Silver Creek Subwatershed Study

Background Report

September 2001

Credit Valley Conservation
Schroeter & Associates
Environmental Water Resources Group
Aquafor Beech Limited
Jacques Whitford Environmental Limited

TOWN OF HALTON HILLS

CVC CREDIT VALLEY CONSERVATION

ACKNOWLEDGEMENTS

We would like to acknowledge those municipal agencies who's jurisdiction extends into the Silver Creek Subwatershed, and who provided valuable input throughout the subwatershed study process:

County of Wellington
Region of Halton
Town of Erin
Town of Halton Hills

Credit Valley Conservation would also like to acknowledge the assistance of all those who worked on the study. Specifically, we would like to acknowledge the following individuals and organizations:

Credit Valley Conservation........Hazel Breton – Subwatershed Study Project Manager
Town of Halton Hills..................Eva Kliwer – Official Plan Project Manager

Aquafor Beech Limited... Craig MacRae
Aquafor Beech Limited... James Luce
Blackport Hydrogeologic... Ray Blackport
Credit Valley Conservation .... Alison Humphries
Credit Valley Conservation .... Brian Morber
Credit Valley Conservation .... Jackie Thomas
Credit Valley Conservation .... Jeff Wong
Credit Valley Conservation .... Lisa Ainsworth
Credit Valley Conservation .... Loveleen Grewal
Credit Valley Conservation .... Merebeth Switzer
Credit Valley Conservation .... Mike Puddister
Credit Valley Conservation .... Robert Morris
Credit Valley Conservation .... Steve Davies
County of Wellington .... Mark Van Patter
D.G. Weatherbe Associates Inc. .... Don Weatherbe
Environmental Water Resources Group .... Chris Doherty
Jacques Whitford Environmental Limited............... Bruce Kilgour
Ministry of Agriculture and Rural Affairs .... Peter Roberts
Ministry of Environment West Central .... John Warbick
Ministry of Natural Resources Aurora..................... Ken Cornelisse
Niagara Escarpment Commission............................ Marion Plaunt
Region of Halton... Steve Stone
Schroeter & Associates .... Harold Schroeter
Town of Erin.. Lisa Hass
Town of Halton Hills .... Rick Henry
Waterloo Hydrogeologic.. Paul Martin

Members of the focus group and general public, including landowners, interest groups and other interested parties are also acknowledged for providing valuable input during meetings.

TABLE OF CONTENTS

APPENDICES

APPENDIX A: Terrestrial

Significant plant and animal species found in the Provincially Significant Wetlands, ANSIs and ESAs found in the Silver Creek Subwatershed

APPENDIX B: Fisheries

A methodology for assessing the biological integrity of fish communities of the Credit River Watershed.

APPENDIX C: Glossary

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Study Background

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. 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 plan 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.

The Silver Creek Subwatershed (Subwatershed 11) is the subject of study in this report. This work has been initiated as one of the supporting studies being carried out as part of the Official Plan process being managed by the Town of Halton Hills.

CVC has been retained by the Town of Halton Hills to complete a Subwatershed Plan for the Silver Creek Subwatershed.

1.2 Purpose of the Study

This report is the first of a series of reports that will be developed for the Silver Creek Subwatershed. The purpose of this report is to summarize the existing available data and information pertinent to the subwatershed. This is to ensure that work is not duplicated and resources are spent appropriately. Following an assessment of this work, data gaps were identified. A field program will now be designed to fill the identified data gaps.

As part of the background review process, a number of issues specific to the Silver Creek Subwatershed have been identified from various sources. This information will be summarized and questions will be formulated, the answers to which will be provided at the end of the subwatershed process.

The following section provides a description of the subwatershed planning process.

1.3 Subwatershed Study Process

Subwatershed planning has been an ongoing activity within the Credit River watershed since 1992. To date, of the 20 subwatersheds identified, 15 have been initiated and are either underway or completed.

Figure 1.3.1 describes the subwatershed process that has been consistently followed to date. Typically there are four phases, Characterization, Impact Assessment, Implementation and Monitoring that flow in sequential order. It should be noted that one cycle of this process does not bring the level of understanding of the natural environment to an end. Rather, the first cycle provides a very comprehensive snapshot of the environmental resources i.e. their form, function and linkages. Using follow up monitoring to test assumptions made during the study and to assess how well management solutions are working, is an important and fundamental need. The results of this monitoring should be used to update and refine management solutions over time. Great importance is placed on the goals and objectives developed for the subwatershed as they will influence the choices made by the municipalities and agencies having jurisdiction over the area. This also allows the public the opportunity to have input and track the success of the implementation of the study findings.

Figure 1.3.2 describes the connection of the CRWMS and the subwatershed process and clearly identifies the questions that each phase will answer. The CRWMS sets out broad levels of direction from the watershed perspective. The subwatershed process then refines this information based on subwatershed scale data and assessment.

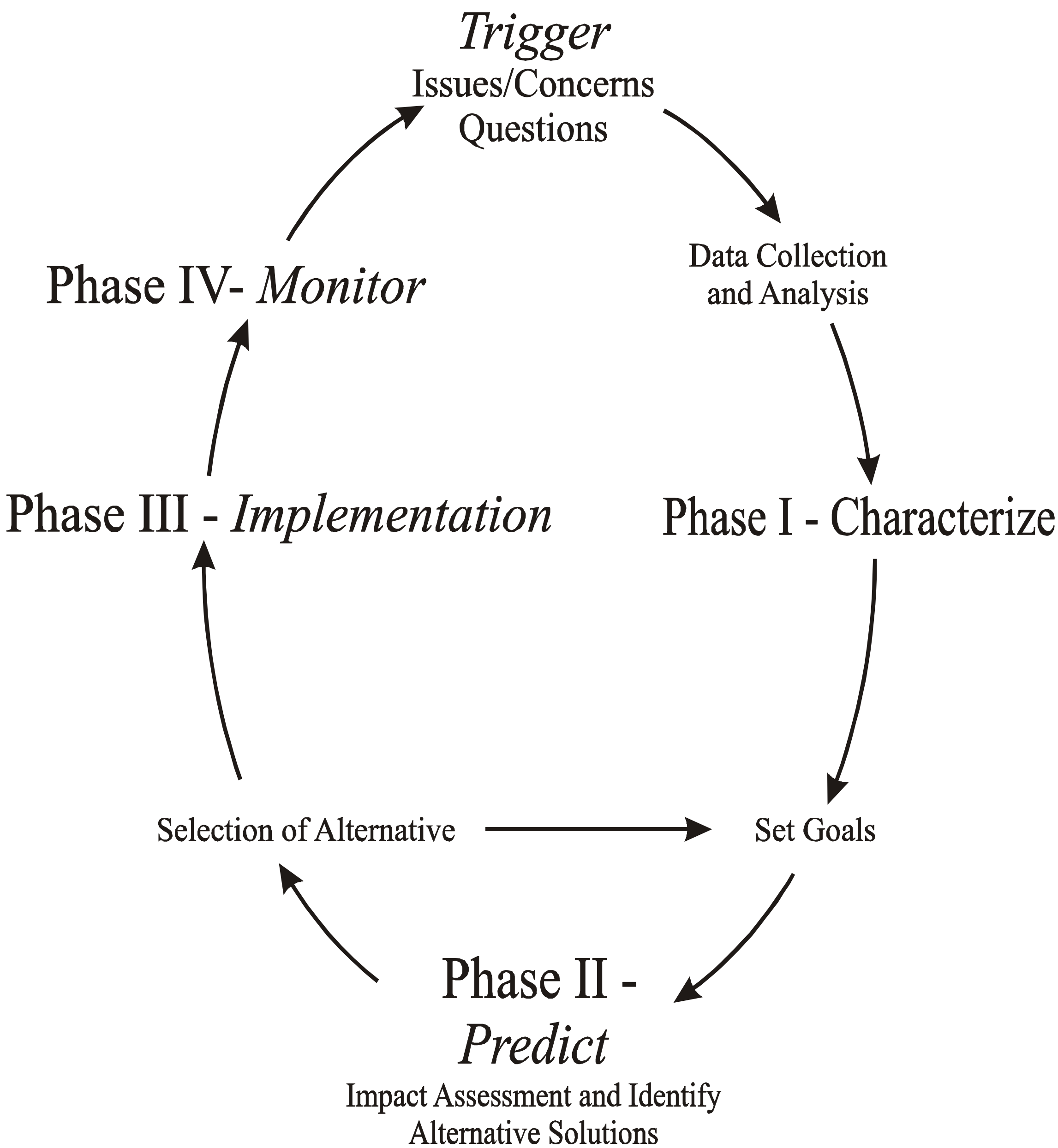


Figure 1.3.1 Monitoring and the Subwatershed Planning Process

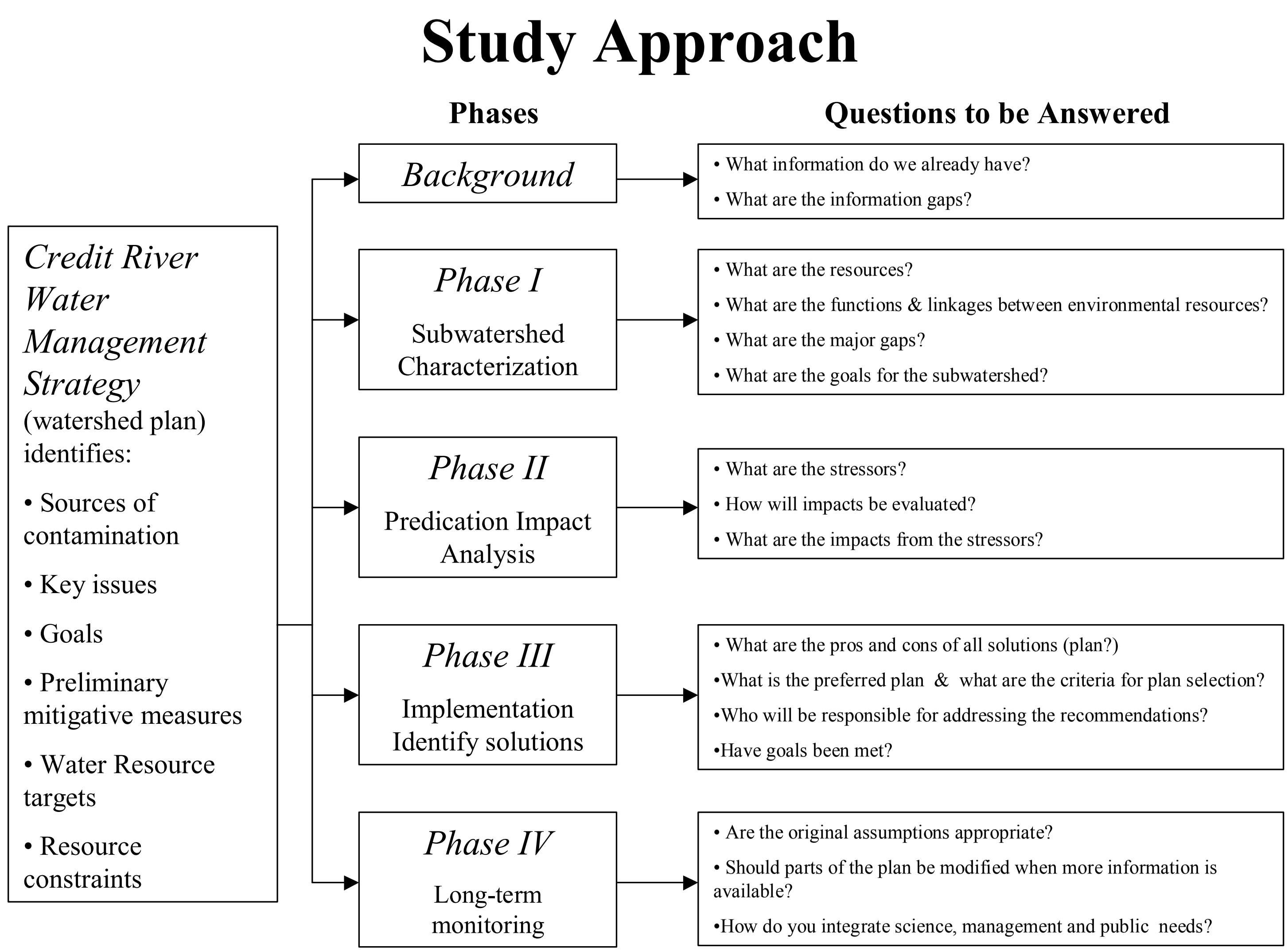


Figure 1.3.2 Subwatershed Study Process

1.4 Study Area

Silver Creek is a tributary of the Credit River and is approximately 52 sq. km in area. The subwatershed is located in the middle section of the Credit River watershed. The headwaters are located within the Town of Erin. This portion of the subwatershed is characteristic of a headwater area with undulating and hummocky terrain. The remaining part of the subwatershed is located within the Town of Halton Hills and is greatly influenced by the Niagara Escarpment, which bisects the subwatershed. The area above the Escarpment is distinctly different from that portion below. Silver Creek joins the Credit River at Norval. Figure 1.4.1 shows the location of the subwatershed within the Credit River watershed. Figure 1.4.2 provides more detail of the subwatershed.

Existing or actual land use was mapped for the Silver Creek Subwatershed according to the Credit Watershed Natural Heritage Project Detailed Methodology (Figure 1.4.3). This mapping is based on 1:8,000 1996 spring aerial photography. The methodology breaks existing land use into active aggregate, inactive aggregate, intensive agriculture, non-intensive agriculture, manicured open space, rural development, urban, roads and wet meadows. Due to land use changes over the last 4.5 years around Georgetown, there may be a need to update portions of the existing land use mapping with the most recent aerial photography (1999 from CVC, or more recent from the Town of Halton Hills or Region of Halton).

The current land use within the subwatershed can be characterized as follows:

Table 1.4.1 Existing Land use and Natural Area in the Silver Creek Subwatershed

Land Use	Hectares	Percentage
Urban	990.4	19.1%
Rural	1790.8	34.6%
Aggregate	32.2	.6%
Natural	2361.0	45.6%

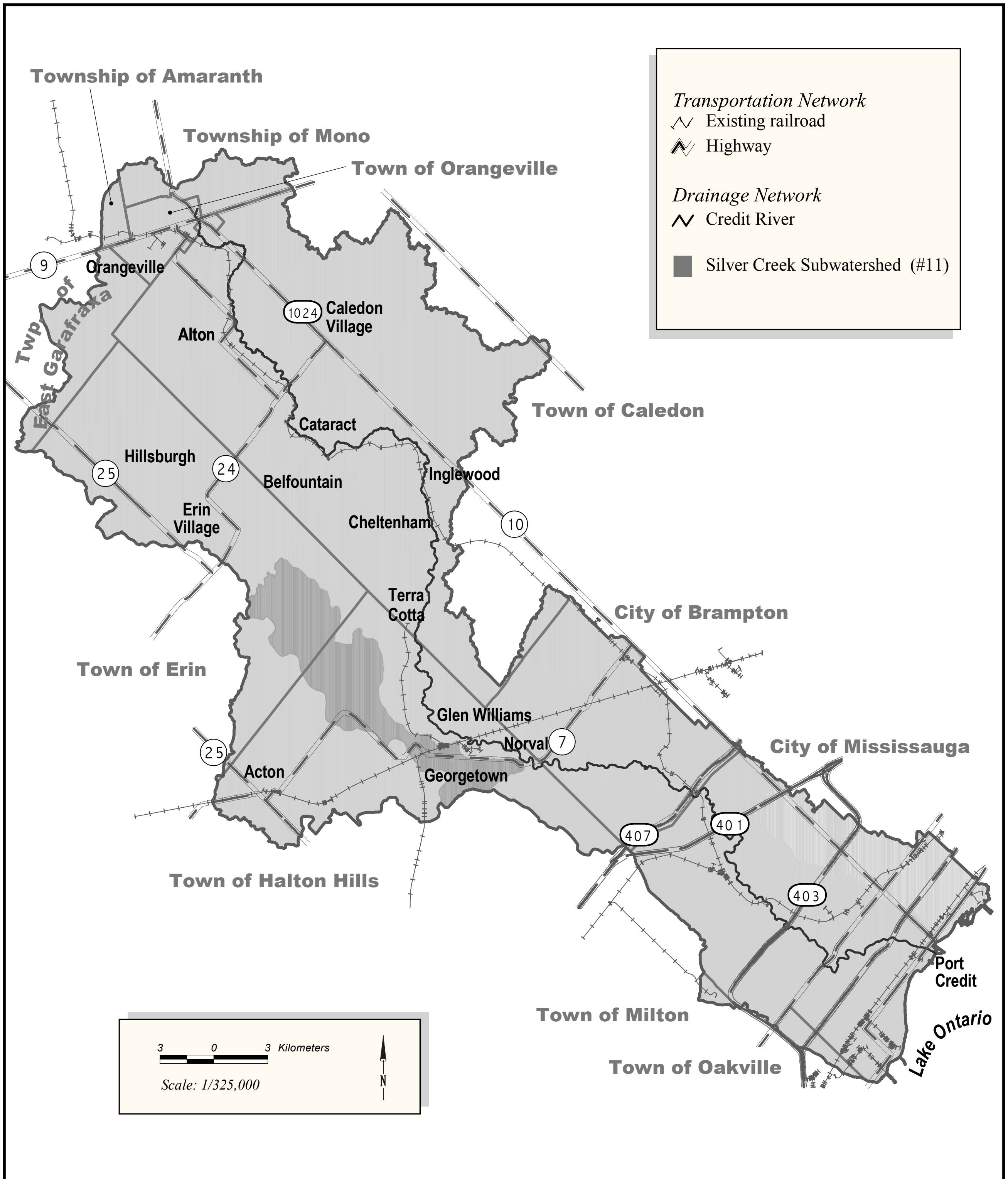


Figure 1.4.1: The Silver Creek Subwatershed within the Credit River Watershed

Sources:
Credit Valley Conservation, 1999; Ontario Ministry of Natural Resources, 1982

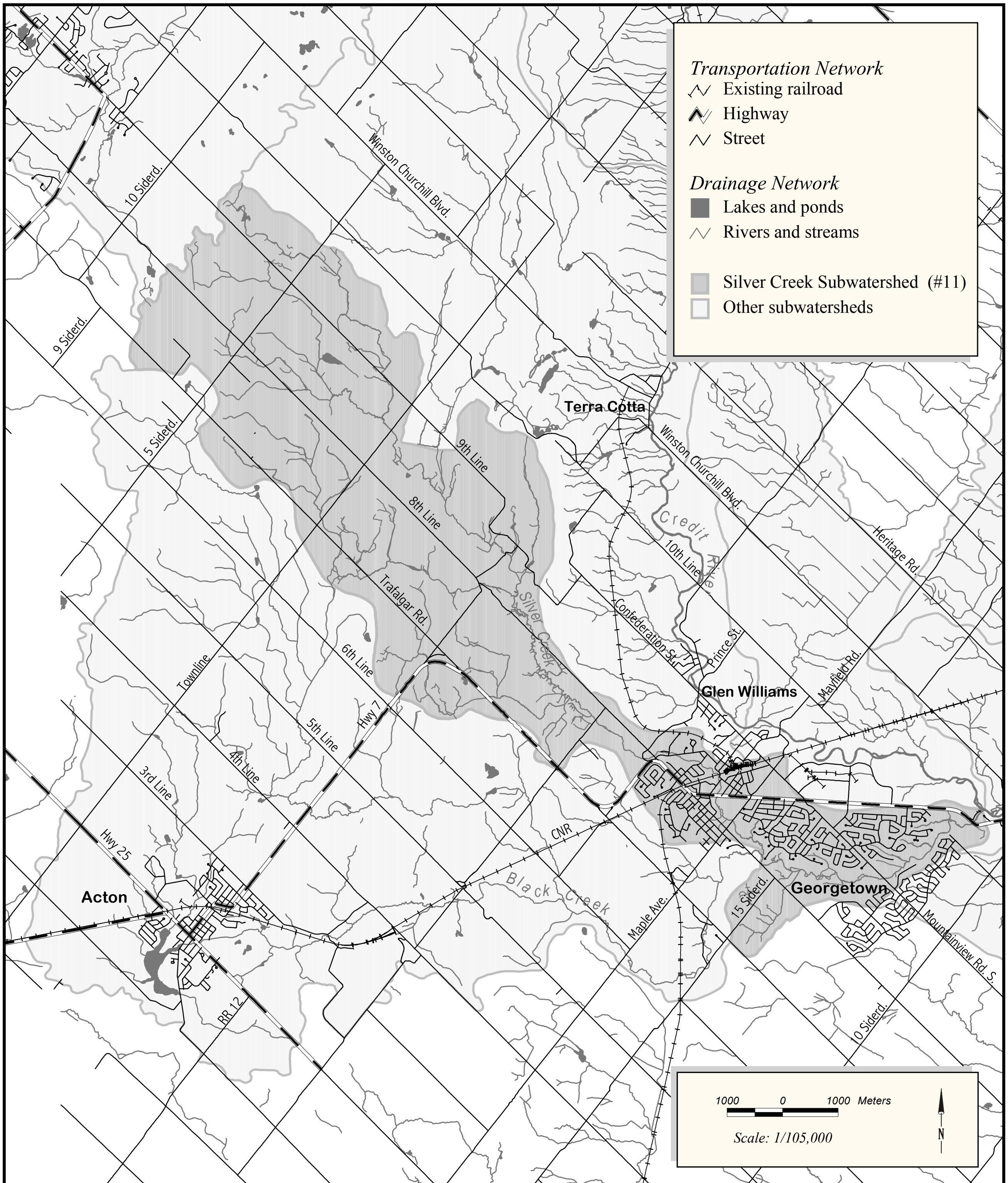


Figure 1.4.2: The Silver Creek Subwatershed

Sources:
Credit Valley Conservation, 1999; Ontario Ministry of Natural Resources, 1982

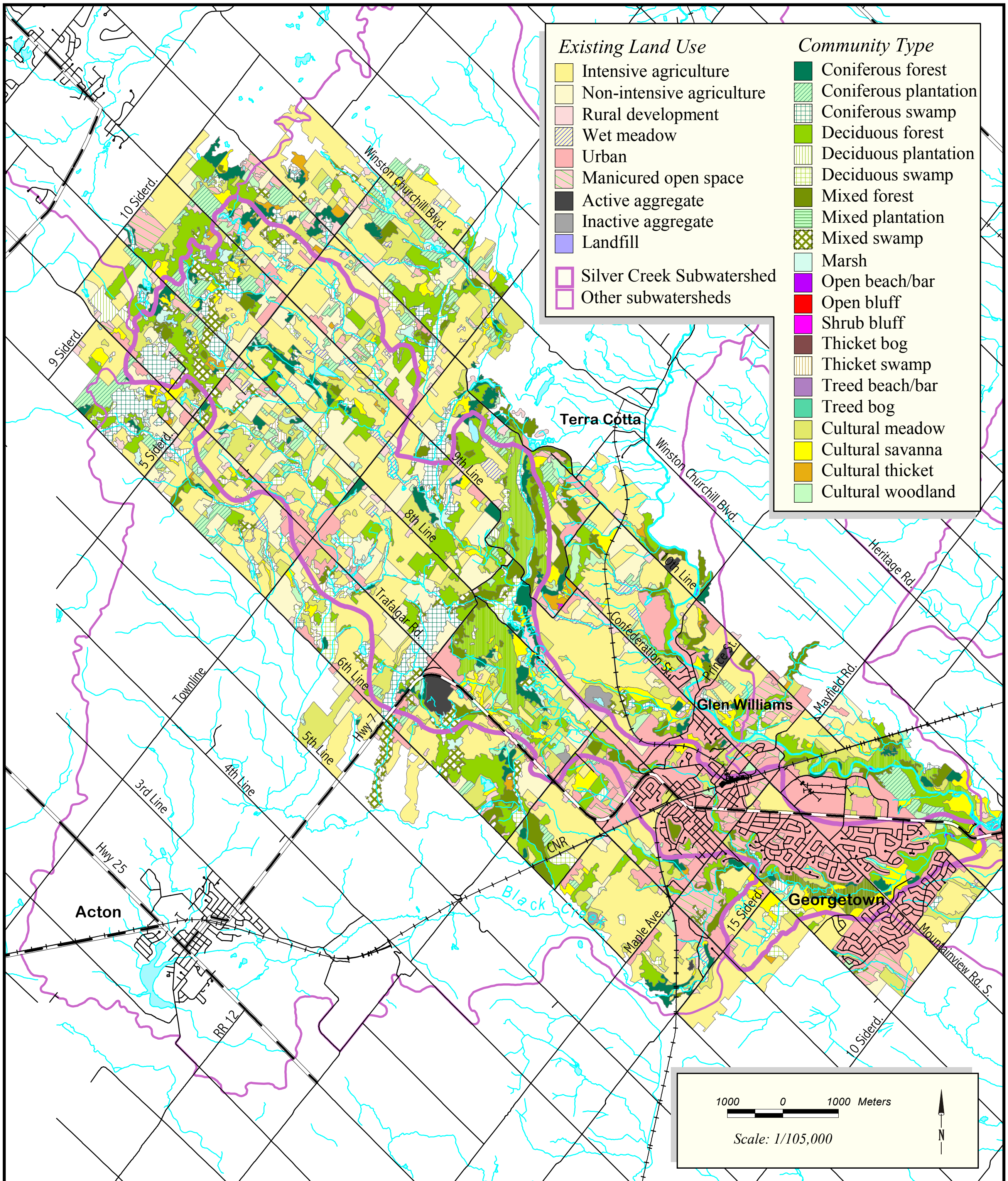


Figure 1.4.3: Ecological Land Classification and Existing Land Use

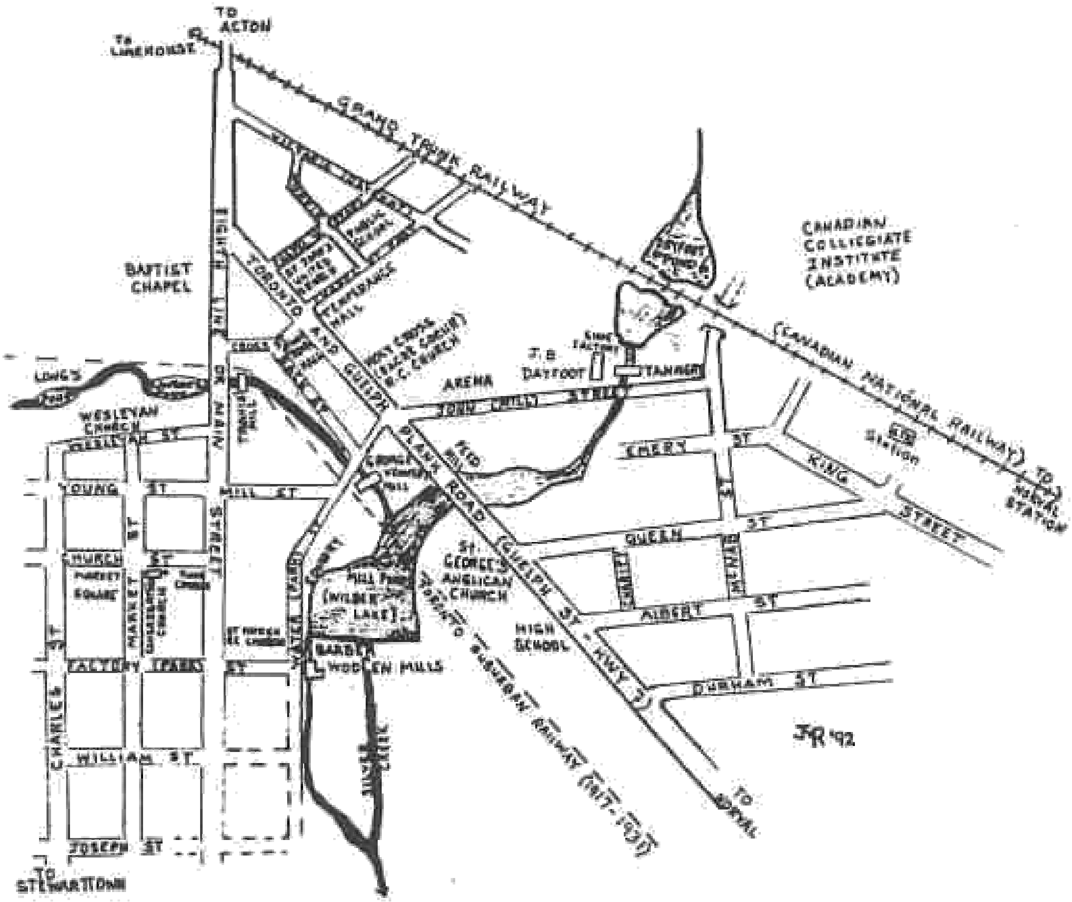
Sources:
Credit Valley Conservation, 1996; Ontario Ministry of Natural Resources, 1982

1.5 Some Historical Facts about Silver Creek

The June 1992 publication by the Esquesing Historical Society of The Story of Georgetown written by John Mark Rowe, refers to the Georgetown (then known as Esquesing Township) area in 1847 as an area of "interminable forest" with "a small hub of industry perched on the banks of Silver Creek". In 1823, George Kennedy dammed Silver Creek and built a sawmill around which, a small settlement developed. The mill was located off of 8th Line down a valley trail. In December 1891, the village received its first piped water from a reservoir at Silver Creek. The 1992 publication goes on to state that "Boating on the pond, Wilbur Lake, followed by a picnic on the bank was a fashionable weekend pastime". With the opening of the Toronto Suburban Railroad (an electric line) in 1917 meant that there needed to be a crossing of the Silver Creek Valley, which necessitated the draining of Wilbur Lake.

From these descriptions, it would appear that Silver Creek has had a history of supporting industry, recreation and water supply to the local area. The map below depicts Silver Creek and the surrounding Subwatershed around the time period discussed above.

Figure 1.5.1 Map of Old Georgetown



Reproduced with permission from the Esquesing Historical Society (Rowe 1992)

1.6 Watershed Goals

The following are the goals for the subwatersheds that have been established by the CRWMS as a starting point. The goals will either be replaced or refined specifically for the Silver Creek subwatershed by the Technical Committee, with input from the public.

Table 1.6.1 Resource Management Goals for the Credit River Watershed

WATER QUALITY

Maintain or restore water quality to a level that maintains ecological integrity and permits desired uses including recreational opportunities.

GROUNDWATER

Protect and maintain groundwater recharge/discharge areas and baseflow to a level that ensures adequate supply for desired uses, including drinking water.

AQUATIC COMMUNITIES

Protect and enhance aquatic communities, with special regard for fish and fish habitat.

NATURAL FEATURES

Protect and maintain self-sustaining natural ecosystems and significant natural features.

RECREATION

Provide diverse recreational opportunities that are in harmony with the environment.

AESTHETICS

Protect and enhance the environment in a manner that is in harmony with the natural features of the watershed.

FLOOD PROTECTION

Control flooding within the watershed through remedial works and land use controls.

EROSION CONTROL

Minimize soil loss through land management practices and remedial control measures.

(Beak et al. 1992)

1.7 Report Content

This report has been broken down into 5 chapters as follows:

Chapter 1 is a brief introduction to the subwatershed study process and provides a physical and historical description of the area.

Chapter 2 is a description of the proposed communications plan for communicating the study to the public, and other interested parties. Concerned parties can check out mapping information and other data to ensure an accurate study.

Chapter 3 is a summary of issues, data gaps and future work necessary for each of the technical disciplines involved in the study: hydrogeology, hydrology, hydraulics, terrestrial, stream geomorphology, water quality, macroinvertebrates, aquatics and planning. Issues specific to each discipline are outlined, as well as areas where information is lacking. Field research plans have been refined using this information.

Chapter 4 describes Adaptive Environmental Management as a tool that will be used in this study process to facilitate the integration of the work into an adaptive and comprehensive environmental study.

Chapter 5 is a summary of what the disciplines will be working on for the next phase of the study.

2.0 COMMUNICATIONS PLAN

Communication activities will act as a catalyst to help the community to have meaningful opportunities for participation and to better understand the subwatershed study findings and, in the long run, to implement the project's recommendations.

We recognize that the Subwatershed 11 study is part of the larger Halton Hills Official Plan process that includes an environmental component. This means that the people we approach may be actively involved in other aspects of the Official Plan and we will continue to work closely to ensure coordination of our efforts

2.1 Communications Working Group

We have established staff-based Communications Working Group consisting of Eva Kliwer (Project Manager – Official Plan, Town of Halton Hills), Hazel Breton, (Water Resources Engineer, CVC), Merebeth Switzer (Communications Officer, CVC) and Loveleen Grewal (Study Assistant, CVC). This group has set up the initial process for soliciting input from the community based on our past experience with other subwatershed studies and community initiatives. However, we will continue to refine this process as we meet with local community members.

2.2 Silver Creek Subwatershed Study Focus Group

To date, we have identified key groups to work with and to be members of the Silver Creek Subwatershed Study Focus Group. We initially identified a number of groups including: POWER, TEAC, Save Our Ravines, Hungry Hollow, local ratepayers associations, youth groups including Scouts Canada and Georgetown District SS, members of the Ontario Federation of Agriculture, local naturalist clubs, fishing clubs. As the study continues, other groups or individuals may be identified and added to this Focus Group or to our larger contact list.

The Focus Group will meet a minimum four times during the course of the study beginning with the introductory meeting which took place on Wednesday May 2nd.

A minimum of three more meetings will be held in the final weeks, or at the conclusion of the each Phase of the study. These meetings will have the following goals:

2nd Meeting – Completion of Phase 1
- to review findings of characterization study
- to review environmental goals for the study

3rd Meeting – Completion of Phase 2
- to report on results from Phase 2

4th Meeting – Completion of Phase 3
- to discuss of implementation priorities and the means of accomplishing these goals

The later meetings may take different formats and may include site tours or other methods of presenting information to this group.

2.3 Phase I Focus Group Meeting

The introductory meeting was used:
- to connect with community groups and networks
- to begin a dialogue to bring forward issues specific to study
- to draw upon community and historic knowledge
- to solicit input or involvement in areas of interest (for example - bird surveys, natural history research, monitoring)
- to seek input to help in creating the most effective approaches to communicating the plan to the public.

This meeting was attended by 17 individuals representing 13 different organizations, councillors and concerned residents. A discussion was held to bring out various concerns of those present and participants were asked to continue to provide contacts or input to the project throughout the course of the subwatershed study.

2.4 Issues Identification

As part of their initial meeting the Focus Group identified the following list of issues of concern (related items have been placed under specific headings for ease of references but they may, in fact, related to more than one heading):

ABOUT THE STUDY
- assure the quality of the ground and surface water models used in the study
- non-subwatershed residents invited to comment or become involved?
- like all subwatershed studies, this one involves representatives from major organizations (MNR, MOE, DFO and so on) and the scientific findings will be peer reviewed

LAND USE AND DEVELOPMENT ISSUES
- Hungry Hollow
- effect of land use near streams – how people influence/use the area and how the environment is impacted
  - "non-intrusive" uses
  - public education process of users (e.g. can we show adverse impacts of trail bikes?)
  - recreation planning & policy to improve use (e.g. paved trails, restricted use)
- effect of development on the valley slopes (below the top of the slope)
- effects of encroachment into riparian areas and local green spaces

- farm management practices ("Best Management Practices")
- impacts of farm dumps and filling in on farmland

NATURAL FEATURES
- have identified 323 plant species (RDH ESA Study)
- have identified 128 bird species (Quest Study)
- significant land features beside rivers – from ELC including ESAs, ANSIs
- Atlantic salmon reintroduction
- fisheries issues – habitat
- forest management issues, research
- identify recharge functions of features

WATER QUANTITY ISSUES
- is there a list of active ponds in the watershed – for example farm ponds?
- do we have records of water use for irrigation?
- information about the cumulative effects of the permits to take water? Will PTTW info be used in the analysis
- what about information for nurseries? golf courses? private wells?
- effects of water-taking (e.g. test well #15) on wetlands
- removal of dams
- cumulative impact of PTTW = no base flow in river

WATER QUALITY ISSUES
- impact of factories, salvage yards and similar businesses near river
- can known contaminated sites be identified?
- effects of dumps and other sources of pollution (e.g. where Silver Creek goes under Guelph Street in central Georgetown)
- are there ways of identifying known polluters?
- impacts of pesticides in stormwater runoff, Stormwater Management Ponds and streams and rivers
- biosolids work at Region of Halton
- septic systems
- impacts of chlorine spill from water treatment plant – are things recovering?
- impacts of stormwater discharge on the physical, chemical and biological properties of receiving water

OTHER
- carrying capacity of the subwatershed
- look at Blue Circle Aggregates on Black Creek and their potential impacts on Silver
- hydro-generation plants in the subwatershed?
- impacts of beavers
- heritage & history of Silver Creek – Marilyn King (e.g. Remembrance Park is where one of the lakes used to be)

- Can CVC share its data protocols with others (perhaps through website) so people know how we want the information gathered and what we need recorded? Also mentioned that if anyone was doing research in the river they should check with CVC in order to avoid problems with test results from existing monitoring sites or research work

COMMUNICATIONS

- need to recognize the target audiences
- It was clarified that, based on CVC's own approaches, we were looking for groups and individuals that had the ability to effect change and whose actions would have significant impact on the issues and actions identified in the study. This would include those organizations and individuals that would be needed to ensure the implementation of the plan's recommendations.
- web – provide reciprocal internet links to region, town and community group sites
- provide information for inclusion in the new Willow Park quarterly newsletter
- in past projects individuals have found the tour approach very helpful to understanding issues

POSSIBLE RESOURCES OR ADDITIONAL CONTACTS

Hungry Hollow

- Save Our Ravines - Merrick Sharpe doing a study
- student report from University of Guelph (check Georgetown library)

Trails

- Master Plan for Trails - Town of Halton Hills (draft stage)

T.E.A.C.

- check sewer line study
- Test Well #15 Studies - check with MNR – Larry Halyk/DFO
- have identified 323 plant species (RDH ESA Study)
- have identified 128 bird species (Quest Study)

Halton Field Naturalists

- completing Herptofaunal atlas including SW11
- will be publishing "Birds of Halton" shortly – includes search of records back to the 1800s + current records
- also have current records; there are also some set locations for CWS bird surveys

P.O.W.E.R.

- want to share information we receive and have information and data to share with study

Ballinifad community group?

2.5 Communications Activities

The group recognized that it would take to time to clarify the audiences, the mechanisms and the messages that need to be communicated and that this might not occur until later in the study.

However, from our past experience we recognize that the communication activities for the Silver Creek Subwatershed will have to respond to community needs as determined by the Focus Group. They will also be designed based on the type of information that needs to be presented as the research progresses. Examples of some of the type of activities that have taken place in response to community and study needs in previous subwatershed studies include:

- presentations by CVC staff and/or project team members to special interest groups
- public open houses including displays
- guided bus tour of areas of special interest or concern
- four page, colour insert into local newspapers
- partnership with local educators to have students conduct parts of the field work as a learning experience

CVC will also highlight the findings and activities relating to this project on its new website. In addition, the site will include reciprocal links between it and the sites of other interested community partners.

All materials needed for focus group and Steering Committee meetings will be produced by CVC. Any mailouts will be the responsibility of the Town of Halton Hills.

3.0 BACKGROUND REVIEW

This section is a summary of identified issues, data gaps and future work necessary for each of the technical team s involved in the study: hydrogeology, hydrology, hydraulics, terrestrial, stream geomorphology, water quality, macroinvertebrates, aquatics and planning.

3.1 Hydrogeology

3.1.1 Background Information

Background information regarding the hydrogeology of the Silver Creek Subwatershed is available from a number of sources. The primary types of existing information are:

- 1:50,000 scale government maps / publications (i.e. Quaternary geology reports);
- Ministry of Environment (MOE) Water Well Record Database;
- Region of Halton Aquifer Management Plan;
- Region of Halton consultant reports related to water supply issues, such as those studies pertaining to Test Well 15 (Well No. 8) prepared by International Water Supply, Ltd., Dames & Moore, Canada and Gartner Lee Limited;
- An in-progress CVC study of the water budget of the CVC watershed, including the Silver Creek Subwatershed, which includes numerical modeling of the entire watershed; and
- Local site specific studies, primarily consultant reports for subdivisions and aggregate extraction / cross-discipline information, and reports such as surface water and fisheries data.

The available data was focused on the urban area of Georgetown, primarily because of the on-going work being completed by the Region in securing additional drinking water resources or protecting existing drinking water sources. Nevertheless, sufficient information was available for a preliminary characterization of the hydrostratigraphy of the subwatershed.

3.1.2 Preliminary Interpretation of Existing Data

The hydrogeology of the Silver Creek Subwatershed is strongly influenced by the local geological and physiographic setting. Groundwater is important throughout the subwatershed as all residential water consumption with the subwatershed is from groundwater obtained from either communal, municipal supply wells or private domestic wells.

The following summarizes the geological and physiographic setting within the subwatershed:

- The most significant physiographic feature of the subwatershed is the Niagara Escarpment, which trends locally in a NE-SW orientation and traverses the subwatershed from Highway 7, just south of 27 Sideroad in the west to the 10th Line, immediately west of Terra Cotta, in the east. The location of the Niagara Escarpment is outlined on Figure 3.1.1.

- The Niagara Escarpment consists of a ridge of resistant dolomite bedrock of the Amabel Formation overlying interlayered sandstones, dolomite and shale of the Clinton and Cataract Groups, which in turn overlie red shales of the Queenston Formation. The escarpment is a result of differential erosion of the softer Queenston Formation to the east under the more resistant dolomites of the Amabel Formation to the west. Figure 3.1.2 illustrates that mapped bedrock geology in the study area.

- In some parts of the study area, the Niagara Escarpment is exposed at ground surface and in other areas, it is mantled by a veneer of more recent glacial deposits.

- The Niagara Escarpment effectively divides the subwatershed into two distinct physiographic regions: the area above the escarpment to the north and west where groundsurface elevations range from approximately 340 m above mean sea level (amsl) to greater than 420 m amsl (Upper Subwatershed); and, the area below the escarpment to the south and east where groundsurface elevations range from approximately 200 m amsl to 340 m amsl (Lower Subwatershed).

- In both the Upper and Lower Subwatershed, glacial sediments overlie the bedrock, with the exception of a few locations predominantly along the escarpment, where bedrock exists at groundsurface.

- The character of the glacial sediments in the Upper Subwatershed is generally distinct from those in the Lower Subwatershed. In the Upper Subwatershed, the glacial terrain is predominated by the Paris Moraine and associated Kame deposits, whereas in the Lower Subwatershed, the terrain is predominated by the Halton Till sheet, although some granular buried valley channel features also occur. Figure 3.1.1 summarizes the surficial geology in the study area.

- The Paris Moraine is a relatively linear glacial feature, which trends in a northeast-southwest orientation and is six to eight kilometers wide. The moraine forms a topographical high and represents a surface water divide between Silver Creek Subwatershed and the West Credit Subwatershed (Subwatershed 15) to the

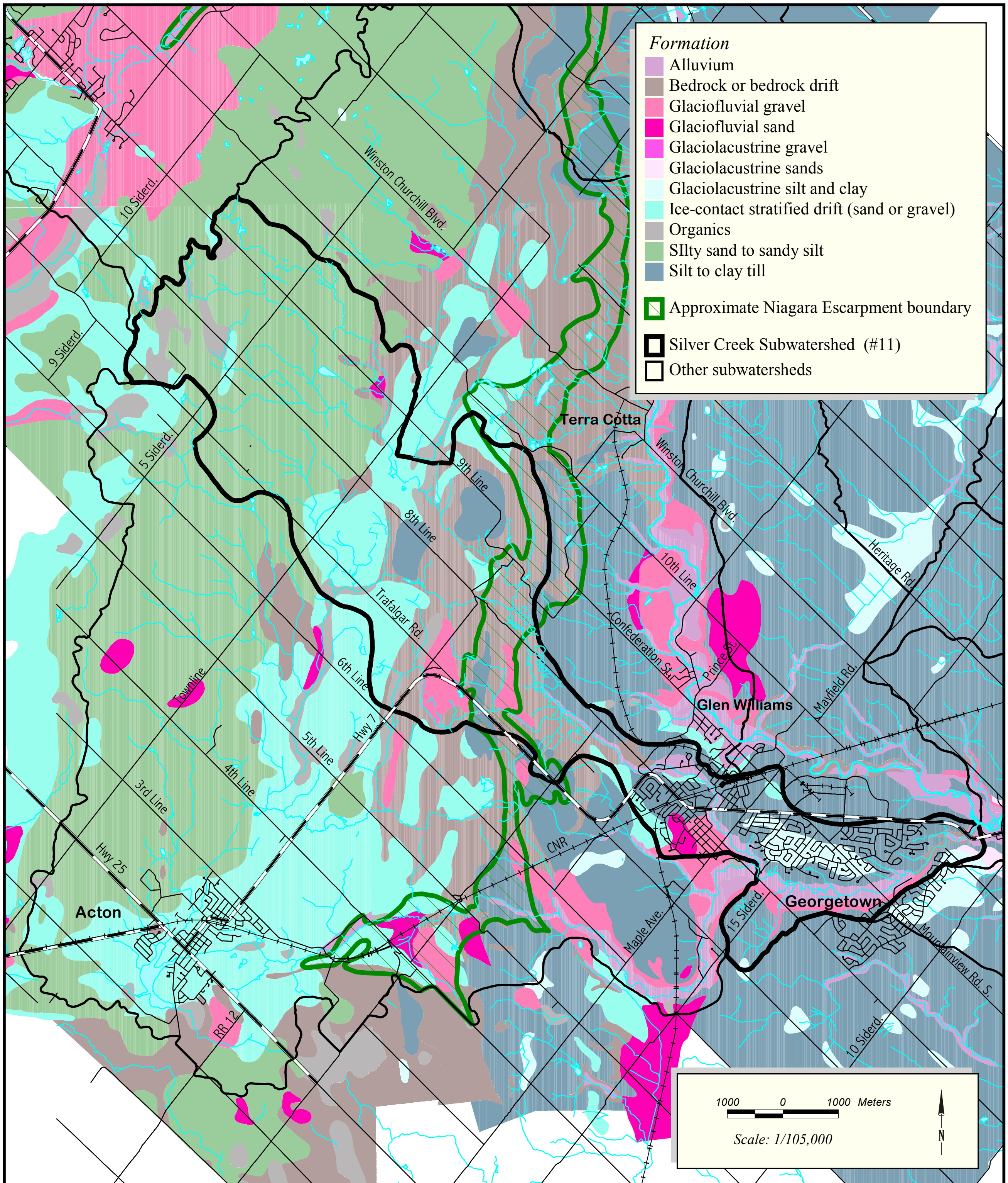


Figure 3.1.1: Surficial Geology

Sources:
Karrow, P. and J. Easton, Preliminary Map 3171, Quaternary Geology, Brampton Area, 1990; Karrow, P., Map 2153, Pleistocene Geology of the Guelph Area, Southern Ontario, 1968; Credit Valley Conservation, 1999; Ontario Ministry of Natural Resources, 1982

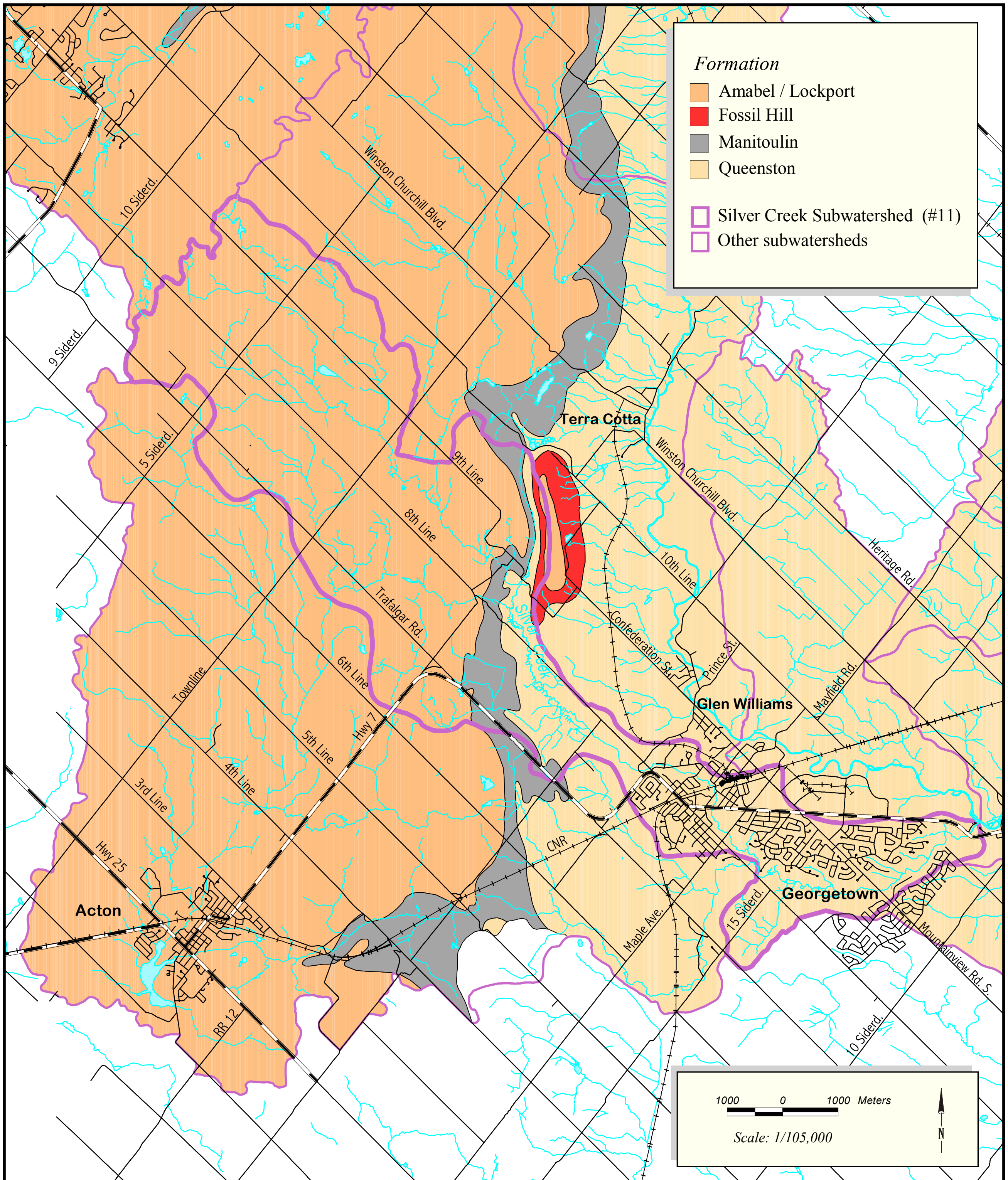


Figure 3.1.2: Bedrock Geology

Sources:
Credit Valley Conservation, 2001; Ontario Ministry of Natural Resources, 1982; Telford, P.G. et al., Map 2337 - Paleozoic Geology of Brampton, 1974; Telford, P.G., Map 2342 - Paleozoic Geology of Guelph, 1976.

north. The moraine is composed mainly of sandy to silty sand till deposits of the Wentworth Till, which was deposited in direct contact with the Ontario ice-lobe during its retreat into the Ontario basin. Within the subwatershed, the area north and west of Townline has been mapped as consisting almost entirely of Paris Moraine till deposits. Kame deposits are associated with the Paris Moraine in the area and consist of irregular hummocky accumulations of sand and gravel that were formed at locations where meltwaters poured off the ice sheet. Kame deposits are sometimes described as ice-contact stratified drift. These deposits tend to be coarser grained and better sorted than the associated till sheets. Within the subwatershed, these kame deposits have been mapped in an irregular northeast-southwest trending band immediately southeast of the Paris Moraine, largely between Townline and 27th Sideroad.

- Geological cross-sections produced by the CVC through the Upper Subwatershed indicate that the overburden deposits are up to 15 m thick. One representative cross-section is presented in Figure 3.1.3.

- The physiography of the Lower Subwatershed is that of a till plain, which has a generally level to gently undulating surface. Within the subwatershed, Halton Till deposits comprise the till plain and this till is predominantly a reddish silt to clay silt till. The reddish colour is due to the colour of the underlying Queenston Shale, which makes up the parent material. The Halton Till terminates at the edge of the escarpment.

- In addition to the Halton Till deposits, a number of buried bedrock valley features have been documented in the Halton Hills area below the escarpment and these features often contain coarser sands and gravels. In Georgetown, a significant buried bedrock valley has been documented that trends in a northwest-southeast orientation through the Silver Creek Subwatershed south of Highway 7. Mapping of the bedrock surface has been completed by the CVC as part of a Groundwater Budget project for the Credit Valley watershed. The interpolated bedrock surface in the study area is presented in Figure 3.1.4.

- A conceptual hydrostratigraphic model has been developed for the watershed as part of the Water Budget project. This hydrostratigraphic model includes Subwatershed 11.

Within the geological / physiographic setting, as summarized above, a number of generalizations have been made with respect to significant recharge and discharge areas, as well as groundwater – surface water interactions, as follows:

- The hummocky topography in the Paris Moraine supports the local wetland complexes that are located in this area (<u>need better description of where these occur)</u> due to the moderate permeability soils and the hummocky nature of the terrain. Furthermore, although the permeability of these deposits is moderate

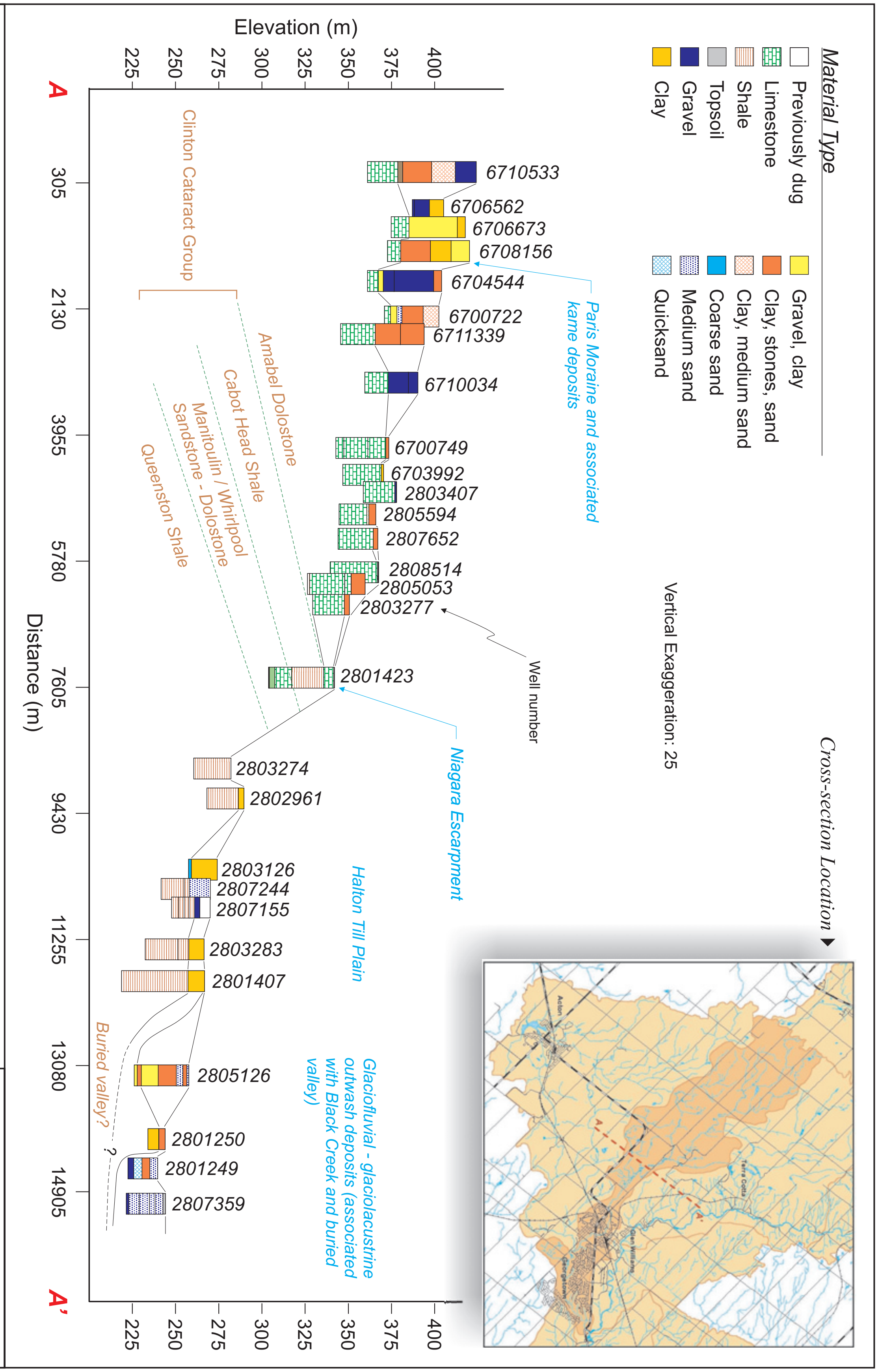


Figure 3.1.3: NE - SW Geological Cross-section Through the Silver Creek Subwatershed

Sources:
Credit Valley Conservation, 2001; Ontario Ministry of Natural Resources, 1982 (inset)

SILVER CREEK
SUBWATERSHED STUDY

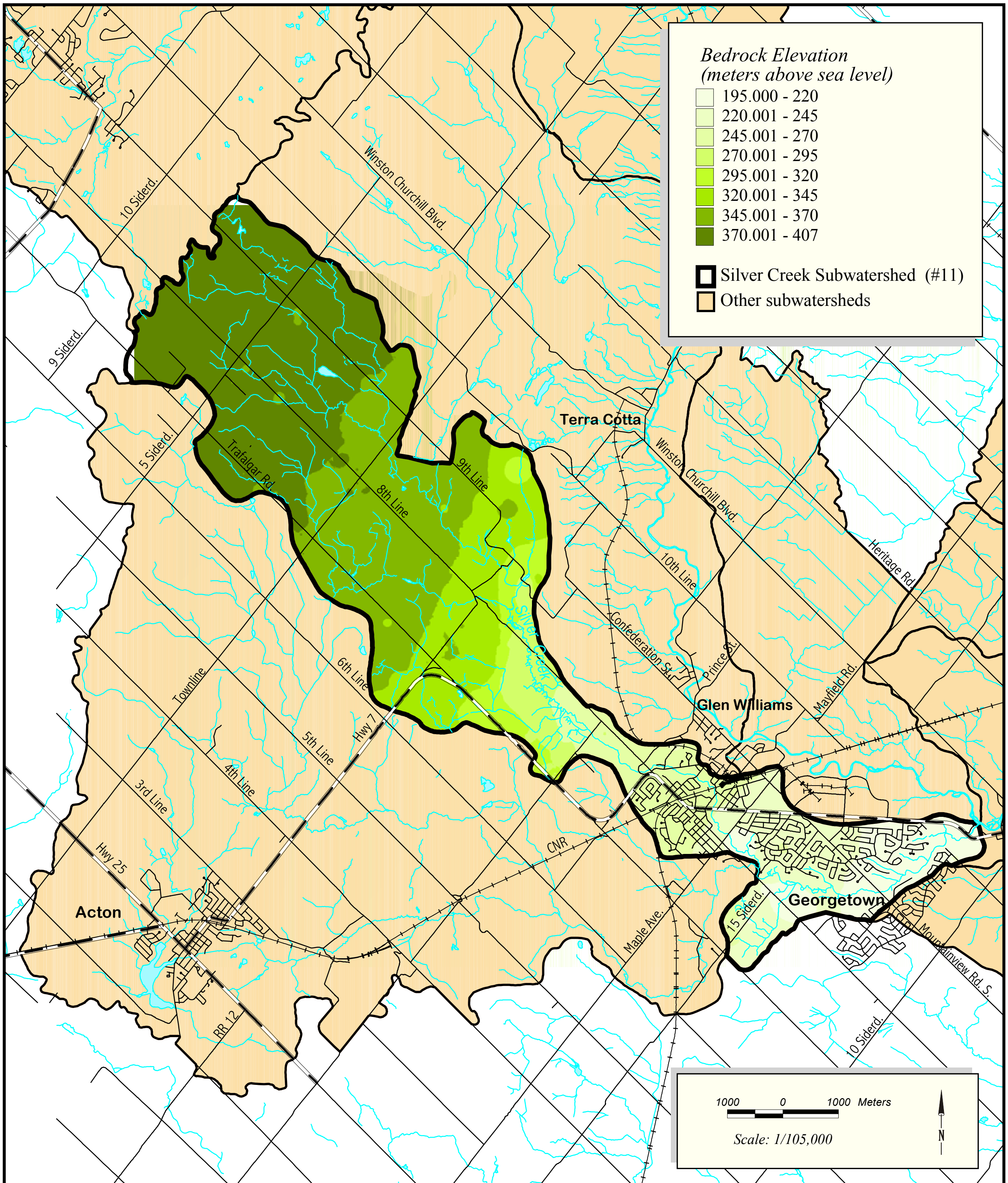


Figure 3.1.4: Bedrock Topography

Sources:
Spot heights for bedrock topography supplied by Waterloo Hydrogeologic; Credit Valley Conservation, 1999; Ontario Ministry of Natural Resources, 1982

only, the hummocky topography tends to maximize infiltration, making these areas significant recharge areas.

- In the Upper Subwatershed, recharge to the Amabel Formation will occur from either direct infiltration of precipitation directly into the bedrock, where it is exposed at surface (mainly in the vicinity of the escarpment), or by vertical migration through the either the Paris Moraine or the associated kames. It is uncertain at this time if groundwater is being transmitted through the Amabel Formations from other subwatersheds with the Credit Valley watershed or from other watersheds.

- A number of the headwater tributaries originate in the upper portions of the subwatershed in the vicinity of the moraine and observations made to date suggest that most of the streams in the upper subwatershed are cold-water streams, presumably due to groundwater discharge. Therefore, it was interpreted that not all of the precipitation infiltrating the moraine or kame deposits recharges the bedrock aquifer; some of the infiltration must travel laterally, presumably along coarser grained beds, and discharge to surface water features.

- Much of the groundwater being transmitted through the Amabel Formation is thought to discharge via springs along the escarpment at the contact between the Clinton and Cataract Group and the underlying Queenston Shale. The relationship regarding groundwater flow between the Amabel Formation above the escarpment and the buried valley features below the escarpment, has yet to be determined.

- Below the escarpment, the rate of recharge to the subsurface will be considerably lower due to the presence of Halton Till deposits. These deposits are considerably less permeable than the overburden in the Upper subwatershed, therefore infiltration will be inhibited. Furthermore, the Halton Till plain is significantly flatter and less hummocky than the overburden above the escarpment. This tends to favour overland runoff rather than infiltration.

- Stream reaches below the escarpment have been classified as a mix of cold-water and cool-water streams. The relationship between areas of significant discharge to surface water to the hydrogeological setting in the Lower subwatershed has yet to be determined.

In terms of groundwater supply for drinking water purposes, there are two regionally significant aquifers within the subwatershed, as follows:

Above the Niagara Escarpment, the Amabel Formation comprises an extensive and very transmissive aquifer. This 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.

Below the Niagara Escarpment in the Georgetown area, the buried bedrock valleys, although not as laterally extensive as the Amabel Formation, yield sufficiently large volumes of water to service the current drinking water requirements of Georgetown. Work is currently underway by the Region to better delineate these features in an attempt to secure additional groundwater resources to service future development demands.

In addition to these significant aquifer systems, some private residential wells above the escarpment are able to obtain groundwater from the coarser grained deposits associated with either the Paris Moraine or nearby kames. Below the escarpment, private residential wells commonly obtain water from the upper portions of the Queenston Shale. Although the Queenston Shale is considerably less permeable than the other aquifers, the upper 3 – 5 m of this unit is commonly fractured and may provide sufficient water for private residential use. Groundwater obtained from this formation is typically of poorer quality for drinking water purposes than the other aquifers.

3.1.3 Water Quality

Natural water quality within Subwatershed 11 will vary, depending on the aquifer through which groundwater flows. As noted, regionally significant aquifers within the subwatershed consist of the Amabel dolostone Formation above the escarpment and the buried bedrock valley system below the escarpment. Additional, lower yielding aquifers that have been used for localized domestic water supply consist of Paris Moraine and associated kame deposits, above the escarpment, and the upper weathered portion of the Queenston Shale, below the escarpment.

At present, there is not a great deal of readily available information regarding natural groundwater quality within the subwatershed. However, based on regionally information, groundwater quality for each of these four aquifer types was characterized for this preliminary report as follows:

- Groundwater from the 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 flow path. Groundwater from the Amabel Formation is generally potable. Previous water quality sampling of the Amabel Formation completed by the MOE indicated that groundwater samples had high total dissolved solids (TDS) and elevated iron concentrations. The elevated iron concentrations have been attributed to the mineralogical makeup of the rock and not from any anthropogenic sources. Groundwater samples obtained by the MOE from bedrock wells within the Amabel did not have elevated nitrate concentrations, indicating that the bedrock had not been subject to bacterial contamination. Previous watershed-wide research has shown that chloride concentrations are variable. The occurrence of elevated chloride concentrations was attributed to road salting practices;

- Groundwater quality in both the Paris Moraine deposits and the bedrock valley deposits are expected to be similar, due to the similar mineralogical makeup of these overburden deposits. Regional studies have indicated that overburden deposits of this nature are generally quite hard similar to the bedrock samples, but that iron concentrations are low. Despite the hardness, groundwater from these deposits is generally potable. Although specific data is not available, localized areas of elevated nitrate concentrations in the upper aquifers were interpreted to exist, due to their unconfined nature and near surface location. Chloride concentrations are also expected to be locally elevated due to road salting practices; and
- Groundwater within the upper weathered portions of the Queenston shale was estimated to be somewhat hard due to the presence of limestone interbeds within the formation and also due to the recharge of groundwater through carbonate rich overburden into the shale deposits. Work completed by the Region of Peel indicated that Queenston shale groundwater had high mineral content, typically chloride, sodium, calcium and sometimes sulphate. As a result, groundwater from the Queenston shale is of marginal quality for drinking water purposes. Specific information is not available, but localized bacterial problems with the groundwater in this deposit is expected due to its common occurrence near surface.

Potential Groundwater Impacts

Potential anthropogenic impacts to groundwater quality could occur from either point sources or non-point sources of contamination. Point sources imply localized concentrated inputs of contaminants to the subsurface from a single specific source, such as a leaking underground storage tank (UST), whereas non-point sources represent more diffuse spreading of contaminants over a larger area, such as fertilizer spreading or bio-solid disposal. The presence of various potential point source and non-point sources of contamination will be addressed in the characterization report. In order to do this, the following types of databases and information sources will be consulted for the entire subwatershed:

- Database of waste receivers;
- Database of waste generators;
- Waste disposal sites inventory;
- Ontario PCB storage / disposal sites inventory;
- Coal Gasification sites inventory;
- Database of private and retail fuel storage tanks; and
- Biosolid spreading permits.

The degree of impact to the groundwater resource from anthropogenic point or non-point sources of contamination will be influenced by the geological characteristics of the area in which the impact is occurring. In this regard, the subwatershed has several relatively distinct geological areas and hence the degree of protection to groundwater contamination is expected to vary. The following generalized characteristics regarding susceptibility to contamination in each of the principle aquifers:

- Amabel Formation – The Amabel is a significant regional aquifer that is overlain by the largely unconfined Paris Moraine, or is exposed at ground surface along the Niagara Escarpment. Although some attenuation of contaminants through the Paris Moraine is expected to occur, the entire area would be moderately susceptible to contamination due to its unconfined nature. At present, highly developed areas and hence the potential for point sources of contamination, occur below the Niagara Escarpment and the Amabel Formation. Various non-point sources of contamination (road salting, bio-solids, fertilizers etc.) potentially occur in the area of the Amabel Formation and therefore represent a risk to this aquifer.
- Paris Moraine and Associated Kame Deposits – These deposits represent localized aquifers for domestic water supply and supply baseflow for a number of headwater streams but they also represent significant recharge areas for the underlying Amabel Formation. Therefore, due to the significance of these deposits on both a local and regional level, the entire area would be highly susceptible to contamination. These deposits would be expected to be slightly more susceptible to contamination than the underlying Amabel Formation because they occur at ground surface; therefore, there is little opportunity for natural attenuation. Similar to the Amabel Formation, these deposits occur above the escarpment and away from highly developed areas and many point sources of contamination but would be susceptible to non-point source impacts.
- Buried Bedrock Valley Sand and Gravel Deposits – These deposits represent a significant localized aquifer system that is used for municipal water supply and also which likely provides significant baseflow to the Credit River below the escarpment. At present, delineation of this aquifer is underway but, at present, it is uncertain how well this aquifer is protected by any low permeability confining layers. The depth to water from ground surface is also variable. Therefore, due to its significance in terms of municipal supply and the lack of appreciable confining layers, this aquifer system is interpreted to be highly susceptible to contamination. Furthermore, the buried valley system occurs below the Niagara Escarpment and partially within the developed areas of Halton Hills. Therefore, there would be potential inputs of contaminants from both point and non-point sources.
- Upper Weathered Portion of the Queenston Shale - This aquifer is a low yielding aquifer of groundwater with marginal water quality. It is typically only used for domestic water supply by single-family dwellings in rural areas below the Niagara Escarpment. Generally, this aquifer is overlain by several meters of low permeability Halton Till deposits. Therefore, this aquifer is interpreted to be only marginally susceptible to contamination.

3.1.4 Identification of Data Gaps

In the area of Georgetown, abundant hydrogeological information is available from the various studies undertaken by the Region of Halton and various consultants. This work relates mainly to the buried bedrock valley systems and their potential for additional groundwater resource development. Despite the extensive work completed in this area, there is still considerable uncertainty with respect to the locations / trends of the valley features and their relationship with groundwater flows coming off of the escarpment. In areas, northwest of Georgetown, only regional data exists, such as the MOE Well Record Database or the 1:50,000 scale Quaternary mapping that was completed. However, the area above the escarpment is not an area where significant development is expected in the near future.

Several tasks would aid in the understanding of the hydrogeology of the subwatershed, as follows:

- Groundwater flow modelling of the subwatershed, based on data provided in the MOE Well Record Database, will provide a detailed hydrostratigraphic model of the entire subwatershed and would enable delineation of linkages between various flow systems, such as that which may occur between the Amabel Formation and the buried valley features.

- Model calibration using available observations of groundwater levels, stream gauge baseflow data, spot flow baseflow data, areas of known surface water discharge or recharge and groundwater flow velocities will ensure that the numerical model developed adequately represents actual conditions.

- Collection of additional surface water level data and surface water flow data at selected locations would aid in understanding groundwater-surface water interactions on a both a local scale and a regional scale. This data would also aid in calibrating the numerical model.

- Compiling a list of potential point and non-point sources of contamination would aid in the assessment of potential groundwater quality impacts.

3.2 Hydrology

3.2.1 Background Information

Meteorology

Long-term monitoring of meteorological quantities has occurred within and surrounding the Credit River watershed for more than 100 years. Historical data are primarily available from Environment Canada's Atmospheric Environment Service (AES). A search of the AES climate data catalogue (which is available on the Internet) was made by describing a latitude/longitude box (or search window) around the Credit River watershed specified as: 43.35^o N to 43.18^o N, and 79.60^o W to 80.50^o W. The Credit River watershed lies essentially along the northwest to southeast diagonal of this box. The search window was widened so that several long-term climate stations with good reliable data that have been referenced in major climate reports (e.g. Brown et al., 1974; Hare, 1979) would be included (e.g. Fergus Shand Dam, Toronto Pearson International Airport). Table 3.2.1 summarizes the search of the AES data catalogue.

Table 3.2.1 Summary Statistics from AES Climate Data Catalogue Search

Meteorological Quantity	**Number of Stations**
Daily Air Temperature (Max and Minimum)	83
Daily Precipitation (Rain and Snowfall)	140
Recording (hourly) rainfall	49
Wind speed and wind direction	10
Evaporation	5
Sunshine	5
Solar Radiation	2
Number of stations that are still active	35
Total Number of stations	159

As noted in Table 3.2.1, 35 of the 159 stations are still active (as of October 1998), and of these 35 stations, only two are within the boundaries of the Credit River Subwatersheds 10 and 11. Table 3.2.2 gives further details about the observing program for 16 stations whose records have been reviewed in previous subwatershed studies (e.g. Subwatershed 16 & 18, see Schroeter & Associates, 1999), and would be appropriate for use in providing inputs to any hydrologic model of Subwatershed 10 and 11. Note that Subwatershed 10 has been included in the hydrology component as this Subwatershed flows into Subwatershed 11. According to Table 3.2.2, some hourly rainfall information is available from the CVCs own operational network, with tipping bucket gauges above Erin, Cataract and Boston Mills. The locations of the stations listed in Table 3.2.2 are noted in Figure 3.2.1.

For detailed energy balance analyses, as required for accurate in stream temperature modelling, a wider array of meteorological variables (e.g. hourly rainfall, air temperature, wind speed and direction, solar radiation, humidity) are available through the Internet from three stations: the Elora Research Station (AES 6142285), the Guelph Turfgrass Institute, and Erindale College. Weather monitoring at the Elora Research Station has been maintained by the University of Guelph since 1969, and digital information (via dataloggers) has been available since 1985. The Guelph Turfgrass Institute weather station is also maintained by the University of Guelph, and has been in operation since 1993. The Erindale College (University of Toronto) weather station has been in operation for a couple of years. Historical energy balance information is also available from the Guelph OAC (AES 6143083) station for the period 1950 to 1973.

Snow course data have been collected bimonthly in the Credit River Watershed for more than 20 years at five locations listed in Table 3.2.3, and whose locations are noted in Figure 3.2.1. Each year the mean of the 10 points (both snow depth and equivalent water content) are collected for the period December 1st to April 15th, and are reported to the Ontario Ministry of Natural Resources as part of the province-wide network. Additional snow course information is available from adjacent conservation Authorities.

Table 3.2.2 Observing climate stations available for study

Station Name	Station Code	Owner	Available Period Of Record*	Data Collected
Above Erin	CVCA003	CVC	1988-1996	RG
Blue Springs Creek IHD	6140818	AES	1966-1980	P,T,RG
Boston Mills	CVCA004	CVC	1988-1996	RG
Brampton MOE	6150916	AES	1962-1993	P,T
Cataract	CVCA002	CVC	1988-1996	RGC
Fergus Shand Dam	6142400	AES	1960-1996	P,T,RG
Georgetown	6152691	AES	1960-1966	P,T
Georgetown WWTP	6152695	AES	1962-1996	P,T
Guelph Arboretum	6143069	AES	1975-1995	P,T,RG
Guelph OAC	6143083	AES	1960-1973	P,T,RG
Guelph Lake Dam	GRCA003	GRCA	1988-1996	P,T,RG
Hillsburgh	6143465	AES	1981-1989	P,T
Hornby IHD	6153545	AES	1967-1978	P,T,RG,E
Milton Kelso	6155187	AES	1966-1987	P,T,RG
Shand Dam	GRCA001	GRCA	1988-1996	P,T,RG
Toronto Pearson Int'l A	6158733	AES	1960-1996	P,T,RG

Notes: P – daily precipitation (rain and snow)
T - daily maximum and minimum air temperature
RG - Recording raingauge (tipping bucket)
E - Pan evaporation estimates
* Denotes period of record for which data were available to the study team. Some of these stations have been in operation much longer than this.

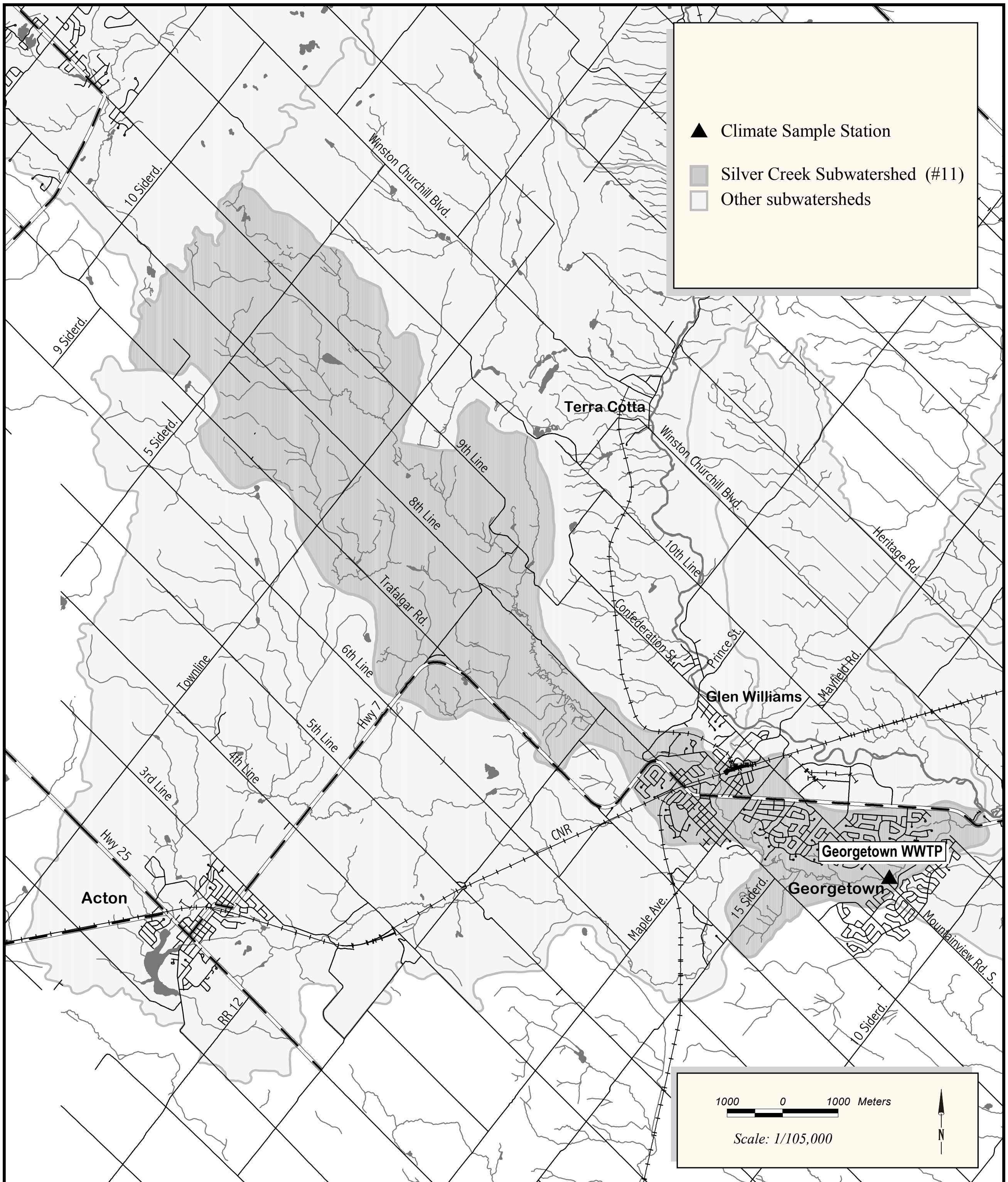


Figure 3.2.1: Climate Stations

Sources:
Credit Valley Conservation, 2001; Environment Canada, 1980; Ontario Ministry of Natural Resources, 1982

SILVER CREEK SUBWATERSHED STUDY

Detailed information about snow accumulation characteristics according to different landscape units in southwestern Ontario have been reported by Schroeter and Whiteley (1986), Schroeter (1988) and Burkart et al. (1991). Typical snow cover distributions for the Credit River Subwatersheds 10 and 11 were confirmed with actual field measurements taken by Dr. H. Schroeter in Black Creek (east of Acton) on February 22, 2000. Figure 3.2.2 gives typical areal snow cover distribution curves taken from the February 2000 snow survey.

Table 3.2.3 Snow course sites within the Credit River Watershed

MNR No.	Snow Course Name	Elevation (m)	Latitude	Longitude	Available Period of Record
1201	Belfountain	366	43 48	80 01	1960 -
1202	Monora (Orangeville)	427	43 56	80 06	1960 -
1203	Terra Cotta	343	43 43	79 57	1960 -
1204	Hillsburgh	480	43 48	80 10	1980 -
1205	Meadowvale	166	43 38	79 44	1980 -

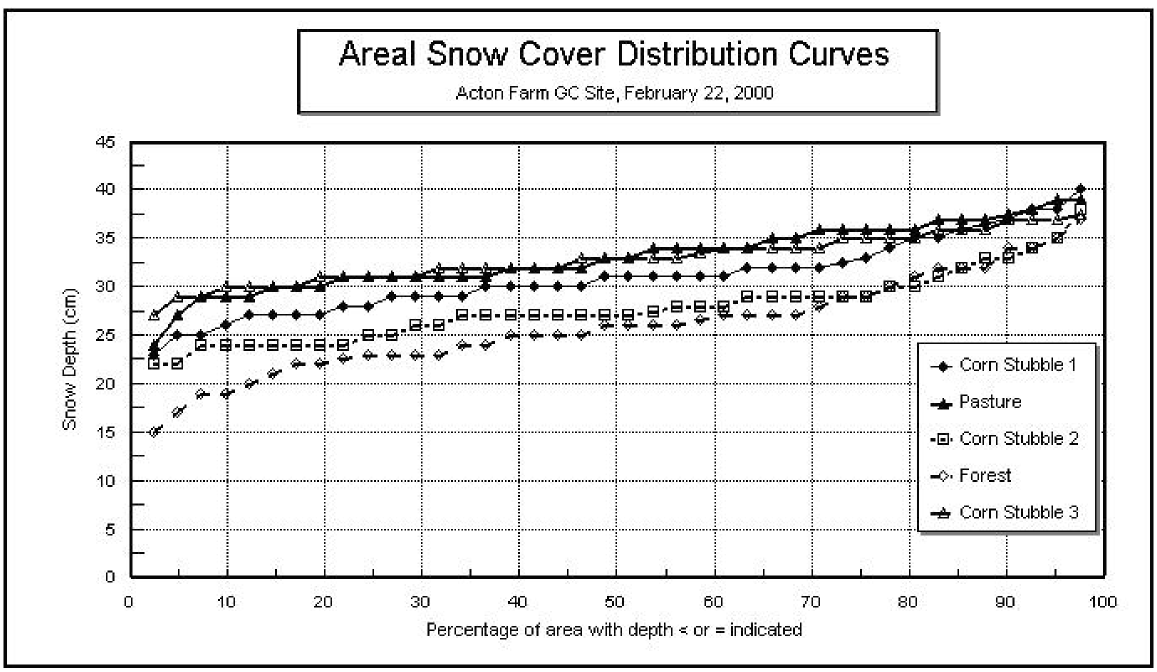


Figure 3.2.2 Sample snow depth areal distribution curves for different land covers.

Streamflow

Long-term monitoring of streamflow in Credit River Subwatersheds 10 and 11 has taken place at the three locations listed in Table 3.2.4, and noted in Figure 3.2.3. Two of these gauges are still in operation, of which the Norval gauge has been in operation for more than 40 years, and the Black Creek gauge for 13 years. Streamflow data are available in real-time for flood forecasting purposes at the Norval gauge only.

Mean daily flow data are available from the Water Survey of Canada for each gauge and period of record shown in Table 3.2.4. Hourly flow data are available from these same gauges for open water periods only, beginning in 1969.

A limited amount of streamflow data are available from a temporary gauge set-up by Burnside Associates for a golf course assessment study (Acton Farms GC) on the northern tributary of Black Creek at Highway 7. This gauge was in operation from December 1999 to July 2000.

Table 3.2.4 Streamflow monitoring locations in Subwatersheds 10 and 11

Station Name	Station Code	Owner	Available Period Of Record*	Drainage Area (km^2)
Black Creek below Acton	02HB024	WSC	1987-	18.9
North Black Creek at Highway 7		Burnside	1999-2000	21.0
Credit River West Branch at Norval *(also called Silver Creek gauge)*	02HB008	WSC	1960-	127

Daily flow data are available from the Acton and Georgetown sewage treatment plants (STPs) to help access their relative contributions to the total flow in Black and Silver Creeks.

Figure 3.2.3 Stream Gauges

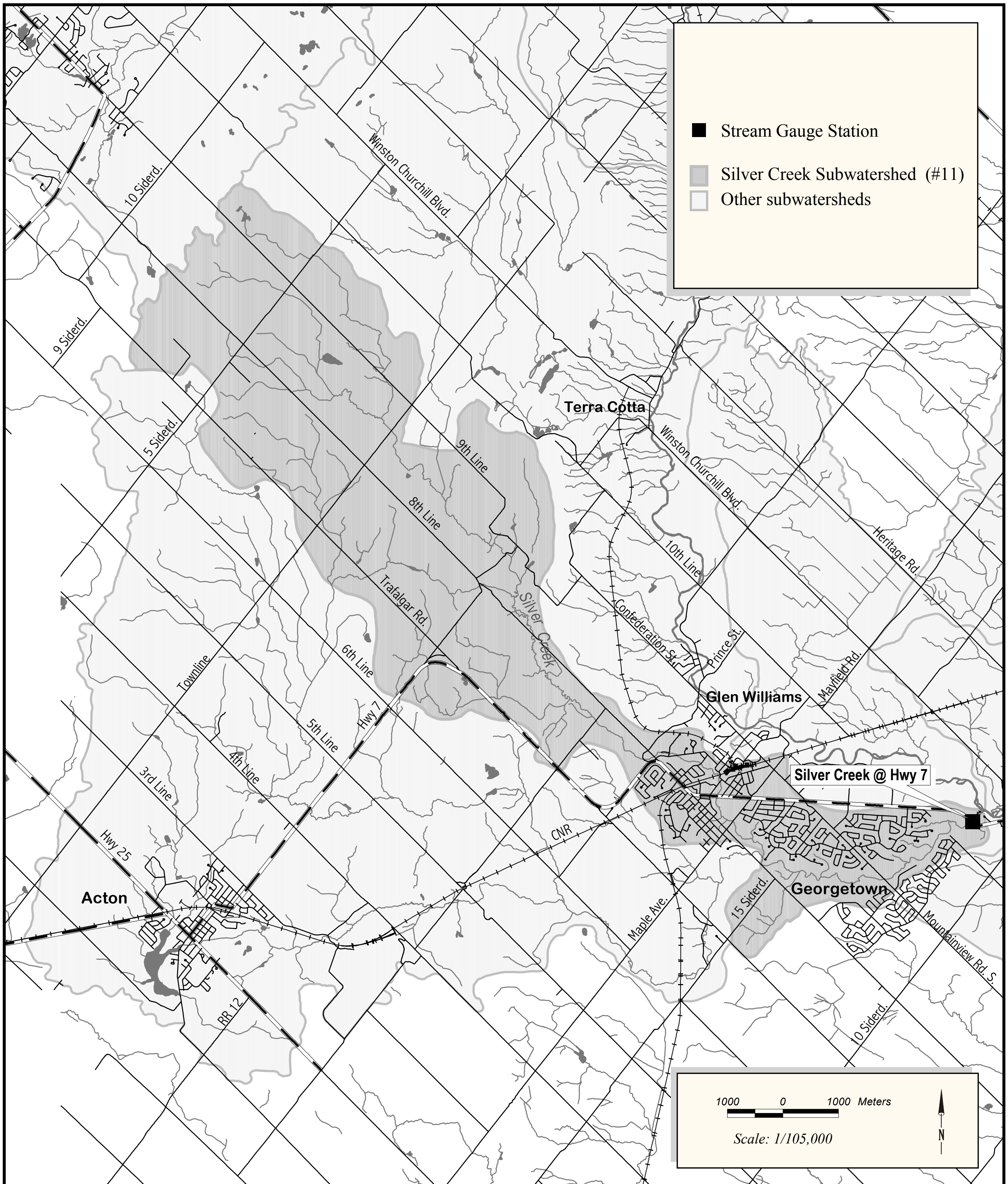


Figure 3.2.3: Stream Gauges

Sources:
Credit Valley Conservation, 2001; Ontario Ministry of Natural Resources, 1982

Hydrologic Models

In the past 18 years, four hydrologic models have been formulated for Subwatersheds 10 and 11. Philips (1984) developed models for Subwatershed 10 and 11 as part of the FDRP (Federal/Provincial Flood Damage Reduction Program) floodline mapping study for the entire Credit River watershed using the USDA's HYMO package. In 1990, Triton Engineering formulated a complete model of the entire Credit River watershed based on the GAWSER (Guelph All-Weather Storm Event Runoff model) package as part of the Phase I Credit River Water Management Strategy. Their model contained 4 subcatchments elements for the 70.4 km^2 Black Creek portion (Subwatershed 10), and 3 subcatchments for the 49.4 km^2 Silver Creek part (Subwatershed 11). This model was calibrated and verified with observed streamflow data from the Norval gauge for 4 rainfall events (May 1974, May 1975, September 1986 and July 1987). The total drainage area for Subwatersheds 10 and 11 taken together in the Triton model is 120 km^2. Notice that this drainage area is 6% smaller than the value published by the Water Survey of Canada (WSC) as noted in Table 3.2.4.

In 1999, Schroeter & Associates re-built the GAWSER (now called Guelph All-Weather Sequential-Events Runoff) model of Subwatershed 10 and 11 as part of a golf course irrigation study in conjunction with Burnside Associates. In this model, the Black Creek watershed was divided into 7 subcatchment elements for a total drainage area of 76.3 km^2, whereas Silver Creek was modelled with 3 subcatchment elements for a total drainage area of 47.0 km^2. The total drainage area for Black and Silver Creek taken together was found to be 123 km^2, which agrees with the WSC value to within 3%. Unlike the previous two models, this one specifically accounts for effluent contributions from the Acton and Georgetown STPs. This model was validated with observed streamflow data from 12 events (3 snowmelt, 9 rainfall), four of which occurred in the year 2000 when all three gauges noted in Table 3.2.4 were in operation. In addition, this model was further validated in continuous simulation mode with measured flow data from the Norval gauge for the period November 1, 1966 to October 31, 1977, the period when the Blue Springs IHD climate station was still in operation.

In late 2000, Schroeter & Associates was contracted by the CVC to further enhance the existing GAWSER model (as of 1999) of Subwatersheds 10 and 11 as part of a geomorphical study of the Credit River through the City of Mississauga. Although this work is still progress, the revised model utilizes the latest soil type/land cover information available in the CVC's GIS (Geographical Information System) database, which is based upon 1:10,000 scale mapping. The revised Black Creek model (Subwatershed 10) is divided into 12 subcatchment elements with a total drainage area of 79.3 km^2, whereas the Silver Creek (Subwatershed 11) portion comprises 8 subcatchments for a total area of 51.7 km^2. The total drainage area for Black and Silver Creeks taken together in this revised model is 131 km^2, which is about 3% larger than that reported by WSC. This model will be available to the project team for the Subwatershed 11 Study.

3.2.2 Preliminary Interpretation of Existing Data

Meteorology

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; OMNR, 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 Credit River Subwatersheds 10 and 11 is about 850 mm, of which 15% appears as snowfall (or 125 cm in depth). These totals are distributed in a fairly even pattern in a northwest to southeast direction. The greatest precipitation amounts occur in the northern part of the subwatersheds south of Erin, due in part to some 'orographic' influence of the Niagara escarpment on 'lake effect' storms originating over Lake Ontario. Lake effect precipitation originating from Lake Huron and Georgian Bay are also possible, but they influence totals primarily in the northern part of the watershed. Total precipitation is distributed such that August, September and November are the wettest months, and January and February are the driest months. The lowest total precipitation (54 mm) occurs in February, whereas the highest precipitation amount occurs in August (95 mm). 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 northern part of the watershed is about 530 mm as deduced from isohyetal maps for southern Ontario (Brown et al., 1974; OMNR, 1984), and can be as high as 600 mm in the southern areas. However, from water balance analyses using observed streamflow data, Singer et al. (1994) computed mean annual evapotranspiration for the area to be about 647 mm. This value is higher than that of the surrounding area, which suggests that a significant amount of water must be available in ponds, swamps and marshes, or held in soil-water storage. The area has an annual frostfree period of 135 days in the north, and 160 days in the south. The growing period is about 195 days in the north, and 210 days in the south. The mean annual air temperature is 6.7°C in the north, where the mean daily temperature in January is about –7.2 °C and 20°C in July. In the southern part of the watershed, the mean annual air temperature is 7.8°C, that is in the range from –4.4°C in January to 21.1°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 evenly 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.

Streamflow

As indicated in Table 3.2.4, two of the three streamflow gauges listed were in operation concurrently during the period 1988-1997. This makes it possible to ascertain the contributions from different parts of the watershed relative to the total flow at the outlet of Silver Creek. For example, Figure 3.2.4 gives the accumulative mean monthly flows in Silver Creek to the Norval gauge, showing the relative contributions from the upstream gauge on Black Creek below Acton. Notice that the flows are highest during the spring freshet and late autumn, and lowest during the summer months.

The influence of topography, geology and climate on the flows along the length of Silver Creek is evident as one looks at the relative contributions from the different parts of the watershed. For instance, in a watershed that is totally homogenous in terms of topography, geology and climate, one would expect the contributions from each part of the watershed relative to the total flow at the outlet to be in the same proportion as their contributing drainage areas. In this regard, the lack of homogeneity in the Silver Creek flows is clearly evident. For instance, the drainage area for the Below Acton gauge represents 15% of the watershed total, and yet it contributes 20% of the flow. It is likely that these higher flow contributions relative to the drainage area percentages for the upper portions of the watershed are attributed to higher precipitation amounts occurring in Subwatershed 10 relative to Subwatershed 11. Moreover, the ‘tighter’ soils found in the hummocky parts subwatershed 10 and 11 could generate more runoff, and hence could explain these differences as well. Nevertheless, the 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).

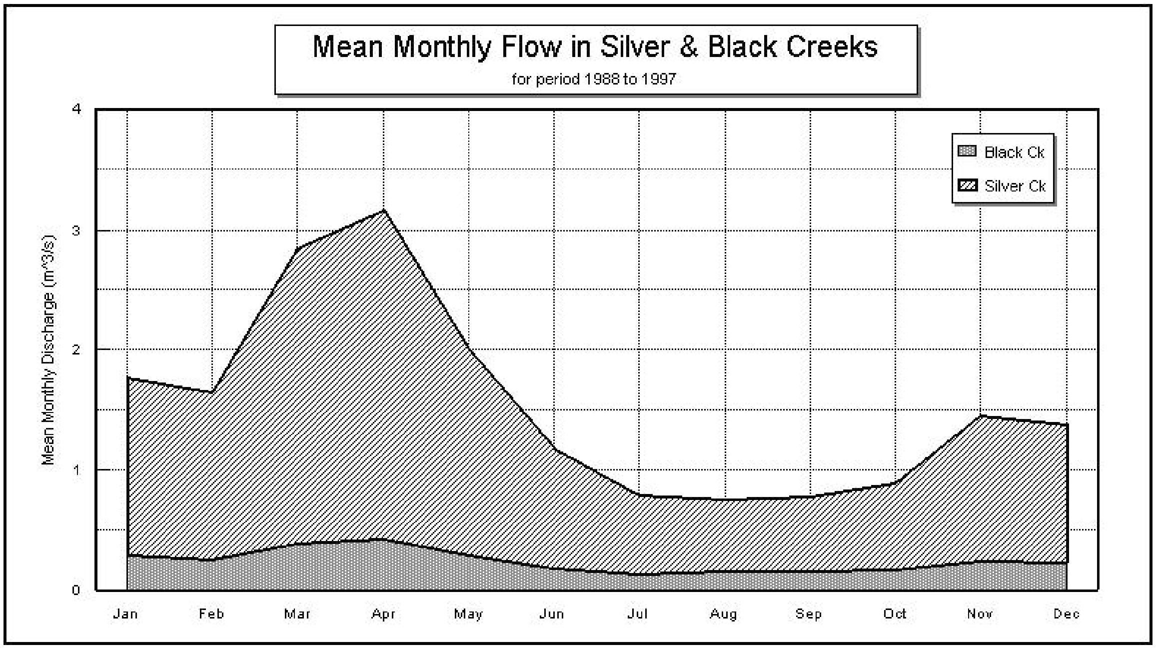


Figure 3.2.4 Monthly mean flow at two locations in Subwatersheds 10 and 11

3.2.3 Identification of Data Gaps

Meteorology

Because of increasing closures of meteorological stations by AES (Atmospheric Environment Service) in the last 4 to 5 years, recent watershed modelling studies have had to rely on precipitation data from whatever gauges are still open, that is whatever's available. Moreover, with increasing use of remote data loggers attached to tipping-bucket raingauges, recording rainfall data are rarely calibrated, so for whatever data may be available, the correct volume may not be known. Recall, that the AES standard procedure for recording rainfall data required a 'standard' raingauge in the immediate vicinity of the tipping-bucket gauge as a check on the rainfall volumes measured by the recording gauge. The standard raingauge would be read daily, and its measured volume used to 'correct' the hourly data. This procedure developed because tipping-bucket gauges tend to 'under-catch' during particularly intense rainfalls. So, even where there is a dense network of recording raingauges, the measured volumes are suspicious.

To account for gaps in the precipitation records, the methodology applied in several recent subwatershed studies (e.g. Schroeter and Boyd, 1998, Schroeter & Associates, 1999), and developed from 12 years of real-time flood forecasting experience in Ontario (see Schroeter et al., 1992; Schroeter et al., 2000) will be applied directly. Essentially, the method requires using the closest available climate (or recording raingauge) station to the study area that is located on the path of the prevailing weather systems which brings the precipitation to the study area. From real-time experience, this does not always mean that the 'absolute closest' climate station to the study area is used in the modelling. For example, during November 1 to 6, 1999 a rather large rainfall event hit Credit Valley Subwatersheds 10 and 11 (Black and Silver Creeks), in which the rain turned to snow near the end of the event. This event originated from Lake Huron, and so rainfall depths measured at Guelph Dam were more representative than those observed at Pearson Airport or the Kelso Conservation Area because the Guelph Dam station was on the path of the prevailing weather system. Close examination of any map for the area reveals that Pearson Airport and Kelso Conservation Area are closer to the Black and Silver Creek watersheds, but are located below the Niagara Escarpment, whereas Guelph Dam is situated above the escarpment.

For other meteorological variables (e.g. air temperature, solar radiation, wind speed and wind direction, humidity), the procedure outlined above can be applied directly (see Schroeter et al. , 2000 for details).

In summary, the climate stations that have been the most reliable and representative of the prevailing weather systems in Subwatersheds 10 and 11, <u>and are still in operation</u> are the following:

Fergus Shand Dam,
Guelph Dam
Georgetown STP, and
Toronto Pearson International Airport

Of these four stations, only one (Georgetown) is located in Subwatershed 11. There is a definite need for more climate information to be measured within the two subwatersheds.

<u>Streamflow</u>

As noted in Table 3.2.4, there are definite information gaps in the streamflow records. The below Acton gauge only monitors flow from 25% of entire Black Creek drainage area, and which represents only 15% of the drainage area to the Norval gauge. This monitoring of Black Creek is insufficient to fully characterize the Silver Creek portion of the flows at the Norval gauge. Moreover, where there are flow data, some records are missing due to ice cover, or gauge malfunctions. However, there is sufficient streamflow data available to validate the important components in any hydrologic model of the combined Subwatershed 10 and 11 areas. A physically-based fully validated model can provide streamflow information where no monitoring stations have existed.

Baseflow contributions to the Black and Silver Creeks are exceptionally high (greater than 50%), and as development pressures continue, increases in impervious areas will contribute to reductions in baseflow. Sewage Treatment Plant (STP) effluents contribute to the baseflow, and the percentage can be high in areas immediately downstream of the STP outflows.

In terms of water balance/budget quantities, recharge rates in the upper reaches of Black and Silver Creek are very high, because of high infiltration soils, and hummocky topography (which directs surface water to the groundwater system). Increasing urbanization will lead to greater runoff volumes, and reduced evapotranspiration and recharge. For accurate prediction of the water balance quantities, there needs to be a correct accounting of the land cover units within Subwatershed 11.

3.3 Hydraulics

3.3.1 Existing Studies & Mapping

The current flood plain mapping was conducted for the Credit River Flood Damage Reduction Study that was completed in 1987 by Philips Planning and Engineering Limited. There are five (5) flood plain maps, numbered 16A through 16E, with a scale of 1:2,000 and 1 metre contours. The five (5) map sheets extend from the Credit River upstream through Georgetown to the base of the Niagara Escarpment. The flood plain maps were updated by Environmental Water Resources Group Ltd. in 1999 in support for a potential Ontario Municipal Board Hearing.

Studies since the Credit River Flood Damage Reduction Study that have reviewed the flood plain mapping along Silver Creek include the following:

- Georgetown West, Master Drainage Plan Report for the Town of Halton Hills by Philip Planning and Engineering in February 1987; and

- Silver Creek, Stormwater Management Implementation Report for Silver Creek, Georgetown Secondary Plan, Halton Hills Village, Phase 2, Stage 1, May 1989 by Winter Associates. In addition, modifications were made to the hydraulic model as part of the reconstruction of Moutainview Road crossing by McCormick Rankin, July 1994.

Flood plain mapping studies conducted prior to the Credit River Flood Damage Reduction Study include the following :

- Fill Line and Floodplain Mapping Study of Credit River, Carolyn Creek, Silver Creek, and Black Creek by Marshall Macklin Monaghan, September 1982; and

- Georgetown Area Flood Level Studies Report, December 1968 by H.G. Acres & Company Limited.

3.3.2 Watercourse Characteristics

Silver Creek is the main watercourse through Subwatershed 11. Tributaries include Rogers Creek to the north and Snows Creek to the south. Also, Silver Creek receives runoff from Black Creek (Subwatershed 10) at Main Street (8th Line) in Georgetown.

The Niagara Escarpment runs in a north south direction through Subwatershed 11. Approximately 75% of Subwatershed 11 lies above the Escarpment and 25% below. Runoff flows in a southeast direction from the headwaters to the Escarpment crest and flows along the Escarpment base in a southerly direction until the confluence with Snows Creek. Silver Creek then conveys runoff in a southeasterly direction through Georgetown and empties into the Credit River at Norval.

Silver Creek is approximately 20 km in length. The maximum watercourse elevation is approximately 420 m at the upstream watershed divide and the lowest elevation is approximately 200 m at the confluence with the Credit River. At the crest of the Niagara Escarpment the watercourse elevation is approximately 340 m and at the base of the Escarpment the elevation is approximately 290 m. The distance between the divide and the crest of the Niagara Escarpment is approximately 6 km. The face of the Niagara Escarpment varies in length from approximately 100 m to 500 m. The distance from the base of the Escarpment to the Credit River is approximately 13 km.

The main communities in Subwatershed 11 are Georgetown and Ballinafad. Georgetown is drained by Silver Creek and is located below the Escarpment. Georgetown occupies the lower 25% of Subwatershed 11. Ballinafad is located in the headwater reaches of Snows Creek above the Escarpment.

3.3.3 Floodplain Characteristics

The five (5) flood plain mapping sheets extend through Georgetown over a watercourse length of approximately 10 km. Silver Creek flows through a well defined "U" shaped valley for the entire length through Georgetown. The lower 20% of the watercourse through Georgetown is flat with a slope of approximately 0.004 m / m. The typical Regulatory Flood Plain width is approximately 60 m, and typical flood depths are approximately 2 m. Through the middle 40% of Georgetown the watercourse slope is approximately 0.004 m / m with typical Regulatory Flood Plain widths of approximately 150 to 200 m and flood depths of approximately 1.5 m. Through the upper 40% of Georgetown the watercourse slope is approximately 0.008 m/m, and the typical Regulatory Flood Plain width varies from 40 to 80 m. Typical Regulatory Flood depths are approximately 2 m.

3.3.4 Flood Damage Centres

The 1987 Credit River Flood Damage Reduction Study identified two (2) reaches along Silver Creek with potential flood damages. The first reach is located near the confluence of Silver Creek and the Credit River. The Study Report identified that approximately 32 buildings located in a trailer park would be susceptible to damages under the Regulatory Flood. For the five (5) year flood approximately 14 buildings in the trailer park would be susceptible to flood damages. The trailer park no longer exists at this location. The second reach contained only one (1) building in the Regulatory Flood Plain. It must be remembered that the Flood Plain mapping did not extend above the Niagara Escarpment where the community of Ballinafad is located. There are probably several buildings within the Regulatory Flood Plain that have not been documented.

3.3.5 Identification of Data Gaps

There is very little available hydraulic data on Silver Creek, Rogers Creek and Snow's Creek above the Niagara Escarpment and there are no flood plain mapping sheets for Ballinafad. Also, the data on the crossing inventory sheets has not been verified for the work performed for the Credit River Flood Damage Reduction Study that was completed in 1987. As part of the Subwatershed 11 Study, data on the crossing sheets will be verified for the existing flood plain mapping sheets, and data will be collected for the remaining crossings above the Escarpment. Estimates of potential flooding will be made through Ballinafad.

3.4 Terrestrial

CVC has recently mapped the Silver Creek Subwatershed terrestrial system 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 the upland and wetland systems. The Natural Heritage Project (NHP) Methodology outlines the methods used to characterize the land use matrix of the watershed. This ELC and Existing Land Use mapping was completed based on 1996 spring aerial photography. The data from these photographs were transferred to 1:10,000 Ontario Base Mapping and then digitized into a GIS or Geographic Information System (Arcview 3.1).

3.4.1 Upland System

The upland system includes forests, plantations, and cultural or successional communities. These communities were mapped to the Community Series level of the ELC for Southern Ontario (Figure 1.4.3). 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 Forest, Mixed Forest, Coniferous Forest, Deciduous Plantation, Mixed Plantation, Coniferous Plantation, Cultural Woodland, Cultural Savannah, Cultural Thicket, Cultural Meadow or Open Beach/Bar.

3.4.2 Wetland System

The wetland system is comprised of marshes, swamps, fens and bogs. Swamps are classified to the Community Series level of the ELC as Deciduous Swamp, Mixed Swamp, Coniferous Swamp or Thicket Swamp (Figure 1.4.3). Marshes are not mapped according to the Community Series level because it is difficult to determine the difference between Meadow Marsh and Shallow Marsh from aerial photography.

Marshes are therefore mapped to the Community Class level of the ELC as Marsh. Fens and Bogs are also difficult to interpret from aerial photography, therefore they are not mapped based on air photo interpretation but are mapped based on fieldwork, Ontario Wetland Evaluations, Environmental Impact Studies and other applicable studies

CVC and the Ontario Ministry of Natural Resources (OMNR) have conducted formal evaluations on many of Silver Creek's wetlands using the Wetland Evaluation System for Southern Ontario. The Ecological Land Classification mapping has been checked against the Wetland Evaluation mapping for discrepancies. Discrepancies could include ELC wetlands that are not identified in the Wetland Evaluation mapping or cases where the ELC mapping identifies a community as upland whereas the Wetland Evaluation mapping identifies the community as wetland. In all cases discrepancies were double-checked in the air photos and corrections were made wherever possible. However, there are cases where no changes could be accurately made to the ELC mapping without field investigations (e.g. Hungry Hollow). As a result, further adjustments to wetland boundaries will be made following this season's fieldwork. Further discussions with the OMNR will be required to deal with any formal changes to evaluated wetlands.

The current ELC and Existing Land Use mapping identifies 641.8 hectares of wetland in the Silver Creek Subwatershed; whereas, the Wetland Evaluation System for Southern Ontario identifies 485 hectares of evaluated wetland and 7.4 hectares of unevaluated wetland. As a result, there are 156.8 hectares of potential and unevaluated wetland in the Silver Creek Subwatershed. Consequently, there is a need to confirm the status of these potential and unevaluated wetlands, under the Wetland Evaluation System for Southern Ontario.

3.4.3 Aquatic System – Watercourses, Lakes and Ponds

Current mapping of watercourses, lakes, and ponds are from the 1:10,000 Ontario Base Mapping. Some updates have been made a part of the Aquatic System component of the ELC and Existing Land Use mapping. These updates include previously unmapped lakes and ponds greater than 0.5 hectare and sections of watercourses where there have been significant changes in the watercourse's size and location. Past subwatershed studies have identified a significant number of inaccuracies and changes in the location and size of watercourses on the Ontario Base Mapping compared to the watercourses on the ground. Having accurate and up-to-date watercourse mapping is important for assessing, modeling and monitoring subwatershed health. Therefore, watercourses and on-line ponds smaller than 0.5 hectare will be updated using aerial photography and ground truthing. Watercourses and on-line ponds will be identified, classified and mapped according to the definitions in Table 3.4.1.

Table 3.4.1 Definitions for Mapping Waterways

Feature	Description
Watercourse	Is constituted when there is sufficient continuous flow of water to form and maintain a defined channel (with bed and banks) of a permanent,

	yet dynamic nature. Ditches can be considered watercourses if they are observed to convey the flow of an upstream watercourse. Watercourses are interpreted from spring aerial photography by the presence of a defined channel observed to contained water.
Intermittent or Ephemeral Watercourse	Is constituted when there is sufficient periodic flow of water to form and maintain a defined channel (with bed and banks) of a permanent, yet dynamic nature. These watercourses will generally flow with most rainfall events. Ditches can be considered intermittent watercourses if they are observed to convey the flow of an upstream intermittent watercourse. Intermittent watercourses are interpreted from spring aerial photography by the presence of a defined channel observed not to contained water.
Watercourse Not Visible	Are watercourses or intermittent watercourses where the exact location of the channel cannot be determined through air photo interpretation because they pass under the canopy of forests or swamps. The location of these watercourses can be estimated from aerial photography based on topographic features or changes in vegetation patterns.
Wetland Flows	Are formed when a watercourse dissipates as it enters a wetland and the water flows as a sheet across the surface of the wetland. The water in these wetlands flows through poorly defined channels, braided channels, or outside a defined channel.
Unevaluated Watercourse	Ontario Base Mapping identifies a watercourse that is not visible in the air photos and requires confirmation in the field. These watercourses will not be shown on hardcopy mapping, but will be tracked through GIS (Geographic Information System) as part of watershed monitoring.
Swales	Are natural drainage courses without defined channels that contain intermittent or seasonally flowing water. These swales will generally only flow during large rainfall events or the snowmelt. Swales are interpreted from spring aerial photography by the presence of a linear depression observed to have contained water. Swales will require field investigations to ensure that they are not watercourses or intermittent watercourses. Swales will only be mapped as part of settlement and/or drainage studies, in response to a subdivision proposal where changes to drainage are anticipated, or where the Ontario Base Mapping has identified a waterway that is interpreted or known to be a swale.
Ponds less than 0.5 hectare	An area of still water lying in a natural or man-made depression. Can be completely enclosed by land or can have either or both an in-flowing or out-flowing stream. A pond can also be created by interrupting the normal flow of a watercourse with a dam. As part of updating waterways across the watershed, only on-line ponds less than 0.5 hectare will be mapped. These ponds are mapped as point data since the pond boundaries are too small to be accurately mapped at a 1:10,000 scale. The size of the symbol does not relate to the size of the pond.
Channelized Watercourse	Any watercourse that has hardened banks and/or beds, including concrete lining, Gabion baskets, Armour stone or riprap. These watercourses have usually also been straightened or smoothed.

3.4.4 Provincially Significant Wetlands, ESAs, ANSIs

3.4.5.1 Provincially Significant Wetlands

Provincially Significant Wetlands (Figure 3.4.1) are wetlands which have been evaluated through the Wetland Evaluation System for Ontario - South of the Precambrian Shield, and have been determined to be either Class 1, 2 or 3. A brief description of the provincially significant wetlands can be found below. A list of significant species can be found in Appendix A for each wetland described.

Ballinafad Ridge Wetland Complex

The Ballinafad Ridge Wetland Complex is a large wetland complex shared between the Grand River and the Credit River watersheds. These wetlands are comprised of large and small pockets of treed swamp, thicket swamp, and marshes on morainal topography. The wetland complex also contains small fen and bog habitats that are considered rare in this region. A diverse, conglomeration of forest, successional woodlands, thickets, plantations, rural estates and agriculture surrounds these wetlands.

Silver Creek Wetland Complex

The Silver Creek Wetland complex is located on top and at the base of the Niagara Escarpment amongst some of the most significant natural areas in the Credit Watershed. The surrounding area is biologically and physically rich, supporting one provincially significant Life Science ANSI, five Environmentally Significant Areas, and a number of significant landforms including an esker, kettle lake, and the Niagara Escarpment World Biosphere Reserve. Swamps and marshes dominate the wetland. The large adjacent tracts of deciduous and mixed forests provide refuge for plants and animals that are considered area sensitive. The wetland also provides habitat for brook trout and the provincially rare redside dace. Regionally and locally rare plants species can also be found in the Silver Creek Wetland Complex. Adjacent land uses include urban and rural development (Ballinafad and Silver Creek), active aggregate, intensive agriculture and non-intensive agriculture.

Hungry Hollow Wetland

Hungry Hollow is a riverine wetland located along Silver Creek from its confluence with Black Creek to where it meets the Credit River at Norval. Swamps dominated by Willow, Poplar, White Elm and Eastern White Cedar characterizes the Hungry Hollow Wetland. A very small fen was also identified in the Hungry Hollow Wetland but was considered to be too small to be included in the evaluation. Adjacent land uses are urban development (Georgetown), agriculture and manicured open space (golf course).

3.4.5.2 Environmentally Significant Areas (ESA)

The locations of the following ESAs are illustrated in Figure 3.4.1. A list of significant species found in each ESA described can be found in Appendix A

Silver Creek Valley ESA
(386.3 ha of the ESA are located in the Silver Creek Subwatershed)

The Silver Creek Valley ESA is a well preserved valley complex covering the face of the Niagara Escarpment which includes a prominent outlier rim, valley, slope and upland forests on both flanks of the valley. The generally undisturbed forest types are comprised of several associations including Sugar Maple-White Ash-Beech upland and escarpment woods; Silver Maple-White Elm-Red Ash swamps, White Birch-Eastern White Cedar-Hemlock talus forest; White Elm-Red Ash-Yellow Birch, and Eastern White Cedar-Balsam Fir-White Spruce swamps along the valley bottom. Cattail marshes and ponds rich with floating aquatics dominate the open water/wetland area along the valley floor. The Silver Creek Valley is designated a Provincially Significant Life Science ANSI and detailed information is available in the recent Biological Inventory and Evaluation ANSI report (1996). The Niagara Escarpment outlier exposes Amabel bedrock formations with Fossil Hill strata along the old quarry floor. A three meter waterfall on Snow's Creek exposes the Fossil Hill-Reynoles bedrock transition and is the site of a regionally significant Earth Science ANSI.

Brisbane Woods I and II ESAs
(256.8 ha of the ESAs are located in the Silver Creek Subwatershed)

Brisbane Woods I and II are situated on the Paris Moraine, comprised of the Wentworth sandy till and kame deposits of sand and gravel. Upland soils comprised of well-drained Dumfries loam with pockets of imperfectly drained Brisbane loam. Scattered depressional swamps throughout the hummock topography are occupied by organic soils. Vegetation community types are diverse but dominated by deciduous and coniferous lowland associations including: Eastern White Cedar-Trembling Aspen, Eastern White Cedar-Mountain Maple-Yellow Birch-Black Ash, Eastern White Cedar, and Eastern White Cedar-Red Maple. Willow and Alder thickets occur in several locations with pockets of upland areas supporting Sugar Maple-Beech and Sugar Maple-Black Cherry associations. The ground flora has been described as moderately diverse. The Brisbane Woods II ESA is a continuous extension of Brisbane Woods I ESA divided by Regional Road 3 (Halton 7th Line).

Hungry Hollow ESA
(172.6 ha of the ESA are located in the Silver Creek Subwatershed)

Located mainly in the Silver Creek Valley and partially in the Black Creek Valley, the Hungry Hollow ESA stretches for approximately 6.5 kilometers from Stewartown to

Norval. Steep slopes between 15-20 meters peer over an alluvial valley floor comprised mostly of outwash gravel. The Hungry Hollow area is one of high groundwater discharge stemming from overburden and bedrock aquifers in sand and gravel deposits to the south. Vegetation communities include open floodplain meadows consisting of scattered Eastern White Cedar, Manitoba Maple, Willow and Basswood. Remnant patches of wooded floodplain consist of Eastern White Cedar, Black Ash, Basswood, and stands of Sugar Maple. The steep slopes support Sugar Maple-Hemlock forests occurring in mature dense stands.

Snow's Creek Woods ESA
(128 ha of the ESA are located in the Silver Creek Subwatershed)

The Snow's Creek Woods ESA is a small wooded wetland situated along the base of a south-facing slope. Upland associations support Sugar Maple-Beech forests while a pure and mature (approx. 120 years old) Sugar Maple stand exists along the northeast section. Other communities include: Eastern White Cedar-Tamarack-White Pine, Yellow Birch-Sugar Maple-Hemlock, Eastern White Cedar-White Birch-Poplar-White Ash along with a variety of wetland habitats. These lowland areas provide significant storage capacity and act as an important headwater for Silver Creek. Wetland corridors provide the obvious link to Waterfall Woods ESA for perhaps an enhanced area of significance in the future.

Waterfall Woods ESA
(24.8 ha of the ESA are located in the Silver Creek Subwatershed)

The Waterfall Woods ESA provide the headwaters for a series of tributaries of Black Creek and is comprised of upland and lowland deciduous, mixed and coniferous communities. Forest communities include Sugar Maple-White Birch, Red Maple-White Birch-Yellow Birch, Sugar Maple-Beech-Red Oak, and pure White Ash stands. Coniferous and mixed communities include: Eastern White Cedar-White Ash-Yellow Birch, White Pine-Hemlock-Red Maple and a pure Jack Pine plantation. Numerous ponds and marshes are scattered throughout the ESA. The Niagara Escarpment provides a deep valley spanning along Concession 7 creating an interesting topographical contrast. Another small valley along the northeast section contains a small waterfall of Silver Creek and creates a very picturesque setting. The wooded valley south of Regional Road 43 (Con.7) is particularly dense and mature.

Acton Swamp III ESA
(24.6 ha of the ESA are located in the Silver Creek Subwatershed)

Part of the large Silver Creek Wetland Complex, the Acton Swamps I, II and III share similar characteristics. Vegetation communities include both upland and lowland associations including: Eastern White Cedar-Poplar-Birch, Eastern White Cedar-Sugar Maple-Beech-Red Maple, Eastern White Cedar-Poplar-White Ash, pure Sugar Maple and pure Eastern White Cedar stands are also scattered throughout. A Black Cherry-Sugar Maple-White Ash stand is located along the east boundary of Acton Swamp III.

Georgetown Credit River Valley ESA
(3.1 ha of the ESA are located in the Silver Creek Subwatershed)

A regionally significant Life Science ANSI, the Georgetown-Credit River Valley ESA, just upstream from Norval is a deep (24 meter) and steep valley (slopes greater than 30 % in some places). Containing a variety of natural vegetation communities including successional old fields, Hawthorn-Poplar scrub, and floodplain forests of Manitoba Maple, Sugar Maple, Poplar and Basswood. Eastern White Cedar, Sugar Maple, Hemlock, Beech and Red Oak dominate the valley slopes. Red Pine and White Spruce plantations of varying ages add to the size of the ESA. Valley floors are comprised of recent alluvial deposits with varying drainage, while tableland soils are comprised of well drained clay loam soils developed over predominantly clay-loam till.

Ballinafad Pond ESA
(1.5 ha of the ESA are located in the Silver Creek Subwatershed)

The Ballinafad Pond ESA is a small kettle lake situated on irregular deposits of kame sand and gravel associated with the Paris and Galt moraines. The kettle depression pond is surrounded by short but steep slopes and is comprised of organic soils with a high water table. Vegetation communities include a Wet-Mesic Red Maple Forest, mixed coniferous swamps comprised of White Pine-Black Spruce-Larch with a Red Maple understory. At the edge of the open water, a floating sphagnum-shrub margin of Leatherleaf, Water Willow, Virginia Chain Fern and Cranberry averages 1-2 meters in width. At the edge of the basin, shrub thickets, semi-open swamp and drier forest types occur.

3.4.5.3 Areas of Natural and Scientific Interest (ANSI)

Silver Creek Valley ANSI
(Summary based on Riley, J.L. et. al., 1996)

Silver Creek Valley (Figure 3.4.1) is a Provincially Significant Life ANSI. This ANSI combines the previously known Silver Creek South Regional ANSI with the Silver Creek Valley Provincial ANSI. The Silver Creek Valley ANSI is located on the slopes and in the valley of a glacial meltwater channel between the Niagara Escarpment and the Silver Creek Outlier.

Biological diversity is high with over 60 different communities types and over 400 vascular plants recorded in the ANSI. There is one nationally threatened, one provincially threatened, four regionally rare, and 22 locally rare vascular plant species at the Silver Creek Valley ANSI. The ANSI is also home to three nationally vulnerable, three provincially vulnerable, one provincially rare, two regionally rare, and three locally rare faunal species. Ten communities would be considered rare or restricted in the Halton Section of the Niagara Escarpment or in the Study Area. Some forest stands are over 100 years old and some of the Eastern white cedar trees along the edge of the Escarpment may be several hundred years old.

The Silver Creek Valley ANSI fulfills many important ecological functions including groundwater discharge area, maintaining low water temperature and turbidity of Silver Creek, providing large core habitats for maintaining viable populations, and functioning as a corridor linking to other large core habitats across the Credit Watershed and the Niagara Escarpment World Biosphere Reserve. The Silver Creek Valley ANSI covers 388.3 hectares (7.5 %) of the Silver Creek Subwatershed. For a listing of the significant vascular plants and vegetation communities, please refer to Appendix A.

Georgetown Credit River Valley
(Regional Life ANSI) 48.7 ha

For details regarding the Georgetown Credit River Valley Regional Life Science ANSI please refer to Georgetown Credit River Valley ESA description above.

3.4.7 Identification of Data Gaps

The following tasks will be completed to address any data gaps as part of the Silver Creek Subwatershed Study.

- Halton Region Ecological and Environmental Advisory Committee (EEAC) was formed by Halton Regional Council to advise the Region in matters pertaining to Halton's natural environment. The Halton EEAC has identified and collected data on Environmentally Significant Areas (ESA). As part of this study it will be important to incorporate that data into the study. ESA boundaries should also be examined to compare them to the ESA boundaries of the CVC's ESA program.

- Naturalist Clubs (e.g. Halton – North Peel Naturalists) and other community groups (e.g. Save Our Ravines) offer a wealth of knowledge and experience to such a study. Therefore, every effort will be made to encourage participation by these groups.

- Reconnaissance fieldwork is required to confirm the Ecological Land Classification and Existing Land Use mapping.

- Detailed community data will be collected through fieldwork to classify a number of significant natural areas according to the Ecological Land Classification for Southern Ontario.

- Ontario's Ministry of Natural Resources needs to be contacted to attain the latest mapping and status of evaluated wetlands.

- The aquatic system mapping will be updated through air photo interpretation and will be used to confirm subcatchment boundaries.

- Crest of slope and steep valley slopes will be mapped to define the physical boundaries of the well-defined valley system.

- Micro and macro corridors will be mapped and assessed.

- Terrestrial communities shall be assessed to determine their relative significance in the Silver Creek Subwatershed based on fieldwork and existing data.

- Forest Bird Monitoring and Roadside Amphibian Call Counts will be carried out to develop a better understanding of the wildlife and their habitats in the Silver Creek Subwatershed.

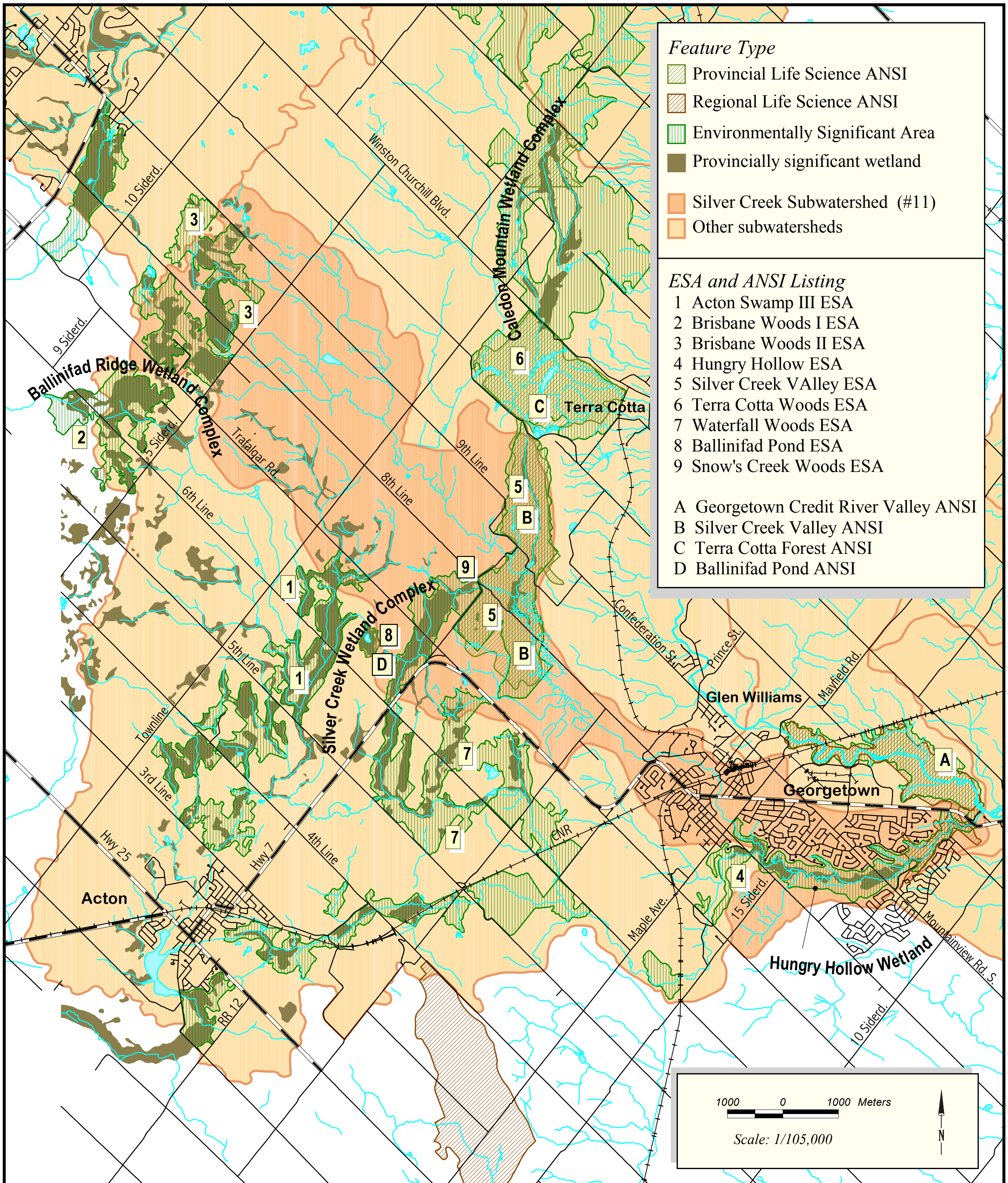


Figure 3.4.1: Provincially Significant Wetlands, Areas of Natural and Scientific Interest and Environmentally Significant Areas

Sources:
Credit Valley Conservation, 1998 (ESA); Ontario Ministry of Natural Resources, 1998 (ANSI), 1982 (base mapping).

3.5 Stream Geomorphology

3.5.1 Background Information

There are a number of studies that have involved the collection of stream morphology data on Silver Creek. These studies include:

- MNR, 1993. Watershed Management and the Health of Fish Habitats: A Perspective from Fluvial Geomorphology.
- Town of Halton Hills, 1996. Georgetown West and Georgetown South: Master Drainage Plan Study Update
- Annabel, 1996. Database of Morphologic Characteristics of Watercourses in Southern Ontario.
- Credit Valley Conservation, 1983. Stream Assessment of Silver Creek and the Major Tributaries.
- Credit Valley Conservation, 2000. Credit River Watershed Monitoring Program.
- Aquafor Beech Limited, 2000. Stream Corridor Management Plan for the East-West Tributary of Silver Creek.

The most technically extensive stream morphology data collection effort on Silver Creek was that of MNR 1993. The objective of this study was to provide examples of geomorphic data that are useful to fish biologists. Detailed geomorphic measurements were taken on Silver Creek at 11 stations above the confluence with Black Creek (i.e. upstream to the base of the Niagara Escarpment) and 7 stations below the confluence. The data collected include channel cross- section, planform, bed and bank material composition, fluid velocities, floodplain vegetation, suspended and bedload sediment transport. These data were used to determine bank erosion volumes, hydraulic geometry relations, riffle pool spacing, and linkages to critical fish habitats.

The fluvial component for the Georgetown West and Georgetown South Master Drainage Plan Update Study was designed to characterize existing conditions, assess changes due to future development and to devise a mitigation strategy to minimize impacts. The spatial scope of assessment was limited to the two planning areas. Geomorphic measurements were taken at three stations on Silver Creek downstream of the confluence with Black Creek. The stations were classified according to the Rosgen, 1996 classification system.

Annabel 1996 conducted a study to develop morphological relationships for Southwestern Ontario Streams that could be used for natural channel design. As part of this work the morphologic character of Silver Creek near Gauge 02HB008 was investigated. The site was classified according the Rosgen 1996 classification system as B4-Type. The site was incorporated into a forty-seven-stream data set that was used to investigate the predictability of channel form. A key assumption of the study was that all the sites must be stable and adjusted to the watershed conditions.

In 1983 a Stream Assessment of Silver Creek was commissioned by the CVC. The objective of the work was to assess the stream for fisheries rehabilitation purposes. The spatial scope of this work covers the vast majority of the watercourse; more extensive than any other work. Two researchers collected data relating to channel form, stability and habitat between 3 June and 25 July 1983. This data was used to create maps of channel morphology, riparian zone character and flow character at the time of survey. The data were also used to identify areas that support a healthy fish community and areas of concern that are limited by a lack of habitat requirements (e.g. stream stability).

Aquafor Beech Limited completed a “Stream Corridor Management Plan for the East-West Tributary of Silver Creek” in November 2000 on behalf of the Town of Halton Hills. This tributary, as well as several other tributaries along the lower reach of Silver Creek are being utilized to receive uncontrolled stormwater from residential developments built out in the 1950s, 1960s and 1970s. The report indicates that the East-West Tributary is degrading in response.

CVC is in the initial stages of implementing a monitoring program to investigate the health of the Credit River Watershed. As part of this monitoring program two fluvial geomorphic monitoring sites were established on Silver Creek in the summer of 2000. The first station is located where Annabel 1996 established his site near gauge 02HB008. The second site is located upstream of Wildwood Road. Detailed measurements of channel form variables are available for these sites.

3.5.2 Preliminary Interpretation of Existing Data

Silver Creek is a Tributary of the Credit River and drains approximately 52 square kilometers. The main branch is 20 kilometers in length and is bisected by the Niagara Escarpment. Development within the watershed is focused in the Georgetown area and the majority of the watershed is still rural agricultural land. The hydrologic regime is typical for Southwestern Ontario streams with peaks occurring in the fall and spring. Lows occur in the summer and winter, but some highs occur in these periods from cyclonic storms and winter thaws.

Three distinct reaches of Silver Creek can be distinguished from backgound sources; Below the Escarpment, Above the Escarpment and where Silver Creek cuts through the Escarpment.

Below the Escarpment, Silver Creek has an average grade of 0.008 m/m but ranges from 0.002 m/m near Norval to 0.0019 m/m between Wildwood Crescent and Mill Street. These slopes suggest that a riffle-pool morphology would predominate. The Master Drainage Plan Update Study indicates that C-Type channels predominate (Town of Halton Hills, 1996). The sinuosity of Silver Creek is 1.4, which is less than the criteria for meandering channels (i.e. 1.5). The straightness of this reach may be due to the fact that it is deeply incised into the North-Western edge of the Peel Plain. The creek is incised into the highly erodible Queenston shale near Norval. The steep valley walls consist of Halton Till, which is clay in texture. This reach of Silver Creek flows in a glacial outwash channel that parallels the Niagara Escarpment. Well-sorted alluvial sand and gravel deposits are located adjacent to the Creek in Georgetown South and a bedrock outcrop occurs in the valley east of Mountainview road. The valley bottom has been characterized as wetlands and fragmentation of the riparian vegetation has occurred where drier areas persist. Soils west of the Escarptment are clay loam and developed on the Halton Till which are derived from shale, sandstone and dolostone or limestone bedrock.

Channel widths ranged from 11 m downstream of the Black Creek Confluence to a minimum of 3 m near the Escarpment (MNR, 1993). Bankside vegetation composition is variable leading to changes in channel form. The abundance and type of floodplain vegetation did not reportedly affect the channel form (MNR, 1993). Mean particle sizes ranged from cobble gravel to fine sand. Suspended sediment concentrations ranged from 2.3 – 150 mg/L, which is relatively clean flowing and generally supportive of salmonid habitation.

Above the Escarpment, there is less known about the morphology of Silver Creek. The Creek has an average grade of 0.010 m/m. This suggests that it is also a riffle pool type stream. The lower half of this reach flows through a wetland belt and is much more vegetated than the upper portion. The upper half supports many tributaries that drain rural agricultural lands. The channel is cut into the Wentworth till and is much less incised than the portion below of the Escarpment.

At the Niagara Escarpment, the average grade of Silver Creek is 0.040 m/m which suggests that its morphology is cascade-pool (e.g. B-Type) or step-pool (e.g. A-Type). A scarp and terrace at the foot of the main Escarpment is formed by a white or tan quartz sandstone of the Whirlpool Formation which overlies the more erodible Queenston shale. It is anticipated that substrates are coarser through this portion because of the higher energy and supply of resistant sandstone. This portion is noted as supporting brook trout populations which suggests that it is relatively stable.

There were three studies that addressed the location and severity of erosion on Silver Creek. The findings are discussed in the following three paragraphs.

The 1983 Stream Habitat Assessment Study reported that the majority of Silver Creek was stable. Some minor erosion was reported on Silver Creek between Georgetown and the Niagara Escarpment. This erosion was attributed to livestock access and sparse bank-side vegetation. Minor erosion sites were reported from Georgetown to the Credit River. The most active sites were located between the CNR tracks and Mountainview Road. This erosion was attributed to flood damage and evidenced by urban debris jams, uprooted trees, log jams and eroding banks. The study reported that Silver Creek was intermittent above Halton Boundary Road (e.g. 16.75 km from mouth). Cumulative departure curves indicate that 1982 and 1983 were below average for stream flow but near the end of a 12 year above average cycle.

As part of the MNR 1993 study, bank erosion volumes were estimated for a 1991 winter event. The erosion rates were determined by resurveying before and after the flood event. The reported rates are 0.003 m3/m for cohesive soils and 0.037 m3/m for non-cohesive soils. Further work is required to determine if these rates are typical for stable streams.

The Master Drainage Plan Study (1996) reported that Georgetown West had no major erosion zones. In Georgetown South, an active erosion zone, located near the confluence with Black Creek (400 m downstream of Section D), was attributed to tilling of the over-bank zone. An additional zone of minor disturbance, toppling of banks, was noted immediately upstream of Mountainview Road.

In summary, background reports indicate that the main branch of Silver Creek is a relatively stable stream. The stream still supports Type 1 habitat and has a significant baseflow contribution and semi-contiguous riparian cover. While the health of Silver Creek is relatively good for Southern Ontario Streams, it is degraded relative to Black Creek. This has been attributed in part to a greater impact from agricultural development and differences in the groundwater regimes.

Research to date has been inconclusive regarding the impact of existing development on Silver Creek due to urbanization within Georgetown. Hydrologic assessments (Town of Halton Hills, 1996) suggest that the peak discharges have decreased, which may be due to the fact that the urban flood peak passes before the rural portion of the watershed reaches Georgetown. This may lead to sedimentation if flushing flows are reduced in frequency. However, the frequency of flows typically increases with urbanization. This can result in an increase in the amount of fine sediment transport. Studies to date have not examined this aspect of sediment transport.

Sediment transport modeling was conducted on four sites (i.e. Sections B, C, D & G) for the Master Drainage Plan. This modeling suggested that future development would result in an increase in erosion potential (i.e. at Sections B & G). The datum for measuring the increase in erosion potential was 1987, which is prior to any development in Georgetown West and South. The appropriateness of this datum will have to be re-evaluated because Silver Creek may have been under stress from development elsewhere but not responding yet (e.g. as evidenced by the lack of wide spread erosion reported).

It is likely that due to the low level of development within the watershed, relative to the size of the drainage basin, only adjustments to micro-scale habitat features (e.g. bed sediment texture, ripples) has occurred to date with only minor and localized disturbance to stream bank stability. Research has shown that when a drainage basin reaches approximately 10% impervious area the rate of stream destabilization increases geometrically. The implications of this type of system destabilization include severe degradation of habitat, degraded water quality, property damage, public safety concerns and costly maintenance of urban infrastructure.

3.5.3 Identification of Data Gaps

The primary data gaps are discussed below. This study must investigate:

The History of Land Use Development within the Watershed. The amount and timing of development within the watershed strongly influences how a stream will respond to changes in the flow and sediment regime. A chronology of amount and nature of development (i.e. measured as percent impervious) must be developed. From this data the amount of channel change and timing can be predicted.

Rates of Bank Retreat. This data can be obtained by resurveying cross-sections from previous studies. Further, active zones can be identified in a semi-qualitative sense from analysis of historical air photographs. Rates of geomorphic activity help the determination of system stability and determination of the timing and severity of potential impacts.

Existing Stream Stability. This will be quantified using a rapid geomorphic assessment form and aerial photographic analysis. These results will be supplemented by a geomorphic interpretation of the field data.

Sediment Source Assessment. Work to date has identified the general location of potential sediments from quaternary geology and physiographic sources. The synoptic field survey and aerial photo analysis will be used to locate sediment sources and assess their importance in maintaining stream stability. The supply of coarse sediments (e.g. coarse gravel to boulder) will be critical to maintaining stream stability. The supply of finer sediments (e.g. coarse sand to coarse gravel) is critical to salmonid spawning and food production. The supply of very fine sediments (e.g. < sand) is critical to the maintenance of channel banks but over supply can limit macroinvertibrate production and successful spawning.

Valley Wall Contacts and Gully formation. Due to the incised nature of Silver Creek, steep valley walls incised with gullies abut existing and proposed development. The stability and function of these locations must be investigated. Grading and drainage plans must avoid funneling excess water through these gullies.

The Extent of the Floodplain and Meander Belt. The meander belt is the area reworked by the stream as it travels across its floodplain. It is anticipated that the meander belt is confined within its valley, East of the escarpment, which requires the assessment of the ability of the stream to erode the valley walls. The width of the meander belt and floodplain require consideration when defining development setbacks.

Current channel data to model morphological change using erosion indices. The impact analysis is typically based on an erosion index that requires that the channel cross-section, slope and nature of bed and bank materials be known. New data must be collected because existing data sets are outdated. The data are outdated because a rare flood has passed since the data from previous studies was collected and because the channel may not have responded to basin wide changes due to urbanization at the time of the previous surveys.

3.6 Water Quality

This section describes the main sources of historical water quality data that will help to characterize the water quality conditions in Silver Creek for Phase I of the subwatershed study. Some preliminary findings from the existing data are discussed and gaps in the data are identified for further investigation.

3.6.1 Existing Information and Data

Long-term water quality data sets exist for two stations on Silver Creek, upstream and downstream of the Georgetown Sewage Treatment Plant (STP) as shown in Figure 3.6.1. The station names and ID numbers are listed below:

Silver Creek at Highway 7	06-0076-004-02 (downstream of STP)
Silver Creek at Mountainview Road	06-0076-022-02 (upstream of STP)

Through the Ministry of Environment's (MOEs) Provincial Water Quality Monitoring Network (PWQMN), CVC has collected water quality samples from these two locations on a monthly basis and MOE has analyzed the samples for a typical suite of water quality parameters. Other relevant measures have been taken by CVC such as dissolved oxygen and water temperature at the time of collection.

Table 1 presents the parameters that are currently being measured at the Highway 7 and Mountainview stations. Sampling at the Highway 7 site began in 1964 while sampling at the Mountainview Road site started in 1979. The current analyses for some parameters began even later, such as metals in 1996, as analytic techniques improved and indicator parameters were added to the suite of parameters.

Table 3.6.1 Descriptions of Parameters from the PWQMN on Silver Creek

Parameters	Category	Potential Sources	Concerns	Common Start Date
• Total Ammonium • Total Kjeldahl Nitrogen (TKN) • Phosphate Phosphorus • Total Phosphorus • Nitrate • Nitrite	Nutrient-related	• Urban Runoff • Rural Runoff • Agricultural Runoff • STP effluent • Septic systems • Aquatic plants	• Ammonium, nitrite and potentially nitrate may be toxic to aquatic biota. • Elevated levels of nitrate, ammonium, and phosphorus may stimulate aquatic plant growth, which may lead to an unhealthy dissolved oxygen regime for aquatic biota. • TKN can be used to determine the amount of 'oxidizable'-nitrogen (NOD) in a water body.	May/ April 1979
• Calcium • Magnesium • Alkalinity • Hardness	Major minerals and related parameters	• Groundwater discharges	• 'hard' water decreases the toxicity of many metals but may require softening for water supplies • higher alkalinity values indicate a higher capacity of the waterbody to buffer pH changes	Sept 1994

Parameters	Category	Potential Sources	Concerns	Common Start Date
• Biological Oxygen Demand (BOD) • Chemical Oxygen Demand (COD) • Dissolved Oxygen (DO)	Oxygen Related	• Urban Runoff • Rural Runoff • Agricultural Runoff • STP effluent	• sufficient levels of DO are required by most aquatic biota • materials with high BOD (includes NOD- Nitrogenous Oxygen Demand) and COD can deplete DO levels	April 1979 (COD Jan 1995)
• Filtered Residue (Dissolved Solids) • Particulate Residue (Suspended Solids – SS) • Conductivity • Water Temperature • Chlorides	Physical and related parameters	• Urban Runoff • Rural Runoff • Agricultural Runoff • STP effluent • Road salting • Septic systems	• SS can damage fish habitat by clogging up spawning areas • an increased temperature regime can be harmful to fish • increased filtered residue and/or conductivity may indicate increases in chlorides or other ions	April 1979
• Aluminum • Barium • Berylium • Cadmium • Chromium • Cobalt • Copper • Iron • Lead • Manganese • Molybenum • Nickel • Strontium • Titanium • Vanadium • Zinc	Trace Metals	• Urban Runoff • STP effluent • Rural Runoff • Erosion of clay soils (which can contain Aluminum, Manganese and Iron oxides)	• acute and chronic toxicity to aquatic biota • buildup in the food chain from elevated levels in aquatic biota.	

Parameters	Category	Potential Sources	Concerns	Common Start Date
• Escherichia coli (*E. coli*) • Pseudomonas Aeruginosa • Fecal Streptococcus	Micro-biological (pathogenic to humans)	• Urban Runoff • Rural Runoff • Agricultural Runoff • STP effluent • Septic systems	• Although not typically directly harmful to aquatic biota, high levels of bacteria can indicate organic pollution • *E. coli* is used as an indicator of health risk in body contact recreational uses of water	Sept 1994 (Fecal Strep April 1979)

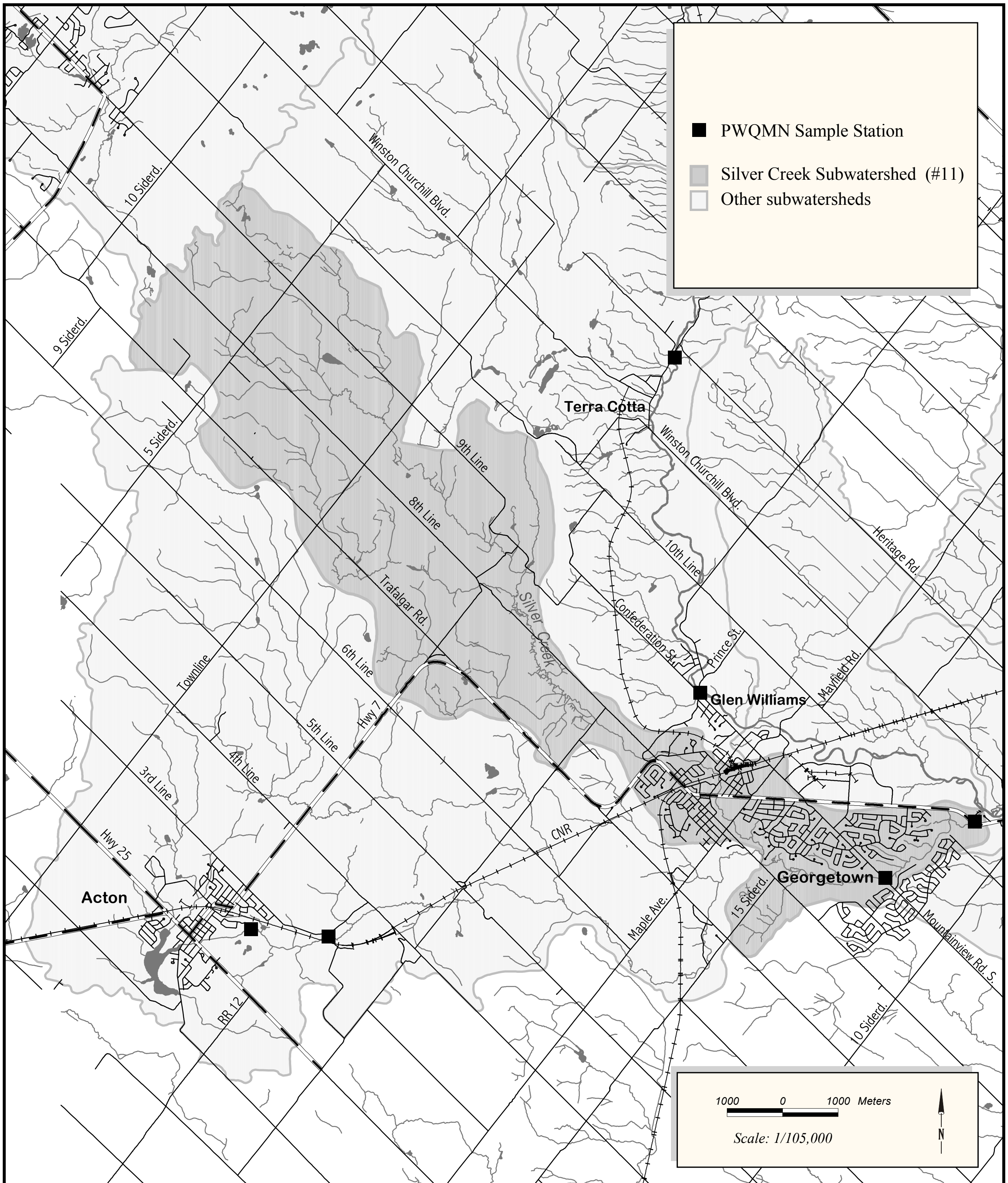


Figure 3.6.1: Provincial Water Quality Monitoring Network Stations

Sources:
Credit Valley Conservation, 2001; Ontario Ministry of Natural Resources, 1982

In addition to the MOE's sampling program, the Georgetown STP keeps effluent flow rates and effluent quality records as part of the requirements of their Certificate of Approval. The plant processes include biological treatment, phosphorus removal, and tertiary treatment by ultraviolet radiation. The annual daily average flows is 14 516 m3/day (pers comm. 2001) and the capacity is 22 727 m3/day. The following effluent criteria are outlined in their Certificate of Approval:

BOD	10 mg/l
Suspended Solids	10 mg/l
Total Ammonia	5 mg/l
E. coli	200 counts/100ml
Total Phosphorus	1 mg/l

3.6.2 Preliminary Interpretation of Existing Data

Water quality measurements represent only a brief snapshot of the water quality conditions at the time of sampling. However, over a longer time period of sampling, general trends and patterns can emerge from the data sets. Averaged or summarized data can be compared against typical values, guidelines, such as those from the Canadian Council of Minister of the Environment (CCME, 1999), and Provincial Water Quality Objectives (PWQOs) (MOE, 1999). CCME guidelines and PWQOs have been specifically developed based on long-term threshold water quality conditions. Therefore, average values for parameters should not exceed their respective guidelines or objectives. Occasional samples that exceed the objectives or guidelines are not problematic as long as levels are not high enough to be acutely toxic.

Under MOE's Policy 2 statement, the MOE will permit no further degradation for a parameter that exceeds its PWQO (MOE, 1999). For those parameters that are below their PWQO, some minimal degree of degradation may be accepted however degradation beyond the PWQO is not acceptable. This approach is outlined in Policy 1 (MOE, 1999). Typically, a 75th percentile value is used for comparison against the PWQO as it represents a conservative, 'worse than average' condition of the water body.

A full analysis of the PWMQN data will be presented and described in the Phase I Characterization report however a preliminary analysis of the MOE data provided a baseline assessment of conditions in the lower reaches of the subwatershed. The results are presented under the same headings described in Table 3.6.1.

<u>Nutrients</u>

1. Mean and 75th percentile values of total phosphorus are 0.021 mg/l and 0.058 mg/l, respectively, for the Mountainview Road station located upstream of the Georgetown STP. The 75th percentile value is above the PWQO of 0.030 mg/l and therefore this reach of Silver Creek may fall into the Policy 2 category, where no further degradation is acceptable. It should be noted that trend analysis (Seasonal Kendall

Test) indicates a decrease in total phosphorus at this station (CVC et al., 2000) and more recent data may not indicate a Policy 2 situation.

2. Mean and 75th percentile values of total phosphorus are 0.041 mg/l and 0.118 mg/l, respectively, for the Highway 7 station located downstream of the Georgetown STP. Although trend analysis (Seasonal Kendall Test) indicates a decrease in total phosphorus at this station (CVC et al., 2000), the 75th percentile value is significantly above the PWQO. Therefore this reach of Silver Creek would most likely fall into the Policy 2 designation, where no further phosphorus loadings are acceptable. It is also noted that the total phosphorus values at the Highway 7 station are almost double those of the Mountainview Road station, which is likely a combination of urban runoff from Georgetown and inputs from the Georgetown STP.
3. Mean Total Ammonium values for the Highway 7 and Mountainview Road station are 0.020 mg/l and 0.016 mg/l, respectively. The un-ionized fraction of ammonium, which is directly proportional to pH levels and water temperature, is the toxic portion of this parameter and is the basis of the PWQO. Based on the average pH values and maximum water temperatures observed in Silver Creek, average values for un-ionized ammonia remain well below the PWQO.
4. Mean nitrate values for the Mountainview Road site were 1.8 mg/l compared to 4.0 mg/l for the Highway 7 site. Furthermore, a Seasonal Kendall test indicated an increasing trend in nitrate at the Highway 7 station (CVC et al., 2000). There is no PWQO or CCME guideline for nitrate however the Ontario Drinking Water Objective (ODWO) is 10 mg/l and recent data (1999, 2000) shows the ODWO is being violated approximately 20% of the time. Some studies have shown detrimental effects on fish eggs and fry and amphibians at nitrate levels as low as 2.5 mg/l (Rouse et al., 1999), and therefore the ODWO may not be sufficient to protect aquatic biota.
5. Mean nitrite values for the Highway 7 and Mountainview Road station are 0.010 mg/l and 0.016 mg/l, respectively. These values are well below the CCME guideline of 0.06 mg/l for the protection of freshwater biota.

Major Mineral and Related Parameters

6. The high levels of calcium and magnesium in the water contribute to the relatively high alkalinity and hardness of the water in Silver Creek at both stations. Mean values for hardness at the Highway 7 and Mountainveiw Road station were 318 and 298 mg/l (as $CaCO_3$). Hard waters reduce the toxicity of many trace metals and in that respect, can be beneficial to aquatic biota.

Oxygen Related Parameters

7. Mean BOD values for the Highway 7 and Mountainview Road station are 3.5 mg/l and 0.9 mg/l, respectively. There are not guidelines for BOD however elevated BOD levels at the Silver Creek Highway 7 station may be caused by loadings from the Georgetown STP and potentially urban runoff.
8. Because of the diurnal fluctuations in dissolved oxygen (DO) from plant photosynthesis and respiration processes, it is difficult to use the MOE dataset for assessing the DO regime in Silver Creek. The lowest DO values tend to occur at

night, when sampling is rarely carried out. Therefore minimum DO values are used as an initial assessment. Minimum dissolved oxygen (DO) values for the Highway 7 and Mountainview Road station are 3.5 mg/l and 5.8 mg/l, respectively. The result at Highway 7 was lower than the PWQO for DO in coldwater streams (5 mg/l) but both these results occurred in the 1980s and may no longer be relevant. Minimum dissolved oxygen (DO) values in the 1990s for the Highway 7 and Mountainview Road station are 7.3 mg/l and 6.4 mg/l, respectively. Further investigation of the diurnal fluctuations are needed to determine whether the conditions observed in the 1980s continue to occur or whether the minimum values observed in the 1990s dataset are more representative of current conditions.

Physical Parameters and Chlorides

9. Mean values for conductivity, filtered residue (dissolved solids), and chlorides for higher at the Highway 7 site when compared to the Mountainview station, as shown below.

Parameter	Highway 7	Mountainview Road
Filtered Residue (mg/l)	586	500
Conductivity (uS/cm)	954	803
Chloride (mg/l)	126	86

Conductivity is a measurement of the electrical conductance of the water and indirectly measures the salt and other dissolved ions in the water. The elevated levels at Highway 7 is likely due to the increased loadings from the Georgetown STP and urban runoff, particularly runoff from road salting practices. The mean values for particulate residue were equivalent at the two sites at 5 mg/l.

10. The observed maximum water temperature for both stations occurred in June of 1994 at 23.2^{o}C. This is significantly above the 20^{o}C recommended to protect a native coldwater fishery and slightly above the 23^{o}C recommended to protect a self-sustaining coldwater fishery (Beak Consultants, 1992)

Metals

11. Mean and 75th percentile values of aluminum are 28.8 ug/l and 91.0 ug/l, respectively, for the Mountainview Road station located upstream of the Georgetown STP. The 75th percentile value is above the PWQO of 75 ug/l and therefore this reach of Silver Creek may fall into the Policy 2 category, where no further degradation is acceptable.
12. Mean and 75th percentile values of aluminum are 44.9 ug/l and 76.0 ug/l, respectively, for the Highway 7 station located downstream of the Georgetown STP. The 75th percentile value is slightly above the PWQO of 75 ug/l and therefore this reach of Silver Creek may also fall into the Policy 2 category, where no further degradation is acceptable.
13. Mean values of iron and manganese appear to be elevated at the Mountainview site compared to the Highway 7 site as shown below:

Parameter	Highway 7	Mountainview Road
Iron (ug/l)	71	141
Manganese (ug/l)	20	36

The 75th percentile value (at 456 ug/l) for iron at the Mountainview Road station significantly exceeds the PWQO of 300 ug/l. When reviewing the data, the most elevated levels of the iron, manganese and aluminum appear to occur between January 1996 and July 1997, which coincides with the period when the Mountainview bridge was built to cross Silver Creek. Since these three parameters are often associated with suspended solids, it is possible that sediment loadings from the construction may have caused the elevated levels but this requires further investigation.

14. Mean values of zinc, copper and nickel appear to be elevated at the Highway 7 site compared to the Mountainview Road site as shown below:

Parameter	Highway 7	Mountainview Road
Zinc (ug/l)	7.3	2.8
Copper (ug/l)	3.8	2.2
Nickel (ug/l)	1.5	0.9

None of these values were above their respective PWQO but the elevated levels may indicate loadings from urban runoff or the Georgetown STP. Further statistical analysis should reveal whether the sampling period was long enough and the values different enough to show a significant difference between the two sites for these three metals.

15. All other metals showed no noticeable difference between the two stations and the mean values were well below any of their PWQOs.

Microbiological Parameters

16. Geometric mean values are used for describing average values for microbiological data because of the exponential growth of bacteria. Geometric mean values of *E. coli*, Fecal Streptococcus, and Pseudomonas Aeruginosa appear to be slightly elevated at the Highway 7 site compared to the Mountainview Road site as shown below:

Parameter	Highway 7	Mountainview Road
E. coli 1994 to 2000 (counts/100 ml)	93	70
Fecal Streptococcus 1979 to 1989 (counts/100 ml)	111	98

Fecal Streptococcus 1990 to 2000 (counts/100 ml)	130	127
Pseudomonas Aeruginosa 1994 to 2000 (counts/100 ml)	4	2

E. coli is the only microbiological parameter with a PWQO, which is set for recreational uses of the watercourse. Although, the geometric mean values for *E. coli* at both Silver Creek stations do not exceed the PWQO of 100 counts/100ml ,seasonal variations should be further investigated since most recreational uses of water occur from May to September. Further statistical analysis should also reveal whether the microbiological results are significantly different between the Highway 7 and Mountainview Road station.

3.6.3 Identification of Data Gaps

Although long-term water quality data has been generated at the Mountainview Road and Highway 7 sites through the PWQMN, there is little water quality data for Silver Creek upstream of Georgetown or on any of the tributaries of Silver Creek. Basic nutrient, biological and physical parameters will be measured during the 2001 field season at numerous locations through the upper subwatershed on both the main watercourse and tributaries to gain some insight into general water quality conditions elsewhere in the subwatershed.

Many water quality parameters fluctuate on a seasonal basis which can be assessed on the longer-term data sets (i.e. those with +20 years). This assessment will be included in the Characterization Phase I report. Other parameters, such as water temperature, dissolved oxygen and pH can also fluctuate over a 24-hr period. There is not sufficient information in the PWQMN data sets to assess these fluctuations since most of the data would be biased towards the typical working hours of the day. To address this problem, remote water quality meters will measure the above mentioned parameters during the 2001 field season to determine whether the fluctuations are problematic.

High levels of iron, manganese and aluminum were observed at the Mountainview Road Station during the time period of Jan 1996 to July 1997. Through qualitative graphical analysis, other parameters, including suspended solids, BOD, chlorides, TKN, nitrite, phosphorus, and chromium appear to be elevated during this same time period. Further investigation will be required to determine whether the building of the bridge at Mountainview Road caused these parameters to be elevated or whether another explanation can be found.

Lastly, the Phase I (Characterization) report will also attempt to integrate the background and 2001 field season data with the macroinvertebrate and fisheries data generated in the background and Phase I reports. This is particularly important if declining water quality conditions are contributing to any observed decline in aquatic biota but may also serve a role in defining optimal water quality conditions for aquatic biota in Silver Creek. Additionally, waste disposal sites will be presented and discussed.

3.7 Macroinvertebrates

3.7.1 Existing Information and Data

A variety of benthic community surveys of Silver Creek have been conducted since the 1950s. First, the Ontario Department of Planning and Development (ODPD) collected the most extensive benthic community data from 7 stations within Subwatershed 11 in 1954 (ODPD, 1956). Reed (1968) repeated the ODPD survey in 1965. In 1993, Portt (pers. comm.) studied the effects of a chlorine spill on the aquatic fauna of Silver Creek, including stations upstream and downstream of the sewage treatment plant in Georgetown. In 1999 and 2000, Credit Valley Conservation sampled benthic macroinvertebrates at three locations (Figure 5.1.1):

- Silver Creek, downstream of the education centre;
- Silver Creek, downstream of Wildwood, and
- Silver Creek, upstream of Highway 7 at Norval.

Finally, on the basis of a relationship between forest cover and Griffiths' (1998) water quality index (WQI) from neighbouring subwatersheds, the Regional Municipality of Halton (RMH, 2001) predicted the quality of benthic macroinvertebrates throughout Subwatershed 11.

3.7.2 Preliminary Interpretation of Existing Data

Benthic communities in Subwatershed 11 indicate that water and habitat qualities have been and currently are of relatively good condition. On the basis of Hallam (1959), Martin (1984) classified 4 stream reaches as marginal cold water, and 3 as warm water (two at the lower end of Silver Creek, and a third downstream of Ballinafad). In Portt's study, the benthic fauna throughout Silver Creek was relatively complete and dominated by insects such as chironomids, mayflies, caddisflies and stoneflies. Portt did however, discover that the benthic fauna downstream of the sewage treatment plant lacked oligochaete worms, reflecting the impact of the chlorine pulse. The effect was relatively temporary, lasting only a few months.

The most recent benthic data for Silver Creek is that collected by Credit Valley Conservation as part of routine monitoring in 1998 and 1999. Those samples were collected using a travelling kick methodology, and were identified to lowest practical levels. The resulting data indicate that the benthic community is presently in good condition. At all three sites, Shannon's diversity (H') is above 3. H' values typically range between 0 and 4, but have no theoretical maximum. Values < 1 are associated with impaired communities, while values > 3 are associated with unimpaired communities

(Wilm and Dorris, 1968). The numbers of taxa per site have also been high (average of 30+ taxa) reflecting relatively good water and habitat quality. Each site surveyed by CVC has had a full assortment of animals including mayflies, stoneflies and caddisflies (i.e., those that are generally considered sensitive), other insects, plus Mollusca and Crustacea. Pollution tolerant forms (e.g., oligochaete worms, chironomids) are generally not abundant like they would be predicted if there were significant water quality issues.

On the basis of forest cover, the RMH (2001) has predicted large areas of Silver Creek to be unimpaired, although there are anticipated to be locally degraded communities in association with sections of the system that do not have canopy coverage.

None of the existing studies has reported invertebrate species that are considered threatened, endangered, or otherwise at risk

3.7.3 Identification of Data Gaps

All of the older (1954, 1965) data are outdated, and are therefore of limited use to the present study. The data reported by Portt and collected by Credit Valley Conservation do help determine the sensitivity of the system, but are limited in their physical coverage. The predictions made by the RMH (2001) should be used cautiously since they were (1) not based on data collected from subwatershed 11, and (2) rely only on forest cover to assess condition of the community. Other factors (e.g., point sources) should also be recognized as potentially contributing to the condition of a benthic community.

The recent data collected by Credit Valley Conservation can be used to characterize current conditions. However, the data are somewhat limited spatially. It is recommended that additional samples be collected within each of the major subcatchments of subwatershed 11 using methods similar to those used by CVC. Samples should be collected during the summer, when benthic communities reflect limiting conditions (Barton, 1996).

3.8 Aquatics

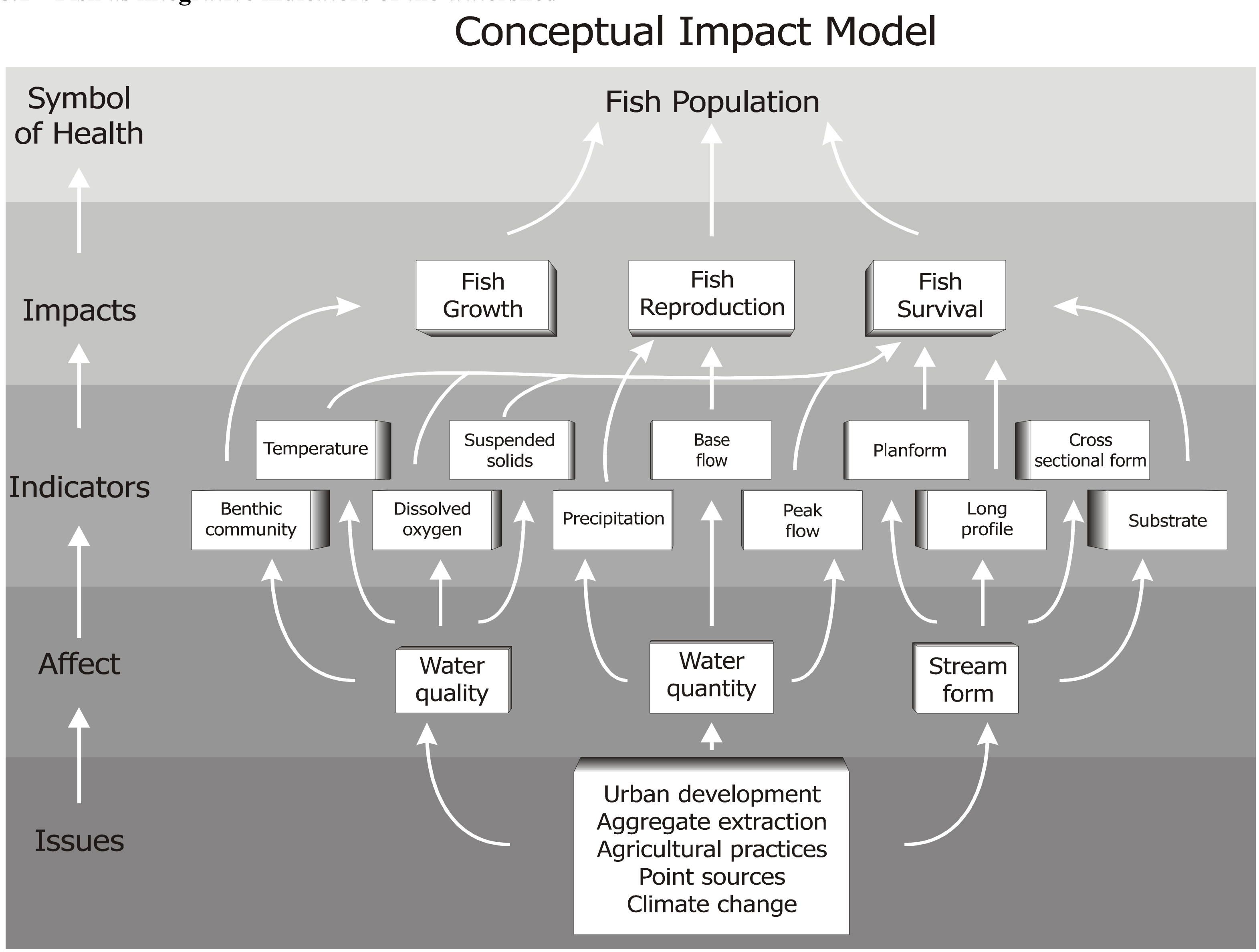
3.8.1 Introduction

The protection and enhancement of fish communities has been clearly identified in the Credit River Water Management Strategy, several Subwatershed Plans and the Credit River Fisheries Management Plan. Some of the advantages of using fish as indicators includes: widespread distribution in all waters (including intermittent streams and wetlands), ease of capture and identification, available literature on life histories and sensitivities, and the occupation of a variety of trophic levels. Fish flesh is also tested for various contaminant levels that bioaccumulate through the food chain. People can relate to statements on fish community conditions and their direct value for food and recreation.

It is also important to note that there are legislative requirements to protect and assess impacts to fish habitat under the Federal Fisheries Act.

Fish communities can serve as integrative indicators of the health of any watershed ecosystem as Figure 3.8.1 illustrates based on a model developed for the Credit River Integrated Water Monitoring Program. Generally fish species can be specialized and intolerant of culturally derived stresses, such as those affecting the hydrological cycle including urbanization, sewage treatment and water taking. Other species are more generalized in their habits and can tolerate many stresses. These species often displace other species as degradation occurs. Fish community measurements of species diversity, numbers or biomass density and the known sensitivities of species present is required in order to assess habitat conditions. These habitat conditions are created and maintained by natural processes related to water quality, flow conditions and the resulting physical or geomorphological features.

Figure 3.8.1 Fish as integrative indicators of the watershed



3.8.2 Fish Communities

Approximately 75 fish collection records on file since the 1980's were compiled and are summarized in Figure 3.8.2. Each station is identified with the year of collection as many sites have been sampled repeatedly. The distribution of samples have been focussed on a half dozen or so sites along the lower main branch from Georgetown to confluence in Norval. The upper tributary reaches including many first and second order streams have not been sampled. Limited sampling does, however, permit generalized extrapolations of fish communities and habitats.

Also shown is the designation of each sample site as cold, mixed or warmwater following the definitions provided by the Credit River Fisheries Management Plan (CRFMP). Coldwater sites are best indicated by the presence of brook trout or mottled sculpin. Brown and rainbow trout are slightly more temperature tolerant and indicate transitional or mixed waters. Warmwater streams can harbour a richer diversity of other species except in intermittent streams or other stressful conditions where very tolerant species such as blacknose dace, creek chub and brook stickleback often dominate. It should be noted that such classifications are applied at more regional scales for management purposes in the CRFMP.

In Figure 3.8.3 the Silver Creek subwatershed is classified as alternating communities of coldwater and cool/coldwater reaches reflecting changes in hydrogeological settings to be verified in this study. Coldwater indicator species are found throughout the Silver Creek subwatershed according to fish collection records. More tolerant warmwater species dominate some collection records and may indicate natural limitations (e.g. wetlands or intermittent) or anthropogenic sources of stress including agriculture and urbanization. Many of the headwater reaches remain unclassified but are recognized for their contributions to the next downstream fishery. As additional fish collections are made in 2001 the classification at particular sample sites can provide further insight to fish production, species composition and habitat conditions.

To further indicate some measure of biotic integrity based on the "sensitivity" and number of species present, a directly correlated numerical value was also presented in Figure 3.8.2. Each species is simply awarded a value from 1 to 3, with 3 being most ecologically valuable. The total score for all species at each sample site is presented with higher values indicative of either high species diversity or the presence of more ecologically valuable species. Table 3.8.1 presents a total of 23 species found in Silver Creek and their corresponding Index of Biotic Integrity (IBI) values as further documented in a methodology (Appendix B). It should be noted that this score may not be scientifically defensible given the variations in equipment, sampling effort and protocols but conveniently summarizes much information about the fish communities that have been qualitatively sampled.

A modified IBI methodology was adopted in order to analyze more quantitative data collected annually for over 30 stations across the Credit River watershed. Such biomass data (total weight of all and each species) in terms of fish density in grams per square

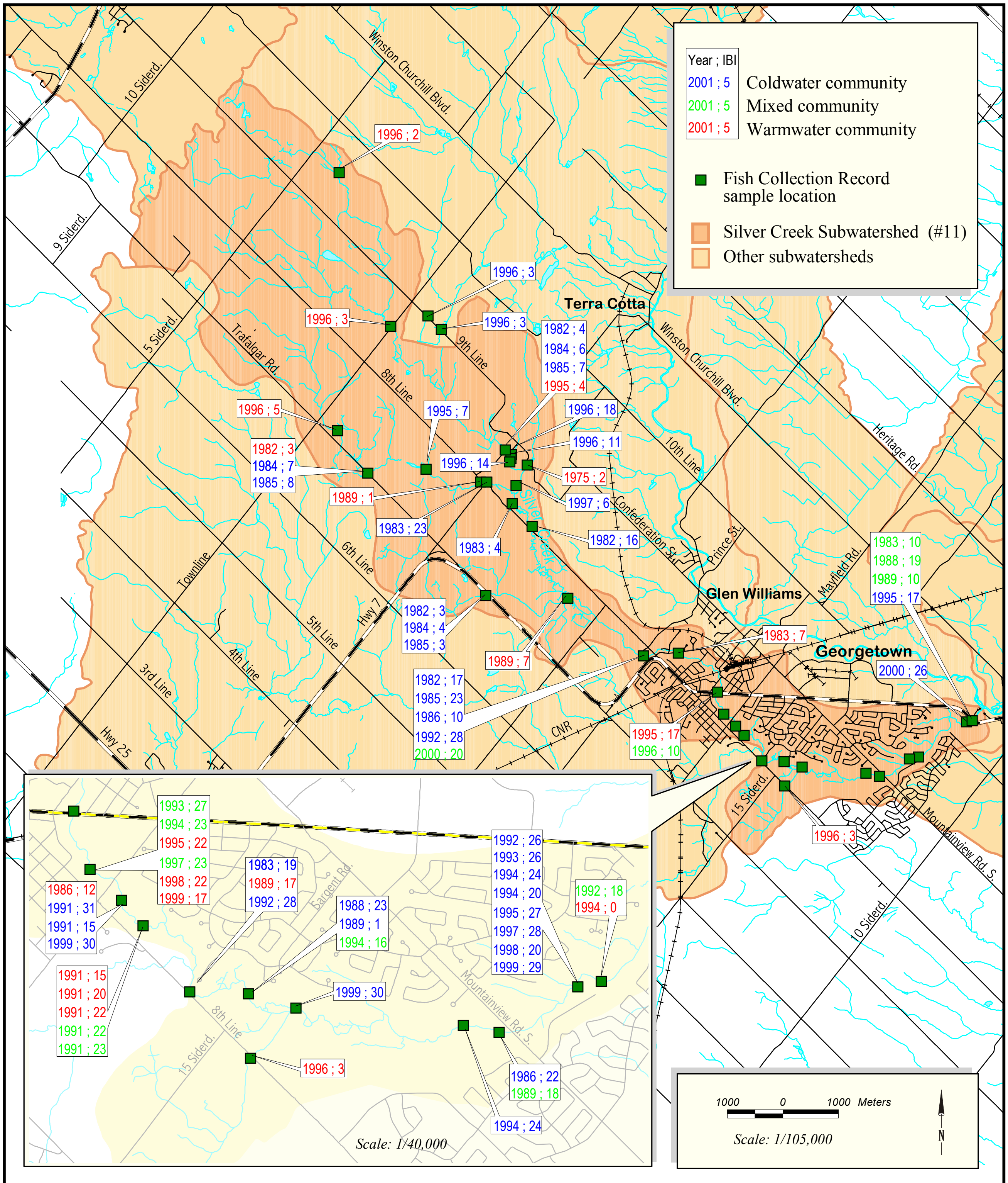


Figure 3.8.2: Fish Collection Records

SILVER CREEK SUBWATERSHED STUDY

Sources:
Credit Valley Conservation, 1975 - 2000; Ontario Ministry of Natural Resources, 1982

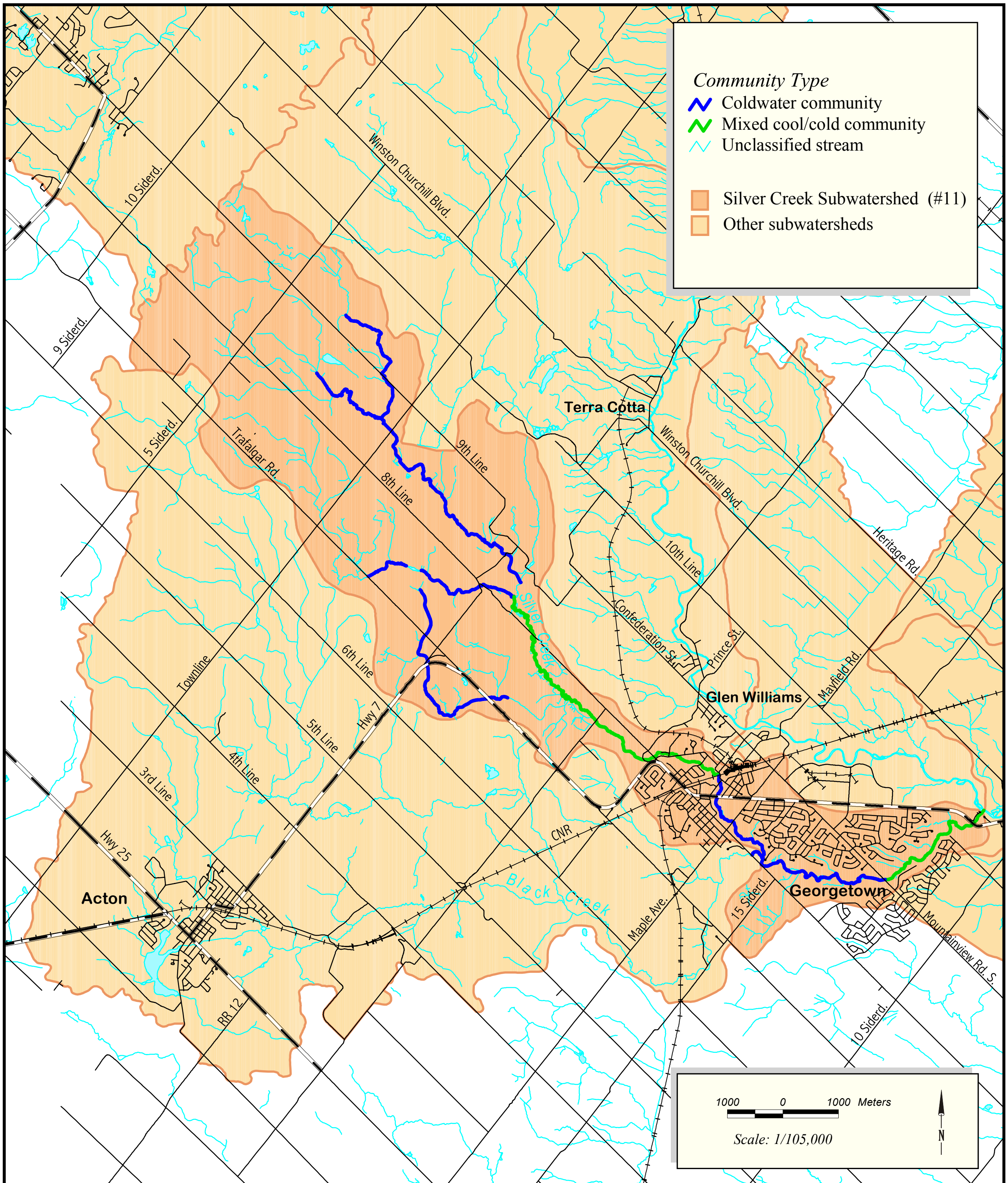


Figure 3.8.3: Fish Community Management Zones

Sources:
Credit Valley Conservation, 2000; Ontario Ministry of Natural Resources, 1982

meter are statistically comparable between stations and over time for long term monitoring purposes. In the fisheries component of the CVC Integrated Watershed Monitoring Program two Silver Creek stations are highlighted in Figure 3.8.4 in context with other stations watershed wide. It is suggested that Silver Creek has fair biological integrity at the upstream reaches of Georgetown and excellent conditions near its confluence with the Credit River at Norval. Explanations related to groundwater/ wetland contributions and those from Black Creek, urban areas and the sewage treatment plant, as well as, agricultural activities will be explored further in this study.

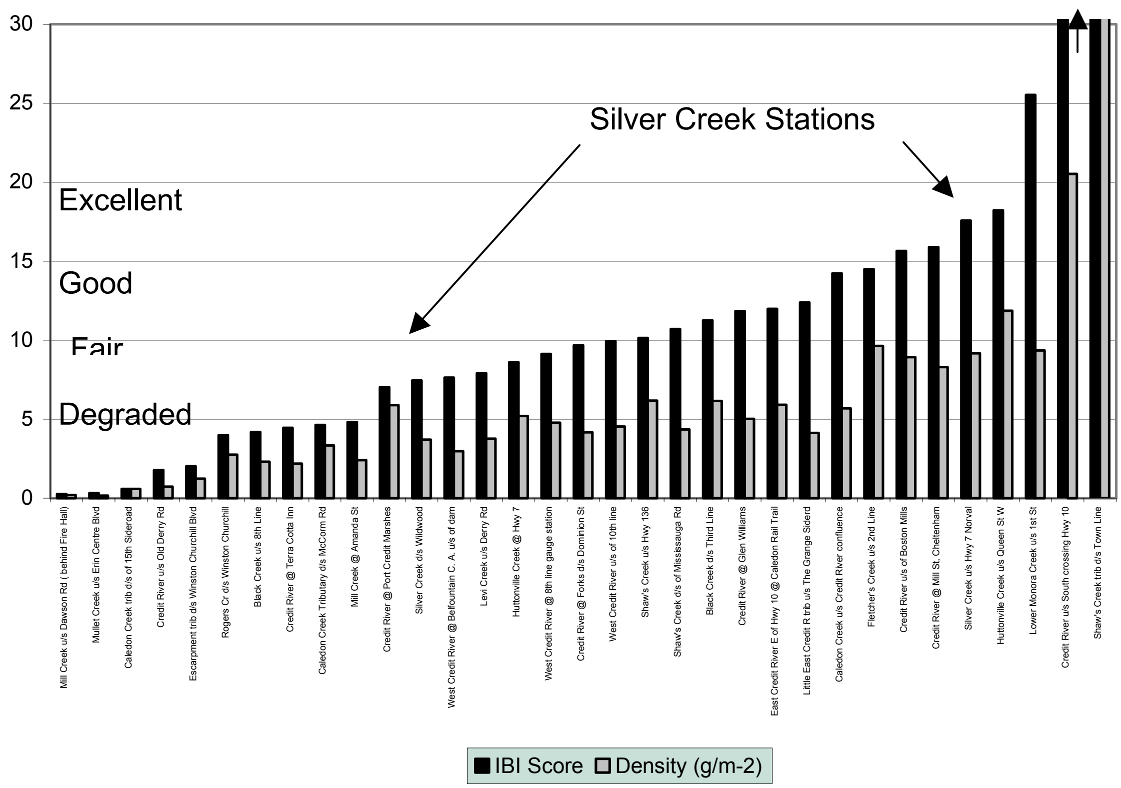


Figure 3.8.4 Credit River Watershed Fish Index of Biotic Integrity Station Results

Generally the most important "indicator" species found in Silver Creek is the native brook trout that is highly dependant on groundwater inputs to maintain water temperatures below its preferred range of 20°C°. In addition, groundwater upwelling areas are sought out to deposit eggs in excavated nests known as redds in the late fall. Groundwater upwellings are responsible for incubating and preventing these eggs from freezing all winter long until hatching occurs in the spring. The native Atlantic salmon and introduced wild brown trout also rely on groundwater for incubating their eggs but there is less documentation indicating upwelling areas are specifically sought out by these species. Their tolerance to slightly higher summer temperatures is also known along with rainbow trout. Rainbow trout both deposit and hatch eggs during the spring season and are somewhat less dependent on groundwater upwelling areas.

Table 3.8.1 Index of Biotic Integrity Metric Scores for Fishes of the Silver Creek Subwatershed.

Species	Index of Biotic Integrity Final Metrics Score	Rare/UncommonNative ++ Native/Endemic Or fully Naturalized + Stocked 0 Exotic/Pest/ Lentic escapees -	Omnivore/ Detrivore – Filter/Herbe-vore 0 Insectivore+ Carnivore ++	Simple Litho-Philic Spawner + Other silt tolerant breeders-	Intolerant Species + Tolerant Species -	Specilaist + (benthic, mid-water, coldwater, bogs and late maturing) Generalist Species –
Rainbow trout	3		++		+	+
Atlantic salmon	3		++		+	+
Brown trout	3	+	++		+	+
Brook trout	3	+	++		++	+
Central mudminnow	2	+	+	-	-	+
White sucker	1	+	-	+	-	+
Northern hog sucker	3	+	+	+	+	+
Northern redbelly dace	2	+			+	+
Brassy minnow	1	+		-		+
Common shiner	1	+	+			-
Bluntnose minnow	1	+	-	-	--	-
Fathead minnow	1	+	-	-	--	-
Blacknose dace	1	+	+	+	-	-
Longnose dace	3	+	+	+		+
Creek chub	2	+	+		-	-
Brown bullhead	1	+		-	--	-
Brook stickleback	1	+	+	-	-	+
Pumpkinseed sunfish	1	+	+	-		-
Rainbow darter	3	+	+	+	+	+
Iowa darter	3	+	+	-	+	+
Fantail darter	3	+	+	+		+
Johnny darter	3	+	+	-		+
Mottled sculpin	3	+	+	-	+	++
Stonecat	3	+	+	-	+	+

Rainbow trout found in Silver Creek are predominantly stocked from hatchery fish in cooperation between the Credit River Anglers Association and the Ministry of Natural

Resources (MNR). According to the CRFMP, the long-term goal is to achieve a population of self-sustaining wild fish once access is provided past the Norval (Reid) Dam which currently blocks their migration from Lake Ontario. Radio tagged rainbow adults will be released into Silver Creek in the spring of 2001 and may offer further interesting information. The reintroduction of the native Atlantic Salmon is still in an experimental stage. The survival and growth of these young salmon has been encouraging in Silver Creek. Brown trout have not been stocked in the Credit for a number of decades and it is believed the wild population in Silver Creek is small with some growth potential. It should be noted that brook trout populations above the Niagara Escarpment best represent the pristine native fish community of Silver Creek as the high gradient barriers prevent the upstream colonization and competition by exotic species. Some exotic or non-endemic species such as sunfish and bass, however, may still have access as escapees from stocked ponds built above the escarpment.

3.8.3 Spawning Habitats

Given the sensitivity and importance of groundwater to all trout species, the documentation of brook (and brown) trout spawning redds are useful in protecting such critical habitats (that are also used as summer thermal refugia). This exercise is also valuable in identifying major groundwater discharge areas for other purposes related to the hydrogeological component of this subwatershed study. Figure 3.8.5 illustrates the distribution of trout redds identified to date along Silver Creek. Effort has only been focussed in Hungry Hollow and in particular as it related to studies of potential impacts from Test Well #15 in search of municipal water supplies. A few spots have significantly higher concentrations that likely relate to certain "micro-habitat" features. Only one other area has been surveyed and that is the high gradient Escarpment gorge reach. More effort should be directed at initial surveys across the subwatershed, especially where other brook trout populations have been sampled or where hydrogeological information suggests significant discharge areas. Priority areas to be surveyed should consider potential impacts from urban development, other land use changes or water taking.

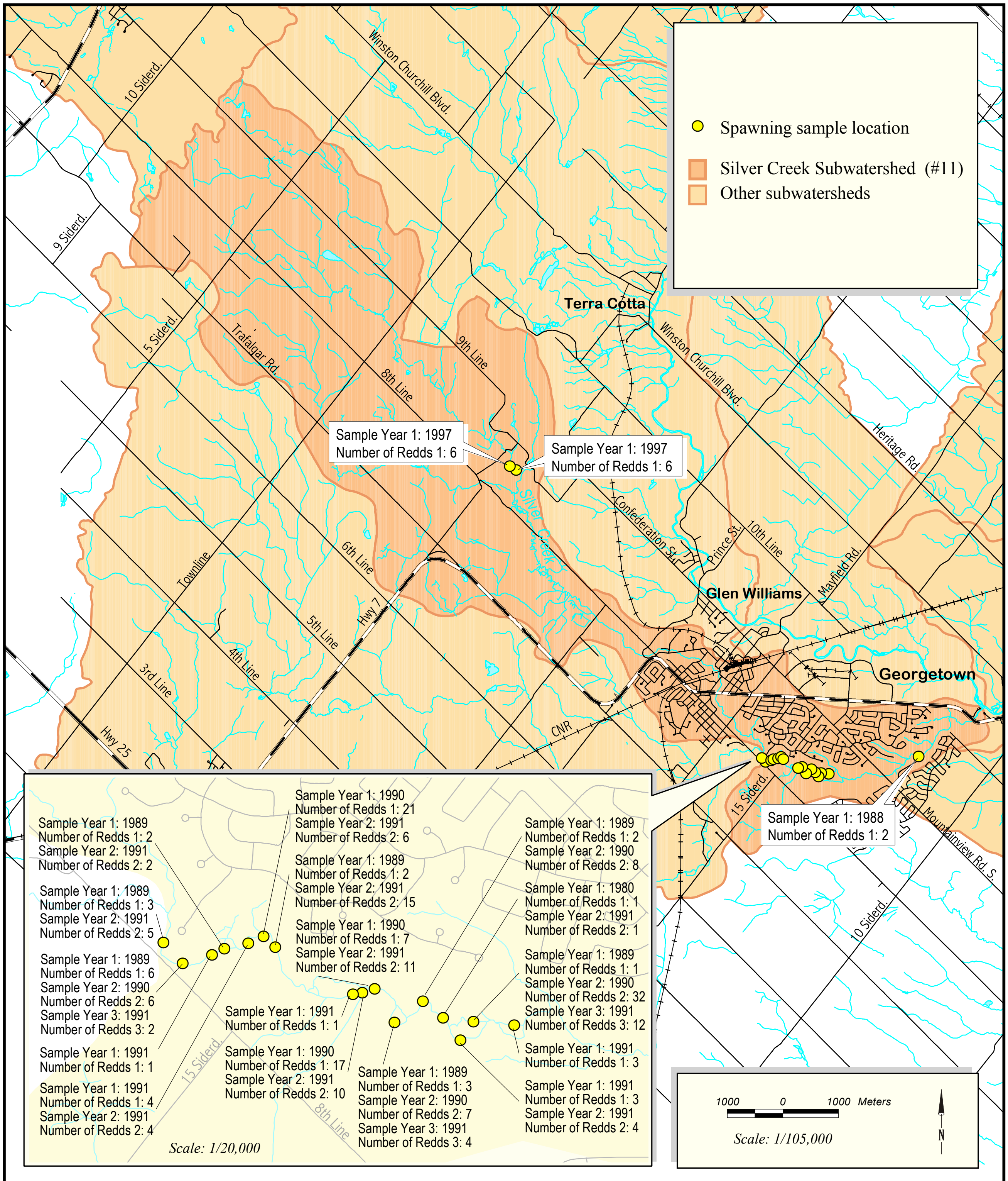


Figure 3.8.5: Trout Redd Surveys in the Silver Creek Subwatershed

Sources:
Credit Valley Conservation, 1980 - 1997; Ontario Ministry of Natural Resources, 1982

3.8.4 Fish Habitat

A formal fish habitat survey was carried out in 1983 using a standard descriptive MNR protocol. Data collected included bank stability, stream canopy, substrate size, pool/riffle/run/flat morphology, instream cover and riparian land use. Summaries by percentage values for consecutive reaches are available and will be considered and integrated with the geomorphological component of this study. Likewise, topographic analysis of gradient and sinuosity were also conducted by CVC and the Izaak Walton Fly Fishing Club in 1997. Riparian cover was also delineated on maps and will be considered and integrated in the terrestrial component of this study.

Preliminary assessments are also based on familiarity with the area that can be summarized into similar reaches as follows:

"Hungry Hollow" from the Credit River confluence upstream to Cedarvale Park is a significant natural valley feature adjacent to urban areas of Georgetown. It falls over a moderate gradient with a typical pool-riffle sequence including well-sorted substrates and woody cover. The widest reaches of Silver Creek begin to warm and combined with the Sewage Treatment Plant may explain the absence of brook trout but the remaining community of species suggest excellent habitat conditions. The lack of significant groundwater discharge may contrast with that suggested by spawning surveys near the confluence with Black Creek. Beaver dams have been reported and managed in Hungry Hollow. Many first order stream in this vicinity have been altered by urbanization and are dominated by stormwater flows that likely sustain only tolerant fish species.

Urban areas of Georgetown encroach more on stream habitats upstream of Cedarvale Park causing many local impacts. These may continue upstream along some rural residential properties as one approaches the Niagara Escarpment. Local physiographic conditions including shales on lower gradients, decreased groundwater inputs and encourage the deposition of finer substrates. Riverine wetland habitats may sustain characteristic minnow species. Brook trout numbers are likely restricted again.

Along base of Niagara Escarpment exist some seepage wetlands and cedar swamps that sustain smaller coldwater streams with brook trout including one near Hwy.7 and Snows Creek. The main branch of Silver Creek is contained within a limestone gorge with local groundwater discharges supporting some spawning and refuge habitat for brook trout. Many natural areas are protected in this area.

The remaining subwatershed area consists of tributaries that seem quite variable in nature including small spring fed brooks and intermittent till plain swales. Land use can be a mix of residential, agricultural and natural areas including wetlands.

3.8.5 Summary

In general, the Silver Creek subwatershed supports a coldwater fish community. Only two critical spawning areas have been located for brook trout to date. There are also mixed reaches with more cool and warmwater species being dominant. These may be related to transitions in physiography and groundwater hydrology influenced by natural areas and wetlands. Impacts related to urbanization and agricultural areas may also be evident in fish communities such as the absence of brook trout in habitats quantitatively scored from fair to excellent in terms of an Index of Biotic Integrity applied across the Credit River watershed.

Further data assessments are required to better manage fish communities as integrative indicators and for recreational values. Issues to be considered for fisheries management purposes include: water taking and baseflow quantities, urbanization, stormwater and sewage treatment, agricultural and aggregate extraction activities and the loss of natural areas and functions, particularly in wetland and riparian areas.

3.8.6 Data Gaps

The following steps will be undertaken to fill in data gaps:

- Conduct fish samples along different stream reaches and smaller tributaries from those already sampled.
- Continue more quantitative fish biomass sampling at two sites and establish new long term monitoring sites.
- Conduct additional spawning surveys to identify critical habitats dependent on groundwater.
- Integrate on-going research and results with other study components.

3.9 Environmental Planning

The planning component will assist in addressing the requirements of provincial legislation and regional and local planning documents during the preparation of the subwatershed plan. This component will also develop policies for the Town of Halton Hills Official Plan in two categories. The first category includes strategic environmental policies which are relevant to all lands in the Town of Halton Hills within the Credit River Watershed. The second category includes specific environmental policies for lands within the Silver Creek subwatershed. This component will have input into the Phase 1 Characterization Report which is due in the Fall of 2001.

4.0 ADAPTIVE ENVIRONMENTAL APPROACH

4.1 Purpose of AEM

Adaptive Environmental Management (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). This concept is particularly suitable to subwatershed planning since it recognizes that ecosystems are by their nature complex and in a state of constant evolution. We therefore start by learning about the functional relationships between key environmental features, develop predictions on the response of these features as to management interventions, and recognize the uncertainty that underlies resource management issues.

AEM is a learning tool, and is just which it claims to be – adaptive. Although there are principles and guidelines that are common in the field of environmental management, they must be altered, or adapted to each specific scenario. The premise of AEM is that goals must be clearly defined, and a model developed, such as a subwatershed framework, in order for the system to be understood. AEM is a planned adaptive approach to learning and can be summarized in terms of its major principles, primary tools and generic process. Table 4.1.1 summarizes the generic approach to AEM.

Table 4.1.1 Generic Approach to AEM

PRINCIPLES	**TOOLS**	**PROCESS**
Continuous and Deliberate Learning	Modeling	Define Boundaries
Formal Experimentation	Teamwork	Identify Uncertainties
Expect Surprise	Experimental Design	Generate Hypothesis
Systems Approach		Design Experiments
Management = Research		Implement
		Monitor

(*Adapted from Ohlson 1996*)

In utilizing the AEM approach, it is important that clearly defined and measurable goals and objectives are identified. The selection of indicators of health that are simply, cheaply and easily measured is necessary if this approach is to be successful in these times of dwindling resources. It is important to note that the views of the public are incorporated into the process, and AEM is not only used to deal with technical issues.

4.2 Generalized Subwatershed Model

The general concept being put forward here is that subwatersheds receive various inputs, e.g. water and nutrients, through their various settings, e.g. geology, topography, modify these inputs to develop such outputs as environmental features and functions which in turn can be modified by human uses.

5.0 NEXT STEPS

As this report is being finalized, preparations are underway for the upcoming field season. A landowner contact process has been developed and is being implemented to gain permission to access private property for monitoring. Stations located in the Silver Creek subwatershed as part of the CVC Integrated Water Monitoring Program will also be monitored (Figure 5.1.1). As we obtain this information, assessments will begin by each discipline. Frequent meetings will be held with the experts to facilitate data and information exchange.

A Characterization Report will be generated as a result of this work in the Fall of 2001. This report will describe the environmental resources, identify functions and linkages between the resources and identify any gaps in knowledge and understanding. Immediatley following the conclusion of this report, subwatershed goals and objectives will be developed.

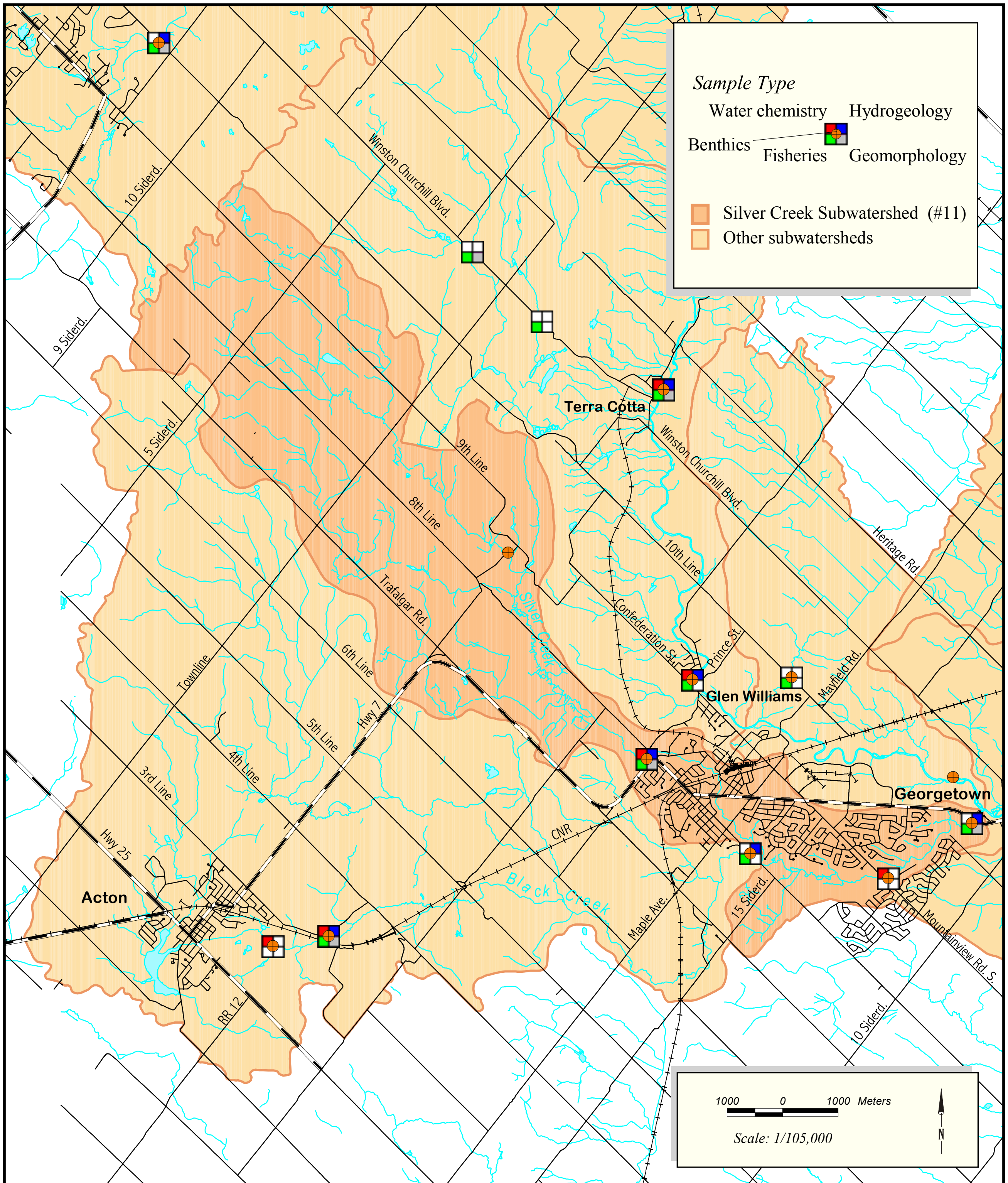


Figure 5.1.1: Integrated Watershed Monitoring Network Stations

Sources:
Credit Valley Conservation, 2001; Ontario Ministry of Natural Resources, 1982

REFERENCES

Atmospheric Environment Services (AES). 1982. *Canadian Climate Normals-Temperature and Precipitation 1951-1980: Ontario*. Publication of the Canadian Climate Program, Environment Canada. UDC: 551.582(713).

Atmospheric Environment Services (AES). 1993. *Canadian Climate Normals-Temperature and Precipitation 1961-1990: Ontario*. Publication of the Canadian Climate Program, Environment Canada. En56-61/4-1993.

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.

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., H.R. Whiteley, H.O. Schroeter, and D.R. Donald. 1991. Snow depth/area relationships for various landscape units in southwestern Ontario. *Proceedings of the 48th Annual Meeting of the Eastern Snow Conference*, pp. 51-65.

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.

Charlton, D.L. and R. Tufgar. 1991. Integrated subwatershed management approach for small southern Ontario rural/urban subwatersheds. *Canadian Water Resources Journal*, Vol. 16, No. 4, pp. 421-432.

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. n.d. Wetland Evaluation File for Ballinafad Ridge Wetland Complex. Credit Valley Conservation. Meadowvale, Ontario.

Credit Valley Conservation. n.d. Wetland Evaluation File for Silver Creek Wetland Complex. Credit Valley Conservation. Meadowvale, Ontario.

Credit Valley Conservation. n.d. Wetland Evaluation File for Hungry Hollow. Credit Valley Conservation. Meadowvale, Ontario

Environment Canada. 1992. *Historical Streamflow Summary Ontario to 1990.* Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa, Canada.

Ghate S. R. and Whiteley, H. R 1982. GAWSER – A Modified HYMO Model Incorporating Areally – Variable Infiltration. *American Society of Agricultural Engineers* (Vol. 25, No.1 pp.134-142 &149, 1982)

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.

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.

Haan, C.T., H.P. Johnson and D.L. Brakensiek. 1982. *Hydrologic Modeling of Small Watersheds*, Mono. No. 5, American Society of Agricultural Engineers.

Hallam, J.C. 1959. Habitat and associated fauna of four species of fish in Ontario streams. Journal of the Fisheries Research Board of Canada, 16:147-173.

Hare, F.K. and M.K. Thomas. 1979. *Climate Canada*, 2nd Ed. John Wiley & Sons.

M. Paul, 2001. Regional Municipality of Halton. Personal Communication on the telephone with Alison Humphries.

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.

Ontario Department of Planning and Development (ODPD). 1956. Credit Valley Conservation Report. ODPD, Toronto.

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 (OMNR). 1986. *Flood Plain Management in Ontario: Technical Guidelines.*, Queen's Park, Toronto, Ontario.

Ontario Ministry of Natural Resources and Credit Valley Conservation. Unpublished Draft 2001. Credit River Fisheries Management Plan.

Reed, D.J. 1968. A resurvey of the fishes of the Credit River. M.Sc. Thesis, Department of Zoology, University of Toronto.

Regional Municipality of Halton (RMH). 2001. Mapping the water quality of watercourses in the Region of Halton, an ecosystem approach to watershed planning. Draft report, February 2001.

Riley, J.L., J.V. Jalava and S. Varga. 1996. Ecological Survey of the Niagara Escarpment Biosphere Reserve. Volume I. Significant Natural Areas. Ontario Ministry of Natural Resources, Southcentral Region, Peterborough, Ontario. pp. 235-242.

Rowe, John Mark Benbow. June 1992. The Story of Georgetown Ontario. C & S Printing, Georgetown, Ontario.

Schroeter & Associates. 1996. GAWSER: Guelph All-Weather Sequential-Events Runoff Model, Version 6.5, Training Guide and Reference Manual. Submitted to the Ontario Ministry of Natural Resources and the Grand River Conservation Authority.

Schroeter & Associates, 1999c. Appendix D: Hydrology. Submitted to Totten Sims Hubicki (lead consultant), Waterloo, as part of the Credit Valley Subwatershed Study and Servicing Plan (Huttonville Creek and Watercourse 8a, 8b).

Schroeter & Associates. 2000. Moira River Integrated Flood Forecast System (MRIFFS). Final Technical Report submitted to Quinte Conservation, Ontario Ministry of Natural Resources, and the Water Survey of Canada.

Schroeter, H.O. 1988. An operational snow accumulation-ablation model for areal distribution of shallow emphemeral snowpacks. Ph.D. Thesis, School of Engineering, University of Guelph.

Schroeter, H.O. 1993. Water Management Strategy for Upper Hanlon Creek and It's Tributaries: Addendum to Hydrology Component. Memo report submitted to Mr. Chris Simms, P.Eng., Gamsby and Mannerow Ltd., Guelph, Ontario.

Schroeter, H.O. and D.K. Boyd. 1998. Eramosa River Watershed Hydrology Study. Final report submitted to the Grand River Conservation Authority, Cambridge, Ontario.

Schroeter, H.O., D.K. Boyd, L.L. Minshall, and H.R. Whiteley. 1992. Grand River Integrated Flood Forecast System (GRIFFS): Development and Real-time Application. *Second Canadian Conference on Computing in Civil Engineering*, Ottawa, Ontario, pp. 782-793.

Schroeter, H.O., D.K. Boyd, and H.R. Whiteley. 1991. Areal Snow Accumulation-Ablation Model (ASAAM): Experience of real-time use in southwestern Ontario. *Proceedings of the 48th Annual Meeting of the Eastern Snow Conference,* pp. 25-38..

Schroeter, H.O., D.K. Boyd, and H.R. Whiteley. 2000. Filling gaps in meteorological data sets used for long-term watershed modelling. *Proceedings of the Ontario Water Conference 2000*, April 26-27, 2000, Richmond Hill, Ontario.

Schroeter, H.O., D.K. Boyd, and H.R. Whiteley. 2000. GAWSER: A versatile tool for water management planning. *Proceedings of the Ontario Water Conference 2000*, April 26-27, 2000, Richmond Hill, Ontario.

Schroeter, H.O. and H.R. Whiteley. 1986. Distribution of snow cover as influenced by landscape units in southwestern Ontario. *Proceedings of the 43rd Annual Meeting of the Eastern Snow Conference,* pp. 32-44.

Schroeter, H.O. and H.R. Whiteley. 1992. Does detailed areal distribution of snow cover improve the utility of a hydrological model for watershed management*? Proceedings of the 49th Annual Meeting of the Eastern Snow Conference*, June 3-4, 1992, Oswego, New York, pp. 181-192.

Singer, S. et al. 1994. Groundwater resources of the Credit River Watershed. Ministry of the Environment and Energy, Environmental Monitoring and Reporting Branch, Toronto, Ontario.

Totten Sims Hubicki (lead consultant). 1998. Torrance Creek Subwatershed Management Strategy; Technical Appendix 5 - Hydrology/Hydraulics. Final report submitted to the Grand River Conservation Authority and the City of Guelph.

Triton Engineering Ltd. 1991. Credit River Water Management Strategy Phase I. Final report submitted to the Credit Valley Conservation Authority.

Williams, J.R. and R.W. Haan. 1972. Hymo, a problem-oriented computer language for building hydrologic models. *Water Resources Research*, Vol. 8, No. 1, pp. 79-86.

APPENDIX A

Table 1: Significant species in Ballinafad Ridge Wetland Complex.

Northern Pintail (*Anas acuta*) [BRWC]
Buckbean (*Menyanthes trifoliata*) [BRWC]
Bullfrog (*Rana catesbeiana*) [BRWC]
Canada Waterleaf (hydrophyllum canadense) [Brisbane Woods I]
Running Pine (Lycopodium clavatum) [Brisbane Woods I]
Snapping Turtle (Chelydra serpentina) [Brisbane Woods I & II]
Bog Laurel (Kalmia polifolia) [Brisbane Woods II]
Brook Trout (Salvelinus fontinalis) [Brisbane Swamp ESA]

Table 2: Significant species in Silver Creek Wetland Complex.

Bullfrog (*Rana catesbeiana*) [SCWC]
Redside Dace (*Clinostomus elongatus*) [SCWC, 1959]
Pink Pyrola (*Pyrola asarifolia*)
American Yew (*Taxus canadensis*)
Meadow Horsetail (*Equisetum pratense*)
Royal Fern (*Osmuda regalis*)
Cooper's Milk-Vetch (*Astragalus neglectus*)
Osprey (*Pandion haliaetus*)
Virginia Chain Fern (*Woodwardia virginica*)
Black Spruce (*Picea mariana*)
Moccasin Flower (*Cypripedium acaule*)
Black Willow (*Salix nigra*) [24T-92011/H]
Swamp Buttercup (*Rannunculus hispidus*) [24T-92011/H]
Flat-topped White Aster (*Aster umbellatus*) [24T-92011/H]
Sedge (*Carex tetanica*) [24T-92011/H]
Mountain-holly (*Nemopanthus mucronata*) [Ballinafad Pond]
Round-leaved Sundew (*Drosera rotundifolia*) [Snow's Creek Wetland]
Cardinal Flower (*Lobelia cardinalis*) [Acton Swamp]

Table 3: Significant species in Hungry Hollow Wetland.

Sundrops (*Oenothera pilosella*)
Brook Trout (*Salvelinus fontinalis*)
Great Blue Heron (*Ardea herodias*)
Green Heron (*Butorides virescens*)
Meadow Horsetail (*Equisetum pratense*)
Varigated Horsetail or Scouring Rush (*Equisetum varigatum*)
Nodding Ladies' Tresses (*Spiranthes cernua*)
Water Avens (*Geum rivale*)
Swamp Rose (*Rosa palustris*)
Great Ragweed (*Ambrosia trifida*)
Highbush Blueberry (*Vaccinium corymbosum*)
Great Bur Reed (*Sparganium eurycarpum*?) [OMNR-Wetland Eval.]

Table 4: Significant species in Silver Creek Valley ESA.

American Ginseng (*Panax quinquefolius*)
Chinquapin Oak (*Quercus muehlenbergii*)
Black Walnut (Juglans nigra) *no longer regionally rare
Clearweed (*Pilea fontana*)
Yellow Water Buttercup (*Rannunculus flabellaris*)
Maidenhair Spleenwort (*Asplenium tricomanes*)
Canada Milk-Vetch (*Astragalus canadendis*)
Water Pimpernel (*Samolus floribundus*)
Dyer's Bedstraw (*Gallium tinctorium*)
Pickerel Frog (*Rana palustris*) [HR,1995]
Black-crowned Night Heron (*Nycticarax nycticarax*) [Geomatics,1995]
Cooper's Hawk (*Accipiter cooperi*) [Geomatics,1995]
Red-shouldered Hawk (*Buteo lineatue*) [Geomatics,1995]
Eastern Bluebird (*Sialia sialis*) [Geomatics,1995]
Cerulean Warbler (*Dendroica cerulea*) [Geomatics,1995]
Louisiana Waterthrush (*Seiurus motacilla*) [Geomatics,1995]
Hooded Warbler (*Wilsonia citrina*) [Geomatics,1995]
Long Earred Owl (*Asio otus*) [Geomatics,1995]
Southern Flying Squirrel (*Glaucomys volans*) [Geomatics,1995]
Varigated Horsetail (*Equisetum varigatum*) [Geomatics,1995]
Red Cedar (*Juniperus virginiana*) [Geomatics,1995]
Bur-reed (*Sparganium eurycarpum*) [Geomatics,1995]
Pondweed (*Potamgeton natans*) [Geomatics,1995]
Bluegrass (*Poa alsodes*) [Geomatics,1995]
Sprengel's Sedge (*Carex sprengelii*) [Geomatics,1995]
Spikerush (*Eleocharis intermedia*) [Geomatics,1995]
Cooper's Milk-Vetch (Astragalus neglectus) [Geomatics,1995]
Hairy Honeysuckle (*Lonicera hirsuta*) [Geomatics,1995]
Stout Goldenrod (*Solidago squarrosa*) [Geomatics,1995]

Table 5: Significant species in Brisbane Woods II.

Bog Laurel (*Kalmia polifolia*)

Table 6: Significant species in Hungry Hollow ESA.

Black Walnut (Juglans nigra) *no longer regionally rare
Sedge (*Carex retrorsa*)
Canada Gooseberry (*Ribes hirtellum*)
Great Blue Heron (*Ardea herodias*)
Sundrops (*Oenothera pilosella*) [Geomatics,1995]
Meadow horsetail (*Equisetum pratense*) [Geomatics,1995]
Wood Horsetail (*Equisetum sylvaticum*) [Geomatics,1995]
Varigated Scouring-rush (*Equisetum variegatum*) [Geomatics,1995]
New York Fern (*Thelypteris noveboracensis*) [Geomatics,1995]
Red Cedar (*Juniperus virginiana*) [Geomatics,1995]
Giant Bur-reed (*Sparganium eurycarpum*) [Geomatics,1995]
Water Sedge (*Carex aquatilis*)
Nodding Ladies' Tresses (*Spiranthes cernua*) [Geomatics,1995]
Dutchman's Breeches (*Dicentra cucullaria*) [Geomatics,1995]
Gooseberry (*Ribes hirtellum*) [Geomatics,1995]
Water Avens (*Geum rivale*) [Geomatics,1995]
Swamp Rose (*Rosa palustris*) [Geomatics,1995]
Water-milfoil (*Myriophyllum exalbescens*) [Geomatics,1995]
Highbush Blueberry (Vaccinium corymbosum) [Geomatics,1995]
Great Ragweed (Ambrosia trifida) [Geomatics,1995]
Heath Aster (Aster ericoides) [Geomatics,1995]
Bog Goldenrod (Solidago uliginosa) [Geomatics,1995]

Table 7: Significant species in Snow's Creek ESA.

Dwarf Ginseng (*Panax trifolius*)
Ginseng (*Panax quinquefoius*) [Geomatics,1995]
Red-shouldered Hawk (*Buteo lineatus*) [Geomatics,1995]
Cerulean Warbler (*Dendroica cerulea*) [Geomatics,1995]
Ebony Spleenwort (*Asplenium playneuron*) [Geomatics,1995]
Black Spruce (*Picea mariana*) [Geomatics,1995]
Blunt-leaf Orchid (*Platanthera obtusata*) [Geomatics,1995]
Upland Willow (*Salix humilis*) [Geomatics,1995]
Rock Elm (*Ulmus thomasii*) [Geomatics,1995]
Great Water-dock (*Rumex orbiculatus*)
Water Avens (*Geum rivale*) [Geomatics,1995]
One-sided Pyrola (*Orthilia secunda*) [Geomatics,1995]
One-flowered Wintergreen (*Moneses uniflora*) [Geomatics,1995]
Bog Goldenrod (*Solidago uliginosa*) [Geomatics,1995]

Table 8: Significant species in Waterfall Woods ESA.

Black Walnut (Juglans nigra) *no longer regionally rare
Cooper's Milk-Vetch (*Astragalus neglectus*) [Geomatics,1995]

Table 9: Significant species in Georgetown Credit River Valley ESA.

Black Walnut (Juglans nigra) *no longer regionally rare
Jack Pine (*Pinus banksiana*)
Black-crowned Night Heron (Nyciticorax nyciticorax) [Geomatics,1995]
Long-eared Owl (Asio otus) [Geomatics,1995]
Cooper's Hawk (Accipiter cooperi) [Geomatics,1995]
Eastern Bluebird (Sialia sialis) [Geomatics,1995]
Southern Flying Squirrel (Glaucomys volans) [Geomatics,1995]
Giant Ragweed (Ambrosia trifida)

Table 3.10: Significant species in Ballinafad Pond ESA.

Pitcher Plant (*Sarracenia purpurea*)
Virginia Chain Fern (*Woodwardia virginica*)
Tawny Cotton Grass (*Eriophorum virginicum*)
Stemless Lady-slipper (*Cypripeddium acaule*)
Black Chokecherry (*Aronia prunifolia*)
Highbush Blueberry (*Vaccinium corymbosum*)
Sedge (*Carex trisperma*) [Geomatics,1995]
Mountain-holly (*Nemopanthus mucronata*) [Geomatics,1995]
Water Willow (*Decodn verticullatus*) [Geomatics,1995]
Leatherleaf (*Chamaedaphne calyculata*) [Geomatics,1995]
Large Cranberry (*Vaccinium macrocarpo*) [Geomatics,1995]
Small Cranberry (*Vaccinium oxycoccos*) [Geomatics,1995]
Black Spruce (Picea mariana) [Geomatics,1995]

Table 3.11: Significant Vascular Plants of Silver Creek ANSI (Riley, J.L. et. al,1996)

Rarity Status	*Scientific Name*	**Common Name**
One nationally and provincially threatened species	*Panax quinquefolius*	Ginseng
One regionally rare species	*Pilea Fontana*	Spring Clearweed
Three regionally and locally rare species	*Ranunculus flabellaris* *Astragalus Canadensis* *Samolus floribundus*	Yellow Water Buttercup Canada Milk-vetch Water Pimpernel
Nineteen locally rare species	*Potamogeton natans* *Potamogeton gramineus* *Poa alsodes* *Carex sprengelii* *Arabis glabra* *Crataegus succulenta (typ.)* *Galium tinctorum* *Lonicera hirsute* *Dryopteris X benedictii* *Acer X freemanii*	Floating Pondweed Variable-leaved Pondweed Woodland Poa Sprengel's Sedge Tower-mustard Succulent Hawthorn Dryer's Bedstraw Hairy Honeysuckle hybrid fern hybrid maple

	Juncus brachycephalus *Wolffia borealis* *Ceratopphyllum demersum* *Salix serissima* *Ulmus thomasii* *Geum rivale* *Rosa acicularis* *Osmorhiza longistylis* *Solidago uliginosa*	Short-headed Rush Dotted Water-meal Common Coontail Autumn Willow Rock Elm Water Avens Prickly Wild Rose Long-styled Sweet-cicely Bog Goldenrod

Table 3.12: Significant Fauna of Silver Creek ANSI (Riley, J.L. et. al,1996)

Nationally Vulnerable, Provincially Vulnerable, Regionally Rare	Louisiana Waterthrush
Nationally Vulnerable, Provincially Vulnerable, Regionally Rare, Locally Rare	Cerulean Warbler
Nationally Vulnerable, Provincially Vulnerable	Red-shouldered Hawk
Provincially Rare	Orchard Oriole
Locally Rare	Hermit Thrush Jefferson Salamander complex

Table 3.13: Significant Vegetation Communities of Silver Creek ANSI (Riley, J.L. et. al,1996)

(NS) Rare or restricted in the Halton Section and Study Area, (N) Rare or restricted in the Halton Section (S) Rare or restricted in Study Area,

Spotted Jewelweed – Rough Sedge – Red-based Spike-rush Seepage Slope Meadow Marsh (NS)
Dry – Mesic White Pine – Hemlock – White Cedar Coniferous Forest (NS)
White Cedar – Hemlock Coniferous Successional Forest (S)
Wet – Mesic Hemlock – White Ash – Sugar Maple Mixed Talus (NS)
Wet – Mesic White Cedar – Hemlock – Sugar Maple Mixed Bedrock Terrace Forest (N)
White Cedar Conifer Bedrock Successional Forest (S)
Spotted Jewelweed – Spotted Joe-pyeweed – Coltsfoot Rocky Streambed (S)
White Cedar – White Birch Mixed Treed Seepage Slope (S)
White Cedar – White Birch Niagara Escarpment Mixed Forest Rim Forest (S)
Water Cress Streambed (S)

APPENDIX B

A METHODOLOGY FOR ASSESSING THE BIOLOGICAL INTEGRITY OF FISH COMMUNITIES OF THE CREDIT RIVER WATERSHED

Robert J. Morris, M.Sc. Credit Valley Conservation

Introduction

The Index of Biotic Integrity (IBI) is the best known approach for compiling fish community data and interpreting it as an index of stream health. The IBI includes a range of geographically derived multimetric indices based on biological measures that can diagnose chemical, physical and biological impacts including cumulative effects at a watershed scale. It is used as a tool for making comparisons and for predictive or monitoring purposes in the "Adaptive Management" of water resources promoted by Credit Valley Conservation. Most research of the IBI is based on Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities, a compilation of over 25 papers edited by Simon, Thomas P. (1999).

"The Index of Biotic Integrity incorporates fish assemblage attributes (called metrics) that reflect predominant anthropogenic effects on streams (Karr et al., 1986). Each IBI metric describes a particular taxonomic, trophic, reproductive, or tolerance feature of the assemblage (e.g. number of darter species, proportion of individuals as top carnivores, proportion of lithophilous spawners, proportion as members of tolerant species). An IBI score represents comparisons between metric values at a sample site and those expected under conditions least affected by anthropogenic disturbance. These expectations serve as a predetermined criteria that are used as standards of comparison for scoring individual IBI metrics; hereafter referred to as "metric criteria." If an observed metric value closely matches its criterion value, then the metric is assigned an arbitrary numeric score. If observed value differs moderately from its criterion, then the metric is assigned a lower score. If the observed value differs greatly from its criterion (a condition reflecting high anthropogenic disturbance), then the metric is assigned the lowest score (typically 1). The IBI score for a site is simply the sum of these metric scores; a high score represents fish-assemblage attributes similar to those of a least disturbed assemblage, i.e., high biotic integrity." (Smogar and Angermeier 1999)

Metrics usually selected to measure fish community attributes include:

- Number of species and/or native species
- Number of trout and/or age classes
- Number of darter and sculpin species
- Number of sucker, sunfish species
- Number of minnow species
- Number of intolerant and/or tolerant species
- Number of sensitive species
- Number of benthic specialists and/or water column species
- Percent or number of simple lithophils
- Percent omnivores, insectivores, carnivores
- Percent large individuals by size
- Percent specialist and/or generalists species
- Percent diseased fish
- Total number of fish

Species relative abundance data that is commonly used in IBI makes it a "rapid bioassessment" tool. Biomass (weight) rather than numbers of fish (that range in size) is generally accepted as better measuring biological productivity and has been utilized in at least one referenced paper (Gammon 1976). In utilizing more quantitative biomass measurements for each species, a more accurate and statistically valid method of bioassessment is expected.

It is suggested that IBIs be regionally developed and tested for relatively homogeneous regions. However, in the Credit watershed, with three distinctly different physiographic regions including cold, cool and warmwater fish assemblages, would be better assessed with a more flexible approach (i.e. one index watershed wide).

Concerns with the traditional IBI is that its does not account for patterns of increasing species diversity with stream size, and actually employs number of species as a dominant metric. Healthy and pristine coldwater streams typically have only a few species. Species diversity will simply be assessed as number of species and need not be important in the proposed biomass index. What is considered important is the number or biomass of the most ecologically important species. It is anticipated that these "indicator" species will also increase with the total number of species downstream. Biomass is also expected to be dominated by "indicator" trout species in coldwater streams. The proposed method will also underestimate the biomass of tolerant/generalized species that typically increase overall species diversity and fish biomass in cold headwater streams.

It is, therefore, generally assumed higher fish productivity is a positive attribute (as reflected in DFO policy) and will decrease with habitat degradation. Since biomass productivity may be expected to increase in a downstream direction and with warmer water habitats it will have to be further tested and accounted for, during interpretation of results. This pattern, however, may be offset by the proportional loss of shoreline and riparian influences along widening river reaches downstream. Such cover has also been demonstrated to correlate with fish productivity. These habitats can be replaced with more productive wetland habitats and log debris deposits provided low gradient areas increase downstream. This does not seem to occur enough in the lower Credit that maintains a relatively moderate gradient and defined valley.

Habitat degradation of the lower river may also explain why preliminary analysis indicates no increase in biomass with stream size, yet the natural increase in species diversity is very apparent. The additional species are likely "minnows" that may have less effect on total biomass.

It can be noted that the application of this index is for monitoring changes over time such that spatial patterns in diversity and productivity with stream size may not be all that great of a concern. Where possible, however, it is useful to be able to hypothesize, statistically test and transfer predictions and cause and effect relationships from spatial to temporal patterns.

All in all it must be emphasized that the objective was to develop a simple, defensible index to combine the most basic ecological attributes of biomass productivity and the diversity of "indicator" species to assess the overall health of a site in space or time. The application of typical IBI metrics in scoring a fish community remains central to the index proposed for the Credit watershed. Selected metrics are described in terms of negative (-) and positive (+) values that are then tallied, following in Table 1.

Species Diversity

Number of species is reported as a separate index that should be interpreted with the expectation of greater diversities in stable warmwater habitats. However, native species are of particular value (+) for comparisons with "pristine" conditions. Rare or uncommon native species are of greatest concern (++) because losses may include genetic resources unique to watershed. "Preferred or managed" species that occupy a particular niche and are now self-sustaining such as brown trout might be considered as a positive (+), but populations (Pacific salmon) known still to be artificially hatched and stocked should be of no value. Even species known only to occasionally visit the lower Credit from their deep habitats in Lake Ontario may be discounted. Species native to Southern Ontario but not known to be endemic to parts of the Credit watershed originally may be considered as a negative (-) value including northern pike, sunfish and bass that escape from impoundments or manmade ponds. This would include stocked trout, particularly where brown and rainbow are found above the natural barrier of the Niagara escarpment. Exotic pest species such as sea lamprey and carp can negatively (-) impact ecosystems.

Trophic Level

What a fish eats best determines where it is in the "food chain" and how sensitive it could be to other biological changes. Top predators are especially valuable (++) as they require larger territories or food supplies and are most sensitive to other processes such as the "bioaccumulation" of toxins. Some smaller fish may not consume other fish but still aggressively feed on insects. These insectivores (+) are closely related to the health of their food supplies, bugs, which are also sampled as biological indicators. Omnivorous fish (-) that can feed on a variety of plant and animal matter and even decomposing, detritus are often able to flourish as food sources become limited for other species. Herbivores have also been associated with excess nutrient inputs. Fish anatomy including mouth position and teeth, length ratio of digestive tracts, feeding behaviour and analysis of stomach contents are used to classify species into feeding guilds. The unique filter feeding strategies of larval lampreys or other specialized species may be assigned more of a neutral value.

Simple Lithophilic Spawners

These species are known to be dependent on gravels to conceal and incubate eggs relatively free of sediment. Excess sediments literally cause oxygen suffocation and is associated with other water quality and habitat impacts. Most species depend solely on a clean stream environment (+) and never care for the nest or young as do sunfish and bass (-) that can fan sediment away. Species such as trout actually prepare more specific nests and bury the eggs. Siltation can still be a problem for these species that are given a neutral value because of this extra precaution.

Tolerance Ratings

Generally species are chosen as key indicator species when they disappear from "polluted" waters. Brook trout are considered as the best indicator species of the Credit (++) but other trout, sculpins and darters are more widespread (+). Smallmouth and stonecats are also good indicator species in warmer reaches along with some of the many minnow species (+). A number of species that are apparently limited in their distribution but appear to be tolerant of some pollution, such as pike, sunfish, rock bass are not rated. Even longnose dace survive in urban streams provided there are high velocity riffles. Other species such as carp and bulhead catfish (--) are known to even flourish where no other fish can. Naturally stressed environments of intermittent streams as well as highly altered streams are often dominated by blacknose dace, creek chub, brook stickleback and bluntnose minnows that are also considered tolerant (-).These species are usually tolerant of low flows and oxygen, turbidity and high temperature fluctuations. Tolerance ratings are meant to be more reflective of water quality rather than of physical habitats discussed next.

Habitat Specialists / Generalists

Many authors have described species according to their physiological abilities to specifically adapt to restricted niches or to survive in a variety of different conditions. Generalists or "opportunists" are nonselective in their habits (-) and range over more than a single trophic level. Creek chub and blacknose dace are often most cited in the literature as an adaptive generalist to degraded habitats or as a colonizing species into new or temporary habitats. In contrast some species are very unique in their anatomy and behaviour that they have evolved for the exploitation of specific habitats (+) such as cold groundwater areas for brook trout or high velocity rock riffles of the longnose dace. These species also tend to produce fewer offspring and sexually mature later (e.g. 3yrs for redside dace) than generalists species that may even spawn more than once a year (e.g. fathead minnow) Any changes to such specific requirements are usually reflected in the simplest form of presence/absence data. A few species were not classified as a generalist nor specialist.

Table 1. IBI Metric Scores for Fishes of the Credit Watershed.

Species	Index of Biotic Integrity Total Metrics Score	Rare/Uncommon Native ++ Native/Endemic or fully Naturalized + Stocked 0 Exotic/Pest/ Lentic escapees -	Omnivore/ Detrivore – Filter/Herbe-vore 0 Insectivore+ Carnivore ++	Simple Litho- Philic Spawner+ Other silt tolerant breeders-	Intolerant Species + Tolerant Species -	Specilaist + (benthic, mid-water, coldwater, bogs and late maturing) Generalist Species –
American brook lamprey	+3	+			+	+
Sea lamprey	+1	-			+	+
Coho salmon	+3	-	++		+	+
Chinook salmon	+3	-	++		+	+
Rainbow trout	+4		++		+	+
Atlantic salmon	+4		++		+	+
Brown trout	+5	+	++		+	+
Brook trout	+6	+	++		++	+
Northern pike	+2		++	-		+
Central mudminnow	+1	+	+	-	-	+
White sucker	+1	+	-	+	-	+
Northern hog sucker	+5	+	+	+	+	+
Goldfish	-6	-	-	-	--	-
Northern redbelly dace	+3	+			+	+
Finescale dace	+3	+			+	+
Redside dace	+7	++	+	+	++	+
Carp	-6	-	-	-	--	-
Brassy minnow	+1	+		-		+
River chub	+6	++	+	+	+	+
Golden shiner	-1	+		-	-	
Emerald shiner	0	+		-		
Common shiner	+1	+	+			-
Spottail shiner	+4	+	+		+	+
Rosyface shiner	+5	+	+	+	+	+
Spotfin shiner	0	+	-	-		+
Bluntnose minnow	-4	+	-	-	--	-
Fathead minnow	-4	+	-	-	--	-
Blacknose dace	+1	+	+	+	-	-
Longnose dace	+4	+	+	+		+
Creek chub	0	+	+		-	-

Pearl dace	+2	+	+	-		+
Brown bullhead	-3	+		-	--	-
Stonecat	+3	+	+	-	+	+
Brook stickleback	+1	+	+	-	-	+
Rock bass	+3	+	++	-		+
Pumpkinseed sunfish	0	+	+	-		-
Smallmouth bass	+4	+	++	-	+	+
Largemouth bass	+1	-	++	-		+
Black crappie	+1	-	++	-		+
Yellow perch	+1	-	++	-		+
Rainbow darter	+5	+	+	+	+	+
Iowa darter	+3	+	+	-	+	+
Fantail darter	+4	+	+	+		+
Johnny darter	+3	+	+	-		+
Mottled sculpin	+4	+	+	-	+	++
Slimy sculpin	+4	+	+	-	+	++
Hornyhead chub	+2	++	-	+		
Troutperch	+5	+	+	+	+	+
Alewife	-1	-	+	+		

IBI Species Biomass Factors

Total scores ranging from –6 to +7 (in one case) are then reduced to three categories and assigned an "IBI Species Biomass Factor as follows:

-6 to +1= 1 X factor (i.e. species providing simple biomass conversion function)
+2 to +3= 2 X factor (i.e. species with several or dominant ecological roles)
+4 to +7= 3 X factor (i.e. most valuable "indicator species" re: biological integrity)

These categories were chosen such that all "negatively" scoring species are equally treated as providing the most basic ecological function of converting energy and nutrients to biomass (as measured). Including scores <1 in this category and assigning scores >+3, a 3X biomass factor resulted in a reasonably even distribution of species in the Credit to each of the three categories summarized in Table 2. The distribution of larger vs. smaller and common vs. uncommon species also appears equitable. It can also be noted that definitive coldwater species (trout and sculpin) score high which may reflect the larger number of functions they may perform to counteract the natural tendency of coldwater habitats to be less diverse and productive.

The reduction of scores to three factor classes is not as sensitive to some disagreement among biologists when assigning a whole range of negative and positive ecological values to each species.

Table 2. Summary of Fish Species by IBI Biomass Factors

IBI Factor: 3X	2X	1X
"Larger fish"		
Rainbow trout	American brook lamprey	*Sea lamprey*
Brown trout	*Coho salmon*	White sucker
Atlantic salmon	*Chinook salmon*	Pumpkinseed sunfish
Brook trout	*Northern pike*	Largemouth bass
Northern hog sucker	Creek chub	*Black crappie*
Smallmouth bass	Stonecat	*Yellow perch*
	Rock bass	Brown bullhead
		Carp
		Alewife
"Minnows"		
Redside dace	Northern redbelly dace	Common shiner
River chub	*Finescale dace*	Bluntnose minnow
Spottail shiner	Central mudminnow	*Spotfin shiner*
Rosyface shiner	*Pearl dace*	Fathead minnow
Longnose dace	*Hornyhead Chub*	Blacknose dace
Rainbow darter		*Emerald shiner*
Iowa darter		*Golden shiner*
Fantail darter		*Brassy minnow*
Johnny darter		Brook stickleback
Mottled sculpin		Goldfish
Troutperch		
Slimy sculpin		

*common and *uncommon* species for the Credit noted

1 X factor (i.e. species providing simple biomass conversion function)
2 X factor (i.e. species with several or dominant ecological roles)
3 X factor (i.e. most valuable "indicator species" re: biological integrity)

Calculation of a Station Health Index

At each sampling station on the Credit the biomass/square meter of each species is now multiplied by its corresponding IBI Species Biomass Factor. All species are then totaled to provide a Fish Health Index of Biotic Integrity for comparisons over time at each station and across the watershed. This single index combines the measures of fish biomass with weighted values related to the diversity of species found and their ecological values. One can still refer to and compare the total number of species and total fish biomass/square meter sampled at each station. Other patterns requiring further hypotheses testing and analysis can be visualized with bar graphs depicting each species biomass with each sampling season.

Descriptive Classifications

After an assessment of the range of values for the Fish Health Index of Biotic Integrity was generated across the watershed a further descriptive classification was assigned:

- >15 Excellent “Health”
- 10-15 Good
- 5-10 Fair
- 3-5 Degraded
- 0-2 Severely degraded

Recommended IBI Statistical Tests

- IBI vs. number of species and total biomass.
- IBI vs. invertebrate indices
- IBI vs. selected water quality parameters (DO, phosphorous, toxins, chlorides, bacteria)
- IBI coldwater vs. warmwater sites (or fish management zones as per Fisheries Management Plan)
- IBI vs. watershed area, width, depth and/or volume
- IBI vs. baseflow and flood peaks / unit watershed area
- IBI vs. erosion or similar geomorphic stability index
- IBI vs. substrate size and embeddedness or % fines
- IBI vs. % watershed urban and/or other ELC land use designations
- IBI vs. instream and/or riparian cover
- IBI vs. “impacted” and “natural” stations considering impacts other than urban area (e.g. # sewage, stormwater or other point sources, water withdrawals, mining, intensive agricultural, dams, length of headwater loss or channelization)
- Individual metrics and/or species could also be tested for different physiographic regions and stream size and how much of a correlation with the IBI it alone can account for.

Preliminary Analysis of Results

Figure 1. Ranking of Stations by IBI score and with biomass density and number of species.

Table 3. Approximation of Stations as warm vs. coldwater, large vs. small size and habitat conditions as natural vs. impacted.

- Species diversity is highest in all main river stations (regardless of habitat conditions) but the IBI is not related to stream size. Likewise there does not seem to be a correlation between biomass density and stream size.
- Species diversity does not appear to be greater in warm vs. coldwater streams.
- Stations first perceived to have the most natural habitat conditions are not necessarily reflected by their IBI. Stations perceived to have "impacted" habitat conditions appear to have a lower IBI.
- Intermittent streams tend to have a lower IBI.
- There is a slight tendency for cold water stations to have a higher IBI and warmwater stations to be less healthy.
- There is a correlation between total biomass density and the derived IBI weighted species biomass densities, as expected but with sufficient variation to suggest the value of using weighted "indicator" species (rather than # of species).
- No correlation is apparent between species diversity and the IBI.
- Species diversity may have a weak correlation with increasing biomass (using more "natural" stations).
- "Impacted" sites correlate better with the IBI than species diversity.

Spatial correlations found to be significant will be further investigated for cause and effect relationships over time at various stations. The IBI based Index proposed for the Credit will consider these tests to better interpret results or to revise the index along with peer reviews and increased knowledge of individual species.

REFERENCES

Gammon, J.R. 1976. The Fish Populations of the Middle 340km of the Wabash River. Purdue Univ. Water Res. Research Cen. Tech. Rep. 86.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing Biological Integrity in Running Waters: A Method and Its Rationale. Illinois Natural History Survey Special Publication 5, Champaign.

Simon, Thomas P. editor, 1999. Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities, CRC Press, Boca Raton, Florida.

Smogar Roy A. and Paul L. Angermeier. 1999. Effects of Drainage Basin and Anthropogenic Disturbance on Relations Between Stream Size and IBI Metrics in Virginia in Simon 1999.

Table 3. Approximation of Stations as warm vs. coldwater, large vs. small size and habitat conditions as natural vs. impacted.

Station Name	large	small	cold	warm	natural	impacted
Mill Creek u/s Dawson Rd		X		X		*
Mullet Creek u/s Erin Centre Blvd				X		X
Caledon Creek trib d/s 15^{th} SR		X		X		
Credit River u/s Old Derry Rd	X			X		
Escarpment trib d/s Winston Churchill Blvd		X			X	*
Rogers Creek d/s Winston Churchill		X				*
Black Creek u/s 8^{th} L			X		X	
Credit River @ Terra Cotta Inn	X				X	
Caledon Creek trib d/s McCorm Rd		X		X		X*
MillCreek @ Amanda St		X				X*
Credit River @ Port Credit marshes	X			X		X
Silver Creek d/s Wildwood					X	
West Credit River @ Belfountain			X		X	
Levi Creek u/s Derry Rd				X		X
Huttonville Creek d/s Queen St		X				
West Credit River @ 8^{th} L						
Credit River d/s Forks	X		X		X	
West Credit u/s 10^{th} L			X			
Shaws Creek u/s Hwy 136				**		
Shaws Creek d/s Mississauga Rd					X	
Black Creek d/s 3^{rd} L			X			
Credit River @ Glen Williams	X				X	
East Credit River trib u/s Grange SR		X	X		X	
Caledon Creek u/s Credit River confluence		X	X			
Fletchers Creek u/s 2cd L				X		X
Credit River @ Ferndale	X				X	
Credit River @ Mill St Cheltenham	X				X	
Silver Creek u/s Hwy 7 Norval				**		
Huttonville creek u/s Queen St		X		X		*
Lower Monora Creek u/s 1^{st} L			X			
Credit River u/s south Hwy 10 crossing	X		X			
Shaws Creek trib d/s Town Line			X		X	

* denotes intermittency that may represent a natural constraint similar to other impacts

** denotes variations where conditions are neither cold nor warm but considered "mixed".

APPENDIX C

Subwatershed 11 Glossary

Abiotic – Not relating to living things.

Aquatic – growing or living in, or frequenting water.

Aquiclude – A saturated geologic unit that is incapable of transmitting significant quantities of water under ordinary conditions.

Aquifer – A saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.

Attenuation (Flow) – Flow that is lessened or weakened, or the severity reduced.

Bank Stability – The ability of a stream bank to resist change.

Base Flow –The water that flows into a stream through the subsurface.

Bedrock – The solid rock underlying unconsolidated surface material

Bedrock Geology – The study of the solid rock underlying unconsolidated surface material. Also refers to the description of bedrock types.

Benthic Invertebrates – Organisms without an internal skeletal structure that live on or in a body of water, e.g., water insects.

Biological Diversity - the variability among organisms and the ecological complexes of which they are a part .

Biomass – The amount of living matter, usually measured per unit area or volume of habitat.

Biotic – Relating to or caused by living beings.

Climate – The average weather conditions of a place or region throughout the seasons.

Conductivity – The quality or power of conducting or transmitting.

Contiguous – Having contact with, or touching along a boundary or point.

Discharge Area - An area where water leaves the saturated zone across the water table surface.

Drainage Density – Length of watercourse per unit drainage area.

Ecological – Relating to the totality or pattern relations between organisms and their environment.

Ecosystem - Systems of plants, animals and micro-organisms together with the non living components of their environment, related ecological process and humans.

Elevation – The height of a portion of the earth's surface in relation to its surroundings.

Entrain – To draw in and transport through water.

Episodic - Made up of separate loosely connected episodes.

Erosion – The wearing away of the land by the action of water, wind or glacial ice.

Flood Pulse – The peak flow during a flooding event.

Floodplain – A plain bordering a river, which has been formed from deposits of sediment carried down the river. When a river rises and overflows its banks, the water spreads over the floodplain.

Flow Regime – The pattern of how water levels change in a stream.

Flow Stability - Determined by measuring the ratio of surface discharge to groundwater discharge on an annual basis.

Fluvial - Relating to a stream or river.

Geology – The science of the composition, structure and history of the earth. It thus includes the study of the materials of which the earth is made, the forces which act upon these materials and the resulting structures.

Geomorphology - The scientific study of the origin of land, riverine and ocean features on the earth's surface.

Glaciation – The covering of an area or the action on that area, by an ice sheet or by glaciers.

Gradient – The rate of regular or graded ascent or descent.

Granular – Having a texture composed of small particles.

Groundwater – Water below the earth's surfaces that lies in the area of total saturation. Groundwater can exist in rock or granular material.

Groundwater Table – The meeting point between the groundwater and the unsaturated layer above it.

Habitat - The environment of an organism; the place where it is usually found.

Hydrogeology - The scientific study of groundwater.

Hydrology - The scientific study of surface water.

Imperfect Drainage – Occurs when water cannot easy flow over the land surface through a well formed drainage network

Infiltration – Water entering the pores of the earth's surface.

Intermittent Stream – A watercourse that does not flow permanently year round.

Invertebrates – Animals lacking a spinal column

Local Discharge – Discharge to a watercourse that originates nearby. The water moves through the upper layers of the groundwater system.

Lowflow - The flows that exist a stream channel in dry conditions.

Macroinvertebrates - Animals lacking a spinal column that are visible with the unaided eye.

Meandering - A curve in the course of a river which continually swings from side to side.

Meltwater Channel - The path of drainage, and leftover sedimentary deposits from ice or snow melt.

Moraine -The debris or rock fragments brought down with the movement of a glacier.

Morphology - see geomorphology

Non Renewable Resources - A resource that is not capable of being replaced by natural ecological cycles or sound management practices within the timeframe of a human life.

Nutrient –Something that nourishes and promotes growth. It is possible to have too many nutrients in an ecosystem, which can result in an unhealthy imbalance or overgrowth of certain species.

Organic Matter – Of, relating to , or derived from living organisms.

Permeability – The quality of having pores or openings that allow liquids to pass through.

Physiography - Study or description of landforms (see geomorphology)

Precipitation – The deposits of water in either liquid or solid form which reach the earth from the atmosphere. It includes rain, sleet, snow and hail.

Productivity – Rate of production, especially of food or solar energy by producer organisms.

Recharge Area - An area where water enters saturated zone at the water table surface.

Regional Discharge – Water that has traveled deep beneath the ground through the saturated zone and resurfaces at the water table.

Renewable Resources – A resources that is capable of being replaced through ecological processes or sound management practices.

Return Period – The frequency in which a flow event in a stream is likely to repeat itself.

Riffle:Pool System – A riverine system that alternates cycles of shallow broken water (riffle) and deeper still water (pool).

Riparian - Relating to or located on the bank of a watercourse.

Riparian Zone – Areas adjacent to a stream that are saturated by groundwater or intermittently inundated by surface water at a frequency and duration sufficient to support the prevalence of vegetation typically adapted for life in saturated soil.

Saturated Soil – Soil that is full of moisture.

Scale – A graduated series or scheme of rank or order.

Sediment – Material deposited by water, wind or glaciers.

Sedimentary Bedrock - Rock formed of mechanical, chemical or organic sediment such as rock formed from sediment transported from elsewhere, by chemical precipitation from solution or from inorganic remains of living organisms.

Slope – Ground that forms a natural or artificial incline.

Spawn – To produce or deposit eggs in the reproductive process (used of aquatic animals).

Stratigraphy – Geology that deals with the origin, composition, distribution and succession of layers of the earth.

Stream – A body of running water flowing on the surface of the earth.

Substrate – The base on which an organism lives.

Subwatershed - A region or area bounded peripherally by a water parting and draining ultimately to a tributary of a larger watercourse or body of water.

Subwatershed Planning – A method used to deal 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.

Surficial Geology – Deals with the study and description of the forms on the outer layer of the earth.

Terrestrial - Living on or growing on land.

Thermal Regime – The characteristic behaviour and pattern of temperature.

Till – A tough unstratified clay loaded with stones originating from finely ground rock particles that were deposited by glacial activity.

Topography – A detailed description or representation of the features, both natural and artificial, of an area. Also the physical and natural features of an area, and their structural relationships.

Valley – A long, narrow depression on the earth's surface, usually with a fairly regular downward slope. A river or stream usually flows through it.

Water Budget - The movement of water within the hydrologic cycle can be described through a water budget or water balance. It is a tool that when used properly, allows the user to determine the source, and quantity of water flowing through a system. From a groundwater perspective the key components of a water budget are: infiltration, contribution to baseflow, deeper groundwater flow outside the study area, and groundwater taking.

Water Cycle – The continuous movement of water from the oceans to the atmosphere (by evaporation), from the atmosphere to the land by condensation and precipitation, and from the land back to the sea (via stream flow).

Water Quality Indicator – An entity that provides information on the condition and quality of water through their life cycle patterns. Water quality can also be determined through non living sources, like chemical sampling.

Watershed - A region or area bounded peripherally by a water parting and draining ultimately to a particular watercourse or body of water.

Weathering -The disintegration of the earth's crust by exposure to the atmosphere, most importantly, rain.

Wetland – An area where the water table is seasonally above the substrate surface, and the saturation period long enough to promote hydric or organic soils. A wetland can provide an important role in the hydrologic cycle and host unique species of flora and fauna.