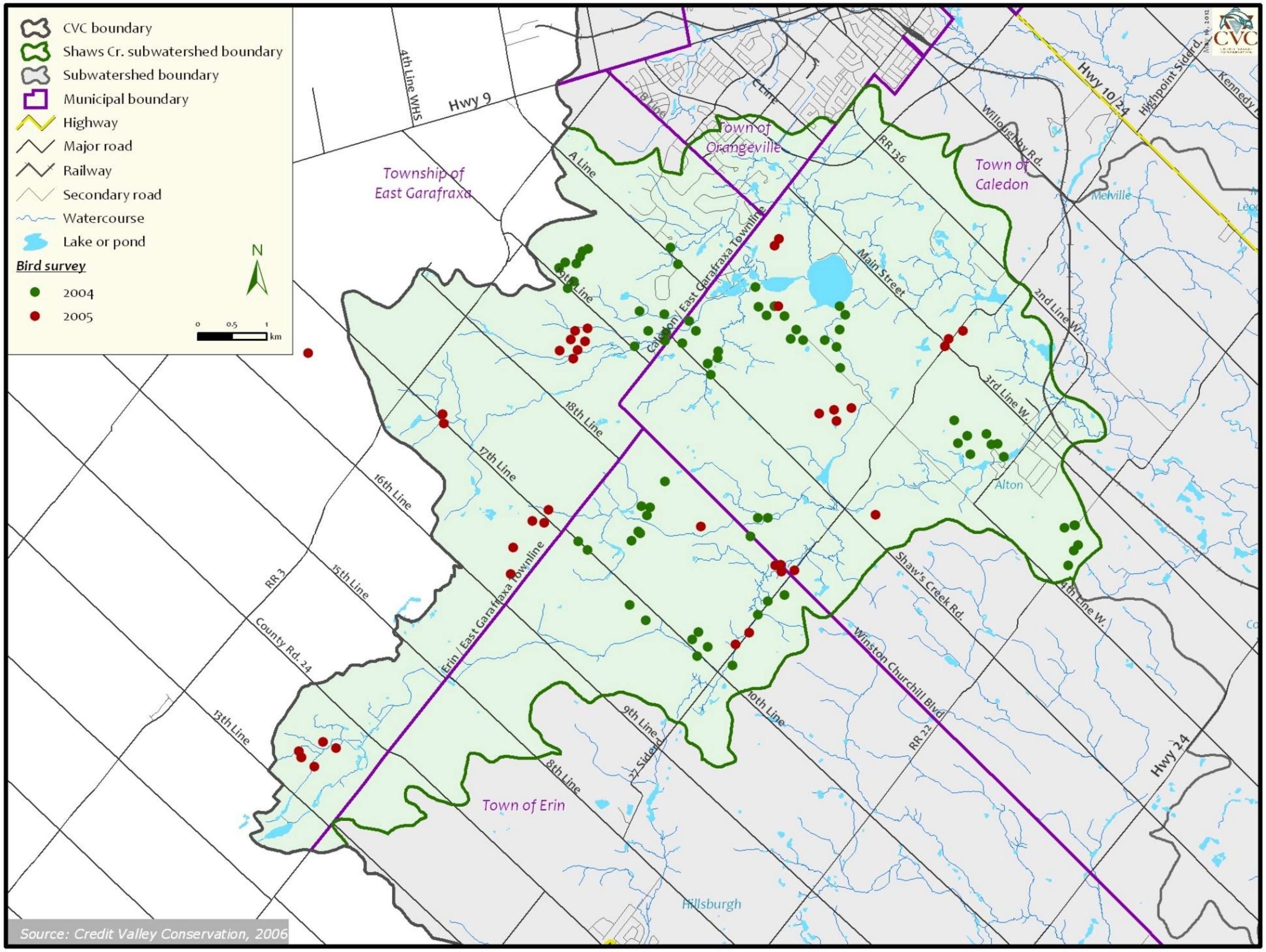


Figure 4.4.6 Breeding Bird Survey Sites

4.4.7.3 Mammals

The presence of a balanced, functioning mammal fauna in an area is an indicator of the general health of that environment. Unfortunately, a recent inventory of the mammal species in the Shaws Creek Subwatershed has not been conducted. Instead, the *Atlas of the Mammals of Ontario* was used to provide baseline data on which species have been documented to occur in the subwatershed (**Table 4.4.9**).

Table 4.4.9 Mammal Species of the Shaws Creek Subwatershed based on the Atlas of the Mammals of Ontario (1994)

Common Name	Scientific Name	Last Documented Occurrence (1900-1969)	Last Documented Occurrence (1970-1993)
Smokey shrew	*Sorex fumeus*	X	
Common shrew	*Sorex cinereus*		X
Northern short-tailed shrew	*Blarina brevicauda*	X	
Big brown bat	*Eptesicus fuscus*		X
Hoary bat	*Lasiurus cinereus*		X
Eastern cottontail	*Sylvilagus floridanus*		
Snowshoe hare	*Lepus americanus*		X
European hare	*Lepus europaeus*		X
Eastern chipmunk	*Tamias striatus*		X
Woodchuck	*Marmota monax*		X
Grey squirrel	*Sciurus carolinensis*		X
Red squirrel	*Tamiasciurus hudsonicus*		X
Northern flying squirrel	*Glaucomys sabrinus*	X	
Beaver	*Castor Canadensis*		X
Meadow vole	*Microtus pennsylvanicus*	X	
Muskrat	*Ondatra zibethicus*		X
Norway rat	*Rattus norvegicus*		X
Porcupine	*Erethizon dorsatum*		X
Coyote	*Canis latrans*		X
Red fox	*Vulpes vulpes*		X
Raccoon	*Procyon lotor*		X
Mink	*Mustela vison*		X
Striped skunk	*Mephitis mephitis*		X
White-tailed deer	*Odocoileus virginianus*		X

4.4.8 Terrestrial Corridors

4.4.8.1 Provincial Scale Corridors

Provincial Corridors are based on extensive physiographic features that have a continuous physical presence, link major ecosystems together, and facilitate the movement of plants and wildlife along migration routes across at a provincial scale. These physiographic features span watersheds and are vital to the maintenance of these watersheds and the health of their ecosystems. Examples of these corridors include the Niagara Escarpment, the Oak Ridges Moraine, the Paris Moraine and the valley related to the main branch of the Credit River. These corridor features support many of the last large natural areas in the settled landscape of southern Ontario.

Based on analysis of Ecological Land Classification, Existing Land Use Mapping and Physiographic Mapping, there do not appear to be any provincial scale corridors in the Shaws Creek Subwatershed. There are however, several corridors that connect the Credit River Watershed with adjacent watersheds, as well as with known provincial scale corridor systems. These watershed scale corridors are discussed below.

4.4.8.2 Watershed Scale Corridors

Watershed Corridors are based on the valleys of the major tributaries of the Credit River and glacial spillways (remnant valleys from glacial rivers). These corridors act to link subwatershed to subwatershed (Black Creek to Silver Creek), and watershed to watershed (e.g. Credit River to the Grand River, Nottawasaga River, or the Humber River). Watershed corridors are essential to the movement of wildlife and the migration of fish across or through the watershed. In many cases these large valleys also act as core habitat for wildlife in settled areas (e.g. Hungry Hollow in Georgetown).

Mapping of Watershed Corridors (**Figure 4.4.7**) is dependant on the Ecological Land Classification, Existing Land Use mapping and the Crest of Slope mapping.

Orangeville Moraine & Spillway

The Orangeville Moraine Corridor links the Credit Watershed with the Grand River Watershed in the west. It also links the Shaws Creek Subwatershed in the north with the West Credit Subwatershed to the south. In the Shaws Creek Subwatershed, the Orangeville Moraine is represented by a three kame moraines, which are positioned to the east, southwest, and northwest of Caledon Lake. These kame moraines create a barrier that breaks the continuity of an otherwise broad channel (spillway) that consists of gravel and sand deposits and extends from Orangeville to Hillsburgh (Chapman and Putnam, 1984). Vegetation communities that have established themselves in the spillway are characteristically wet, with swamp communities dominating. In comparison, the dry terraces have been cleared and cultivated, and are currently dominated by agricultural and cultural (old field) communities (**Figure 4.4.1**). The complex wetland communities that have formed in the spillway support a diversity of habitat types and maintain large core areas that sustain numerous plant and wildlife species.

Shaws Creek Corridor

This Shaws Creek Corridor is located at the southern edge of the Shaws Creek Subwatershed and extends between 9th Line in Erin and 3rd Line in Caledon, where it joins with the Credit River (and the Credit River at Alton ESA). The Shaws Creek Corridor was formed as a result of a glacial spillway that formed between the southern edge of the Orangeville Moraine and the northern edge of the drumlinized till plains, which are a part of the Guelph drumlin field. A well-defined valley thus shapes the Shaws Creek Corridor.

The slopes of the valley are dominated by coniferous forest and successional woodland communities with dominant species such as white cedar (*Thuja occidentalis*), white birch (*Betula papyrifera*), American elm (*Ulmus americanus*) and trembling aspen (*Populus tremuloides*). Other trees species abundantly found along the upland portions of the corridor include sugar maple (*Acer saccharum*), black cherry (*Prunus serotina*), tamarack (*Larix laricina*), balsam fir (*Abies balsamea*), and eastern hemlock (*Tsuga Canadensis*). The valley floor contains the Shaws Creek itself, and sustains habitat types including shallow marshes, thicket swamps, coniferous swamps, and cultural (successional) woodlands. The Shaws Creek Corridor enables an east-west migration of fish and wildlife along the southern edge of the Shaws Creek Subwatershed and links this area with the larger north-south Credit River Corridor system.

Caledon Lake to Grand River Corridor (Mud Lake & Reading Swamp)

The Caledon Lake Corridor links the Caledon Lake Wetland Complex with both the Mud Lake Swamp and Reading Swamp Wetland Complexes. Once again, this corridor predominantly consists of a series of wetland communities that developed at the base of a glacial spillway. In addition, adjacent upland communities (including deciduous, mixed and coniferous forest) provide “stepping stone” habitats that can assist species migrating from one watershed to another. Many of the wetland communities are found along the existing tributaries of subcatchment 17.01 (**Figure 2.1.2**). While sections of the corridor are well vegetated, other sections consist of thin riparian strips that are surrounded by agricultural and old field communities. It is recommended that stewardship efforts target improving the connectivity of this corridor (by creating additional habitat blocks along the Caledon Lake-Grand River Corridor and/or by increasing the vegetation along the riparian strips).

Caledon Lake to the Credit River at Alton Corridor

Located in the portion of the Shaws Creek Subwatershed, the Caledon Lake to Credit River at Alton Corridor links two provincially significant wetland complexes and two Environmentally Significant Areas. A well-defined valley runs through this area, which supports a number of different ecological communities. The valley slopes support a variety of habitats including cultural savannah, and deciduous, mixed and coniferous forest, while the valley floor is dominated by habitats including coniferous and thicket swamp, meadow marsh and shallow marsh.

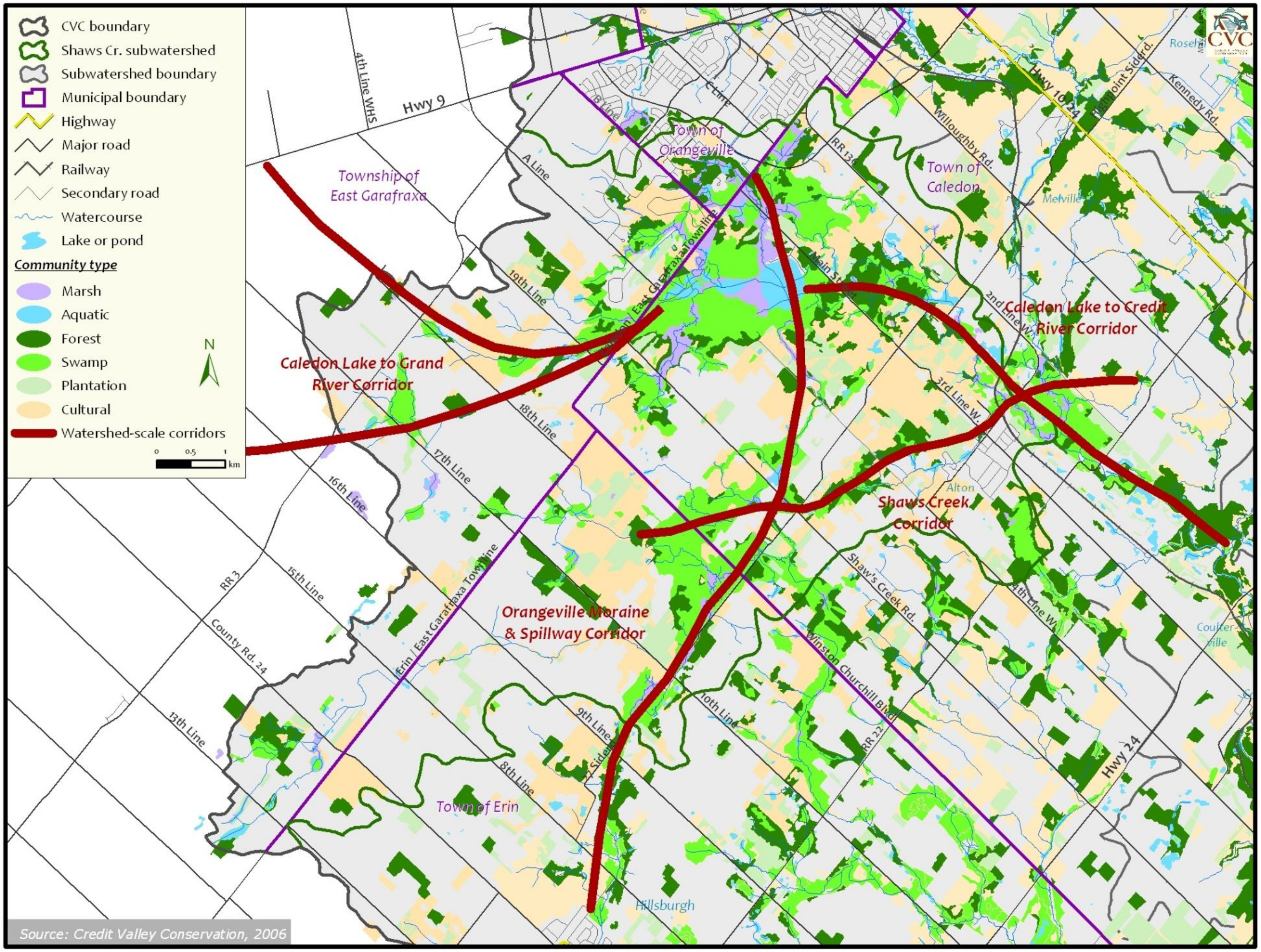


Figure 4.4.7 Watershed Scale Corridors

4.4.8.3 Subwatershed Scale Corridors

Subwatershed corridors aid the movement of wildlife and the dispersal of flora throughout a subwatershed. Watercourses and their associated valleys are the foundation of the subwatershed corridor system. These corridors provide cover for species, such as reptiles and amphibians, when they are moving from one habitat to another. In the settled and agricultural landscape of the Credit Watershed these watercourse-based corridors can sometimes be the only natural feature left to link natural areas to one another.

Mapping of subwatershed corridors is dependant on the mapping of watercourses, lakes, ponds, crest of slope, Ecological Land Classification and existing land use. Subwatershed Corridors are generated through GIS by buffering the watercourses, lakes and ponds of the subwatershed. These buffers are then merged with the boundaries of the associated valleys to define the subwatershed corridor system. In the final step the corridors are assessed through GIS to determine their degree of naturalness and the relative importance to connecting habitat to one another.

Subwatershed Corridor Impact Assessment

One of the measures used to assess subwatershed scale corridor quality is to evaluate the level of impact that the land uses contained within the riparian corridor might have on the movement of plants and wildlife. Each land use type has been assigned a rank and a score based on the level of disturbance associated with each of the natural vegetation patterns and the ability of wildlife to utilize the corridor.

The vegetation along most of the corridors in the township of Caledon (subcatchments 17-01, 17-02, 17-03, 17-06, 17-09, 17-10, and 17-11, see **Figure 2.1.2**) remains intact. The riparian areas in the northeastern portion of the Township of East Garafraxa (subcatchment 17-01) are similarly well vegetated. Abundant natural cover in the corridor system can be attributed to the large protected areas in the watershed, and particularly wetland areas that are considered unsuitable for farming practices.

Conversely, most of the southwestern portion of the watershed, including tributaries in subcatchments 17-04 and 17-05, is moderately impacted by adjacent land uses. These impacts are primarily related to intensive and non-intensive agricultural practices. Riparian vegetation in this area has been confined to relatively narrow buffer strips, which means that wildlife have few opportunities to move along this corridor without being subjected to disturbance and predation. In order to improve the functional connectivity of these areas, it is recommended that stewardship efforts focus not only on enhancing the riparian vegetation along these tributaries, but on creating additional habitat blocks, particularly in subcatchment 17-04.

For further details, refer to Figure 1 in Appendix B.

Subwatershed Corridor Connectivity

Part of the assessment of corridor quality is based on the significance of the natural areas that each reach of the watercourse-based corridors connects. Due to the abundance of significant natural areas in the Shaws Creek Subwatershed, most of the corridors connect to High Priority Natural Areas.

For further details, refer to Figure 2 in Appendix B.

Subwatershed Corridor Overall Significance

The Subwatershed Corridor Impact and Connectivity Assessments have been combined to produce an overall assessment of corridor significance (**Figure 4.4.8**). Most of the subwatershed scale corridors in the Shaws Creek Subwatershed have been classified as highly significant. The reasons for the high degree of significance are largely associated with their value in providing connections between “high priority” natural areas in the subwatershed.

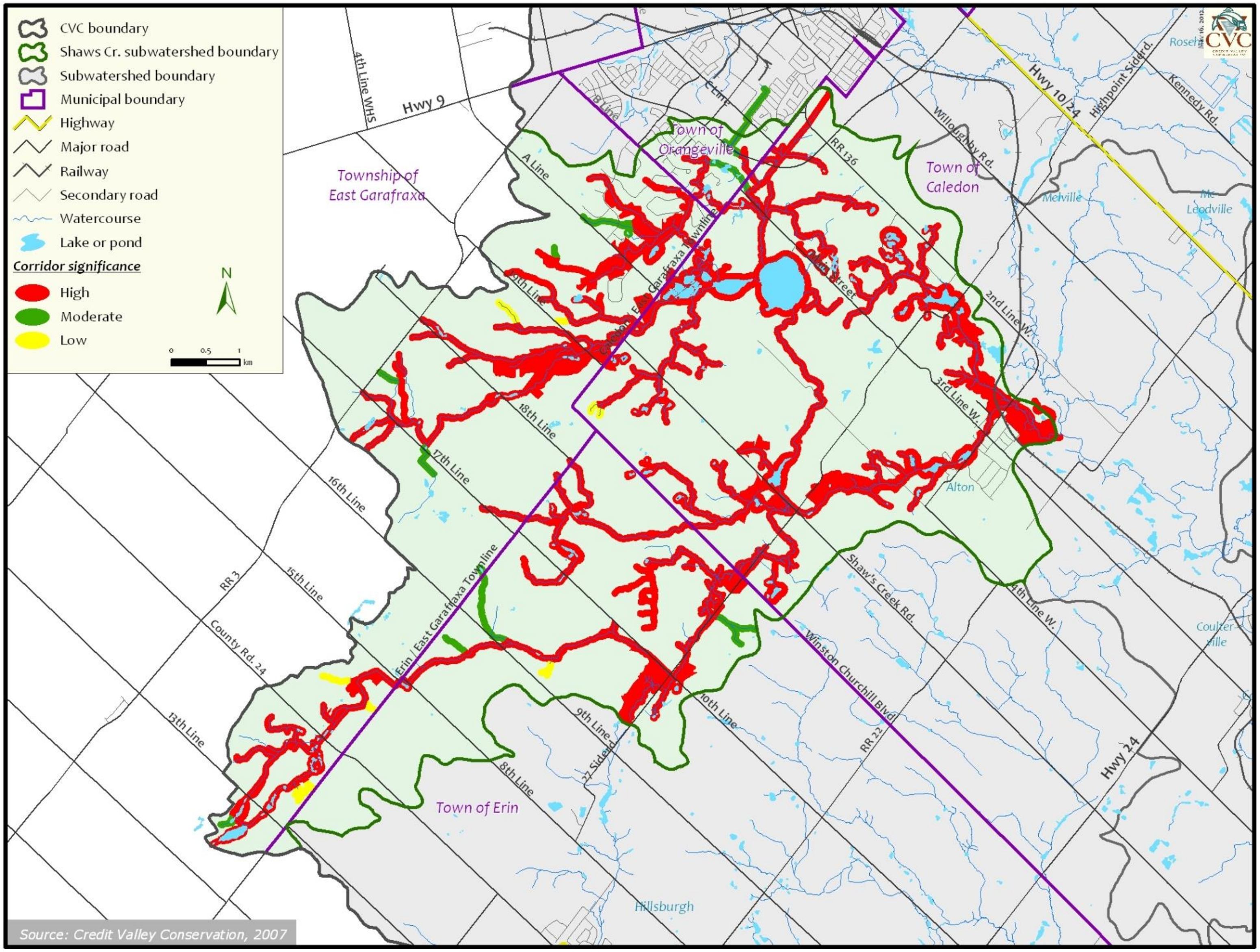


Figure 4.4.8 Subwatershed Scale Corridor Overall Significance

4.4.9 Results of Landscape Scale Community/Patch Analysis

What follows, is a brief summary of the criteria that have been used to evaluate the relative importance or significance of individual mapped natural area patches, or blocks of patches at a landscape or subwatershed scale and the resulting findings. As recommended by the Province (Natural Heritage Training Manual for Policy 2.3 of the Provincial Policy Statement, MNR, 1997), the majority of this analysis relies on the "Minimum Standards" evaluation method or as Smith and Theberge (1987) referred to as the "Disjunctive Method". This method ranks candidate sites based on whether they meet a minimum standard for at least one criterion, regardless of whether they meet minimum standards for any of the other criteria. This approach is considered more ecologically and mathematically valid than other approaches (such as weighting and ranking) when comparing measures at different scales and/or of different ecological criteria (MNR, 1997). In our approach, we rank each isolated patch or cluster of patches, as appropriate, based on each of the individual measures. "Special Features" (such as old forest) are also considered when evaluating the natural areas.

In order to facilitate the integration of this analysis of the terrestrial communities with the various component studies for the characterization of the subwatershed, a summary map identifies the overall significance of the natural areas (**Figure 4.4.9**). Table 4.4.11 is a summary of the criteria and the findings for the Shaws Creek Subwatershed. For a more detailed explanation of each criterion (see Appendix B).

Based on the analysis of the terrestrial system of the Shaw Creek Subwatershed, virtually all of the medium and large natural areas of the subwatershed have been designated as “high priority” (**Table 4.4.10**). Although the analysis only requires a candidate site to meet one criterion in order to be included, more than 80% of the subwatershed’s natural areas met several criteria. As an example, much of the land that has been designated as part of the regionally significant Alton Swamp Complex ESA has also been provincially designated as part of the Alton Branch Swamp ANSI, and the Alton-Hillsburgh PSW. These designations in turn often rely upon factors such as high community and species diversity, and result in the protection of large areas of land, including core habitats. The majority of the moderate priority areas are coniferous plantation communities that are situated next to high priority areas, thereby acting to buffer and enhance the quality of the high priority areas. Low priority areas include an isolated fragment of deciduous forest, and several cultural communities that have limited connections to large natural areas.

Table 4.4.10 Summary of Priority Areas for the Shaws Creek Subwatershed

Natural Area Priority	Area (ha)	Percentage of Subwatershed	Percentage of Natural Area
High	2760.63	39.05	80.02
Medium	361.61	5.11	10.48
Low	327.57	4.63	9.50
Total	3449.81	48.80	100.00

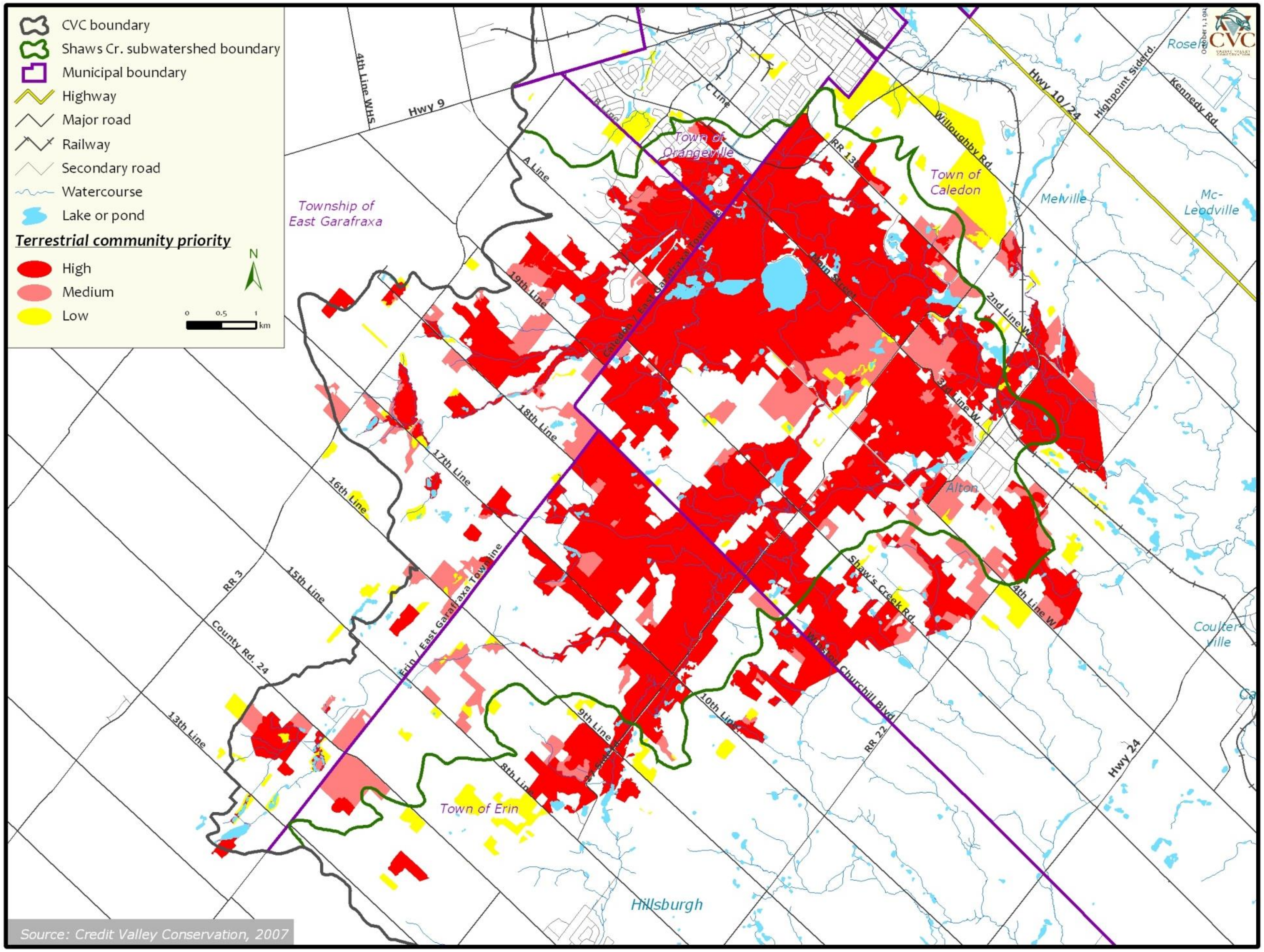


Figure 4.4.9 Overall Significance of the Natural Areas

Table 4.4.11 Summary of Landscape Scale Terrestrial Findings for Natural Communities

Criterion	Description	Results
Community Diversity or Complexity (Figure 3 in Appendix B)	Number of different communities compared to the number of polygons within a given natural area (i.e. patch)	Most diverse natural areas are located in the vicinity of the Caledon Lake and Alton Swamp Complex Environmentally Significant Areas. The least diverse natural areas are to the west end of the subwatershed (west and southwest of Winston Churchill Blvd) where intensive agricultural communities are acting to fragment natural communities on the landscape.
Relative Community Size (Figure 4 in Appendix B)	Significant communities based on the relationship between their size and frequency of occurrence	Caledon Lake ESA (Coniferous, Deciduous, Mixed and Thicket Swamp and Marsh Communities), Orpen Lake Estates (Deciduous Forest and Mixed Swamp), south of the Town of Orangeville (Coniferous Forest), south of Highpoint Sideroad & east of Shaws Creek Road (Coniferous Forest), in the Alton Branch Swamp ANSI (Coniferous and Mixed Swamp, Mixed Forest), along the Erin/East Garafraxa Townline, west of 18th Line (Thicket and Mixed Swamp), between 16th and 18th Lines, south of RR3 (Deciduous, Mixed and Thicket Swamp, Marsh), and between 12th Line and County Rd 24. north of Erin/East Garafraxa Townline (Deciduous and Thicket Swamp, Marsh)
Interior Habitat or Core Area (Figure 5 in Appendix B)	Area surrounded by a buffer of 100 (core) and 200 meters (deep core)	There are 63 patches of core habitat (100m). The total area of 100m core is 1077.85 ha. The largest 100m core patch in the Shaws Creek subwatershed is 115.19 ha, and the smallest is 3.11 ha. Both of these patches are located within the Alton Branch Swamp Area of Natural and Scientific Interest. There are 2 patches of deep core habitat (200m). The total area of deep core is 55.519ha. Both of these patches are found in coniferous swamp habitats. One is in the Caledon Lake Forest ANSI, and the other is in the Alton Branch Swamp ANSI.
Special Feature (Figure 4.4.2)	Provincially Significant Wetlands	2 PSWs: Alton-Hillsburgh Wetland Complex and Caledon Lake Wetland Complex.
Special Feature	Species at Risk	1 species located primarily within the Caledon Lake Wetland Complex.
Special Feature	Escarpment Natural Area	Not applicable.
Special Feature (Figure 4.4.3)	Areas of Natural and Scientific Interest (provincial life science only)	2 Life Science ANSIs: Alton Branch Swamp and Caledon Lake Forests.
Special Feature (Figure 4.4.4)	Communities with 3 or more Rare Species (of which there are 10 or less occurrences in the watershed)	1 community with 10 CVC/Peel rare species, 1 community with 9 CVC/Peel rare species, 7 communities with 8 CVC/Peel rare species, 4 communities with 7 CVC/Peel rare species, 7 communities with 6 CVC/Peel rare species, 4 communities with 5 CVC/Peel rare species, 13 communities with 4 CVC/Peel rare species, and 20 communities with 3 CVC/Peel rare species.
Special Feature (Figure 4.4.4)	Rare Communities (5% or less in area of the natural communities identified)	Rare Communities: Bog (Trace), Fen (Trace), Aquatic (2.2%) and Mixed Forest (3.6%)
Special Feature (Figure 4.4.3)	Environmentally Significant Areas	3 ESAs – Alton Swamp, Caledon Lake and Credit River at Alton
Special Feature (Figure 4.4.4)	Forests older than 125 years	According to Forest Resource Inventory mapping, 1 mixed forest and 1 deciduous forest have trees over 125 years old. The deciduous forest was visited during the 2004 field season and was noted to contain physical characteristics that indicate old growth.

4.4.10 Terrestrial Characterization

The ecology of an area is determined by numerous factors; these factors include the physical landscape (abiotic conditions), the species composition of the area (and associated interactions), any disturbances that influence species, populations, communities or ecosystem dynamics (can be natural or anthropogenic in origin) and the time that these processes have had to interact with each other. All of these factors have shaped the ecology of the Shaws Creek Subwatershed in various ways, each of which will be discussed below.

Physiography
The physiography of a landscape dictates elevation, drainage patterns, soil texture and chemistry, and influences local climate, hydrology, productivity and the movement of materials across the landscape (Lee, et al., 2001). Physiographic features will therefore have an important influence on the ecological patterns in the Shaws Creek Subwatershed.

Extending from Orangeville to Hillsburgh, the Hillsburgh Sandhills are a legacy of the glaciers that once covered southern Ontario. This land was the first to appear when the glaciers melted, and contains some of the highest elevations of land in the Credit River Watershed (between 425 and 488 meters in height). The steepest slopes in the area run along the sides of the spillway north of Hillsburgh, between and around the Orangeville Moraine, though knobby hills are present throughout much of the watershed. Soils in this area contain a high proportion of fine sands, which is not typically associated with kame moraines (Chapman & Putnam, 1984). These fine sandy-loam soils are well suited for crop production, except on steep slopes, where cattle production may occur instead.

A notable exception to the above text occurs three miles south of Orangeville, where Caledon Lake sits in the bottom of the glacial spillway. Caledon Lake is a shallow, marl-floored lake that appears to have been created because of the mass of sandy drift that was dropped in the spillway just south of it (Chapman & Putnam, 1984). Poor drainage patterns in the area have permitted the establishment of many wetland communities, which support a number of regionally and locally rare species.

Pre-settlement Vegetation Communities
The townships of the Credit River Watershed were surveyed between 1806 and 1822. From the surveyors' notes, it is clear that prior to European settlement, the forests in the Credit River Watershed were relatively unbroken, with the exception of the occasional beaver meadow, or windfall event. Based on these survey notes, Credit Valley Conservation and the University of Guelph were able to reconstruct a map of the pre-settlement vegetation of the Credit River watershed (Mercey and Puddister, 2002).

In the Shaws Creek Subwatershed, upland species and communities established themselves on the lobes of the Orangeville Moraine. Most of these vegetation communities (> 85%) consisted of sugar maple-dominated forests, though poplar-birch mixed forests were also present. Wetland species and communities established themselves in the glacial spillway that was formed around the lobes of the Orangeville Moraine. The dominant lowland vegetation communities were coniferous and mixed swamps, though their historic species composition is not known.

Current Settlement Patterns (Anthropogenic Disturbances)
Today, the dominant land use in the Shaws Creek Subwatershed is agriculture (43.56%), most of which is considered to be of an intensive nature (37.69%). In addition, a small proportion of the watershed is used for rural and urban development (5.29%). Based on the Ecological Land Classification and Existing Land Use Mapping, 74.18% of the Shaws Creek Subwatershed is currently, or has been historically used by humans. As a result, less than 26% of the subwatershed can be considered to exist in a relatively natural state (forest or wetland), though field investigations indicated that several communities have been affected by human disturbance at some level (e.g. selective logging, dumping and earth displacement practices). For the most part, the natural areas of the Shaws Creek Subwatershed were not cleared because they exhibited poor drainage patterns (i.e. wetland habitats) or were in areas with steep slopes. These areas are now considered to be among the most significant in the Credit River Watershed.

4.5 STREAM MORPHOLOGY

Subwatershed 17, Shaws Creek, is dominated by headwater streams. Headwater streams are defined as first-and second–order streams and are typically short and drain relatively small areas. They tend to be production zones, feeding sediment to the downstream system. Flow within these channels can be perennial or ephemeral and they have narrow or sometimes unconfined channels (Leopold et al., 1964). Low order streams determine the quality and quantity of water in higher order streams (Burt, 1992) and as much as 70% of water in large rivers is derived from first- to third-order streams (Vought et al., 1995). These channels constitute a significant portion of total stream length within watersheds (Sidle et al., 2000) and provide habitat for unique and diverse assemblages of aquatic animals (Dietrich and Anderson, 1995). Therefore, a stream corridor management plan for this unique watershed should be cognizant of the dominant proportion of headwater streams. Protection of headwater streams is an integral aspect of subwatershed planning and management.

The fluvial geomorphology of Subwatershed 17 is complicated and diverse. This is expected given the topography and underlying geology of the subwatershed. The underlying geology influences the rate of channel change (e.g. migration), the sediment input (i.e. amount and type), and channel geometry. The surficial geology in the area upstream of and around Caledon Lake is comprised of bog deposits (peat, muck and marl). Downstream of the lake, Shaws Creek flows through glacio-fluvial outwash (sand and gravel). As Shaws Creek begins to flow in an easterly direction, it reworks its own alluvium. Near the confluence with the Credit River, bog deposits again dominate (Cowan and Sharpe, 1976). The variation in channel substrate observed in previous studies attests to the complicated surficial geology. The physiography also dominates the type of channel, such as, near the confluence with the Credit River, where bog deposits have developed due to the low channel gradients and a depositional environment.

From a review of background materials (i.e., CVC, 1986; 1987) it is evident that there has been little modification to land use other than shifts in agricultural and aggregate activity over the past 50 years. These trends are unlike the more southern ranges of the Credit River watershed that have been modified by urbanization. Therefore, observed changes to channel form and function with respect to Subwatershed 17 are likely explained by agricultural and aggregate activities. Historical observations of past land use is provided in CVC's 1987 Shaws Creek Assessment. In 1987, human impact on land in the Shaws Creek catchment was generally low: about 61% of land remained primarily in its natural state. The remainder was used for residential developments (23%), recreation (12%), pasture (7% - above pond at Millcroft Inn Dam) and industrial developments (1% - mostly confined to Alton) (CVC, 1987). Although land cover has only changed slightly over the last 50 years, the channels are likely still adjusting to previous changes in land cover, and associated impacts on the flow and sediment regime, such as the shift from forest cover to farming.

Characterizing channel form and function is important in subwatershed planning as it allows stream corridor management plans to be developed that consider natural processes within the subwatershed. Stream corridors also provide important natural linkages within the subwatershed. This is particularly important in headwater systems. Before management plans can be developed there needs to be an understanding of historic context, drainage pattern and density, reach characteristics, existing conditions and issues with respect to erosion and sedimentation. These topics are discussed in the following sections.

4.5.1 Stream Morphology

A geomorphic assessment characterizing the form and function of channels within Subwatershed 17 was conducted and included both desktop and field components. It endeavored to assess the subwatershed at a series of scales both temporally and spatially. Observations of changes over time were completed through a historical analysis using aerial photographs. Field observations, which highlighted systematic adjustments also provide a view of past adjustment and future trends. A range of spatial scales was examined, moving from a basin to reach scale, to examination of individual cross sections. In headwater systems the basin scale assessment is of particular importance given the cumulative effects of the numerous low order streams.

In context of the provincial framework for stream corridor management, this section provides data needed to identify issues, explore past and future trends, channel response, present subwatershed function and forecast the ultimate subwatershed and stream corridor configuration. This provides the information needed to evaluate the feasibility of a given solution and allows alternatives to be defined and assessed. This follows the background report that was produced previously.

The stream morphology was characterized for the:

- Identification of existing and potential constraints and opportunities related to channel form and function.
- Identification of systematic adjustments to help identify instability related to land use impacts. Establishment of these baseline conditions is essential for future monitoring efforts that assess the effectiveness of prescriptions implemented as a result of this subwatershed study.
- Identification of any links in physical processes that are responsible for existing channel form, to enable identification of links with other subwatershed elements (e.g. riparian corridor, groundwater, fisheries, etc.). It is also important to identify the link between this subwatershed and the Credit River watershed as a whole, particularly given the importance of the headwaters to the health and stability of the entire system.

4.5.2 Historical Assessment

Historical analyses provided insight into the degree of natural fluvial activity and human impacts, such as channel straightening or changes in land use. A historical assessment of the reaches within Subwatershed 17 was conducted to document historical changes in land use and channel planform.

Existing and historic land cover and characteristics of the subwatershed were examined from aerial photographs. Black and white aerial photographs from 1944, 1978 and 2002, infrared photographs from 1997 and colour digital aerial photographs from 2004 were used to examine historical channel patterns and changes in land use. Unfortunately due to the scale of the 1997 aerial photographs and limited size of the channel system, it was difficult to ascertain additional information on the channel corridors.

From the historical assessment it is evident that there have been minimal changes in land use over the last 60 years. Agricultural activity and impacts to watercourses (i.e., channel straightening and modifications) occurred prior to 1944. There is evidence of channel straightening along a number of swales, and 1st and 2nd order streams causing decreased sinuosity. This has also likely lead to an increase in stream gradient and potentially greater sediment supply related to the channel's attempt to re-establish a natural planform and geometry. Given agricultural production, there has likely been increased discharge and peak flows compared to pre-settlement conditions. Overall, subwatershed 17 is a relatively stable system with localized instabilities noted mainly within agricultural drains and adjacent to road crossings.

The town of Alton underwent growth between 1954 and 1978 but development was minimal between 1978 and 2002. Between 1978 and 2002, forested lands surrounding the town of Alton had diminished and were replaced with agricultural and residential land use. Also, two quarries were present in 2002 that were not visible in the 1978 aerial photographs.

Overall, the subwatershed has been modified primarily through agricultural land use prior to 1944. The west and southwestern sides of the subwatershed have generally maintained the same degree of agricultural intensification over the past 60 years. In the central and eastern portions of the subwatershed sections of agricultural land have reverted to scrub and wetland forest. For example, a comparison of 1944 and 2002 air photos shows that there have been slight increases in scrub and wetland forest adjacent to Caledon Lake. Overall, changes have increased parceling of agricultural areas, resulting in an increase of forest cover from expanding hedgerows and naturalized property lines.

With respect to dams, ponds and wetlands there have been limited changes to these features over the past 60 years. The majority of dams and ponds were created for water control or for livestock prior to 1944. Special attention was provided to Caledon Lake in the historical assessment, there was no noticeable change in the shoreline configuration over the 50-year record examined. Although channel alignment has changed the overall channel form of wetland channels has been consistent over the past 60 years. Caledon Lake has seen little change in the development of cottage properties since 1944. Sedimentation along the southeastern shoreline fluctuated between 1944, 1978 and 2002 most likely due to water level changes. Water level fluctuation is a common characteristic of kettle-lake formations due to the high percentage of peat material.

The most recent land use change within Subwatershed 17 has been the encroachment of development. Development from the town of Orangeville is moving in a southwest direction into the northern extent of Subwatershed 17. Development may impact forested areas, in turn, influencing the structure and function of receiving watercourses. Generally, through subwatershed studies the main emphasis is urbanization, and it should be recognized that agricultural practices also impact watercourses through alteration of hydrology and sediment inputs. Given the limited existing urbanization, agricultural impacts are likely more substantial within this watershed.

4.5.3 Basin Relations

This study has delineated ten subcatchments within Subwatershed 17, some of which have inputs from other subcatchments. From a geomorphic perspective, this complicates analyses and overall data interpretation. Therefore, subcatchments were re-organized where necessary to provide a delineation that is more consistent with methods used for geomorphic assessments (**Appendix C**). The six subcatchments used in analyses were isolated from adjacent subcatchments, whereas multiple inputs and outputs occurred along the main branch of Shaws Creek. Therefore, CVC subcatchments in the southeast portion of the watershed were not included in basin calculations. For basin-scale calculations, larger catchments provide a more stable and accurate interpretation compared to basins with few stream segments. Basin relations were calculated for each geomorphic subcatchment (e.g., GM1, GM2, etc.,) and summed to provide overall descriptive measures for Subwatershed 17 (Figure 4.5.1).

Specifically, the basin level parameters measured for the subwatershed were drainage density and bifurcation ratio. Drainage density is a measure of total stream length divided by the area of the catchment basin. The overall drainage density for Subwatershed 17 is 1.84. This value is comparable to values reported for other southern Ontario watersheds. For example, drainage densities of 2.08 and 1.5 were reported for Carruthers Creek and Duffins Creek (TRCA, 2000a; 2000b). The drainage density for Subwatershed 17 is indicative of the high number of low order channels and the underlying geology.

Bifurcation ratio is the total length of one stream order divided by the total length of the next highest stream order. In other words, bifurcation ratio is the proportion of small order streams to large order streams. The bifurcation ratio for Subwatershed 17 is 1.89. This value is lower than those reported for Carruthers and Duffins Creek (3.2 and 2.2) (TRCA, 2000a; 2000b). This low value is indicative of numerous tributaries draining the subwatershed that are well branched and distributed. Based on values calculated for Subwatershed 17, an event hydrograph (e.g., plot showing the magnitude of flows over time) would likely produce a very broad, gradual shape, with little peakedness during a storm event because water would be gradually delivered from the numerous tributaries to the main channel.

Swales or zero (0) order streams are generally defined as channels with no defined bed or banks. These features were added to the calculation of basin relation parameters to determine if drainage density or bifurcation ratios would be significantly affected. It was determined that drainage density remains the same, but the bifurcation ratio changes to 1.53. Since the total stream length of zero order streams is considerably lower than identified first order streams, the bifurcation ratio of these two orders is very low. This in turn reduces the overall average for the subwatershed. It was decided that swales or zero order streams would not be included in the basin relation calculations, as they do not significantly affect the parameter results. Also, given that these drainage features were identified from a desktop exercise they may be under represented.

Table 4.5.1 Calculated basin relations for Subwatershed 17

Subcatchment	Drainage Density	Bifurcation Ratio
GM 1	2.16	1.34
GM 2	1.67	4.00
GM 3	1.91	3.99
GM 4	1.44	1.84
GM 5	2.62	6.73
GM 6	2.10	2.59
Subwatershed 17	1.84	1.89

Subcatchments 1, 3, 5, and 6 have reasonably high drainage densities that are related to catchment characteristics and a larger number of headwater streams compared to subcatchments 2 and 4. Bifurcation ratios are relatively high for the individual subcatchments. A review of the reach map (**Appendix C**) shows a large proportion of first and second order channels that contribute to the high bifurcation ratios. The basin calculations also confirm that headwater streams dominate Subwatershed 17. Thus, a comprehensive management plan should give appropriate consideration to maintaining form or at least the function of this important part of the channel network.

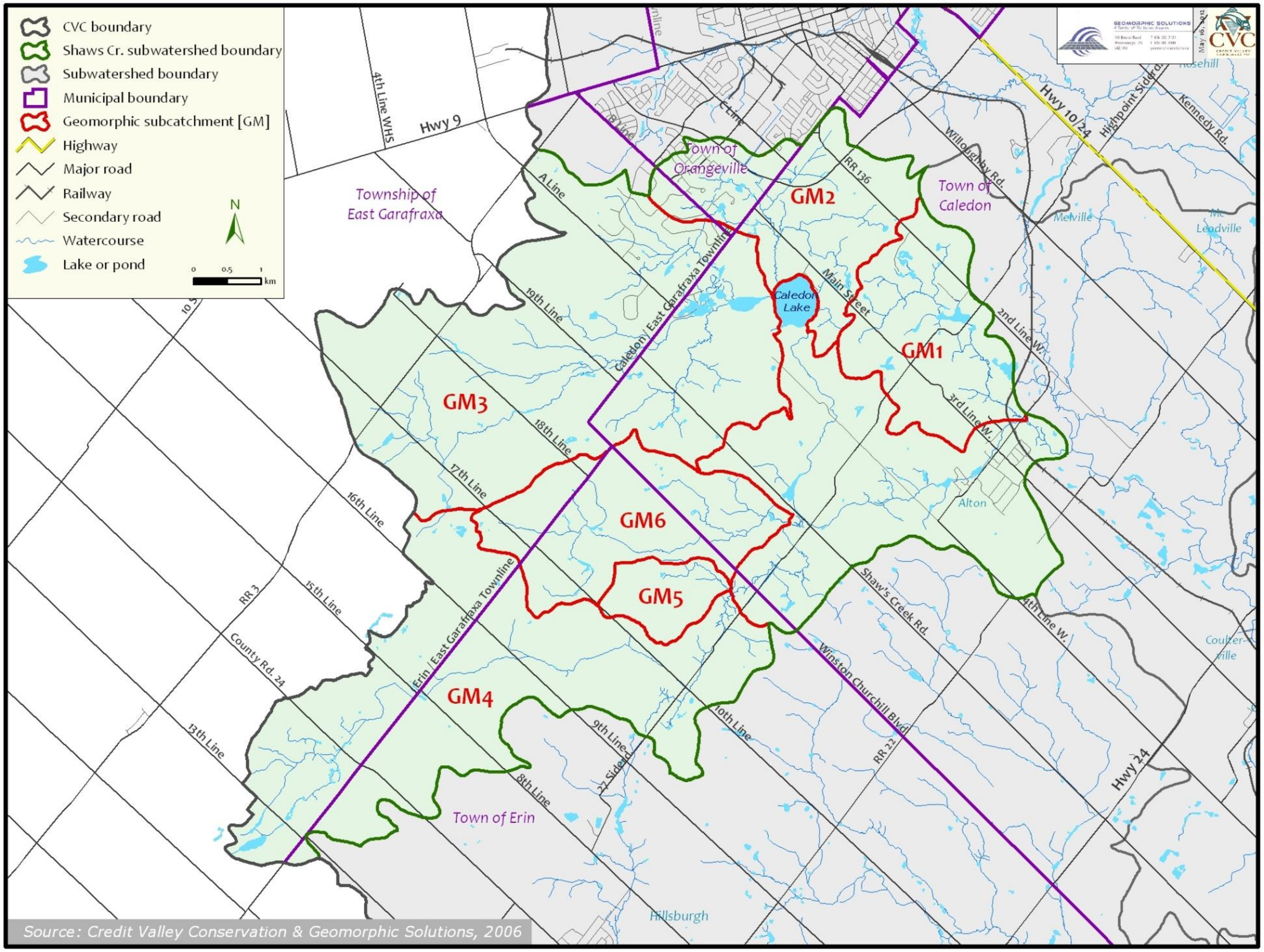


Figure 4.5.1 Subcatchments used in Drainage Density Analysis (refer to Table 4.4.1)

4.5.4 Stream Classification

A background review was completed using topographic and geological mapping and aerial photographs to understand existing and historical channel and valley form. Channel form is a product of the channel flow regime and the availability and type of sediments within the stream corridor. The 'dynamic equilibrium' of these inputs dictates the channel form. To understand the interactions among these factors, the existing channels were separated into reaches of homogeneous character, based on physical characteristics such as channel form, function, and valley setting. Delineation of reaches typically considered planform, gradient, hydrology, local surficial geology, physiography, and vegetative/land cover control (Montgomery and Buffington, 1997; Richards et al., 1997).

Subwatershed 17 is comprised of thirty-three (33) reaches (see **Figure 4.5.2**) representing homogeneous units of morphology, history of modification, adjustment type and surrounding land use. Three steps were required to delineate the management reaches:

- Basic delineation by secondary sources (slope, quaternary geology, soils, planform, land use, hydrologic consistency);
- Field data collection, and geomorphic analysis (including aerial photo analysis) to identify areas that could behave abnormally; and
- Classification of channel morphology and type of adjustment.

The high proportion of low order streams, discontinuity of drainage features, complex topography, and the prevalence of wetland features complicated reach delineation. Consequently, a modified approach to reach delineation was used to maintain management focus on the upper headwater streams. Branched sections of the watershed consisting of swales or 0 order streams, 1st and 2nd order channels were grouped and labeled as 'grouped drainage features' (GDF) for simplicity. Drainage features lacking continuity with the drainage network at the upper end of drainage basins were not defined. GDFs are not described in detail. These lower order reaches are better described using basin parameters. As individual elements they may not be of importance to the system but as a group provide impact (i.e. sediment and flow regimes) to higher order streams.

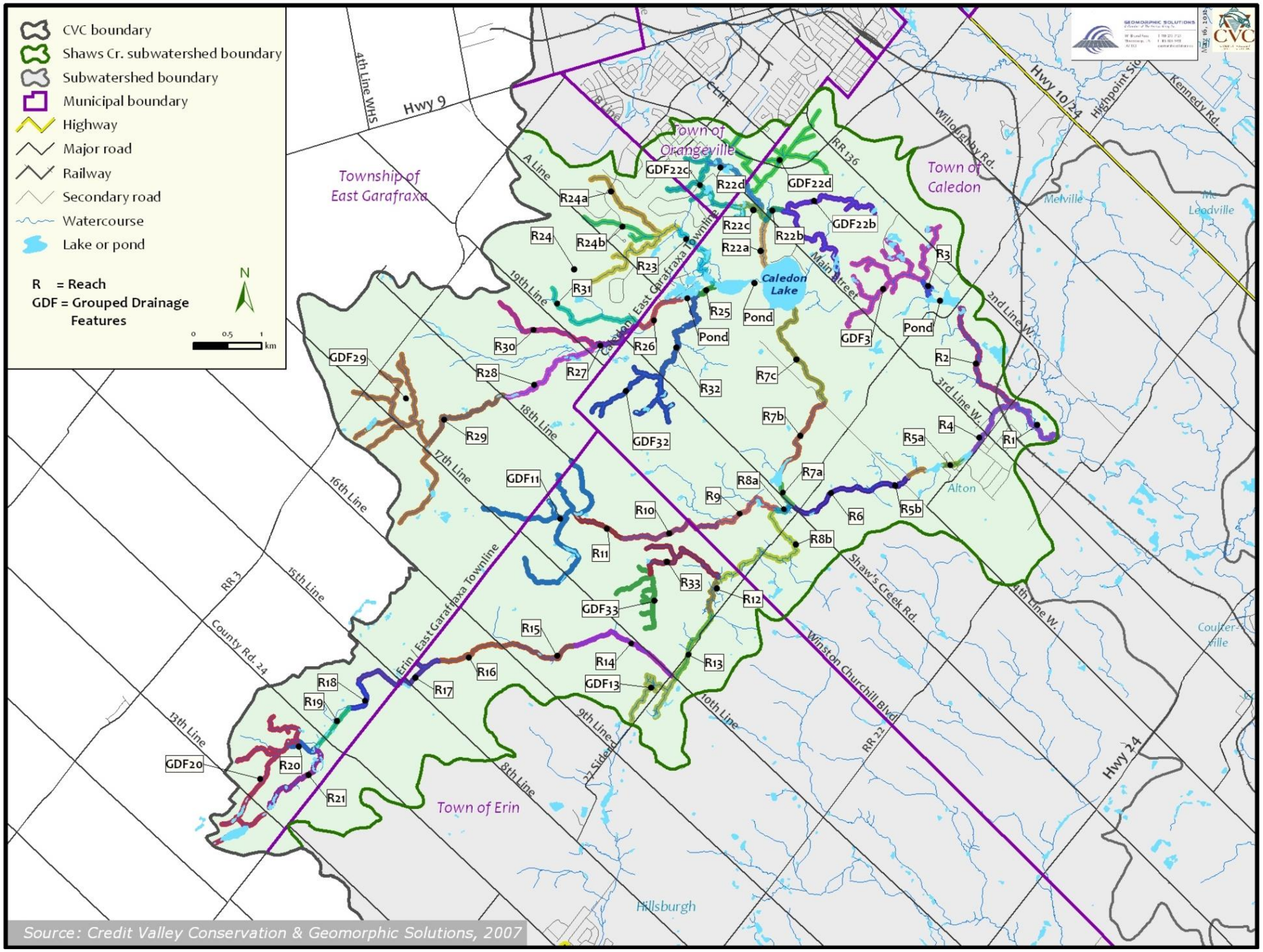


Figure 4.5.2 Geomorphic Reaches

Table 4.5.2 provides both channel gradient and stream order for each reach. With a few exceptions, Subwatershed 17 has a classic drainage pattern with low order headwater channels generally having a higher gradient compared to larger channels. Agricultural drains in the western portion of Subwatershed 17 generally have lower channel gradients compared to headwater channels in the northern portion of the subwatershed likely due to channelization, alteration and drain maintenance. The channel gradient for Reach 1 (0.47%) is fairly typical of temperate lowland channels.

Channel classification systems are often applied during the reach delineation process. Channel classification systems provide a simple means of describing channel form or stage of evolution. From a management perspective, they are important for documenting existing channel conditions and setting management priorities, assisting in defining the end state for restoration projects, and providing information about management measures that are likely to be successful (Kondolf, 1995). Many classification schemes have been developed, and two were applied to Subwatershed 17, as described in the following paragraphs.

Under the Rosgen (1996) classification system, stream characteristics are organized into relatively homogeneous stream types based on the degree of entrenchment, gradient, width-to-depth ratio and sinuosity. Each type is then divided into six subcategories depending on the dominant bed and bank materials. A general description of the channel types found in the study area is provided in **Table 4.5.3**. Additional reference to the Rosgen approach can be found in Annable (1996).

Table 4.5.2 Reach summary of stream order and channel gradient.

Reach	Stream Order (Strahler, 1952)	Channel gradient (%)	Reach	Stream Order (Strahler, 1952)	Channel gradient (%)
1	5	0.47	17	3	0.52
2	3	0.57	18	3	0.67
3	3	1.00	19	3	0.27
4	5	2.53	20	2	0.27
5	5	1.26	21	2	0.89
6	5	0.43	22	1	Insufficient contours
7	4	0.21	23	2	2.86
8	4	0.34	24	2	3.02
9	3	0.57	25	4	0.25
10	2	1.33	26	3	0.25
11	2	1.33	27	3	0.25
12	1	1.23	28	3	1.28
13	3	0.86	29	3	0.78
14	3	0.86	30	2	1.41
15	3	0.86	31	2	2.55
16	3	0.52	32	3	Insufficient contours
			33	3	0.80

The Rosgen classification approach provides a common language for defining channel form and inferring channel process, and provides continuity between this and previous studies. Nevertheless, the Rosgen system is limited in its ability to classify channels that are undergoing adjustment. Downs (1995) developed a classification scheme to account for trends and patterns of adjustment to the fluvial and sediment processes responsible for driving channel change (**Figure 4.5.3**). Unlike classifications based on morphology, the Downs Evolution Model assesses the current nature of channel adjustment processes. Unfortunately, pertinent channel information (e.g., historical records of channel change) may not always be available, and historic patterns of change may not be representative of current or future adjustments. The geomorphologists Downs classification system therefore requires training to reliably assess the stage of evolution based on channel morphology.

Channel adjustment types are based on the mode of adjustment and include the following: stable, depositional, lateral migration, enlarging, compound, recovering and undercutting. Application of this classification system requires the researcher to examine the field evidence and determine the predominant mode of adjustment. For example, depositional channels can be indicated by various factors including excessive bar development, coarse sediment being deposited over fines, and burying of infrastructure. Enlarging channels can be indicated by various factors including leaning trees, outflanked and undermined structures. Channels have been classified according to Downs (1995) in **Table 4.5.3**.

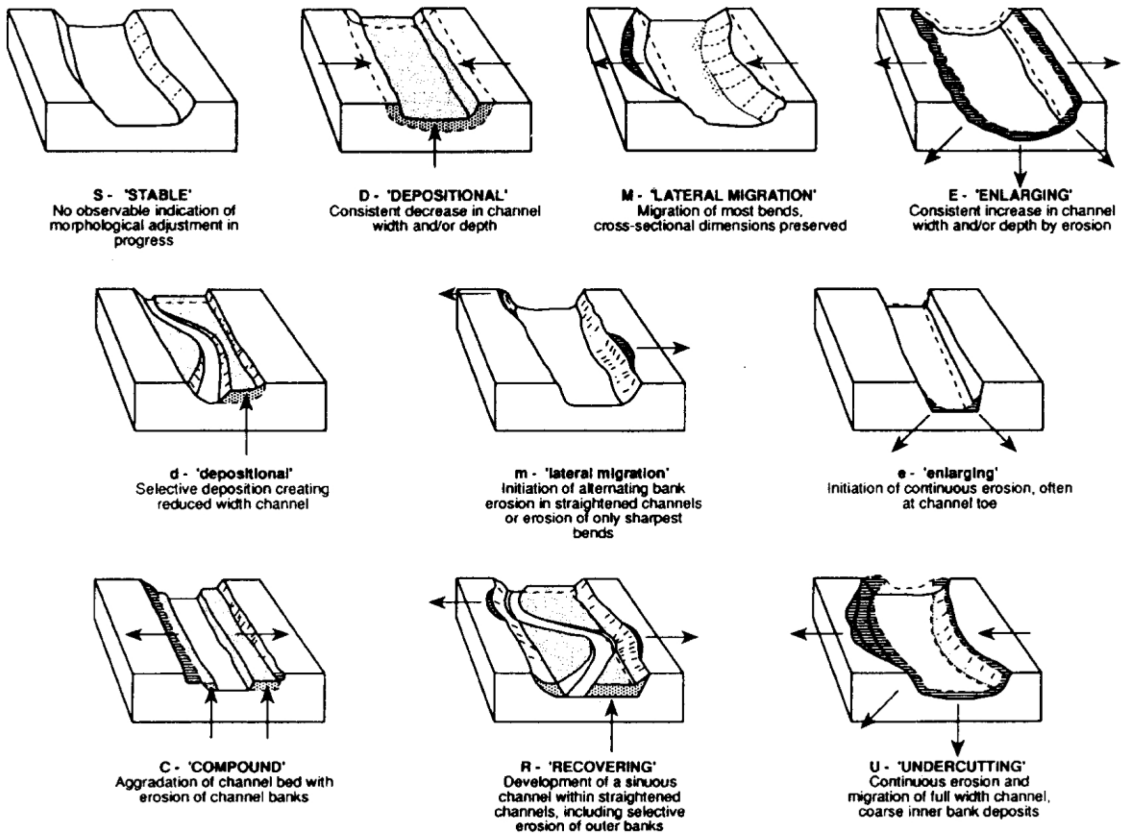


Figure 4.5.3 Channel classification based on trends and types of morphological change (Downs, 1995)

Once reach delineation was complete, an assessment of channel characteristics and land use change was undertaken to identify areas of concern and/or areas requiring protection for subwatershed planning and management. These assessment tools usually focus on a component of channel form or function (i.e., biology, habitat, water quality, stability, or erosion), and a more objective and complete overview is gained by applying more than a single method (Ward et al., 2003). Therefore, a combination of the Rapid Geomorphic Assessment (RGA) (MOE, 1999) and Rapid Stream Assessment Technique (RSAT) (Galli, 1996) were used for this study. The RGA documents indicators of channel instability (MOE, 1999) providing not only a relative measure of stability but types of systematic adjustments occurring in the system (e.g., widening, planform adjustment), and therefore, insight into the outcome of further stress on the system due to alterations in the sediment or flow regime. The RSAT considers the ecological functioning of the stream (Galli, 1996). RGA, RSAT and stream classification models could not be performed on Reaches 3, 9-23, 25, 28-33, as they were either not defined or were wetland channels. RGA and RSAT scores for the remaining reaches are provided in **Table 4.5.3**.

Table 4.5.3 Summary of rapid assessment results and channel classifications

Reach	RGA		RSAT		Rosgen Classification	Downs Evolution Model
	Score	Condition	Score	Condition		
1	0.22	In transition	30	Good	C5c	S – “STable ”
2	0.21	In transition	26	Good	G5c	e – “Enlarging”
4	0.25	In transition	32	Good	C4	e – “Enlarging”

5	0.13	In regime	38	Excellent	C3	S – “STable ”
6	0.04	In regime	29	Good	C3c	S – “STable ”
7A	0.29	In transition	18	Fair	C5c	C – “Compound”
7B	0.18	In regime	19	Fair	C5c	D – “Depositional”
8A	0.25	In transition	21	Fair	C5c	e – “Enlarging”
8B	0.18	In regime	24	Fair	C5	e – “Enlarging”
13	0.04	In regime	21	Fair	E5	S – “STable ”
22	0.07	In regime	23	Fair	E5	S – “STable ”
23	0.22	In transition	21	Fair	E5	C – “Compound”
26	0.13	In regime	28	Good	E5	S – “STable ”

Based on the RGA scores, channel conditions were either in regime or in transition, indicating minimal channel modifications. RSAT scores ranged from fair to excellent, suggesting variable stream ‘health’ throughout the subwatershed. Physical habitat and riparian habitat conditions were common limiting factors identified in the RSAT due to the high number of low gradient wetland channels. According to the Rosgen classification, channels ranged from low gradient sand-dominated channels with varying degrees of sinuosity to moderate gradient gravel and cobble dominated channels with low to moderate sinuosity. The Downs Evolution Model indicated that channels were stable, enlarging, compound or depositional. Most channels had either minimal or no noticeable evidence of erosion.

To further document existing conditions, rapid measurements of bankfull channel dimensions, type of substrate, vegetative cover, channel disturbance, areas of erosion and other observations were collected. General morphology, sediment characteristics and sites of aggradation and erosion were also identified and documented.

Representative photographs are provided to illustrate the variation in channel morphology throughout the subwatershed (Appendix C). The fourteen detailed survey site locations are also provided (**Appendix C**). The results of existing conditions are presented in **Table 4.5.4**.
Overall, channels in the western portion (Reaches 10, 11, 12, 14-21) and the northern portion of the subwatershed (Reach 29) have been modified by agricultural development. Modifications include straightening, widening, damming for irrigation, and tile drainage. Most modifications in natural segments of stream are located in wetland areas or areas where the channel has recovered from modifications made 50 to 100 years ago. Uppermost headwater reaches are typically unable to collect enough flow to modify their bed and banks. As the upstream drainage area increases the stream has more ability to adjust back to a more natural condition through deposition and lateral migration.

The most sensitive headwater channel types observed are Rosgen E Type that flow through wetland areas (Reaches 2, 3, 13, 22, 23, 24). The morphology of these channels is strongly influenced by streamside vegetation. Channels predominantly flowing through cedar forest are relatively shallow and wide (Reaches 5, 6, 8B, 26). Immediately downstream of Caledon Lake, channels are predominantly wetland channels. However, due to channel gradients, sediment supply from Caledon Lake and underlying geology, these channels are largely depositional.

Towards the east, Shaws Creek begins reworking its own alluvium. The stream gradient increases through Reaches 4, 5 and 6, and bed material is relatively coarse (e.g. gravel to cobble). In these areas, the channel bed is generally more resistant to erosion than the banks and the channels typically adjust to stress by moving laterally. Downstream of the confluence of Reaches 2 and 4, the gradient is low allowing the channel to function as a deposition zone. Beaver activity is common within these reaches. Reach 1 is predominantly comprised of fine-grained materials (i.e., sand, silt) reflecting underlying geology and channel gradient.

Overall results from **Table 4.5.4** are typical for the subwatershed. For example, small swale and headwater channels have small bankfull width and depth and substrate consisting of small particle sizes or organic materials. Riparian vegetation was consistent with channel size, with wetland vegetation, pasture, grasses and shrubs bordering the majority of smaller channels. Trees were more common along higher order channels.

As part of field reconnaissance, detailed cross-sections were collected; standard protocols and known field indicators were used to quantify the bankfull cross-sectional dimensions of the reaches (e.g. bankfull depth and width). The substrate was also generically characterized. Desktop assessment in GIS was completed to calculate a local grade. From these observations, in support of modeling in the next phase of the subwatershed study, planning level erosion thresholds and bankfull discharge were modeled from the field observations, as well as observations of lower flow discharge measurements, which were collected during field reconnaissance (provided in **Appendix C**).

Table 4.5.4 Summary of existing conditions within each reach

Reach	Bankfull Width (m)	Bankfull Depth (m)	Substrate		Riparian Vegetation	Notes
			Pool	Riffle		
1	7-15	0.5-1.0	Sand	Sand/gravel	Trees; grasses; wetland vegetation	Woody debris; debris jams
2	1-2	0.2-0.5	Sand	Sand-gravel	Grasses; shrubs	Woody debris; beaver dam
3	0.6-1.0	0.2-0.3	Sand/gravel	Gravel	Cedar; herbaceous species	Culvert elevated by 0.3-0.4 m
4	8-15	0.2-1.5	Gravel	Sm-lrg cobble	Trees; shrubs; grasses	Woody debris; railway and road crossings
5	5-15	0.4-1.0	Sm-lrg cobble	Med-lrg cobble	Trees; grasses	Woody debris; debris jams
6	4-7	0.3-0.7	Gravel	Med-lrg cobble	Trees; grasses	Rapid flow
7A	10-15	0.5-1.5	Sand	Sand	Grass; sedges	Downstream of lake
7B	6-12	0.8-1.5	Fine sand	Sand	Grasses; shrubs; trees	Gravel subsurface; algae
8A	4-6	0.6-1.0	Sand	Sand/sm. Gravel	Grasses; shrubs	Woody debris
8B	4-6	0.3-0.7	Silt/sand	Gravel/sm. cobble	Trees; shrubs; grasses	
9	No defined channel				Grasses	Depressional features, disconnected channel
10	No defined channel				Shrubs; grasses	Dry/ephemeral
11	No defined channel				Shrubs; grasses	Dry/ephemeral
12	0.5	0.1	Sand/gravel	Sand/gravel	Shrubs; grasses	Dry/ephemeral
13	1.2-2.0	0.2-0.4	Sand/gravel	Sand/sm. gravel	Grasses; wetland vegetation	Wetland channel with in-channel grass
14	No defined channel				Pasture	Dry/ephemeral
15	No access				Pasture	Dry/ephemeral
16	No defined channel				Pasture	Dry/ephemeral
17	1.5	0.4-0.5	Silt/sand	Silt/sand	Grasses	Armourstone and grass in channel
18	No defined channel				Wetland vegetation	Poorly defined, heavily vegetated channel
19	0.5-1.0	0.1	Organic	Organic	Wetland vegetation	Poorly defined, heavily vegetated channel
20	No defined channel				Grasses; shrubs	Agricultural drain
21	No defined channel				Grasses; shrubs	Agricultural drain
22	1.2-1.8	0.15-0.25	Silt/organic	Silt/organic	Grasses	Wetland channel; in-channel vegetation; urban debris
23	1.5-3.0	0.2-0.4	Silt/organic	Silt/organic	Sm. trees; shrubs; grasses; wetland vegetation	Wetland channel; multiple channels; woody debris
24	1.2	0.4	Med. sand	Med. sand	Pioneering spp; grasses	Woody debris
25	1.5	0.5	Organic	Organic	Shrubs; small trees; grasses	In-channel vegetation
26	1.5-3.0	0.4-0.9	Silt/sand	Sand	Grass; cedar	Woody debris
27	3.4	0.7	Sand over gravel	Sand over gravel	Cedar; ferns	Weir
28	Wetland channel				Wetland vegetation	Wetland channel; in-channel

			vegetation;
29	Wetland channel	Wetland vegetation	Wetland channel
30	No defined channel	Grasses; shrubs	Poorly defined, heavily vegetated channel
31	No defined channel	Grasses; shrubs	Poorly defined, heavily vegetated channel
32	Wetland channel	Wetland vegetation	Wetland channel; in-channel vegetation;
33	Wetland channel	Wetland vegetation	Wetland channel

An erosion threshold provides a depth, velocity or discharge at which sediment of a particular size class, usually the median or averaged material, may potentially be entrained. This does not necessarily mean systemic erosion (i.e., widening or degradation of the channel); it simply indicates a flow, which may potentially entrain sediment (i.e. initiation of motion of materials). Given the variability of the watercourses and the number of the tributaries in this watershed this approach, although providing only a planning level approximation of the individual sites erosion thresholds, a good overview of the sensitivity of the system. The thresholds were based on bulk properties of the substrate. These values were extracted from the following sources (Chow, 1959; Miller *et al.,* 1977; Fischenich, 2001). Critical threshold calculations were incorporated into simplified versions of the measured cross-sections in each reach in order to translate these results into a more meaningful representation of flow discharge. This will fit into the hydrology modeling proposed for the next phase of the subwatershed study.

4.5.5 Erosion and Sedimentation

Along higher order channels, the channels can be examined and managed in terms of dynamic stability. Channel stability is a relative term where there is a balance between sediment supply and transportability. Eroding channels can have a deficiency of sediment and progressively degrade the stream bed and/or banks. Stable channels have no progressive change in channel cross sectional form although short-term variations may occur during floods. The material eroded in stable channels is replaced by material supplied from upstream. Therefore a stable channel can still migrate across its floodplain while maintaining similar cross sectional dimensions. Depositing channels have an excess sediment load delivered to the stream which results in progressive aggradation and/or bank deposition.

Most of the higher order streams in Subwatershed 17 appear to be stable with most sites of significant erosion apparently related to local factors such as channelization, damming, land use (i.e., pasture land) vegetation removal.

Site visits were conducted on July 27, August 15 and October 24, 2005 of all the major tributaries through Subwatershed 17. The form, function and conductivity as well as identification of open watercourse were conducted. Overall, a large portion of the subwatershed is characterized as having numerous 0 order or swales. The tributaries were walked from Shaws Creek to their primary discharge location. The purpose of the survey was to characterize the form and stability of the watercourses. Specific objectives included:

1. Describing the form and stability; and
2. Locating major erosion zones (e.g. sediment sources) and deposition zones.

Overall, a field reconnaissance indicated that a high number of tributaries have been previously modified by agricultural practices. Channels are primarily swale features with adjacent lands dominated by agricultural land use. Streams that have been heavily modified have more defined channels and are often entrenched. The number of dams and wetland features within the subwatershed mitigates downstream impacts of sediment erosion.

The lower order tributaries are production sites, and therefore their main function is supply of sediment to the downstream systems. In these terms, management strategies need to be developed that do not exacerbate current or natural levels of erosion, but also do not shut down the erosion processes. It is also important that the modifying factor these channels play on downstream hydrology are maintained.

4.5.6 Geomorphology Characterization

The fluvial geomorphology of Subwatershed 17 is complicated and diverse. This is expected given the topography and underlying geology of the subwatershed. Overall, Subwatershed 17 is dominated by headwater, low order channels, which modify the downstream flow and sediment regime. Many headwater channels are impacted by agricultural activity. It is suspected that there is more rapid aggradation within wetland and low lying features, but our diagnostic methods because not appropriately used in wetland channels, were unable to detect evidence of this process. Low order channels have been impacted by agricultural activity, likely as a consequence of their relatively small size and ease of modification for agricultural purposes. Several sinks for sediment (i.e., dams and wetlands) are present within the subwatershed. These sinks play a large role in mitigating the potential effects of agricultural impacts (i.e., sedimentation) on receiving watercourses.

The drainage density and bifurcation ratio calculated for Subwatershed 17 supports field reconnaissance findings in that there are a high number of relatively small headwater channels within the subwatershed. RSAT scores determined through field visits indicate that channels generally range from fair to good. RGA scores suggest stream conditions ranging from in regime to in transition. Channels were described as in transition likely as a result of systematic adjustments associated with agricultural activity.

Any stream corridor management plan needs to be cognizant of the unique nature of this subwatershed and the dominance of headwater systems. Improving buffering of these features, where possible, would likely improve downstream conditions.

The overall management plan should develop subwatershed drainage density targets. Where low order tributaries are potentially lost, appropriate replication in function should be prescribed.

Modeling in the next phase of the subwatershed study should examine the potential loss of low order channels to the higher order network downstream. Erosion thresholds are provided in Appendix C to support this modeling activity.

The numerous dams within the Shaws Creek watershed likely play a major factor in the watershed's sediment regime. It is understood that the management plan may identify within the watershed for decommissioning or removal. This would improve connectivity and reduce present impacts on the watershed's sediment regime. Any modifications of these features need to be cognizant of the potential impacts with regards to the release of sediment and change in local grade control, which would impact both upstream and downstream. Geomorphic monitoring should be installed on one or two of the higher order channels on the two under represented branches of Shaws Creek.

4.6 WATER QUALITY

4.6.1 Introduction to Parameters of Concern

For the purposes of this study, water quality is defined as the combined chemical, physical and microbiological properties of the water in relationship to habitat for aquatic biota and recreational use for humans. Through the work on the Water Quality Strategy Phase I Report (CVC et al., 2003), Parameters of Concern (POCs) have been identified on a watershed scale for the Credit River. The watershed POCs were used as indicators for characterizing the subwatershed. In addition, a number of other parameters that identified to be potential POCs, on a subwatershed scale based on results of the Background Report (CVC, 2006). **Table 4.6.1** presents the parameters that were chosen for further analysis, with the watershed-wide POCs indicated in bold.

Table 4.6.1 Description of parameters evaluated for Shaws Creek

Type	Parameters	Objectives	Associated Concerns	Sources
Nutrients	Total Phosphorus (TP)	PWQO – 0.03 mg/L (MOEE 1994)	• TP and Nitrate can cause excessive aquatic plant growth leading to oxygen depletion • Nitrate (also has a drinking water objective), and particularly nitrite and ammonia, can be toxic to aquatic biota. • Ammonia can exert oxygen demand similar to BOD (see below)	• Urban, Rural and Agricultural Runoff • Sewage Treatment Plant (STP) Effluent • Erosion of banks and bed
	Nitrate Nitrite	CWQG – 2.93 mg/L (CCME 2003)		
	Ammonia	PWQO – 20 µg/L (MOEE1994)		
Oxygen Related	Biochemical Oxygen Demand (BOD)	6mg/L (CCREM 1987)	• High BOD levels can reflect high oxygen consumption leading to low DO levels • Low DO levels can be harmful for fish and other aquatic biota	• Urban, Rural and Agricultural Runoff • Sewage Treatment Plant Effluent
	Dissolved Oxygen (DO)	CWQG – 6.5 mg/L (CCME 2003)		
Metals	Copper	PWQO – 5 µg/L (MOEE 1994)	• Metals can be directly toxic to aquatic biota • In general, the toxicity of metals increase as the pH and alkalinity decreases • Some metals such as iron, aluminum and manganese are found naturally adsorbed to clay soils	• Urban Runoff • STP Effluent • Natural Groundwater (Mineralization) Inputs
	Zinc	PWQO – 20 µg/L (MOEE 1994)		
	Nickel	PWQO – 25 µg/L (MOEE 1994)		
	Iron	PWQO – 300 µg/L (MOEE 1994)		

	Aluminum	PWQO – 75 µg/L (MOEE 1994)		
Alkaline Earth Metals	Calcium	N/A	• The high levels of calcium and magnesium in the water contribute to high alkalinity and hardness • Hard waters reduce the toxicity of many trace metals and in that respect, can be beneficial to aquatic biota.	• Calcium is naturally found in limestones, gypsum, leaves, bones and shells. • Magnesium is mostly found in dolostone, bones and shells
	Magnesium			
Physical	Suspended Solids (SS)	CWQG – 25 mg/L (CCME 1999)	• High suspended solids can clog spawning areas when settling out • Metals, bacteria and TP are readily absorbed on SS • High SS can make recreational uses of water more dangerous (clarity of water decreases) • Increasesin summer WT can be harmful to fish due to metabolism stresses and reduced capacity of water to hold DO • Decreases in winter WT can freeze spawning areas and potentially kill fish eggs • Ammonia toxicity also increases with increased WT	• Urban and Agricultural Runoff • STP Effluent • Bed and bank erosion • Lack off riparian vegetation to shade water courses
	Water Temperature (WT)	Absolute Maximum Summer Water Temperature – 26 C Daily Maximum Summer Average Water Temperature – 20 C (Ontario Ministry of Natural Resources and Canadian Department of Fisheries and Oceans)		
Microbiological	*E. coli*	100 *E. coli* per 100 ml (MOEE 1994)	• High E.coli levels are indicative of the presence of pathogenic bacteria which can cause respiration and gastrointestinal illnesses in humans	• Urban and agricultural runoff • STP Effluent

Other	Chloride	120 mg/L (CCME 2011)	• High levels may be toxic to aquatic biota • Chloride is a conservative element meaning it doesn't break down in the environment. Increasing trends across the Credit River Watershed indicate it is accumulating in the environment	•Road Salting •STP Effluent •Septic Systems

4.6.2 Methodology and Data Analyses

Four approaches for fully understanding water quality in the Shaws Creek subwatershed was undertaken:

1. Long-term water quality data assessment
2. Local 2005 field water quality data assessment
3. Diurnal water quality data assessment
4. Temperature Logger Deployment

Shaws Creek at the Bruce Trail site has been monitored as an additional Provincial Water Quality Monitoring Network (PWQMN) station since 2002, allowing for the evaluation of selected parameters for annual statistics, seasonal means, trend analysis, correlation with other water quality parameters and guideline exceedance frequencies. The parameters chosen for these analyses were those identified for need of further study in the Background Report, which included total phosphorus, nitrate, chloride, suspended solids, hardness, alkalinity, ammonia, calcium, six metals (Cu, Fe, Mg, Al, Ni, and Zn), *E. coli*, Dissolved Oxygen, Biochemical Oxygen Demand (BOD), and water temperature.

The Bruce Trail PWQMN station is located upstream of the Credit River confluence on the subwatershed's eastern border. Supplementary water quality data were also collected across the subwatershed during the 2005 field season to provide an estimation of water quality conditions throughout the subwatershed. Ten additional stations were sampled once a month from May to September for nutrients, BOD, suspended solids, *E. coli*, pH, DO, metals and water temperature.

Another gap identified in the Background Report was the lack of diurnal information for specific in water quality parameters within the subwatershed. Some water quality parameters are known to fluctuate significantly over a 24-hr period, which is problematic since the vast majority of sampling occurs during the daytime hours. Dissolved oxygen and water temperature are of particular concern since the most detrimental levels for aquatic biota occur outside normal working hours. Dissolved oxygen is typically at its lowest point during the early morning hours, before the sun rises and stimulates photosynthetic and oxygen production in aquatic plants. Water temperature is typically highest between 4:30 and 5:30pm, after a full day of heating from the sun. Conductivity and pH can also fluctuate through evaporation processes and the production of carbonic acid (from carbon dioxide, affected by algal production and respiration), respectively. To address this data gap, continuous water temperature measurement was collected at all 11 sites and *in-situ* dissolved oxygen levels were monitored hourly over a 5 day period at 4 stations.

The results were compared with the Provincial Water Quality Objectives (MOE, 1999), Canadian Water Quality Guidelines (CCME, 1999) and Drinking Water Quality Objectives (DWQO) for chloride (MOE, 2001). Water temperature was evaluated against limits set for the protection of aquatic biota based on warm, cold or mixed water fisheries (OMNR and CVC, 2002). Except for water temperature, these guidelines are all based on long-term conditions and chronic toxicity values. Typically, the results of surface water quality measurements are highly variable and therefore many measurements are needed before background conditions can be determined. Therefore, the purpose of the statistical analyses is to look at composite sets of data to determine background water quality conditions to compare to the long-term exposure guidelines.

4.6.3 Data Analyses

Long-term Data

Ten stations on Shaws Creek were sampled monthly in 2005 while the Bruce Trail site has been monitored since 2002 for a full suite of parameters listed in **Table 4.6.1**, above.

Parameters identified for further study from the Background Report underwent the following analyses:

- Annual means and geometric means (for E. coli)
- Annual 75th percentile values
- Seasonal means and geometric means
- Percent violation of a standard guideline
- Trend analysis for selected parameters
- CCME Water Quality Index (WQI)

The first four statistics used the Provincial Water Quality Objectives (PWQO, MOE, 1999) for comparison, except for nitrate. While nitrate does not presently have a provincial objective, there is a federal guideline developed by the Canadian Coucil for the Ministers of the Environment (CCME). Currently, it is CVC's practice to require nitrate concentrations to be below 2.93 mg/l, as recommended by the CCME for the protection of aquatic biota.

Seasonal means were calculated to identify trends based on time of year (spring melt, fertilizer applications, road salting practices etc.) For this analysis summer months include June, July and August, fall includes September, October and November, winter encompasses December, January and February and the remain are spring.

Spearman-Rank correlation tests were conducted to identify those parameters most closely associated with suspended solids. The test determines the degree of correlation between values of the parameters potentially associated with the suspended solids and the suspended solids values. Parameters having a high degree of correlation with suspended solids are most likely from erosional sources. Parameters with a low degree of correlation with suspended solids may reflect no association.

The long term Bruce Trail dataset was also analyzed using the CCME WQI (CCME, 2001) and presented with a value of 1 to 100 evaluating the overall water quality at this particular station. This index requires at least four consecutive years of data and no fewer that four parameters. The index also requires an objective or guideline for each value to be compared against and compensates for different water body characteristics (stream or river reach compared to lake). The higher the value in relation to 100, the higher the quality of water being analyzed.

Field Season Data

Water quality sampling was carried out once a month, at ten stations, from May to September in 2005. Samples were analyzed for a basic suite of parameters including nutrients, suspended solids, BOD, DO, conductivity, water temperature, pH, *E. coli*, Fecal Streptococcus, Pseudomonas Aeruginosa, chlorides and metals near urban areas.

The stations listed in Error! Reference source not found. correspond to the stations presented in

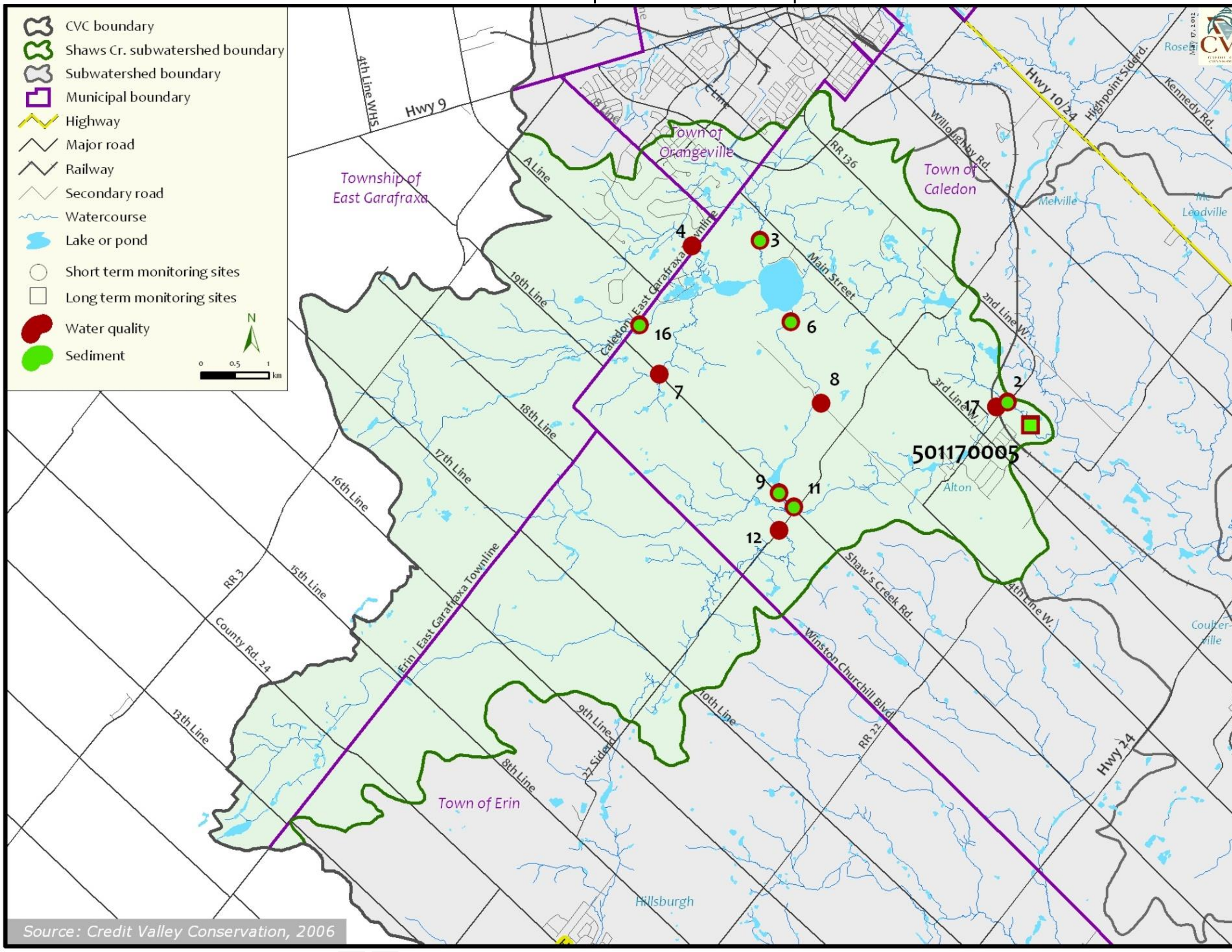


Figure 4.6.1.

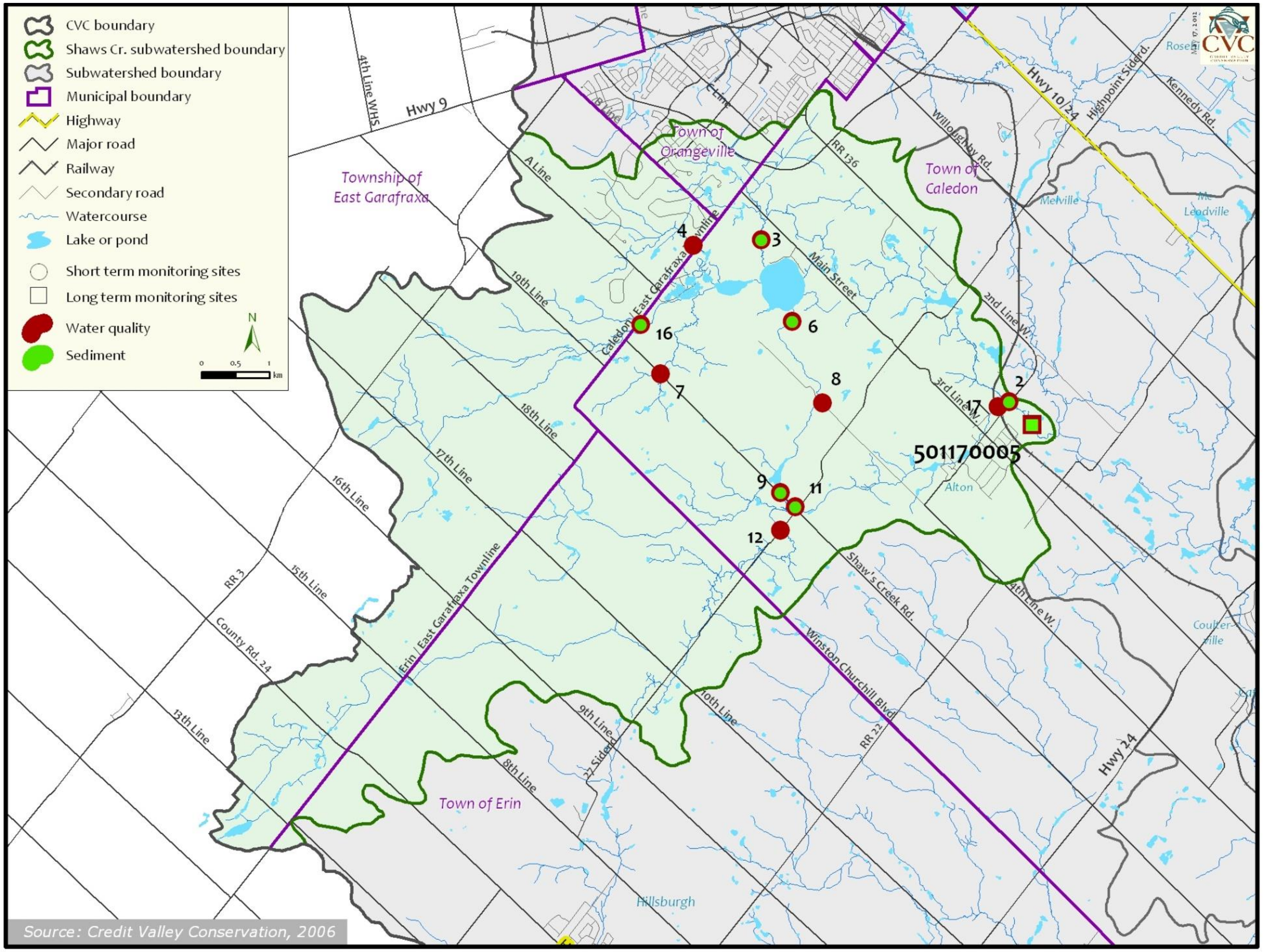


Figure 4.6.1 Water and Sediment Chemistry Monitoring Sites

Table 4.6.2 List of stations in order as they appear in the Subwatershed from North to South, measured parameters and years of available data.

Station Id	Station Name	Suite of Parameters Sampled	Years of Data Available
Site 4	At Townline between A Line & B Line	Monthly water quality sampling including: • Nutrients • Oxygen • Major minerals • Physical • Trace Metals • Microbiological Sediment chemistry sampling at Sites 16, 3, 6, 9, 11 and 2	May – September 2005
*Site 16	At Townline b/w Shaws Cr Rd & A Line		
Site 7	Upstream of Shaws Creek Road		
Site 3	Upstream of Caledon Lake		
Site 6	Downstream of Caledon Lake At Field Centre		
*Site 8	Upstream of Mississauga Rd		
Site 9	Downstream of Cedar Falls		
Site 12	At Highpoint Sideroad and West of Shaws Creek Rd		
Site 11	Upstream of Highpoint Sideroad and East of Shaws Creek Road		
*Site 2	Tributary downstream of 136		
Site 17	Upstream of Hwy 136		
*501170005 PWQMN	Shaws Creek at Bruce Trail	Monthly water quality sampling including: • Nutrients • Oxygen • Major minerals • Physical • Trace Metals • Microbiological Sediment chemistry sampling	January 2002 – November 2005

** indicates Hydrolab deployment in 2005*

The results from these samples were compared against their respective PWQOs (MOE, 1998), Drinking Water Quality Objective (DWQO) for chloride (MOE, 2001) and Canadian Water Quality Guidelines (CWQG) (CCME, 1999) and evaluated for any major spatial trends across the subwatershed.

Diurnal Data

The diurnal survey of basic water quality parameters, including water temperature, pH, DO and conductivity, was completed twice during the 2005 field season. The first survey was completed in late June when aquatic plant growth is typically at its peak and the second survey was undertaken in August in order to observe the fluctuations in water quality under low flow conditions. Hydrolab MiniSonde® water quality loggers were deployed at the 4 stations listed below:

1. Shaws Creek at Bruce Trail
2. Site #2 - Tributary downstream of 136 (June only)
3. Site #8 - Shaws Creek At Mississauga Road
4. Site #16 - At Townline b/w Shaws Cr Rd & A Line (June only)

The August deployment captured conditions at only 2 of the 4 sites. Site 2 experienced equipment malfunction while the Hydrolab Minisonde accidentally sank into the soft substrate at site 16. Site 6, downstream of Caledon Lake, was initially chosen for Hydrolab deployment but due to similar substrate conditions it was decided to move the data logger further downstream to Site 8. The results were compared to PWQOs and critical water temperatures outlined for various fish species in the Credit River Management Strategy (Beak et al., 1992). In addition, the natural oscillations of the parameters measured were examined for obvious trends or atypical results.

Temperature Logger Deployment

Water temperature loggers were deployed at all 11 stations on Shaws Creek from June until November 2005. These loggers recorded temperature every half hour daily and seasonal minimum and maximums. The data were then used to calculate percent violations regarding cold and warm water fish habitats. Since this monitoring took place during the warmest time of the year (warm water has a lesser ability to hold dissolved oxygen), therefore the data represents the worst case scenario for fish and aquatic life in this subwatershed.

4.6.3 Results and Discussion

Long-Term Data

Nutrients

Total phosphorus is a required nutrient for growth of aquatic plants. High concentrations can lead to excessive plant growth which, in turn, can lead to depleted dissolved oxygen levels. Many watercourses in southern Ontario are considered to be Policy 2, with respect to Total Phosphorus. Policy 2 is a designation by Ministry of Environment (MOE) which states that no further degradation of water quality is permissible and all practical steps must be taken to upgrade water quality (MOE, 1999). A watercourse is typically considered to be Policy 2 if the 75th percentile value of the dataset, which represents a worst case long-term exposure scenario, is above the PWQO. Sources of phosphorus may be attributed to urban runoff, agricultural runoff (i.e. containing chemical, manure or biosolids fertilizers), wastewater discharges and erosion of soils with high phosphorus content that may enter the watercourse.

The long-term MOE data indicates that Shaws Creek is not a Policy 2 watercourse, as all the statistics, including the annual mean, 75th percentile and seasonal mean concentrations fell below the PWQO set by MOE. This site experienced its highest concentrations of Total Phosphorus in the spring and summer months when run-off and precipitation was highest and the majority of fertilizer applications take place. Of 44 samples taken between 2002-2005, this station exceeded its PWQO 7 times resulting in a violation rate of 17.1%. The results of these analyses are shown in **Table 4.6.3**.

Table 4.6.3 Results of statistical analyses for Total Phosphorus in Shaws Creek At The Bruce Trail station

Common Time Period 2002-2005	
	TP (mg/L)
PWQO	0.03
Summer Mean	0.020
Fall Mean	0.017
Spring Mean	0.018
Winter Mean	0.009
50th	0.016
75th	0.021
Percent Violation	17.1

The total phosphorus data collected through the subwatershed fieldwork in 2005 revealed that the phosphorus levels across the watershed are generally below the PWQO of 0.03 mg/L. Only nine of the fifty values exceeded the

PWQO taken at the 10 stations. These results are summarized in **Table 4.6.4** below. The complete dataset for all measured parameters is presented in Appendix D.

Table 4.6.4 Average Total Phosphorus results from the 2005 fieldwork

Station ID	Description	Average (mg/L)
Site 4	At Townline between A Line & B Line	0.034
Site 3	Upstream of Caledon Lake	0.070
Site 16	At Townline b/w Shaws Cr Rd & A Line	0.017
Site 6	Downstream of Caledon Lake At Field Centre	0.010
Site 7	Upstream of Shaws Creek Road	0.014
Site 2	Tributary downstream of 136	0.034
Site 17	Upstream of 136	0.016
Site 9	Downstream of Cedar Falls' confluence	0.025
Site 11	Upstream of Highpoint Rd- E of Shaws Cr Rd	0.016
Site 12	At Highpoint Sd Rd- W of Shaws Cr Rd	0.020

On average Sites 2, 3 and 4 exceeded the PWQO of 0.03 mg/L with 8 violations of 15 samples. It should also be noted that of the 50 samples taken in 2005 there were 20 non detectable concentrations of TP below 0.002 mg/L. Sites 2, 3, 4 and 9 exceeded the PWQO at the 75th percentile, indicating these sites are considered Policy 2 by MOE for total phosphorus concentrations (**Figure 4.6.2**). As shown throughout this section Site 3 has elevated levels of most nutrients and metals in comparison to other sites throughout the subwatershed. These elevated levels suggest Shaws Creek is being influenced by the town of Orangeville to the north, through connecting surface and groundwater channels.

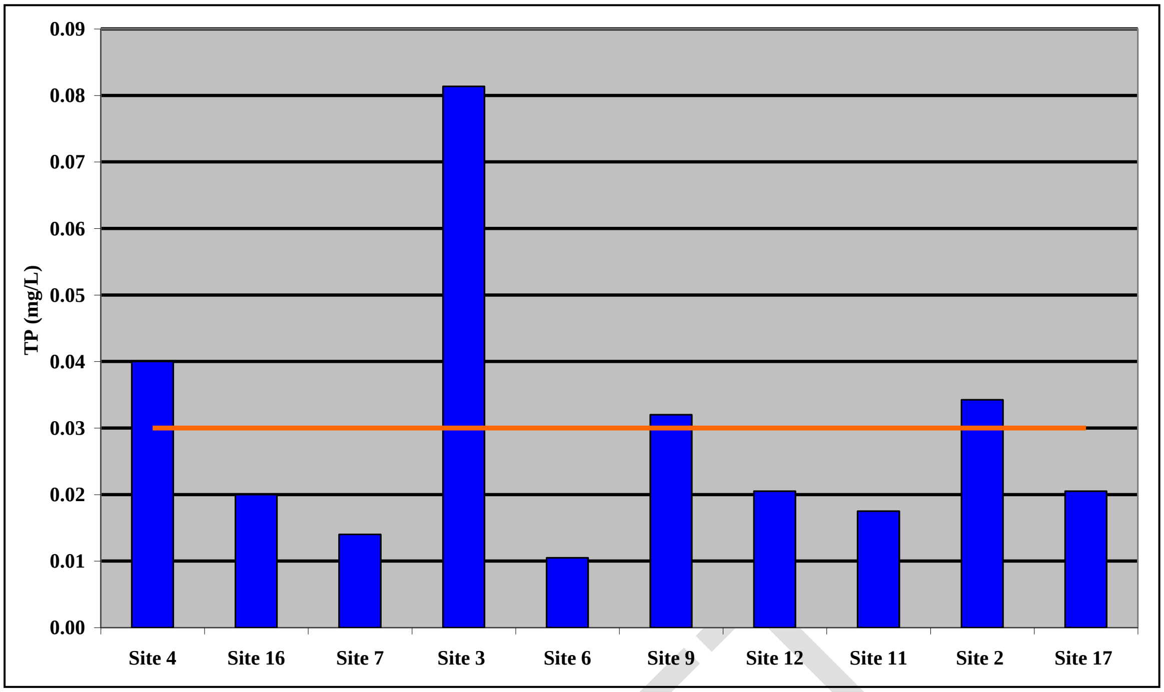


Figure 4.6.2 Comparison of Total Phosphorus 75th percentile concentrations (■) against PWQO (—) for all short term monitoring stations

The Spearman Rank Correlation test was performed on Site 3 as it is Policy 2 and is located upstream of Caledon Lake. There appears to be no correlation between total phosphorus concentrations and suspended solids, indicating the sources of phosphorus are not likely contributed by erosional processes occurring upstream. High phosphorus levels may be due to commercial and private fertilizer applications upstream. Site 2 has known groundwater inputs which may be a contributing factor in the elevated phosphorus concentrations found in the surface water channel. Excessive watercress growth at Site 2 confirms groundwater inputs and high concentrations of nutrients in the water.

Nitrate

Nitrate is a dissolved nitrogen species that acts as a nutrient to stimulate aquatic plant growth and may be toxic to aquatic biota at elevated levels. Excessive aquatic plant growth can lead to an unhealthy dissolved oxygen regime, since nighttime DO levels will be reduced by plant respiration. The long-term nitrate data from the PWQMN station on Shaws Creek indicated the mean and 75th percentile were below the criteria of 2.93 mg/L NO_3-N set by CCME (CCME, 2003). There are no major variations in seasonal means. However, summer appeared to have the lowest nitrate concentrations which may be the result of uptake by aquatic plants. These results are presented in Error! Reference source not found..

Table 4.6.5 Results of statistical analyses for nitrate in Shaws Creek at the Bruce Trail

Common Time Period 2002-2005	
	Nitrate mg/L
PWQO	2.93
Summer Mean	0.77
Fall Mean	0.79
Spring Mean	0.93
Winter Mean	1.55
50th	0.87
75th	1.00
Percent Violation	0.00

Nitrate results from the 2005 fieldwork indicated low nitrate levels for the subwatershed other than Site 16 which showed exceedances on 3 out of 4 sampling occasions. The average values from 6 out of the 10 stations within the subwatershed were below 1 mg/l. Site 16 had an elevated average nitrate-nitrogen concentration of 2.73 mg/l, as shown in

Table 4.6.6.

Table 4.6.6 Average nitrate results from the 2005 fieldwork

Station ID	Description	Average (mg/L)
Site 4	At Townline between A Line & B Line	1.06
Site 3	Upstream of Caledon Lake	*ND
Site 16	At Townline b/w Shaws Cr Rd & A Line	2.73
Site 6	Downstream of Caledon Lake At Field Centre	0.73
Site 7	Upstream of Shaws Creek Road	1.70
Site 2	Tributary downstream of 136	0.20
Site 17	Upstream of 136	0.80
Site 9	Downstream of Cedar Falls' confluence	0.45
Site 11	Upstream of Highpoint Rd- E of Shaws Cr Rd	0.85
Site 12	At Highpoint SdRd- W of Shaws Cr Rd	1.48

**ND: Not detected by Maxxam Laboratories*

The Background Report noted that both ammonia (un-ionized ammonia as calculated based on temperature and pH was below the PWQO of 20 ug/l) and nitrite levels observed at the PWQMN stations were well below their PWQO and CWQG, respectively (**Table 4.6.7**). The nitrite and ammonia results across the subwatershed from the fieldwork for 2005 further confirmed that these parameters are not currently at levels considered harmful to aquatic biota (**Figure 4.6.3**).

Table 4.6.7 Results of statistical analyses for un-ionized ammonia in Shaws Creek at the Bruce Trail

Common Time Period 2002-2005	
	NH_3 (ug/L)
PWQO	20
Summer Mean	5.071
Fall Mean	1.283
Spring Mean	1.286
Winter Mean	0.458
50th	0.981
75th	2.252
Percent Violation	2.70

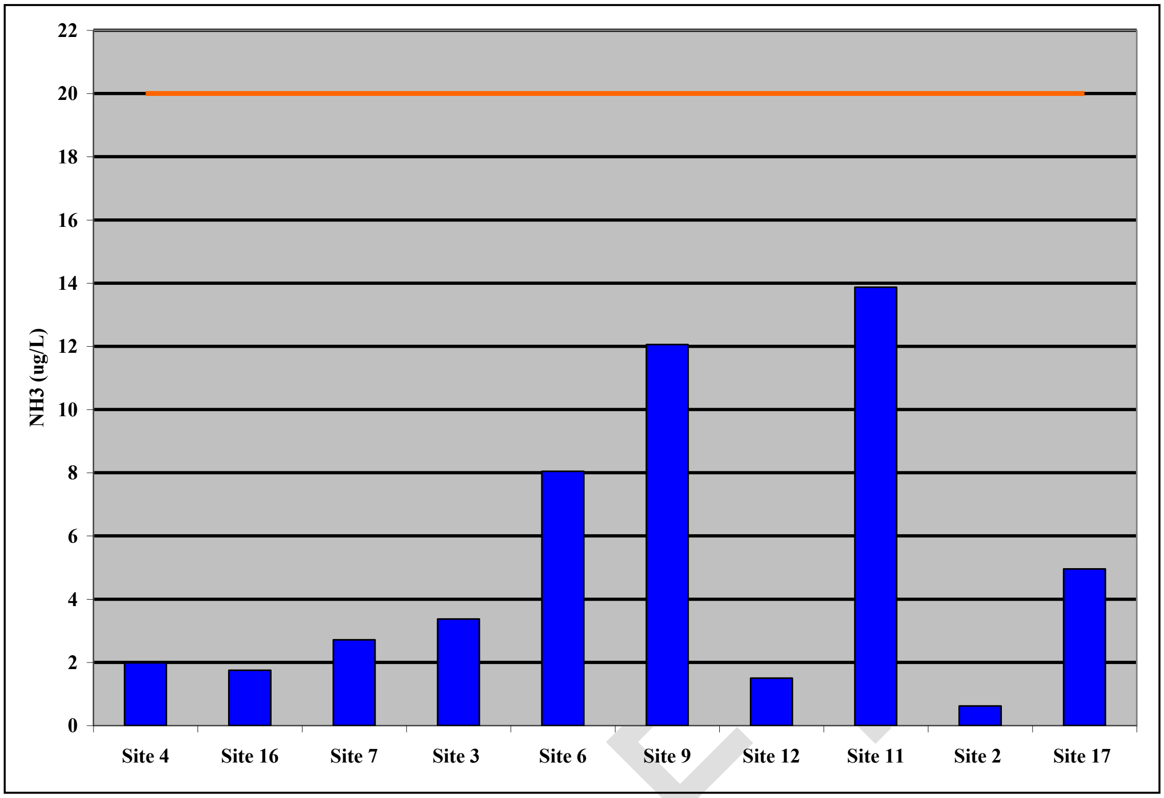


Figure 4.6.3 Comparison of un-ionized ammonia seasonal 75th percentile concentrations (■) against PWQO (—) at the short- term monitoring stations

Metals

Shaws Creek at the Bruce Trail is not considered Policy 2 with respect to aluminum, since the 75th percentile value for this station is below the PWQO. The seasonal means indicate that the highest concentrations occur during the spring and it could be argued, based on the results from
Table 4.6.8, this station is Policy 2 under spring conditions.

Table 4.6.8 Results of statistical analyses for aluminum at Shaws Creek at the Bruce Trail

Common Time Period 2002-2005	
	Al ug/L
PWQO	75.0
Summer Mean	42.69
Fall Mean	27.08
Spring Mean	77.91
Winter Mean	47.0
50th	30.5
75th	58.5
Percent Violation	16.7

The Spearman-Rank correlation technique, shows a high degree of correlation between suspended solids and aluminum concentrations at this long term monitoring station. This suggests that the sources of aluminum are most likely due to upstream erosional processes, such as runoff or bed and bank erosion.
Statistical analysis of the dataset indicates that only Site 3 is considered a Policy 2 in regards to aluminum concentrations in the water column (). The Spearman Rank performed for Site 3 indicates a strong relationship

between aluminum and total suspended solids (**Figure 4.6.4**). These elevated levels suggest that Shaws Creek is being influenced by the town of Orangeville to the north, through connecting surface and groundwater channels.

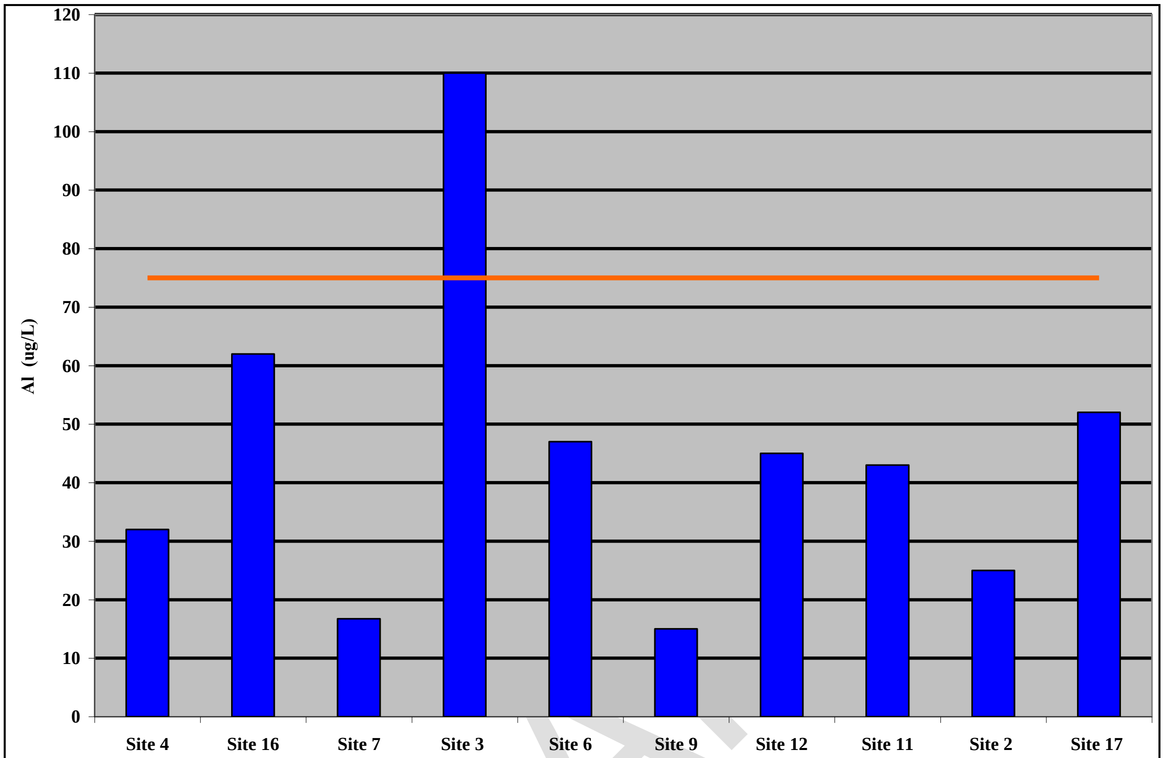
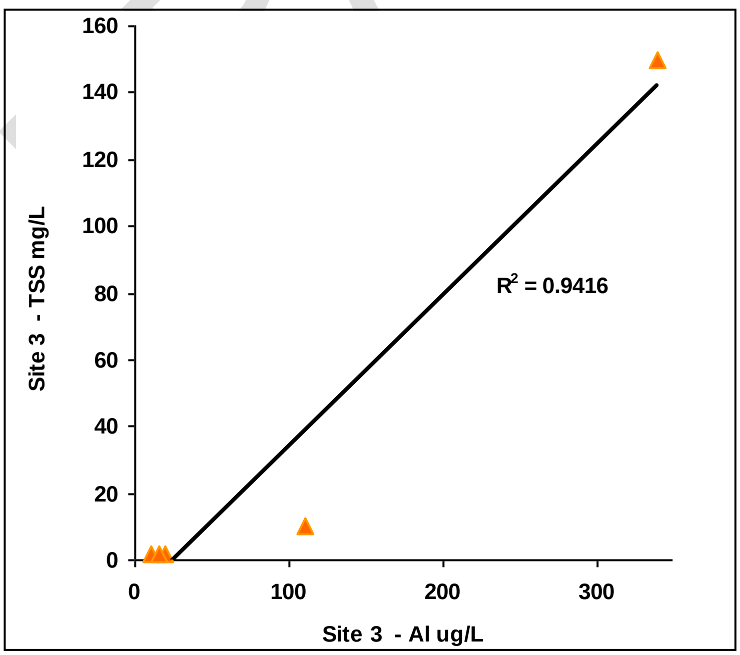


Figure 4.6.5 Seasonal 75th percentile values for aluminum (■) against PWQO (—) as they appear in the watershed from North to south



The 75th percentile values for iron were also calculated on a seasonal basis for Shaws Creek at Bruce Trail (Error! Reference source not found.), which indicated that iron did not exceed the PWQO of 300 ug/L during the sampling season.

Table 4.6.9 Results of statistical analyses for iron for Shaws Creek at Bruce Trail

Common Time Period 2002-2005	
	Fe ug/L
PWQO	300.0
Summer Mean	143.85
Fall Mean	73.25
Spring Mean	82.18
Winter Mean	36.25
50th	80.0
75th	120.0
Percent Violation	0.0

The Spearman coefficient of correlation between iron and suspended solids indicated no significant relationship between these parameters. This suggests that the iron at Bruce Trail may have sources other than erosion, such as groundwater inputs. Of 50 samples at the short term monitoring stations only 3 exceeded the PWQO.

Site 3's average and 75th percentile values exceed the PWQO due to one anomalous relating iron concentrations of 2000 ug/L. Without this outlying value, average concentrations at Site 3 were 166 ug/L, well below the PWQO (**Figure 4.6.4**).

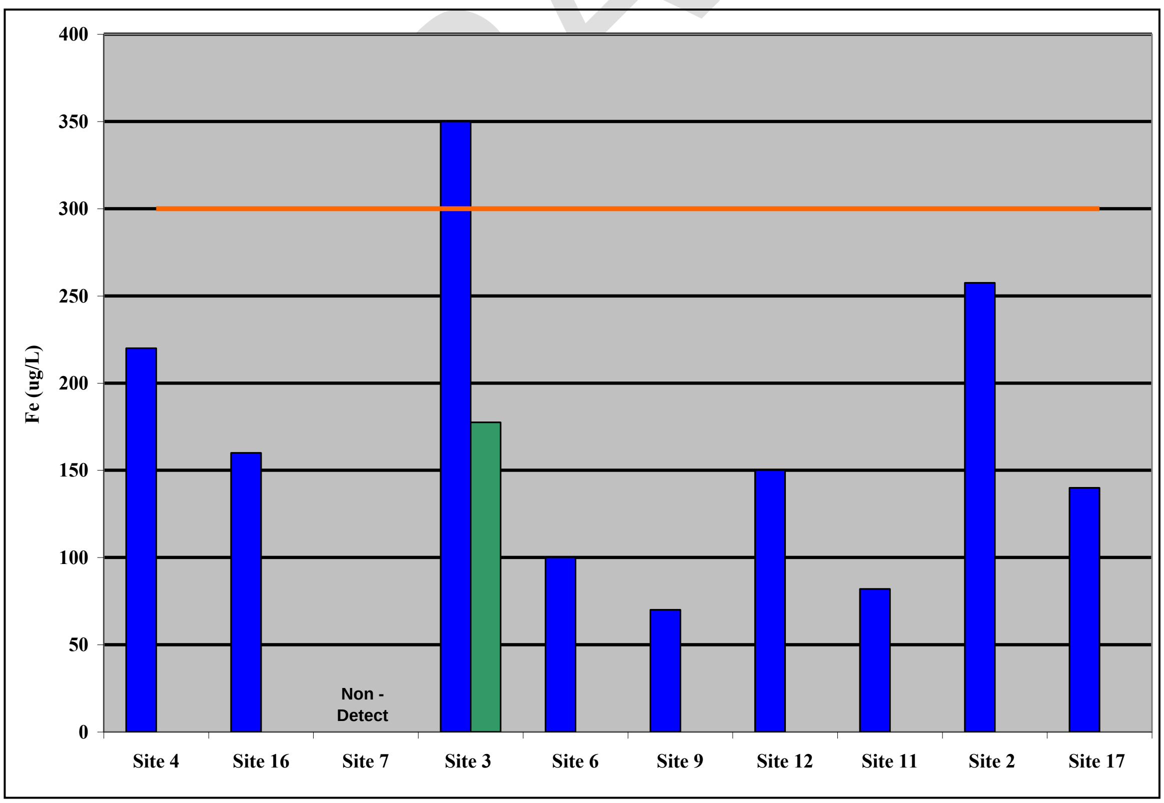


Figure 4.6.6 Seasonal 75th percentile values for iron including the full dataset (■) and excluding the outlier (■) compared against PWQO (▬). The Blank value at Site 7 indicates the results were below the detection limit of 50 ug/L

Similar to aluminum and total phosphorus the average iron concentrations indicate elevated levels at Site 3 upstream of Caledon Lake. The minimum detection limit for iron is 50 ug/L in which many samples fell below especially at Site 7. Co-relation analysis indicates there is a significant relationship between iron and suspended solids at Site 3.

Both means and 75th percentile values for copper, nickel and zinc were below their respective PWQO and showed no strong seasonal variations as shown in **Table 4.7.10**. Copper did not show a significant relationship with total suspended solids at this site. It should also be noted that zinc had the highest percent violation of the metals at 16.67% compared to nickel with 0%, and copper at 2.50% (**Table 4.6.10**).

Table 4.6.10 Results of statistical analyses for copper, nickel and zinc at Shaws Creek at Bruce Trail

Common Time Period 2002-2005			
	Copper (ug/L)	**Nickel (ug/L)**	**Zinc (ug/L)**
PWQO	5.0	25.0	20.0
Summer Mean	2.07	1.00	9.62
Fall Mean	0.67	1.36	15.45
Spring Mean	0.82	1.00	19.09
Winter Mean	0.82	0.88	10.00
50th	0.80	1.00	5.00
75th	1.00	1.00	5.00
Percent Violation	2.50	0.00	16.67

Copper, nickel and zinc were sampled at all sites throughout the subwatershed and analyzed by an independent laboratory. The minimum detection limit (MDL) used by the lab for nickel and copper is 1ug/L. The majority of samples fell below the MDL resulting in percentiles of concentrations to be well below the PWQO. Many samples throughout the subwatershed resulted in non-detectable values for zinc as well and there were 3 occurrences of values exceeding 20 ug/L, one each at Site 3, 6 and 17.

Alkaline Earth Metals

All fresh water sources contain calcium and magnesium in varying quantities. Harnesss is a property of water that causes the formation of an insoluble residue when the water is used with soap and a scale in vessels in which water has been allowed to evaporate. It is due primarily to the presence of ions of calcium and magnesium. Magnesium or calcium have no PWQO, therefore only comparisons of the statistical values against other sites throughout the subwatershed can be made. The Table below depicts the seasonal means of Mg and Ca concentrations and includes an average of all available data used in the comparison. The Bruce Trail site has a total average of 18.1 mg/L which is among the lower average magnesium concentrations found in the subwatershed (**Table 4.6.11**).

Table 4.6.11 Results of statistical analyses for magnesium and calcium at Shaws Creek at the Bruce Trail

Common Time Period 2002-2005		
	Magnesium mg/L	**Calcium mg/L**
Summer Mean	17.4	63.2
Fall Mean	15.7	65.7
Spring Mean	16.1	65.8
Winter Mean	16.9	76.0
50th	18.0	65.8
75th	19.2	70.8
Total Average	18.1	66.7

Alkalinity is the capacity of solutes in an aqueous system to neutralize acid. The high levels of calcium and magnesium contribute to the relatively high alkalinity and hardness of the water in Shaws Creek. The mean value for alkalinity at the Bruce Trail station was 200.8 mg/L (as $CaCO_3$) as is shown in **Table 4.6.12**. Interestingly, hard waters actually reduce the toxicity of many trace metals and in that respect, can be beneficial to aquatic biota.

Table 4.6.12 Statistical analysis of hardness and alkalinity at Shaws Creek at the Bruce Trail

Common Time Period 2002-2005		
	Hardness mg/L	Alkalinity mg as CaCO3/L
Summer Mean	237.17	199.50
Fall Mean	234.24	203.60
Spring Mean	699.00	187.55
Winter Mean	271.33	192.38
50th	239.50	200.00
75th	254.75	210.25
Total Average	312.27	200.8

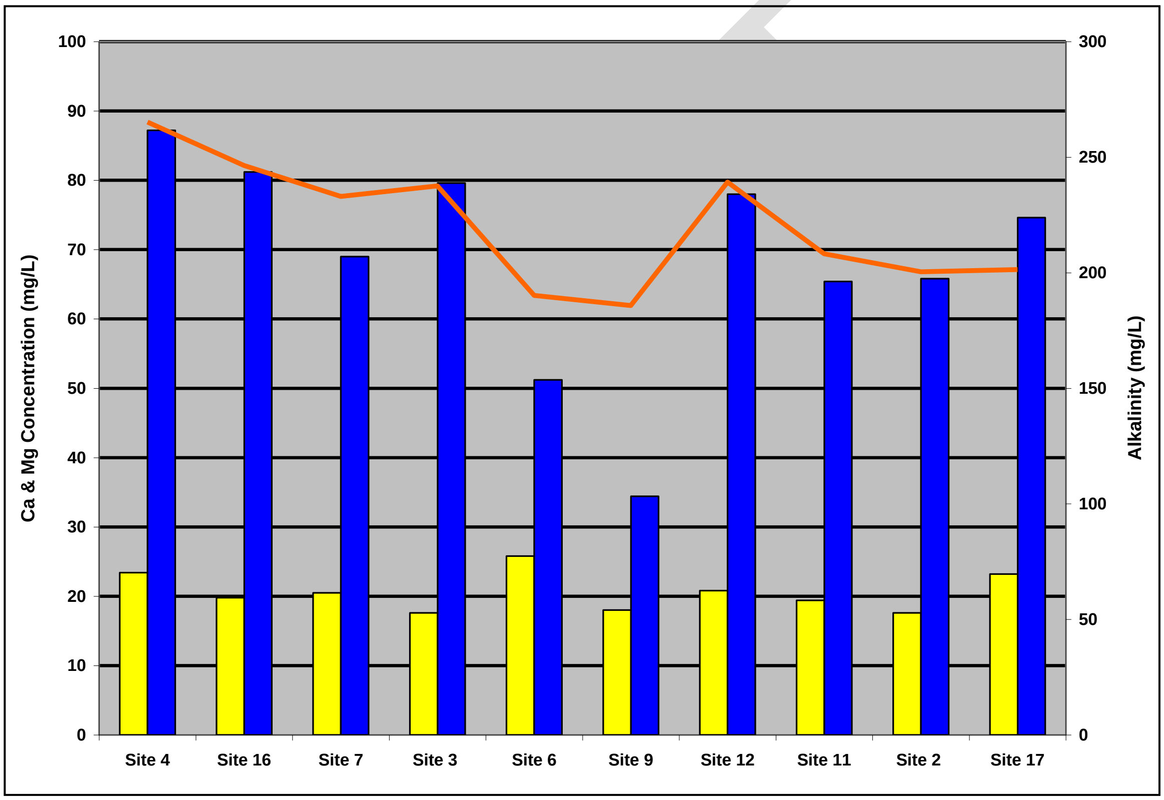


Figure 4.6.7 Average concentrations of Calcium (■) Magnesium (■) compared with Alkalinity (—)

Site 4 has the highest values for alkalinity, hardness and calcium and the second highest value for magnesium of the short term monitoring stations.

Dissolved Oxygen and Oxygen Demand

Dissolved oxygen (DO) and DO percent saturation were measured *in situ* using the Hydrolab MiniSonde. Dissolved oxygen levels respond to temperature and pH fluctuate diurnally and should therefore be measured over the course of a day. These two parameters will be discussed below in the Diurnal Monitoring section. Biochemical Oxygen Demand is a measure of oxygen consumption conducted in a lab over a 5 day period (BOD_5). This test accounts for the concentration of the oxidizable materials present in a water sample as a potential load on receiving water. The BOD_5 value is the amount of oxygen used in the metabolism of biodegradable organics over a 5 day period. While

Canada has no guideline for $BOD_{5,}$ the U.S.Environmental Protection Agency (EPA, 2001) enforces the water quality guideline of < 4 mg/L for fisheries.

Table 4.6.13 Results of statistical analyses for BOD at Shaws Creek at the Bruce Trail

Common Time Period 2002-2005	
	BOD mg/L
EPA WQG	<4
Summer Mean	1.20
Fall Mean	0.76
Spring Mean	1.27
Winter Mean	0.57
50th	0.75
75th	1.28
Percent Violation	0

Throughout the years no BOD value has exceeded 4 mg/L at this long term site. For the 10 short-term monitoring stations all 50 samples resulted in undetectable BOD levels from Maxxam Laboratories (< 2 mg/L).

Diurnal Monitoring

Two sets of diurnal monitoring tests for dissolved oxygen, pH, conductivity and water temperature were completed at 4 stations across the subwatershed, one in late June and one in late August. During these sampling periods, the dissolved oxygen did not fall below the PWQO of 5 mg/l for coldwater fisheries, which indicates a relatively healthy dissolved oxygen regime.

It is important to capture maximum and minimum water temperatures in order to detect variances in dissolved oxygen. Warm water is less capable of holding DO therefore in order to catch worst-case scenarios for fisheries habitat diurnal sampling must be conducted. All sites portray healthy fish habitat with no violations of dissolved oxygen concentrations below 5 mg/L.

Also measured in diurnal monitoring is conductivity which is the water's ability to carry an electrical current. Conductivity is affected by dissolved solids found in the water such as chloride, nitrate, sulfate, and phosphate anions (negatively charged ions) and sodium, magnesium, calcium, iron, and aluminum cations (positively charged ions). Another factor affecting conductivity is water temperature which has higher conductivity at higher temperatures.

pH is the measurement of acidity or alkalinity of the water and is another measure for assessing fish habitat quality. pH is rated on a logarithmic scale (from 0-14) meaning a small change in 1 unit represents a 10 fold change in the hydrogen ion concentration. pH is affected by plant and animal respiration, plant photosynthesis and geologic features such as limestone which has a natural buffering capacity in many watercourses. Values within the range of 6.5 – 9 are considered acceptable fish habitat. No violations were recorded in either of our diurnal surveys for 2005. As with dissolved oxygen, diurnal monitoring is needed in order to capture fluctuations as is illustrated in
.

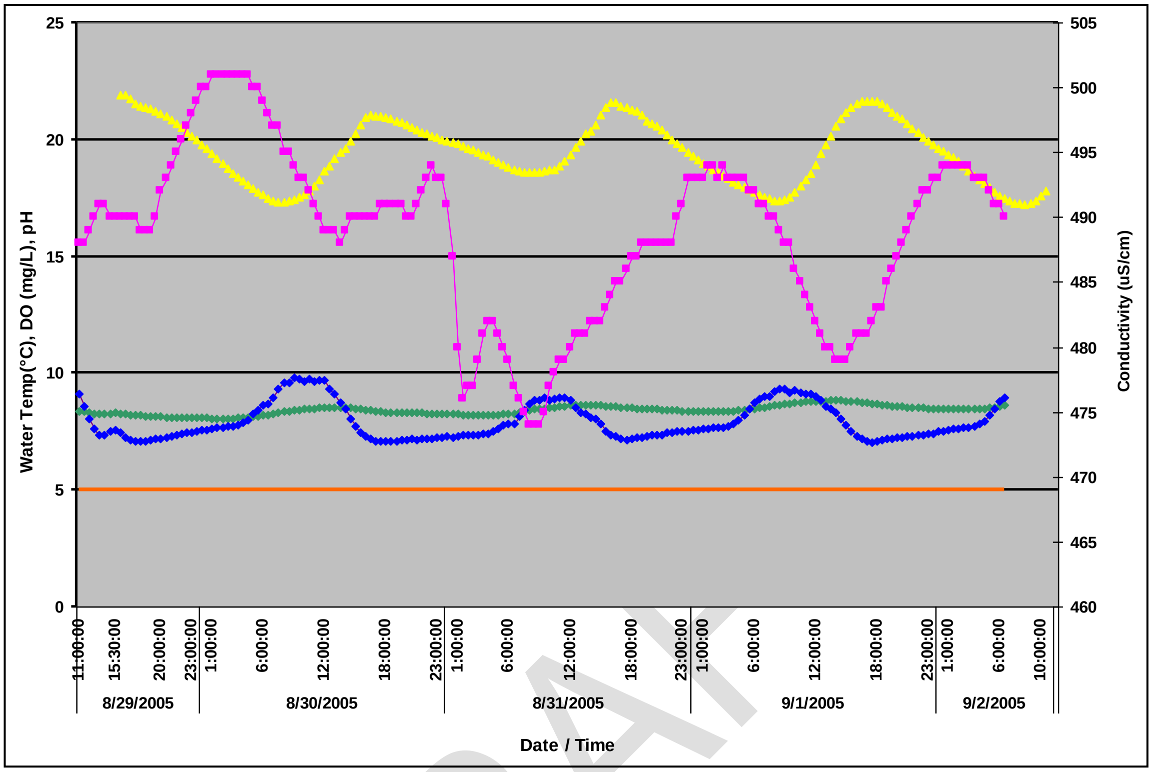


Figure 4.6.8 Diurnal monitoring at Shaws Creek at Bruce Trail for dissolved oxygen (—),DO PWQO (—), pH (—), conductivity (—) and water temperature (—).

A time series analysis of dissolved oxygen concentrations was conducted with the diurnal monitoring data from 4 stations across the subwatershed. DO concentrations are depicted over the five days of Hydrolab deployment and all concentrations surpassed the minimum DO objective of 5 mg/L at all sites (**Figure 4.6.9**).

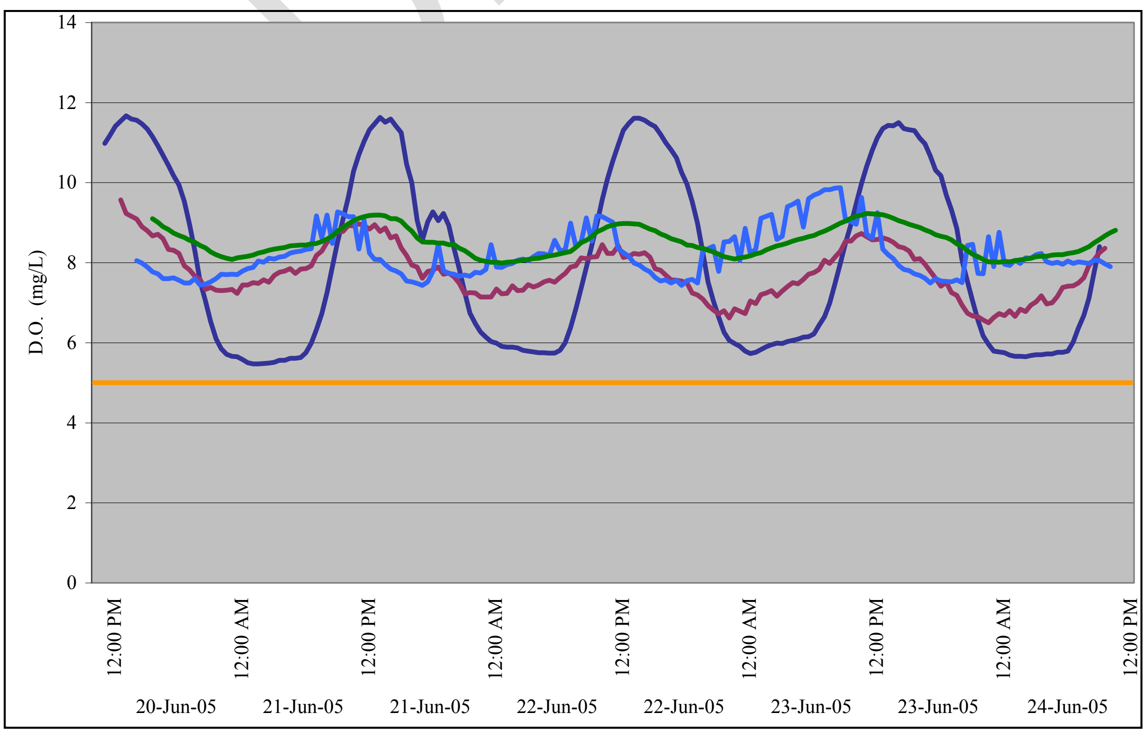


Figure 4.6.9 Dissolved oxygen concentrations (mg/L) at all four sites in June 2005. Site 8 (—) Site 16 (—) Site 2 (—) Bruce Trail (—) and the DO Guideline (—).

Compared to the DO results from the Credit River, there appears to be significant noise in the DO data for Shaws Creek, which would not be unusual for a smaller watercourse. The greatest daily fluctuations are noticed at Site 8 At Mississauga Road. The dissolved oxygen regime at this location is heavily influenced by the inputs of low DO stream flow from near-by Caledon Lake. In any case, the lowest DO value for Shaws Creek occurring during both surveys was at a DO concentration of about 5.5 mg/l, above the PWQO for dissolved oxygen of 5 mg/l.

Site 2 has a large amount of aquatic plant growth with the majority being Watercress. Dissolved oxygen rates vary with water temperature and plant respiration. Groundwater inputs typically lower the overall temperature of the tributary and watercress commonly thrives around groundwater upwellings. With water temperatures being lowered by the groundwater inputs and plant respiration being high the results of these fluctuations are not surprising.

Physical Parameters

Suspended Solids

There is no PWQO for suspended solids but it is recognized that high levels can clog critical spawning areas for fish, increase sediment oxygen demand (SOD) which can deplete DO levels, reduce or eliminate plant growth and results in poor water clarity for recreational uses. The CWQG for suspended solids suggests that during clear flow conditions suspended solids levels should not increase from anthropogenic activities to over 25 mg/l of background levels for a 24-hr period and 5 mg/l for periods of longer-term exposure (24-hr to 30 d). On June 29, 2005 the suspended solids concentration at the Bruce Trail was 1200 mg/L. Since this value was much higher than all other readings taken over 4 years, statistical analyses were performed including and excluding this outlying value, shown below in **Table 4.6.14**.

Table 4.6.14 Results of statistical analyses for Suspended Solids at Shaws Creek at the Bruce Trail

Common Time Period 2002-2005		
	Total Suspended Solids mg/L	
	Including Outlier	Excluding Outlier
Summer Mean	142.67	9.33
Fall Mean	3.08	3.08
Spring Mean	6.45	6.45
Winter Mean	2.75	2.75
50th	4.00	3.50
75th	5.00	5.00
Percent Violation	n/a	n/a

Employing the CWQO for long-term exposure of 5 mg/L and excluding the outlying value this site meets the guideline at its 75th percentile and exceeds it in the spring and summer. Results for the average suspended solids concentrations at the short-term monitoring stations are shown in **Table 4.6.15**. Due to the high variability in suspended solids data during the 5 sample events, there may not be sufficient information to accurately characterize the short-term monitoring stations.

Table 4.6.15 Average Suspended Solids results from the 2005 fieldwork.

Station ID	Description	Average (mg/l)	Range (mg/l)
Site 4	At Townline between A Line & B Line	6.75	nd - 11
Site 3	Upstream of Caledon Lake	33.2	2 - 150
Site 16	At Townline b/w Shaws Cr Rd & A Line	3.8	2 - 10
Site 6	Downstream of Caledon Lake At Field Centre	2.75	nd - 5
Site 7	Upstream of Shaws Creek Road	2	nd - 2
Site 2	Tributary downstream of 136	5.8	2 - 10

Site 17	Upstream of 136	5	nd - 8
Site 9	Downstream of Cedar Falls' confluence	2.25	nd - 4
Site 11	Upstream of Highpoint Rd- E of Shaws Cr Rd	3.8	1 - 8
Site 12	At Highpoint Sd Rd- W of Shaws Cr Rd	4.2	2 - 9

* nd – Non-detect

Water Temperature

Water temperature is one of the most critical water quality parameters for the health of fisheries and can determine what species of fish can survive and thrive in a watercourse. Routine sampling that occurs during normal working hours typically misses the critical period when the water is likely to be at its warmest (between 4:30 pm and 5:30 pm.). Extensive monitoring of water temperature took place this field season with Hydrolab and temperature logger deployment. All sites throughout the subwatershed had water temperature loggers that recorded measuring temperature every half-hour. Temperatures are typically at their highest from June through September. Analysis is therefore based on data from this time period, with three exceptions. The logger at Site 8 was moved to Site 7 on August 11, 2005 to correspond with the change in location of the water quality sampling site. The temperature analysis for Site 8 is therefore based on data up to August 11 and for Site 7 the analysis is based on data after August 11. In addition, the logger at Site 11 disappeared at some point prior to July 7 and was replaced on that date.

shows the temperature fluctuation at Shaws Creek at the Bruce Trail.

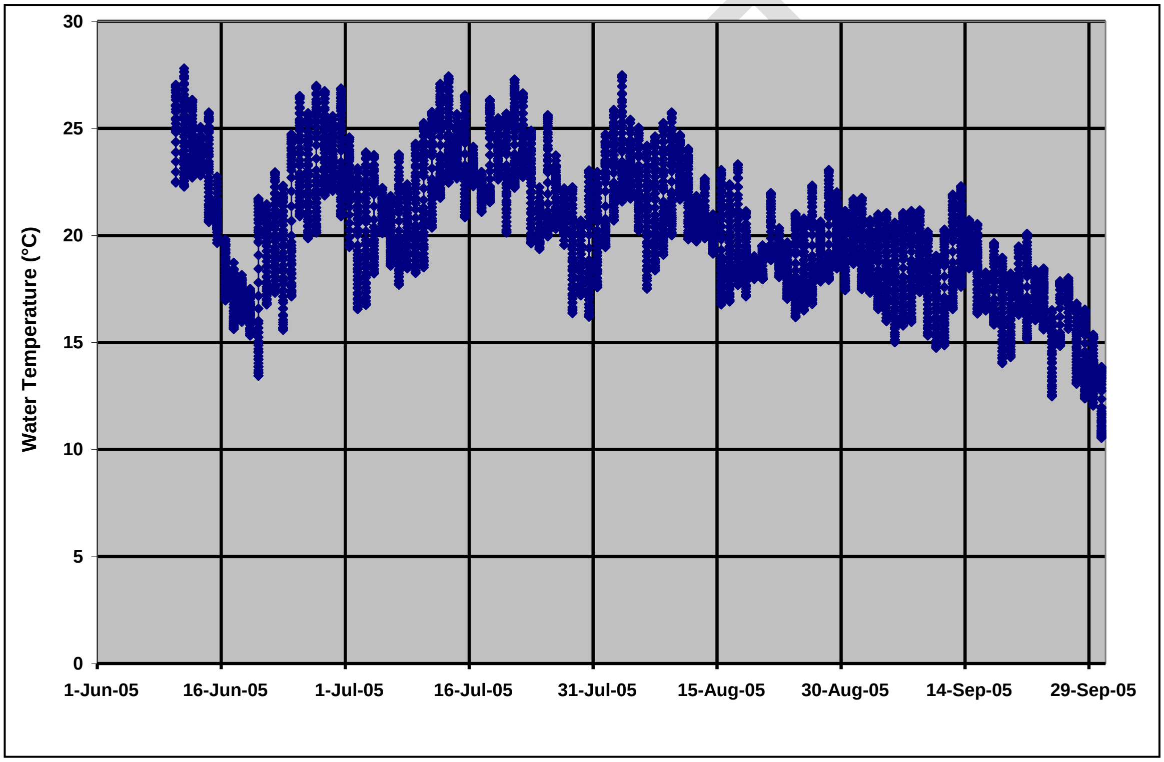


Figure 4.6.10 Water temperature measurement from temperature logger deployment at Shaws Creek at Bruce Trail

Water temperatures were well below the maximum air temperatures observed during the time period of both the June Hydrolab survey (max. air T ≈ 34.6 °C) and August Hydrolab survey (max. air T ≈ 33.8 °C) (www.ec.gc.ca). All sites are classified as coldwater fisheries habitat according to the Credit River Fisheries Management Plan (OMNR and CVC 2002). Two targets are recommended for water temperature: the average daily summer maximum (20°C) and the overall summer maximum temperature (26°C). The average daily summer maximum temperatures and the percent violations over the 26°C target are presented in .

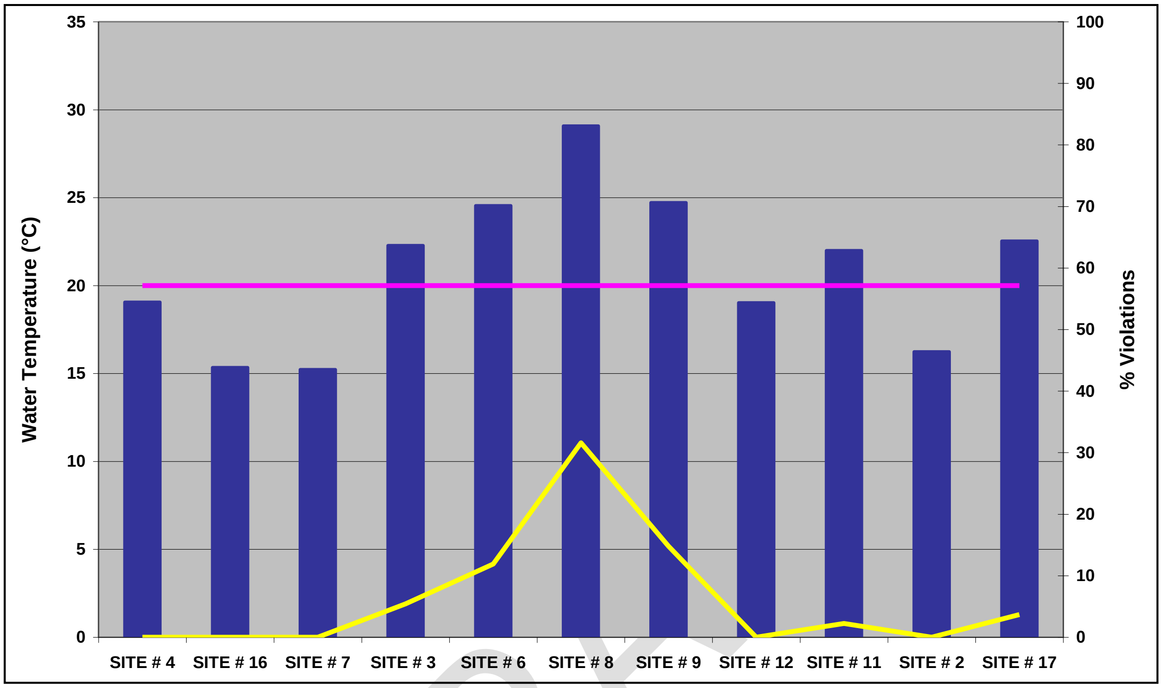


Figure 4.6.11 Average Daily Maximum Temperature (■), % Violations over 26°C (—), Coldwater Fisheries Guideline (—).

Site 8 had the highest number of temperature violations over the 26°C guideline for coldwater fish habitat. Site 8 also had the highest average daily summer maximum temperature (29.07°C), although it should be noted that this only accounts for data up to August 11, the date on which the logger was removed. As air temperature is typically lower in the summer, the value reflected is probably somewhat higher than the full summer's average daily maximum temperature. Other sites with average daily maximum temperatures exceeding the 20°C target include: Sites 3, 6, 9, 11, 17. The summer of 2005 had markedly high air temperatures with the closest gauge (Island Lake Conservation Area) recording 13 days with temperatures over 30°C. Water temperatures for 2005 were influenced by these high air temperatures. Other factors that may have contributed to the relatively high temperatures recorded at these sites could include a reduced volume and velocity of the water, reduced riparian cover, and the presence of upstream ponds (e.g. Caledon Lake upstream of Sites 6 and 8; pond upstream of Site 9). Site 7 had the lowest average daily summer maximum. However, its analysis is based on data beginning August 11 so the true average summer maximum temperature is probably higher than the value observed (15.22°C). Other sites with low average daily summer maximum temperatures include Sites 16 and 2. The ability of these sites to attenuate water temperatures during hot summer air temperatures suggests substantial groundwater input into these channels.

Chlorides and Conductivity

Chlorides tend to show an increasing trend throughout the Credit River watershed. Sources of chlorides (Cl^-) include loadings from STP effluents and road salting practices for ice in the winter (NaCl) and as a dust suppressant ($CaCl_2$) on dirt roads in the summer. Because chloride has a high solubility and is a conservative parameter, it can readily move through groundwater systems and into surface waters through runoff or groundwater discharges (Bowen and Hinton, 1998). Chloride does not have a freshwater guideline for the protection of aquatic biota however the current aesthetic drinking water quality objective for chloride is 250 mg/l (MOE, 2003) which is within the range of the lowest concentrations observed to be harmful to aquatic biota (Environment and Health Canada, 2000). Chloride levels at the Shaws Creek at Bruce Trail () do not appear to fluctuate seasonally and are well below the DWQO of 250 mg/L.

Table 4.6.16 Results of statistical analyses for chlorides at Shaws Creek at the Bruce Trail

Common Time Period 2002-2005	
	Choride mg/L
DWQO	250
Summer Mean	26.42
Fall Mean	24.15
Spring Mean	24.95
Winter Mean	26.19
50th	25.7
75th	26.8
Percent Violation	0

Results from the 2005 field season showed higher chloride levels, in general, for the upper portion of the subwatershed (**Table 4.6.17**). The upper portion of the subwatershed may have a lower population density, it is located downstream of Orangeville where development and anthropogenic activities are influencing the watercourse. Road salting, agriculture run-off, industry wastewater, and effluent from WWTP may be responsible for the chloride traces found. These averages, collected during the summer season only, would most likely be higher if winter sampling had been included in the study.

Table 4.6.17 Average chloride results from the 2005 fieldwork

Station ID	Description	Average (mg/l)
Site 4	At Townline between A Line & B Line	42.20
Site 3	Upstream of Caledon Lake	56.68
Site 16	At Townline b/w Shaws Cr Rd & A Line	15.94
Site 6	Downstream of Caledon Lake At Field Centre	27.38
Site 7	Upstream of Shaws Creek Road	9.00
Site 2	Tributary downstream of 136	20.68
Site 17	Upstream of 136	24.94
Site 9	Downstream of Cedar Falls' confluence	26.18
Site 11	Upstream of Highpoint Rd- E of Shaws Cr Rd	19.94
Site 12	At Highpoint SdRd- W of Shaws Cr Rd	10.20

Microbiological

E. coli is a bacterium found in the intestinal tracts of humans, birds, and other mammals. It therefore indicates the presence of fecal matter in the water and has been used to estimate the likelihood of the existence of pathogenic bacteria in a water body. As the concentrations of *E. coli* increase, so does the risk of becoming ill due to pathogenic bacteria in the water. The PWQO for *E. coli* is 100 counts/100 ml for human recreational uses of water, such as swimming and boating. Since the drinking water objective for *E. coli* is zero, no natural water body should be considered suitable for drinking water without disinfection.

The statistical results from the *E. coli* dataset are presented in **Table 4.6.18** and depict summer and fall exceedances of the PWQO, Geometric means (or geomeans) are used to measure 'average' bacteria values since this bacterial growth occurs at a logarithmic scale. The highest concentrations were observed in the summer, as would be expected, due to increased recreational and biological activity from such sources as waterfowl, domestic animals and livestock occurring in and around watercourses.

Table 4.6.18 Results of statistical analyses for *E. coli* at Shaws Creek at the Bruce Trail

Common Time Period	
2002 - 2005	
PWQO	100 (CFU/100ml)
Summer Mean	185.85
Fall Mean	177.90
Spring Mean	39.30
Winter Mean	13.71
Geomean	49.44
Percent Violation	27.50

The highest geometric mean from the stations sampled through the 2005 field season was Site 17 which is upstream of 136 and Site 2, downstream of 136, as shown in . Eight of ten sites experienced geomeans exceeding 100cts/100ml. Possible sources of the elevated levels include upstream agricultural sources, urban runoff and from human sources (septic impacts).

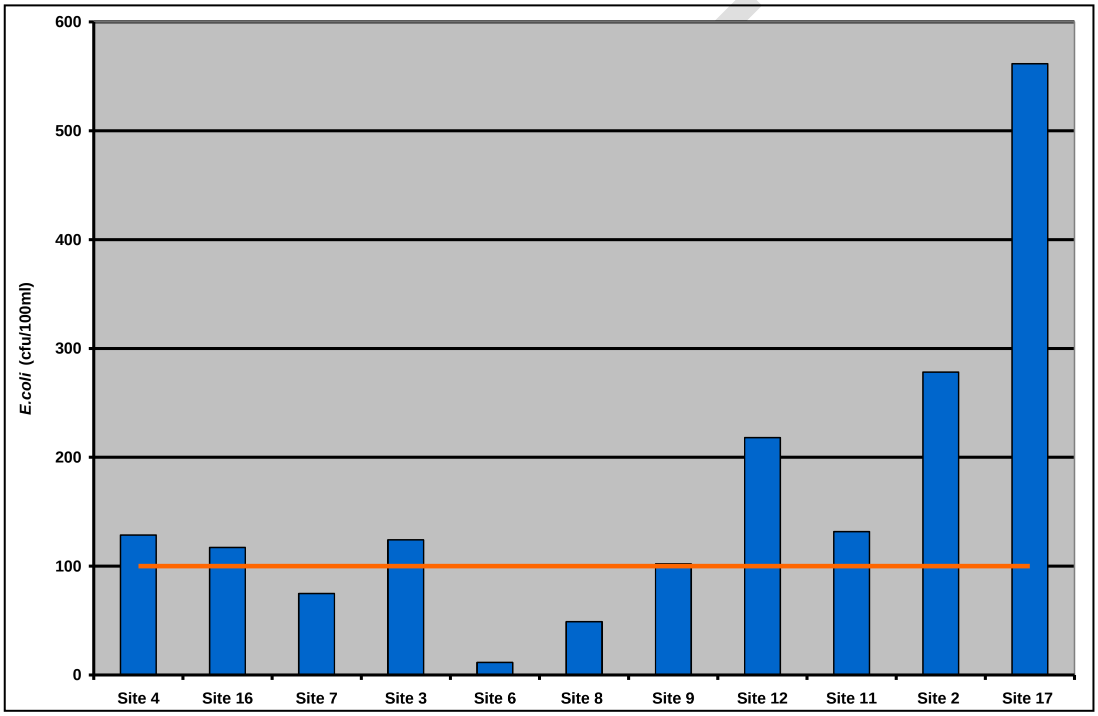


Figure 4.6.12 Geomean E. coli results from the 2005 fieldwork

4.6.4 Long Term Water Quality Characterization

To assess the overall water quality at Shaws Creek at the Bruce Trail, we examined individual parameters were examined as they relate to their respective objectives and guidelines. As well, this data was analyzed using the Canadian Council of Ministers of the Environment's revised Water Quality Index (CCME, 2001). This index takes type and size of waterbody into consideration when assessing the data and recommends 4 consecutive years of data was included with at least 4 comparable parameters throughout those 4 years (**Figure 4.6.13**).

For this analysis, metals (copper, aluminum, iron, zinc and chloride), nutrients (TP and nitrate) and bacteriological (*E. coli*) data from Shaws Creek at Bruce Trail were examined from January 2002 until September 2005. This analysis provides the user with an annual average for an overall score based on excursions, number and variability of samples.

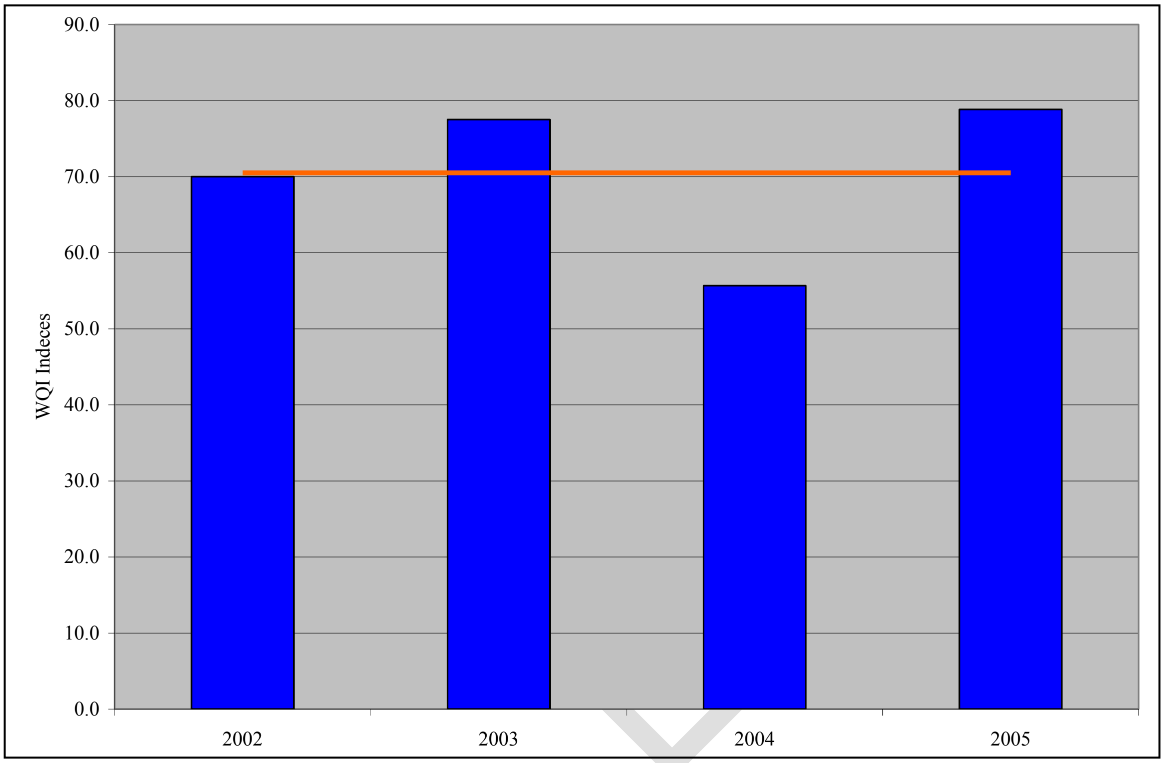


Figure 4.6.13 WQI results (■) and average (—) at the Bruce Trail station of Shaws Creek

According to this index the average water quality in Shaws Creek at the Bruce Trail station is fair. 2004 experienced a lower rating due to repeated excursions of more than 10 times the objective. The overall majority of excursions appeared with *E.coli* although zinc exceeded the PWQO on several occasions throughout the 4 years of data.

4.6.5 Sediment Chemistry Sampling

Sediment chemistry monitoring was conducted in the 2004 and 2005 field season at the Bruce Trail site while Sites 2, 3, 6, 9, 11 and 16 were sampled once in 2005. These sites were chosen in the upstream vicinity of Alton and major tributaries of Shaws Creek. This analysis allows a deeper look into the historical chemical compounds employed, their mobility and ability to bioaccumulate. Bioaccumulation occurs in the sediments which are consumed by benthic macroinvertebrates. These benthic invertebrates are then consumed by larger predators such as fish that are then consumed by carnivorous animals and humans. Bioaccumulation occurs with metals, Polychlorinated Biphenyls (PCBs), Phenanthrene (PAHs), and Organo-Chlorides (OC), all of which are explained in further detail below. These results are compared against 4 standards described below:

- **Federal Probable Effect Level (PEL)** - level above which adverse effects are expected to occur frequently (CCME. 1999).
- **Federal Threshold Effect Level (TEL)** – concentration below which adverse biological effects are expected to occur rarely (CCME 1999).
- **Provincial Severe Effect Level (SEL)** – level in sediments that could potentially eliminate most of the benthic organisms (MOE, 1993).
- **Provincial Lowest Effect Level (LEL)** – level at which actually ecotoxic effects become apparent. It is derived using field based data on the co-occurrence of sediment concentrations and benthic species (MOE, 1993).

Polychlorinated Biphenyls (PCB)

PCBs were commonly used as ballast in electrical equipment such as transformers and capacitors due to their chemical stability. Althought the use of PCBs has been severely restricted in North America over the last two decades, the main sources to aquatic environments continue to be leaks, spills, municipal and industrial effluents, runoff from contaminated soils, leachates from unsecured landfills, and atmosphere deposition (WHO, 1992). Like many other organochlorine compounds, PCBs are persistent, bioaccumulative and toxic. Once released into the environment PCBs tend to change composition and bind to sediments. The majority of PCBs that are introduced into the aquatic environment are eventually incorporated into bed sediments (Baker et al., 1985). Therefore, sediment represents an important exposure route for aquatic biota to PCBs. They are the cause of the majority of the fish consumption advisories in each of the Great Lakes and are considered a priority pollutant by many authorities. Displayed in **Figure 4.6.14** below, are all sites sampled listed in order as they appear in the subwatershed from north to south. A blank indicates a non-detect.

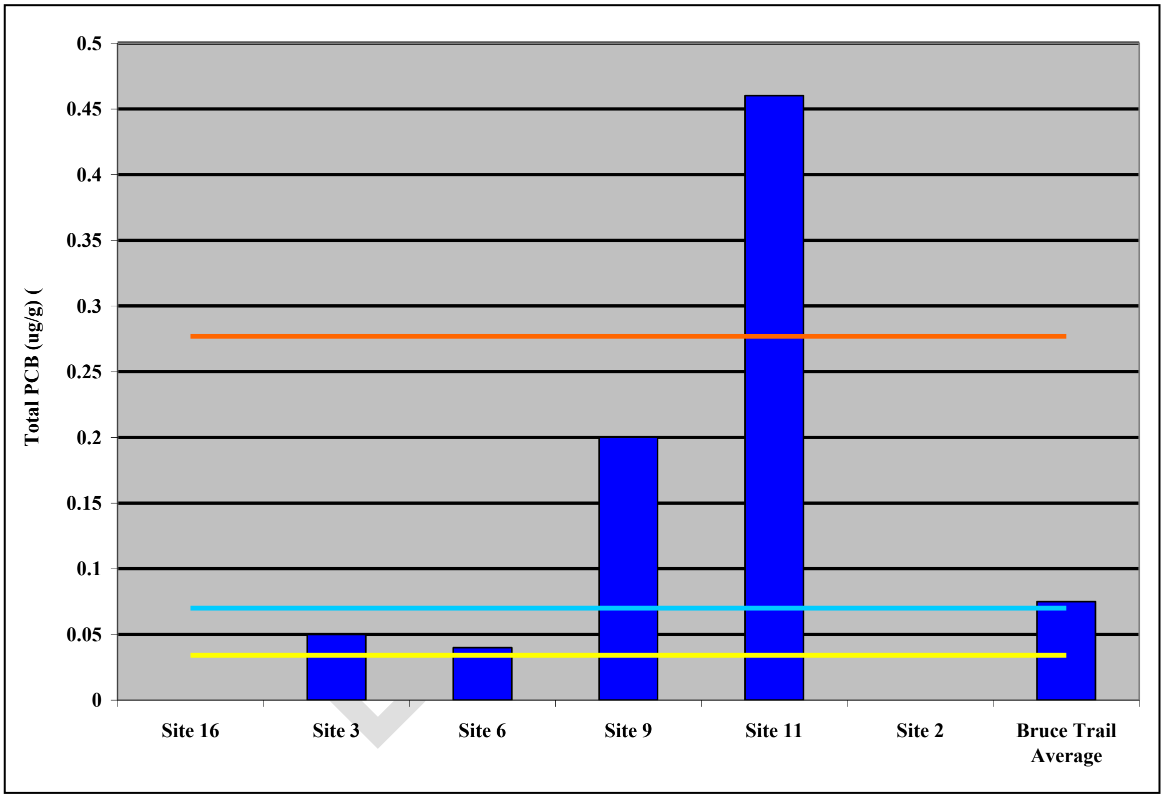


Figure 4.6.14 Results of sediment chemistry sampling focusing on PCB concentrations throughout the subwatershed. Total PCBs (■), Probable Effect Level (—), Threshold Effect Level (—), and Lowest Effect Level (—).

Arsenic

Arsenic is a metalloid and non-essential trace element. Its release from anthropogenic sources is mainly from gold and base metal refining facilities, with smaller releases from the use of arsenical pesticides, wood preservatives, coal-fired power generation and disposal of domestic and industrial waste (Environment Canada, 1993 All arsenic concentrations were well below the LEL but still present in the sediments throughout the subwatershed (

).

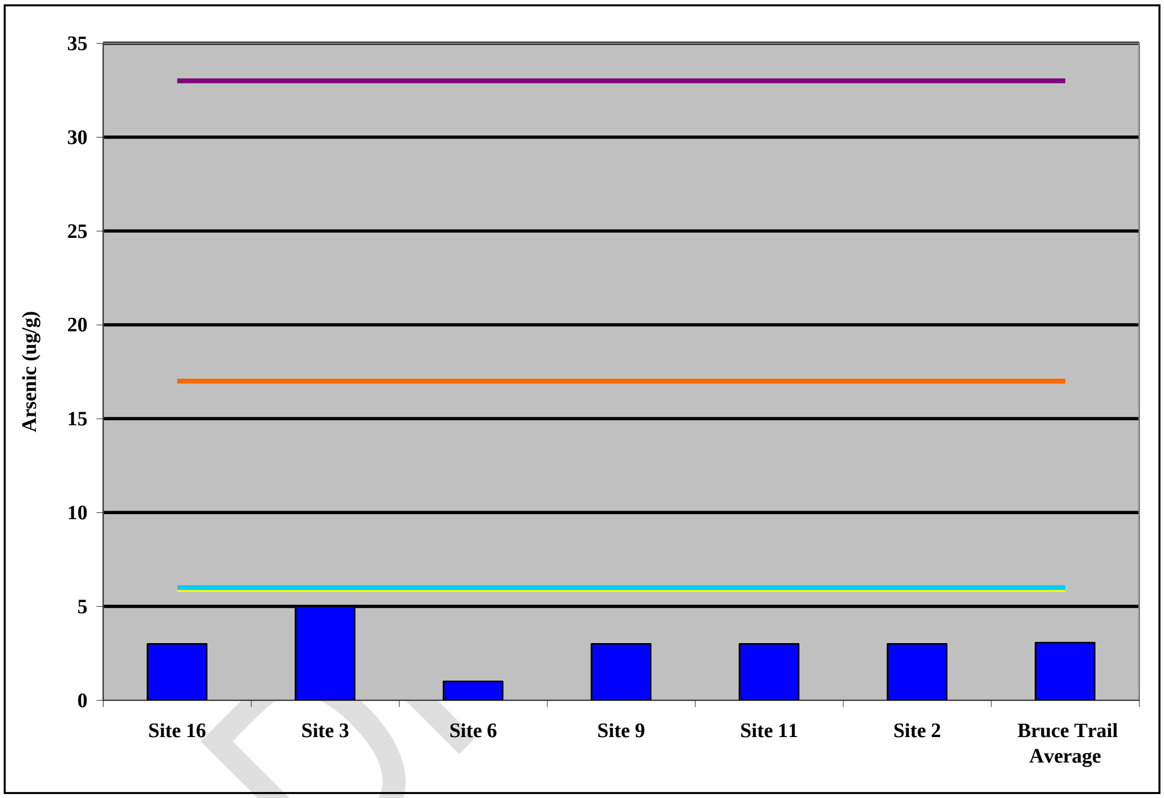


Figure 4.6.15 Sediment Arsenic Concentrations (■),Threshold Effect Level (—), and Lowest Effect Level (—),Probable Effect Level(—), Severe Effect Level (—)

Copper

Although copper is an integral part of all plant and animal life and is not directly toxic, when found in high concentrations for extended periods of time it is known to have chronic effects. Toxicity of copper is dependent on water temperature, hardness and alkalinity. Anthropogenic sources of copper in the environment are related to textiles, electrical products, smelting operations, copper plumbing and equipment. Only sites 3 and 6 remained below the Lowest Effect Level for copper concentrations while The Bruce Trail Site had average concentrations above the Threshold Effect Level ().

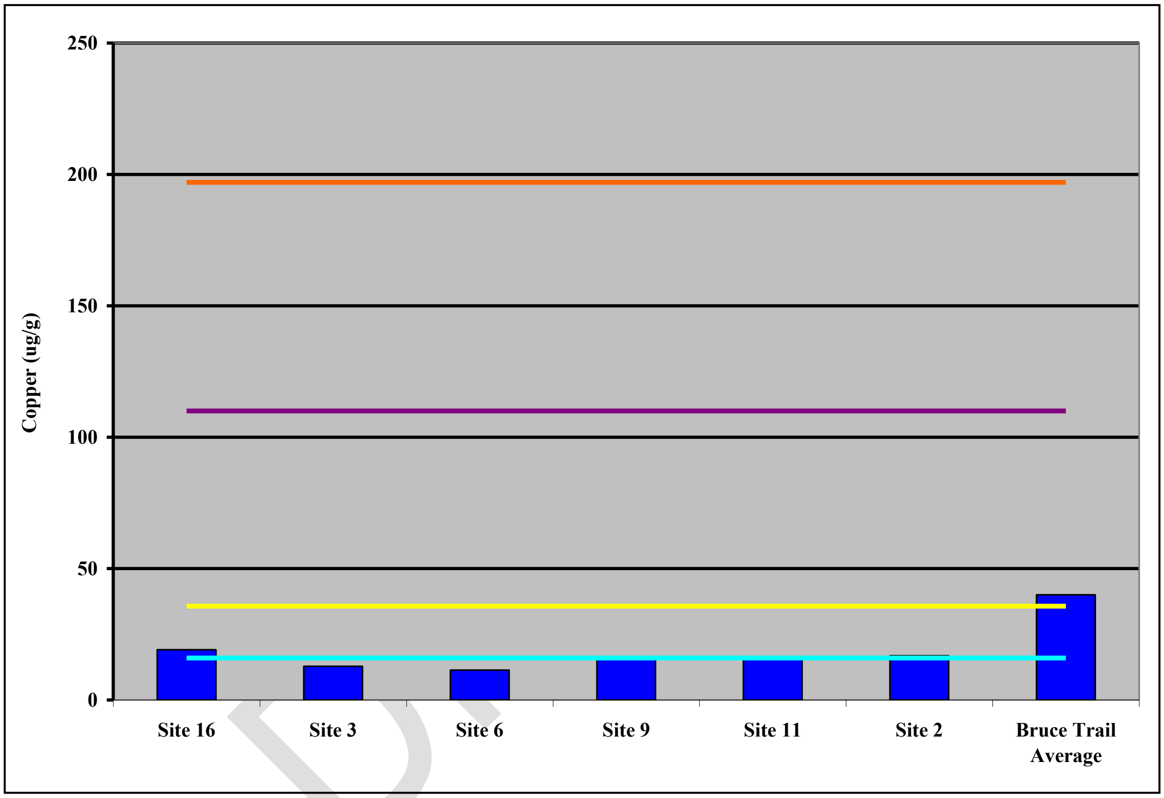


Figure 4.6.16 Sediment Copper Concentrations (■),Threshold Effect Level (—), and Lowest Effect Level (—),Probable Effect Level(—), Severe Effect Level (—)

Mercury
Mercury is a non-essential trace element that is toxic, persistent and bio-accumulative. Fish consumption advisories are in effect for mercury in much of the Great Lakes ecosystem. Current uses of mercury include some batteries, dental fillings, thermometers and switches, cathode tubes and household cleaners. Anthropogenic sources of mercury to the environment include mining and smelting, wastewater, fossil fuel combustion and waste incineration.

Mercury is a well known contaminant found in the tissue of larger predator fish and therefore guidelines have been set on consumption limits for humans. Mercury has a tendency to move through the food chain and bio-accumulative at higher trophic levels Therefore elevated concentrations found in the larger fish threaten the health of humans who are consuming these game species. Mercury concentrations at the long-term and short-term monitoring stations are shown in

Figure 4.6.17.

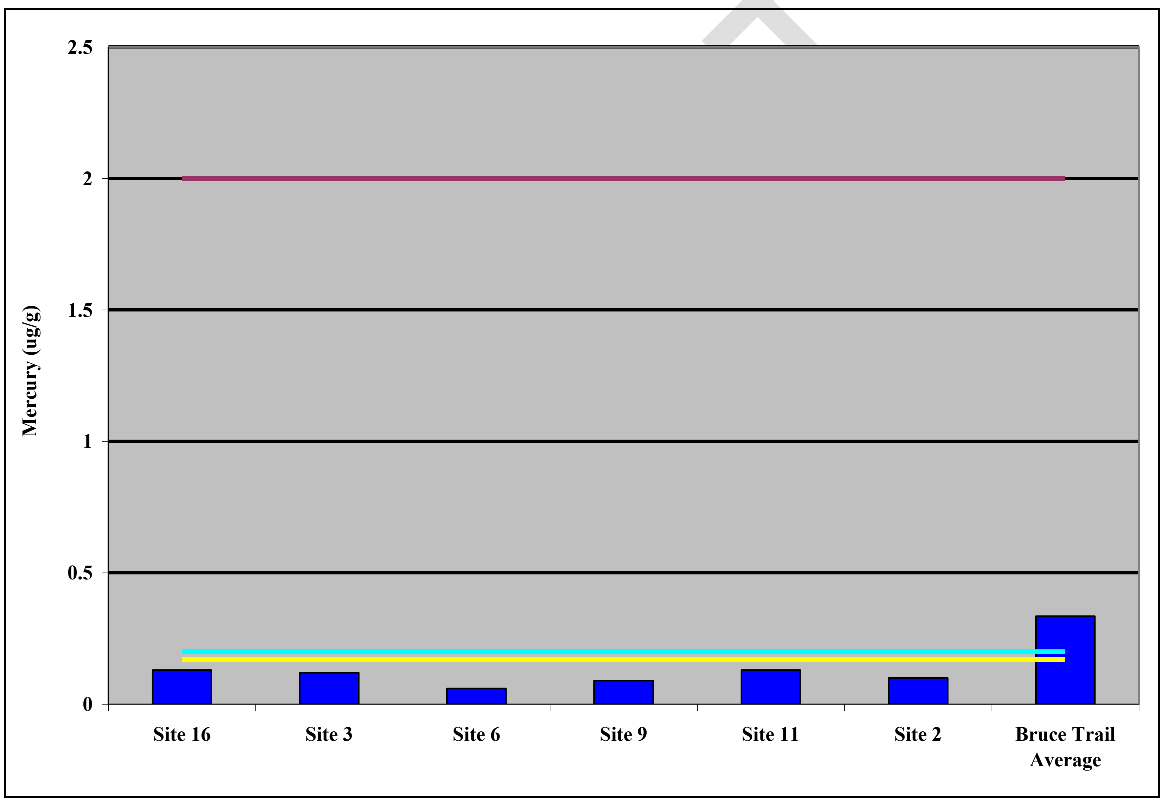


Figure 4.6.17 Mercury (■), Probable Effect Level, Threshold Effect Level (—), Lowest Effect Level (—) and Severe Effect Level (—).

Polycyclic Aromatic Hydrocarbons (PAHs) and Organochlorines (OC)

Polycyclic aromatic hydrocarbons are produced during the incomplete combustion of organic substances, most commonly the combustion of fossil fuels. As an indicator of human industrial activities, PAH contamination is relatively widespread throughout the Great Lake Basin. This study included an analysis of 15 different PAH chemicals. Five PAHs were detected at two stations in the subwatershed, all at concentrations well below the Lowest Effect Level.   portrays Phenanthrene (1 example of the 5 PAH species) that was found at two sites in the watershed.

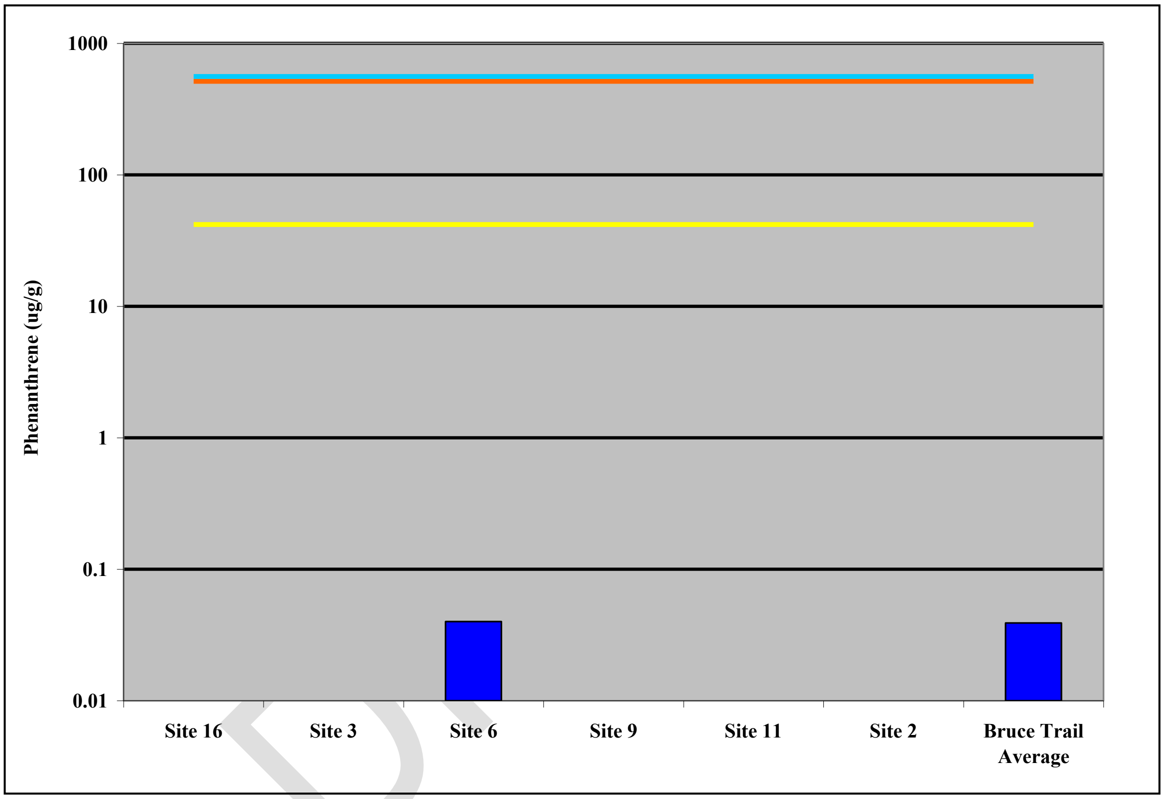


Figure 4.6.18 Sediment Phenanthrene Concentrations (■), compared with the Threshold Effect Level (—), and Lowest Effect Level (—), and Probable Effect Level (—)

The study also tested for a broad range of organochlorines including DDT and metabolites, and other common pesticides (Dieldrin, Chlordane, Endosulfate, Lindane and Mirex). These chemicals were all utilized for their pesticide properties, ranging from a broad spectrum pesticide to specific target receptors. All data indicate non-detect levels for all OCs in Shaws Creek watershed.

4.6.6 Summary

Overall, the water quality in Shaws Creek subwatershed is good in terms of supporting healthy aquatic biota. In general, the tributaries that flow in a north-easterly direction towards the main branch of the Shaws Cheek meet the selected water quality standards with the notable exceptions:

1. The long-term monitoring data indicates that Shaws Creek is not a Policy 2 watercourse with respect to total phosphorus, as concentrations fell below the PWQO set by MOE. Although the short term site 3 exhibited elevated levels of total phosphorus. Longer term study would need to be conducted to determine if it is in a Policy 2 situation and to isolate possible sources.

2. Nitrite levels across the subwatershed were rarely measured above the CCME guideline and violations of the un-ionized ammonia PWQO (based on chronic exposure) are non-existent. A notable exception is site 16 in the northern part of the watershed, where nitrate results exceeded the CCME guideline during 75% of the sampling occasions.

3. Based on the observed low violations of the PWQOs for metals, pollution from metals is not considered to be a significant concern for most of the subwatershed. A notable exception is Site 3 (below Orangeville) which exhibited elevated levels of most metals compared to other sites throughout the subwatershed and regularly exceeds water quality guidelines. These elevated levels suggest Shaws Creek is being impacted by the developments to the north through surface and groundwater connections.

4. The dissolved oxygen and temperature regime is relatively healthy in the Shaws Creek subwatershed. There were no measured exceedances of the dissolved oxygen guideline. The greatest daily fluctuations were noticed at Site 8 at Mississauga Road, as the dissolved oxygen regime at this location is heavily influenced by the inputs of low DO stream flow from near-by Caledon Lake. The coolest water temperatures occured in the upper portion of the subwatershed and in the groundwater fed tributaries. The warmest water temperatures were seen in watercourses influenced by Caledon Lake and in tributaries with slow flow rates draining into wetlands.

5. Chlorides were below levels thought to be deleterious to aquatic life but the increasing trends observed in the long-term data and the higher values observed in the lower, more urbanized portion of the subwatershed are a concern for future urban development. It is important to note that samples were collected during the summer season only. Results mostly likely would be higher if winter sampling had been included in the study.

6. Bacterial levels as indicated by *E. coli*, were generally above what is considered to be acceptable levels for recreational uses, through the watershed. Site 17, upstream of Hwy 136 recorded the highest levels, with concentrations over five times the acceptable limits for recreational uses. Possible sources of the elevated levels include upstream agricultural sources, urban runoff and from human sources (septic impacts).

7. Suspended solids concentrations at the longer term Shaws Creek station at Bruce Trail exhibited values below levels thought to be deleterious to aquatic life. Suspended Solids concentrations were highly variable at the short term stations over the study period. There was not sufficient information to accurately characterize suspended solids levels at the short term stations.

8. Sediment Chemistry results were generally indication of a health aquatic environment with minimal point source impacts. There was no indication of heavy metals or hydrocarbon accumulation in the subwatershed. PCB's were found at one site above the probably effect level which indicate adverse effects are expected. Exact sources of the PCBs are difficult to determine as they persist and accumulate in the sediment over long time periods.

4.7 BENTHICS

4.7.1 Introduction to Benthic Macroinvertebrates

Benthic macroinvertebrates are larger-than-microscopic organisms that live on a stream bottom. Examples of benthic invertebrates include aquatic insects, worms and crayfish. Benthic macroinvertebrates are a commonly used indicator group of aquatic environmental conditions for several reasons. First, they integrate biologically relevant variations in water and habitat quality. Second, they are limited in their mobility and therefore reflect local conditions and can thus be used to identify point sources of inputs or disturbance. Their short life spans (about 1 year) also allow them to integrate the physical and chemical aspects of water quality over annual time periods and provide early warning of impending effects on fish communities (Kilgour and Barton, 1999). Finally, based on known tolerances of benthic taxa, it is possible to re-create the environmental conditions determining the animals present (Rooke and Mackie, 1982a,b).

As part of the Phase I Study in support of understanding the ecology and functions of Subwatershed 17, surveys of benthic macroinvertebrates were undertaken at 10 representative locations. These data were used to characterize the existing condition of the benthic community, and will be used during Phase II (Impact Assessment) of the subwatershed study for identifying reaches and subcatchments that are potentially sensitive to proposed land use changes.

Amphipoda

Chironomidae

Coleoptera

Trichoptera

Ephemeroptera2

Figure 4.7.1 Benthic Macroinvertebrates commonly found in the Shaws Creek Subwatershed

4.7.2 Reference Condition Approach

The objective of the Subwatershed 17 benthos analysis was to determine the condition of the benthic community relative to a reference condition. The expected condition can be determined by quantifying conditions in areas known to be unaffected by human development. In urbanizing areas, it is difficult to classify sites as “reference” because there is inevitably some degree of urban or agricultural development. Conditions throughout CVC’s jurisdiction are no exception.

Kilgour and Stanfield (2006) recently described an approach for estimating the pre-development biological condition using gradients of disturbance. In an analysis of benthic and fish data from throughout the southern Ontario region, they used a gradient of imperviousness (land development index) as a measure of the amount of urban development in the catchments upstream of sites at which there were collections of benthic and fish communities. Multiple linear regression equations were used to model relationships between metrics of benthic community composition and the land-development index (LDI). Those models were then used to predict the index values for an assumed historical condition based on 100% forest cover.

Credit Valley Conservation has been collecting benthic community data for the past seven years at a number of locations. Though many locations are considered in good condition, classifying them as reference sites is difficult because they have experienced at least a minimal amount of development. Hindcasting was used here to provide pre-development estimates of indices of benthic community composition, and to quantify the degree of deviation from that pre-development condition for all sites in the CVC long-term monitoring network, as well as those from Subwatershed 17. It should be noted that this is a relatively new approach to analyzing a biological condition and that there has been limited application in this region.

4.7.3 Methodology

In this study, benthic macroinvertebrates were sampled at a total of ten stations (**Figure 4.7.**). Two of these stations (501070001 and 501070003) are sampled annually as part of CVC's Integrated Watershed Monitoring Program and data exist at these stations for 1999-2005 and 2004-2005, respectively. The additional eight stations were sampled in 2005 only and were chosen specifically for this study. Site selection was based on landowner permission, spatial distribution among catchment areas and relative position upstream or downstream of impoundments.

Field Procedure

Samples were collected in July or August to correspond with the period during which benthic sampling has traditionally been conducted by CVC. There is good evidence that samples from mid-summer are indicative of limiting conditions. That is, when sites are impaired, samples collected in mid summer will show impairment to a greater degree than will samples collected in either spring or fall (Barton, 1996).

At each of the 10 stations, a single composite traveling kick sample was collected from all microhabitats in the sampled stream reach (riffle, run and pool) following the methodology proposed by Reynoldson et al. (1999). Samples were collected and washed in a D-framed net with 500-μm mesh. Each sample was preserved on site using 10% buffered formalin.

Laboratory Procedure

In the laboratory, samples were rinsed and filtered to remove excess formalin and silt. A minimum of 300 animals was removed and identified. Sorted individuals were identified to lowest practical levels using current taxonomic literature.

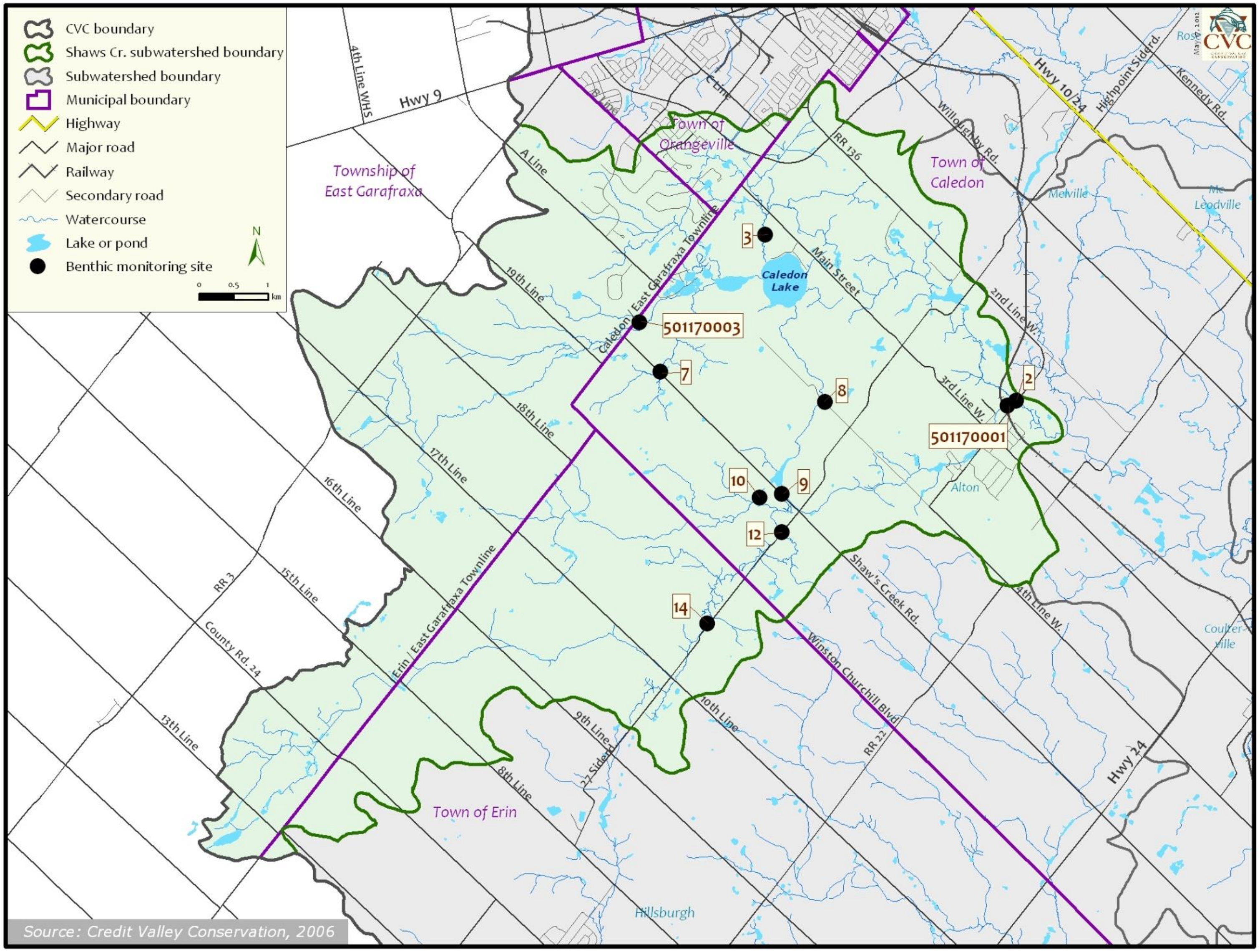


Figure 4.7.2 Benthic Macroinvertebrate Sampling Stations

4.7.4 Data Analyses

4.7.5 Results and Discussion

A number of summary metrics of benthic community composition were calculated including Hilsenhoff's biotic index (HBI) (Hilsenhoff, 1987), number of taxa (richness), % EPT (mayflies, stoneflies, caddisflies), % Oligochaeta (worms), % Chironomidae (midges) and % Isopoda (sowbugs). These indices have been used by CVC for the past seven years as general descriptors of benthic communities. The Hilsenhoff biotic index was calculated as follows:

$$HBI = \frac{\sum t_i n_i}{\sum n_i}$$

where t_i is the tolerance of taxon *i* to organic enrichment and n_i is the number of taxon *i* in the sample. Hilsenhoff's index was originally designed to reflect nutrient status with values ranging between 1 (pollution sensitive taxa dominant) and 10 (pollution tolerant taxa predominate). Taxa tolerance values used in this assessment were taken from Bode (1988) and Hilsenhoff (1988).

The number of taxa is normally high in waters with good water quality, as is the percentage of the community dominated by EPT taxa. Percent Oligochaeta, Chironomidae, and Isopoda (all relatively tolerant groups) tend to increase in watercourses with degraded water quality. A definition of each of the indices as well as the direction of the index response to disturbance are presented in **Table 4.7.1**.

Table 4.7.1 Definitions of indices used and respective directional response to disturbance

Index	Definition	Direction of Response to Disturbance
Hilsenhoff biotic index (HBI) (Hilsenhoff, 1987):	A measure of organic enrichment based on species tolerance values	Increase
% EPT	Proportion of the sample represented by Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) taxa. These taxa are generally considered to be sensitive to pollution	Decrease
Taxa Richness	Number of taxa represented in the sample	Decrease
% Oligochaeta	Proportion of the sample represented by oligochaete worms	Increase
% Chironomidae	Proportion of the sample represented by chironomid taxa (midge flies)	Increase
% Isopoda	Proportion of the sample represented by isopod taxa (sow bugs)	Increase

CVC provided estimates of percent imperviousness in the catchment upstream of each site where benthos were collected, while the Ontario Ministry of Natural Resources provided estimates of catchment area, baseflow index and slope of the stream 100 m upstream to 100 m downstream. Those landscape attributes are considered fundamental and reflect the "template" conditions that influence natural assemblages in streams. Catchment area influences flow volumes. Baseflow index is a measure of the likelihood of high volumes of baseflow, and is based on the surficial geology in the upstream catchment. Baseflow is considered a good determinant of stream temperatures during winter and summer. Slope of the stream reach influences water velocities. These landscape attributes were all "extracted" from digital map layers using GIS-based queries as described in Stanfield and Kilgour (2006). Imperviousness estimated using 2004 landcover information was used, except for sites within subwatershed 17 that were not part of CVC's long-term monitoring program, in which case the MNR measures of land use disturbance (LDI) based on landcover from 1990 were used. Development pressures within subwatershed 17 have been minimal, so the LDI from the MNR data layer is assumed here to adequately approximate what would have been obtained by CVC using the 2004 data layer.

Multiple regression was used to construct models relating indices of benthic community composition (for 2005) and the four landcover attributes (imperviousness, catchment area in m2, baseflow index and stream slope). Catchment area was log transformed because it spanned a number of orders of magnitude. Regression models included the squared terms of each of the four attributes to take into account curvilinear relationships (as per Kilgour and Stanfield, 2006). Models retained predictors only when they accounted for significant variability in benthic metrics ($p<0.05$). The MSE from these models provides an estimate of the residual, unexplained variability. The square root of the MSE is an estimate of the among-sites standard deviation (SD).

Regression models were used to estimate the pre-development benthic index values for each site assuming 100% forest cover (0% imperviousness). Deviations from the predicted historical condition were expressed relative to the estimated among-sites standard deviation (SD from above). This form of expressing effect sizes has been used since about 1997 in federal monitoring programs (Lowell, 1997; Environment Canada, 2005) and is useful because it puts all indices (metrics) on a common scale of measurement. Deviations exceeding about 2 SDs can be considered evidence of potential impairment, while those in excess of about 3 SDs are more likely indications of probable impairment relative to the pre-development reference condition.

4.7.6 Results and Discussion

Since 1999, close to 250 distinct taxa have been identified through CVC's benthic sampling of Shaws Creek, with seventeen major taxonomic groups represented. The highest number of individuals came from the following taxa groups (listed in order of dominance): Chironomidae (midge flies), Ephemeroptera (mayflies), Coleoptera (beetles), Trichoptera (caddisflies), and Amphiphoda (scuds). Scores for the six chosen indices from above and proportions of major taxonomic groups are listed in **Table 4.7.2**.

Table 4.7.2 Index scores and major taxa groups found at stations in Shaws Creek from 1999-2005

STATION	501170001							501170003		2	3	7	8	9	10	12	14
YEAR	1999	2000	2001	2002	2003	2004	2005	2004	2005	2005	2005	2005	2005	2005	2005	2005	2005
HBI	5.22	4.63	4.63	5.15	5.01	5.03	4.74	5.63	4.95	5.50	6.90	6.00	7.09	4.55	6.49	4.94	6.51
Taxa Richness	49	41	55	46	43	31	60	28	28	56	50	34	41	51	26	45	60
% EPT	27	52	57	35	51	44	47	36	24	20	15	11	19	61	12	54	13
% Oligochaeta	3	2	4	5	3	3	1	2	1	0	2	3	2	1	2	1	0
% Chironomidae	32	17	17	33	17	21	17	34	25	28	16	5	35	12	47	22	27
% Isopoda	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0
%Acarina	0	0	0	1	1	0	5	1	0	0	0	0	0	0	0	0	1
%Gastropoda	5	0	0	1	0	0	0	0	0	1	0	0	8	0	0	0	9
%Bivalvia	2	1	1	0	0	0	0	2	0	6	7	1	2	2	16	3	1
%Ephemeroptera	10	32	37	27	41	36	28	30	15	15	9	8	9	22	2	17	8
%Odonata	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1
%Plecoptera	3	6	3	2	0	3	2	1	5	0	0	0	0	2	3	0	0
%Hemiptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
%Trichoptera	13	14	17	6	10	5	17	5	5	5	7	3	10	37	8	37	5
%Coleoptera	20	19	16	20	24	25	24	2	0	3	25	2	5	17	0	14	8
%Megaloptera	3	2	1	0	2	1	1	0	0	2	1	0	1	4	0	3	4
%Chironomidae	32	17	17	33	17	21	17	34	25	28	16	5	35	12	47	22	27
%other Diptera	7	5	2	5	2	4	5	5	34	28	3	6	0	2	7	1	7
%Oligochaeta	3	2	4	5	3	3	1	2	1	0	2	3	2	1	2	1	0
%Hirudinea	0	0	0	0	0	0	0	0	0	0	1	0	1	0	3	0	0
%Amphipoda	0	0	0	0	0	0	0	16	16	1	28	70	26	0	13	2	30
%Isopoda	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0
%Decapoda	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The models resulting from the statistical analyses are presented in **Table 4.7.3** below, while the estimated pre-development index values, and standardized deviations are presented in **Table 4.7.4** HBI, % EPT, % Oligochaeta and % Isopoda were each related to % imperviousness, while richness and % Chironomidae were not. The average and standard deviation of percent midges from sites with < 5% imperviousness was used as the estimated pre-development condition for that metric.

Table 4.7.3 Model coefficients for equations describing the relationships between indices of benthic community composition and descriptors of landcover

Landscape Predictor	Benthic Metric					
	HBI	Richness	%EPT	%Oligochaeta	%Chironomidae	%Isopoda
Constant	-6.57	-21.5	2.25	-0.051	NO	0.055
Imperviousness	0.059			0.0254	Model	-0.016
Imperviousness^2			-0.0001	-0.0005		0.0007
Log Area	3.615		-0.6129			
Log Area^2	-0.269		0.0472			
Baseflow Index						
Baseflow Index^2						
Slope		44.05				
Slope^2		-7.03				
Model Statistic						
R^2	0.43	0.27	0.23	0.32		0.75
F	14.089	10.79	6.07	13.11		77.62
P	<0.0001	0.0001	0.0014	<0.0001		<0.0001
MSE	0.869	119.5	0.0334	0.0099		0.0056
SD	0.93	10.9	0.18	0.099		0.075
N	52	54	52	52		52

Table 4.7.4 Observed and predicted index values, for six indices of benthic community composition, as well as estimated effect sizes (deviations from a reference condition expressed as standard deviations).
Yellow highlighted cells indicate deviations from the predicted pre-development condition in excess of 2 SDs, while red highlighted cells indicate deviations exceeding 3 SDs. BFI = Base Flow Index; Obs = observed values from field studies in 2005; Pred = values predicted for the pre-development condition, based on specific landscape attributes for that site (e.g., slope, area); ES = effect size, or the deviation from predicted standardized by division over the among-sites standard deviation (SD).

					Hilsenhoff			Richness			% EPT			% Oligochaeta			% Chironomidae			% Isopoda		
Station	IMP04	Area (m^2)	BFI	SLOPE	Obs	Pred	ES	Obs	Pred	ES	Obs	Pred	ES	Obs	Pred	ES	Obs	Pred	ES	Obs	Pred	ES
501020001	36	5,788,068	39	1.78	7.24	5.63	1.74	15	35	-1.82	0.31	0.26	0.27	0.02	0.00	0.21	0.04	0.23	-1.38	0.57	0.04	7.06
501030003		1,916,348	39	2.09	7.61	5.58	2.19	18	40	-2.02	0.16	0.26	-0.56	0.00	0.00	0.01	0.01	0.23	-1.64	0.80	0.04	10.16
501040001	41	24,107,337	38	1.74	8.01	5.51	2.68	28	34	-0.56	0.02	0.30	-1.54	0.15	0.00	1.54	0.03	0.23	-1.47	0.69	0.04	8.63
501040004	44	117,338	40	1.43	7.07	4.90	2.34	29	27	0.15	0.12	0.36	-1.28	0.02	0.00	0.16	0.08	0.23	-1.13	0.63	0.04	7.94
501050001	29	19,829,646	39	1.45	9.02	5.54	3.74	26	28	-0.17	0.01	0.29	-1.55	0.65	0.00	6.48	0.13	0.23	-0.75	0.14	0.04	1.36
501050004	36	34,205,169	39	1.54	9.10	5.45	3.92	16	30	-1.27	0.00	0.31	-1.71	0.33	0.00	3.29	0.49	0.23	1.97	0.15	0.04	1.48
501050005	35	42,094,661	39	1.78	5.88	5.41	0.51	47	35	1.11	0.30	0.32	-0.14	0.01	0.00	0.06	0.38	0.23	1.17	0.05	0.04	0.13
501050008	35	43,097,586	39	1.83	6.54	5.40	1.22	44	36	0.75	0.25	0.32	-0.38	0.06	0.00	0.61	0.37	0.23	1.07	0.06	0.04	0.30
501060002	12	1,199,264	39	1.14	5.09	5.52	-0.45	40	20	1.85	0.36	0.27	0.52	0.00	0.00	0.00	0.29	0.23	0.46	0.01	0.04	-0.36
501070001	4	16,975	39	1.32																		
501070003	4	70,766	39	1.78	6.40	4.69	1.84	33	35	-0.17	0.32	0.39	-0.37	0.00	0.00	0.04	0.41	0.23	1.40	0.00	0.04	-0.53
501090001	6	771,023,230	54	3.19	5.21	4.36	0.91	48	48	0.03	0.43	0.53	-0.55	0.01	0.00	0.15	0.08	0.23	-1.11	0.00	0.04	-0.53
501090002	5	771,023,230	54	3.19	4.57	4.36	0.22	38	48	-0.89	0.31	0.53	-1.21	0.03	0.00	0.32	0.06	0.23	-1.26	0.00	0.04	-0.53
501090003	11	10,534,021	39	1.94	5.28	5.60	-0.34	47	38	0.85	0.66	0.27	2.08	0.01	0.00	0.12	0.10	0.23	-0.94	0.00	0.04	-0.52
501100001	6	84,656,695	64	2.83	5.51	5.23	0.29	50	47	0.27	0.30	0.36	-0.34	0.19	0.00	1.89	0.14	0.23	-0.68	0.00	0.04	-0.53
501110001	9	130,114,620	61	3.06	5.73	5.10	0.67	54	48	0.58	0.21	0.39	-0.98	0.14	0.00	1.41	0.21	0.23	-0.10	0.02	0.04	-0.32
501110002	4	35,013,080	59	3.36	5.33	5.44	-0.13	48	47	0.06	0.39	0.31	0.44	0.08	0.00	0.78	0.13	0.23	-0.76	0.00	0.04	-0.53
501110004	2	20,346,097	63	2.28	4.21	5.53	-1.42	26	43	-1.52	0.45	0.29	0.89	0.00	0.00	0.00	0.23	0.23	0.00	0.00	0.04	-0.53
501120002	2	9,691,780	67	2.19	7.05	5.61	1.55	35	41	-0.59	0.23	0.27	-0.23	0.00	0.00	0.03	0.31	0.23	0.66	0.00	0.04	-0.53
501120003	4	636,453,932	57	3.32	4.47	4.46	0.02	52	47	0.41	0.63	0.51	0.65	0.00	0.00	0.01	0.14	0.23	-0.63	0.00	0.04	-0.53
501120004	4	629,322,095	57	3.33	4.75	4.46	0.31	51	47	0.33	0.60	0.51	0.45	0.00	0.00	0.01	0.16	0.23	-0.50	0.00	0.04	-0.53
501130002	1	3,319,678	69	4.91	4.38	5.62	-1.33	24	25	-0.13	0.48	0.26	1.22	0.03	0.00	0.28	0.11	0.23	-0.84	0.00	0.04	-0.53
501130003	3	4,235,647	69	4.54	4.96	5.63	-0.71	38	34	0.39	0.29	0.26	0.17	0.07	0.00	0.71	0.36	0.23	0.98	0.00	0.04	-0.53
501130004	3	8,669,408	69	4.20	4.99	5.61	-0.67	35	40	-0.43	0.10	0.27	-0.92	0.03	0.00	0.29	0.27	0.23	0.31	0.00	0.04	-0.53
501140001	4	636,499,461	57	3.32	4.40	4.46	-0.07	57	47	0.87	0.52	0.51	0.00	0.01	0.00	0.10	0.03	0.23	-1.48	0.00	0.04	-0.53
501140002	2	16,708,212	51	1.68	6.68	5.56	1.20	30	33	-0.27	0.04	0.29	-1.37	0.04	0.00	0.39	0.62	0.23	2.97	0.00	0.04	-0.53
501150001	3	123,245,034	54	2.77	5.27	5.12	0.16	40	47	-0.62	0.27	0.38	-0.63	0.04	0.00	0.36	0.43	0.23	1.54	0.00	0.04	-0.53
501150003	3	427,086	73	2.84	4.55	5.31	-0.82	57	47	0.90	0.43	0.30	0.76	0.06	0.00	0.64	0.22	0.23	-0.04	0.00	0.04	-0.53
501150005	3	50,024,784	58	2.90	5.45	5.37	0.08	37	47	-0.95	0.20	0.33	-0.74	0.03	0.00	0.26	0.19	0.23	-0.31	0.00	0.04	-0.53

Station	IMP04	Area (m^2)	BFI	SLOPE	Hilsenhoff			Richness			% EPT			% Oligochaeta			% Chironomidae			% Isopoda		
					Obs	Pred	ES	Obs	Pred	ES	Obs	Pred	ES	Obs	Pred	ES	Obs	Pred	ES	Obs	Pred	ES
501160001	2	207,052,976	55	2.70	5.60	4.94	0.70	47	46	0.05	0.38	0.42	-0.22	0.01	0.00	0.09	0.11	0.23	-0.85	0.14	0.04	1.36
501160004	2	11,325,041	27	1.91	5.96	5.60	0.39	36	37	-0.11	0.03	0.28	-1.35	0.02	0.00	0.24	0.16	0.23	-0.48	0.00	0.04	-0.53
501160006	3	7,466,238	27	2.06	4.83	5.62	-0.85	54	40	1.31	0.43	0.27	0.88	0.01	0.00	0.09	0.21	0.23	-0.14	0.00	0.04	-0.53
501180001	5	129,266,159	55	2.92	4.74	5.11	-0.40	39	47	-0.77	0.65	0.39	1.47	0.01	0.00	0.10	0.08	0.23	-1.08	0.00	0.04	-0.52
501180002	5	218,588,002	56	2.64	4.55	4.92	-0.40	61	46	1.37	0.56	0.42	0.72	0.01	0.00	0.07	0.32	0.23	0.69	0.00	0.04	-0.53
501180003	5	218,260,039	56	2.64	5.16	4.92	0.26	68	46	2.01	0.50	0.42	0.42	0.05	0.00	0.49	0.22	0.23	-0.05	0.00	0.04	-0.51
501180006	5	218,249,196	56	2.64	4.45	4.92	-0.50	55	46	0.82	0.58	0.42	0.86	0.02	0.00	0.23	0.11	0.23	-0.88	0.02	0.04	-0.31
501180007	5	218,249,196	56	2.64	4.35	4.92	-0.61	51	46	0.46	0.75	0.42	1.78	0.01	0.00	0.09	0.11	0.23	-0.90	0.01	0.04	-0.46
501190001	22	7,638,198	66	2.29	7.38	5.62	1.89	30	43	-1.17	0.01	0.27	-1.43	0.19	0.00	1.96	0.25	0.23	0.20	0.00	0.04	-0.53
501190008	13	63,571,642	57	2.86	8.09	5.31	2.99	48	47	0.07	0.10	0.34	-1.32	0.50	0.00	4.98	0.16	0.23	-0.51	0.01	0.04	-0.45
501200001	4	347,658,083	56	3.08	4.82	4.73	0.09	53	48	0.49	0.51	0.46	0.27	0.01	0.00	0.07	0.11	0.23	-0.91	0.00	0.04	-0.53
501200004	4	636,453,932	57	3.32	4.41	4.46	-0.05	53	47	0.51	0.30	0.51	-1.15	0.00	0.00	0.04	0.05	0.23	-1.37	0.00	0.04	-0.53
501200005	3	52,625,024	65	4.00	6.99	5.36	1.75	26	42	-1.50	0.03	0.33	-1.66	0.07	0.00	0.69	0.33	0.23	0.77	0.00	0.04	-0.49
501200007	5	129,300,513	55	2.93	4.71	5.11	-0.43	49	47	0.14	0.71	0.39	1.78	0.00	0.00	0.02	0.12	0.23	-0.77	0.00	0.04	-0.53
501200009	4	65,290	39	2.93	4.80	4.65	0.16	55	47	0.69	0.33	0.39	-0.32	0.00	0.00	0.01	0.20	0.23	-0.17	0.00	0.04	-0.52
501220002		30,917,600	46	2.49	7.90	5.47	2.61	27	45	-1.63	0.13	0.31	-0.99	0.28	0.00	2.80	0.47	0.23	1.86	0.07	0.04	0.38
501170001	3	65,418,483	61	2.80	4.74	5.30	-0.60	60	47	1.19	0.47	0.34	0.69	0.01	0.00	0.11	0.17	0.23	-0.44	0.00	0.04	-0.53
501170003	2	12,785,288	50	2.92	4.95	5.59	-0.68	28	47	-1.78	0.24	0.28	-0.20	0.01	0.00	0.06	0.25	0.23	0.18	0.00	0.04	-0.53
501170013	2	71,984,918	62	3.03	5.50	5.28	0.23	56	48	0.76	0.20	0.35	-0.82	0.00	0.00	0.00	0.28	0.23	0.43	0.11	0.04	0.88
501170014	2	30,097,780	60	2.74	6.90	5.47	1.54	50	47	0.31	0.15	0.31	-0.84	0.02	0.00	0.20	0.16	0.23	-0.47	0.00	0.04	-0.53
501170015	2	30,088,153	60	2.74	6.00	5.47	0.57	34	47	-1.16	0.11	0.31	-1.07	0.03	0.00	0.34	0.05	0.23	-1.31	0.00	0.04	-0.53
501170016	2	31,780,953	60	2.80	7.09	5.46	1.74	41	47	-0.54	0.19	0.31	-0.63	0.02	0.00	0.16	0.35	0.23	0.96	0.00	0.04	-0.53
501170017	2	34,133,087	61	2.82	4.55	5.45	-0.96	51	47	0.36	0.61	0.31	1.62	0.01	0.00	0.07	0.12	0.23	-0.78	0.00	0.04	-0.53
501170018	2	3,082,695	68	2.46	6.49	5.61	0.94	26	45	-1.70	0.12	0.26	-0.76	0.02	0.00	0.18	0.47	0.23	1.81	0.00	0.04	-0.53
501170019	2	25,583,835	61	2.63	4.94	5.50	-0.60	45	46	-0.09	0.54	0.30	1.30	0.01	0.00	0.09	0.22	0.23	-0.07	0.00	0.04	-0.53
501170020	2	23,710,178	61	2.47	6.51	5.51	1.07	60	45	1.41	0.13	0.30	-0.91	0.00	0.00	0.03	0.27	0.23	0.32	0.00	0.04	-0.53

The Hilsenhoff biotic index demonstrated impairment more times than the other indices, and tended to co-occur with large deviations in either % worms or % isopods. Hilsenhoff values ranged between about 4.4 and 5.6 depending on the catchment area, and with an among-stations SD of about 0.9, so the normal range for a given catchment area was ± 1.8 units. Richness also varied between about 20 and 48 taxa depending on stream slope, with an among-stations SD of 11 taxa. Percent EPT varied between 26 and 53 depending on catchment area, with an among-station SD of 18%. The normal range of values in a pre-development condition for worms was 0 to 20%, while for midges was 0 to 48%, and for sowbugs was 0 to 18%. These ranges of values are similar to numbers previously published in peer-reviewed works.

4.7.7 Benthics Characterization

All of the stations from Subwatershed 17 had community index values that were representative of pre-development conditions, and did not indicate any significant levels of impairment (**Figure 4.7.**).

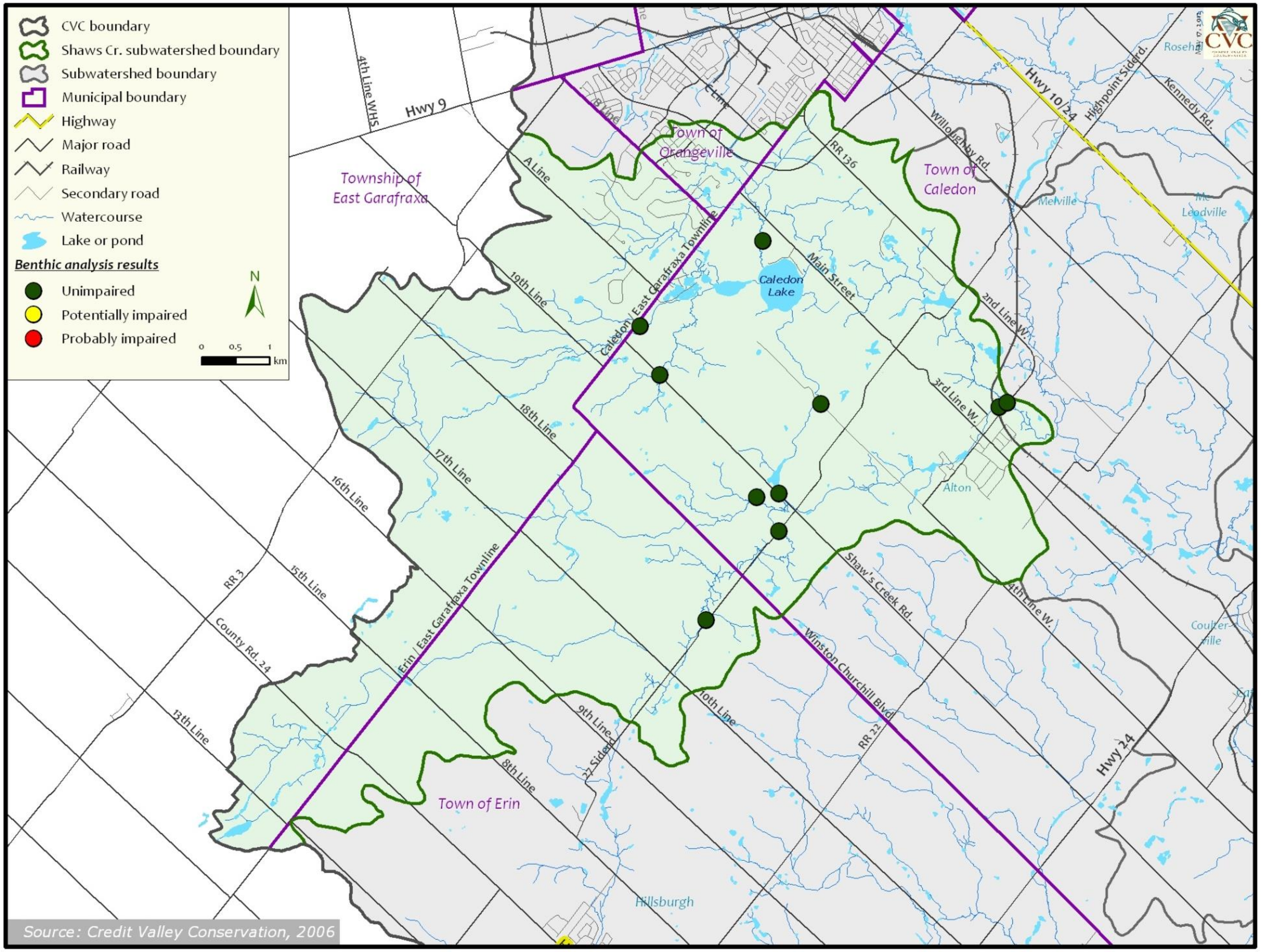


Figure 4.7.3 Benthic Characterization

4.8 AQUATICS

The objective of this study component is to identify and characterize the fish communities throughout the study area that provide integrative environmental indicators of the health of their respective subwatersheds. The sensitivity of the fishery needs to be understood, including habitat requirements, in order to prevent any degradation as stipulated by the Federal Fisheries Act and supported by MNR and CVC policy.

Specifically, hydrological linkages associated with land use change (e.g. agriculture, urbanization and aggregate extraction), infrastructure/servicing (water and sewage) or other stresses on fish also need to be documented in order to predict potential impacts based on future scenarios and planning applications. Likewise mitigation and restoration of fish habitat can be better implemented at the landscape and stream reach levels with such an integrated and forward looking study. Fish community monitoring will confirm any long term trends in the health of the Shaws Creek subwatershed.

4.8.1 Fish Collection Records

Fish collection records have been compiled for the study area since the 1980's. Thirteen new stations were sampled in 2005. No new species were found, except in Caledon Lake. Over 30 sampling locations are illustrated in **Figure 4.8.1** along with those sampled for biomass since 1999 (see section 4.8.3 - Fish Productivity). Fish dots are colour-coded where indicator brook trout were sampled. Only on one tributary had coolwater species not associated with trout. Warmwater sites are more reflective of intermittent headwaters and the permanent reach downstream of Caledon Lake.

All these records are useful in determining the presence of fish species that are listed in **Table 4.8.1**. Each species has a different set of habitat requirements based on life stages and behavioral traits (e.g. feeding strategies, cover, water quality and temperature, swimming adaptations, etc) that reflects the conditions and health of the waters sampled. Detailed information on each species as it relates to prefered habitat conditions are available from literature sources and have been conveniently summarized as a high (1) to low (3) environmental sensitivity.

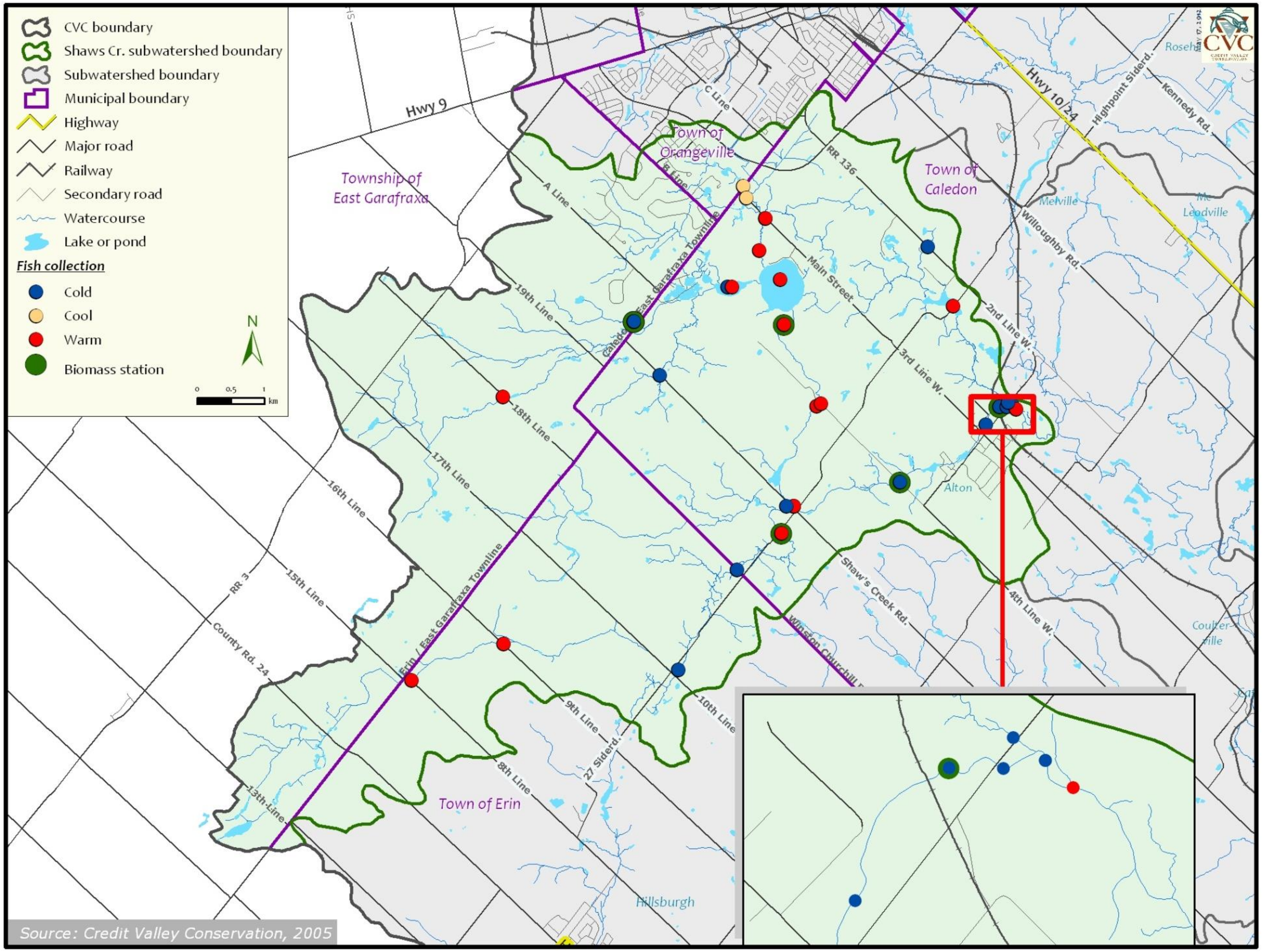


Figure 4.8.1 Fish Collection and Biomass Records

Table 4.8.1 Fish species present in the Shaws Creek Subwatershed

Fish Species	*Fish Sensitivity	Community Classification
Brook trout *(Salvelinus fontinalis)*	3	Cold
Rainbow Trout *(Oncorhynchus mykiss)*	3	Cold/Cool
Common shiner *(Luxilus cornutus)*	2	Warm
Iowa darter *(Etheostoma exile)*	2	Cool
Longnose dace *(Rhinichthys cataractae)*	2	Warm
Pumpkinseed sunfish *(Lepomis gibbosus)*	2	Warm
Rock bass *(Ambloplites rupestris)*	2	Warm
Yellow perch *(perca flavescens)*	2	Warm
Largemouth Bass (*micropterus salmoides)*	2	Warm
Black crappie *(pomoxius nigromaculatus)*	2	Warm
Brook stickleback *(Culaea inconstans)*	1	Warm
Bluntnose minnow *(Pimphales notatus)*	1	Warm
Blacknose dace *(Rhinichthys atratulus)*	1	Warm
Brown bullhead *(Ictalurus nebulosus)*	1	Warm
Central mudminnow *(Umbra limi)*	1	Cool
Creek chub *(Semotilus atromaculatus)*	1	Warm
Fathead minnow *(pimephales promelas)*	1	Warm
Northern redbelly dace *(Phoxinos eos)*	1	Cool
White sucker *(Catostomus commersoni)*	1	Warm
Pearl Dace *(Semotilus margarita)*	1	Cool

* 1= Low, 2=Moderate and 3=High Sensitivity

4.8.2 Fish Community Classification

Based on fish species presence and their sensitivities, stream reaches can be classified into the following categories consistent with the Fisheries Management Plan. It should be noted that although these communities are predominantly classified according to preferred thermal regimes as the names imply, other habitat factors also play an important role. These other factors may be correlated with temperature including dissolved oxygen, nutrient status, turbidity and siltation. Riparian conditions, stream size and channel structure are usually independent of temperature. Anthropogenic impacts may at times completely alter the fish community classification (i.e dams and urbanization).

Resident Coldwater

In Shaws Creek, these communities contain self-reproducing populations of resident brook trout. This species relies on significant groundwater contributions to incubate overwintering eggs and to maintain summer temperatures, preferably not exceeding 20C for extended periods. Trout stocked annually in Caledon Lake do not qualify as indicator species in this case.

Coolwater

Species including northern redbelly dace and central mudminnow, although tolerant of warm temperatures are more often associated with riverine wetlands with permanent flows or refuge. These species were commonly found in coldwater reaches as well.

Small Warmwater

This community is usually made up of species that are not habitat “specialists” and are adaptable to a variety of environmental conditions. Although found in other communities they will dominate small warmer water tributaries and wetland habitats. They often utilize intermittent tributaries and seasonal wetlands. The warmwater stations found below Caledon Lake exhibit species preferring more permanent and deeper pool or wetland habitats including rock bass, white sucker, common shiner and Iowa darter.

Figure 4.8.2 conservatively extrapolates Existing Fish Community classifications from sampled sites to illustrate the Existing Fish Communities of Shaws Creek. Although at first there appeared to be a random distribution of cold and warmwater fish communities, an explanation is offered and simplified pattern mapped. One coolwater reach is designated where indicator species were present. These species are common with brook trout in coldwater reaches elsewhere but in this case stand alone. There is potential this tributary could support brook trout and be re-classified. **Figure 4.8.2** can be considered a refinement to that in the CRFMP that had more generally mapped the entire watershed as coldwater.

Physiography based mapping suggests those potential or historical fish communities based on hydrogeology. The CRFMP, again, from a watershed perspective designated the Shaws Creek subwatershed was coldwater. According to mapping provided from the Hydrogeology section there is some explanation related to bedrock, water table elevations, soils and major discharge zones. Areas mapped as major discharge zones that do not presently harbor healthy brook trout numbers should be further investigated or considered for rehabilitation.

Wetland mapping highlights the paucity of wetlands along the warmwater reach downstream of Caledon Lake and in warmwater headwaters upstream of Erin/EG Townline. It was suggested in the background report that warmwater communities might dominate streams passing through large wetland complexes where large valley floor wetlands warm groundwater discharges to the exclusion of trout, yet this is not apparent. Groundwater discharges from wetlands in this case seem to support preferred brook trout temperature regimes. Many reaches are associated with organic soils as well.

Western Headwaters

Most headwater tributaries across the entire subwatershed have been left unclassified to recognize the number of short reaches that could not be reasonably sampled, while some had tolerant cyprinids and stickleback present. Many 1st order stream may be expected to be seasonally dry as water tables in the highlands drop. Often they also act as local recharge for wetlands or coldwater reaches downstream. Headwater reaches above Erin/ EG Townline are mostly intermittent warmwater communities and coincide best with Guelph formation bedrock. A silt to clay soils are overlain but extend further down. These areas are not likely to be rehabilitated to more permanently flowing trout streams.

Middle Reaches -Tributaries upstream of Caledon Lake and upstream Shaws Creek Rd./ Highpoint SR.

Brook trout inhabit tributaries upstream and along Highpoint SR and upstream of Caledon Lake. The healthiest brook trout population throughout the Credit watershed is represented by the biomass station on the tributary near the Caledon-EG Townline. The reach is found in one of the largest swamps of the study area and is dominated by organic soils. A similar and adjacent tributary has experienced subdivision expansion from Orangeville. Suspected brook trout presence was confirmed for the first time in this area in 2005.

Caledon Lake

There is only one record of four brook trout gill netted in 1980 from Second Caledon Lake along with 2 rainbow trout, 14 rock bass and 66 white sucker. All trout were apparently part of a put and take stocking program endorsed by the MNR at the time. Stocked trout that do not survive the summer period cannot be considered as indicators of coldwater habitat. The only other report of trout is from an angler that noted trout rising near the coldwater stream inlet(s) to Second Lake. This observation at the very least suggests there may be limited use of the lake that could be expanded with restoration efforts. Trap net fish sampling indicates Caledon Lake is now dominated by rock bass. Results from 2005 are summarized from a total sample of 211 fish in terms of biomass as follows: rock bass 69%, brown bullhead 16%, largemouth 7.6%, yellow perch 6%, white sucker 1% and black crappie 0.5%. The largemouth bass and black crappie were confirmed as new species in 2005 and were likely introduced recently. It is suspected that yellow perch were also introduced many years ago. Stocked trout have likely also displaced the former brook trout population from deeper waters more difficult to sample. Residents rarely report brook trout and confirm that both rock bass and the rainbow trout were introduced in around the 1950s. In earlier days hatchery brook trout were stocked for fishing but now rainbows are annually stocked. In the early 1900s 300 fish limits were decreased over the years to 12 by 1949. Now current provincial limits are applied to the stocked fishery. The mix and dominance of introduced species have negatively affected the native fish community. It once abounded with large brook trout according to historical documentation and photos of the original hunting and fishing company established between 1886-1889. There was even a deliberate attempt to rid the lake of white sucker by erecting a barrier. The lake also provides ideal habitat for the banded killifish historically reported somewhere in the Credit watershed. Caledon Lake needs to be properly sampled with seines or minnow traps for this species.

Caledon Lake Outlet Channel
The reach downstream of Caledon Lake if indicated as a major discharge zone should be investigated further during spawning season and for the effects of rock bass originating from Caledon Lake. The downstream end of the outlet creek reach is a dammed pond (Cedar Falls) that prevents the upstream migration of trout, essentially isolating those brook trout populations above Caledon Lake. Brook trout appear absent downstream of Caledon Lake that tends to warm water temperatures or exhibit lower dissolved oxygen due to aquatic plant respiration and excess nutrient sources from poor land uses and septics. Aerating riffles are also lacking along this reach. Furthermore introduced rock bass are still dominant from Caledon Lake and would also add significant competition over brook trout. The original refuge habitat in the lake may also be impacted.

Main Channel Through Alton
The warm outlet channel from Caledon Lake meets the cold southern tributaries (Highpoint Rd) to form the main branch. The main branch has limited wetlands and discharge conditions. Land use and the presence of 2 dams may also explain the occasional presence of trout. Trout in this reach could also represent migrating “drop downs”. There are more reports of trout and historical spawning activity further downstream at the confluence with the Credit where the main river offers additional habitat and possibly another source of trout. The main river population however is still recognized as limited compared to healthy populations found nearer the confluence with Caledon Creek.

It should be noted that the numbers of brook trout found in the lower sections below Alton are poor or absent indicating that populations are stressed. Historical records do suggest that spawning populations on the lower reaches were more abundant at one time. Potential impacts may include municipal well pumping, high groundwater nitrate levels from septics, land use practices and the introduction of northern pike in the area.

Habitat conditions are also characterized by a lack of coarser substrates and aerating riffles. Based on monitoring recorders deployed water temperatures are also stressful and there is very little indication of spawning activity after repeated surveys. Recently this area was the focus of some major stream rehabilitation efforts. Some results may not be apparent for years to come such as the effects of planted buffers and the mitigation or eventual removal of dams in Alton and Melville. The main river does not offer good refuge habitat until nearer its confluence with Caledon Creek where abundant groundwater discharges.

Orpen Lake Tributary
This tributary has also been suggested as the source of trout found in the lower reaches of Shaws Creek given the presence of spawning activity and many young of year trout during electrofishing surveys. Water temperatures also offer coldwater refuge from lower Shaws Creek. The headwaters of this tributary are affected by dams and on-line ponds, the largest being Orpen Lake.

Given that brook trout can generally be found throughout the Shaws Creek subwatershed and that physiographic mapping of potential or historical habitat also indicate surface or subsurface linkages and contributing habitats, the entire subwatershed has been designated as a Coldwater Management Zone in the Credit River Fisheries Management Plan and is supported by this subwatershed study. It should be noted that even warmwater reaches mapped in this subwatershed context may have historically or are seasonally or very infrequently used by brook trout. This will still be reflected in the overall Management Zone in both this Subwatershed Plan and the CRFMP. All contributing waters to coldwater reaches need to be managed in the same terms of buffers and other “contributing” factors to the more sensitive downstream reaches.

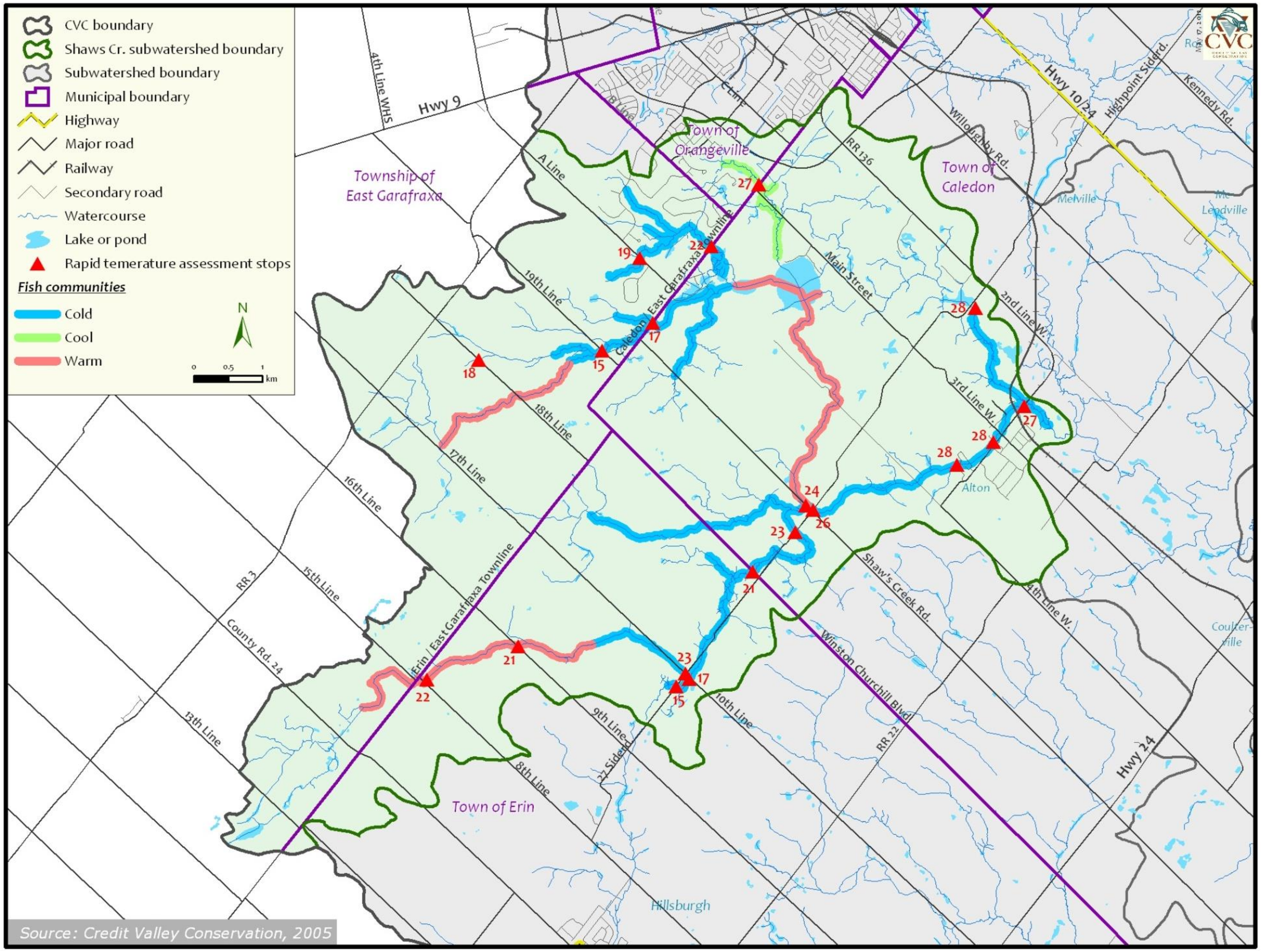


Figure 4.8.2 Existing Fish Community Zones

4.8.3 Fish Productivity

Quantitative information on fish abundance can provide data that can be analysed with other study components such as geomorphology and water quality. Fish data collected under a scientific protocol developed by the Ministry of Natural Resources was used on Shaws Creek in this study. These fish biomass stations are located (**Figure 4.7.**) on the Caledon-EG Townline tributary upstream of Caledon Lake and two found up and downstream of the Alton dams. At these locations electrofishing equipment was used over a measurable area of habitat with fish species recorded by total weight or biomass in order to estimate biological productivity in terms of grams of fish per square meter. Fish biomass results collected annually since 1999 are presented in **Figure 4.8.3** to **Figure 4.8.7**.

These sites provide good baseline data for a headwater tributary, mid and lower reaches of the subwatershed over 5 years or more. Two new biomass sites were established in 2005 in the mid reaches, one in a coldwater reach and another in the outlet channel below Caledon Lake. All results have been analysed as an Index of Stream Health in A Methodology for Assessing the Biological Integrity of Fish Communities in the Credit River Watershed (1999). This methodology puts additional weighting on more sensitive indicator species as listed in **Table 4.8.1**. The average IBI scores tabulated for the sites across the watershed are shown in **Figure 4.8.3** (and **Figure 4.8.4** through **Figure 4.8.8** for all species at each station). Note that the stations sampled for this study varied in health and ranked as 1st (excellent), 11th (good), 17th (good), 29th (fair) and 36th (fair) in terms of fish community health across 50 sites in the Credit watershed.

In terms of at-a-station trends over time. The following regression equations for IBI scores (n / Y=mX + b / R2 and +-SD) have been calculated where Y is the average IBI score over the number of years (n) sampled. R2 represents the strength or accuracy of the trend in time with values approaching 1 being the most predictable. The Standard Deviation (SD) best represents the amount of “scatter”. M is the slope indicating whether the trend over time represents degradation in health (indicated by a negative value) or improvement (positive value). Stations remaining relative stable in health will exhibit a value nearer to zero (positive or negative).

Shaws Creek tributary d/s Townline (6 yrs excellent / 77.6 = -23.36x + b / R2=0.67 +-53.4): Changes seem to be related to smaller rather than less brook trout at the site. Trout biomass has been consistent in the last 4 years while rock bass have declined and should be interpreted as good in terms of inter-species competition. The loss of older trout could be related to habitat parameters but angling pressure is also suspected. Extreme weather and flow patterns over some years are more likely contributing to any decreases given no major land use changes or point sources of pollution upstream have been identified. Even at the lowest IBI of 38.5 this score is ranked as excellent health in comparison to other watershed stations. The downward trend still remains a concern given the relative statistical strength of the regression.

Shaws Creek d/s Mississauga Rd. (6 yrs good / 14.6 = -1.2x + b / R2=0.07 +- 8.5)

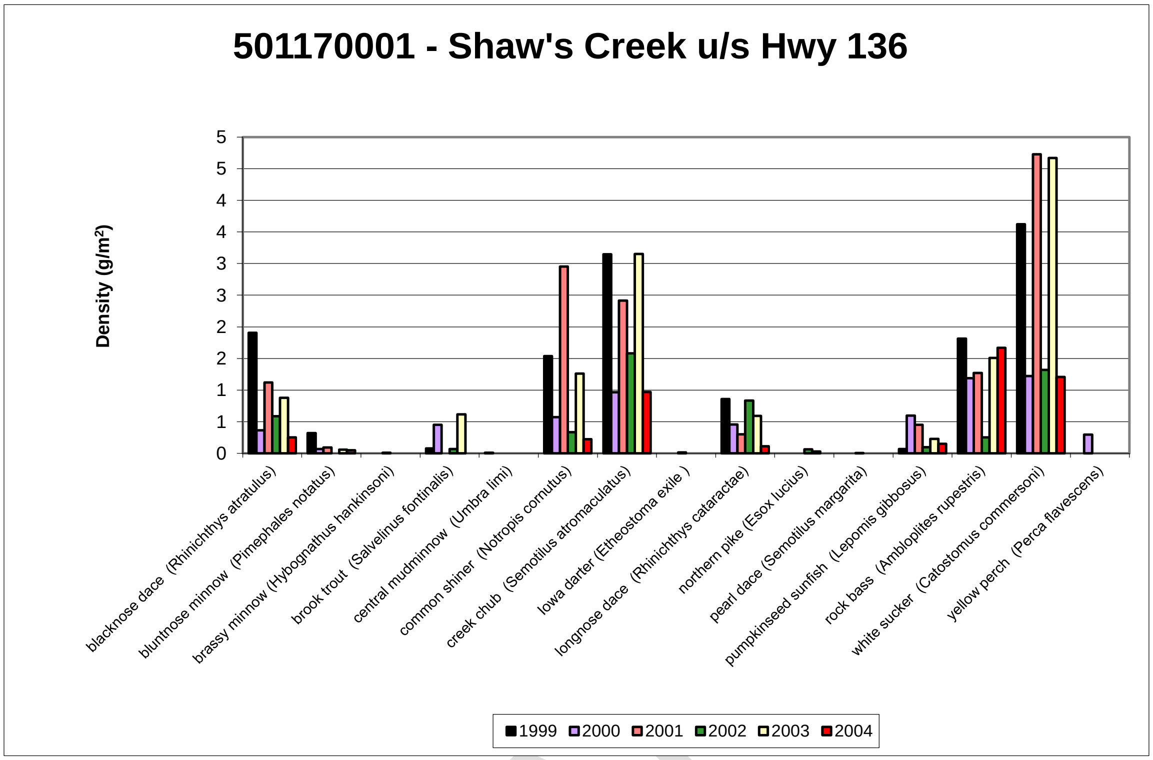


Figure 4.8.3 Fish Biomass in Shaws Creek u/s Hwy 136

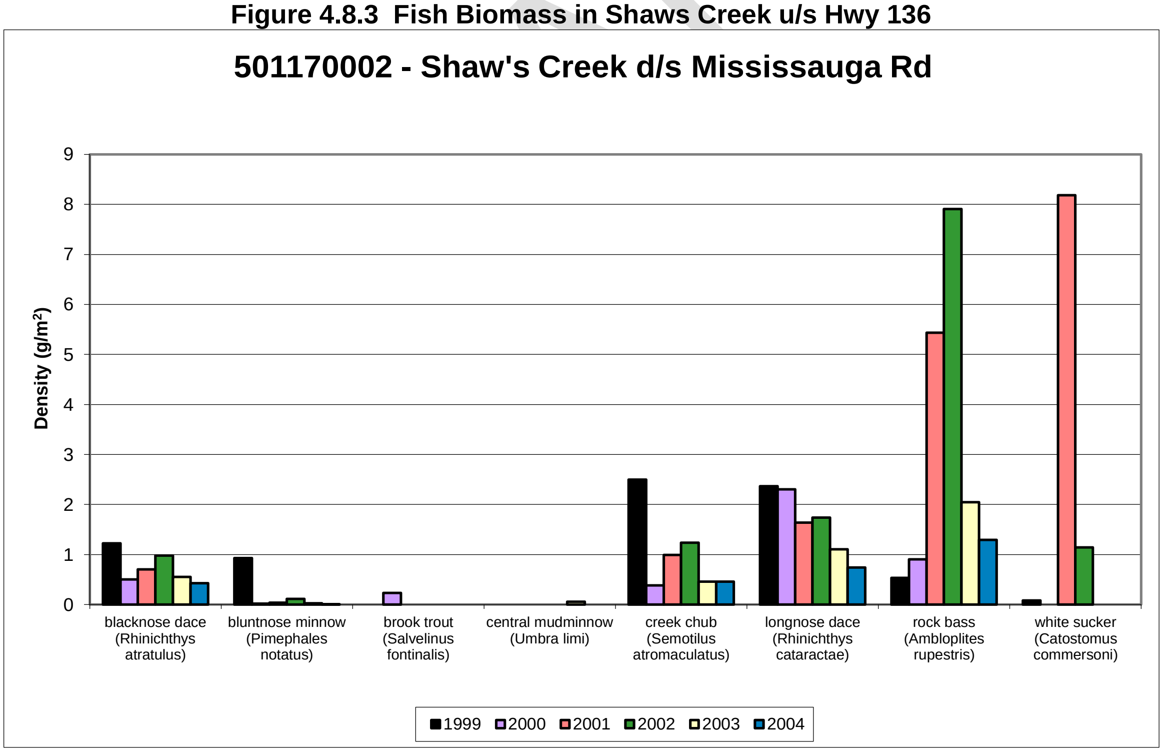


Figure 4.8.4 Fish Biomass in Shaws Creek d/s Mississauga Rd

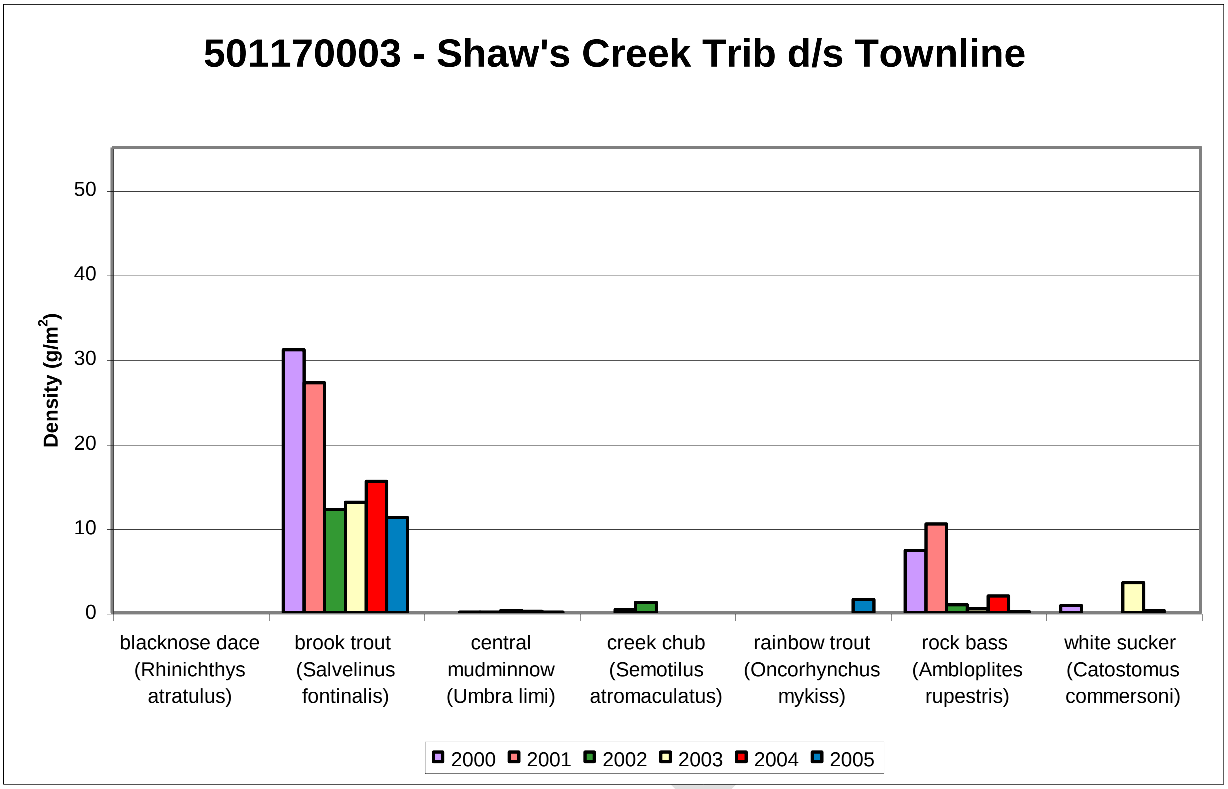


Figure 4.8.5 Fish Biomass in Shaws Creek Trib d/s Townline

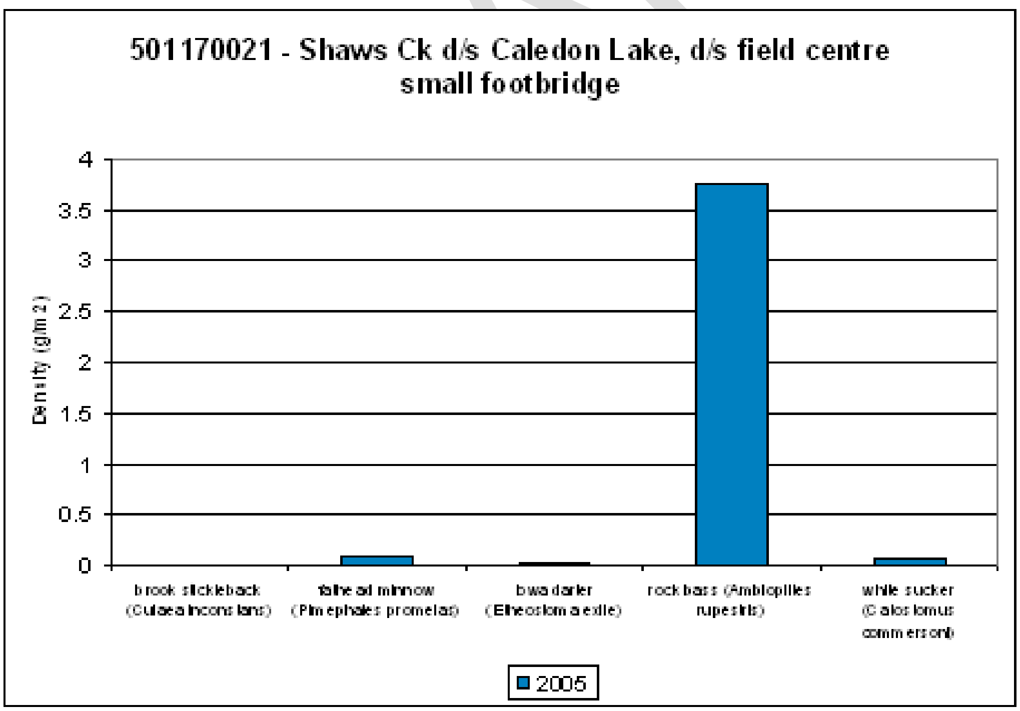


Figure 4.8.6 Fish Biomass in Shaws Ck d/s Caledon Lake, d/s field centre small footbridge

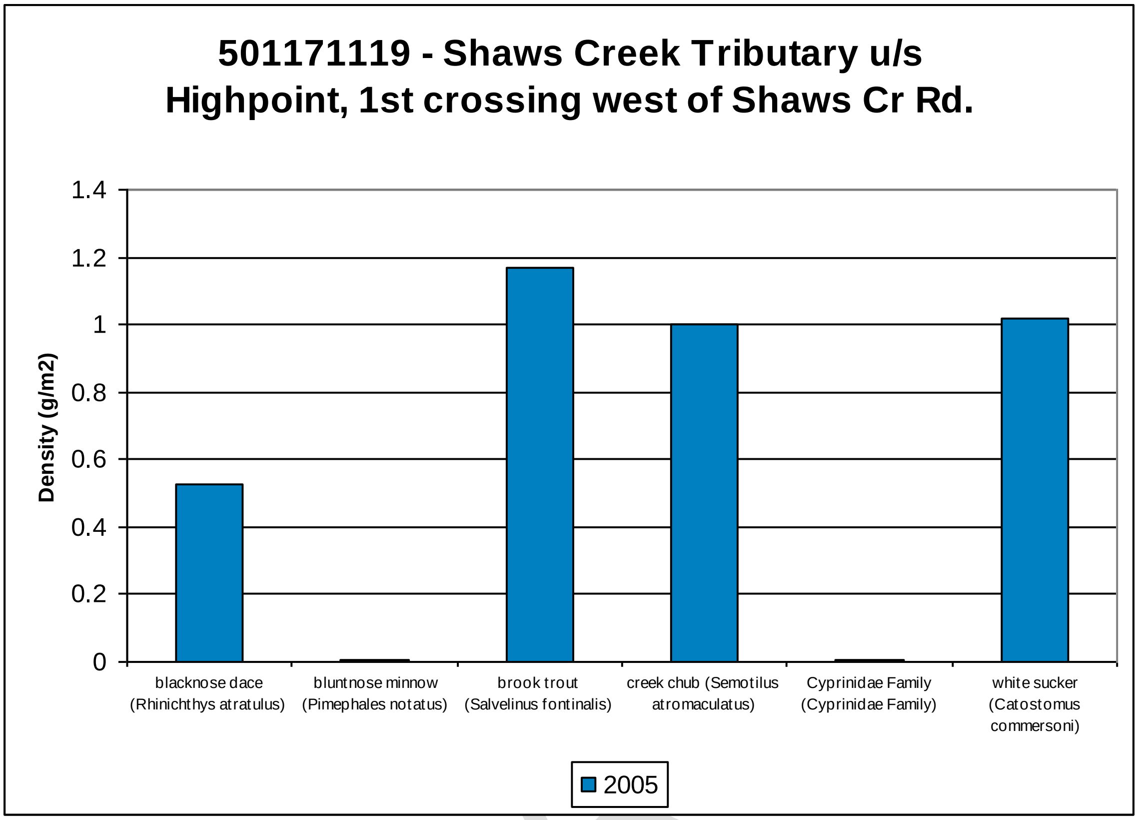


Figure 4.8.7 Fish Biomass in Shaws Creek Tributary u/s Highpoint, 1st crossing west of Shaws Cr. Rd.

The IBI score fell from excellent to a fair rating for the last 2 years. The land use of Shaws Creek upstream of Alton has been stable and includes many protected wetlands. White sucker and the predatory rock bass have widely fluctuated over the years and may take up seasonal residence in the headpond downstream which appears to be filling with sediment at an accelerated rate. Only longnose dace, a riffle specialist has experienced a steady decline.

Shaws Creek u/s Hwy 136 (5 yrs good / 13.1 = -0.2x + b / R2=0.01 +- 7.7)
This site has alternated between excellent scores to fair stream health each year. This variability may relate to being downstream of Alton and two dams and experiences some fishing pressure. Brook trout are absent from the sample 1/3rd of the time. Chub, shiners, rock bass and white sucker dominate the community and are considered more tolerant of impacts.

All 3 sites suggest overall fish health is in generally good condition across the subwatershed even downstream of the Alton dams. The downward trend for the Townline station remains a concern. Some variability due to natural fluctuations, weather patterns and anthropogenic impacts are likely. A longer term data base will provide for better analyses.

Averages and regression equations have not been calculated for the mid-reach stations sampled only once in 2005 and caution must be exercised in conclusions related to health until more years of data become available. Both stations are equated with fair health even though species composition are very different. Brook trout co-dominate with creek chub and sucker in the coldwater tributary whereas rock bass represent 95% of the biomass in the warmwater channel below Caledon Lake.

4.8.4 Spawning Surveys

Spawning nests or “redds” were investigated in this study as they represent critical habitats that often are the single limiting factor to fish production for specialized species such as brook trout. Brook trout are known to specifically seek out and detect groundwater upwelling areas for winter long egg incubation. They are less choosey about substrate composition in these circumstances. The same areas also offer coldwater refuge during heat waves and drought conditions.

Figure 4.8.8 summarizes spawning redds surveyed in recent years along Shaws Creek. The lower reach survey downstream of Alton in 1999 noted 11 potential redds. This compares to an average of 24.2 redds in 1981-1985 surveys. Subsequent surveys failed to confirm this historical data from the 80's on lower Shaws Creek. Due to natural variability in brook trout numbers, weather conditions, woody cover and observer error it is recommended that surveys still be repeated when feasible. It is noted more productive spawning areas exist along the Orpen tributary that were confirmed with the collection of young of the year trout. Identifying new spawning areas throughout the subwatershed was a higher priority for the 2005 field season.

The majority of newly discovered spawning sites in 2005 are concentrated in the coldwater Middle Reaches, particularly along the Caledon-EG Townline above Caledon Lake where biomass samples indicated excellent health. There was possibly a spawning redd found in the adjacent Orangeville subdivision tributary. The second largest concentration of spawning redds were located on the two coldwater tributaries west of Winston Churchill. Only one redd was found along the main branch upstream of Alton. Figure 4.8.8 also shows those reaches surveyed with no spawning evidence. These areas should be surveyed again before any further conclusions are drawn along with other priority areas still not surveyed to date as indicated.

No spawning surveys were attempted on Caledon Lake given the historical loss of brook trout due to overfishing, competition with stocked rainbow trout and rock bass, and potential alterations to habitat and downstream dams. Brook trout are known to spawn where lake bottom upwelling occurs. The marl deposits of the lake however may limit such spawning habitats. The original lake stock may have migrated up or downstream to more suitable spawning reaches.

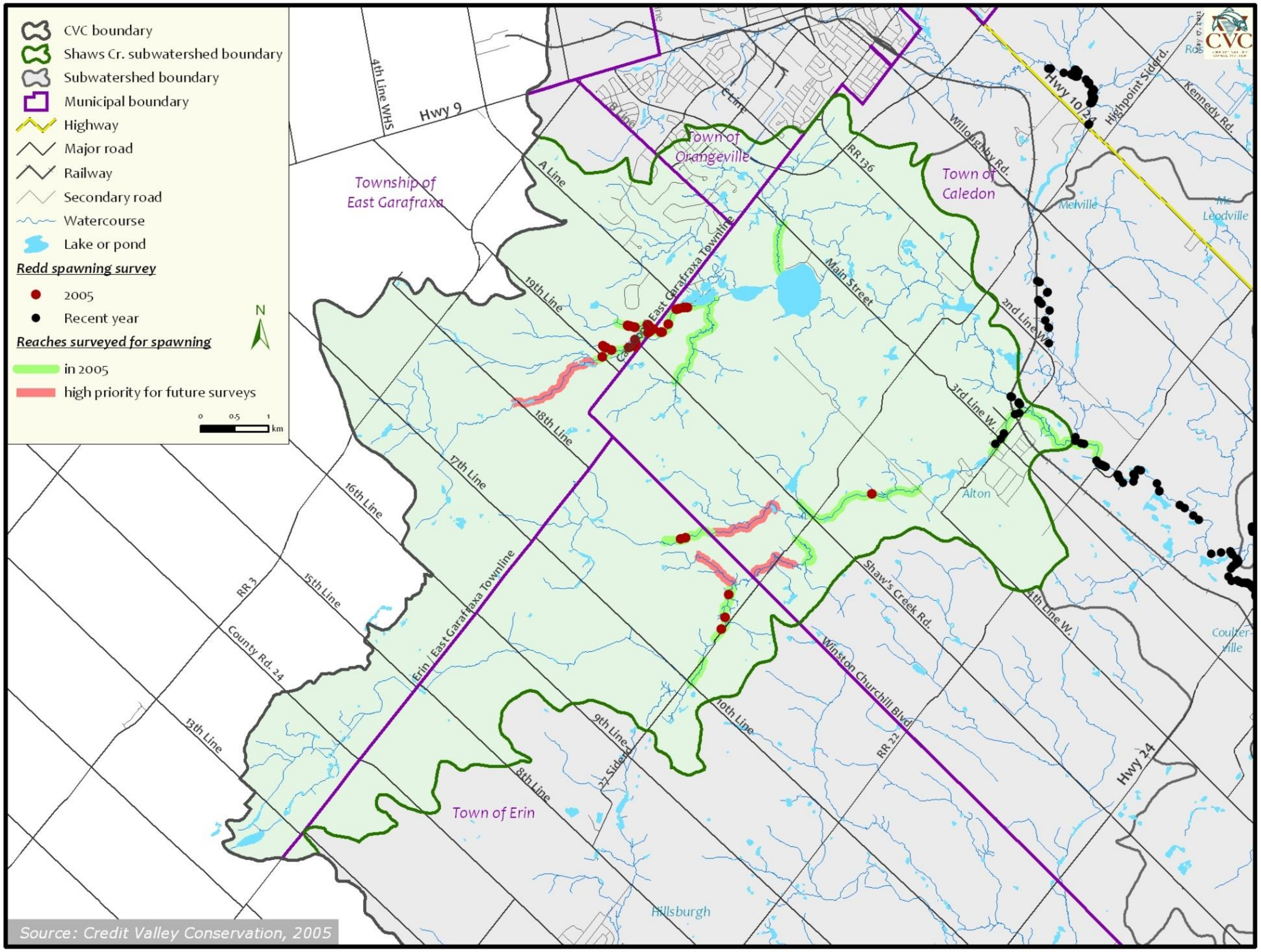


Figure 4.8.8 Trout Redd Surveys in the Shaws Creek Subwatershed

4.8.5 Fish Habitat

Fish species and abundance are determined by a variety of habitat factors. Observations and past surveys can be referenced from fisheries files including pool-riffle ratios, riparian conditions, woody cover, aquatic plants and substrate. More accurate measurements and characterizations will be provided in the geomorphology component that also reviewed past fish habitat surveys. The water quality component also documents water chemistry and in particular dissolved oxygen as it relates to aquatic plants and fish.

<u>Stream gradient and valley confinement</u> are typically moderate on Shaws Creek resulting in a predictable meander alternating with deeper runs and pools and shallow turbulent riffles. Past surveys and literature suggest a ratio of 40% pool – 60% riffle provides ideal fish habitat in river systems. The main creek downstream of Caledon Lake to Alton appears to fit this description. Gravel riffles are in most short supply as gradients decrease approaching the main Credit River.

There are a significant number of tributaries in the Shaws Creek watershed that meander more widely over a broader floodplain or wetland. The channels are known for their low width:depth ratios with stable undercut banks. The riparian vegetation and adjacent wetland communities can be the most diverse and productive habitats. Fish communities here are likely limited by oxygen rather than temperature. Fish or stream invertebrates may be best compared to amphibians as indicators in floodplain wetlands. Flooding and beaver ponds are also more common. Wetlands could contribute either cold or warmwater baseflows depending on the groundwater discharge route and travel time. Reference mapping should be consulted not only on groundwater discharge but also with extensive wetland mapping available in other sections.

<u>Substrates</u> provide important fish habitats. The interstitial spaces amongst gravel riffles also provide habitat for macroinvertebrates utilized as food. Some fish species live and feed within these interstitial spaces. Of greatest importance are those areas used to deposit and incubate eggs that are free of siltation that can smother fish eggs. A lack of gravel riffles has been observed throughout Shaws Creek. These areas are dominated with sand, silt or organics that likely limit trout production. It should be realized that in some cases this is a natural limitation and whether preventative or rehabilitative actions are even warranted. Wetland reaches with finer substrates are more easily colonized and stabilized with plants providing habitat for many minnow species. Manmade dams and poor agricultural practices are known to negatively impact sediment regimes.

<u>Aquatic plants</u> can benefit fish communities by providing cover and food. In excess, however, plant growth may result in low oxygen supplies during nightime respiration. Within stream habitats many fish species do not adapt well to low oxygen. More tolerant species such as stickleback, mudminnow, redbelly dace and creek chub present in the subwatershed can be abundant however. Additional stresses from further nutrient enrichment will reduce fish production. Algae may become more abundant in these cases. Fish collection records have not yet identified any problem areas within wetland areas and in fact sometimes find trout that are most oxygen demanding. Below Alton however there is evidence of problem plant growth when their thermal thresholds are reached. Low oxygen readings occur in the reaches identified as having stressed trout populations. It should be noted that the apparent lack of riffles may fail to re-oxygenate waters in the lowest reach.

<u>Temperature</u>, as part of the past water quality assessment, was collected on Shaws Creek in relation to two on-line impoundments. The results confirm that brook trout populations are stressed with temperatures regularly exceeding a 20C target above and below the dams. The most stable thermal regimes providing important refuge and spawning habitat are found in the Orpen Lake tributary entering Shaws Creek at RR 136. Comparative temperature data throughout the subwatershed was collected in 2005 following the Rapid Assessment Protocol of MNR. Out of 15 sites across the subwatershed 4 remained within the thermal preference for brook trout during maximum heating. These sites are spread across the Middle Reaches classified as coldwater, one being the reference biomass station on Caledon EG Townline at 17C. Just upstream temperatures were at 15.5C. The adjacent tributary draining the subdivision starts out at 19C but rises quickly to a 22C maximum showing some stress. The coolwater tributary downstream of new construction or a pond was lethally high at 27C. The coldest temperature of 15.5C (with air temperature at28C) was also at a small headwater near 10th Line and 27th SR Hillsburg that then mixes with another flow at 17C. Although the most western headwaters upstream remained dry, once flows become evident after 8th Line, temperatures are acceptably cold (low 20's) as designated over a few kilometres until near the confluence of a second coldwater tributary in the middle reaches where temperatures rise to 24C. The main channel then rises an

additional 2C with waters from the Cedar Falls dam and upstream from Caledon Lake. Temperatures then reach a maximum of 28C below Alton and are lethal to trout without access to refuge pockets. Also temperatures at the outflow of Orpen Lake were also critical at 28C. How far down this excludes trout is unknown but the lower reaches, however, are known to recover as they pass through swamps. Temperatures can become lethal to all fish life when combined with low oxygen associated with excess plant (wetland) growth or nutrient enrichment (i.e. dammed impoundments).

<u>Woody cover</u> is an essential component within the stream system for increasing flood roughness and reducing erosion especially along outside bends or wherever it is integrated into the bank. Woody material should be sufficient throughout the study area on average. A few areas lack cover associated with rural landscaping and agriculture. Some reaches may have excess material bunched up in log jams but generally contributes to fish habitat. There is abundant woody cover along the swamp tributary scoring the highest biomass of trout.

<u>Riparian vegetation</u> provides important functions related to fish habitat including shade for temperature regulation, overhanging and instream cover, bank stabilty and erosion protection, water quality improvement through sedment trapping and nutrient upake and as buffer from adjacent land uses. Observations in this study area were variable and will be better characterized from land use mapping and the assessment of valley and stream corridors in the Terrestrial component. It should be noted that there is an expectation of less canopy cover naturally in streams crossing large marsh areas. Agricultural areas lacking riparian vegetation are apparent in the western headwaters and along the outlet channel from Caledon Lake and may in part be responsible for warmwater designations. Riparian cover is also lacking in the built-up areas of Alton.

<u>Instream barriers</u> mostly in the form of dams with impoundments alter stream habitats significantly for fish and further shift the community towards more wetland and lake adapted species. The impoundment act as nutrient traps and further depress oxygen levels. Waters typically warm up in the impounded waters and exclude trout for a distance downstream. As sediment traps they only pass fines in suspension. The loss of the coarser bedloads gives added power to water downstream of the dam that erode channels downstream. Often the greatest impact is the isolation of populations from spawning or refuge areas and the long term exchange of genetic material with other populations until stresses lead to their premature extirpation. A Dam Inventory conducted by CVC has identified about 45 dams or online ponds. Many are located on spring sources of many small headwaters and isolate relatively short reaches upstream but may significantly impact water temperatures cumulatively. The most significant barriers from a watershed perspective and more effectively places populations at genetic risk are those beginning downstream in Alton, followed by Cedar Falls. One other dam was recently removed between Cedar Falls and Caledon Lake. The Orpen Lake dam and another upstream of 19th Line on a coldwater reach with a significant drainage area is also of concern.

Beaver activity and dams are common throughout the Shaws Creek subwatershed but are a natural part of the ecosystem regenerating wetlands and providing fish habitat with built-in mitigation processes. In fact brook trout and minnows such as redbelly dace and beaver are often synonymous having evolved together. Beaver dams are rough that aid fish migration along with side channels at certain flood stages. Their porous nature also allows for the seepage of colder bottom waters. They are generally small and relatively short lived in such stream systems.

Caledon Lake

Unlike other subwatersheds in the Credit, Shaws is unique in having a natural 33 ha marl lake situated in the mid reaches of the stream network. It has shallow littoral zone and falls off up to 10 meters deep. Caledon Lake is associated with a large wetland around it with extensive organic soils. The marl layer beneath may also act similar to a clay aquatard and influence groundwater movements. Second lake is a shallower arm where a major tributary enters the lake. Other smaller ponds are flooded marl pits from excavation. A 1989 MNR survey noted Caledon Lake does stratify with warmer waters (over 25C) flowing out and colder bottom waters (below 6 m) having oxygen levels to low for trout. The latter may be indicative of bottom sediment accumulation or other nutrient inputs such as septics. The MNR 1989 report noted that the process of converting septics to pump out systems could improve anoxia in the lake. Oxygen profiles of the lake have not been done recently.

There have and continue to be a number of attempts on the lake to control erosion and water levels, that along with motor boats may have a negative effect on shallow offshore and shoreline vegetation communities. Emergent vegetation on Second lake appears more diverse and healthy, although wild rice beds were reportedly introduced for waterfowl. The main lake was observed to have a lack of submergent and emergent vegetation in wave washed shallows, but weed removal activity is also reported, especially in the outlet channel. There is also a lack of large woody debris around the lake indicating large trees are not supported by surrounding marshlands or that the lake has been “cleaned up:”

Recreational Fisheries

Creel surveys of anglers completed for the CRFMP identified 7 areas along Shaws Creek that were accessed. The most popular area was within Alton downstream of the dams followed by the lower reaches on the MNR Grange property. The remaining areas are at road crossings from Alton and along 27th Sideroad as well as the Caledon-EG Townline tributary. No public fishing has been recorded on the outlet channel from Caledon Lake and could be explained by the lack of trout confirmed in this study. There is no public access to Caledon Lake, which is reserved for Company members only. There have been discussions regarding the right to access water and fish in the lake that is crown property. All lands around the lake is private property but whether access by canoe from Shaws Creek or other connected ponds has been raised given regular boating activity in the area to challenge “navigability”. A past court decision upheld the Company’s right. Nevertheless the fishery remains protected under the Fisheries Act and Fish and Wildlife Conservation Acts, as it is connected to the publicly accessible Credit River recreational and bait fishery. The MNR and the Company should discuss a number of private options. CVC would be supportive of a stewardship partnership and a Lake and Fisheries Management Plan given its connection to the Shaws Creek subwatershed and its other designated ANSI and PSW natural values. CVC is currently reviewing management options for the Caledon Lake Conservation Area that is the largest land parcel of the area and adjacent to the Company.

4.8.6 Aquatic Characterization

Over 30 fish sampling sites were used to characterize the Shaws Creek subwatershed. Overall 20 fish species have been documented. Generally it is considered a coldwater system based on the presence of native brook trout in the middle reaches. Populations in the lower reaches through Alton appear more sporadic and stressed with the Orpen Lake tributary providing the best source and refuge area. Historical documentation of spawning redds in the lower reaches suggests there has been a decline in populations since the 1980’s. Two of the western headwater reaches are intermittent in nature and have been classified as small warmwater where more tolerant headwater species are most common. Another tributary has been classified as coolwater that suggests some potential for brook trout. Caledon Lake and the reach downstream were historically coldwater but introduced species to the lake (hatchery trout and rock bass) and potential impacts related to eutrophication and dams is now responsible for a warmwater fishery. The overall distribution of coldwater habitats appears to be related to hydrogeology and the distribution of wetlands. If discharge mapping confirms the reach below Caledon Lake should be coldwater, restoration efforts should focus on lake eutrophication and the mitigation of the Cedar Falls dam. The next priority would be on the Alton Dams.

There exists good baseline biomass data analysed as an Index of Biotic Integrity that rates fish community health from excellent to poor. One headwater site in this study ranks as excellent and the most productive fishery in the entire Credit watershed. There is some concern that there has been some decline of health noted over the last 6 years at this site. Two sites around Alton are more variable over the years but are generally in good health even though brook trout are not always present over the years of sampling. The two new biomass stations set up in 2005 within the mid reaches of the subwatershed scored as fair health.

Critical spawning habitats for brook trout are concentrated in the coldwater middle reaches above Caledon Lake and two tributaries west of Winston Churchill Blvd. as well as Orpen Lake tributary in the lower reaches. Other spawning locations were also identified with priority reaches for future surveys.

Recreational trout fishing was identified at 7 access points in the subwatershed. Caledon Lake is also managed and stocked for private fishing by the Caledon Lake Company with a long history as a fishing and hunting club. It is recommended that a stewardship partnership be further developed with the MNR and CVC in the form of a Lake/Fisheries Management Plan.

5. Integration – Characterizing the Subwatershed

5.1 INTRODUCTION TO INTEGRATION

Integration is a mechanism by which we examine the parts of the system and their structure and provide an understanding of their functioning. This analytical process is essential if we as managers, residents, businesses and society in general are to make decisions that in the short and long-term provide the greatest good to us while providing a sustainable and resilient natural system for our children to use in the future. We must know the consequences of our actions and determine the relative risks to the system, our selves and the long-term economics of our community. The cost of poorly designed development and management decisions can be enormous. The cost of protecting people and property from degraded water quality and a stream and valley that is undergoing major changes due to erosion can be enormous. Sound design and planning decisions can avoid most of these potential costs to the community and its' taxpayers.

5.1.1 What is integration?

Subwatershed integration is the act of synthesizing, interpreting and developing a systemic understanding of the subwatershed. Integration is needed because the total (the watershed with its air, water, land, people and other living things) is greater than the sum of its parts. In order to study a complex system, we often must take the system and break it into its constituent parts (physical, chemical, biological, etc.) for analyses. However, in order to truly understand how the system functions, we need to reconstitute these pieces in order to understand the whole. Therefore, studying the component parts of a watershed — hydrology, hydraulics, water quality, groundwater, aquatic systems, terrestrial systems, human uses — in isolation from each other does not allow us to adequately characterize the existing system, or make predictions about the future.

Subwatershed 17 accomodates many human uses that could affect the functioning of the natural system, including development in Alton, the south of Orangeville, and East Garafraxa, the recreational community around Caledon Lake, and the aggregate and agriculture industries. In terms of future planning for Subwatershed 17, decision-makers need to know how all of these activities will affect streamflow <u>and</u> water quality <u>and</u> aquatic communities <u>and</u> recharge to our water supply <u>and</u> recreational use of water resources. Each of these components is interconnected in complex, subtle, sometimes unknown ways. In order to make sound decisions, we need to understand the interrelationships of the physical, biological and chemical components of watersheds through integration of information across disciplines.

The concept of integration as applied to the study of subwatersheds is illustrated in Error! Reference source not found.. The stressors of land use change, water supply or wastewater treatment discharge affect the various physical, biological and chemical components of a subwatershed, including water quantity, water quality, stream form (i.e., geomorphology), and the quantity and quality of habitat. We measure these impacts through environmental indicators, such as water chemistry, benthic macroinvertebrates, surface water, groundwater, channel form, precipitation, and different forest/wetland/riparian measurements (i.e., species, etc.). The measurement of these indicators has been presented throughout Section 4 of this report, and encompasses a wealth of knowledge and understanding of the Shaws Creek subwatershed. It is the goal of integration to then interpret and synthesize these measurements, drawing conclusions on the overall aquatic and terrestrial health of the subwatershed.

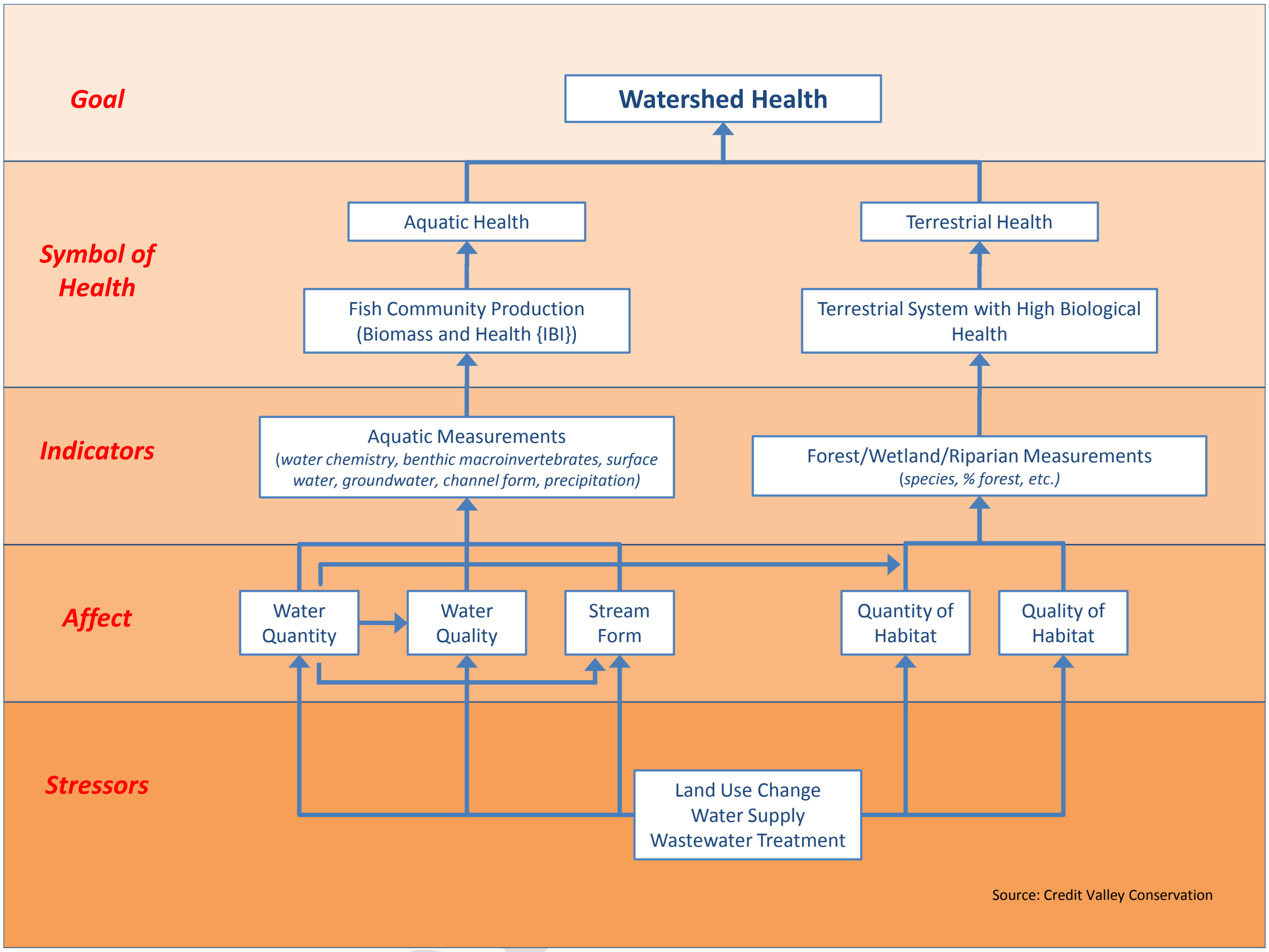


Figure 5.1.1 Understanding watershed health using integration

The linkages of the various physical characteristics and processes that affect watershed health are numerous and complex. In carrying out an analysis of a subwatershed, developing an understanding of it and assessing the impact of stressors these interrelationships need to be understood. At the same time, to make the subwatershed characterization and analysis process manageable, the individual elements need to be looked at separately, but then pulled together in an integration process to develop an understanding of the interrelationships and the overall watershed ecosystem.

This section of the report provides insight into those interrelationships in evaluating overall watershed characteristics and its health.

5.1.2 Context for using AEM in Subwatershed 17

There are uncertainties about how to estimate the response time frames of streams to human and natural perturbations. There are a paucity of models and supporting professional knowledge for how to analyze and manage such systems over the long term. These facets have led to the adoption of a new approach to environmental management - adaptive environmental management for watershed planning.

In lay-person terms, the adaptive environmental management approach is:

> "Lacking knowledge of cause/effect methodologies, we make changes based on our best guess, observe the changes, and then change the action (e.g., the management activity)".
>
> (Holling 1978)

The basic conditions that led to the development in the early 1970's of the Adaptive Environmental Management (AEM) approach include (i) the critical need for integration of different technical disciplines together with (ii) the need to explicitly account for the uncertainty involved and (iii) learning from experience (through monitoring) in order to improve future designs

Hence, the underlying principles include continuous and deliberate learning, formal experimentation, expecting surprise, taking a systems approach and implementing management from relevant research.

In building a framework for the subwatershed planning process that recognizes the principle of AEM, four major components have been identified, and are illustrated in **Figure 5.1.2**.

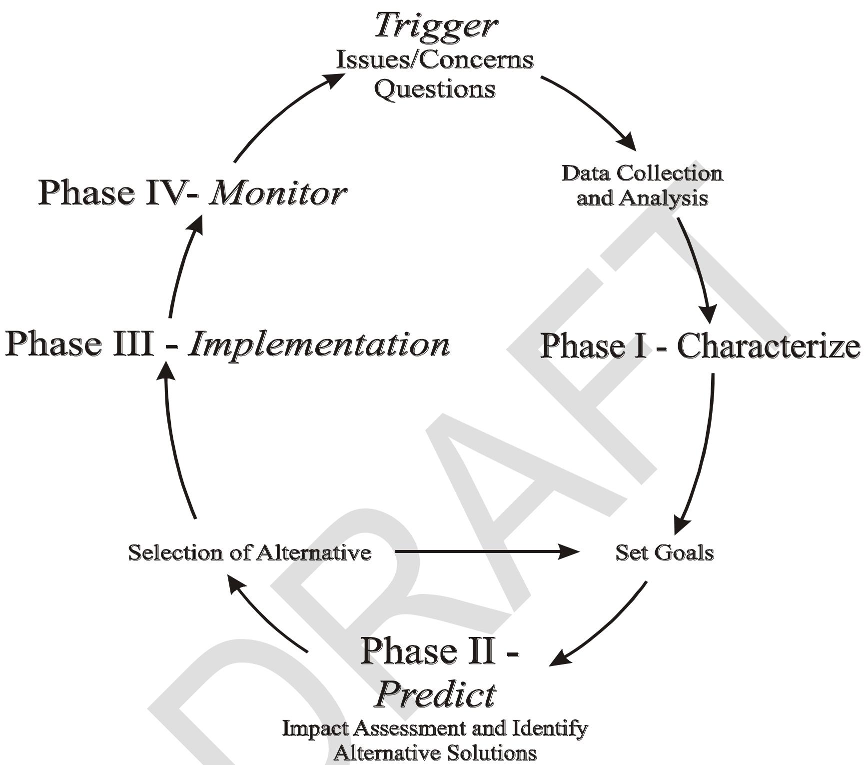


Figure 5.1.2 AEM Components of the Subwatershed Planning Process

In completing the Characterization component (Phase I), the process of learning about the functional relationships between the key environmental features has begun. With this understanding, we have developed clear subwatershed goals against which our future efforts and the degree of their success will be measured. During our next phase (Prediction), various models will be used to evaluate how various land use changes can affect the key functions and processes derived in Phase I. The Implementation Phase will follow to ensure that our findings are recognized by those who are responsible for land use change. Through the Monitoring phase, our understanding of the system will improve over time and the subwatershed plan will continue to be updated accordingly.

As displayed in **Figure 5.1.3**, subwatershed planning begins with a vision, allowing the goals and objectives of the planning process to be set. Once there are firm goals and objectives, specific targets for key physical processes can be set through the characterization and impact analyses. The specific targets will allow the selection of SWM measures to achieve the required results as outlined in the goals and objectives, and then a SWM plan can be put into place. Following the implementation of the Plan through policies, ongoing monitoring will report on the effectiveness of the selected measures, and adjustments will be made to maintain the original goals and objectives.

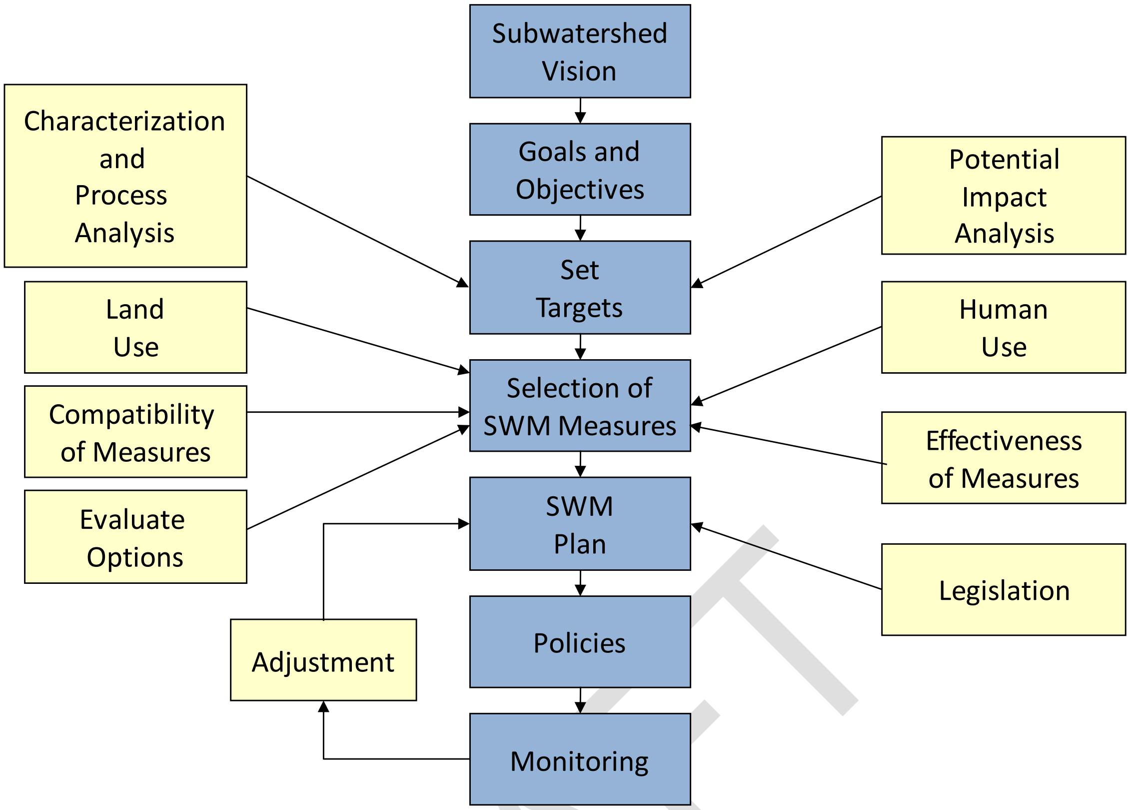


Figure 5.1.3 Process in Developing a Subwatershed/SWM Plan

5.1.2.1 Key Uncertainties in Sub 17

The uncertainties that affect management of Subwatershed 17 over the long term include:

1. An integrated picture of how the present lands and waters function;
2. An availability of quantitative models which can be used in Phase II of a subwatershed study for predicting the impacts of different land uses and management approaches on different receiving water ecosystem features;
3. The time for the present aquatic systems, including fish habitat, stream geomorphology, groundwater quality and its hydrogeology in subwatersheds to respond to past perturbations and existing forms of development; and
4. The future pattern of development and rehabilitation/ restoration in the subwatersheds.

Uncertainties such as items 2, 3, and 4 are more fully addressed in Phase II (Impact assessment) and Phase III (Plan Implementation) of this study; the first uncertainty is addressed in this section.

5.1.3 Developing an Integrated Characterization of the Subwatershed

This subwatershed study was initiated as part of the Credit Valley Conservation's overall Watershed Management Plan, to provide contextual information for future land use changes that may occur, and to identify opportunities for environmental rehabilitation opportunities. The Shaws Creek subwatershed is used heavily for agriculture, but there are small areas of urbanization that are currently growing or may grow in the future, namely Alton, the south of Orangeville, and East Garafraxa. In addition, there are existing aggregate extraction industries in the subwatershed with increasing interest in developing the industry further.

There is a historical legacy of human land use that has had some impacts on renewable resources of the Shaws Creek subwatershed. However, these impacts, to a large degree, may be reversable, and with proper care could provide the community with a high quality environmental area through the center of the community.

The Shaws Creek valley has been used for over 150 years. One of the key features of the valley is Caledon Lake, a natural marl pond in the north-central subwatershed that is home to an established recreational community. Several other marl ponds have been excavated as more people have established cottages there. Caledon Lake also supports a provincially significant wetland complex, one of three in the subwatershed. Near the confluence with the Credit River, in the Village of Alton, Shaws Creek has been dammed in several locations forming ponds that were once used to power mills and other such facilities. The Town of Orangeville, located north of the subwatershed, has begun to expand southward into the upper areas of the subwatershed, approaching the sensitive areas around Caledon Lake. East Garafraxa has been approved for low-density residential development in three areas with a total area of approximately 40 acres. Throughout the entire subwatershed, intensive agriculture has risen to dominate almost half of the total land area. All these changes have occurred over the past 150 years since settlement began.

5.1.4 The Geophysical Foundations of Integration

The form, structure and functioning of the Shaws Creek subwatershed is created by the interplay of physical and chemical processes such as precipitation, weathering, and erosion operating over long periods of time. The type or form of any watershed is created by the interaction of the earth's climate acting over time with the geology of the landscape. Geology provides the type of rock and its topography and climate the precipitation and conditions over time that modify the landscape so that soils are built up, glaciers form and melt, moving materials overtop of the bedrock and deposit, shift, sort and redeposit materials. Vegetation, based upon the recent and current climate, colonize and exploit the topography, soils and climatic characteristics.

A watershed ecosystem is therefore an interplay between the non-living materials (bedrock and surficial geology, water) and the living organisms that exploit and modify the processes and forms generated by the non-living components: the soils, topography and the movement of water over and through the watershed. Water plays a key role in connecting watershed characteristics and its processes and stressors in influencing its overall characteristics. An understanding of how water moves over and through the Shaws Creek subwatershed and the work it does and materials it carries is fundamental in understanding the past, present and possible future states of this watershed. The movement of water over and through a watershed is described by the water cycle. The pathways of movement of water over and through the watershed is controlled by the watershed's surface and bedrock geology, climate, topography, land cover (i.e. vegetation) and land uses.

The use man makes of the landscape has an influence on these pathways of movement of water, soil and nutrients. Approximately 150 years ago, the clearing of forested lands for agriculture within the headwaters of the Credit River resulted in changes to the water pathways (i.e. evapotranspiration) resulting in significant increases in the amounts of water available for generating runoff from the land. This factor along with the mechanical disturbance of the soils for agricultural development meant that enormous changes occurred in the flood flow volumes and patterns from the watershed and radical increases in sediment into the river's channel and floodplain. Many of the present lands along the Credit River are old floodplains buried under one to three metres of alluvium that washed into the river and its' floodplains during this period of agricultural development. Even after more than 100 years, the river is still contending with this material as it slowly tries to redefine its floodplain.

In addition to land clearing, other land uses under certain conditions can also have major impacts on the form and function of the watershed. These uses include:

- agricultural drainage, tiling and maintenance;
- cropping with associated soil and nutrient losses;
- onstream dam building or the remains of the alluvium of these activities;
- culvert placement and road and bridge crossing;
- channelization, straightening and armoring;
- urban development with increases in impervious surfaces and traditional stormwater management; and,
- aggregate extraction and quarrying.

These are just a few examples of man's modification of his landscape in North America and Europe. Not all presently apply to Subwatershed 17. The sad truth is that none of these impacts are new. Evidence of the affects of land use change on the ecology of rivers, streams and landscapes and the negative consequence of these changes on people are recorded by monks living in 11th century Europe (Hoffmann 1996). Unfortunately, we seem to wish to repeat history rather than learn from it. Hopefully, this cycle will be broken by sound information derived through watershed studies such as this.

5.1.5 Generic Geophysical Flow Model

Ecosystems are defined by the interplay of the landscape and its' processes on the communities of animals and plants within the system. This interplay occurs at a range of spatial scales over time and is examined and described using three major attributes:

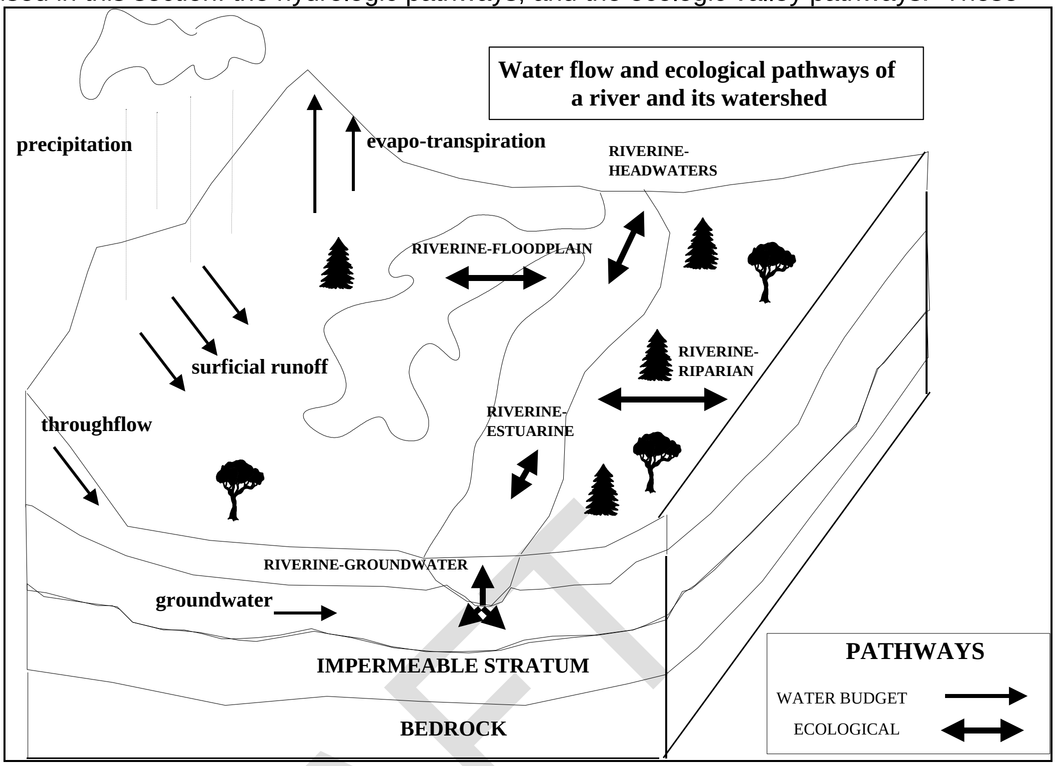
- Composition - the living and non-living pieces that make up the system;
- Structure - how those pieces look on the landscape;
- Function - how the pieces work together.

Functioning ecosystems come in different sizes. Determining the distribution of a rare plant may require an understanding of its' preferred soil type, moisture content and organic matter content within a certain climatic zone. Much of the analysis may occur within a small area of dozens of square meters to several hectares. Understanding the distribution of brook trout populations, habitat and community health requires an understanding of the subwatershed and its' hydrogeological nature and flow network. This requires an understanding of a watershed ecosystem of 1 to 100km^2. Understanding the habitat and ecosystem requirements of certain types of warblers requires a spatial scale that is continental in size. The size and appropriate ecosystem to study is selected based upon the fundamental management issues and questions. When concerns revolve around the use of water in conjunction with land use activities and the consequences of these uses on environmental features, then the appropriate ecosystem unit is the watershed and the subwatersheds' within the watershed system.

We can develop an integrated understanding of the subwatershed through the use of three major components:

- Use of a conceptual pathway model;
- Develop an understanding of the linkages between geology, topography, vegetative cover and the movements of water;
- Determine if the linkages help to explain the patterns seen in the Subwatershed.

Two pathway models are used in this section: the hydrologic pathways; and the ecologic valley pathways. These



pathways are illustrated in **Figure 5.1.4**.

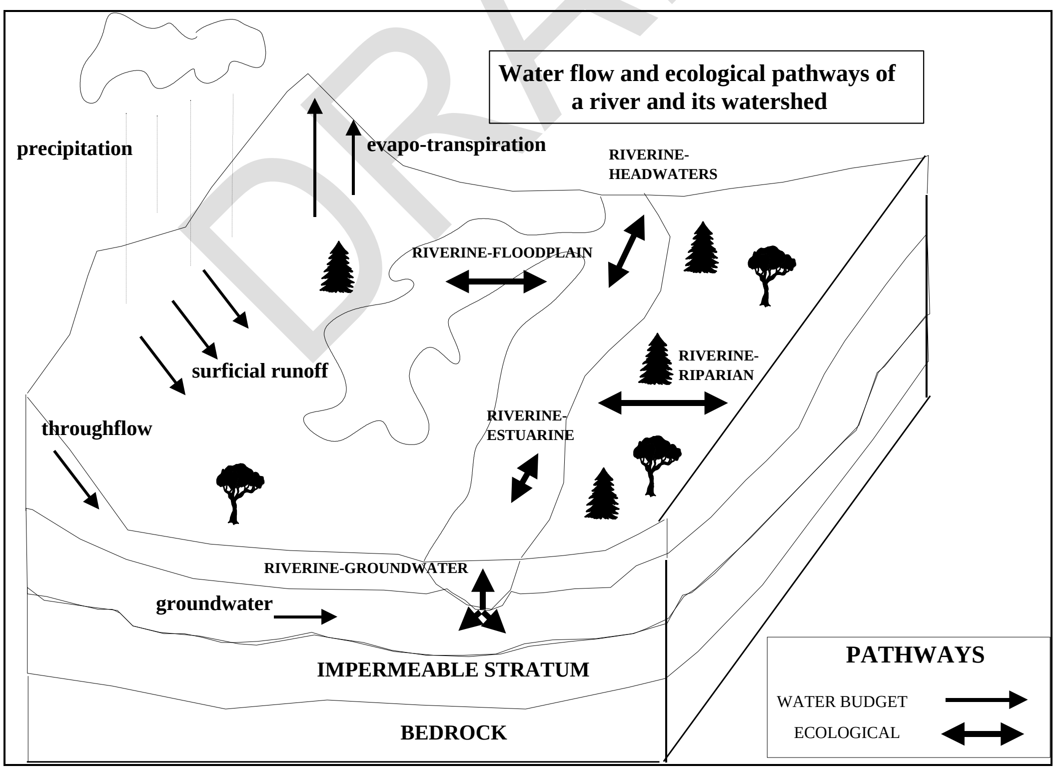


Figure 5.1.4 A landscape model showing two pathways of water interaction with the landscape: Hydrologic Pathway; and Ecologic (valley) Pathway.

Water is the element within this sub-basin that links to other functions and uses of interest to people. The movement of water (quantity and quality) over and through the landscape of this subwatershed creates the opportunities for various ecosystem components such as wetlands, forests, streams and groundwater tables. The movement of water also can carry with in dissolved nutrients, dissolved and particulate organic matter and sediments, all of which create and modify the landscape and watershed and provide opportunities for life within the system. In order for us to determine how we can obtain personal and economic benefit from the subwatershed, we need to understand at a conceptual and where possible quantifiable level how and why water with its linked properties moves over and through this subwatershed and how past and present activities have and will modify it. This then leads to the ultimate questions of what are the consequences of these changes in rates and pathways of movement of water and energy on the ecosystem components that rely on water and the energy it carries.

The hydrologic cycle or water budget approach is used to understand the movements of water on, over and through the broader landscape. The ecologic pathways are used to understand how water, sediments and nutrients interact with animals and plants within the valley system of the watershed. There are strong connections that occur in these ecologic pathways:

- River - Headwaters (the movement of water, nutrients and sediments out of headwaters and the movement of animals both downstream from and upstream into headwaters);
- River - Estuary (similar to above);
- River - Floodplain (movement of water, sediments, nutrients, animals and plant material in and out of the floodplain);
- River - Riparian (movement and interactions of water, sediments, nutrients, animals and plants in and over the riparian zone);
- River - Groundwater (interaction of river and groundwater movement in and out of the stream).

Geology, topography and climate are the controlling, or state, variables that determine the specific volumes of water available to the overall system in time and space and the potential pathways by which the water moves over and through the system. These form the foundation for the determination of specific flow pathways over and through the subwatershed.

Surface flow is an expression of the amount of water within a watershed that discharges off the land as surface runoff or is discharged from the ground into the stream at various locations along its length. The frequency, magnitude and duration of various flows, both high and low, are controlled by the subwatersheds water budget, which is ultimately controlled by the subwatersheds geology, topography, climate and landcover. Ecologists, engineers and planners must be aware of 4 controlling flows (**Figure 5.1.5**):

- Baseflow or Habitat Flow
- Bankfull Flow
- Riparian/Floodplain Flow
- Regional/100 year Floodflow

High flows occur during periods when precipitation and/or snow melt rates exceed the subwatershed's ability to infiltrate, transpire or evaporate the water, and when water tables and/or soils are saturated. These high flow periods occur several times a year with varying levels of magnitude. Spring flows are often the highest on an annual basis and are the flows that modify and adjust the structure of the stream channel (i.e. Bankfull Flow). Occasional summer high flows can occur, especially during convective weather patterns that create severe thunderstorms.

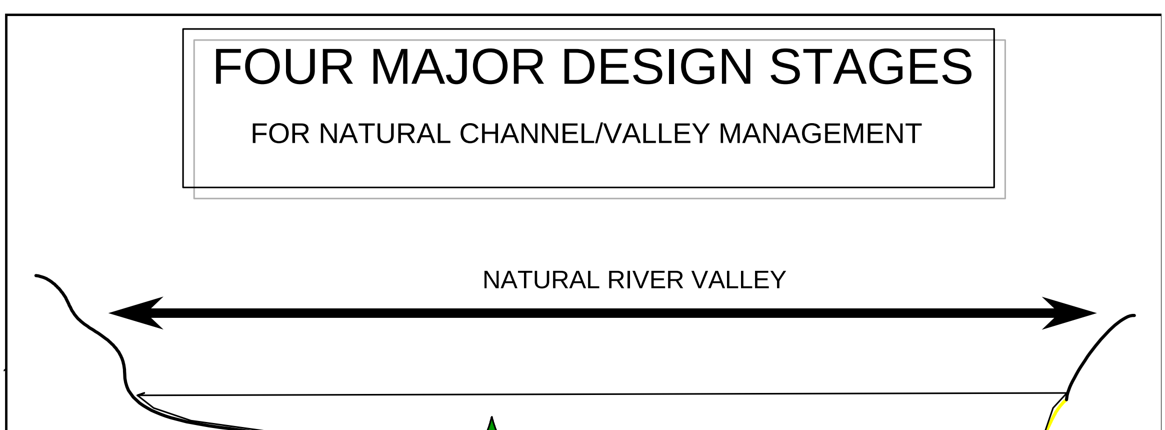


Figure 5.1.5 Four major design flows for healthy channels and valleys

Unusually high flows can occur infrequently (i.e. Riparian Flows - every 2-20 years) based upon unusual weather and watershed conditions. These infrequent high flows adjust floodplain and riparian characteristics, but cumulatively are not as important to channel health and stability as the more frequent, bankfull flows: the flow that forms the channel, which has a return period of approximately 1.1 - 1.8 years in Ontario. In highly urbanized watersheds (i.e. impervious surfaces > 10 - 15%) the channel forming flow will occur much more frequently, sometimes as often as 5 - 20 times per year resulting in accelerated channel and valley changes.

Low flow is not a single value but a type of flow pattern that can be defined like high flows by their frequency, magnitude and duration. Low flows are important to aquatic life because they are the periods of minimum habitat volume in any stream (i.e. Fisheries or baseflows in **Figure 5.1.3**). Therefore, these flows ultimately dictate the maximum biomass and densities of aquatic organisms in the stream for that year. However, the structure of the stream channel is controlled by the bankfull flows and therefore the quality of the habitat available during baseflow periods is controlled by the stability of the bankfull flow regime (frequency, magnitude and duration).

These low flows occur during periods when little precipitation falls on the subwatershed. At this point during the year, flow in the channel of the stream is derived primarily or exclusively from shallow and/or deep groundwater. Therefore, the minimum flow volume in a stream is controlled by the extent and quality of the groundwater system. This is in turn controlled by the surficial and bedrock geology.

Landcover is a major modifier of water flow or yield off a landscape. During growing periods, vegetation such as trees, shrubs, sedges and grasses absorb large amounts of moisture through their roots and pump this moisture (after using it) through their leaves. During a heavy rainstorm in the summer, a well forested watershed can capture and transpire back into the atmosphere up to 60% of the precipitation that falls, thereby reducing the amount that flows into a stream as surface runoff. Depression storage wetlands and riparian wetlands can capture, infiltrate, store and gradually release water during and after major precipitation or melt events thereby moderating the severity of high flows.

As naturally vegetated areas are lost, the yield of surface runoff from a watershed during a storm event will increase dramatically. These changes in flow pattern can have major effects on the stability of the stream channel, water quality and aquatic life.

Over hundreds or thousands of years, surface runoff, interacting with groundwater and geology create drainage patterns designed to provide natural drainage to the land (water, obeying gravity will attempt to flow down a slope). An assessment of drainage pattern such as the density of stream channel per km^2 can provide an inference of the relative proportion of stream flow that is contributed by groundwater versus surface runoff. For example, the lower the drainage density, the more infiltration capability a subwatershed possesses (water can infiltrate into the ground easier than running off) while the higher the drainage area, the less permeable the watershed (water flows off the land easier than infiltrating). The relationships between high and low flows, drainage density, geology and topography provide a means for us to understand how the subwatersheds generate the patterns of surface flows that aquatic life require. Additional information on the surface flow characteristics of the two subwatersheds can be found the hydrology section of the report. The consequences of surface hydrology on the living components of each of the subwatersheds is worth noting.

5.2 INTEGRATION MODEL

This section presents an analysis of the major structural elements (geology, terrain, major water bodies) at work in Subwatershed 17. The structural elements are then used to develop a conceptual model of the water movements (recharge, discharge, groundwater flow and surface water flow) of the subwatershed and the implications to resource features found within the watershed. This conceptual understanding then uses an analysis of the results from the other disciplines to create an understanding of how this particular subwatershed functions. Error! Reference source not found. illustrates the layering of disciplines that leads to an integrated understanding of the system.

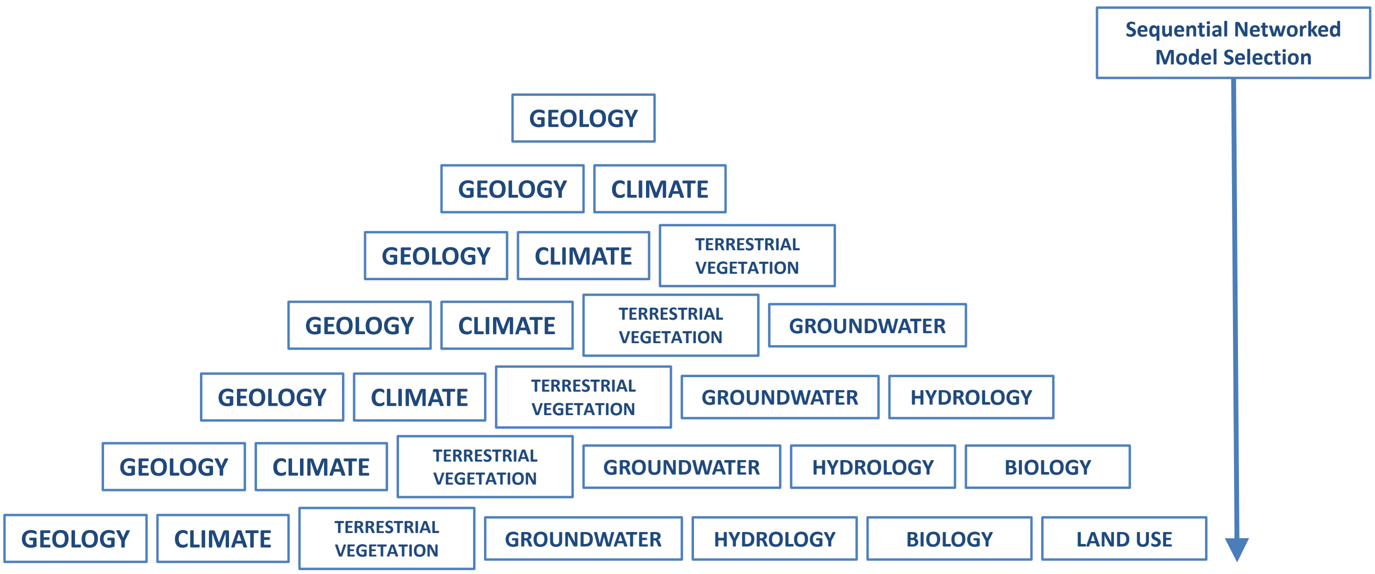


Figure 5.2.1 Building blocks of the disciplines, used to develop an integrated understanding of a subwatershed.

5.2.1 Composition and Structural Elements

Quantifying the elements of the water cycle: specifically, the location of stored water (wetlands, ponds, groundwater) and flowing surface water, the rate of flow between stored areas, and the influence of humans on the water cycle is the key concept which provides the foundations for integrated understanding of Subwatershed 17. Geology and climate are the controlling variables that determine the “water budget” and the shape, geology and characteristics of the valley determine the characteristics of the ecologic pathways.

Geology creates the fundamental compositional (e.g. types of geological features) and structural (e.g. depth, areal extent, layering, topography) components of the subwatershed. The geology of the Shaws Creek subwatershed can be divided into several major components within this sub-basin:

- bedrock geology (the type and nature of the crust of rock under the land or exposed);
- surficial geology (the type and nature of material overlaying the bedrock); and
- topography (the elevations of bedrock and surficial materials that create the form of the landscape).

In the Shaws Creek subwatershed, the **bedrock geology** is buried under drifts of surficial materials left after the last glacial period. The movement of water over and through the subwatershed is dictated by the type of structure (includes depth) and composition of the surficial materials and the type and depth to the bedrock under the surficial materials. Vegetative landcover on the landscape can act as a modifier of water movement over and through these materials. Water movements can be further modified by different landuses.

Climatic characteristics are relatively stable over long periods of time and provide the state characteristics for precipitation patterns and volumes over large areas. Localized differences can occur in precipitation based upon topography and landcover.
After geology, land cover has the next important influence in controlling or modifying the “water budget” or “water cycle” and in modifying certain pathways of movement of water, nutrients and materials through the landscape of the subwatershed.

Terrestrial features are separated into ecosystem units based on ecological interactions of biotic and abiotic features within the Table lands and valleys of the subwatershed.

Water pathways are based on major routes of surface and subsurface water flow.

Nutrient pathways follow water pathways. Aquatic and riparian life takes advantage of the nutrients and water being moved from upland areas to the valley and stream system. Links between the water budget pathways and the ecological pathways of the stream and valley provide a means of understanding the distribution, productivity, and types of aquatic animals found in the river. The terrain provides a means of understanding the terrestrial plants found in the valleys.

Understanding spatial scale of analysis and interpretation is also a very important element in any understanding of a watershed/subwatershed. For example, the locations and volumes of recharge to a groundwater system within a watershed need to be understood at a subwatershed level. At the next lower scale, the location of potential discharges is influenced by the structure and composition of the geology, within a reach of valley. The actual location of discharge of the groundwater is often driven by specific features found at the site.

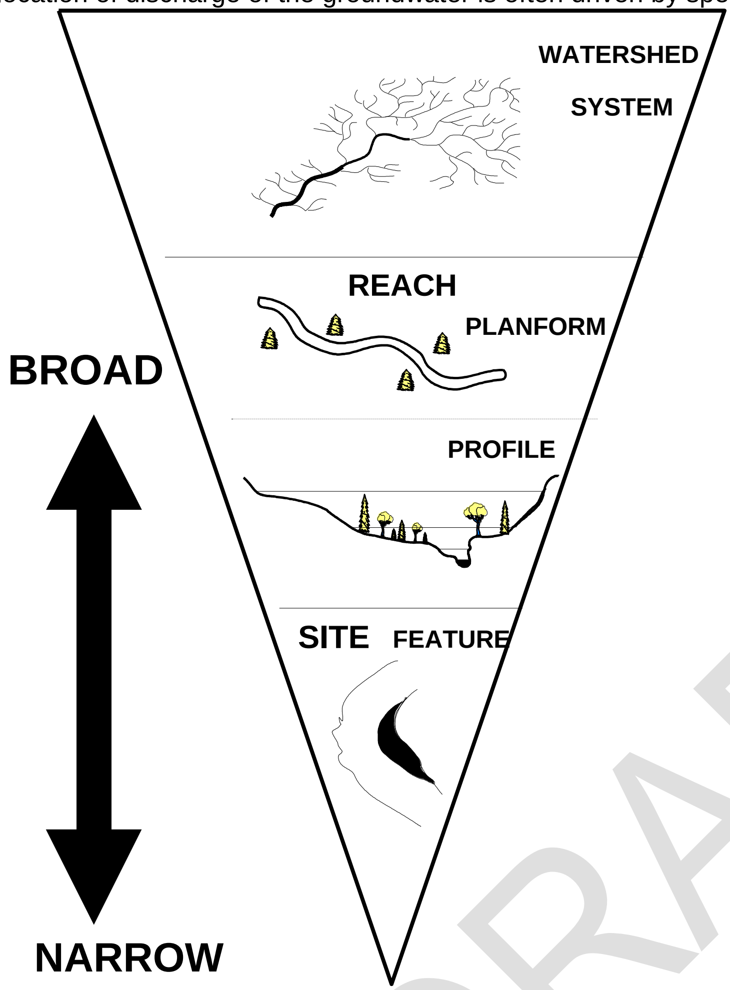


Figure 5.2.2 demonstrates the hierarchies of scale of used in subwatershed studies.

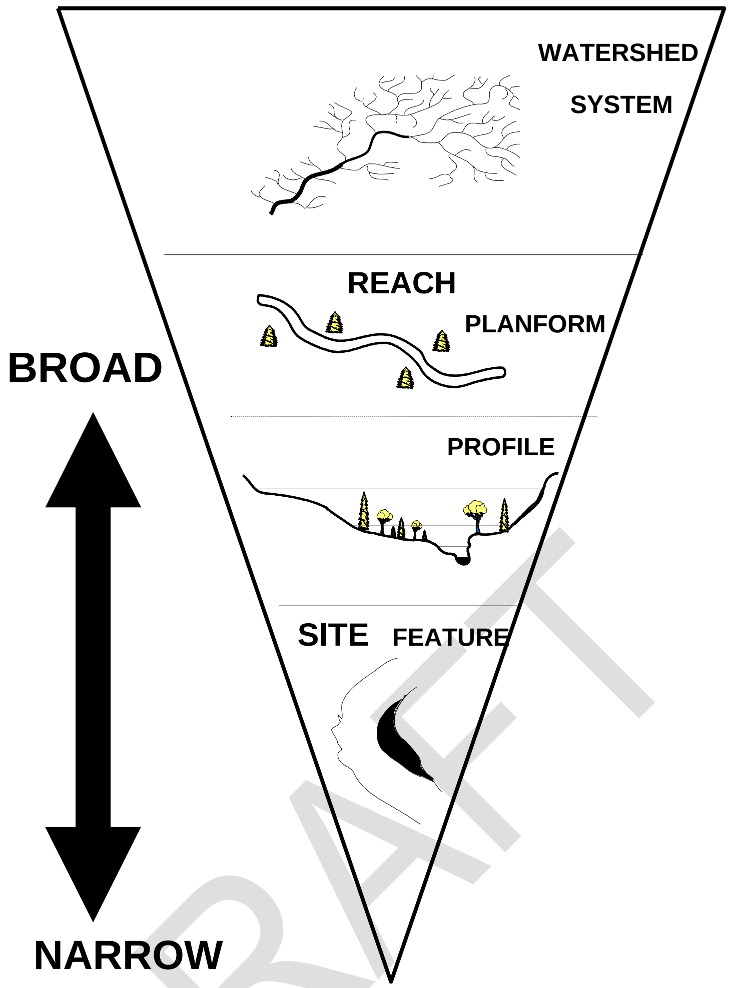


Figure 5.2.2 Demonstration of the various spatial scales that are considered in watershed analysis and characterization.

5.2.2 Assumptions

Several considerations have been used in the development of the conceptual "bucket and pipe" models for the subwatershed:

1. The structure and composition of the surface of the landscape governs the movement of water, sediment, nutrients and contaminants over and though the landscape. Surface form, slope or gradient, and elevation determine the storage potential and/or rate of flow over the land of precipitation.

2. Landcover, soil and overburden texture govern infiltration of water from the surface into the groundwater table and the potential for recharge of any part of the landscape to the groundwater table (e.g. Runoff Discharge = Rainfall - Infiltration; and Groundwater Discharge = Infiltration - Storage). The rate of

movement of water over or through the ground is a function of texture of the surficial materials, gradient or slope and elevation.

3. The recharge/discharge patterns of the groundwater system can be examined on different scales and can be divided into that controlled on a local scale by local gradients such as nearby hills(shallow watertable), on a mid scale by local conditions such as hummocky topography (shallow watertable and/or regional aquifer), and on a large scale by landscape topography, bedrock geology and elevations (regional aquifer).

4. At all scales the patterns of recharge and discharge are moderated through interactions between surface gradient, soil texture, landcover, depth to bedrock and bedrock type and spatial pattern.

5. The parameters identified above are important in explaining recharge/discharge pattern and are the fundamental variables used in groundwater movement models such as the model described by D'arcy's Law (Freeze and Cherry, 1979). D'arcy's law is used to describe how water flows through the ground.

5.2.3 Conceptual Model of Water Pathways

The characteristics exhibited by Shaws Creek are controlled by a series of processes and linkages that exist within the subwatershed. Many of these processes are part of the water linkages that are illustrated in **Figure 5.2.3**. This only illustrates water based linkages, and it is important to note that there are often linkages as well, such as terrestrial habitat linkages that reflect the movement of wildlife between terrestrial features.

The water based linkages (see **Figure 5.2.3**) provide a means of describing processes that influence the watershed characteristics as well as conditions of some of the features within the watershed. Some of the primary ones include:

- The majority of the headwaters in the watershed are on active agricultural land, within some areas including urban development (Orangeville upstream of Caledon Lake) or aggregate extraction areas. Runoff from these lands tends to be somewhat flashy as compared to woodlots on wetlands and can have high sediment loads (particularly agricultural lands);
- There are significant NHS features along the streams that provide habitat as well as enhance riparian stream conditions;
- Significant portions of the stream reaches have poor riparian habitat which impact on temperature, sediment levels in the streams and degrade aquatic health.

The on-line storage including Caledon Lake and other ponds degrade aquatic habitat, increase stream temperatures, and result in barriers to fish movement.

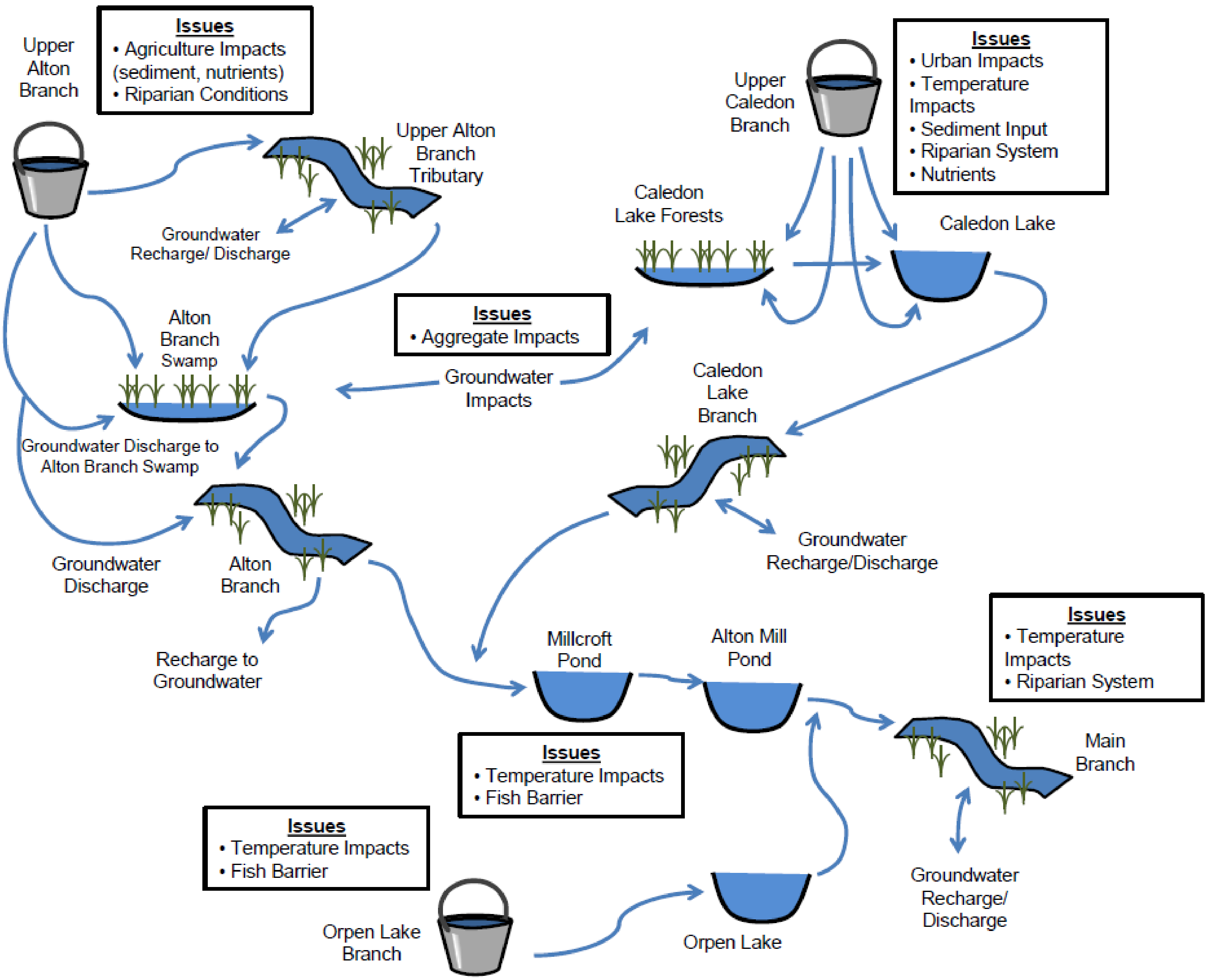


Figure 5.2.3 Shaw's Creek Water Linkages

5.2.4 Influence of the Surficial and Bedrock Geology on Subwatershed 17

The Shaws Creek subwatershed is comprised of three distinct physiographic regions: the Guelph Drumlin Fields, the Hillsburgh Sandhills, and the Dundalk Till Plain. Each region was formed during a distinct depositional environment and thus has different geologic characteristics. The majority of the watershed is dominated by the Hillsburgh Sandhills, more commonly known as the Orangeville Moraine. This feature is composed of moderately to highly permeable stratified drift deposits and encourages groundwater recharge due to its hummocky topography.

The surficial geology of the subwatershed is dominated by four significant features: the Orangeville Moraine, the Tavistock Till Plain, the Port Stanley Till Plain and the Hillsburgh Meltwater Channel. These overburden layers overlay the bedrock formations in thicknesses of up to 70m, but are also relatively thin in some places, such as along the Hillsburgh Meltwater Channel and in the Village of Alton where there is some exposed bedrock along Shaws Creek.

There are three underlying bedrock formations in Subwatershed 17: the Manitoulin, Amabel and Guelph formations. The Manitoulin formation underlies only a small portion of the subwatershed near the Village of Alton. The central portion of the subwatershed is dominated by the Amabel formation, while the western portion is underlaid by the Guelph formation. The Amabel and Guelph formations have similar geologic and hydrogeologic properties, and thus are sometimes treated as a single hydrostratigraphic unit. These bedrock formations are both capable of producting large quantities of groundwater due to secondary porosity features such as fractures and dissolution cavities.

These geologic components combine to create the four main hydrostratigraphic units throughout the subwatershed identified in the geological study (see **Section 4.2**):

- An upper sand and gravel aquifer (associated with the Orangeville Moraine);
- A clay till aquitard (Port Stanley and Tavistock Till);
- A lower basal sand and gravel aquifer; and
- Guelph/Amabel/Manitoulin Formation bedrock.

Thes units, combined with the general hummocky nature of the terrain, create an area of rich groundwater recharge and provide significant baseflow volumes to the Shaws Creek tributaries.

5.3 CHARACTERIZATION OF PROCESSES IN SHAWS CREEK SUBWATERSHED

The linkages that are illustrated in **Figure 5.2.3**Error! Reference source not found. are explained further in the consideration of how processes and characteristics are integrated. The following sections describe these characteristics and processes.

5.3.1 Surface Water Characterization and Functions

As part of the Water Pathways Model, the Shaws Creek system consists of three main branches: the Alton Branch, the Caledon/Caledon Lake Branch and the Orpen Lake Branch. These branches are illustrated in **Figure 5.2.3**. The Caledon and Alton branches drain the majority of the subwatershed, primarily from agricultural lands, and then join together upstream of the Village of Alton. The combined Shaws Creek then enters the Village, encountering two major ponds: the Millcroft Pond and the Alton Mill Pond. The Orpen Lake Branch joins with Shaws Creek downstream of the Village, just before the confluence with the Credit River.

The subwatershed is primarily rural in land use, but there are some existing aggregate extraction and urban land uses that impact the surface water regime through disruption of the natural landscape. The rural agricultural land use defines a great deal of the surface water flow in the subwatershed, as the farms tend to retain water on site and infiltrate it into the groundwater. As described in the following paragraphs, this interaction between surface water and groundwater defines the flow of water in this subwatershed.

The Shaws Creek subwatershed surface water is dominated by the interactions with the groundwater system, due to a combination of hummocky terrain and an abundance of high porosity soils. Other dominant characteristics identified during this study include: significant closed drainage systems, the presence of large wetlands, well defined valleys, marshy areas within the floodplains, and surface water storage features (i.e., ponds).

The hummocky topography associated with the Orangeville Moraine and large wetland areas above the Niagara Escarpment have resulted in large areas with either no surface drainage outlet or restricted outlets. These areas are referred to as closed drainage systems. Precipitation is retained in these areas, and either recharges the groundwater aquifers or evaporates. Existing land use practices, such as aggregate extraction and agriculture, also contribute to the retention and subsequent infiltration of precipitation, contributing further to baseflows.

The predominance of high infiltration soils, results in additional recharge to groundwater aquifers, and reduced surface water runoff to flow within the watershed. This was confirmed through the streamflow analysis at the Alton Branch gauge for Shaws Creek, where it was determined that high flows were more likely to occur during the spring freshet, when frozen ground conditions contribute runoff for all soil types.

The significant baseflows attributed to Shaws Creek subwatershed is represented in the unit area low flows (

) as compared to other monitoring stations in the Credit River Watershed. For all return periods, the Alton Branch has a higher per-unit-area low flow contribution than measured at the Cataract station (i.e., 4.9 $L/s/km^2$ vs. 3.3 $L/s/km^2$ at a 2-year return period low flow). Subwatershed 17 is an important contributor of baseflows to the Credit River system.

The Shaws Creek waterway has several important detention features that significantly affect surface water flow along its length; three of these have potential flooding impacts: Caledon Lake, the Millcroft Pond and the Alton Mill Pond. Caledon Lake is located in the northern portion of the subwatershed (south of Orangeville), and affects the ability of runoff from its tributary area to reach the main creek. This has resulted in some flooding issues around Caledon Lake. The two ponds in Alton (Millcroft and Alton Mill) are smaller than Caledon Lake. There are few flooding issues in the Village of Alton due to these ponds (a few properties around the Alton Mill Pond are within the floodplain, including the Alton Mill), but the ponds and the dams that have created them act as flow attenuation and control features, as well as providing water quality (temperature) impacts and barriers to fish passage.

There are two major ANSI/ESA wetland complexes in the Shaws Creek subwatershed: the Caledon Lake Forests, and the Alton Branch Swamp. These wetland features are areas of significant groundwater discharge to Shaws Creek.

5.3.2 Groundwater Characterization and Functions

The surficial and bedrock geology of the Shaws Creek subwatershed is dominated by the Orangeville Moraine and the Amabel Formation, respectively. Both of these features are capable of producing large amounts of groundwater, due to high porosity in the Moraine and in secondary porosity features in the bedrock, such as fractures and dissolution cavities.

Most of the groundwater flow into the subwatershed occurs from the west, where groundwater enters from the Grand River Watershed. The groundwater flow divide between the Credit River and Grand River Watersheds is thought to occur a few kilometers west of the Shaws Creek subwatershed boundary. Very little groundwater flows into Subwatershed 17 from Subwatershed 19, as the bulk of the groundwater flows from west to east along the subwatershed boundary. Groundwater flows out of this subwatershed primarily into Subwatershed 18 towards the deep buried bedrock valley, and to Subwatershed 15 following ground surface and bedrock topography.

Groundwater flow in the overburden is generally from north to south, with localized flow in the eastern portion of the subwatershed towards the Credit River. Generally, the hydraulic gradients are steepest at the eastern edge of the subwatershed for both surface and bedrock groundwater flows.

The generally high infiltration rates throughout the subwatershed means that Subwatershed 17 has among the highest mean annual baseflow rates in the Credit River Watershed, estimated at 233mm or 0.532m3/s (see **Section 4.2**). All of the subcatchments were observed to have flows throughout the field season. The largest contributor to baseflows was subcatchment 17-01 (see **Figure 2.1.2**), which comprises approximately 30% of the overall area but contributes half of the baseflow, primarily due to its location on top of the Orangeville Moraine and the interactions with the fine grained organic deposits above Caledon Lake. This is the area of the Upper Caledon Branch, as shown in **Figure 5.2.3**.

The chemistry of the groundwater is laregely controlled by the underlying geology, with the groundwater being enriched with calcium, magnesium and bicarbonate from the dissolution of the carbonate righ Guelph and Amabel bedrock, composed of dolostone. Other ions encountered in addition to these include sodium, potassium, suplhate and chloride.

Few areas within the subwatershed have been identified as being highly susceptible to groundwater contamination from surficial sources. Thes areas that have been identified include those places where there is a high water table where there is a thick layer of permeable sand and gravel near the surface, where the bedrock aquifer is exposed at ground level in the Village of Alton, or where only a thin layer of overburden is present. More areas were identified to be of moderate susceptibility to surficial contamination, usually associated with the permeable sediments of the Orangeville Moraine. However, this susceptibility applies only to the uppermost overburden aquifer and not to the deep bedrock aquifer.

5.3.3 Terrestrial Integration Characterization

The dominant land use in the subwatershed is agriculture (43.56%), most of which is considered intensive (37.69%). Less than 26% of the subwatershed can be considered to be in its natural, pre-development state, and even these areas have been impacted by human development through selective logging, dumping and earth displacement practices. The natural areas of the Subwatershed include Provincially Significant Wetlands, Areas of Natural and Scientific Interest, Envrionmentally Significant Areas, rare communities and old growth forests. Resident species in these habitats include rare species and species of conservation concern. Natural areas within the watershed have been mapped based on associated overall significance.

Identification of terrestrial communities and open water bodies identified corridors within the natural area. Corridors provide cover to species moving from one habitat to another and aid the movement of wildlife and the dispersal of flora between habitats as well as small and large scale watershed. Watershed scale corridors within the Subwatershed provide links from the Credit River Watershed to the Grand River Watershed, Shaws Creek to the Credit River and provincially significant wetlands to Environmentally Significant Areas. Improvement and enhancement of corridors would provide a greater link between habitats, and will be a cornerstone of the overall subwatershed management recommendations. As well, enhancement of riparian vegetation along tributaries would also provide beneficial terrestrial links. Corridors within the watershed have been mapped by based on associated overall significance.

Increased road traffic within the Subwatershed is a concern for amphipians. A study of high mortality areas and consideration for amphian crossings should be included in future management plans.

Landscape scale community/patch analysis prioritized natural areas into high, medium and low classifications. Areas of moderate priority included coniferous plantation communities situated next to high priority areas and low priority areas included isolated fragments of habitat with limited connections to large natural areas. It is less important to maintain small pockets of swamp and a greater importance should focus on creating and maintaining larger, diverse wetland habitats.

5.3.4 Geomorphic Characterization and Functions

The fluvial geomorphology of Subwatershed 17 is complicated and diverse given the varied geology and topography characteristics of the subwatershed. These streams are an integral component of overall watershed health as they often determine the quality, quantity of water and sedimentation within higher order streams. The dominance of the headwater system within this Subwatershed requires management plans to recognize the unique function of these systems.

The watershed has historically been impacted by agricultural and aggregate landuses, with minimal landuse change occurring in the last 60 years. As many of the tributaries are 1st and 2nd order streams, many reaches have been entrenched and straightened to provide agricultural drainage. Conversely dams and ponds were created in the watershed to provide water control for agricultural uses and now function as sediment sinks.

Characterisation of channel reaches considered topography, channel dimensions, substrates, vegetative cover, channel disturbance, erosion, morphology, sediment characteristics, and aggradation. Channel gradients range from 3.02% to 0.21%. RGA scores varied from in transition to in regime (0.29-0.04) with in transition reaches likely a result of systematic adjustments associated with agricultural activity. RSAT scores varied from fair to excellent with scores of 18-38 and the Rosgen classification system produced classification results of C, E, G systems. The downstream model indicated channels were enlarging, compound or depositional. It is suspected that there is more rapid aggregation within wetland and low lying features.

Management plans should include Subwatershed drainage density targets to ensure that if low order tributaries are lost, the function of these systems is replicated. Future modeling of this Subwatershed should examine the impact of potential loss of low order channels on higher order channels. Future management plans should also consider the removal of dam structures within this watershed, as these structures currently provide a sediment sink and removal efforts should consider potential sediment release and change in local grade control. Geomorphic monitoring stations should be implemented on both higher order channels and under represented branches of Shaws Creek.

5.3.5 Water Quality

This study considers water quality as the combined chemical, physical and microbiological properties of surface water. Parameters of concern (POC) were selected to be sampled at 10 stations in 2005, in addition to the PWQMN station located at Shaw's Creek and the Bruce Trail with sampling results available from 2002- 2005. A summary of parameter results and the overall significance of each parameter is shown in **Table 5.3.1**.

Table 5.3.1 Water Quality Summary

Parameter	Comment	Significance
Phosphorus	Longterm monitoring data showed phosphourus levels typically remain below the PWQO of 0.03 mg/L, with a 17% of samples exceeding the objective. Short term monitoring data showed phosphorus concentrations at sites 2, 3, 4 and 9 exceeding the PWQO at the 75th percentile, and site 3 exhibited significantly higher results. A longer term study would need to be conducted to determine possible sources.	High concentrations lead to excessive plant growth, and decreased DO levels. Sources of phosphorus may include urban runoff, agricultural runoff, wastewater discharges and erosion of soils containing high phosphorus levels.
Nitrate	Levels across the subwatershed currently below levels considered harmful to aquatic biota. A notable exception is site 16, where nitrate results exceeded the CCME guideline during 75% of the sampling occasions.	Nitrate is a dissolved nitrogen parameter stimulatating aquatic plant growth and may be toxic to aquatic biota at elevated levels.
Metals	Metals exhibited low violations of PWQOs and are not considered to be a significant concern for most of the subwatershed. An exception is Site 3 which exhibited elevated levels of most metals compared to other sites throughout the subwatershed and regularly exceeded water quality guidelines. These elevated levels suggest Shaws Creek is being impacted by the developments to the north through surface and groundwater connections.	Metals are typically most prevalent in urban drainage, but may also be associated with soil erosion and suspended solids. High levels of metals are often toxic to aquatic organisms.
Dissolved Oxygen	The dissolved oxygen regime is relatively healthy in the Shaws Creek subwatershed. There were no measured exceedances of the dissolved oxygen guideline of a minimum of 5 mg/L. The greatest daily fluctuations were noticed at Site 8 at Mississauga Road, as the dissolved oxygen regime at this location is heavily influenced by the inputs of low DO stream flow from near-by Caledon Lake.	Minimum dissolved oxygen concentrations are required to support aquatic habitat.
Temperature	The coolest water temperatures occur in the upper portion of the Subwatershed and in the groundwater fed tributaries. The warmest water temperatures were seen in watercourses influenced by Caledon Lake and in tributaries with slow flow rates draining into wetlands.	Coldwater habitats typically support the most sensitive aquatic habitat.
Chlorides	Chlorides were below levels thought to be deleterious to aquatic life. However, increasing trends in the long-term data and higher concentrations observed in more urbanized portion of the subwatershed are a concern for future urban development. It is important to note that samples were collected during the summer season only. Results mostly likely would be higher if winter sampling had been included in the study.	Sources of chlorides include loadings from STP effluents, road salting practices or ice in the summer and dust suppressant ($CaCl_2$) in the summer. High concentrations can be harmful to aquatic biota.
E. coli,	*E. coli* levels throughout the watershed were generally above	Is used to estimate likelihood of

	what is considered to be acceptable levels for recreational uses. Long-term data showed summer and fall results to typically exceed the PWQO. Site 17, upstream of Hwy 136 recorded the highest levels, with concentrations over five times the acceptable limits for recreational uses.	pathogenic bacteria in the water body. Possible sources of the elevated levels include upstream agricultural sources, urban runoff and from human sources (septic impacts).
TSS	Suspended solids concentrations at the long-term Shaws Creek station at Bruce Trail exhibited values below levels thought to be deleterious to aquatic life. Suspended Solids concentrations were highly variable at the short term stations and did not provide sufficient information to accurately characterize suspended solids levels.	High levels can be clog spawning areas, decrease DO levels, reduce plant growth, and reduce water clarity.
Sediment Chemistry	There was no indication of heavy metals or hydrocarbon accumulation in the subwatershed. PCB's were found at one site above the probably effect level which indicates adverse effects are expected. Exact sources of the PCBs are difficult to determine as they persist and accumulate in the sediment over long time periods.	Generally an indication of aquatic environment health and detrimental point source impacts.

Results showed overall the water quality in Shaws Creek subwatershed is good in terms of supporting healthy aquatic biota. In general, the tributaries that flow in a north-easterly direction towards the main branch of the Shaws Cheek meet the selected water quality standards. Water quality monitoring results indicate that tributaries neighboring the Town of Orangeville exhibit elevated water quality results compared to other stations within the Subwatershed. Development in this area may be impacting water quality through surface and groundwater connections.

5.3.6 Benthic Characterization

Benthic macroinvertebrates are a commonly used indicator group of aquatic environmental conditions for several reasons. First, they integrate biologically relevant variations in water and habitat quality. Second, they are limited in their mobility and therefore reflect local conditions and can thus be used to identify point sources of inputs or disturbance. Their short life spans (about 1 year) also allow them to integrate the physical and chemical aspects of water quality over annual time periods and provide early warning of impending effects on fish communities (Kilgour and Barton, 1999). Finally, based on known tolerances of benthic taxa, it is possible to re-create the environmental conditions determining the animals present (Rooke and Mackie, 1982a,b).

Benthic macroinvertebrates were sampled at a total of 10 stations during July-August 2005. All stations within Subwatershed 17 had community index values that were representative of predevelopment conditions, and did not indicate any significant levels of impairment. Historical monitoring data (1999- 2005) from Station 501170001 does not indicate a change in the overall benthic community.

5.3.7 Fisheries Characterization

Shaws Creek Subwatershed was designated enitirely as a coldwater system by the Credit River Fisheries Management Plan (CRFMP). Aquatic sampling at 30 sites within the subwatershed provided baseline biomass data and analyses produced an Index of Biotic Integrity (IBI) rates for fish community health. These IBI results ranged from excellent to poor and verified that the Subwatershed ranges from warm to coldwater habitat. Other temperature data confirmed habitat findings. Coldwater habitats within Shaw's Creek Subwatershed appear to be related to hydrogeology and location of wetlands within the Subwatershed.

The two western headwater reaches, upstream of Erin-EG Townline are intermittent in nature and have been classified as small warmwater where more tolerant headwater species are most common. One headwater site in this study ranks as excellent and the most productive fishery in the entire Credit watershed. There is some concern that there has been some decline of health noted over the last 6 years at this site.

The middle reaches and tributaries upstream of Shaws Creek Rd./Highpoint SR are habitat to brook trout and has been classified as coolwater. The two new biomass stations set up in 2005 within the mid reaches of the subwatershed scored as fair health.

Caledon Lake and the reach downstream were historically coldwater but introduced species to the lake (hatchery trout and rock bass) and potential impacts related to eutrophication and dams are now responsible for a warmwater fishery.

Two sites around Alton are more variable over the years but are generally in good health even though brook trout are not always present over the years of sampling. Populations in the lower reaches through Alton appear more sporadic and stressed with the Orpen Lake tributary providing the best source and refuge area. Historical documentation of spawning redds in the lower reaches suggests there has been a decline in populations since the 1980's. Further groundwater discharge mapping should confirm whether the reach below Caledon Lake should be lends to coldwater habitat. Restoration efforts should focus on Lake Eutrophication and the mitigation of the Cedar Falls dam. The next priority would be on the Alton Dams.

Critical spawning habitats for brook trout are concentrated in the coldwater middle reaches above Caledon Lake and two tributaries west of Winston Churchill Blvd. as well as Orpen Lake tributary in the lower reaches. Other spawning locations were also identified with priority reaches for future surveys.

Recreational trout fishing was identified at 7 access points in the subwatershed. Caledon Lake is also managed and stocked for private fishing by the Caledon Lake Company with a long history as a fishing and hunting club. It is recommended that a stewardship partnership be further developed with the MNR and CVC in the form of a Lake/Fisheries Management Plan.

There are several barriers to fish passage along Shaws Creek, two major ones of which are in the Village of Alton: the Millcroft Pond and the Alton Mill pond.

5.4 APPLICATION OF THE INTEGRATION MODEL

5.4.1 Integration of Subwatershed Processes

The interactions between the subwatershed components characterized in the previous sections are described in **Table 5.4.1**

5.4.2 Key Interactions in the Shaws Creek Subwatershed

The Shaws Creek Subwatershed exhibits an overall high level of aquatic and terrestrial health. This can most likely be attributed to the relatively stable land use in the subwatershed, as few significant changes have occurred in at least the past 60 years, except for the encroachment of urban development from Orangeville into the areas upstream of Caledon Lake.

As illustrated in Error! Reference source not found., the stressor of land use change affects several components of the aquatic and terrestrial ecosystems of a subwatershed, including water quantity, water quality, stream form, and quantity and quality of habitat. These components were evaluated during this study through the use of key indicators in order to determine the extent of any impacts from the stressor of land use change. Since few land use change stessors have occurred in recent history, the evaluation has shown relatively healthy regimes in each of these components.

Subwatershed 17 is an area of rich groundwater recharge, due to its location on the Orangeville Moraine and the underlying bedrock formations. The hummocky terrain of the Moraine also contributes to the recharge through detaining and infiltrating surface water in topographical depressions with no natural outlet, particularly in the western areas of the subwatershed. The recharge in turn fuels extensive baseflow discharges to the tributaries of Shaws Creek, among the highest levels in the entire Credit River Watershed. This ensures that a large quantity of high-quality aquatic habitat is available, making Shaws Creek and its tributaries one of the most productive fisheries in the Watershed.

The large stream baseflows have also helped to maintain a healthy water quality throughout the surface water conveyance system. In many areas there are some elevated levels of phosphorus and bacteria, but with no harsher contamination typically associated with urban development, such as metals, hydrocarbons, or chlorides. The baseflows have also helped to maintain many stream reaches as coldwater fisheries, supporting large populations of spawning brook trout, typically in the wetland systems surrounding Caledon Lake and the Alton Branch Swamp.

The predominance of agricultural land uses in the subwatershed has ensured that the majority of the first and second order tributaries of Shaws Creek have been maintained, even though many of them have been straightened or entrenched for drainage. Similarly, several significant terrestrial habitat corridors have also been maintained among the agriculture, although this is due to the fact that the marsh and wetlad areas around Caledon Lake and the Alton Branch Swamp are unsuitable for agriculture and have thus not been developed.

These subwatershed components, fueled by a healthy groundwater recharge/discharge regime, produce a subwatershed with a high level of aquatic and terrestrial health. However, there have been preliminary indications of negative impacts from urban development around Orangeville, and there are several long-term existing impoundment features that adversely affect the surface water regime of Shaws Creek.

Water quality monitoring upstream of Caledon Lake has consistently yielded levels of metals higher than those of other monitoring stations in the subwatershed, a contaminant that is typically associated with urban development. In addition, there is an increasing trend of chlorides in many of the monitoring stations, which is another contaminant associated with human activities such as road de-icing, dust suppressant and sewage treatment plants. Increased sampling should be performed, particularly during the spring freshet, to determine mass loadings to Shaws Creek and potential sources. The benthic communities in these areas, used as indicators for local aquatic environmental conditions, have yet to be affected by these water quality issues.

Existing, built impoundments along Shaws Creek, including the Millcroft Inn, Alton Mill, Cedar Falls and Orpen Lake dams, act as sediment sinks, create water temperature impacts and barriers to fish passage, disrupting the natural function of the subwatershed system. Potential enhancements to the aquatic environment will consider these impacts and methods to rehabilitate/mitigate these impoundments.

The geological composition of Subwatershed 17 is very conduvice to maintaining healthy aquatic habitat, the benefits of which ripple out to the rest of the Credit River Watershed in terms of baseflow and fishery production. The preservation of the groundwater recharge characteristics of the subwatershed, including the protection of high infiltration areas and of the major wetland systems, should be the cornerstone of any future development strategies. This is of particular importance when considering the aggregate industry, which may have significant impacts on the groundwater regime, and urbanization, which may impact overall water balances.

Table 5.4.1 Shaws Creek Subwatershed Integrated Condition Assessment

	Hydrology and Hydraulics	Groundwater	Terrestrial	Biology/Aquatics	Geomorphology	Water Quality	Land Use	
Hydrology and Hydraulics		▪ Strong connection between ground water and surface water ▪ Base flow varies but groundwater contribution is strong, Shaws Creek is an important baseflow contributor to the Credit River ▪ Significant wetland areas are strong contributors to baseflows	▪ On-line ponds acting to reduce peaks, providing flow attenuation ▪ Existing wetland areas provide flow attenuation	▪ Habitat is strongly supported by base flow and bankful forming processes.	▪ Uncontrolled development lands have increased and continue to increase stream erosion	▪ Peak events washing pollutants from past/uncontrolled development reducing water quality ▪ Drought and low flow period results in a decreased ability for river to assimilate potential contamination (agricultural runoff, urban runoff, septic system discharges)	▪ Agricultural land use tends to retain surface water and infiltrate into groundwater ▪ Aggregate and urban land uses impact natural surface water regime ▪ Flood damage centre ….main street in flood plain	CONDITION ASSESSMENT
Groundwater	▪ Changes to infiltration (due to land use) may impact groundwater table ▪ Changes to groundwater table may impact location and volume of groundwater discharge (baseflow)		▪ Significant wetland areas are strong contributors to baseflows ▪ Hummocky terrain and high porosity soils contribute to high infiltration levels ▪ Recharge processes influence groundwater quality	▪ Strong base flows supporting fish habitat; Shaws Creek one of the healthiest fisheries in the Credit River watershed but there are signs of degradation over the last decade.	▪ Base flows have influenced stream form, erosion and sedimentation	▪ Base flow contributions cooling temperatures in headwater areas ▪ High nitrate concentration linked to septic systems have caused the closure of municipal wells in Alton ▪ Bedrock influences on water quality noted ▪ Potential development related impacts at stream noted at north edge of subwatershed	▪ Land use that retains surface water (e.g. agriculture) promotes recharge ▪ Hummocky terrain and high porosity soils contribute to high infiltration levels ▪ Urban development currently limited ▪ Few areas are highly susceptible to contaminants, some areas identified as moderately susceptible	
Terrestrial	▪ Increased woodlot and wetland coverage would reduce flow peaks	▪ Increased aggregate extraction may impact stream baseflows ▪ Increased woodlot and wetland coverage may affect infiltration or discharge ▪ Hummocky topography important to maintain for recharge function		▪ Aquatics have been degraded by lack of riparian vegetation in many reaches but in general extent of natural areas support good aquatic health.	▪ Degraded riparian corridor have impacted stream form in some areas	▪ Lack of riparian vegetation in some reaches impacts temperature and reduces filtering of pollutants ▪ Caledon Lake contributing to low DO in streams and elevated water temperatures.	▪ Extensive historical agricultural practices have adversely affected terrestrial linkages ▪ Increased road traffic a concern for amphibians ▪ High nitrates coming from septic systems have potential to impact amphibian species in riparian areas and fisheries in-stream	
Biology/ Aquatics	▪ Online ponds cause barriers to fish migration ▪ Potential impacts to fisheries and benthics with changes in baseflows or bankful forming processes. ▪ Increased flooding on Caledon Lake could offset ongoing channel works on outlet channel or increase risks of dam failures in subwatershed.	▪ Potential impacts to fisheries and benthics with changes in groundwater discharge or quality	▪ Terrestrial enhancement along the riparian corridor would contribute to increased aquatic habitat directly as well as wetland/terrestrial restoration indirectly.		▪ Streams are in a "natural" form in most areas providing good fish habitat ▪ Increased erosion with past uncontrolled land use has degraded habitat as well as dams interrupting sediment processes	▪ Water quality impacts from historic uncontrolled land use activities impacting fisheries ▪ Water temperature warming from on-line ponds has potentially impacted cold water fishery in specific reaches ▪ Benthic communities generally healthy throughout subwatershed	▪ Benthic communities generally unimpaired due to relatively stable land use in past 60 years. ▪ Dams present barriers to fish passage and adverse temperature impacts ▪ Nutrient management and restoration of wetlands, forest and riparian cover to benefit fish.	
Geomorphology	▪ Increased flow peaks and volumes from urban development may impact geomorphic stability, increase erosion	▪ Changes in baseflows (related to changes in groundwater discharge) may affect stream form	▪ Enhanced riparian vegetation would reduce erosion and enhance natural stream form	▪ Lower order tributaries have been historically channelized, potentially impacting habitat ▪ Potential impacts of dams on sediment regime.		▪ Sediments/bed load trapping in ponds reducing suspended sediment downstream of ponds	▪ Many headwater reaches have been straightened for agricultural drainage ▪ Past land use activities have increased erosive forces and impacted stream form ▪ On-line ponds act as sediment sinks, reducing bed load and increasing erosion	
Water Quality	▪ Potential water quality impacts due to increased urban development in Alton and Orangeville (SWM) ▪ Sediment and erosion impacts from construction activities ▪ On-line ponds cause water temperature warming and sediment traps	▪ Potential changes to groundwater table may impact water temperature through reduction of cooler base flows ▪ Changes in groundwater quality can affect stream water quality ▪ Continued development on septics will impact ground water quality. Tertiary level of septic system treatment will be required in vulnerable areas	▪ Potential terrestrial enhancement may improve water temperature ▪ Wetland enhancement could improve water chemistry	▪ High temperature resulting from on-line ponds and riparian conditions impacting fisheries ▪ High nitrates coming from septic systems have potential to impact amphibian species in riparian areas and fisheries in-stream ▪ Temperature and nutrient enrichment impact DO for fish	▪ Removal of online ponds may restore natural sediment loading in creek, changing water quality profile		▪ Water quality influenced by agricultural runoff in certain reaches ▪ Water quality impaired in areas receiving drainage from urban development ▪ On-line ponds and dams impacting temperature water quality ▪ Dense use of septic systems in Alton has caused water quality impacts. Many system are very old, unmaintained and on very small lots.	
Land Use	▪ Land use changes that affect groundwater table may impact stream baseflows ▪ Increased urban development may impact flow regime in creek	▪ Land use changes (e.g. urban development) may impact groundwater quality, water table levels or site recharge potential ▪ Potential impacts (e.g. changes in discharge location or volume) can also be associated with expansion of aggregate extraction	▪ Potential opportunities for terrestrial enhancement through riparian corridor buffers and plantings ▪ Potential impacts to terrestrial linkages due to increased urban development	▪ Removal of online ponds will facilitate fish passage ▪ Nutrient management and restoration of wetlands, forest and riparian cover to benefit fish.	▪ Increased urban development may impact geomorphologic stability ▪ Potential land use restoration efforts can enhance geomorphic conditions in tributaries ▪ Removal of online ponds can restore natural sediment flows	▪ Increased urban development may impact creek water quality (SWM) ▪ Removal of online ponds may mitigate temperature impacts		
	POTENTIAL IMPACTS							

6. Vision and Goals

Watershed Goal
To ensure abundant, safe, clean water for environmentally, socially and economically healthy communities within the Credit River Watershed.

Vision for the Shaws Creek Subwatershed
Our vision of the Shaws Creek Subwatershed consists of a place where human uses are in harmony with the environment. It consists of natural heritage systems linking its terrestrial, aquatic and riparian systems, which contain healthy, diverse and self-sustaining populations of fish and wildlife. The residents of the region will value the area and be aware of their impacts on the environment. They will use the Subwatershed for responsible agriculture and passive recreation, including bird watching, and hiking, and they will attempt to live in balance with nature.

Shaws Creek Subwatershed Objectives & Targets
Key issues that triggered the undertaking of this Subwatershed Study include the presence of aggregate extraction in the area (and the potential for further industry development), increasing pressures from land development, and a large number of active agriculture areas.

Targets under the following Subwatershed objectives have been developed:

- Demonstrate and promote awareness of the linkages between healthy water, healthy lifestyle and the economic viability of rural and urban land uses
- Promote the wise use of surface and groundwater having regard to both human and ecological needs
- Promote the need for environmental stewardship and better understanding of the importance of natural features and functions of the Credit River Watershed
- Preserve and re-establish the natural hydrologic cycle
- Maintain, enhance or restore natural stream processes to achieve a balance of flow and sediment transport
- Manage stream flow to reduce erosion impacts on habitats and property
- Minimize risk to human life and property due to flooding
- Maintain groundwater levels and baseflows (groundwater discharge to streams) to sustain watershed functions, human uses and climatological change
- Maintain or enhance water and sediment quality to achieve ecological integrity
- Protect, restore or enhance the integrity of the watershed ecosystem, through an integrated network of natural areas, habitats and connecting links
- Protect, restore or enhance native terrestrial and aquatic plan and animal species, community diversity and productivity
- Promote integrated resource management of the aquatic and terrestrial systems and areas within the watershed for plan, animal and human uses
- Monitor and conduct research to continue to enhance our understanding of the Subwatershed and to monitor environmental conditions and stresses.

7. References

Annable, W.K. 1996. Morphologic Relationships of Rural Watercourses in Southern Ontario and Selected Field Methods in Fluvial Geomorphology. Ontario Ministry of Natural Resources and Credit Valley Conservation.

Baker, J.E., S.J. Eisenreich, T.C. Johnson, and B.M. Halfman. 1985. Chlorinated hydrocarbons cycling in the benthic nepheloid layer of Lake Superior. Environ. Sci. Technology. 19:854-861.

Barbour, M.T., J. Gerritsen, B.D. Snyder and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish. Second Edition. EPA 841-B-99-002.

Barton, D.R. 1996. The use of percent model affinity to assess the effects of agriculture on benthic invertebrate communities in headwater streams of southern Ontario, Canada. Freshwater Biology, 36:397-410.

Barton, D.R. and B.W. Kilgour. 1999. A preliminary evaluation of the behaviour of the BioMAP water quality index. Canadian Water Resources Journal, 24:139-146.

Beak Consultants, Aquafor Engineering Limited and Donald G. Weatherbe Associates Inc. (1992) Credit River Management Strategy.

Blanchfield, P.J. 1998. Lake spawning by an iteroparous salmonine: the mating system of brook trout (Salvelinus fontinalis). Ph.D. thesis, York University, 198 pages.

Blower, R. 2001. Ontario Breeding Bird Atlas Observations (17NJ83) from May - June 2001. Field Observation Notes. 2 pgs. + map.

Bode, R.W. 1988. Quality assurance workplan for biological stream monitoring in New York State. Stream Biomonitoring Unit, Bureau of Monitoring and Assessment, Division of Water, NYS Department of Environmental Conservation, Albany, NY.

Bowen, G. S. and M. J. Hinton. (1998) The Temporal and Spatial Impacts of Road Salt on Stream Draining the Greater Toronto Area. Groundwater in a Watershed Context Proceedings. Burlington, Ontario, pages 303 to 309.

Brown, D. M., G. A. McKay and L.J. Chapman. 1974. The Climate of Southern Ontario.Climatological Studies Number 5, Environment Canada, Atmospheric Environment Services, En57-7/5.

Burkard, M.B. and R.A. Kostaschuck, 1995, Initiation and Evolution of Gullies along the Shoreline of Lake Huron, Geomorphology, 14, pp 211-219.

Burt, T.P. 1992. The hydrology of headwater catchments. pp. 3-28. In: P. Calow and G. Petts (eds.). The Rivers Handbook Vol 1. Blackwell Scientific Publications, London.

Canadian Council of Ministers of the Environment. (1999) Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment. 2001. Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, User's Manual. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Chapman, L.J. and D.F. Putnam. 1984. Physiography of southern Ontario., Third Edition, Ontario Geological Survey Special Volume 2, Ontario Ministry of Natural Resources.

Chow, V.T., 1959. Open-channel hydraulics. McGraw Hill. Boston MA.

Cowan, W.R., 1976. Quaternary Geology of the Orangeville Area, Southern Ontario; Ontario Division of Mines, Ministry of Natural Resources, Geoscience Report 141.

Credit Valley Conservation Authority, 1955. Credit Valley Conservation Report: Forest Section (Proof Edition). Ontario Department of Planning and Development, Conservation Branch. p. 1 and Table : Remaining Woodland in Per Cent Estimated from Census of Canada Figures.

Credit Valley Conservation, (2006) Shaws Creek Subwatershed Study Background Report.

Credit Valley Conservation, April, 1998. Credit Watershed Natural Heritage Project Detailed Methodology: Identifying, Mapping and Colletcing Field Data at Watershed and Subwatershed Scales, Version 3. Credit Valley Conservation, Meadowvale, Ontario

Credit Valley Conservation, The Regional Municipality of Peel, and Toronto and Region Conservation Authority. 2001. The Vascular Plant Flora of the Region of Peel and the Credit River Watershed, prepared by J. Kaiser, M. Sc., Meadowvale, Ontario. Pgs. 34 + appendices.

Credit Valley Conservation, Totten Sims Hubicki Associates, Donald G. Weatherbe and Associates, EBNFLO Environmental, D.W. Draper and Associates, Schroeter and Associates, Blackport Hydrogeology (2000) Water Quality Strategy: Phase I Report (Draft).

Credit Valley Conservation. 1986. Shaws Creek Assessment.

Credit Valley Conservation. 1987. Shaws Creek Assessment.

Credit Valley Conservation. 1998. Credit Watershed Natural Heritage Project – Bird Species of Conservation Concern. Unpublished document available through CVC.

Credit Valley Conservation. 1995. Credit Watershed: Environmentally Significant Area Update Report. Credit Valley Conservation. Meadowvale, Ontario. pp. 31-38, 45-48, 73-76, 81-82.

Credit Valley Conservation. 1998. Credit Watershed Natural Heritage Project Detailed Methodology.

Credit Valley Conservation. Environmentally Significant Areas (ESA's) in the Credit River Watershed. (Report to The Chairman and Members of the Executive Committee). 22 pp.

Credit Valley Conservation. n.d. E.S.A. File for Alton Branch Swamp. Credit Valley Conservation, Meadowvale, Ontario.

Credit Valley Conservation. n.d. E.S.A. File for Caledon Lake. Credit Valley Conservation, Meadowvale, Ontario.

Credit Valley Conservation. n.d. P.E.S.A. File #25 for Credit River at Alton. Credit Valley Conservation, Meadowvale, Ontario.

Credit Valley Conservation. n.d. Wetland Evaluation File for Alton-Hillsburgh Wetland Complex. Credit Valley Conservation, Meadowvale, Ontario.

Credit Valley Conservation. n.d. Wetland Evaluation File for the Caledon Lake Wetland Complex. Credit Valley Conservation, Meadowvale, Ontario.

David, S.M., K.M. Somers, R.A. Reid, R.J. Hall and R.E. Girard. 1998. Sampling protocols for the rapid bioassessment of streams and lakes using benthic macroinvertebrates. 2nd edition. Dorset Environmental Sciences Centre, Aquatic Science Section, Ontario Ministry of the Environment, Dorset, Ontario.

Dieterich, M., and Anderson, N.H. 1995. Lifecycles and food habits of mayflies and stoneflies from temporary streams in western Oregon. Freshwater Biology, 34: 47-60.

Dobbyn, J. 1994. Atlas of the Mammals of Ontario. Federation of Ontario Naturalists, Don Mills, 120 pp.

Don Scallen. Data from CVC frog monitoring program. 1998. 2002.

Downs, P.W. 1995. Estimating the probability of river channel adjustment. Earth Surface Processes and Landforms, 20: 687-705.

Ecologistics Limited. 1979. Credit River Watershed Environmentally Significant Areas. 207 pp.

Environment and Health Canada (2000) Priority Substance List Asessment Report: Road Salts. August, 173 pages.

Environment Canada, Canadian Wildlife Service. 2004. How Much Habitat is Enough? A Framework for Guiding Habitat Rehabilitation in Great Lakes Area of Concern, Second Edition. Downsview, 80 pp.

Environment Canada, Ontario Ministry of Natural Resources, and Ontario Ministry of Environment. 1998. A Framework for Guiding Habitat Rehabilitation in Great Lakes Areas of Concern. Canada – Ontario Remedial Action Plan Steering Committee. 76 pgs.

Fischenich, C., 2001. Stability thresholds for stream restoration materials. USACE Research and Development. Technical note SR-29. 10pp.

Freeze, R. A. and J. A. Cherry. 1979. Groundwater. Prentice-Hall. 604 pp.

Frelich, L.E. and P.B. Reich. 1996. Old growth in the Great Lakes region. Pp.144-160, in Davis, M.B. (ed.) Eastern Old-growth Forests: Prospects for Rediscovery and Recover. Island Press. Washington, 383 pp.

Galli, J., 1996. Rapid stream assessment technique, field methods. Metropolitan Washington Council of Governments. 36pp.

Geomatics International Inc. 1995. Regional Municipality of Halton Environmentally Sensitive Area Study - Draft. Regional Municipality of Halton, Oakville, Ontario. pp. 211-213, 221-238, 247-256.

Geomatics International., 1995. Management options for old-field sites in Southern Ontario. Southern Region Science & Technology Transfer Unit, OMNR, Brockville. 65 pp.

Griffiths, R.W. 1998. Sampling and evaluating the water quality of streams in southern Ontario. A how to manual. Ministry of Municipal Affairs and Housing, Planning and Policy Branch, Toronto, Ontario.

Groundwater Science, November 2003. Alton Village Study Phase 1 – Environmental Component Septic System Impact Assessment Level II Final Report.

Gunderson, L.H., C.S. Holling and S.S. Light (eds.) 1995. Barriers and Bridges to the Renewal of Ecosystems and Institutions, New York: Columbia University Press.

Hallam, J.C. 1959. Habitat and associated fauna of four species of fish in Ontario streams. Journal of the Fisheries Research Board of Canadda, 16:147-173.

Hare, F. K. and M.K. Thomas. 1979. Climate Canada, 2nd Ed. John Wiley & Sons.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomologist, 20:31-39.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. Journal of the North American Benthological Society, 7:65-68.

Holling, C.S. (ed.). 1978. Adaptive Envrionmental Assessment and Management. Published by John Wiley and Sons.

Kaiser, J., 2001. The Vascular Plant Flora of the Region of Peel and the Credit River Watershed. Prepared for Credit Valley Conservation, The Regional Municipality of Peel and Toronto and Region Conservation Authority. 34 pp.

Kilgour, B.W. and D.R. Barton. 1999. Associations between stream fish and benthos across environmental gradients in southern Ontario, Canada. Freshwater Biology, 41:553-566.

Kondolf, G.M. 1995. Geomorphological stream classification in aquatic habitat restoration: uses and limitations. Aquatic Conservation: Marine and Freshwater Ecosystems, 5: 127-141.

Konze, K. and M. McLaren. 1997. Wildlife Monitoring and Inventory Techniques for Ontario. OMNR Northeast Science and Technology Technical Manual TM-009. 139 pp. AND Weeber, R. and M. Vallianatos. 2000. The marsh monitoring program: 1995-1999: monitoring Great Lakes wetlands and their amphibian and bird inhabitants. Bird Studies Canada, Port Rowan.

Larson, B.M., J.L. Riley, E.A. Snell, and H.G. Godschalk. 1999. The Woodland Heritage of Southern Ontario. Federation of Ontario Naturalists, Don Mills. 262 pp.

Lee, H. T., D. Leadbeater, P. Uhlig, and K. Ursic. 2001. Ecological Land Classification for Southern Ontario: Training Manual. Ontario Ministry of Natural.Resources, Science and Information Resource Division, Science and Information Branch, Southcentral Science and Information Section, SCSIS Training Manual TM-01. p.p. 21-35.

Lee, H. T., W.D. Bakowsky, J. Riley, J. Bowles, M. Puddister, P. Uhlig, S. McMurray. 1998. “Ecological Land Classification for Southern Ontario-First Approximation and its Application”. Ontario Ministry of Natural Resources, Southcentral Region, Science Development and Transfer Branch.

Lee, H.T., W.D. Bakowsky, J. Riley, J. Bowles, M. Puddister, P. Uhlig, and Leopold, L.B., Wolman, M.G., and Miller, J.P. 1964. Fluvial Processes in Geomorphology. W.H. Freeeman and Sons. San Francisco, California, U.S.A.

Margules, C., and M.B. Usher. 1981. Criteria used in assessing wildlife conservation potential: a review. Biological Conservation. 21, pp. 79-109.

Martin, D.K. 1984. The fishes of the Credit River, cultural effects in recent decades. M.Sc. Thesis, Department of Zoology and the Institute for Environmental Studies, University of Toronto.

McIllveen, W. D. 2001. Credit Watershed Field Observations by W. D. McIllveen for the years up to 1993 and 1998 to 2001. Microsoft Excel Format.

Mersey, J. E. and M. Puddister. 2002. Mapping Pre-settlement Vegetation from Surveyors Records – Credit River Watershed ca. 1806. Unpublished.

Miller, J.P., McCave, I.N., and Komar, P.D., 1977. Threshold of sediment motion under unidirectional currents. Sedimentology, 24, 507-527.

Milne, R. and L. Bennett. 2004. Amphibian Road Call Count (ARCC) and Field Survey, Subwatershed 17: Shaws Creek Subwatershe. Credit Valley Conservation.

Milne, R. and L. Bennett. 2006. Breeding Bird Survey, Subwatershed 17: Shaws Creek Subwatershed. Credit Valley Conservation.

Ministry of Environment. 1999. Ontario Ministry of Environment. Revised Stormwater Management Guidelines Draft Report.

Ministry of Natural Resources. 1997. Natural Heritage Training Manual for Policy 2.3 of the Provincial Policy Statement. Version 1.0. 141 pp.

Ministry of the Environment (1999) Water Management: Policies, Guidelines and Provincial Water Quality Objectives.

Ministry of the Environment (2001) Ontario Drinking Water Standards.

Ministry of the Environment, 2001. Technical Terms of Reference for Groundwater Studies.

Montgomery, D.R and J.M. Buffington, 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin, 109 (5): 596-611.

Old Growth Policy Advisory Committee. 1994. Conserving Ontario's Old Growth Forest Ecosystems. OMNR, Toronto, 90 pp.

Ontario Department of Planning and Development (ODPD). 1956. Credit Valley Conservation Report. ODPD, Toronto.

Ontario Ministry of Enviornment (1993). Guidelines for the protection and management of aquatic sediment quality in Ontario.

Ontario Ministry of Natural Resources (OMNR). 1984. Water Quantity Resources of Ontario. OMNR Publication No. 5932, Queen's Park, Toronto, Ontario.

Ontario Ministry of Natural Resources and Credit Valley Conservation (2002) Credit River Fisheries Management Plan

Ontario Ministry of Natural Resources. 2002. Ontario Wetland Evaluation System Southern Manual, Peterborough.

Ontario Ministry of Natural Resources. 1999. Natural Heritage Reference Manual for Policy 2.3 of the Provincial Policy Statement. 127 pp.

Ontario Ministry of Natural Resources.1994. Ontario Wetland Evaluation System – Southern Manual, 3rd Edition. Ontario Ministry of Natural Resources. p. 82.

Ontario Ministry of the Environment (1999). Water Management: Policies, Guidelines and Provincial Water Quality Objectives.

Ontario Ministry of the Environment (2001) Ontario Drinking Water Standards.

Ontario Natural Heritage Information Centre. 1997. Community List and Ranks for Southern Ontario Web Page. Ontario Ministry of Natural Resources. http://www.mnr.gov.on.ca/MNR/nhic/veg/lists/commlist.html

Payne, N.F., Bryant, F.C. 1994. Techniques for Wildlife Habitat Management of Uplands. McGraw-Hill, Inc. New York.

R. Klinkernbergy. 1984. Life Science Areas of Natural and Scientific Interest in Site District 6.1. Ministry of Natural Resources, Richmond Hill. 79 pp.

Reed, D.J. 1968. A resurvey of the fishes of the Credit River. M.Sc. Thesis, Department of Zoology, University of Toronto.

Reynoldson, T.B., C. Logan, R. Pascoe and S.-A.P. Thompson. 1999. Methods manual: I. The creation of reference-condition data bases for benthic invertebrate community structure. NWRI Contribution No. 99-211.

Rice, S.P., M.T. Greenwood, and C.B. Joyce, 2001. Tributaries , sediment sources, and the longitudinal organization of macrointertebrate fauna along river systems., Canadian Journal of Fisheries and Aquatic Scientce, 58: 824-840

Richards, C., R.J. Haro, L.B. Johnson, and G.E. Host. 1997. Catchment and reach-scale properties as indicators of macroinvertebrate species traits. Freshwater Biology, 37: 219-230.

Riley, J.L., and P. Mohr. 1994. The Natural Heritage of Southern Ontario's Settled Landscapes. Ontario Ministry of Natural Resources, Southern Region, Aurora, Science and Technology Transfer, Technical Report TR-001. 78pp.

Rooke, J.B. and G.L. Mackie. 1982a. An ecological analysis of lotic environments: I. design and testing. Journal of Freshwater Ecology, 1:421-431.

Rooke, J.G., and G.L. Mackie. 1982b. An ecological analysis of lotic environments: II. comparison to existing indices. J. Freshwat. Ecol. 1:433-442.

Rosgen, D.L. 1994. A classification of natural rivers. Catena, 22: 169-199.

Rosgen, D.L. 1996. Applied River Morphology, Wildland Hydrology, Pagosa Springs, Colorado. U.S.A.

Rouse, J.D., Bishop, C.A. and J. Struger (1999) Nitrogen Pollution: An Assessment of Its Threat to Amphibian Survival Environmental Health Perspectives Volume 107, Number 10, pgs 799 to 803.

S. McMurray. 1998. Ecological Land Classification for Southern Ontario: First Approximation and its Application. Ontario Ministry of Natural Resources, Southcentral Science Section, Science Development and Transfer Branch. SCSS Field Guide FG-02.

Scallen, D. 2001. Species List Pers. Comm. September 2001.

Sidle, R.C., Tsuboyama, Y., Noguchi, S., Hosoda, I., Fujieda, M., and Shimizu, T. 2000. Stormflow generation in steep forested headwaters: a linked hydrogeomorphic paradigm. Hydrological Processes, 14: 369-385.

Singer, S., T. Cheng, S. Emami, H. Hassan, M. Scarfe, G. Sheikh, B. Whitehead and W. Zaia, 1994. Groundwater Resources of the Credit River Watershed; Ontario Ministry of Environment and Energy.

Singer, S.N., Cheng, C.K., and Scafe, M.G. 2003. The Hydrogeology of Southern Ontario, Second Edition. Hydrogeology of Ontario Series (Report 1). Ministry of the Environment, Toronto, 200p.

Smith, P.G.R. and J.B. Theberge. 1987. Evaluating natural areas using multiple criteria: theory and practice. Environmental Management. 11:4, pp. 446-460.

Strahler, A.N. 1952. Dynamic basis of geomorphology. Geological Society of America Bulletin, 63: 1117-42.

Thorne, C., R. Hey and D. Newson (Eds.), 1997. Applied Fluvial Geomorphology for River Engineering and Management, John Wiley and Sons, New York, N.Y.

TRCA. 2002a. Carruthers Creek: State of the Watershed – Fluvial Geomorphology. Toronto Region Conservation Authority. June 2002.

TRCA. 2002b. Duffins Creek: State of the Watershed – Fluvial Geomorphology. Toronto Region Conservation Authority. June 2002.

Van Stempvoort, D., Ewert, L., and Wassenaar, L., 1992. AVI: A Method for Groundwater Protection Mapping in the Prairie Provinces of Canada. Prairie Provinces Water Board. Regina, Saskatchewan.

Vought, L.B.M., Pinay, G., Fuglsang, A., and Ruffinoni, C. 1995. Structure and function of buffer strips from a water-quality perspective in agricultural landscapes. Landscape and Urban Planning, 31(1-3): 323-331.

Vrba, J. and A. Zaporozec. 1994. International Association of Hydrogeologists Guidebook on Mapping Groundwater Vulnerability. Volume 16 International Contributions to Hydrogeology.

Ward, T.A., Tate, K.W., Atwill, E.R., Lyle, D.F., Lancaster, D.L., McDougald, N., Barry, S., Ingram, R.S., George, H.A., Jensen, W., Frost, W.E., Phillips, R., Markegard, G.G. and Larson, S. 2003. A comparison of three visual assessments for riparian and stream health. Journal of Soil and Water Conservation, 58(2): 83-88.

Waterloo Hydrogeologic Inc, 1995. Preliminary Delineation of Well Field Capture Zones. Unpublished report to the Regional Municipality of Waterloo.

Waterloo Hydrogeologic Inc, 2000. Delineation of Well Field Capture Zones within the Waterloo Moraine. Unpublished report to the Regional Municipality of Waterloo.

WHO - World Health Organization (1992). Polychlorinated biphenyls and terphenyls. Environmental Health Criteria No. 140. World Health Organization, Geneva.

Wilm, J.L and T.C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience, 18:477-481.