IMPACT ASSESSMENT REPORT

Phase II

Silver Creek Subwatershed Study
Subwatershed 11

May, 2003
Silver Creek
Subwatershed Study
Subwatershed 11

Phase II
Impact Assessment Report

May 2003

Credit Valley Conservation
Schroeter & Associates
Environmental Water Resources Group
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1.0 INTRODUCTION

1.1 PURPOSE OF PHASE II

This report describes the second phase of the subwatershed study process in which the impacts from future land use changes will be determined, assessed and addressed in the Silver Creek Subwatershed within the Credit River system (see Figure 1.1.1). This report follows the first phase of the subwatershed study process, which identified key functions and linkages and is described in a report entitled Silver Creek Subwatershed Study: Phase I Characterization Report available under separate cover (CVC et al. 2002).

1.2 APPROACH

The approach taken involves the development of an impact assessment model that predicts changes from hypothetical land use changes. Potential changes in surface and groundwater characteristics of stream systems can ultimately impact the biology of receiving streams. The impact assessment model utilizes a stress-response framework, which looks at three possible land use scenarios over time and the predicted accompanying changes to environmental function. All predicted changes are measured relative to existing conditions (1999 for vegetation, and 2001 for development). This concept allows for sensitivity testing by assessing the component elements (hydrogeology, hydrology, stream morphology, terrestrial, water quality/benthic and aquatics). Three land use scenarios were developed for this analysis and compared to existing conditions: sensitivity test 1 (interim conditions), sensitivity test 2 (ultimate conditions), sensitivity test 3 (ultimate conditions with maximum allowable water pumping).

In recognition of the linkages between a diverse and productive aquatic presence and relative health of the environment, aquatic resources are used as the ultimate indicator of subwatershed health. What happens on land and in the surface and groundwater in the subwatershed is linked to aquatic habitat by a series of critical functions represented by key indicators in Figure 1.2.1.

1.3 OTHER INITIATIVES

The Silver Creek Subwatershed Study was initiated as one of the supporting studies for the update of the Official Plan process for the Town of Halton Hills. An Official Plan is a comprehensive set of policies used for decision-making and to provide clear direction regarding the growth of the municipality to meet the current and future needs of its population. This subwatershed study has been working in close coordination with the Town of Halton Hills Official Plan Update.

The Halton Hills Official Plan includes a policy commitment that the Official Plan will undergo a comprehensive review within five years to measure the achievement of the plan policies against its goals and to revise goals, policies and methods of implementation...

Given the existing Halton Hills Official Plan was adopted in 1982, a comprehensive review is justified based on the age of the document. Other factors making a review timely include: revisions to The Planning Act and the release of the Provincial Policy Statement; updates to the Niagara Escarpment Plan; a new Regional Official Plan (1995) as well as the current 5 year review of that document; completion of a Community Strategic Plan in 1999; growth pressures resulting from Halton Hills’ location in the Greater Toronto Area; and community concerns regarding the protection and enhancements of the Town’s environmental resources.

A new draft Halton Hills Official Plan will be released in mid-2003, followed by a process of public and agency consultation.
Figure 1.1.1: The Silver Creek Subwatershed within the Credit River Watershed

Sources:
Credit Valley Conservation, 2001; Ontario Ministry of Natural Resources, 1982
Changes in Watershed Hydrology

Surface Water: amount of flow
- flow duration
- flow frequency

Groundwater: direction
- time
- hydraulic head

Changes in Stream Hydrology

Changes in Water Quality

Changes in Riparian Zone

Changes in Stream Morphology

Changes in Aquatic Habitat

Figure 1.2.1 Environmental Impact Flow Model
1.4 **REPORT OUTLINE**

This report has been broken down into 8 chapters as follows:

Chapter 1 provides a brief introduction to this phase of the subwatershed study process and provides the connection to the phase I study.

Chapter 2 provides generalized impacts that urbanization can have on a subwatershed.

Chapter 3 describes the land use scenarios that were developed to assess existing conditions. It also forecasts the potential environmental changes related to the possible land use changes identified in each scenario. Each of the three land use scenarios were used in modeling techniques to forecast impacts and determine sensitivity. The assessment models used are described.

Chapter 4 describes the subwatershed sensitivity and the assumptions made in determining tributary sensitivity by discipline. Sensitivity is examined under the titles of tools, indicators, impact assessment and sensitivity. An overall assessment of tributary sensitivity is established by integrating the various discipline components.

Chapter 5 reiterates the Vision and Goal statements developed earlier by the Focus group, and ties them into the objectives and targets developed through the sensitivity analysis for each subwatershed component (hydrogeology, water quality etc.).

Chapter 6 describes a number of management options that allow for alternative ways of dealing with the proposed land use changes.

Chapter 7 describes the importance of monitoring in the context of adaptive environmental management in order to influence future environmental management decisions.

Chapter 8 provides a very brief outline of the third and final phase of the subwatershed study.

1.5 **PUBLIC INVOLVEMENT**

1.5.1 **The Focus Group**

The Focus Group has met twice during this study, initially in May 2001 and then in November 2001 to review the findings of *Phase 1 - The Characterization of the Silver Creek Subwatershed Study*. A third meeting will be held in November or early December to review Phase 2 findings with the fourth meeting organized on the completion of Phase 3. During these final two meetings the group will be asked to provide input to help increase public awareness of the study, its findings and the recommendations for implementation.
1.5.2 Communications Activities

Information continues to be posted on the CVC and Town of Halton Hills websites, and a public Open House will be held to present this information. Reference copies of the reports continue to be made available at the Town and CVC offices.

Other communication activities will be developed following the next meeting of the Focus Group.

1.5.3 Landowner Contact

Private landowners own the majority of the Silver Creek subwatershed. Access to some of the properties was needed for the purposes of collecting data for the subwatershed study. More than half of the landowners responded to our request to access their lands for data collection. Some denied us permission, but most landowners were quite cooperative.

Data was collected over the course of two summers for many components of the study, and is now complete. Results of the work conducted on these sites will be forwarded to the landowners.
2.0 GENERAL IMPACTS OF DEVELOPMENT ON A SUBWATERSHED

The following section describes some of the impacts that urban development can have on environmental resources at a subwatershed scale. It is not intended to be a complete list of impacts. Furthermore, each subcatchment (figure 2.0.1) will react differently to a change in land use. The physiography, geology, present land use, climate change, wildlife habitat and terrestrial cover are some of the factors that will influence how a subwatershed will respond to change.

In general, urban development decreases the amount of infiltration into the subwatershed, and increases runoff. Urban development, development of housing, or commercial property, alters the hydrologic cycle within the subwatershed, which affects the hydrogeology, hydrology, stream morphology, terrestrial system (upland, wetland and riparian), water quality and aquatic resources.

Urbanization may change the hydrologic cycle by:

- increasing the volume of runoff and reducing the degree of infiltration due to the hardening of surfaces;
- increasing peak flows;
- reducing the amount of depression storage due to regrading, or reducing evapotranspiration due to removal of vegetative cover; and
- reducing the time of travel to the receiving body of water due to the construction of efficient sewer systems. In some cases, small streams have been completely replaced by pipes and concrete trapezoidal channels after urbanization, resulting in streams that are completely dry between storms.
Figure 2.0.1: Subcatchments and Gauge Locations

Sources:
Credit Valley Conservation, 2001; Ontario Ministry of Natural Resources, 1982
2.1 **CHANGES IN HYDROLOGY**

Relationships between land use changes and receiving water characteristics provide one approach for describing and potentially quantifying the stress that subwatershed development has on surface water ecosystems.

In presenting the relationships for urban areas, the amount of imperviousness on a site or in a subwatershed is used as a unifying theme. Imperviousness is the percentage of the total drainage area covered by the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape. Operationally for mature urban areas, subwatershed imperviousness can be defined as the fraction of subwatershed area that is un-vegetated.

Development can impact hydrological pathways for runoff water. For example, the subwatershed runoff coefficient, and other hydrological response characteristics, can change as a result of site imperviousness:

- **Subwatershed imperviousness and storm runoff coefficient.** The runoff coefficient, which ranges from zero to one, expresses the fraction of rainfall volume that is actually converted into storm runoff volume. Data from more than 40 runoff monitoring sites across the USA (see Figure 2.1.1) show that the runoff coefficient closely tracks percent impervious cover, except at low levels where soils and slope factors also become important.

- **Runoff coefficients (Rv) for meadows and parking lot.** The changes in the coefficients used for simulating the different hydrological characteristics of a meadow and a parking lot can be used as an index for quantifying the effects of urbanization upon subwatershed runoff characteristics. In practical terms this means that the total runoff volume for a one-acre parking lot (Rv=0.95) is about 16 times that produced by an undeveloped meadow (Rv = 0.06). (Schueler, 1994b).

- **Subwatershed imperviousness, hydrology, and fluvial geomorphology.** The graph from Booth and Reinelt (1993) shows the relationship between imperviousness (X-axis) and the ratio of flows (10-yr forested /2 yr current, Y-axis) (see Figure 2.1.2). The work by Booth and Reinelt (1993) is significant in the field for suggesting that a threshold for urban stream stability exists at about 10% imperviousness of a subwatershed. Subwatershed development beyond this threshold consistently resulted in unstable and eroding channels.

The most profound effect of subwatershed development on the hydrological cycle was associated with European settlement of Southern Ontario. Changes in the agricultural economy (e.g. from rotation agricultural in which a field is essentially a grass land 5 years out of 7, to row crop), removal of vegetation (e.g. construction, or plowing pastureland for corn fields), and aggregate extraction have more subtle effects which must consider local topography, climate, and other factors. Complete urbanization also
has a profound effect. These effects on an average annual basis are illustrated in Table 2.1 for the major elements of the hydrologic cycle for a relatively homogeneous tributary with sandy soils. The values have been simulated for a period of record from 1960 to 1999 (CVC et al 1998).

The hydrologic cycle describes the pathways for water in subwatershed, where it originates from, and where it goes. The source of water is precipitation (rainfall and snowmelt). The three pathways by which water leaves the subwatershed are evapotranspiration, infiltration into the ground, and overland runoff to the watercourse (see Table 2.1.1).
Figure 2.1.1 Watershed Imperviousness and the Storm Runoff Coefficient

Figure 2.1.2 Channel Stability as a Function of Imperviousness (Booth and Reinelt, 1993)
Table 2.1.1 Effect of Development on the Hydrological Budget

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<th>Component of Water Budget</th>
<th>Forested lands</th>
<th>Agricultural Lands</th>
<th>Urban lands with 40% imperviousness</th>
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*Numbers in brackets are for above water table extraction, while numbers without brackets are for below water extraction.

In forested lands (before European settlement in the mid 1800's, or in those subwatersheds which are still completely forested), very little water leaves the subwatershed through overland runoff, however, about two-thirds of it leaves through evapotranspiration or infiltrates into the ground.

Agricultural development that occurred during the late 1800's increased the volume of runoff by approximately 4 times. Evapotranspiration and infiltration are only slightly affected.

Urbanization further alters the hydrological cycle by significantly increasing the volume of runoff and further reducing the volume of water that infiltrates or that returns to the atmosphere via evapotranspiration. If urbanization of forested lands occurs (compare columns 2 and 6 in Table 2.1.1), the effects on the hydrological cycle are even more dramatic. The volume of overland runoff increases by a factor of 60 (compare columns 2
and 6 of Table 2.1.1), even though the decrease in evapotranspiration and infiltration are much more modest.

The example in Table 2.1.1 illustrates the effects of land development on the hydrologic cycle, but does not take into account all factors, including the effect of clay soils, which significantly reduce the volume of infiltration for agricultural and urban conditions.

The net effect of development is a dramatic change in the hydrologic cycle. The effects include:

- an increase in the magnitude and frequency of severe flood events;
- more of the annual flow is delivered as surface storm runoff rather than baseflow or interflow (or releases from soil-water storage), and the velocity of flow during storms increases.

### 2.2 Changes in Hydrogeology

Increasing cover provided by buildings, pavement and concrete within an urban area is expected to:

- reduce the volume of water available for recharge;
- lower the water table;
- alter the groundwater flow direction; and
- reduce the stream baseflow, which is provided by groundwater discharge.

The relative magnitude of these effects is dependent upon the subwatershed topography, soils, and changes or responses in adjacent subwatersheds. For example, if sandy soils are covered by pavement, the reduction in infiltration will be much more dramatic than if clay soils are covered with urban surfaces.

Increased demand for water is generally associated with development. Increased groundwater extraction may:

- lower the water table;
- alter groundwater flow directions; and,
- reduce the stream baseflow, which is provided by groundwater discharge.

The relative magnitude of these effects is dependent upon the physical characteristics of aquifer, the aquifer’s connection to surface water bodies (e.g. streams and wetlands), and the amount of recharge available. The greatest effects will be observed where groundwater extraction is increased in areas where recharge has been reduced by a change in land use.

The development associated with land use changes is also likely to affect groundwater quality. Expected effects include both point and non-point source pollution from
activities such as petroleum stations and from road salt application, respectively. The threat that these sources may pose will depend on the location with respect to the system. The greatest effects are likely to be observed where aquifer susceptibility is high (see Phase1 Characterization Report).

2.3 CHANGES IN HYDRAULICS

Hydraulics is the science concerned primarily with the flow of liquids. For subwatershed studies, hydraulics looks at the characteristics of flow along the watercourse (channel and flood plain), and the environmental (natural, social and economic) impacts that result from development changes. Hydraulic characteristics include water levels, flood plain and channel storage, flow capacities, flow velocities, flow depths, and flow widths.

Hydraulic characteristics are influenced by runoff volumes/rates, topography, vegetation, erosion, deposition, and by social development (urban and rural). Social development includes watercourse crossings, flood plain uses, storage facilities (i.e. dams), channels, etc. Crossings (road/rail), and flood plain uses can have a significant impact on flow rates, flow velocities and water levels. Generally, crossings can act as barriers or dams along a watercourse and can increase erosion and sedimentation that changes the shape, and the dimensions of the watercourse. The end result is change in the hydraulic characteristics such as flow velocity and flow width.

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

If social development can be prevented from encroaching on the flood plain, then the change in runoff rates is the primary agent that causes changes to the hydraulic characteristics. Generally, increasing development runoff rates will increase flood depths, and flow velocities. Increased flood depths and velocities will result in a higher risk to life, to personal injury, and to property damage. Generally, more buildings will be located in the flood plain, road/rail crossings will be overtopped more frequently, and flow in the flood plain will occur more frequently. By maintaining new development runoff rates to existing levels, changes to the hydraulic characteristics can be minimized.

2.4 CHANGES IN TERRESTRIAL SYSTEM

An increase in urban development can have both direct and indirect affects on terrestrial communities. Such effects result in impacts to the diversity and ecological integrity of the terrestrial system over the short and long term. For example:

- direct impacts from vegetation and topsoil removal for infrastructure crossings, golf courses, houses, etc.; and,
- loss of connective corridors from vegetation removal
have direct impacts on the size, shape and connectivity of natural patches, resulting in loss of habitat, lower diversity of native species and longer term affects on species mortality and reproductive capabilities.

In addition, unmitigated urban development can have dramatic impacts on the hydrologic regime, resulting in a number of indirect affects to the terrestrial system, such as:

- changes in nutrient and streamflow and flooding regime;
- changes in water table elevation in upland and riparian areas can alter wetland and other vegetation through changes in available moisture by over saturating or under saturating the soil.

These affects can result in such changes as:

- a decrease in biological diversity and biological integrity and loss of species sensitive to hydrologic conditions; and,
- increases in runoff and the severity of frequent stream events can result in the erosion of stream banks, downcutting of the channel and in turn causing riparian vegetation to topple in the river.

### 2.5 Changes in Stream Morphology

The form and function of watercourses and the processes that take place within them are a result of the interaction between various controlling (e.g., flow) and modifying (e.g., land use) factors. When any of these factors change, and when the change is greater than what the watercourse can naturally tolerate, then the channel will respond by altering one or more of its degrees of freedom (i.e., change to channel form or function). The nature, severity, and extent of stream adjustments is a function of the pre-existing condition of the channel (e.g., stability before increasing basin imperviousness), characteristics of the channel (e.g., bed and bank materials), drainage basin (e.g., generally pervious or impervious), and the degree of subwatershed imperviousness.

Various studies of channel response to urbanization have shown that the response tends to occur in phases. Phase one coincides with the period during and immediately after construction when the sediment load that enters the channel increases. Phase two refers to the post-construction period in which sediment loads decline and the frequency and magnitude of flows begin to define channel form. Adjustments made by the channel are linked to the age, and distance downstream, of the urban development. General channel adjustments that have been reported within the scientific literature, in response to urbanization, include the following (Knighton, 1998; Neller, 1988, 1989; Dunne and Leopold, 1978):

- *sediment yield* tends to be high during and immediately after construction and lower when urban areas become established;
- *channel contraction* occurs in response to excess sediment deposition in the channel during, and immediately after, construction;
• **channel enlargement** occurs in response to the greater frequency and magnitude of flood discharges and associated bank erosion with time after construction. The amount of enlargement is correlated with the age and type of urban developments (Knighton, 1998) and may involve widening, deepening or both processes;

• **high rates of bank erosion** due to a diminishing sediment supply from construction sites and increased capacity associated with the altered flow regime (i.e., flow frequency and magnitude) which has energy to entrain and transport sediment;

• **high rates of knickpoint retreat** can occur due to a changed flow regime;

• **increased sediment load** due to increased streambank erosion and upland construction site runoff;

• **channel pattern instability** in response to enlargement and alterations in sediment supply/load;

• **changes in bed morphology** due to alteration in sediment load and particle size distribution;

• **substrate sediment size distribution** shifts from coarse grained particles towards a mixture of fine and coarse grained particles;

• **gully enlargement** due to disturbance during construction;

In addition to the indirect impacts of land-use change on watercourses (i.e., flows and sediment load), urbanization often involves the direct alteration of watercourses or drainage networks. Typical channel changes that accompany urbanization include:

• **enclosure** of headwater streams to "improve" drainage by reducing flooding risks in intensively urbanized areas. Enclosure may also be undertaken to increase developable land areas;

• **decrease in drainage density** due to removal of low-order ephemeral channels from the drainage network;

• **armoring** streams at road and pipeline crossings to inhibit bank and/or bed erosion. Immediately downstream of bank hardening, erosion often occurs;

• **straightening** to improve flow efficiency and to reduce the space that the watercourse occupies on its floodplain causes an increase in stream gradient and stream power which may induce erosion and downstream channel change.

In Ontario, and in many places within North America and Europe, various regulations exist that minimize the effects of construction on the sediment supply to watercourses.

### 2.6 Changes in Water Quality

CVC’s Water Quality Strategy has identified a number of water quality parameters that are either currently a concern or have the potential to become a concern in the future, based on the current conditions and the type of land use changes expected in the watershed. These parameters were short-listed for a Parameter of Concern list to include only parameters that are, in general, a watershed-wide concern and have cumulative, long-term impacts. These include the following parameters.
### Table 2.6.1 Watershed-wide Parameters of Concern

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Watershed Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow regime/Stream Power</td>
<td>A healthy flow regime is critical to maintaining healthy fish habitat directly and indirectly. Water flow rates affect contaminant wash-off and transport into watercourses. Flow variations affect channel stability and fish habitat. This parameter will also likely be affected by climate change.</td>
</tr>
<tr>
<td>Water Temperature</td>
<td>Fish community types are temperature dependent. Temperature also affects physical, chemical and biological water quality parameters. This parameter is affected by urban runoff, loss of riparian vegetation, aggregate activity, and in the future, climate change.</td>
</tr>
<tr>
<td>Nitrates</td>
<td>Nitrates are a nutrient affecting algae growth, can potentially be toxic to fish and can become a drinking water issue in groundwater. Nitrates are related to total population discharging treated sewage (both surface and subsurface) and related to farming extent and intensity.</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>Total phosphorus is a nutrient affecting algae growth. It is related to total population discharging treated sewage, urban runoff, and to farming extent and intensity. Point and non-point sources of total phosphorus can contribute to loadings to watercourses. Management parameter for point sources.</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>Adequate levels of dissolved oxygen are critical for most aquatic biota. DO is related to aquatic plant growth (from increased nutrients such as phosphorus) and increased loadings of oxygen demanding material from urban and rural point and non-point sources</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>Environment Canada recommends road salt to be regulated as a toxic substance. This parameter is potentially toxic to fish and a drinking water issue in groundwater. Road salts are related to urban population, road density and some cases, the use of water softeners.</td>
</tr>
<tr>
<td>Metals (Ni, Cu, Al, Zn, Fe)</td>
<td>High metal levels can be toxic to aquatic biota. This parameter is typically associated with urban runoff but wastewater effluent can also be a source. Some metals are elevated naturally due to background mineral levels in soil.</td>
</tr>
<tr>
<td>Organic (representative pesticide or industrial organic)</td>
<td>These types of parameters are linked to fish advisories on consumption and can be directly toxic to fish and other aquatic biota. The parameter may originate from background levels from historical use, urban runoff, point sources or current application.</td>
</tr>
<tr>
<td><strong>Parameter</strong></td>
<td><strong>Watershed Significance</strong></td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Bacteria affect safe swimming conditions and can be indicative of the presence of other contaminants such as nutrients and BOD material. Bacteria are associated with suspended solids and loadings can originate from urban point and both rural and urban non-point sources.</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>Sediment can affect fish directly and fish habitat. Sediment loads affects channel erosion. Many pollutants including total phosphorus, metals and bacteria are associated with suspended solids. Sources include rural and urban runoff, urban point sources, and in-stream erosion.</td>
</tr>
<tr>
<td>(sediment)</td>
<td></td>
</tr>
</tbody>
</table>

In Subwatershed 11, the alternate scenarios tested for potential impact changes include increased urban areas and increased aggregate activities. The following paragraphs describe water quality parameters that specifically relate to these two types of land use changes. Although the scenarios focus on urbanization and increased aggregate activity, potential changes from increased agriculture, such as intensification of existing agricultural activities, is also described.

**Water quality changes from urbanization**

Changes in water quality from development typically result from runoff from increased impervious areas, erosion of exposed and disturbed soils, and impacts from increased water and wastewater services. Water quality impacts from development include increased contaminant and thermal loadings to the watercourses and a loss of baseflow, which may have attenuated preexisting contaminant and thermal loadings. Water quality changes from aggregate extraction are often associated with extraction below the groundwater table and runoff from exposed and disturbed soils, which may lead to increased water temperatures and contaminant loadings, respectively.

Urban development typically causes greater and more erosive (i.e. higher velocities) runoff and stream flow because of increased impervious areas through the construction of roads, parking lots, driveways, and buildings. Without stormwater controls, contaminants that are on or near the impervious areas, may be washed off and transported directly into nearby watercourses. These contaminants can include road salt, bacteria, nutrients, oxygen demanding material (such as BOD: biological oxygen demand, SOD: sediment oxygen demand, etc), trace metals, and soil particles. Since the treatment mechanism for stormwater quality controls is primarily based on settling out of solids, which does not achieve complete removal of suspended solids, some sediments and contaminants attached to those sediments (i.e. some metals, bacteria and phosphorus) and most dissolved contaminants, such as chlorides and nitrates, will enter the watercourse. In-stream erosion from increased stream velocities can also introduce additional sediment and related contaminant loadings to the watercourse.
Increased contaminant loading may also occur from new and expanding sewage treatment and disposal systems, which may discharge to the subsurface or directly to the watercourse. Treated effluent may range in nutrient (phosphorus and nitrogen), bacteria, chloride, suspended solids and BOD material concentrations, depending on the level of treatment achieved (primary, secondary or tertiary). Direct discharges are typically located at sites where sufficient mixing occurs (higher volumes and velocities), so that the effluent is diluted quickly to minimize impacts to aquatic biota at discharge concentrations. Subsurface discharges can generate identical loads to the environment, but the subsurface material may allow for attenuation through processes such as adsorption to soil particles and denitrification. However, soluble contaminants, such as chlorides and nitrates, are often very mobile in the groundwater and can cause groundwater contamination off-site. Contaminated groundwater upwellings are of particular concern because they provide habitat to sensitive aquatic biota, such as fish eggs and fry, and are not diluted by surface waters in these habitats.

The construction phase of development may generate the highest sediment loads to the watercourse since the soils are disturbed and have minimal or no vegetative cover, both factors that increases the soil’s susceptibility to erosion. Sediment fences and traps are design to minimize erosion but are not perfectly effective or always properly maintained. Secondly, contaminants such as phosphorus and metals that are typically attached to sediments, may enter the watercourse at high rates during the construction phase as well.

Water temperature changes from runoff events are another impact from increased impervious areas. The impervious areas interrupt the hydrologic cycle, which would normally allow the water to infiltrate and cool underground, before being discharged through groundwater upwellings in the watercourse. Instead, the water runs off at a temperature close to the ambient air temperature and enters the watercourse. In the summertime, the runoff collected in the stormwater ponds may be further warmed through increased water surface area exposed to warm air temperatures and solar radiation. Alternatively, the water collected in the stormwater ponds may also be cooled from increased evaporation from the increased surface area. In the winter, the runoff water from precipitation or melting events may be cooler than the receiving stream due to exposure to below freezing air temperatures. If under these conditions, groundwater upwellings are reduced or eliminated, the entire watercourse may freeze over, thereby freezing fish eggs which would normally be protected by relatively warmer groundwater upwellings. Lastly, stream temperatures may increase due to the lack of riparian cover providing shade during the warm summer months.

In some cases of development, there are reductions in nutrients, bacteria, suspended solids, and oxygen demanding material loadings to the watercourse if previous landuse consisted of poorly managed or very intensive agricultural lands.

The in-stream effect of these contaminant loadings and water temperature changes are outlined in Table 2.6.2. Those parameters that are included in the watershed-wide Parameters of Concern list have been bolded.
Table 2.6.2  Summary of water quality changes due to development

<table>
<thead>
<tr>
<th>Potential Contaminants</th>
<th>Category</th>
<th>Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Total Ammonium</td>
<td>Nutrient-related</td>
<td>• Un-ionized ammonium, nitrite and nitrate can be toxic to aquatic biota.</td>
</tr>
<tr>
<td>• Phosphate Phosphorus</td>
<td></td>
<td>• Elevated levels of nitrate, ammonium, and both forms of phosphorus may stimulate aquatic plant growth, which may lead to an unhealthy dissolved oxygen regime for aquatic biota.</td>
</tr>
<tr>
<td>• Total Phosphorus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Nitrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Nitrite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Dissolved Oxygen (DO)</td>
<td>Oxygen Related</td>
<td>• sufficient levels of DO are required by most aquatic biota</td>
</tr>
<tr>
<td>• Biological Oxygen Demand</td>
<td></td>
<td>• materials with high BOD, NOD, COD and SOD can deplete DO levels</td>
</tr>
<tr>
<td>• Chemical Oxygen Demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Nitrogenous Oxygen Demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Sediment Oxygen Demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• (BOD, COD, NOD, SOD)</td>
<td>Physical and related parameters</td>
<td>• SS can damage fish habitat by clogging spawning areas</td>
</tr>
<tr>
<td>• Filtered Residue (Dissolved Solids)</td>
<td></td>
<td>• An increase in water temperature will allow the water to hold less DO while increasing the metabolism of most fish</td>
</tr>
<tr>
<td>• Particulate Residue (Suspended Solids – SS)</td>
<td></td>
<td>• A decrease in water temperature may cause over-wintering fish eggs to freeze</td>
</tr>
<tr>
<td>• Conductivity</td>
<td></td>
<td>• increased filtered residue and/or conductivity may indicate increases in chlorides or other ions</td>
</tr>
<tr>
<td>• Water Temperature</td>
<td></td>
<td>• Chloride can also be toxic at high concentrations</td>
</tr>
<tr>
<td>• Chlorides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Aluminum</td>
<td>Trace Metals</td>
<td>• acute and chronic toxicity to aquatic biota</td>
</tr>
<tr>
<td>• Barium</td>
<td></td>
<td>• buildup in the food chain from elevated levels in aquatic biota.</td>
</tr>
<tr>
<td>• Beryllium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Cadmium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Chromium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Cobalt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Copper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Iron</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Lead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Manganese</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Molybenum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Nickel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Strontium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Titanium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Vanadium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Zinc</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Potential Contaminants

<table>
<thead>
<tr>
<th>Potential Contaminants</th>
<th>Category</th>
<th>Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Escherichia coli</em> (E. coli)</td>
<td>Microbiological</td>
<td>• <em>E. coli</em> is used as an indicator of health risk in body contact recreational uses of water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High <em>E. coli</em> levels are indicative of an increased likelihood of bacterial infection of the ear, eyes, and/or gastrointestinal system after swimming in the water</td>
</tr>
</tbody>
</table>

### Water quality changes from aggregate extraction

Water quality changes may also be caused by aggregate extraction activities, particularly with respect to water temperature and increases in sediment loadings. Changes in water temperature can be due to reductions in baseflow if the aggregate activity extends below the water table and interrupts the flow of groundwater. Similar to the effect of stormwater facilities, the open water resulting from extraction below the water table may have a cooling effect, through increased evaporation, or warming, through exposure to warmer air temperatures and solar radiation, effect on the water. Any loss of riparian cover will reduce the cooling effects of shade and further increase the warming of the water through direct adsorption of solar radiation.

Sediment and contaminants such as nutrients and metals adsorbed to these sediments may be washed-off from the exposed and disturbed soils on-site during the extraction phase. If baseflows are reduced, velocities may be decreased which result in lowered reaeration rates for dissolved oxygen. In addition to reduced reaeration rates and increased water temperature, dissolved oxygen may be depleted through Sediment Oxygen Demand (SOD) from the sediment accumulation in slower moving waters. The in-stream effects of these contaminants are described in Table 2.6.2 above.

### Water quality changes from increased agricultural activity

Agricultural activities can greatly influence the local environment. Potential agricultural impacts include the following:

- Disruption of the hydrological cycle (i.e., reduced baseflow due to increased evaporative losses, increased peak storm flow due to tile drainage),
- Water withdrawal from streams for irrigation and other needs (i.e., baseflow),
- Loss of riparian cover to filter out runoff and provide shading for watercourses
- Soil erosion causing stream contamination by solids, nutrients and pesticides,
- Bacterial contamination of surface and groundwater,
- Contamination of groundwater by fertilizer nitrates,
- Contamination of surface and groundwater through poor manure management and land spreading of domestic sewage sludges,
- Contamination of streams through direct cattle access,
• Contamination of surface and groundwater by milkhouse washwater, and
• Pesticide and other agrichemical spills.

It is recognized that conventional agricultural practices can result in poor water quality. The adoption of best management practices can help to alleviate stress factors of soil erosion and poor water quality. Aquaculture operations are required to have permits to take water and to treat fish wastes produced in their operations. Recent outbreaks of groundwater contamination near Walkerton and other communities in Ontario and Canada have emphasized the need for vigilance in this regard. The creation of enabling Ontario legislation in June of 2002 – the Nutrient Management Act will set standards for intensive livestock operations. A main focal point of this is the necessity for a nutrient management plan for the application of all nutrients (fertilizers/manure and biosolids) to agricultural lands.

2.7 Changes in Benthics

The composition of the benthic macroinvertebrate fauna will reflect the surrounding physical-chemical environment. Urban systems produce a variety of changes in the local environment, the nature of which can depend on the original system. Runoff from urban areas typically contains nutrients, suspended solids, and a suite of organic and inorganic chemicals. If uncontrolled, that runoff can significantly alter the chemistry of urban streams to the point that sensitive taxa such as mayflies, stoneflies and caddisflies are replaced by more tolerant generalist taxa such as isopods, chironomids and oligochaete worms. Where the fluvial geomorphological processes are affected, changes in the benthic fauna can be variable depending on the nature of the changes. Where substrates change from coarse to fine, small organisms like chironomids and worms may be favoured, whereas changes in substrate from fine to coarse may favour larger-bodied invertebrates like isopods or mayflies. Where stream temperatures change, the impacts on the benthic community may be very similar to the effects caused by increased nutrients. Generally, mayflies, stoneflies and caddisflies require cooler water temperatures than do chironomids and oligochaete worms. Further, the hatching and emergence cycles of insect fauna (including chironomids) are usually temperature dependent. Thus, any change in thermal regimes can be considered potentially significant to the composition of the benthic macroinvertebrate fauna.

There are numerous studies that have shown the effects of urbanization on benthic macroinvertebrates including Jones and Clark (1987), Pratt et al. (1981) and Pedersen and Jenkins (1986), to name a few. Some authors have concluded that the percent impervious area is a good predictor of the potential for effects in a catchment. For example, in Maryland, Klein (1979) showed that impairment is first observed in catchments with 12% impervious area, while severe impacts do not occur until imperviousness reaches 30%. Shaver et al. (1995) produced similar results.
2.8 **Changes in Aquatic Resources**

The goal statement presented in the Phase I Report and later on in Chapter 5 of this report, describes the desire to protect the fishery, its supporting food web and habitat as one of the key resource objectives for consideration in an impact assessment. Aquatic resources can be used as the ultimate indicator for the impact assessment in this study.

The ecology of urban streams is shaped and molded by the extreme shifts in hydrology, geomorphology and water quality that accompany the development process. Urban impacts in this case also include the increased withdrawal of groundwater. The stresses on the aquatic community of urban streams are both subtle and profound, and are often manifested in the following ways:

- nutrient concentrations;
- concentrations of toxic compounds;
- removal of riparian canopy causes the stream waters to heat up, causing shifts from cold water habitat to cool or warm water habitat conditions;
- loss of infiltration, recharge and baseflows that sustain habitat area at low flows and maintain cooler and more stable thermal regimes;
- the riffle-pool structure associated with a stream's meanders is altered as the sinuosity, stream length along its thalweg and stream gradient are changed;
- instream cover provided by bank undercuts is increased at points of bank-toe erosion; and
- an alteration of substrate characteristics due to interbedding or changes in pavement-subpavement ratios reduced the extent of fish habitat for critical life-stages, depending upon the fish species;
- armouring reduces or eliminates fish habitat provided by the stream bank; and
- bank stability can decrease, leading to changes in fish habitat in undercuts etc.
- groundwater withdrawals can reduce baseflows noted above but also directly reduce hydraulic gradients in trout spawning areas that results in increased mortality of eggs.

Riparian zone stream habitat is the vegetation on the stream banks which protects the stream banks from the erosive forces of fast flowing waters and shades the stream from the hot sun maintaining cool stream temperatures; and other vegetation in the floodplain where some fish and other organisms spawn or nurse during periods of flood flow.

Changes in the habitat, food web or structure of the aquatic ecosystem caused by urbanization may result in:

- a shift from external (leaf matter) to internal (algal organic matter) stream production;
- a reduction in diversity in the stream community;
- destruction of freshwater wetlands, riparian buffers and springs; and
- changes from cold water communities to cool or warm water communities.
3.0  IMPACT ASSESSMENT

This chapter summarizes the major elements of the hydrological system for the Silver Creek Subwatershed. It presents an overview of potential changes and predicts the result (impact) that occurs in the subwatershed due to land use changes. For the purposes of this study, aquatics have been selected as the indicator for subwatershed health. Land use change is used as a basis for the impact assessment framework adopted for this study.

The foundation for the impact assessment is the concept that subwatershed development will effect the hydrologic cycle. Changes on the land base trigger a sequence of changes that occur within the surface and subsurface hydrologic systems. There are impacts on the subwatershed resulting from increased urbanization caused by a change in surface water and groundwater flow. The techniques used to determine the impacts of land use change on the environmental components of the subwatershed, and particularly the aquatic ecosystem, are discussed. The assessment of additional, often more indirect, impacts on the other environmental components of the natural system (e.g. wetlands and woodlands) are discussed within Chapter 4. The assessment models used are described.

3.1  IMPACT ASSESSMENT METHODOLOGIES

Unlike the weather forecasters with complex meteorological models, a comprehensive model for forecasting the effects of subwatershed development on aquatic ecosystems does not exist. But like the meteorologist, one can anticipate some imprecision when predicting subwatershed response to change. In this study, a combination of mathematical models, empirical literature and professional experience were utilized to complete the impact assessment.

A framework for a comprehensive integrated assessment was adopted based on stress-response concepts. The main stressor of concern in this subwatershed is urban development.

The framework is a sequential set of hypotheses of effect (Figure 1.2.1) linking subwatershed development and the consequential changes to the receiving water ecosystem. The effects occur as a result of sequence of changes that include:

- watershed changes caused by land use changes;
- changes in stream hydrology;
- changes in groundwater infiltration and baseflow recharge;
- changes in stream morphology;
- changes in stream water quality;
- changes in riparian zone stream habitat;
- changes in stream habitat and ecology (instream cover, benthic invertebrates, channel morphology and thermal conditions); and
- changes in the stream ecosystem.
This sequence of changes is called "impact flow". The "flow" of impacts occurs first through physical pathways and then chemical, biophysical or biochemical pathways, dependent upon which part of the sequence that one is considering. For example for the sequence of:

1. hydrogeology
2. hydrology
3. fluvial geomorphology
4. surface water quality
5. fish habitat (instream, riparian canopy)
6. aquatic ecosystem

Numbers 1-3 are physical, 4 is chemical / biochemical while 5 and 6 are physical / biophysical in nature.

Different procedures were used to evaluate development impacts and subwatershed sensitivity, dependent on the component of concern. Impact is defined as the anticipated response or the magnitude of the response and sensitivity is defined as the capacity of an environmental indicator to be subject to change. The Guelph All Weather Sequential Events Runoff (GAWSER) model was used for the hydrology modeling, and the Finite Element Flow (FEFLOW) model was used for hydrogeology modeling. Details of these procedures are provided in section 3.3.1 and in appendix I. Data from Phase 1 of this study, professional experience, the biophysical characteristics of the subwatershed and the impact flow structure were used to evaluate the other components considered in the impact assessment.

### 3.2 Land Use Scenarios

Four scenarios have been developed to assess potential impacts of future land use change to the environmental features, functions and linkages of the Silver Creek Subwatershed. These scenarios have been developed to estimate change in the hydrologic cycle. The four scenarios are:

1. **Scenario 1 - Existing Conditions**
   Represents existing land use conditions from the year 1999 for vegetation, and the year 2001 for development based on CVC air photo interpretation. Simulates the current average annual pumping rate for wells in the Halton Hills (Georgetown) Area.

2. **Scenario 2 - Interim Conditions**
   Represents potential development based on approved or pending development applications, licensed aggregate extraction areas, approved land use designations in the current Town of Halton Hills Official Plan, Niagara Escarpment Planning Area development
restriction, as well as hypothetical assumptions with respect to development outside the current Georgetown Urban Area, in order to sufficiently stress the system to cause changes in the environment. Simulates the current average annual pumping rate for wells in the Halton Hills (Georgetown) Area.

3. **Scenario 3 - Ultimate Conditions**

Represents total development across the subwatershed for modeling purposes. Natural areas remain static from Scenario 2. Simulates the current average annual pumping rate for wells in the Halton Hills (Georgetown) Area.

4. **Scenario 3b - Ultimate Pumping Conditions**

Represents total development across the subwatershed for modeling purposes and the maximum permitted average annual pumping rate for wells in the Halton Hills (Georgetown) Area. Natural areas remained static from Scenario 2.

The interim scenario builds upon the existing scenario, and the ultimate scenarios build upon the interim scenario etc. Although the interim and ultimate scenarios may never be realized, they are proposed for the purpose of modeling and assessing ecosystem response and were not intended to form an Official Plan policy framework or be used in a local policy context.

The four scenarios have accounted for the Town of Halton Hills Official Plan, Town of Erin Official Plan, approved or pending development applications, licensed aggregate areas, Niagara Escarpment Planning Areas, and existing land cover. Hypothetical growth was included in Scenarios 2, 3 and 3b to simulate change to assess ecosystem response.

Each scenario was broken down into four land cover types: settled, natural, aggregate and agriculture. The following defines each of the land cover types.

- **Settled areas** - urban, rural development (.5 to 2ha of land that contains buildings such as houses and barns), landfill
- **Natural areas** – forest, wetland, culturally influenced natural communities
- **Aggregate** – active and inactive pits or quarries
- **Agriculture** – intensive and non-intensive agriculture; wet meadow

All natural areas were considered to be static through all 4 scenarios, except for the few where Official Plan designations, development applications or approvals exist. Agricultural areas were assumed to be less impervious than developed areas. The Supporting Document titled *Land Use Scenarios* provides a more detailed discussion on the development of the four land use scenarios used to test the sensitivity of the Silver Creek Subwatershed.
3.3 **HYDROLOGY AND HYDROGEOLOGY ASSESSMENT MODELS**

3.3.1 **Hydrology**

A surface water hydrology model, the Guelph All-Weather Sequential-Event Runoff model (GAWSER), was selected for use in evaluating the effects of land use scenarios on the hydrological cycle of the Silver Creek Subwatershed. This model, described in detail in Appendix G, was originally developed to evaluate sources of runoff in rural watersheds from areally distributed soil-types for the purpose of tracking water borne pollutants to the Great Lakes in the original PLUARG (Pollution from Land use Activities Reference Group, see Whiteley and Ghate, 1977) studies. Since then, the program has been greatly expanded to include major hydrological processes over the land surface, accounting for evaporation (from open water surfaces), evapotranspiration (water losses from interception and depression storage, and soil-water storage due to plant respiration), snow accumulation, ablation (melt, refreeze and compaction), and re-distribution, and releases from groundwater and soil-water storage (baseflow and interflow). The program uses meteorological sequences of hourly rainfall, and daily maximum and minimum air temperature, rainfall and snowfall as inputs to drive the model. The program is capable of simulating hydrologic responses from a watershed for individual events, or long-term periods of more than 30 plus years.

In any mathematical model of the natural environment, such as GAWSER, there are “model input variables and parameters” which need to be estimated, in order to properly represent the physical processes controlling moisture levels in soils, overland runoff processes and infiltration. Streamflow data available from two gauging stations in the Silver Creek Subwatershed were used for this purpose: Black Creek below Acton, and Silver Creek at Norval (see Figure 2.0.1).

This resulted in developing a model for both Black and Silver Creek together, in order to describe the hydrological characteristics of the Silver Creek Subwatershed. The calculations of infiltration and baseflow for the surface water model must agree with the estimates derived for the groundwater model. Because separate models are used for surface water and groundwater, there was close interaction between study leads to ensure that results were consistent.

The results of the long-term (40-year) water balance simulations are given in Table 3.3.1 for existing, interim and ultimate land use conditions. Equation 1 gives the water balance formula used to compute the infiltration ‘losses’ noted in the Table. Table 3.3.1 gives a complete summary of the mean annual water balance quantities for the entire Subwatershed 11.

[Equation 1] \[ \text{Precip} = \text{ET} + \text{Runoff} + \text{Baseflow} + \text{Losses} \]
Table 3.3.1 Existing Water Balance for Subwatershed 11

<table>
<thead>
<tr>
<th>Silver Creek Subwatershed</th>
<th>Average Annual Precipitation (mm)</th>
<th>Average Annual Evapotranspiration (mm)</th>
<th>Average Annual Streamflow (mm)</th>
<th>Average Annual Runoff (mm)</th>
<th>Average Annual Baseflow (mm)</th>
<th>Average Annual Infiltration Lost (mm)</th>
<th>Average Annual Total Infiltration (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Scenario</td>
<td>821.7</td>
<td>504.0</td>
<td>320.8</td>
<td>89.3</td>
<td>231.5</td>
<td>-3.0</td>
<td>228.5</td>
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<tr>
<td>Interim Scenario</td>
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<td>501.8</td>
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<td>92.3</td>
<td>245.1</td>
<td>-17.5</td>
<td>227.6</td>
</tr>
<tr>
<td>Ultimate Scenario</td>
<td>821.7</td>
<td>486.9</td>
<td>373.1</td>
<td>118.8</td>
<td>254.3</td>
<td>-38.3</td>
<td>216.0</td>
</tr>
<tr>
<td>Ultimate with Maximum Pumping Scenario</td>
<td>821.7</td>
<td>486.9</td>
<td>373.1</td>
<td>118.8</td>
<td>254.3</td>
<td>-38.3</td>
<td>216.0</td>
</tr>
</tbody>
</table>

3.3.2 Hydrogeology

The Characterization Report of Phase 1 of the Silver Creek Subwatershed Study (CVC et al, 2002) states that:

“The geological setting provides a major control for the amount of precipitation that will infiltrate into the ground and recharge the water table. Lower permeability geological units will force groundwater to move laterally. The topographical relief will determine whether this water that moves laterally seeps out or discharges as baseflow into a local stream valley and then moves to a more regional river valley.”

The characterization report details the variability of the geological and hydrogeological system within the Silver Creek Subwatershed. To understand and reliably predict groundwater flow and linkages between surface water and groundwater, a numerical model of the groundwater flow system was developed. The model incorporates the three-dimensional variability of the geological layering and features controlling the groundwater flow. The model domain (Figure 3.3.2) encompasses the entire area contributing groundwater to the Subwatershed 11 including the contribution from outside the subwatershed. The model also provides a means for developing a water budget for a given area in the model (e.g. a subcatchment) that is physically based through explicit simulation of the features of the groundwater system.

FEFLOW (WASY Ltd., 2002), developed by WASY Ltd., Berlin, Germany, was chosen for groundwater modelling because of its finite element numerical approach. The finite element method employed by FEFLOW is better suited to modelling the complicated geology and steep hydraulic gradients that exist at the Niagara Escarpment in the Silver Creek Subwatershed.

The advantages of the Feflow modeling package include:

- versatility in the discretization of the model domain;
Silver Creek Subwatershed Study

- allows for efficient model discretization in critical areas (e.g. around wellfields);
- represents geologic layering and the water table boundary naturally;
- represents boundary conditions naturally;
- recharge is partitioned in a physical manner; and,
- allows for a valid representation of anisotropy.

The Flux Analyzer and Budget Tools built-in to FEFLOW are particularly well suited to subwatershed impact assessment studies as they provide quantitative information on groundwater flow and stream discharge over any user-defined section or area. This functionality provides feedback to the surface water model (GAWSER, Schroeter and Assoc., 1996) to ensure harmony of results through parallel calibration.

The ability of the groundwater model to simulate current conditions of groundwater flow and surface water – groundwater interaction can be evaluated by comparing the observed and predicted groundwater discharge. Groundwater discharge is considered to be equal to the observed streamflow during baseflow conditions.

Model simulated stream baseflow (groundwater discharge) was compared to 24 spot flow locations along Silver Creek and its tributaries as well as with the Highway 7 Water Survey Canada (WSC) stream flow gauge. Spot flow measurements were collected during baseflow periods between June and November 2001. Baseflow at the Highway 7 gauge was estimated from low flow measurements in the summer period from 1988 – 1997 (see Appendix H).

The results of the groundwater model calibration process are summarized in two figures (Figures 3.3.2 and 3.3.3). Figure 3.3.2 shows a three-dimensional view of the discretized finite element model mesh. This illustrates the complex geometric shape used in the groundwater model to accurately model the geological variability. Figure 3.3.3 shows the model simulated water table contours (model layer 4, Contact Zone) in meters above sea level for Current Conditions. This figure shows the final groundwater table elevations for the area contributing to subwatershed 11. The model simulated groundwater discharge to each stream reach is also shown in cubic metres per day. Included in Appendix H of this report is a detailed summary of the groundwater model development and calibration.

Important subwatershed scale detail was incorporated into the model including the interpreted location and character of buried valley system below the escarpment in the vicinity of Georgetown (Appendix H). The buried valley system is an important feature to include in the groundwater flow model as it:

- influences groundwater and surface water interactions;
- transmits large quantities of groundwater as inter-subwatershed groundwater flow (i.e., groundwater flow from Subwatershed 10 into Subwatershed 11); and
- provides all of the municipal groundwater supply for Halton Hills.
The current model representation of the buried valley system reflects the broad nature of the valley and the variable hydraulic conductivity. This representation is interpreted from geologic mapping and available water well record information. The location and depth of the buried valley system is highly variable and is likely to differ locally from the model representation. However, the function of the valley is sufficiently represented at the subwatershed-scale for current predictions. Variability in the surficial geology reflecting local features was also incorporated into the model to reflect local controls on groundwater flow.

Figure 3.3.3 shows the importance of regional groundwater flow as the Silver Creek subcatchments receive groundwater from subwatershed 10 and Sixteen Mile Creek subwatershed (south of Georgetown) in the Halton Region Conservation Authority (HRCA) watershed. Equally important is the groundwater that flows from Subwatershed 11 to the main Credit River (Subwatersheds 6, 9, 12, 14).

Changes in land use were simulated as changes in groundwater recharge. For example, where a land use changes from Woods to Urban in an area underlain by glaciofluvial sand, recharge is reduced in that area relative to the current conditions. The magnitude of the change is estimated from infiltration properties defined in the GAWSER model (see section 3.3.1). This process conducted for the entire subwatershed and the model simulate the effect of all land use changes for each scenario. Where pumping rates are changed the pumping rate of the well is adjusted.

An assessment of the impact of the changes in each scenario is completed by comparing the current water budget for each of the 13 subcatchments with the predicted water budget for each scenario. Impacts are also assessed by comparing water table elevations and groundwater flow directions.
Figure 3.3.2 Three-dimensional finite-element mesh of Credit River Watershed.

Figure 3.3.3: Model simulated water table contours (m) - existing conditions

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982;
Waterloo Hydrogeologic, 2002
3.4 CHANGES IN SURFACE WATER AND GROUNDWATER

3.4.1 Land Use Scenarios and Changes in Surface Water

Upon examination of the quantities summarized in Tables 3.4.1 to 3.4.9, one can see that changes in the hydrologic response of Subwatershed 11 are occurring as we progress from the existing conditions, through the Interim Scenario to the Ultimate conditions Scenario. The degree of these changes with their associated impacts varies significantly depending upon the whether the changes are viewed on a subcatchment scale, or at the outlet of the entire subwatershed.

For Scenario 2 (Interim), the mean annual streamflow at the outlet of Subwatershed 11 is expected to increase by only 5%, with similar increases in mean annual runoff (3%) and baseflow (6%). The return period flood flows (2, 20 and 100 year) are expected to increase by 18 to 28%, with similar shifts (increases) in the flow durations. These changes are primarily due to increased development in the lower subcatchments below the Niagara Escarpment. With adequate controls in place for new developments, the increases in flood flows would be minimal. However, on an individual subcatchment basis, these changes can be much larger, particularly in places where most of the development is expected to occur. For example, the increase in the mean annual flow at the outlet of Silver Creek subcatchment 1109 is expected to increase by 33%, primarily due to specific development expected in that subcatchment. The flood flows in the main stem of Silver Creek are expected to increase by only 10%, primarily because the increased flows resulting from the new development in Subcatchment 1109 will have proceeded downstream before the flows from the upstream portions of Silver Creek have arrived at the outlet of Subcatchment 1109. Baseflows in the areas above the escarpment are not expected to increase, because much of the infiltrated water leaves the upper subcatchments through the groundwater flow system.

For Scenario 3 (Ultimate conditions), the large amounts of development considered throughout Subwatershed 11 will result in significant changes to the hydrological response in every location. However, the degree of those changes will vary according to the scale of application considered. For example, at the outlet of Silver Creek, the mean annual flow is expected to increase by 16% for the Ultimate conditions, with corresponding increases in the flood flows (2 to 100 year) by more than a factor of 4. The flood flows are increasing so much higher than the mean annual streamflow, because of flow synchronization. In the existing conditions, the varied responses of the rural subcatchments caused runoff water to enter the main stem of Silver Creek at varying times so the flows would be less additive. However, in the ultimate conditions scenario, the runoff response for each subcatchment will be greatly enhanced due to the more efficient drainage systems resulting from the development. The timing of the runoff response in each subcatchment will be more similar, causing greater additive effects of increased streamflow as we proceed downstream in Silver Creek. For individual subcatchments, the increased runoff response resulting from development will not only greatly increase the flood flows (has high as factor of 30 for subcatchment 1101), but will...
shift the flow duration curves to the left. This means that certain flow levels (like bankfull flow or higher) will occur more frequently, whereas certain critical low flows (e.g. 50 and 80% duration flows) will occur less frequently. For example, in Subcatchment 1101, the 50% duration flow is expected to decrease by 50%.

For scenario 3b (Ultimate conditions with Maximum Allowable Pumping), the model showed no significant difference in results from the Scenario 3 (Ultimate conditions). Therefore, similar results are shown in the tables for scenario 3b as scenario 3.

Table 3.4.1 Modelled 100 Year Peak Flows for Each Development Scenario

<table>
<thead>
<tr>
<th>Location</th>
<th>Hyd #</th>
<th>Existing</th>
<th>Interim</th>
<th>Ultimate</th>
<th>Ultimate with Max Pumping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Ck below Acton</td>
<td>4210</td>
<td>6.66</td>
<td>6.66</td>
<td>6.66</td>
<td>6.66</td>
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<tr>
<td>Black Ck outlet at Silver Ck</td>
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<td>21.9</td>
<td>21.9</td>
<td>21.9</td>
</tr>
<tr>
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<td>1.92</td>
<td>61.5</td>
<td>61.5</td>
</tr>
<tr>
<td>Silver Ck u/s Snows Ck</td>
<td>4237</td>
<td>5.0</td>
<td>4.96</td>
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<td>55.6</td>
</tr>
<tr>
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<td>1.12</td>
<td>19.3</td>
<td>19.3</td>
</tr>
<tr>
<td>Snows Ck at Ballinafad</td>
<td>4239</td>
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<td>2.05</td>
<td>16.8</td>
<td>16.8</td>
</tr>
<tr>
<td>Snows Ck outlet Sub 1109</td>
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<td>3.0</td>
<td>15.9</td>
<td>15.9</td>
</tr>
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<td>62.8</td>
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<tr>
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<td>13.1</td>
<td>62.2</td>
<td>62.2</td>
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### Table 3.4.2 Modelled 2 Year Peak Flow for Each Development Scenario

<table>
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<tr>
<th>Location</th>
<th>Hyd #</th>
<th>Existing</th>
<th>Interim</th>
<th>Ultimate</th>
<th>Ultimate with Max Pumping</th>
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<tr>
<td>Black Ck below Acton</td>
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<td>2.30</td>
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<td>0.46</td>
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<td>17.0</td>
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<td>19.0</td>
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<tr>
<td>Silver Ck at Norval gauge</td>
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### Table 3.4.3 Modelled 2 Year 7-Day Low Flow for Each Development Scenario

<table>
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<tr>
<th>Location</th>
<th>Hyd #</th>
<th>Existing</th>
<th>Interim</th>
<th>Ultimate</th>
<th>Ultimate with Max Pumping</th>
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<td>0.12</td>
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### Table 3.4.4  Modelled Avg Annual Streamflow for Each Development Scenario

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<th>Ultimate with Max Pumping</th>
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### Table 3.4.5  Modelled Average Annual Runoff for Each Development Scenario

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<th>Existing</th>
<th>Interim</th>
<th>Ultimate</th>
<th>Ultimate with Max Pumping</th>
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<td>Black Ck below Acton</td>
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<td>150.9</td>
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<td>32.7</td>
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</tr>
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Table 3.4.6  Modelled Average Annual Baseflow for Each Development Scenario

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<th>Ultimate with Max Pumping</th>
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Table 3.4.7  Modelled Avg Annual Infiltration Lost for Each Development Scenario

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<th>Ultimate with Max Pumping</th>
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Table 3.4.8  Modelled 50% Avg Annual Flow Duration for Each Development Scenario

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<th>Existing</th>
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<th>Ultimate</th>
<th>Ultimate with Max Pumping</th>
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Table 3.4.9  Modelled Evapotranspiration for Each Development Scenario

<table>
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<tr>
<th>Location</th>
<th>Hyd #</th>
<th>Existing</th>
<th>Interim</th>
<th>Ultimate</th>
<th>Ultimate with Max Pumping</th>
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<tbody>
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</tr>
<tr>
<td>Silver Ck at Sideroad 4</td>
<td>1101</td>
<td>522.8</td>
<td>522.8</td>
<td>463.8</td>
<td></td>
</tr>
<tr>
<td>Silver Ck u/s Snows Ck</td>
<td>4237</td>
<td>522.5</td>
<td>521.8</td>
<td>467.7</td>
<td></td>
</tr>
<tr>
<td>Snows Ck at Sideroad 4</td>
<td>1105</td>
<td>526.8</td>
<td>522.1</td>
<td>463.6</td>
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</tr>
<tr>
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<td>4239</td>
<td>524.0</td>
<td>518.4</td>
<td>466.9</td>
<td></td>
</tr>
<tr>
<td>Snows Ck outlet Sub 1109</td>
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<td>513.6</td>
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<td></td>
</tr>
<tr>
<td>Snows Ck outlet at Silver Ck</td>
<td>4242</td>
<td>519.9</td>
<td>513.6</td>
<td>457.2</td>
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</tr>
<tr>
<td>Silver Ck d/s Snows Ck</td>
<td>4243</td>
<td>521.7</td>
<td>519.3</td>
<td>464.5</td>
<td></td>
</tr>
<tr>
<td>Silver Ck at outlet Sub 1113</td>
<td>4244</td>
<td>521.2</td>
<td>519.0</td>
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<td></td>
</tr>
<tr>
<td>Silver Ck at Sideroad 22</td>
<td>4245</td>
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<td>517.1</td>
<td>469.1</td>
<td></td>
</tr>
<tr>
<td>Silver Ck at outlet Sub 1117</td>
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<td>517.9</td>
<td>515.7</td>
<td>468.7</td>
<td></td>
</tr>
<tr>
<td>Silver Ck u/s Black Ck confluence</td>
<td>4247</td>
<td>516.0</td>
<td>512.6</td>
<td>468.5</td>
<td></td>
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<td>Silver Ck d/s Black Ck confluence</td>
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<td>504.7</td>
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<td>Silver Ck d/s subcatchment 1121</td>
<td>4249</td>
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<td>503.7</td>
<td>488.3</td>
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<tr>
<td>Silver Ck at Mountainview Road</td>
<td>4251</td>
<td>505.1</td>
<td>502.9</td>
<td>487.7</td>
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<tr>
<td>Silver Ck at Norval gauge</td>
<td>4250</td>
<td>504.0</td>
<td>501.8</td>
<td>486.9</td>
<td></td>
</tr>
</tbody>
</table>
3.4.2 Land Use Scenarios and Changes in Groundwater

Changes in hydrogeological conditions (indicators) due to changes in land use associated with Scenario 2 (Interim Conditions) and Scenario 3 (Ultimate) conditions include changes in groundwater recharge, groundwater discharge, water table elevations and groundwater flow directions. Additional changes in these indicators are predicted with increased pumping from existing wells and ultimate land use conditions in Scenario 3b.

Interim Conditions (Scenario 2)

Figure 3.4.1 shows the groundwater head contours for model layer 4, (Contact zone) as well as the change in groundwater flux, in and out of the subwatershed, and the change in baseflow for each subcatchment as a percentage of the current conditions. This figure should be compared to the current conditions presented in Figure 3.3.3.

Interim conditions simulate an increase in settled land use in the Georgetown area and in the vicinity of Ballinafad. These changes have a low impact on the water table and groundwater flow directions as a result of the relatively low permeability Halton Till deposits and underlying Queenston shale deposits that predominate the geology in the area. It is important to note that local variations do occur, due in large part to the heterogeneity of the buried valley deposits below the escarpment. Groundwater discharge is reduced downstream of Ballinafad in subcatchment 1115 and other smaller reductions are observed around Ballinafad. Little change in baseflow is predicted in the Georgetown area due to changes in land use. The reduction in recharge and the expected reduction in baseflow is not observed in these areas as the groundwater discharge in these subcatchments is maintained by recharge that occurs in Subwatershed 10. Impacts in Subwatershed 6, 9, and 12 are also observed as less water leaves Subwatershed 11. However, local conditions will have to be evaluated through this subwatershed study.

Ultimate Conditions (Scenario 3)

Figure 3.4.2 shows the groundwater head contours for model layer 4, (Contact zone) as well as the change in groundwater flux, in and out of the subwatershed, and the change in baseflow for each subcatchment as a percentage of the current conditions. This figure should be compared to the current conditions presented in Figure 3.3.3.

Ultimate conditions simulate a large increase in the settle land use category as all agricultural area above the escarpment is replaced by settled area. The ultimate conditions show increased impacts in areas that were impacted in Scenario 2. However, the impacts on the water table and groundwater flow directions are generally small but indicate an impact. Groundwater discharge is further reduced in the Ballinafad area and Georgetown areas. Increases in settled area above the escarpment are predicted to have a measurable impact on groundwater discharge. In these areas recharge is derived locally through more permeable materials compared to the low permeability materials in the Georgetown area. Therefore the reduction in recharge from settlement under Scenario 3 is simulated to measurably reduce baseflow above the escarpment.
Under the conditions of Scenario 3 the groundwater discharge (baseflow) is maintained in Georgetown by water that recharges in subwatershed 10, despite a decrease in local recharge resulting from development.

**Ultimate Conditions and Increased Pumping Volumes (Scenario 3b)**

Figure 3.4.3 shows the groundwater head contours for model layer 4, (Contact zone) as well as the change in groundwater flux, in and out of the subwatershed, and the change in baseflow for each subcatchment as a percentage of the current conditions. This figure should be compared to the current conditions presented in Figure 3.3.3.

The land use conditions in Scenario 3b are identical to Scenario 3 but municipal pumping well volumes in Georgetown are simulated at the maximum permitted rate rather than the current average rate. Throughout the watershed, the water table and groundwater flow directions are generally consistent with current conditions. Groundwater discharge above the escarpment shows similar impacts to Scenario 3 as no municipal wells are simulated in this area.

Below the escarpment in the vicinity of the municipal wells the water table and groundwater flow directions are modified by the increased pumping. For example, the area west of subcatchment 1117 shows a minor water table depression but more importantly a reversal in groundwater flow direction. A significant decrease in groundwater discharge is observed in the Georgetown area. Subcatchment 1117, which is currently a net losing stream section, shows a 58% increase in water lost from the river and recharging the aquifer.

The decrease in groundwater discharge in the Georgetown area that was compensated for in other scenarios by recharge in Subwatershed 10 is not available in Scenario 3b. At the maximum pumping rates recharge from Subwatershed 10, a large proportion of which is transmitted by the buried valley, is intercepted by the pumping wells. The combined effect of recharge reduction in Georgetown from land use changes and the increased extraction from pumping wells exceeds the capacity of the buried valley to supply water to the maintain baseflow and significant impacts are observed. Impacts in Subwatershed 6, 9, and 12 are also observed as less water leaves Subwatershed 11.
Figure 3.4.1: Groundwater flow (Scenario 2)

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982; Waterloo Hydrogeologic, 2002
Figure 3.4.2: Groundwater flow (Scenario 3)

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982; Waterloo Hydrogeologic, 2002
Figure 3.4.3: Groundwater flow (Scenario 3b)

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982; Waterloo Hydrogeologic, 2002
3.4.3 Relative Sensitivity of Surface Water & Groundwater to Development Scenarios

The surface water hydrology of the main stem of Silver Creek is very sensitive to the development scenarios, particularly peak flows resulting from large runoff events (e.g. Regional, 100 year and 2 year storms). The 7-day low flows and baseflows are relatively insensitive for the whole subwatershed, but in local areas (e.g. Subcatchment 1105, 1107), the impacts are very sensitive.

The surface water system of Silver Creek is generally more sensitive than the groundwater system. However the discharge/baseflow is considered moderately to highly sensitive to changes in land use in a number of subcatchments above the escarpment where recharge is moderate to high and low flow volumes are observed (subcatchments 1101, 1103, 1105, 1107, 1109, 1113, and 1115). Groundwater discharge/baseflow is also considered to be highly sensitive due to large groundwater takings in the vicinity of Georgetown and seasonal fluctuations in net gaining and losing conditions (subcatchments 1119, 1121, 1123, 1125). As the level of development proceeds the sensitivity increases.

The groundwater flow direction and the water table elevation are highly sensitive to increases in large groundwater takings in the vicinity of Georgetown (subcatchments 1117, 1119). As pumping rates are increased the sensitivity increases. In subcatchments 1107, 1109, 1111, 1113, and 1115 local groundwater flow directions and water table elevation are considered moderately sensitive to land use changes, which are likely to directly affect the wetlands that are located in these subcatchments.

3.5 Water Balance

The following sections provide a description and an example of how a water balance calculation can be used to identify impacts due to land use changes. The example shown for illustrative purposes as the scale of assessment for the subwatershed study does not allow for this site-specific level of analysis. This section is intended to remind the reader of the impact of water balance as more detailed work is completed at the subcatchment and site level scale of analysis.

3.5.1 Hydrologic Cycle

The hydrologic cycle (See Figure 3.5.1) is a continuous cycle of precipitation, evaporation, transpiration, condensation and again precipitation. Precipitation includes both snowfall and rainfall. Evaporation occurs mainly from lakes, rivers, oceans, or ponded water. Transpiration is process whereby the moisture evaporates from plant surfaces. Evapotranspiration is the collective term for all the processes resulting the cycling of liquid or solid phase water to vapour in the atmosphere.
Water may follow several routes between precipitation and evaporation / transpiration. Water that falls on land can evaporate or transpire immediately, or runoff directly to streams/lakes/oceans where evaporation occurs. Also, water can infiltrate into the ground and seep back to streams/lakes/oceans or become groundwater storage.

In addition, human intervention through water takings, water discharges, and land surface changes can impact significantly on the regional and local components of the hydrologic cycle. Significant impacts can also affect the quality of the water thereby affecting the suitability of the water for domestic purposes or impacting the natural environment.

**Figure 3.5.1 The Hydrologic Cycle**

**Precipitation** - includes both rain and snow;  
**Interception** - water that is held above the ground and eventually evaporates to the atmosphere;  
**Depression Storage** - water confined to topographic depressions and empties by evapotranspiration and infiltration;  
**Evapotranspiration** - is the evaporation from all soil, snow, ice and other surfaces plus transpiration from plants; Potential evapotranspiration would occur for unlimited water supplies;  
**Soilwater Storage** - detention or retention of water in the pores of soil or rock; soilwater storage moves downward and contributes either to subsurface storm flow (discharges to a stream) or to groundwater storage; water that is held by capillary forces is called capillary water storage and depletes by evapotranspiration;  
**Streamflow** - is composed of overland runoff, sub surface storm flow, and groundwater flow;  
**Overland Runoff** - water that flows to a defined stream;  
**Groundwater Flow** - contributes to streamflow during non runoff and sub surface storm flow periods;  
**Infiltration** - entry of water downward through the soil;  
**Water Takings** - for agricultural, domestic and industrial water supplies;  
**Sewage Discharges** - from several sources including storm sewers, and wastewater treatment plants.
3.5.2 Water Balance Use

A water balance can be used to determine the changes to portions of the hydrologic cycle that result from urban development. Water balance refers to the inflow of precipitation and the outflow from evapotranspiration. Once precipitation and evapotranspiration have been computed, other moisture parameters such as water surplus, water deficit, soil moisture storage and water runoff can be determined using hydrologic/hydrogeologic methodologies.

When the impacts of urban development are significant, water balance methods can be used to determine amounts of water that should be infiltrated to compensate for reductions caused by large paved areas or changes to vegetation. Impacts can be significant when reductions in infiltration reduce the amount of water that can be extracted for domestic and agricultural water uses or when reductions baseflow impair aquatic habitats. Water balance methods should be calibrated and verified wherever possible.

The water balance method developed by C. W. Thornthwaite and J.R. Mather (1957) determines the potential and actual amounts of evapotranspiration and water surplus. Infiltration factors are used to determine the fraction of water surplus that infiltrates into the ground and the fraction that runs off to nearby streams. Thornthwaite and Mather’s method requires monthly or daily precipitation, monthly or daily temperature, latitude of the site, vegetation type, soil type, and a series of tables. The tables define a heat index, potential evapotranspiration, water holding capacity, and soil moisture retention. Snowfall, and alternating wet and dry cycles are included. Soil water holding capacity is dependent upon the soil type, soil structure and the type of vegetation growing on it. Porous soils will tend to hold less water than silts or clays and deep rooted vegetation will hold more water than shallow rooting vegetation. The Thornthwaite and Mather water balance method assumes mature vegetation and does not account for growing seasons where evapotranspiration would be less for immature vegetation.

Water Balance - An Example

Water balance computations should be calculated on a site-by-site basis. Table 3.5.1 shows the results of a water balance for various vegetation types in different soil types for a basin in southern Ontario with a latitude of 45°. Infiltration factors were calculated for each soil and vegetation type and were determined for rolling land. More details on infiltration factors can be found in the Hydrogeological Technical Information Requirements for Land Development Applications (Ontario Ministry of the Environment).

The results shown in Table 3.5.1 below were computed using average annual monthly values. More accurate answers would be obtained using monthly recorded precipitation and temperature for a period of 10 to 20 years. The accuracy of the water balance results could be further improved if daily precipitation and temperature values were used.
## Table 3.5.1  Hydrologic Cycle Component Values

<table>
<thead>
<tr>
<th>Water Holding Capacity (mm)</th>
<th>Hydrologic Soil Group</th>
<th>Precipitation (mm)</th>
<th>Evapotranspiration (mm)</th>
<th>Runoff (mm)</th>
<th>Infiltration* (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Urban Lawns / Shallow Rooted Crops (spinach, beans, beets, carrots)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Sand</td>
<td>50</td>
<td>A</td>
<td>940</td>
<td>515</td>
<td>149</td>
</tr>
<tr>
<td>Fine Sandy Loam</td>
<td>75</td>
<td>B</td>
<td>940</td>
<td>525</td>
<td>187</td>
</tr>
<tr>
<td>Silt Loam</td>
<td>125</td>
<td>C</td>
<td>940</td>
<td>536</td>
<td>222</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>100</td>
<td>CD</td>
<td>940</td>
<td>531</td>
<td>245</td>
</tr>
<tr>
<td>Clay</td>
<td>75</td>
<td>D</td>
<td>940</td>
<td>525</td>
<td>270</td>
</tr>
<tr>
<td><strong>Moderately Rooted Crops (corn and cereal grains)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Sand</td>
<td>75</td>
<td>A</td>
<td>940</td>
<td>525</td>
<td>125</td>
</tr>
<tr>
<td>Fine Sandy Loam</td>
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<td>B</td>
<td>940</td>
<td>539</td>
<td>160</td>
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<tr>
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<td>940</td>
<td>543</td>
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<tr>
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<td>940</td>
<td>543</td>
<td>218</td>
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<tr>
<td>Clay</td>
<td>150</td>
<td>D</td>
<td>940</td>
<td>539</td>
<td>241</td>
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<tr>
<td><strong>Pasture and Shrubs</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Sand</td>
<td>100</td>
<td>A</td>
<td>940</td>
<td>531</td>
<td>102</td>
</tr>
<tr>
<td>Fine Sandy Loam</td>
<td>150</td>
<td>B</td>
<td>940</td>
<td>539</td>
<td>140</td>
</tr>
<tr>
<td>Silt Loam</td>
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<td>940</td>
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<td>177</td>
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<tr>
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<td>546</td>
<td>197</td>
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<tr>
<td>Clay</td>
<td>200</td>
<td>D</td>
<td>940</td>
<td>543</td>
<td>218</td>
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<tr>
<td><strong>Mature Forests</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Sand</td>
<td>250</td>
<td>A</td>
<td>940</td>
<td>546</td>
<td>79</td>
</tr>
<tr>
<td>Fine Sandy Loam</td>
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<td>940</td>
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<td>118</td>
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<tr>
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<tr>
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<td>940</td>
<td>550</td>
<td>176</td>
</tr>
<tr>
<td>Clay</td>
<td>350</td>
<td>D</td>
<td>940</td>
<td>549</td>
<td>196</td>
</tr>
</tbody>
</table>

**Notes:** Hydrologic Soil Group A represents soils with low runoff potential and Soil Group D represents soils with high runoff potential. The evapotranspiration values are for mature vegetation. Streamflow is composed of baseflow and runoff.

* Infiltration refers to total infiltration, some of which discharges back to the stream as base flow. The infiltration factor is determined by summing a factor for topography, soils, and cover.

**Topography**
- Flat Land, average slope < 0.6 m/km: 0.3
- Rolling Land, average slope 2.8 m to 3.8 m/km: 0.2
- Hilly Land, average slope 28 m to 47 m/km: 0.1

**Soils**
- Tight impervious clay: 0.1
- Medium combinations of clay and loam: 0.2
- Open Sandy loam: 0.4

**Cover**
- Cultivated Land: 0.1
- Woodland: 0.2
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Precipitation = Evapotranspiration + Streamflow (Runoff + Baseflow (Infiltration Discharged)) + Infiltration Lost from the Subwatershed

Total Infiltration = Infiltration Discharged + Infiltration Lost from the Subwatershed

As shown in the following simple example, Table 3.5.1 can be used to determine infiltration amounts for varying land uses.

Example - Pre Development Conditions

• The site area is approximately 10.0 ha with pasture type vegetation in fine sand soil. The average annual site infiltration would be approximately 307 mm (Table 3.5.1) or approximately 30 700 m$^3$ (307 mm X 10.0 ha).

Example - Post Development Conditions

• Of the total site area 3.5 ha (35 %) would be converted to impervious area. The infiltration for this area would be 0 mm. The remaining 6.5 ha of the site (65 %) is assumed to be covered with urban lawns (shallow rooted crops) with an average annual infiltration of 276 mm or approximately 17 940 m$^3$ (276 mm X 6.5 ha). There would be a net reduction in infiltration of 12 760 m$^3$. If the reduction has a significant impact, then 12 760 m$^3$ may have to be infiltrated using BMP measures.

3.6 SUMMARY

3.6.1 Sensitivity

Sensitivity is defined as the capacity of the indicator to be subject to change. The purpose of Phase II of the subwatershed study is to use modeled land use change, based on potential for development, to stress environmental resources and anticipate environmental impacts. Areas that respond greatly to land use change are classified highly sensitive. Areas that will have little response to land use change are classified as having low sensitivity. The middle category is moderate sensitivity.

3.6.2 General Impacts

Impacts from unmanaged urban development are well documented and have been summarized previously in Chapter 2 of this report. The reader is reminded that the scale of analysis in this work has been conducted at a subwatershed scale. Impacts on a local scale can vary and must be analysed through further subcatchment or site specific work.
The characterization discussed in the Phase I report helps to understand the impacts identified in the modeling of land use scenarios 2 and 3. That is, the subwatershed was divided into 3 ecological units as follows:

**Unit 1** in the headwaters of Silver Creek acts as a major recharge and storage system for the underlying bedrock aquifer, the Amabel Formation.

**Unit 2** encompasses the reach of subwatershed from just upstream of the Niagara Escarpment to the base of the Escarpment. This is a very small, but extremely distinct unit from a hydrological and ecological perspective.

**Unit 3** begins at the base of the escarpment and continues downslope to the confluence of Silver Creek with the Credit River at Norval. This unit does not have the sheer volume of recharge and discharge compared to Units 1 and 2 respectively, but compensates by being the most complex, based upon the unusual interactions between groundwater and surface water.

Critical watershed ecosystem health indicators can include:
- Recharge areas not impervious;
- Protection of major wetlands;
- Contiguous and healthy riparian zone maintained;
- Critical discharge areas protected;
- Channel structure (for the most part) still in equilibrium; and
- Persistence of Heritage species (e.g. brook trout)

Many of the functions being carried out in Unit 1 influence conditions in Unit 2 and Unit 3. In addition, functions within Subwatershed 10 (Black Creek) influence portions of Silver Creek.

For surface water conditions, Subwatershed 10 does influence the portion of Silver Creek below 8th Line. The effects of urbanization on Subwatershed 10 have not been assessed in this work and should be evaluated when a subwatershed study is undertaken.

Within Subwatershed 11 under scenario 2, individual tributaries where growth is identified are more impacted than the main branch. Since very little land use change is expected in Unit 3, only localized impact was seen on individual tributaries in Unit 3.

For groundwater conditions, scenario 2, localized changes to baseflow may be observed in areas where land use changes occur. However, on a subwatershed scale, little change is observed in Unit 3 for two reasons. Land use changes, under this scenario, are not expected in Unit 1 (no disruption to recharge function) and no land use changes are expected in subwatershed 10, which provides most of the discharge to this area.

Under scenario 3 conditions, there is measurable impact on groundwater discharge in Unit 2 resulting from reduction in recharge in Unit 1 as a result of land use changes. The increased pumping rates result in changes to baseflow within Subwatershed 11 and
Subwatershed 12 as the recharge from Subwatershed 10 is picked up by the pumping wells.

In summary, at a subwatershed scale, some resiliency exists within the water resources of the subwatershed to allow for land use change. However, localized impacts can be expected in areas of growth which will have to quantified at a tributary level of analysis. There are limits to the amount of change the subwatershed water resources can sustain in a sustainable manner. These limits will have to be identified through work done for future updates to the subwatershed study.

3.6.3 Climate Change

Over the past few decades there has been a lot of debate and discussion about climate change. The amount of carbon in the atmosphere has been increasing (Environment Canada pers. comm) most likely as a result of burning fossil fuels. A by-product of burning fossil fuels is carbon dioxide, and it is possible that increased levels of carbon dioxide in the atmosphere will lead to entrapping more long wave radiation causing the surface of the earth to heat up. As consumption of fossil fuels has not subsided, production of carbon dioxide is expected to increase, and double by 2060 (Environment Canada, pers. comm). Models prepared by Environment Canada have predicted the impacts of doubling the amount of carbon dioxide on the earth’s atmosphere.

Possible effects and their impacts on Subwatershed 11 include:

- increasing the overall temperature;
- altered hydrologic cycle from increased water vapour held in a gaseous state in warmer atmosphere;
- milder winters that do not allow for an accumulation of snow, resulting in more flooding and less infiltration;
- more severe droughts resulting in lower baseflows and lake levels on a local scale which can stress fish and other animal populations;
- lower groundwater levels in years of drought; and
- more intense rainfalls resulting in more flooding and erosion.

It should be noted that the potential results of the greenhouse effect and global warming are debatable, and the aforementioned points are hypothesized. However, when planning activities in the future in the subwatersheds, it is recommended that trends in temperatures and water levels be consulted. Assumptions made with respect to climatic parameters in any of the phases of this study may not be valid in the future and must be revisited, as more information is available.
4.0 SUBWATERSHED SENSITIVITY

4.1 SENSITIVITY ANALYSIS

The Silver Creek subwatershed was broken up into smaller areas, called subcatchments. There are 13 subcatchments in Subwatershed 11, numbered 1101 to 1125 (Figure 2.0.1). A sensitivity analysis was completed for each subcatchment using the modeled land use scenarios described in section 3.2. Estimates of subwatershed sensitivity were made for 8 components; surface water hydrology (section 4.2), hydrogeology (section 4.3), hydraulics (section 4.4), terrestrial (section 4.5), stream morphology (section 4.6), water quality (section 4.7), benthics (section 4.8) and aquatics (section 4.9). Having the sensitivity evaluated sequentially by following the impact flow model, allows for consideration of the environmental effects of development as a sequence of changes or adjustments:

- large-scale subwatershed changes;
- smaller-scale tributary changes;
- changes in stream hydrology;
- changes in groundwater infiltration and baseflow recharge;
- changes in stream morphology;
- changes in stream water quality;
- changes in riparian zone stream habitat;
- changes in stream habitat (instream cover components, benthic invertebrates, channel morphology, thermal conditions); and
- changes in the stream's ecosystem.

The sensitivity of each tributary to the interim and two ultimate land use change scenarios was evaluated and is summarized for each study component (hydrogeology, hydrology, geomorphology, etc.) in Appendix I under the titles of

- tool
- indicator
- impact
- sensitivity
- objective (management objective)

An example of an analysis is presented in Table 4.1.1 for the ultimate scenario, for subcatchment 1107, for "indicators" and "impacts". The information presented in Table 4.1 is an excerpt of Appendix I. The following definitions were used:

**Tool:** The instrument(s) used by each discipline to investigate the effects of land use change.

**Indicator:** The "symptom" that will show a change. It is the parameter used to determine sensitivity.
Impact: The anticipated response or the magnitude of the response.

Sensitivity: The capacity of the indicator to be subject to change.

Objective: Defined targets for an area, which support subwatershed vision and goals. Objectives are measurable, realistic, and achievable.

The tools, indicators, impacts, sensitivity and objectives are unique for each discipline.

Table 4.1.1 Typical Impact Analysis - Subcatchment 1107 – Scenario 3

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Indicator</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogeology</td>
<td>• Groundwater Flow Direction</td>
<td>• Low</td>
</tr>
<tr>
<td></td>
<td>• Water Table Elevation</td>
<td>• Low</td>
</tr>
<tr>
<td></td>
<td>• Baseflow/Discharge</td>
<td>• Low</td>
</tr>
<tr>
<td>Hydrology</td>
<td>• 0% to ≤5% - low impact</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>• &gt;5% to 20% - moderate impact</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• &gt;20% - high impact</td>
<td></td>
</tr>
<tr>
<td>Geomorphology</td>
<td>• Bed – composition; aggradation/degradation</td>
<td>Moderate – minor increase in sediment transport, some aggr. Moderate – increasing width Low – migration and development sensitivity in wetlands</td>
</tr>
<tr>
<td></td>
<td>• Hydraulic geometry and enlargement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Migration/development</td>
<td></td>
</tr>
<tr>
<td>Terrestrial</td>
<td>Riparian:</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>• width and quality of vegetation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• changes to hydrologic regime</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Wetland:</strong></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>• changes to hydrologic regime</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• size and representation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• buffer width</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Upland</strong></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>• size and character of patch</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• community representation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• depth to water table</td>
<td></td>
</tr>
<tr>
<td>Water Quality</td>
<td>• Water temperature</td>
<td>Low impacts to water temperature</td>
</tr>
<tr>
<td></td>
<td>• Suspended solids</td>
<td>Moderate impacts to dissolved oxygen</td>
</tr>
<tr>
<td></td>
<td>• Total phosphorus</td>
<td>High impacts to suspended solids, total phosphorus and groundwater nitrate and chloride</td>
</tr>
<tr>
<td></td>
<td>• Dissolved oxygen</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Nitrate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Chloride</td>
<td></td>
</tr>
<tr>
<td>Aquatic</td>
<td>Fish species composition and Abundance or Biomass</td>
<td>High</td>
</tr>
</tbody>
</table>
4.2 HYDROLOGY

4.2.1 Tools

Development, whether urban, rural, or resource abstraction, can have significant impacts on the risk to life and property damage, and to the loss of resource use (domestic and agricultural water supplies, the natural environment, etc). Development impacts can be direct at the time of construction, or indirect through the hydrologic cycle over time.

The hydrologic cycle is the flow of water from precipitation, to evaporation, to condensation, and then back to precipitation. Between precipitation and evaporation the path can be through vegetation (evapotranspiration), through the ground (infiltration, groundwater etc), or over the surface (overland runoff, streams, rivers, etc.) to ponding areas (lakes, oceans, etc.). Streamflow is the combination of surface runoff and groundwater discharge. Not all of the infiltrated water discharges directly back to the stream, and is lost from the subwatershed. The flow of water through the hydrologic cycle is both temporal and spatially variable. Temporal as the process can take decades to complete one cycle and spatial in the sense that it occurs across the subwatershed.

Several tools were chosen to measure the impacts of development, including the following:

- 100 year peak flow rates;
- 2 year peak flow rates;
- 2 year low flow rate;
- average annual streamflow;
- average annual runoff;
- average annual baseflow; and
- infiltration that did not discharge back to the watercourse (change in groundwater flow direction).

Development impacts are best determined using measured data. Unfortunately, measurements usually assess impact once construction has taken place and the trade-off between development and the increased risk of property damage and the loss of resource use cannot be assessed until impacts have occurred. Hydrologic computer simulation modelling can be used to predict impacts that result from development and can be used to assess mitigation measures to minimize development impacts.

A computer simulation program was used to model the hydrologic cycle in the Silver Creek subwatershed. The model was calibrated and verified with recorded precipitation, stage measurements, and streamflow data. Data used in the calibration and verification of the model was recorded by external agencies, and subwatershed study team members. Some of the data had been recorded from as far back as the 1920's.

The hydrological model was used to predict the hourly values of evapotranspiration, runoff, infiltration, baseflow, infiltration lost from the subwatershed, and total...
streamflow. Average annual totals and average monthly values were determined for each of the hydrologic quantities over a 40-year simulation period.

Hydrologic quantities were predicted for different land use scenarios that represented existing conditions, hypothetical interim development, ultimate development, and ultimate development with maximum allowable pumping. For a description of how the land use conditions were developed, refer to section 3.2.

4.2.2 Indicators

Indicators were used to determine the degree of development impact on the hydrologic cycle. Impacts were categorized as low, moderate or high using the following definitions:

- 0 % to 5 % low hydrologic impact
- 6 % to 15 % moderate hydrologic impact
- > 16 % high hydrologic impact.

For example, if there was a change (plus or minus) resulting from development of between 0 % and 5 % in the average annual streamflow volume, then the hydrologic impact was considered low. The percentage change that was considered for low, moderate, and high impacts was based on the experience of the study team. Generally, changes in greater than 15% in any of the hydrologic cycle components will result in significant impacts with regard to the risk to life, property, and resource use. Aquatic and terrestrial life can be significantly impacted by changes of only 15 % in any of the hydrologic quantities.

4.2.3 Impact Assessment

Impacts on the hydrologic cycle were determined on a tributary (catchment) basis for each of the four development scenarios (existing, interim, ultimate, and ultimate with maximum pumping). Impacts were considered low, moderate, or high based on a change in any of the selected tools. These tools included 100 year peak flow rates, 2 year peak flow rates, 2 year low flow rate, average annual streamflow, average annual runoff, average annual baseflow, and infiltration that did not discharge back to the watercourse. If a change occurred to just one tool, then the hydrologic impact (low, moderate, high) for the catchment was determined using that tool. For instance, the 100 year peak flow rate changed by 20 % with only a 5% change in the volume of streamflow, the hydrologic impact for that basin would be high based on the peak flow rate change.

Generally, on a tributary basis, urbanization has the opposite hydrologic impacts than aggregate extraction. Urbanization without mitigation can increase the volume of runoff and reduces the volume of infiltration.

The change in any one catchment may not significantly impact the remaining subwatershed, and impacts will probably decrease as flow proceeds downstream through the subwatershed. However, the combined or cumulative change in all catchments within
a subwatershed can be very significant. In addition, tributary changes can be moderate or low but at an individual site level the changes could be high. Site level changes were not considered in detail as this document addresses subwatershed and tributary level changes. Also, tributary changes can be low if the predicted development area is small compared to the tributary area. An example is catchment 1113 where there are considerable natural areas that will not be developed.

Development Scenarios

Generally, the interim development scenario will have minor hydrologic impacts at the subwatershed level, but when considered at the individual tributary scale (or subcatchment level) the impacts can be significant. For example, the impact of development in the upper subcatchments (e.g. 1101 to 1117) on the 100 year peak flow is low, because the amount of interim development is low. However, in subcatchments 1119 to 1125, the amount of interim development is very high, and this is reflected in large changes (high impacts) to the 100 and 2 year peak flows. On the other hand, some interim development will occur within subcatchments 1107, 1109 and 1111, and so the increases in 2 year flows and mean annual streamflow are significant, even though there are minimal changes to the 100 year peak flow and the 7-day low flows.

Overall, the interim development scenario will have moderate to significant impacts at the local level. The ultimate development scenarios will have significant impacts throughout subwatershed 11.

4.2.4 Sensitivity

Generally, subwatershed 11 is very sensitive to changes in the hydrologic cycle (see Figure 3.5.1). Several important issues include the following:

- **Risk to Life and Property -** several buildings are located in the regulatory storm floodplain throughout Subwatersheds 11. Increases in peak flow rates would increase flood levels and potential flood damages and increase the risk to life. In addition, there are several small dams and ponds. Increases in the volume or the peak of runoff could increase the incidence of overtopping and the risk of embankment failure. Property damage includes crop damage or damages from longer ponding duration.

- **Resource Use -** several ponds rely on the ability to receive runoff in its natural state both from a quantity and quality perspective. Changes to either quantity or quality could reduce existing reliance on runoff for agricultural water supplies, irrigation, and aesthetics.

Refer to Appendix I for a break down of sensitivity by tributary.
4.3 HYDROGEOLOGY

4.3.1 Tools

The hydrogeology impact assessment tool is a three-dimensional subwatershed-scale numerical groundwater flow model developed using FEFLOW (WASY). To simulate the current groundwater conditions and to predict impacts of changes in land use and pumping, the model was calibrated to observed steady-state conditions using average annual measurements of:

- groundwater flow directions;
- water table elevations; and
- stream baseflow (groundwater discharge), estimated from streamflow measurements at spot locations and stream flow gauges.

The model incorporates architecture of the complex and variable geology in the Silver Creek subwatershed to accurately assess the impact of land use changes on the groundwater system. A detailed description of the model is presented in Appendix H of this report (see also Figure 1 in appendix H).

Changes in land use and groundwater pumping were simulated in FEFLOW as a changes in groundwater recharge and pumping well volumes, respectively. The recharge estimates were developed iteratively using output from GAWSER (the hydrology tool) and reconciliation of results with the groundwater model. The estimate of pumping volumes for Scenario 3b was based on the maximum permitted value for existing wells, which are generally, close the maximum capacity of the wells. Additional water supply may be necessary and the effect of new wells can be simulated based on these needs. However, Scenario 3b shows that pumping is an important consideration in assessing development impact.

4.3.2 Indicators

The indicators used to assess whether land use and pumping volume changes may impact the groundwater system are:

- stream baseflow (groundwater discharge);
- water table elevations; and
- groundwater flow directions.

**Stream Baseflow (Groundwater Discharge)**

The volume of baseflow is the other key indicator of groundwater impact that is easy to measure and is very sensitive from an impact perspective. The model was calibrated against the baseflow data from 24 spot flow locations along Silver Creek and its tributaries as well as with the Highway 7 WSC stream flow gauge. The calibration to
these data was performed with a relatively high level of accuracy with the model predicting baseflow values that fell near the centre of the observed range for all locations. Lower volume flows (upper reaches) were the most difficult to simulate but were simulated within the measured range (see appendix H).

The spot flow data are consistent with the WSC gauge data. The spot flow data is however representative of a single year. Additional monitoring data will allow for a better assessment of the range of baseflow at these locations. The observed values are at the same time suitable for model calibration as they provide a range of values throughout multiple periods of baseflow.

The baseflow generated within each subcatchment, in the calibrated model, was used as the existing conditions and the relative changes in baseflow under different land use change scenarios were compared against these values.

**Water Table Elevation**

The water table elevation is a useful indicator parameter since it is easy to monitor at specific points throughout the subwatersheds. It is also one of the most important parameters to measure change within the groundwater system throughout the subwatershed. A change in the water table elevation can affect the groundwater flow direction, the discharge to surface waters including baseflow and wetlands, and regional movement of groundwater between subwatersheds.

Utilizing the groundwater flow model, sensitivity analysis can be performed by varying the hydrogeologic parameters and land use activities to determine the relative changes in the water table throughout the system. There is approximately 170 m variation in the water table elevation throughout the area modeled. A five percent accuracy in the calibration of the model would be considered good, however this still translates into a range of error of up to ± 8.5 m at any specific location. The calibrated model has accuracy on the order of ±5 m, which is considered good for a subwatershed-scale model. Additional monitoring information and local scale information would be necessary to calibrate the model to local conditions if the goal of modelling is to assess local scale problems, such as Wellhead Protection areas. This additional data would improve the representation of the water table at the local-scale.

The subwatershed-scale assessment calculates the relative change in water levels at specific locations and determines which areas are more sensitive to change and what type of land use change causes the greatest change in water levels. Figure 3.3.3 shows the simulated water table contours for the existing water table conditions, and the relative change under the three development scenarios is shown in Figures 3.4.1-3.4.3.

**Groundwater Flow Directions**

Groundwater flow directions are dictated by surface and subsurface topography and water inputs to the system. The water table or hydraulic head elevation in each
A comparison of net groundwater flow direction and net volume (considering each model layer) was used as an indicator of groundwater flow impacts under a development scenario. Figures 3.3.3 illustrates the existing groundwater flow directions and magnitudes into and out of each of the subcatchments. The contours also indicate the direction of flow (high to low) but are only representative of one layer in the model (contact zone aquifer) and may not be representative of all layers. Figure 3.4.1-3.4.3 show the change in groundwater flow direction for each scenario compared to current conditions.

**4.3.3 Impact Assessment**

There are two approaches to describing the potential impacts related to the hydrogeologic component of the subwatershed system:

- Potential impacts on the groundwater system; and
- Potential impacts related to the use or function of the groundwater.

Determining the potential impacts on the groundwater system is really an estimation of the component response of the system to land use changes. In the case of the groundwater component, the changes are related to changes in the hydrologic cycle. Although there may be impacts to the hydrological cycle that are measurable, as described in the previous section, these impacts may not be important depending on the function or use of the groundwater and the sensitivity of this use or function. In other words, the potential impact of land use changes is more related to the use or function of the groundwater rather than the changes in the groundwater system itself. The impact of land use changes on the groundwater system; however, needs to be well understood in order to assess the impact of these changes on the function or uses of the groundwater.

As part of the impact assessment, sensitivity analyses were performed during calibration and testing of the model. As well, various simulations were performed for the existing conditions and interim land use scenarios to gain a better understanding of the sensitivity of the hydrogeologic system to specific aspects of land use changes. In particular, the extent and connectivity of buried bedrock valleys was determined to be a critical factor in the potential impact on changes to the hydrogeologic system. A number of different configurations were simulated to determine the type of configuration that created the greatest impact on the groundwater system.

The development and calibration of the model provided an understanding of the groundwater system. The criteria used to assess an impact on each indicator with the simulated land use change were developed in consideration of model accuracy and the
significance of the change as a proportion of the water balance for each subcatchment. The following presents the guidelines used in assessing the impact on each indicator:

**Change in Baseflow (Discharge to River)**
- low hydrogeologic impact: ± 0 to 4.9%
- moderate hydrogeologic impact: ± 5 to 9.9%
- high hydrogeologic impact: ≥ ±10%

**Change in Average Water Table Elevation**
- low hydrogeologic impact: 0 to 0.09 m
- moderate hydrogeologic impact: 0.1 to 0.9 m
- high hydrogeologic impact: ≥ 1.0 m.

**Change in Groundwater Flow Direction**
- low hydrogeologic impact: No observed change in flow direction
- moderate hydrogeologic impact: Minor Observed change
- high hydrogeologic impact: Major change including reversal of flow direction

The criteria for assessing impacts recognizes that seasonal variability could be greater than the impact observed from land use changes alone. However, only the impact from land use changes and increased pumping are being assessed and the cumulative effect of seasonal changes and land use and pumping induced impacts may result in an even greater impacts.

Impacts on groundwater quality were not modelled, as land use changes proposed are not specific as to potential contaminant sources. General potential non-point source impacts, such as nitrates and chloride, were considered and are discussed in Section 4.7. The aquifer vulnerability map (Figure 4.3.2), originally developed for Phase 1, provides a method for assessing impact of development on groundwater quality. Development should consider aquifer vulnerability when proposing locations for potentially contaminating activities in order to maintain groundwater quality. The relative estimate of vulnerability provides an indication of the likelihood of observing impacts on groundwater quality if a contaminant releases at or beneath the ground surface.

Table 4.3.1 lists the five classes of intrinsic vulnerability shown on map 4.3.2, which are based on travel times. The classes are based on typical values used in Wellhead Protection studies, such as those conducted by the Regional Municipality of Waterloo (Waterloo Hydrogeologic, Inc., 1995: Waterloo Hydrogeologic, Inc., 2000). The user of this map is cautioned to keep the following limitations in mind.

1. The travel time estimate may not be representative of contaminants that are more or less dense than water, those that interact with the soil, or those that are naturally degraded since the travel time assumes the contaminant has the mobility of water.
2. Contaminant transport considerations such as concentration, sorption and degradation are not accounted for, as these are contaminant specific and should be evaluated at a local scale or in a specific vulnerability analysis.

3. The travel time estimate is presented in years. This estimate is subject to the previously presented approximation that allows classification of relative aquifer vulnerability.

<table>
<thead>
<tr>
<th>Table 4.3.1 Aquifer Vulnerability Class Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intrinsic Vulnerability Class</strong></td>
</tr>
<tr>
<td>Class 1</td>
</tr>
<tr>
<td>Class 2</td>
</tr>
<tr>
<td>Class 3</td>
</tr>
<tr>
<td>Class 4</td>
</tr>
<tr>
<td>Class 5</td>
</tr>
</tbody>
</table>

### 4.3.4 Sensitivity

Sensitivity of the hydrogeologic system and its function and use are derived for each subcatchment and presented in Appendix I. Sensitivity values were assigned based on the impacts observed in the previous section, and the likelihood that the indicator may change function under a given stress (land use/development scenario). Sensitivity is assigned as:

1 – “low” or small capacity for indicator to change function (e.g. change from gaining to losing conditions)
2 – “moderate” or a approaching a condition where function may change under stresses
3 – “high” or a likelihood that function will change (e.g. recharge area becomes discharge area).

Groundwater discharge/baseflow sensitivity is assessed by comparison of existing function, net gaining or net losing stream subcatchment. If a subcatchment is currently net gaining then the sensitivity of discharge/baseflow is assessed according to whether or not the proposed land use change is likely to reduce recharge sufficiently to induce a net losing condition. Areas of low discharge and high recharge (headwaters) are inherently more sensitive to land use changes than areas of low discharge and low recharge (till areas below escarpment). However, if large pumping exists in these low recharge areas the sensitivity will increase, as a greater quantity of water is intercepted that would have previously discharged.
Most of the proposed development (Scenarios 2) exists in areas where the amount of recharge contributed to the system is already low based on the existence of low permeability materials at surface (Georgetown). However in Scenario 3, 3b additional development is proposed in the headwaters resulting in greater baseflow sensitivity as stresses increase. Increases in groundwater pumping (Scenario 3b) cause significant to unacceptable impacts in the subcatchments below the Escarpment in the Georgetown area. Increases in pumping greatly affect the function of the groundwater system in these areas, as baseflow will be reduced by pumping that will affect other components such as fish species. The buried bedrock valley provides the largest volume of water from Subwatershed 10 into Subwatershed 11 and out to Subwatersheds 6, 9, and 12. With the land use changes and increased pumping, flow through is reduced as the capacity of the buried valley to supply water is exceeded and discharge is reduced in Subwatershed 11 and at the Credit River (Subwatershed 6, 9, 12).

The sensitivity of water table elevation is assessed by comparison of existing function, recharge or discharge conditions. This indicator is less sensitive than groundwater discharge/baseflow as land use changes alone may not change the overall function of the water table at the subcatchment scale. Subcatchments affected by large pumping wells (1117, 1119, 1121, 1123, 1125) have greater water table sensitivity than other subcatchments. In subcatchments with significant wetland area (1107, 1109, 1111, 1113, and 1115) the water table elevation is more sensitive to development as land use changes may often affect the function of wetlands, which control the water table elevation locally.

The sensitivity of groundwater flow direction is assessed by comparison of existing function, moving water into or out of the subcatchment. This indicator is most sensitive in subcatchments affected by large groundwater pumping where a reversal in groundwater flow direction is observed. As pumping increases the groundwater flow direction in a catchment may become more sensitive. The capacity of the groundwater flow direction to change is tied to changes in water table elevation. Where a significant change in groundwater flow direction is observed you are likely to see a significant change in the water table elevation. However the reverse is not always true.

Pond construction and aggregate extraction below the water table (not simulated explicitly, considered local scale, not subcatchment scale) may increase the sensitivity of all three indicators as potential discharge is intercepted and the flow directions and water table are modified locally.
Figure 4.3.2: Aquifer Vulnerability

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

Refer to Appendix J for a detailed hydraulics report, including raw data and analysis.

4.4.1 Tools

Development, whether urban, rural, or resource abstraction, can have significant impacts on the risk to life and property damage, and to the loss of resource use (domestic and agricultural water supplies, the natural environment, etc.). Development impacts can be direct at the time of construction, or indirect over time.

Runoff hydraulics has many characteristics that can be used to determine the impact of development. Included are water surface levels, flood plain and channel storage, flow capacities, flow velocities, flow depths, flow widths, number and frequency of inundated buildings, frequency of road overtopping, Regulatory Flood Plain area, and culvert capacity.

The following characteristics or tools were chosen to determine the impact of new development:

Where Small Scale Topographic Maps Exist

- Water Surface Elevations
- Number of Inundated Buildings

Where Small Scale Topographic Maps Do Not Exist

- Ratio of Flow Rate to Culvert Capacity

The tools were divided into two (2) categories to reflect the existence of small scale topographic maps that can be used to derive the hydraulic characteristics required to determine hydraulic impacts. Flood Plain maps with a scale of 1:2,000 has been conducted in the lower reaches of Silver Creek through Georgetown. The mapping and supporting hydraulic computer simulation models are sufficient to determine water surface elevations, and the number of inundated buildings. Ontario Base Mapping at a scale of 1:10,000 has been completed throughout the entire Silver Creek watershed. The scale of mapping is not sufficient to allow the calculation of water surface elevations, flood plain areas, flow depths, flow velocities, flow widths, and flood plain storage. Culvert capacities can be calculated with data from the field inventories.

The impact of new development on public safety can be reflected by the change in the number of buildings within the Regulatory Flood Plain. The risk to property can be reflected increases in water surface elevations. Although the number of buildings within the Regulatory Flood Plain may not change, the frequency of flooding maybe increased.

For areas without small-scale topographic mapping, the impact of new development is difficult to determine because of the lack of suitable topographic information to
determine hydraulic characteristics. We have chosen the ratio of peak flow rate to culvert capacity as a tool for lack of better information. Culvert data is easily obtained, and culvert capacities can be estimated from field data.

### 4.4.2 Indicators

Indicators were used to determine the degree of development impact on the risk to life, property damage, and on resource use. We have used the following indicators to determine the impact of new development:

<table>
<thead>
<tr>
<th>Where Small Scale Maps Exist</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Surface Elevations</td>
<td>&lt; 0.05 m</td>
<td>0.05 - 0.30 m</td>
<td>&gt; 0.30 m</td>
</tr>
<tr>
<td>Number of Inundated Buildings</td>
<td>0</td>
<td>1 - 2</td>
<td>&gt; 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Where Small Scale Maps Do Not Exist</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of Flow Rate to Culvert Capacity</td>
<td>&lt; 1.0</td>
<td>1.1 - 1.5</td>
<td>&gt; 1.5</td>
</tr>
</tbody>
</table>

The three (3) categories of impact considered are low, medium, and high. The categories and impacts were based on the experience of the Study Team. The indicators above reflect the impact to the risk to life, and property damage. The impact to existing development can be significant if just 1 additional building is flooded, and if the frequency of flooding is just slightly increased. New development will have a significant impact if flooding that once began at the 10 year return period is increased to the 5 year return period or 1 return period shift. Flooding adjacent to culverts / bridges is very sensitive to discharge capacity. If peak flow rates are increased by only 10%, there could be a significant change to the upstream flood plain and to flow depths.

### 4.4.3 Impact Assessment

**Existing Conditions**

A total of three (3) buildings were identified as being located in the Regulatory Flood Plain (Figure 4.4.1):

- One (1) building is located adjacent to Silver Creek north of Maple Avenue;
- One (1) building is located adjacent to Silver Creek upstream of 22nd Sideroad; and
- One (1) building is located adjacent to Snows Creek upstream of Townline in Ballinafad.

Flow characteristics have not been significantly altered along Tributary 1, Snows Creek, and Tributary 2 except in the vicinity of road / rail crossings. Flow characteristics have
been altered adjacent to Silver Creek through Georgetown, specifically in the vicinity of road / rail crossings.

Flood damages have not been significant along any of the watercourses in Subwatershed 11. There are potentially only three (3) buildings located in the Regulatory Flood Plain along Silver Creek, Tributary 1, Snows Creek, and Silver Creek.

Generally, the change in any one catchment is probably the result of increases in peak flow rates that propagate in a downstream direction. The impact of those changes decrease as drainage area increases.

The major urban area, Georgetown, is located in the downstream portion of the Silver Creek watershed. As development increases through Georgetown and in an upstream direction, potential hydraulic impacts will increase. The upstream areas will only experience significant change in the ultimate land use scenario.

Generally, the interim development scenario will only have significant hydraulic impacts through Georgetown. Impacts are the difference between existing and developed land use conditions. Hydraulic impacts for the ultimate development scenario will be significant for entire Silver Creek subwatershed.

Hydraulic impacts were determined on a tributary (catchment) basis for interim and ultimate development scenarios by comparing hydraulic characteristics to existing conditions. Impacts were considered low, moderate, or high based on a change in any of the selected tools. Tools included the ratio of flow rate / culvert capacity for areas without small scale topographic mapping, and water surface elevations for areas with small scale mapping. The number of buildings within the Regulatory Flood Plain were used as an additional tool for small scale topographic mapping areas.
Interim Conditions

Impacts for each catchment within the Silver Creek subwatershed under interim development conditions are shown in Table 4.4.1.

For sub catchments upstream of Georgetown, impacts are expected to be low. For sub catchments through Georgetown, impacts are expected to be high. Water surface elevations are expected to increase by over 0.3 m.

Ultimate Conditions

Impacts for each catchment within the Silver Creek subwatershed under ultimate development conditions are shown in Table 4.4.1. Water surface elevations are expected to rise by over 0.3 m throughout the Silver Creek watershed. Significant flood damages are expected through Georgetown.

Table 4.4.1 Hydraulic Impacts

<table>
<thead>
<tr>
<th>Sub-Catchment</th>
<th>Interim Conditions</th>
<th>Ultimate Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Buildings</td>
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<tr>
<td></td>
<td>Water Within the</td>
<td></td>
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<td></td>
<td>Surface Elevations</td>
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<tr>
<td></td>
<td>Regulatory Flow</td>
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<td></td>
<td>Rate to Flood</td>
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<td></td>
<td>Plain Culvert</td>
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<td></td>
<td>Capacity</td>
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<td></td>
<td>Buildings</td>
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<td></td>
<td>Water Within the</td>
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<tr>
<td></td>
<td>Surface Elevations</td>
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<tr>
<td></td>
<td>Regulatory Flow</td>
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</tr>
<tr>
<td></td>
<td>Rate to Flood</td>
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</tr>
<tr>
<td></td>
<td>Plain Culvert</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Capacity</td>
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</tr>
</tbody>
</table>

4.4.4 Sensitivity

Generally, the lower portions of the Silver Creek watershed (Georgetown) are very sensitive to new development. Sensitive issues include the risk to life and property. Increases in peak flow rates would increase flood levels, potential building flood damages, and road overtopping that increases the risk to life. Property damage would include building damages and the loss of land that results from stream erosion. Stream erosion will increase as flow velocities increase.
4.5 Terrestrial

4.5.1 Tools

Impacts to the terrestrial system from land use change may be direct (e.g. tree clearing) or indirect (e.g. a drop in the water table). In either case, the Community Diversity and Ecological Integrity of the affected natural area is likely to experience an adverse impact or impacts. A key concept related to the management of ecosystems is that biological diversity, or biodiversity, is the basis for their sustainability over time (Margules and Usher, 1981, Payne and Bryant, 1994). Biodiversity can be defined as the variability among organisms and the ecological complexes of which they are a part (United Nations Convention on Biodiversity, 1992 cited in Riley and Mohr, 1994). Riley and Mohr have also stated that, "to a large extent, the fate of an ecosystem is determined by its biodiversity".

Biodiversity can be measured at several scales. The analysis of terrestrial communities through this subwatershed plan, while supplemented with field data, is primarily carried out at the landscape scale. This in fact may be the preferred scale, given that ecosystems are "open" systems (with the exchange of energy, nutrients and species), versus the study of single sites (Noss, 1983, Harris, 1984, Payne and Bryant, 1994). Accordingly, the following impact assessment is focused at the community or landscape level.

Landscape diversity is defined, in part, by descriptions of size, shape and the spatial arrangement of patches (Riley and Mohr, 1994). These are commonly referred to as “patch metrics”. (A patch can be defined as a cell or polygon, or several abutting cells or polygons, of natural area.) Research has generally supported the theory that there is a positive correlation between diversity and the stability or integrity of ecosystems (Margules and Usher, 1981, Riley and Mohr, 1994). The concept of "integrity" speaks to the resilience and balance of ecosystems maintained close to their natural state (Riley and Mohr, 1994). Maintaining the “biological integrity” of natural communities therefore relates to a large extent on our ability to maintain its various support systems. Changes to the biological, chemical and hydrological regime within or adjacent to a natural ecosystem, will ultimately result in changes to the features and functions associated with that ecosystem. It should be recognized, however, that change itself is part of natural system processes (e.g. succession).

The composition of plant communities reflects many variables that govern ecosystem functioning (Lotspeich, 1980). The focus of this impact assessment is the parameters or characteristics of the natural system upon which the vegetation (and in turn the natural habitat) depends. In particular, changes to the hydrologic regime and the matrix of patches in the landscape are assessed as indicators of change in the diversity and integrity of the natural communities that comprise the subwatershed’s terrestrial system. Three key community level systems are assessed at a landscape scale: riparian, upland forest and wetland. The general extent of the riparian zone is captured by the valley and stream corridors that were mapped and evaluated as part of Phase 1 of the subwatershed study.
The upland areas consist of the forest, plantation and cultural (i.e. old field) communities and the wetland areas consist of the swamps and marshes assessed in Phase 1.

### 4.5.1.1 Riparian

Beschta (MNR, 1994) has defined the riparian zone as those areas 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. The riparian zone or community is a very diverse and dynamic system, or ecotone, which straddles the boundary between the aquatic and upland systems. The aquatic system is very much dependent on the riparian zone and the direct and indirect influence it plays in governing the diversity, integrity and biological productivity of the stream (e.g. leaf fall and shading). To a large extent, riparian vegetation determines the health of the stream or river (Riley and Mohr, 1994). Riparian vegetation influences light and temperature regimes; exerts physical control over bank erosion, sediment routing, and channel morphology; contributes organic matter; and provides habitat and food for fish and other wildlife (Ward and Stanford, 1989). This zone also functions as a buffer to the stream by filtering shallow groundwater flows through root uptake, and attenuating overland runoff, which can contain excessive sediments and chemical contaminants. In addition, this ecotone contains not only species common to both systems (i.e. aquatic and upland), but may include a number of highly adaptable species that tend to colonize such transitional areas. It can also play a significant role as a wildlife corridor in fragmented landscapes. Because of this, the variety and density of life is often the greatest in such areas (Leopold cited by Smith, 1974, Forman, 1995).

The cardinal rule of riparian ecosystem management (and any ecosystem for that matter) is to protect the external forces that regulate the ecosystem (Brown et al., 1979). As reported by Goodwin and others (1997), water availability is the single most important factor controlling the growth of riparian vegetation. As would be expected, any impacts from changes in surface and subsurface hydrology would be most evident within and adjacent to the stream.

Typically, the riparian zone would be associated with the “natural flood plain” area. A key feature of riparian areas is that they are in a constant state of flux as water levels rise or fall, or simply flow through the reach. However, it should also be recognized that as a result of their adaptations to the intense changes in conditions that occur regularly in their natural environments, riparian communities tend to be relatively hardy and resilient (Daigle and Havinga, 1996).

4.5.1.2 Wetlands

It is widely recognized that wetlands are inextricably linked to both the surface and subsurface hydrology of a watershed. They both depend on it for their function, and in turn influence the hydrologic regime of a watershed by influencing the quality and quantity of water movement within the system (Roulet, 1998).

Wetland function is driven by many of the same hydrologic forces that exist in the riparian system. In fact, the riparian zone often contains vegetation typically found within wetlands. (For example, many of the willows and dogwoods are both found in riparian and wetland sites.) The riparian zone may in fact be coincident with the boundaries of a riverine wetland. Wetlands have been defined by the Ontario Government (1997) as *lands that are seasonally or permanently covered by shallow water, as well as lands where the water table is close to or at the surface. In either case the presence of abundant water has caused the formation of hydric soils and has favoured the dominance of either hydrophytic plants or water tolerant plants.*

In addition to the hydrologic drivers, wetland ecology is also significantly influenced by their physical setting, complexity and size. The surrounding landscape can have a considerable impact on a wetlands ecological diversity and integrity. The condition of adjacent lands is important in terms of mitigating potential impacts of up slope land uses. Adjacent non-wetland areas provide critical wildlife habitat for wetland species that must spend a portion of their life cycle on land (e.g. turtles). The representation of wetland types is also an important measure of their significance within a landscape. For example, if marshes are uncommon within a given area, even the very smallest marsh pocket may provide critical habitat for local waterfowl.

4.5.1.3 Upland

At the subwatershed or landscape scale impacts on upland systems are most effectively measured by physical or area related changes. In other words, the patches either gets larger or smaller, connected, or fragmented. As discussed in the Phase 1 Characterization Report, the characteristics of complexity, size, interior area, connectivity and shape of patches all serve as measures of their ecological diversity and integrity. The application of these landscape metrics in current practice has typically been focused on forested communities. In addition, to function and sustain themselves, forested landscapes must retain their natural biological flow patterns. Blocked or significantly altered water, nutrient, and energy flows can lead to forest ecosystem impoverishment (Hammond, 1997). The availability of water is critical to the healthy functioning of all plants. Too much water may be as detrimental as too little.
4.5.2 Indicators

4.5.2.1 Riparian

The riparian zone often provides habitat for a wide variety of wildlife species, including a range of amphibians, reptiles, birds and small mammals. In addition, it exercises considerable influence over the health of the adjacent aquatic system. The extent and condition of the riparian zone or buffer can therefore be considered a reasonable surrogate for a measure of its function in mitigating against adjacent stresses, and providing habitat. Generally, the greater the amount of natural area within the riparian zone or buffer, the better for the health of the aquatic system.

Information from the analysis carried out by several other components (hydrogeology, hydrology and fluvial geomorphology) will determine the characteristics of the adjacent channel, potential thresholds of change, changes in the interaction between riparian and flood plain zones, and the implications for management. It is widely recognized that hydrologic regime is the key external or forcing function that determines riparian vegetative composition, productivity and health. In particular, the more frequent 2 to 20 year floods have a considerable influence on the character of the riparian zone, affecting moisture levels, sediment deposition and nutrient availability. Flood frequency, and duration, are independent hydrologic factors known to affect vegetation patterns; they can be destructive or constructive depending on flow volume and velocity, the site conditions and the vegetation type (Szaro, 1991). The 2-year High Flow generated from the preceding hydrological analysis will be used to assess changes to flood frequency, duration, volume and velocity.

Vegetation and stream flow are normally in equilibrium, the plant species present in any reach being those that are adapted to tolerate both the mean annual flows and normal storm flows of the reach (Szaro, 1991). The extreme affects of flooding will stress the biotic community and reduce productivity. In contrast, seasonal flooding, characteristic of natural flood plains, generally increases productivity (Odum, 1979). As a rule, an increase in mean annual flows would have a negative affect on the riparian zone.

A major flood can destroy an existing riparian ecosystem, which may take decades to re-establish itself, depending on regional climatic conditions (Wolman and Gerson, 1978 cited by Goodwin et al., 1997). Floods remove and drown plants and cover them in sediment, in addition to scouring stream channels and root systems. Disruption of normal flow patterns results in changes in the development of riparian communities. In addition to increasing water levels, there is usually also increased turbulence, causing erosion of the surface (Szaro, 1991). The removal of the riparian vegetation can destroy a major food source, as well as habitat for a number of aquatic organisms. With the loss of its modifying influences, bank erosion and stream temperatures will increase.

The soils and sediments of riparian communities have characteristics that depend, in part, on the hydrological regime and the rate of supply and quality of the nutrient rich source material that is delivered from upstream and within the floodplain itself (Brown et al.,
In this regard, both increases and/or decreases in stream flow can have an adverse impact on the riparian system. Confinement of flood flows to the channel eliminates the periodic inundation of the flood plain, and thereby decreases the level of soil moisture and the availability of nutrients in the riparian zone. Channel shortening and steepening resulting from increased velocities, may cause the alluvial water table to drop, turning groundwater-dependent riparian ecosystems into drier, and likely less productive, upland types (Goodwin et al., 1997). This finding is supported by Ward and Stanford (1989), who report that groundwater levels, or the water table elevation, plays a major role in determining the composition and productivity of riparian and flood plain vegetation. They cite an example in Europe, where an increase in stream flow velocity resulted in a deepening of the channel. This in turn lowered the water table, causing the withering of riparian forests and the drying of backwaters. In general, the biomass and species composition of riparian vegetation varies with increasing distance from and elevation above the river (Szaro, 1991).

### 4.5.2.2 Wetland

Depending on whether the wetland is a riverine, palustrine (i.e. headwater) or isolated type, and whether it is directly connected to the local groundwater table, or sitting in a perched condition above the water table will determine the degree to which it is affected by changes in the hydrologic or hydrogeologic regime. Generally, however, changes to the water table elevation, or the mean annual stream flow will result in some change to the composition of the wetland community. For instance, a drop in the water table may be manifested in a shift from marsh (which is based on surface water) to a swamp (which is more often based on high groundwater elevations). In the extreme, such changes could shift the community from wetland to upland or non-wetland (Weller, 1981).

As is the case with the riparian zone, riverine wetlands would be affected by changes to flood velocity, volume, duration and frequency. Such modifications to the hydrologic regime may alter the channel morphology (through aggradation or degradation) and/or the moisture conditions, which would in turn cause a shift in the vegetative community. For example, a decrease in the frequency of flood plain events would tend to encourage the growth of less water tolerant species. Similarly, an increase in the depth of the adjacent stream channel (resulting from an increase in flood velocity), that would result in a lowering of the local water table, would also favour more upland species. This may result in a swamp wetland taking on characteristics more commonly associated with an upland forest.

As in the case of forests (see below), the larger the swamp wetland the better. Larger forested wetlands provide greater opportunities for wildlife and provide habitat for area sensitive species. The case for marsh wetlands is more complex, with a range of sizes providing the maximum diversity of habitat types. Hydrologically, the larger the wetland size, the greater the potential role played in the moderation of stream and groundwater flows. Therefore, as a general rule, the loss of large wetlands would have a greater impact on the condition of the subcatchment than the loss of smaller wetlands.
The amount of natural area surrounding a wetland is also important to maintaining its ecological integrity. This is especially true of marsh wetlands. In addition to providing a buffer and filtering out excess nutrients, adjacent natural vegetation is critical habitat for many wetland-dependent species. The width of wetland buffers should be greater than 30 metres and up to 240 metres (Env. Can. et. al, 1998).

In the Characterization Report, it was noted that the significance of a community is based, in part, on its size relative to the percentage cover of that community type within a study area. Accordingly, even small wetlands may be important if they are underrepresented within the subcatchment. Maintaining the full representation of community types is therefore an important indication of the quality and quantity of wetland habitats available in the subwatershed.

4.5.2.3 Upland

Upland communities are also dependent on equilibrium of moisture conditions. However, in general, an increase in soil moisture (resulting from a reduced depth to water table) is likely to have a more adverse impact than a lowering of the water table and resulting decrease in soil moisture. High water tables result in shallow-rooted trees that are easily toppled by the wind and are sensitive to drought and frost. In addition, upland plants subject to prolonged flooding, particularly during the growing season, will die from the lack of oxygen in the root level of the soil (Smith, 1974). Alternatively, the lowering of the water table by a meter or more at places where the water table is presently close to the surface would obviously have a profound effect on the types of plants that can be supported. In effect, a lowering of the water table selects against those plant species that prefer wet ground conditions and have shallow root systems. At the same time, this drop in the water table favours those plant species that prefer drier ground surface conditions and have deeper rooting systems. Essentially, this would result in a shift to drier upland habitat from existing high moisture conditions.

Soil moisture is an integration of all the variations in soil moisture supply throughout the complete vegetation cycle. The moisture regime is estimated from inferences of pore pattern and depth of the mineral soil material, the topographic position of the site and characteristics of the soil profile (Ontario Centre for Soil Resource Evaluation, 1993). Therefore, the actual impact from a change in the water table on an individual tree or community is site specific and complex. Not only does it depend on the species affected, but the site and soil conditions. For instance, the rooting depth of trees can vary from 1 metre to several metres depending on the species and the depth of the soil. Therefore, the assessment of impacts from changes to the elevation of the water table on the upland communities are generalized, given the lack of detailed soils data.

Community complexity or diversity refers to the number of different communities within a given area or patch. Changes to a community, which would reduce its complexity, such as the removal of some of the forested area within a matrix of forest and old field, would result in a reduction in the overall diversity of the patch. As noted under wetlands, it is important to evaluate the size of a community within the context of the percentage cover
of that community within the study area. Therefore, the representative nature of a community-type (or “relative community size”) is important, in addition to its size. For example, a small patch, which contains a community that is quite common within the area, is not as important as a small patch of a rare community.

The shape of a patch, or the amount of edge it contains, has traditionally been used as one measure of its internal integrity. In areas of relatively undisturbed landscapes, edges often represent areas of high structural and biotic diversity. However, in fragmented landscapes (such as in the Silver Creek Subwatershed), ecological impacts are likely to be negative at the edge of disturbed habitats. As Riley and Mohr (1994) have stated, where converted ecosystems meet native ecosystems, edge effects can be less beneficial, causing ecological imbalances. Land use changes that increase edge habitat, or remove patches that appear to have high ecological integrity (i.e. those with limited edge) would be considered to have a high impact.

Related to the shape and size of an upland community is the amount of interior or core habitat that it provides. Studies carried out primarily on bird species have determined that often certain patch sizes are required for a species to successfully breed (Riley and Mohr, 1994, Environment Canada et al., 1998). While little data exists for other wildlife, the reduction of forest habitat likely affects other forest dependent species such as Mole Salamanders, Wood Frogs and many mammals (Environment Canada et al., 1998). Related to size is the amount of buffer or edge that is provided around the perimeter of a natural area. Research has determined that forest interior bird species tend to nest inside forests, and a high proportion of them nest 100 metres or farther from the forest edge. Forest interior species are deep woods inhabitants which usually nest 200 metres or farther from the edge (Environment Canada et al., 1998, Riley and Mohr, 1994).

Interior or core habitat is generally free from the often negative effects found in edge habitats such as increased predation, competition, pollution and wind. The literature suggests that on average, edge effects are felt at least 100 metres into a forest patch (Riley and Mohr, 1994). Some species, however, such as those associated with deep woods, require a 200 metre buffer from the edge of the patch (Environment Canada et al., 1998).

One of the most important indicators of the ecological integrity of a subcatchment is the percentage of forest cover that it contains. Forests have a major influence on the hydrology, water quality and habitat of a watershed. Given that most of the landscape within this part of Ontario was at one time forested, the watersheds have been in a continual state of adjustment as forest has been replaced by agriculture, which in some areas has been replaced by urbanization. It has been recommended that watersheds should contain 30% forest cover (Environment Canada et al., 1998). In order to achieve adequate structural diversity and species representation, this number needs to be applied at the subwatershed level. At present, the Silver Creek Subwatershed has 21.5% forest cover. Therefore, at a subwatershed scale, any reduction in the percentage of forest cover would be considered to have a negative impact.
4.5.3 Impact Assessment

The impact assessment for Scenario 1 – Existing Conditions has no effect on the terrestrial system. The evaluation carried out for Phase 1 remains in tact.

Under Scenario 2 – Interim Conditions, the direct or area related changes due to development are focused in a few specific areas (within subcatchments 1115 and 1117) (Figure 4.5.1). The loss of natural areas results in impacts to several of the measures of their significance. Several communities that contribute to patch diversity are affected by urban and aggregate development in the area of 22nd Sideroad (at the boundary of 1115 and 1117) and significant aggregate expansion south of Highway 7. In the area of aggregate expansion the Waterfall Woods ESA also appears to be directly impacted. This is also an area of core and deep core where reductions of over 5 hectares occur. Overall a total of almost 35 hectares of high priority and over 7 hectares of medium priority terrestrial communities are lost.

The effects within subcatchment 1115 are the most severe, with a direct loss of almost 30 hectares of natural area. Several tributaries within the subcatchment are also impacted, directly affecting the characteristics that established their high level of significance, dropping them to moderate quality and thereby adversely affecting their habitat function and the condition of the adjacent and downstream aquatic system. Specifically within 1117, south of Ann Street and east of Ontario Street, a 10.7 hectare area of cultural (old field) communities is lost to urban development. This area had been identified as being of Low Sensitivity (i.e. low to moderately low biodiversity at the landscape scale).

Indirect effects are most severe on the riparian and wetland components downstream of subcatchment 1105 with moderate impacts anticipated within the valley-based natural communities within subcatchment 1121. Anticipated effects are a result of changes to the hydrologic regime from the development scenario.

Under Scenario 3 – “Ultimate Conditions” all of the above impacts become more pronounced, as all of the remaining agricultural lands within the subwatershed are developed, resulting in a wide range of indirect affects on the terrestrial communities. The riparian and wetland communities all receive a high level of impact as the hydrologic regime within the subwatershed is severely altered as a result of the widespread land use changes. On the other hand, the upland communities are less affected, as the water table elevations are not predicted to be altered to a significant degree. Other direct and indirect impacts on all remaining natural areas are expected to be severe however, as they become surrounded by varying intensities of human use.

Scenario 3B - “Ultimate Pumping Conditions” results in a further intensification of impacts on the terrestrial communities. In particular, a significant drop in water table elevations results in reductions in available moisture for upland plant communities causing a number of moderate to severe impacts.
With regard to off-site impacts (i.e. those likely to be experienced outside of the subwatershed), the affects appear to be negligible, as changes to the terrestrial system resulting from the various scenarios are contained within the Silver Creek Subwatershed. There appear to be no direct impacts to the external linkages provided by the corridors that had been identified in the Phase 1 Characterization Report.

### 4.5.4 Sensitivity

In general, terrestrial components that were determined to be of High Priority through the Phase 1 Report are of greatest sensitivity (Figure 4.5.2 and Figure 4.5.3). Significance or priority serves as a surrogate for sensitivity. These are the areas and features that contain the highest concentration of significant ecological functions. The riparian zones and wetland communities are especially dependent on the hydrologic regime for their functioning. As a result, they are the most sensitive to changes in that regime, regardless of their significance.
Figure 4.5.1: Sensitivity of Riparian (Valley and Stream) Corridors

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982
Figure 4.5.2: Sensitivity of Wetland and Upland Terrestrial Communities

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982
Figure 4.5.3: Terrestrial System Area Losses from Scenario 2

<table>
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</tr>
<tr>
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<td>12.2</td>
</tr>
</tbody>
</table>

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982
4.6 STREAM MORPHOLOGY

4.6.1 Tools

The two dominant controls of channel form and processes are climate (i.e., precipitation) and geology (i.e., control on physiography, floodplain and underlying materials) since they, both directly and indirectly, affect the rate and volume of water and sediment discharged through a watercourse. The process of urbanization has implications to both the hydrologic and sediment regimes of the receiving watercourses and, for this reason, impacts of land use change on the physical form and function of watercourses are best evaluated in the context of alterations to these regimes. Since channel form and function are a function of various controlling and modifying influences, geomorphologists study not only the physical form of watercourses but also draw on analyses completed by other study disciplines (e.g., hydrology) to link observed or inferred channel changes to other watershed processes. The tools used in this study to assess the potential impacts of urbanization on the physical condition of Subwatershed 11 watercourses relies primarily on geomorphic analyses and results of hydrologic modeling.

Within the scientific literature, the impact of altering catchment imperviousness on channel stability has been well documented. Morisawa and Laflure (1979) have found that, for Canadian watercourses, instability in channel form and in cross-section enlargement tends to occur when total basin imperviousness reaches between 7 – 10%. Although dependent on the nature and rate of urbanization and on various physical parameters, most watercourses adjust in form within several decades after urbanization. Analyses were completed to link existing channel conditions with changes in basin imperviousness that has occurred since 1954. These results were used to estimate the effect of further increases in imperviousness on channel stability for both the interim and future scenarios.

As part of the hydrologic assessment completed for this study, various analyses were undertaken to quantify peak flows, flow durations, and frequencies for each urbanization scenario. Results form the hydrologic modeling (continuous simulation corresponding to field site locations and SCS Type II 24 hour storm for all catchment areas) were reviewed to examine how these parameters changed from 1954 to the existing, interim and future scenarios. This information was linked to existing channel stability and used to infer effect on potential future channel form.

A sediment transport model which draws upon results from hydrologic modeling was used to quantify sediment transport potential at each of the field sites for each urbanization scenario considered in this study.

To examine how increasing flows are accommodated in a channel, hydraulic geometry analyses were used. These analyses consist of power functions that, based on cross-sectional shape, identify what proportion of flow is accommodated by each of the parameters that define discharge (i.e., width, depth, velocity). Whether an increase in
flow results in increasing width or depth within the channel is, in part, a function of the resistance of boundary materials. A channel will tend to be relatively wide and shallow if the banks are more erodible than the channel bed. Conversely, if the channel bed is more erodible than the banks, then the channel will tend to be relatively narrow and deep. Understanding how the channel currently accommodates flow enables estimates of future channel response to increasing flows to be made.

*Aerial photos and topographic mapping* were used to gain insight into planform properties of the channel and its tributaries. Examination of the photos and maps enabled planform stabilities and instabilities to be identified. This information can be linked to previous changes in surrounding land use and used to identify potential future changes in each of the development scenarios considered.

In Phase 1 of the study, the *existing condition and stability* of the main branches of Silver Creek and various tributaries were assessed. This information provided insight into the ability of each channel to absorb changes in hydrologic and sediment regimes. Since existing stability is a pre-existing channel condition, it was a valuable tool when completing the impact assessment as it can indicate which reaches are predisposed to change and which ones would have a higher tolerance threshold. The position of a reach within the drainage network is also an important pre-existing condition that will determine the relative impact that an alteration in flow or sediment regimes on the channel.

### 4.6.2 Indicators

When the hydrologic and sediment regimes of a watercourse are altered beyond the capability of the channel to absorb, then channel form become unbalanced with respect to its controlling influences. In response, the channel begins to adjust one of its parameters to regain a quasi-equilibrium state between form and the hydrologic and sediment regimes that are conveyed through it. There are several indicators of channel change that can be easily measured or observed and, indeed, are often used in geomorphic field assessment tools to evaluate channel stability and to identify dominant channel processes. The predominant modes of channel adjustment include aggradation/degradation, cross-sectional area, profile and planform configuration. Different indicators of channel response were identified that would aid in identifying potential impacts of urbanization on Silver Creek and its tributaries. The indicators were selected to ensure that each mode of channel response would be evaluated.

When the hydrologic regime is altered (e.g., increase in the duration and/or magnitude of flows), the channel defining flow may be altered and, in response, the channel adjusts its *cross-sectional area* through *enlargement or constriction*. The direction of enlargement (e.g., width, depth) is affected by the relative resistance of bed and bank materials and the role of bank vegetation. Change in cross-section area can be measured in the field and, with time, can be observed and measured on aerial photographs. Scientific research has linked the likelihood of channel enlargement to increasing basin imperviousness.
When flows change, the capacity for sediment transport as well as the competence (size of sediment that flow can entrain and transport) of the frequent flow events will change which could lead to *aggradational or degradational conditions* in the channel. The change will be even more pronounced when sediment sources to the channel change or are limited. Changes in sediment conditions within a channel can be measured and observed in *substrate composition*, bedload or suspended sediment load, depositional features (e.g., bars), and erosional forms (e.g., bank erosion, incision).

The *planform configuration* of a watercourse is adjusted to the flows that are conveyed through it so that both water and sediment can be transported efficiently through the channel. The meandering form is a function not only of discharge, but also of channel width. Hence, as the cross-sectional dimensions change to accommodate an altered flow regime, subsequent changes to the planform configuration occur to maintain flow efficiency through the reach. In addition to changes in meander form, rates of migration may also be altered.

### 4.6.3 Impact Assessment

Before assessing the impact of potential future urbanization scenarios, it was imperative to gain an understanding of how the watercourses responded to previous land use and urbanization changes. This was made possible through modeling 1954 and existing flow and land use conditions and linking this to existing channel conditions. By understanding what changes have occurred within the drainage basin and the channel response to these changes, insight was gained for estimating and understanding the type and magnitude of future potential channel responses to urbanization. Results from these analyses were also used to determine whether findings reported within the scientific literature were directly applicable to the study area.

From a geomorphologic perspective, the impact of increasing urbanization on the physical form of watercourses requires an assessment of how each of the dominant modes of channel adjustment are affected. As the flow and sediment regimes that are conveyed through a watercourse are altered, the dominant responses of watercourses include:

- Enlargement in cross-sectional area.
- Increased sediment transport potential, leading to increased erosion and potential change in substrate material composition.
- Adjustment in planform configuration; this may involve development of a planform configuration in previously straightened channels and changes in meander form for currently sinuous channels. Rates of both downvalley and lateral migration could also increase.
- Change in overall stability.

The anticipated impacts of urbanization on watercourses within Subwatershed 11 are, in part, a function of existing conditions. Watercourses that are currently considered to be sensitive have a lower tolerance for change in hydrologic and sediment regimes than watercourses that are currently stable. Similarly, watercourses that are currently in
transition and which have almost adjusted to previous changes in flow regimes could
degradation with further changes in flow regime. The extent of urbanization impacts is,
therefore, a function of, and directly related to, existing channel conditions and the
tolerance for change.

Although the impact of urbanization in any one catchment area may not be large, the
cumulative impact increases in the downstream direction. Thus, even if virtually no
change occurs in a downstream catchment area, the reach would be affected by all
changes that have occurred in upstream catchments. Overall, the impact of the interim
scenario is less than the impact of the ultimate scenario and varies between catchment
areas.

During the process of urbanization, alteration of the drainage network frequently occurs
through the elimination and piping of headwater and low order channels. As a result, the
drainage density is altered and a change in the hydrologic regime of the drainage network
occurs. Storm sewer outfalls are often constructed and deliver water directly to the
drainage network or are placed at the head of a new channel that links the outfall to the
watercourse. All of these changes alter the rate and pathway of water movement through
the drainage network. Since the location and extent of drainage network alteration cannot
be predicted for each scenario, it was assumed that no change would occur.

The direction of channel enlargement is determined by the relative resistance of boundary
materials and how well the channel is connected to its floodplain. Enlargement will
occur predominantly in the direction of least resistant materials which, in Subwatershed
11 tends to be the channel banks. When banks are more erodible, then widening is
anticipated to accommodate the increased flow. Dense rooting networks of bank
vegetation enhance bank material strength. Incised or entrenched channels tend to
enlarge through both bed and bank material erosion in response to an increase in flow
duration and magnitude. When the channel is well-connected to its floodplain (i.e., is
able to spill during bankfull and larger flow events), then widening tends to be the more
predominant mode of enlargement.

In Phase 1, several gullies were evaluated which have been impacted by previous
urbanization; all were considered to be sensitive to erosion. Naturally, gullies will
enlarge and incise over time. When an alteration to flow regime occurs, then the rate of
change will be exacerbated leading to overall instability and an increase in sediment
delivery to the main channel. Given that the gullies are currently sensitive, it is expected
that further urbanization could increase stress on existing gully systems.

An increase in flow duration and volume will increase the capacity for sediment transport
and, therefore, erosion. If a channel is sediment supply limited, then an increase in flow
could enhance the sediment erosion potential and transport capacity of the flows,
especially if they exceed the erosion threshold of boundary materials. Depending on the
bed material and change in flow regime, the substrate material composition may change
and become coarser since finer materials would be entrained and flushed through the
drainage network more rapidly. Fine sediment would, however, be delivered to channels
in urban areas due to runoff from roads, especially in winter (i.e., when sand is used). Variable sized materials would also be delivered to the channel through erosion of channel banks and at valley wall contacts. Thus, although sediment may be mobilized more frequently, sediment will continue to be delivered to the channel. If the duration of flows that are less than bankfull stage increases, then undercutting and subsequent bank failure would be anticipated. These processes would be part of the process of channel enlargement, meander development, and channel migration.

Alterations in the flow and sediment regimes of a reach affect the planform configuration of watercourses. Specifically, the stable radius of curvature of meander bends is directly linked to the width of the bankfull channel. Thus, enlargement of a channel will induce changes in meander configurations. Further, depending on the energy of the flow regime, the channel may increase its sinuosity to decrease its slope. An increase in sinuosity would also be anticipated in channels that have previously been straightened. This type of planform development would occur regardless of a change in flow regime, but could be accelerated by such a change. Migration rates could be impacted by causing an increase in flow through the channel and associated erosion until the channel has adjusted to the new flow regime.

Overall, geomorphic impacts will vary spatially and are a function of existing characteristics as well as the controls that influence channel form. Many of the headwater and low-order channels have been previously straightened, are surrounded by herbaceous vegetation, and flow through wetland areas. These channels would be especially sensitive to alterations in flow regime corresponding to each of the scenarios and would develop a meandering configuration and increase the cross-sectional area. Erosion from these channels would tend to provide fine-grained sediment to downstream reaches. Higher order watercourses that are situated within the central portion of the subwatershed are characterized by more bedrock control, have a better developed planform and localized areas of instability or sensitivity. Downstream reaches have been impacted from previous alterations in flow regime and receive sediment from gullies and upstream sources. These reaches and subwatershed areas are highly sensitive to change since changes in flow regime will cause further degradation of channel conditions, widening and alterations of substrate composition.

### 4.6.4 Sensitivity

Each of the watercourses within Subwatershed 11 is sensitivity to changes in flow regime, although the sensitivity varies by subcatchment area. Furthermore, the sensitivity is a function of existing conditions (i.e., stability), the relative controls of modifying and controlling variables, and the magnitude of the impacts. The sensitivity of the watercourses is due to straightening of headwater channels, the occurrence of wetland channels, boundary conditions (e.g., erodible or resistant bank materials) and cumulative impacts of previous alterations in flow regime (i.e., downstream reaches). The relative geomorphic sensitivity of watercourses within each of the subcatchment areas is illustrated in Figure 4.6.1.
Although none of the watercourses have been classified as having a low sensitivity, they are described here for reference purposes. Low sensitivity channels would have an existing stable configuration that is able to absorb an alteration in flow regime by making minor adjustments that would not quickly lead to excessive changes in channel form or function.

Moderately sensitive watercourses are those that are able to absorb some changes in flow regime by making adjustments, but would, more quickly, lead to excessive erosion and impacts to channel stability, form and function.

Highly sensitive watercourses reflect channels that are currently geomorphically unstable or would quickly become unstable in response to a change in flow regime. Typically, watercourses situated within headwater regions (i.e., straightened, flow through wetlands) and in areas already impacted by previous alterations in flow are considered to be highly sensitive.

Intermediate between the moderate and highly sensitive watercourse classifications, are moderately highly sensitive channels. These channels are characterized by local areas of instability or potential instability in response to impacts. Other sections may be relatively stable and better able to absorb impacts.
Figure 4.6.1: Geomorphology Sensitivity

Sources:
Aquafor Beech Ltd., 2002; Ontario Ministry of Natural Resources, 1982
4.7 WATER QUALITY

4.7.1 Tools

A number of assessment tools and methodologies were employed to assess water quality impacts from the future growth scenarios. These included mass balance calculations, unionized ammonia calculations, dissolved oxygen modeling, groundwater dilution calculations and relating changes in key hydrology, hydrogeology and riparian vegetation parameters to typical changes in water quality parameters.

Tools for Assessing the Impacts from Georgetown Water Pollution Control Plant

Mass balance calculations were used in this study to estimate the loadings and resulting mixed concentration of a parameter from the primary point source loading to Silver Creek, the Georgetown Water Pollution Control Plant (WPCP). Equation 1 describes these calculations:

$$Q_{PS} \cdot C_{PS} + Q_{R} \cdot C_{R} = Q_{MIX} \cdot C_{MIX}$$  \hspace{1cm} (Equation 1)

where
- $Q_{PS}$ = flow rate of the point source (L/s)
- $C_{PS}$ = concentration of the specified parameter in the point source (mg/L)
- $Q_{R}$ = flow rate of the receiving watercourse, before mixing (L/s)
- $C_{R}$ = concentration of the specified parameter in the receiving watercourse, before mixing (mg/L)
- $Q_{MIX}$ = total flow rate of the receiving watercourse, after mixing (L/s)
- $C_{MIX}$ = resulting concentration of the specified parameter in the receiving watercourse, after mixing (mg/L)

Although a WPCP normally discharges year round, the amount of stream flow available to dilute the effluent tends to decrease during the summertime months. Therefore, as a safety factor, a low flow condition is applied when determining the flow rate of the receiving course. For this study, the 7Q20 flow, which represents the averaged lowest flow over 7 days during a period of 20 years, was chosen as a representative low flow. The 7Q20 flow is a standard estimation of low flow and is typically used in assimilative capacity studies for point source discharges by the Ministry of the Environment.

Another safety factor included in the mass balance calculations is the determination of the background concentration of the specified parameter in the receiving watercourse. The 75th percentile of the data set for the specified parameter is used as representing a worse case scenario. With the exception of water temperature, the maximum or higher percentile values are not used since these would not likely occur for very long periods of time. The 75th percentile values for total phosphorus, suspended solids, nitrate, nitrite and ammonia were calculated for the Georgetown WPCP discharges to Silver Creek. Due to the known daily fluctuations in water temperature, the maximum observed water
temperature was used since a Rapid Temperature Assessment in 2001 captured maximum water temperatures after several above 30°C days.

The effluent flow was based on recent flow rates and growth estimations, per unit consumption of 1000 L/day and a multiplication factor of 1.5 to account for leakages into the collection and treatment system and additional water use. Estimations of potential units were based on the scenario land use mapping and were prepared by Walker, Nott, Dragicicvic Associates Limited. The maximum potential units were used from each scenario for an additional safety factor. The population for the interim and ultimate scenarios are presented in Table 4.7.1.

**Table 4.7.1 Estimation of additional potential units for the Georgetown urban area within the Silver Creek watershed**

<table>
<thead>
<tr>
<th></th>
<th>Interim Scenario</th>
<th>Ultimate Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>1175</td>
<td>1275</td>
</tr>
<tr>
<td>Maximum</td>
<td>1420</td>
<td>1470</td>
</tr>
</tbody>
</table>

The effluent concentrations were based on the plant’s Certificate of Approval (C of A) effluent criteria or observed concentrations, where no C of A criteria existed. The effluent criteria are listed below in Table 4.7.2.

**Table 4.7.2 Required or observed effluent concentrations for the Georgetown WPCP**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Criteria</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>NA</td>
<td>25.9°C (assumed maximum stream temperature)</td>
</tr>
<tr>
<td>5 Day Biochemical Oxygen Demand</td>
<td>5 mg/L</td>
<td>NA</td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>5 mg/L</td>
<td>NA</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>0.3 mg/L</td>
<td>NA</td>
</tr>
<tr>
<td>Un-ionized Ammonia</td>
<td>0.02 mg/L</td>
<td>NA</td>
</tr>
<tr>
<td>Nitrate Nitrogen</td>
<td>NA</td>
<td>19.6 mg/L</td>
</tr>
<tr>
<td>Nitrite Nitrogen</td>
<td>NA</td>
<td>0.21 mg/L</td>
</tr>
<tr>
<td><em>E. coli</em></td>
<td>NA</td>
<td>12 count/100</td>
</tr>
</tbody>
</table>

Assessing impacts from ammonium inputs requires one extra step since the un-ionized fraction of ammonium, which is positively related to pH levels and water temperature, is the toxic component to aquatic biota. Un-ionized ammonia was calculated using Equations 2, 3 and 4 as described in MOE’s Water Management (1999) based on the mixed pH values, water temperatures and total ammonia values calculated from Equation 1.
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\[ f = \left[ \frac{1}{10^{\text{pK}_a - \text{pH} + 1}} \right] \]

\[ \text{pK}_a = 0.09108 + \frac{2729.92}{T_K} \]

\[ T_K = T_C + 273.16 \]

(Equations 2, 3, and 4)

where:

- \( f \) = percentage un-ionized ammonia from total ammonia
- \( \text{pH} \) = pH value
- \( T_K \) = temperature in Kelvin
- \( T_C \) = temperature in degrees Celsius

Dissolved oxygen modeling was also completed for the reach upstream and downstream of the Georgetown Water Pollution Control Plant. This modeling exercise takes into account oxygen demanding material in the WPCP effluent and watercourse and predicts impacts to the dissolved oxygen regime of the receiving. A description of this model can be found in Appendix K.

### Tools to Assess Impacts from Key Hydrological, Hydrogeological and Riparian Parameters

The results of the hydrogeology, hydrology and riparian vegetation impact assessment were used to look at general water quality changes from changes in land uses. Specifically, predicted changes in baseflow and riparian vegetation were used to estimate impacts to water temperature while changes in runoff and 2-yr high flows were evaluated for changes in suspended solids and total phosphorus. Since phosphorus is typically adsorbed to soil particles, increased suspended solids from runoff will tend to increase total phosphorus levels in the watercourse. Changes to the dissolved oxygen regime were evaluated based on water temperature, to account for the decreased ability of water to hold oxygen as the temperature rises, total phosphorus, to account for the process of eutrophication, current dissolved oxygen regime and reaeration rates, as they are affected by water velocity.

### Tools to Assess Risk to Groundwater Quality

Rough groundwater nitrate dilution calculations were completed to assess the potential impacts from additional septic systems in the growth areas outside of Georgetown. Subcatchments areas outside the Georgetown urban area were assumed to continue to develop on individual septic systems. As outlined in MOE’s Technical Guideline for Individual On-site Systems (MOE, 1996), the scenario development areas, infiltration values, total effluent flow rates and typical nitrate concentrations in septic system effluent were used to estimate the potential increase in nitrate in the groundwater. Due to complexity of groundwater flow paths and potential sources of nitrates from agricultural...
activities versus septic effluent, these nitrate calculations represent a relative risk assessment of nitrate contamination of groundwater. If development does proceed in these areas, more detailed assessment will be needed to consider the appropriate level of servicing (i.e. municipal, versus communal, versus private) and to calculate site specific assessment of impacts to nitrates to groundwater and surface water features. The calculations used to estimate groundwater nitrate concentrations are presented in the Appendix K.

Rough groundwater chloride dilution calculations were also completed to assess the potential risk of chloride contamination from additional road salting activities associated with urban growth. An estimate of increases in road network length, salt application rates and infiltration rates were used to calculate potential groundwater concentrations of chloride for the interim and ultimate scenarios. Again, more detailed and site-specific study is needed to better predict the impacts from road salting as this area becomes developed. The calculations used to estimate groundwater chloride concentrations are presented in the Appendix K.

### 4.7.2 Indicators

The primary indicators used in the impact assessment included water temperature, suspended solids, total phosphorus, dissolved oxygen and the risk of groundwater contamination from nitrate and chloride. In the last reach, where the Georgetown WPCP discharges to Silver Creek, an assessment of un-ionized ammonia, nitrite and surface water nitrate and chlorides are also used to determine potential impacts to water quality. The following paragraphs provide more detail on each of the primary indicators.

A certain range in water temperatures is vital for a healthy fishery. Increased water temperatures in the summer cause dissolved oxygen levels to decrease while at the same time increase the metabolic rate of the fish. Coldwater species of fish are particularly sensitive to changes in water temperature. In the summer, water temperature may increase from thermal pollution such as warmer runoff water, decreases in cooler groundwater upwellings, and loss of riparian vegetation. In the winter, groundwater upwellings help to maintain ice-free conditions in areas where fish spawn. Without these upwellings, air temperatures below freezing would cause the watercourse to freeze over and potentially kill overwintering eggs.

There is no provincial guideline for suspended solids but it is recognized that high levels can clog critical spawning areas for fish, increase sediment oxygen demand (SOD) which can deplete dissolved oxygen levels, and result in poor water clarity for recreational uses. The Canadian Water Quality Guideline (CCME, 1999) for suspended solids suggests that during clear flow conditions suspended solids levels should not increase from anthropogenic activities to over 25 mg/l of background levels for a 24-hr period and 5 mg/l for period of longer-term exposure (24-hr to 30 d).

Total phosphorus is a water quality parameter that is often used to measure the nutrient status of a watercourse. High values of total phosphorus in a watercourse can stimulate
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aquatic plant growth and cause eutrophic conditions. Eutrophic conditions can cause a lack of dissolved oxygen in the water column, which can effectively suffocate fish and other aquatic biota. The Provincial Water Quality Objective (PWQO) for total phosphorus is 30 µg/l (MOE, 1999) which represents the minimum concentrations of phosphorus that may stimulate excessive plant growth in rivers. By itself, total phosphorus is non-toxic to fish, other aquatic biota or humans. Many watercourses have phosphorus levels above the PWQO but do not exhibit unhealthy dissolved oxygen conditions. This may be in part due to the buffering capacity of high re-aeration rates, low loads of other material that consume oxygen (i.e. BOD), and low temperatures that allow more oxygen to dissolve into the water. However, it would be expected that if these watercourses continue to increase in phosphorus and lose one or more of their buffering factors, that the dissolved oxygen conditions would become degraded. Like humans, fish require sufficient levels of dissolved oxygen in the water to maintain respiration processes. The PWQO for dissolved oxygen states that minimum levels of 5 and 4 mg/L is required to maintain a healthy coldwater and warmwater fishery, respectively.

The Drinking Water Standard (ODWS) for nitrate is 10 mg/L, which is related to human health, in particular, the prevention of methaemoglobinaemia (blue baby syndrome) in susceptible infants. From CVC’s perspective, aquatic biota require a higher level of protection than the drinking water standard since most or all of their life cycle occurs in the water environment, which implies constant exposure to background contaminant concentrations. Aquatic biota, such as amphibians and salmonid fry and eggs, have been shown to be negatively impacted from nitrate levels as low as 2.5 mg/L (Rouse et al., 1999). Further, the Ministry of Natural Resources initially had a standard of 2 mg/L which was later replaced with ‘fully minimize’ nitrates. Environment Canada is also considering a Canadian Water Quality Guideline of 2.9 mg/L for nitrate for the protection of freshwater aquatic biota. However, until this guideline is approved and CVC is satisfied that it will protect sensitive biota in our watershed, targets for groundwater levels of nitrate will be set at below 2.5 mg/L to ensure protection of any nearby existing, potential, or future upwellings that may be impacted by groundwater originating from the sources of nitrate, such as septic systems. Groundwater upwellings are of particular concern because they are not diluted by in-stream flows.

Increasing trends for chlorides are observed for most stations in the Credit River watershed and in many other watersheds in Ontario (Bowen and Hinton, 1998). Chloride is a highly soluble and mobile ion in groundwater since it does not biodegrade, volatize, easily precipitate or significantly adsorb onto mineral surfaces. It travels readily through soils, enters groundwater and eventually discharges into surface waters (Bowen and Hinton, 1998). Road salts, which includes sodium chloride, were assessed as part of Environment Canada’s Priority Substance List and were found to be toxic to aquatic biota (Environment and Health Canada, 2001). Chloride does not have freshwater guideline for the protection of aquatic biota however the current aesthetic drinking water quality objective for chloride is 250 mg/L (MOE, 2001) which is within the range of the lowest concentrations observed to be harmful to aquatic biota (Environment and Health Canada, 2001).
4.7.3 Impact Assessment

An assessment on impacts to water temperature considered loss of baseflows, thermal loadings from the Georgetown WPCP and impacts to stream corridor vegetation in the alternative scenarios. Groundwater discharges play a crucial role in regulating water temperatures in watercourses for aquatic biota; maintaining cooler refuge habitat in the summer and maintaining above freezing conditions during the winter. Even small shifts in water temperature can alter the ecosystem significantly because most biological and some chemical and physical processes in the environment are affected by temperature. Therefore, high impacts to baseflows have been translated to potential high impacts to water temperature. The treated sewage effluent would not have higher maximum water temperatures compared to Silver Creek so a change to the maximum temperatures is not expected from the Georgetown WPCP effluent. Based on the expected changes in stream corridor vegetation in the scenario mapping, the reduction in shading potential and related changes in water temperature was assessed.

Changes in suspended solids were related to increases in runoff, 2-yr high flow and loadings from the Georgetown WPCP. Subcatchments that were predicted to have minimal changes in runoff and 2-yr high flow were designated as having minimal change in suspended solids loads. In addition, for subcatchment 1125, an increase in suspended solids from the Georgetown WPCP was considered minimal if the resulting mixed suspended solids concentration was less than 5 mg/L greater than dry weather flow concentrations (taken as the 10th% of the data) as per the Canadian Water Quality Guidelines (CCME, 1999). Suspended solids in subcatchments that were predicted to experience large or moderate changes in runoff or 2-yr flow values were predicted to be highly or moderately impacted, respectively. If future growth scenarios caused the Georgetown WPCP to increase dry-weather suspended solids above 5 mg/L over background levels, than the subcatchment 1125 would be designated as highly impacted with respect to suspended solids.

Changes in total phosphorus levels in each subcatchment were related to increases in suspended solids and loadings from the Georgetown WPCP. Since phosphorus is typically adsorbed to soil and sediment particles, erosion of bank soils and suspended solids in runoff introduce additional phosphorus loads to the watercourse. Large increases in suspended solids were translated to large increases in in-stream total phosphorus concentrations. With respect to the Georgetown WPCP effluent, subcatchment 1125 was designated as highly impacted where resulting in-stream phosphorus concentrations were greater than the Provincial Water Quality Objective of 0.03 mg/L.

Impacts to the dissolved oxygen regime were estimated from potential increases in phosphorus levels, in-stream temperatures, the current observed dissolved oxygen regime and velocities. Excessive phosphorus concentrations can stimulate aquatic plant growth, which in turn, can cause decreases in dissolved oxygen levels through plant respiration and decomposition processes. Increases in water temperature can also affect dissolved oxygen levels since as water warms, its ability to hold oxygen decreases. Dissolved
oxygen modeling for subcatchment 1125 was completed to take into account dissolved oxygen concentrations and oxygen demanding materials (including biological and nitrogenous oxygen demands) from the Georgetown WPCP. The dissolved oxygen model used in this study was based on the O'Connor and DiToro(1970) version of the Streeter-Phelps equation. A description of the dissolved oxygen model setup is provided in Appendix K.

Potential changes in groundwater nitrate levels were compared against CVC’s guideline of 2.5 mg/L. The calculations outlined in MOE’s Technical Guideline for Individual On-site Systems (1996) provide very conservative estimates of potential nitrate concentrations in groundwater from septic systems as they do not account for dilution from upgradient groundwater flows or denitrification. Those subcatchments where groundwater concentrations were estimated to be between 2.5 and 3.5 mg/L were designated as moderately impacted and those subcatchments where nitrate concentrations were estimated to be above 3.5 mg/L were designated as highly impacted. Finally, subcatchments where additional septic systems were not expected to be built, such as in the Georgetown urban area, or where concentrations were estimated to be below 2.5 mg/L were designated as being minimally impacted.

The potential changes in groundwater chloride concentrations were compared to the Drinking Water Objective 250 mg/L (MOE, 2001), which has also been identified as a level for the protection of aquatic biota (Environment and Health Canada, 2001). Those subcatchments with calculated chloride concentrations of less than 250 mg/L and less than 10% change in chloride concentrations were designated as minimally impacted. Those subcatchments with a calculated concentration of less than 250 mg/L but a change of greater than 10% in chloride concentrations were designated as moderately impacted. Finally, any subcatchments with a calculated groundwater chloride concentration greater than 250 mg/L were designated as highly impacted.

The following table summarizes the subcatchments that were designated as having the greatest impact to the individual parameters when evaluating the interim, ultimate and ultimate with pumping scenarios.
Table 4.7.3 Summary of subcatchments with greatest impacts, classified by indicators

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<td></td>
<td></td>
<td>1123, 1125</td>
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</table>

NOTE: Water Temp = Water temperature

4.7.4 Sensitivity

This section will summarize the most sensitive subcatchment with respect to the different indicators used to evaluate water quality for the three future scenarios.

Based on the impact assessment above, subcatchment 1115 appears to be the most sensitive with respect to increases in water temperature due to loss of baseflow and riparian cover in the interim scenario due to increase aggregate activity in this area. Reaches with subcatchment 1115 were designated as coldwater fisheries zones and therefore impacts to temperature may alter the fish community within this subcatchment. Under ultimate conditions, subcatchment 1109 (in Ballinafad) is predicted to have significant changes in water temperature from a loss of riparian cover and baseflow due to development. Subcatchment 1109 also provides habitat for a coldwater fishery and therefore impacts to water temperatures within this subcatchment would likely result in degradation to the fish community. Under the ultimate pumping conditions, the water temperature in subcatchments 1117 and 1119 (main branch of Silver Creek on north end of Georgetown) is predicted to significantly increase due to loss of baseflow from the additional pumping. Subcatchment 1117 provides cool/coldwater fisheries habitat while subcatchment 1119 provides coldwater fisheries habitat, which would indicate that both subcatchments would be sensitive to changes in water temperature.
Under the interim scenario, suspended solids and total phosphorus in three subcatchments near Ballinafad (1107, 1109, and 1111) and four subcatchments in and around the Georgetown area (1119, 1121, 1123 and 1125) are predicted to be significantly impacted from increased runoff and instream flows during storm events as a result of increased development. Out of these highly impacted subcatchments, subcatchments 1109, 1111, 1119 and 1123 provide habitat to coldwater fisheries and the increased suspended solids may cause clogging of spawning areas. Under the ultimate scenario, both with and without pumping, significant increases in suspended solids and total phosphorus levels are expected to occur from development in all subcatchments due to increases in runoff and in-stream flows during storm events. The remaining subcatchments that support coldwater fisheries (1101, 1103, and 1115) in the subwatershed would be at risk from high suspended solids causing siltation of spawning areas.

The interim scenario impact assessment predicted that the dissolved oxygen regime in subcatchment 1109 (near Ballinafad) would be most sensitive to changes from development due to increased temperatures (from loss of riparian cover) and increased nutrient loads. Within Georgetown, subcatchments 1119 and 1123 show the most sensitivity to changes in dissolved oxygen from development due increased nutrients loads. All three of these subcatchments support coldwater fisheries, which would be sensitive to changes in dissolved oxygen. Furthermore, the current dissolved oxygen regime in subcatchments 1119 and 1123 appears to be impacted under present day conditions and it is expected that increased nutrient loads will have a further impact on the current dissolved regime. Under the ultimate scenario, the dissolve oxygen regime in all subcatchments, except for 1105 and 1107, are expected to be significantly impacted due to loss of baseflow and riparian vegetation increasing temperatures and increased runoff from development increasing nutrient loads to the watercourses. Although subcatchments 1105 and 1107 are predicted to have increase nutrient loads, other contributing factors such as losses of baseflows and riparian cover and an impacted dissolved oxygen regime under current conditions will expect to buffer the additional nutrient loads from runoff.

Groundwater nitrate levels are most sensitive to increases in the developments near or within hamlet area outside of the Georgetown area which were predicted to proceed on private septic systems. These included subcatchments 1105, 1107, 1109, 1111, and 1115, which demonstrated significant increases in groundwater nitrate levels in all three future scenarios tested. In addition, nitrate levels in Silver Creek downstream of the Georgetown WPCP had significantly impacted nitrate levels under current and all three future scenarios. Out of the highly impacted subcatchments, the most sensitive subcatchments to increased groundwater nitrate levels would include 1109 and 1111 as these two subcatchments have interpreted significant or potential groundwater discharge, which is likely supporting spawning activity for coldwater fisheries in these subcatchments and contamination of these upwellings with nitrate may have an impact on the development of the fish eggs and fry.

Under interim scenario conditions, groundwater chlorides are most sensitive to changes in increase road salting from increased development in the Georgetown urban area. This
development is expected to occur at a higher density compared to urban areas in the rural residential or rural hamlet areas in the watershed. Significant impacts to groundwater chlorides were predicted for subcatchments 1117, 1119, 1121, 1123 and 1125 for the interim scenario. Under the ultimate scenario conditions, subcatchments 1107, 1109 and 1111 also demonstrated significant impacts to groundwater chloride due to increased urban areas, which will require increased road salt applications. The most sensitive subcatchments to groundwater chloride levels would include 1121, 1123, 1125, 1109 and 1111 since these subcatchments have interpreted significant or potential discharge, which is likely supporting spawning activity for coldwater fisheries in these subcatchments. Similar to groundwater nitrate levels, contamination of these upwellings with chlorides from road salting may have an impact on the development of the fish eggs and fry.
Figure 4.7.1: Water Quality Sensitivity

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982
4.8 **Benthics**

### 4.8.1 Tools

The objective of this section is to predict impacts to benthic invertebrate communities in the subwatershed. In the characterization phase of the study, benthic macroinvertebrates were selected as an integrator of environmental conditions. Benthos integrate physical and chemical stream conditions over their lifetimes (generally 1 to 2 years), while the condition of the benthic community can be predictive of the condition of the fish community.

### 4.8.2 Indicators

In the characterization phase of the study, samples of benthic macroinvertebrates were collected from a variety of locations in the subwatershed. Counts of taxa at each location were used to calculate a variety of indices of composition (e.g., Hilsenhoff’s Biotic Index, BioMAP water quality index) representing the condition of the community. Those indices were used to classify the condition of communities as being unimpaired (sensitive) or potentially impaired (Table 4.8.1). No sites were classified as impaired.

<table>
<thead>
<tr>
<th>Index</th>
<th>Impaired</th>
<th>Possibly Impaired</th>
<th>Unimpaired</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>Number of Taxa (S)</td>
<td>&lt; 15</td>
<td>15 to 20</td>
<td>&gt; 20</td>
<td>Barton (1996), Griffiths (1998)</td>
</tr>
<tr>
<td>Number of EPT Taxa</td>
<td>0</td>
<td>1 to 3</td>
<td>&gt; 3</td>
<td>Barton (1996)</td>
</tr>
<tr>
<td>% EPT</td>
<td>&lt; 5</td>
<td>5 to 10</td>
<td>&gt; 10</td>
<td>David et al. (1998), Kilgour (1999)</td>
</tr>
<tr>
<td>Diversity (H')</td>
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<td>1 to 3</td>
<td>&gt; 3</td>
<td>Wilm and Dorris (1968)</td>
</tr>
<tr>
<td>HBI</td>
<td>&gt; 8</td>
<td>6 to 8</td>
<td>&lt; 6</td>
<td>Barton (1996)</td>
</tr>
<tr>
<td>WQI</td>
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<td>7 to 9</td>
<td>&gt; 9</td>
<td>Griffiths (1998) for fixed-area samples</td>
</tr>
<tr>
<td>% Oligochaeta</td>
<td>&gt; 30</td>
<td>10 to 30</td>
<td>&lt; 10</td>
<td>Griffiths (1998), David et al. (1998)</td>
</tr>
<tr>
<td>% Chironomidae</td>
<td>&gt; 40</td>
<td>10 to 40</td>
<td>&lt; 10</td>
<td>Griffiths (1998)</td>
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<tr>
<td>% Isopoda</td>
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<td>1 to 5</td>
<td>&lt; 1</td>
<td>Griffiths (1998)</td>
</tr>
</tbody>
</table>

### 4.8.3 Impact Assessment

Benthic macroinvertebrates respond to a variety of physical and chemical factors. Here, impacts on benthic invertebrates are predicted where there are significant changes in substrate, water temperature, suspended solids, total phosphorus, and dissolved oxygen.
concentrations. Impacts to those indicators from development (Scenarios 2 and 3) were predicted in other sections. Impacts to substrate are assumed to occur where there are impacts to fluvial geomorphological process.

Here, a score of 1 was assigned to those subcatchments where development was predicted to have minimal impacts on benthos, while sensitivity scores of 2 were assigned for moderate impacts, and scores of 3 for major impacts. Within subcatchments, assigned scores were the averages of scores for fluvial geomorphology, water temperature, suspended solids, total phosphorus, and dissolved oxygen. In subcatchments where the benthic community was already classified as potentially impaired by existing land uses, the overall sensitivity score was reduced by 1.

### 4.8.4 Sensitivity

Overall, Interim Conditions (Scenario 2) is predicted to have no effects in the upper headwaters in subcatchments 1101, 1105 and 1103 (Figure 4.8.1). Moderate to significant effects are predicted for subcatchments just downstream of Ballinafad (1107, 1109, 1111). Further downstream in the system, impacts are predicted to be moderate to significant (e.g., 1121, 1123, 1125).

Ultimate conditions, including ultimate pumping, are anticipated to produce much more significant effects, particularly in the headwater areas, but also in the middle subcatchments (1113, 1115, 1117, 11119).
Figure 4.8.1: Benthic Sensitivity

Sources:
Bruce Kilgour, 2002; Ontario Ministry of Natural Resources, 1982
4.9 AQUATICS

4.9.1 Tools

Karr (1981) summarizes the advantages of using fish as indicators including: availability of life histories, occupation of a variety of trophic levels, relative ease of identification, typically present in all waters (including intermittent streams) and that the general public can relate to statements on fish community conditions and their utilization for food and recreation. Fish flesh can also be tested for contaminant levels that bioaccumulate through the food chain to indicate the presence and concentration of pollutants in the environment.

The protection and enhancement of fish communities have been identified as a goal in the subwatershed study as a component of a healthy ecosystem and in providing recreational/commercial opportunities. Fish communities are recognized as integrative indicators of the health of a subwatershed and the lands they drain. As such they also serve as barometers for human health and well-being (Loftus et al. 1980). Generally fish species can be specialized and intolerant of culturally derived stresses, such as those affecting the hydrological cycle including urbanization, water taking, sewage treatment and aggregate extraction. Other species are more generalized in their habits and can tolerate many stresses (Ryder and Edwards 1985). As such tolerant species may increase and/or dominate impacted habitats but even these species will disappear in the most degraded reaches. For preferences and sensitivities of particular species, *Freshwater Fishes of Canada* (Scott and Crossman, 1973) provides good guidelines. Comparative sensitivities of species found in the Credit Watershed can be found in Appendix E.

Lastly it is important to note that there are legislative requirements to protect and assess potential impacts to fish habitat under the Federal Fisheries Act. The policy of the Department of Fisheries and Oceans is to consider impacts in relation to overall fish productivity. This is often measured most accurately through electrofished samples of all fish present in a representative reach. Total weights or biomass per unit area are calculated to reflect overall productivity and then compared either spatially or through time to identify changes associated with impacts or restoration efforts. Biomass and a related Index of Biotic Integrity to account for species composition has been for only two sites in this subwatershed as part of a larger Credit watershed wide monitoring program. It is possible to monitor or predict changes at more sites within the Silver Creek subwatershed.

4.9.2 Indicators

Fish communities can be considered a product of habitat conditions including water quality, quantity (flow conditions) and the geomorphological or physical features of a waterbody. The majority of fish tend to reside in definable stream reaches and utilize various microhabitats through limited seasonal or life stage migrations. Some migratory species such as the Atlantic salmon (*Salmo salar*) and the rainbow trout (*Onchorhynchus*...
mykiss) in this subwatershed study can utilize greater habitat ranges such as Lake Ontario and the Credit River at a watershed scale.

Changes in habitat can result in changes either to the species composition of a fish community (i.e. a disappearance/replacement of sensitive species) or a change in the relative abundance or biomass of any species or the entire fish community. For this study sensitive indicator species were used to characterize three community types of which total biomass measurements can be made or predicted. Any changes to species composition or biomass will provide indicators of environmental change related to other parameters measured in hydrogeology, hydrology, geomorphology, terrestrial ecology (wetlands and riparian habitats) and water quality. The linkages and changes in aquatic habitat were conceptually modelled in Figure 3.8.1 of the Characterization Report.

4.9.3 Impact Assessment

Although fish communities have been broadly characterized in order of sensitivity it should be noted that even tolerant fish communities can be impacted. The ability of predicting changes in fish communities or overall productivity can be difficult given the interaction of a number of environmental and limiting factors that now exist and threshold levels of change are not always well understood. One should relate and also rely on other disciplinary indicators to better identify direct causal relationships of impacts predicted or observed in fish communities.

The following discussion explains the indicators chosen from other discipline components to help identify impacts on fish communities as used in Appendix I.

The first two habitat indicators chosen relate directly to the presence of Coldwater species that can be impacted by changes in water table and groundwater baseflows. Brook trout are most sensitive to such changes as they specifically select and require groundwater upwellings for the winter long incubation of their eggs at constant temperatures of about 8°C. Brown trout and Atlantic salmon are known to tolerate warmer temperatures but also benefit from groundwater from winter long egg incubation needs. Rainbow trout lay and incubate eggs during the spring when stream temperatures approximate groundwater temperatures.

All trout, nevertheless, experience stress and higher mortality rates with water temperatures (more specifically addressed under Water Quality) exceeding 20°C and without cooler thermal refuges. Brown trout and perhaps rainbows may survive at slightly higher threshold of 23°C. Darters may also be sensitive to temperatures. These and even more tolerant species may also be affected at higher temperatures e.g. 26°C when other related variables such as dissolved oxygen begin playing a more dominant role. Even though some tolerant warmwater minnows can survive in the deepest isolated pools, water tables may drop sufficiently to dry up refuge pools or headwater wetlands that also provide baseflows.
Streamflow from runoff and storage areas such as wetlands combine with groundwater contributions to result in a particular flow regime. Hydrological baseflows are defined and measured differently from groundwater discharges. An acceptable target was expressed at a watershed scale (Beak et al 1992) as a ratio of 20% baseflow to total streamflow or mean annual flow. It is also important to note that hydrology was used to delineate the smaller subcatchments by which all other disciplines based their spatial impact analysis on.

Changes in many of the hydrological flows reported, especially those that equate to peak runoff or bankfull flows strongly determine fluvial geomorphology of a stream channel. Processes of aggradation/degradation can degrade habitat features including channel shape (flow depths) and planform (pool-riffle diversity), cover, food and egg production within substrates. Most species prefer gravels rather than silt dominated substrates and may have sight feeding and respiration impaired by higher suspended solid levels that may be associated with aggradation/degradation processes (not double counted as a water quality parameter).

Water quality impacted by urbanization and sewage treatment may also impact on fish community composition and productivity. Nutrient enrichment mostly by Total Phosphorous is of greatest concern and is associated with algal blooms and lower dissolved oxygen. Toxic contaminants whether of a groundwater or surface origin are either at very low levels of concern or very localized in nature. Impacts on fish by groundwater contamination are of concern as it relates to a more widespread and potentially threatening pollutant even to human health. Nitrates measured as unionized ammonia may be most toxic to incubating fish eggs and amphibians living in wetlands.

Riparian changes were the most difficult to predict. Riparian vegetation can maintain channel stability with the root network and hydraulic roughness of plants. Furthermore many fish species utilize overhanging vegetation to provide food and overhead cover especially from avian predators. The role of riparian vegetation in moderating stream temperatures was considered very important for coldwater communities as well. Wetlands were discussed earlier for their roles related to base flows. Wetlands adjacent to streams or otherwise isolated were not sampled in this study but are considered as potential fish habitat that may be impacted.

Benthic invertebrates do make up the majority of fish diets; however, consumption is probably based more on availability than species composition. The species composition of benthic invertebrates is used most often as indicators of water quality and may be better related as a parallel biological measure rather than a direct influence on fish communities. Community health and predicted impacts for both benthics and fish should exhibit a good correlation. However, differences were observed in intermittent reaches since fish, unlike bugs, migrate into these reaches to take advantage of seasonal availability of habitat for cover, food and reproduction.

The Fisheries column of modelled impact scenarios in Appendix I reflects an average score from ten chosen interdisciplinary indicators including: water table elevation,
baseflow/discharge, streamflow, baseflow, fluvial geomorphology, water temperature, total phosphorous unionized ammonia, riparian and wetland areas. Scores that were unanimously low remained so for the fisheries component. Score averages from 1.1 to 2.0 were designated as a moderate impact and 2.1 and greater were considered a High impact.

The final High to Low designation simplifies the tendency of fish communities to negatively change to different land use scenarios (stepped increases in urbanization, sewage treatment and water taking). The prediction of such impacts can only be understood in relation to an objective such as “no net loss” of habitat or fish productivity as measurable in terms of biomass or an Index of Biological Integrity.

It should be noted that, technically, any impact on fish habitat might be an issue under federal and other policies. The species community present is naturally controlled by hydrogeology and flow regimes such that both cold and warm type fisheries can be equally healthy and valued. The Fisheries Act, for example, does not differentiate for protection purposes. It is also recognized that there are biological interactions between different fish community types. Nevertheless the classification of species can still further suggest their potential for negative change (i.e. sensitivity) based on simpler designations such Coldwater and Warmwater fisheries.

### 4.9.4 Sensitivity

It is common to observe similar associations of different fish species throughout aquatic environments. These may or may not indicate direct interspecific relationships such as predator-prey, but also that habitat preferences for breeding/feeding, cover/resting, temperature, flow regimes may be similar. Particular species within these associations can be isolated, usually due to well known sensitivities or dominance, to serve as an indicator or representative of that association.

Based on sampling in the subwatershed the following communities and indicator species were selected:

- **Coldwater** (resident brook trout and mottled sculpin);
- **Mixed Cool/Coldwater** (brown and rainbow trout and darter species);
- **Small Warmwater** (tolerant headwater species)

These are listed in order of sensitivity with some emphasis on temperature preferences as the names suggest. However it must be understood that other sensitivities exist that may be correlated with temperature. For example coldwater communities, generally, inhabit smaller streams with high oxygen, less silt loads, stable flow regimes and less nutrients and lower overall productivity. Any of these characteristics alone or in combination may determine or impact species composition and productivity.

It should also be noted that this subwatershed is somewhat unique in that intermittent headwater streams classified as small warmwater should be managed for their
contribution to the coldwater streams in which they drain into. This recognizes that any upstream impacts are more likely to affect more sensitive fish communities directly downstream. Although the Fish Community Management Zones adopted from the Credit River Fisheries Management Plan reflected this approach a more useful “sensitivity” map (Figure 4.9.1) is presented here for impact analyses at a more local scale (i.e. headwater reaches in isolation of downstream coldwater communities). Appendix I summarizes the relationships and status of all impacts and scenarios on fishery tools/indicators, sensitivities and objectives.

Discussion of Results

Before summarizing the predicted impacts on fish communities as presented in the Sensitivity Tables for three scenarios (Interim and Ultimate urbanization and Ultimate Pumping Conditions) one should recall the distribution of fish community types as they relate to a baseline physiographic and land use conditions.

The most sensitive and productive coldwater communities originate in sand and gravel deposits above the Niagara Escarpment (1103, 1111 and 1115) and another sand/gravel deposit following the main valley in the lower reaches (1119 and 1123). This valley deposit also extends up Black Creek that exhibits a relatively healthier trout fishery. Although intermittent warmwater tributaries may be found over short headwater reaches in many subcatchments they are most extensive in the very headwater reaches of 1101 where tills exhibit high silt content. The remaining Mixed cold-cool reaches may represent transitional or smaller physiographic zones that have “diluted” effects only. The influence of organic wetlands also found along the escarpment are not fully understood but it is suspected that both baseflows and temperature increase thus neutralizing any benefits to the trout fishery immediately downstream of the escarpment. Stream gradient also sharply decreases away from the escarpment (1113). The negative impacts associated with urbanization is the next most important factor to consider in explaining mixed waters (1117), except at and just below Black Creek (1119 and 1123). The hydrogeologic and baseflow inputs to Silver Creek suggest that indeed perhaps the main branch after the confluence should carry the Black Creek name instead. (It has also been called the West Branch at this point.) Finally the mixed waters below Mountainview Road (1125) coincide with increasing urbanization and the Georgetown Sewage Treatment Plant.

In the second scenario (Interim Conditions) only 2 subcatchments (1101 and 1117) are predicted not to have any or little change to fish communities based on a consensus of other disciplinary indicators. The land use in 1101 is not expected to change nor be affected by upstream areas, as this is the headwaters area. Subcatchment 1117 would however experience land use change but within a very small area relative to the upstream catchment and on less impermeable surficial geology. Subcatchment 1103 could have easily been rated low in terms of impact sensitivity if not for some caution regarding ammonia in this coldwater reach.
The highest impacts are predicted for 1107, 1109 and 1111 in and downstream of the Ballinafad area to be further developed (with impacts to runoff, baseflow, fluvial geomorphology, phosphorous, ammonia, riparian and wetland indicators) and 1125 downstream of urban areas and the Sewage Treatment Plant. Water quality parameters of concern include dissolved oxygen downstream of the Sewage Treatment Plant and septic effluent ammonia from areas north of Georgetown. Although not selected as a primary indicator, suspended solids are predicted to impact fish spawning areas downstream of Ballinafad and in Georgetown in the water quality assessment.

All other subcatchments are expected to be moderately impacted for a variety of reasons. Upland areas near Georgetown exhibit less groundwater supplies or are offset by contributions from Black Creek. Water quality (particularly dissolved oxygen) and terrestrial indicators seem to be more important factors responsible for moderately impacted fisheries, except for geomorphological changes in the urban subcatchments of 1123, 1121 and 1125.

Subcatchment 1115 contains a full spectrum of fish community types such that impacts may have a wider range of effects including more biotic competition. This is also the area predicted to have the greatest impact on water temperatures related to loss of baseflows and riparian cover with increased aggregate activity. High nitrates from septs are another concern in this area. This subcatchment could have easily been rated high in terms of impact sensitivity.

In the two Ultimate Scenarios impacts are unacceptably high across the board related to development of all agricultural areas. Subcatchment 1123 at the confluence of Black Creek where the buried bedrock valley provides the largest supply of groundwater is the only area buffered and moderately impacted. Groundwater pumping below the escarpment and in the Georgetown area will have impacts on water table elevations, baseflow discharges and temperature. The water quality assessment also warns of widespread siltation of spawning areas for trout and impacts to dissolved oxygen (except for 1105 and 1107). It is interesting to note that the benthic macroinvertebrate assessment also predicts widespread effects under both ultimate scenarios.

The preceding assessment again assumed that any fish community type could be impacted especially given that 10 indicators from other disciplines were cumulatively considered and that the Fisheries Act also makes no distinction. As an alternate assessment and to suggest that some impacts could be more easily tolerated, mitigated or compensated for some communities the following can be proposed. In order to consider sensitivity in terms of community type one can combine impact and sensitivity such that colder water communities are given a bias to reflect their direct dependence on groundwater as well as their greater social and recreational value. By giving a combined score of predicted impact sensitivity with fish community type sensitivity an overall ranking (maximum of two highs or 3x3=9) was also produced. In order from most sensitive / impacted to most protected or unchanged are:
Silver Creek Subwatershed Study

High x High: 1109 and 1111
High x Moderate: 1103, 1107, 1115, 1119, 1121, 1123 and 1125
Moderate x Moderate: 1113
Moderate x Low: 1105 and 1117
Low x Low: 1101

Again, these results are generated only for the Interim Conditions, given the two Ultimate Scenarios are unacceptably high across the board except for subcatchment 1123 at the confluence of Black Creek.
Figure 4.9.1: Fish Community Types and Sensitivity

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982
4.10 **INTEGRATION**

This section will focus on integrating the study components from sections 4.2 to 4.9. The findings of each study component have been reflected on individual maps.

4.10.1 **Summary of Sensitivity of Subwatersheds to Individual Components**

The sensitivity of each of the 13 subcatchments within the subwatershed are summarized in Table 4.10.1 for Scenario 2 conditions, Table 4.10.2 for Scenario 3 (ultimate) conditions and Table 4.10.3 for Scenario 3b (ultimate with increased pumping).

Indicators which were considered when modelling impacts included, but were not limited to:

- **hydrology** – mean annual flow, high flows, low flows;
- **hydrogeology** – groundwater level and baseflow changes;
- **hydraulics** – presence of buildings in the floodplain and risk of flooding;
- **fluvial geomorphology** – hydraulic cross-section form and channel plan form;
- **terrestrial** – sensitivity of riparian, upland and wetland vegetation loss of area due to development or connection to significant changes in the water table;
- **water quality** – changes in thermal (cold water, warm water) and nutrient conditions;
- **benthic** – changes in type and number of macroinvertebrates; and
- **aquatics (fish communities)** – increase in temperature, loss of riparian cover, lower baseflow, loss of habitat due to channel aggradation.
### Table 4.10.1 Sensitivity Table for Interim Scenario (Scenario 2)

<table>
<thead>
<tr>
<th>SUBCATCHMENT #</th>
<th>Hydrogeology</th>
<th>Hydrology</th>
<th>Water Quality</th>
<th>Terrestrial</th>
<th>Benthics</th>
<th>Fisheries</th>
<th>OVERALL WATERCOURSE SENSITIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1101</td>
<td>L L L L</td>
<td>1101 L</td>
<td>L L L L L L L L</td>
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<td>1103</td>
<td>L L L L</td>
<td>4237 L</td>
<td>L L L L L L L L</td>
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<td>M M M M</td>
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<td>M H M L</td>
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### Table 4.10.2 Sensitivity Table for Ultimate Scenario (Scenario 3)

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<th>Hydrology</th>
<th>Water Quality</th>
<th>Terrestrial</th>
<th>Benthics</th>
<th>Fisheries</th>
<th>OVERALL WATERCOURSE SENSITIVITY</th>
<th>Terrestrial</th>
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<td>Water Table Elevation</td>
<td>Baseflow/discharge</td>
<td>Streamflow</td>
<td>ET/SUB</td>
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<td>Mean Annual Flow</td>
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<td>L</td>
<td>L</td>
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<td>H</td>
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<td>L</td>
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Table 4.10.3  Sensitivity Table for Ultimate Scenario with Maximum Allowable Pumping (Scenario 3b)

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4.10.2 Summary of Subwatershed Sensitivity

The sensitivity of individual components was developed using a stress response framework, which accounts for the sequential effect of one component on the next subwatershed component (sections 4.2 to 4.9). Hence, from one perspective, the sensitivity of the fish community should be one integrative measure of subwatershed sensitivity. However, some factors in intermediate components will be highly sensitive, but not result in having significant effect on aquatic communities.

Two maps provide the basis for summarizing the subwatershed sensitivity to the development scenarios:

1. Upland and Wetland Sensitivity (Figure 4.5.2)
2. Composite Sensitivity for Flowing Water and Aquatic System (figure 4.10.1)

Section 4.5 describes how Figure 4.5.2 was developed. In terms of the tableland (wetland and upland communities) sensitivity, the analysis conducted in the Characterization (Phase 1) Report was used as an effective surrogate for sensitivity. At the subwatershed scale, tableland features exists in the upper and mid reaches but are confined to the Silver Creek corridor in the lower reach.

An overall watercourse sensitivity was developed based on the sensitivity of fluvial geomorphology, water quality, riparian cover and fisheries components. It was felt that these four components were heavily influenced by hydrogeology and hydrology. From a review of Tables 4.10.1, 4.10.2, 4.10.3 and Figure 4.10.1, Silver Creek and associated corridors appear to be highly sensitive to change in the lower reaches (subcatchments 1119, 1121, 1123 and 1125) and in the mid reaches (subcatchments 1107, 1109 and 1111). The mid reaches appear to be influenced by high inputs of groundwater (the sources area of which is situated in subwatershed 10). This, together with the local influences of channel form, riparian cover and presence of sensitive fish species makes these reaches particularly sensitive to change. In the lower reaches, these subcatchments have and continue to experience impacts from urbanization. Further impacts could push existing conditions beyond our capacity to restore to a sustainable system. Targets should be established in a conservative manner and follow-up monitoring must be used to refine these targets over time.
Figure 4.10.1: Composite Sensitivity for Flowing Water and Aquatic System

Sources:
Credit Valley Conservation, 2002; Ontario Ministry of Natural Resources, 1982
5.0 SUBWATERSHED OBJECTIVES

5.1 INTRODUCTION

As part of the overall study for the Credit River Watershed entitled the Credit River Water Management Strategy (CRWMS), completed for the Credit River in 1992, watershed wide goals were developed (Beak et al. 1992). Table 5.1.1 lists the goals for the watershed while Table 5.1.2 is a factsheet, which further refine these goals by subwatershed (Beak et al. 1992). The intent was that these goals and objectives be used as a starting point and refined as each subwatershed study is undertaken.

Table 5.1.1 Resource Management Goals for the Credit River Watershed

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER QUALITY</td>
<td>Maintain or restore water quality to a level, which maintains ecological integrity and permits desired uses including recreational opportunities.</td>
</tr>
<tr>
<td>GROUNDWATER</td>
<td>Protect and maintain groundwater recharge/discharge areas and baseflow to a level that ensures adequate supply for desired uses, including drinking water.</td>
</tr>
<tr>
<td>AQUATIC COMMUNITIES</td>
<td>Protect and enhance aquatic communities, with special regard for fish and fish habitat.</td>
</tr>
<tr>
<td>NATURAL FEATURES</td>
<td>Protect and maintain self-sustaining natural ecosystems and significant natural features.</td>
</tr>
<tr>
<td>RECREATION</td>
<td>Provide, diverse recreational opportunities that are in harmony with the environment.</td>
</tr>
<tr>
<td>AESTHETICS</td>
<td>Protect and enhance the environment in a manner that is in harmony with the natural features of the watershed.</td>
</tr>
<tr>
<td>FLOOD PROTECTION</td>
<td>Control flooding within the watershed through remedial works and land use controls.</td>
</tr>
<tr>
<td>EROSION CONTROL</td>
<td>Minimize soil loss through land management practices and remedial control measures.</td>
</tr>
</tbody>
</table>

Source: Beak et al. 1992
### Table 5.1.2 Subwatershed Goals for Silver Creek (Subwatershed No. 11)

| Resources/constraints | Water quality/quantity: major source of baseflow to Credit River  
Aquatic Community: self-sustaining coldwater fishery (brook trout, brown trout), Atlantic salmon in lower reaches  
Natural Features: Niagara Escarpment; Hungry Hollow (ESA (v), ANSI); Silver Creek Swamp Wetland Complex (includes ESA 21, 22, 42, 45, 46, 47, PESA 11 (w); Class 2, 3, 5, 6-currently being reevaluated, likely to be upgraded); Brisbane Woods II (part of ESA 24); Ballinafad Woods (PESA 18 (w), Class 6)  
Recreation: Silver Creek C.A.; Bruce Trail; river swimming, coldwater fishery (brown trout)  
Sources of Contamination | Urban: existing and proposed development; STP  
Industrial: aggregate mining; old landfills; spills  
Rural: septic systems; agricultural runoff  
Key Issues | Water quality/quantity: agricultural runoff; groundwater and baseflow  
Aquatic Community: maintenance of adequate water quality and habitat conditions to support coldwater species  
Natural features: protection of Escarpment valleys and wetlands from intensive recreational use  
Recreation: provision of access to coldwater fishery; intensive use of recreational facilities located in sensitive ecosystems  
Land use: rural estate development  
Goals | Water quality/quantity: agricultural runoff; groundwater and baseflow  
Aquatic Community: maintenance and enhancement of coldwater fishery  
Natural features: protection of wetlands  
Recreation: provision for recreational facilities and opportunities to support intensive use  
Erosion: minimize streambank erosion  
Proposed mitigative measures | Urban: infiltration with upstream sedimentation basin (25mm rainfall event)  
Industrial: spill protection (44 gallon) on all industrial and commercial developments  
Rural: non-structural measures; innovative rural development  
Resource protection: 60 m riparian buffer strip; reforestation/wetland creation; stream and riparian canopy rehabilitation  
Water resource targets | Groundwater (July – August): ≥ 25% of total flow  
Suspended Solids: < 5 mg/l (dry); < 100 mg/l (wet)  
Dissolved Oxygen: > 5 mg/l  
Maximum water temperature: < 20°C  
Metals: soluable copper < 6 mg/l  
Nutrients: total P < 30 ug/l dry, < 90 ug/l  
Riparian canopy: > 80%  
Source: Beak et al. 1992
5.2 **Subwatershed Vision and Goals**

The Focus Group, a volunteer group of citizens that live, work and recreate in the Silver Creek subwatershed, met to review the research to date and to develop the vision and goals for this work. The following Vision and Goals were developed by the Focus Group.

**Vision**

*To protect, enhance and rehabilitate corridors, tablelands and areas important to the ecological functions of the Silver Creek Subwatershed within the limits of the natural system.*

*Revisit and adapt this vision as our knowledge of the system and practices change.*

**Goals**

**Protect:**
- key subwatershed functions
- functions at risk, or areas whose functions would degrade and affect other areas

**Maintain:**
- base flow
- stream temperature
- valley corridors
- health of the system

**Enhance:**
- water quality
- fish habitat and communities
- woodlots and develop new woodlots
- education, partnerships and connection to others - Erin, Acton
- implementation - i.e. policy, enforcement, integration with Official Plans

**Understand and Address:**
- permanent monitoring of key parameters of ecological function to support future decision-making (with financial & public support)
- cumulative effects of water taking (permitted & non-permitted) and development on water quality & quantity
• carrying capacity of the Silver Creek system and the relationship between it and other systems
• impacts of people movement
• data & information coming from the Glen Williams' study

ENCOURAGE:
• wellhead protection strategies
• stewardship ("best management practices" rural & urban; innovation; reforestation; natural streamside vegetation; Storm Water Management)
• landowners/interest groups to monitor "Land Watch" or "Stream Watch" (issues relating to encroachment)

PROVIDE:
• environmentally-friendly trails

OTHER:
• review Sewage Treatment Plant's Certificate of Approval
• retrofit engineered drainage systems
• reduce or eliminate pesticide runoff
• limit encroachment

5.3 OBJECTIVES AND TARGETS

It is necessary to develop objectives and targets for the Silver Creek subwatershed that reflects its unique features and sensitivity. To make the process of developing objectives and targets easier, the subwatershed was divided into subcatchments. This was necessary given the diverse conditions within the subwatershed and the diversity of future land use changes. Objectives were developed for each tributary and when needed, targets were identified. Much emphasis was placed on the derivation of these objectives and targets in order to provide clarity in needs and direction. Appendix I lists the objectives and targets by tributary. This is important if the principles of Adaptive Environmental Management, as discussed in the Phase I report (CVC et al 2002), are to be employed. For successful implementation, objectives must be clear and measurable so that through monitoring efforts it can be determined whether or not they have been achieved in a given timeframe.

5.3.1 Hydrology Objectives

The objectives should support the vision and goals established for the subwatershed, as well as being realistic and achievable. Three objectives have been set:
• no increase in peak flow rates;
• no change in stream energy; and
• no attenuation of runoff volume

Peak flow rates have been modeled for many locations within the Silver Creek subwatershed for a variety of land use scenarios, including existing conditions (refer to Table 3.4.1). With this information, the concise objectives set for the subwatershed is easy to measure. If the objective is realized, then one aspect of the current hydrologic system can be maintained. If stormwater is not properly controlled, there is a potential for higher peak flows and volumes over a longer period of time.

Should the objectives not be realized, there are implications that could result in flooding, erosion, loss of aquatic habitat and loss of integrity of the riparian zone. However, each subcatchment is different, and impacts will vary from subcatchment to subcatchment (see Appendix I).

5.3.2 Hydrogeology Objectives

The objectives should support the vision and goals for each subwatershed, as well as being realistic and achievable. Nine objectives have been set for the subwatershed:

• no additional decrease in water table elevation;
• no additional decrease in baseflow;
• maintain recharge within and outside the subwatershed;
• maintain groundwater flux;
• maintain groundwater flow directions;
• no additional degradation of groundwater quality;
• no additional increase in groundwater temperature;
• locate potential contaminant source outside high groundwater vulnerability areas; and
• focus local-scale management efforts in areas of groundwater upwellings.

The objectives recognize that the largest portion of recharge within Subwatershed 11 occurs through the permeable materials, which are most extensive above the escarpment. Development in these areas will have a greater impact locally on the system than development in areas that are less permeable (e.g. on till units in Georgetown). In addition, the area above the escarpment in Subwatershed 10 functions as the recharge area for the buried bedrock valley and the drives flow into Subwatershed 11.

Keeping in mind that industrial, municipal and rural water supply needs will increase the impacts on the groundwater system resulting from land use changes, it is important that the hydrogeology objectives are held in high regard when land use change is considered in the subwatersheds. The principles of source water protection suggest that all areas contributing recharge need to be protected to maintain the health of the system. The objectives are therefore also applicable to the adjacent Subwatershed 10. Development changes in the recharge area for the buried bedrock valley may impact the ability to meet the objectives of Subwatershed 11.

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A variety of tools and indicators can be used to determine if the objectives are being realized, and are detailed in Appendix I.

5.3.3 Hydraulics Objectives

Hydraulic objectives will maintain existing return period water levels, and flow velocities throughout the Silver Creek watershed. By maintaining existing water levels, the number of buildings within the associated return period flood plains will not be increased and the risk to life and property will not be changed by interim or ultimate development. By maintaining existing flow velocities, stream erosion will not be increased as a result of new development.

The hydraulic objectives need not be implemented if existing streamflow rates and volumes can be maintained through best management practices. Increased streamflow rates and volumes will increase water levels and flow velocities.

5.3.4 Terrestrial Objectives

Typically, as development proceeds within a subwatershed, the greatest changes are physical through a shift in land use (i.e. natural to agriculture to urban). Significant but less visible terrestrial impacts are experienced through a loss or change in habitat when development encroaches upon the remaining natural areas. In addition, development can also alter the supporting ecological and hydrological processes, which can lead to a further degradation of the natural features and their functions.

The current and past landscape conditions serve as important points of reference for ecologically sound protection and management in the future. In pre-settlement times, the Silver Creek Subwatershed was covered by a complex of forests and wetlands. The original surveyors’ records indicate that this part of the Credit Watershed was dominated by deciduous forest, consisting primarily of stands of maple and beech with some basswood, oak and elm; on the valley slopes hemlock was common (Puddister and Mersey, 2002). Wild turkey, wolf, bear, lynx, wolverine, bobcat and other wildlife species roamed freely through the valleys and tablelands of the Silver Creek Subwatershed.

Under these conditions, stream flow was maintained by groundwater discharge, as there was little runoff except for extreme events. The subwatershed ecosystem was adapted to the natural disturbance regime within which it had evolved. With forest clearing, primarily from agricultural expansion, which was then followed by areas of concentrated urbanization, the ecosystem was significantly altered. Runoff and erosion increased, soil moisture was reduced and stream channels were modified. At the same time, the biodiversity of the subwatershed was simplified, as some of the best quality sites were converted to human uses, reducing community structure and function. The focus for the present and future terrestrial system is to strive for conditions that will maintain or
enhance the diversity and ecological integrity of the subwatershed’s riparian, wetland and upland communities.

5.3.4.1 Riparian

The hydrologic regime is the primary force that permits the continued ecological function of the riparian zone. As noted in the previous section, changes to this regime will result in changes to the riparian ecosystem. In addition, the riparian zone is strongly influenced by groundwater levels. As a result, a primary objective at the subwatershed and subcatchment scale is to maintain the current hydrologic regime to the extent practical.

While it is difficult to provide specific objectives for the width of the riparian zones (or buffers) because their effectiveness is based on site conditions, there are general guidelines based on scientific research that can be used. For species movement and species diversity, widths of three to 200 metres have been suggested (Daigle and Havinga, 1966, Environment Canada et. al, 1998). Other important buffer functions relate to sediment and nutrient removal and water temperature modification. For these functions widths range from three to 90 metres (Environment Canada et. al, 1998, Castelle et. al, 1994). For purposes of this study a 100-metre buffer has been selected as the preferred target. Efforts should be made to maintain or enhance, where necessary, a riparian corridor that is at least 60 metres in width (30+30) with preference given to those corridors that approach 100 metres (50+50).

5.3.4.2 Wetland

Wetlands provide a variety of habitat and hydrological functions within a watershed. They are therefore key to the long-term health of the system. Environment Canada and others (1998) reported on a number of studies that suggest if less than 10% of a watershed’s area is wetland habitat, that watershed has significantly reduced functions with regard to base flows, water quality and flood control. Therefore, a key wetland objective for the Silver Creek Subwatershed is 10% or greater in area.

Similar to the riparian zone, wetlands are highly dependent on the local hydrology and hydrogeology. Maintaining stream flows during both high and low periods is essential, especially for riverine wetlands. Other wetlands depend on surface runoff or a high water table for their functioning. As a result, changes to the hydrologic regime (both surface and subsurface flows) should be minimized in areas where wetlands have been identified.

Research has concluded that natural vegetation around the wetland boundary is essential to maintain its habitat functions. Not only does this buffer protect the wetland from adjacent impacts (e.g. excess nutrients), but it also provides critical areas for those species that must spend part of their life cycle outside of the wetland (e.g. turtles and some waterfowl) (Environment Canada et. al, 1998). The same Environment Canada report describes a range of adjacent vegetation widths from less than 30 metres to between 120 and 240 metres, providing a range of habitat functions. Accordingly, an adequate natural buffer should be maintained or enhanced around all wetlands.
For the same reason that it is important to provide a number of large forest patches for interior habitat, large forested swamp wetlands should also be maintained or created. These wetlands have the ability to provide important habitat necessary for interior sensitive species (e.g. Louisiana Waterthrush and Barred Owl). In addition, marsh wetlands will attract a variety of species depending on their size. The Mallard duck can find suitable habitat in very small marshes, while Black Tern and Short-eared Owl require very large marsh wetlands (Env. Can., et. al, 1998). Providing or maintaining a range of wetland sizes and types will result in a diversity of habitats being available for wildlife within the Subwatershed.

5.3.4.3 Upland

Upland communities in general, are not quite so dependent on the hydrologic regime as wetland or riparian communities are, given that they derive a considerable portion of their required moisture from precipitation. Certain communities, such as fresh to moist deciduous forests do, however, depend on a particular relationship between the water table and the rooting zone. Accordingly, efforts must be made to maintain current water table elevations.

As noted in Phase 1, it has been suggested that the importance placed on the size of an upland community or woodland be understood within the context of the percent of cover of that community type in the area under study. On this basis, it is important to maintain or enhance the representation of community types within the Subwatershed.

Principles of landscape ecology can be used to guide future changes with the subwatershed. These measures or metrics provide an indication of the trajectory in which the health of the terrestrial system is moving.

In fragmented landscapes, edge habitats tend to have a negative impact on the ecological integrity of upland natural systems. Therefore, minimizing the length of new edge around existing upland communities is important in assisting in the protection of their ecological functions. Maintaining or enhancing the connectivity of forested communities is also an important consideration in minimizing edge, providing sufficient opportunities for species movement and survival and maintaining the maximum diversity of native species and communities.

To ensure that a diversity of habitats is available for both interior species and interior/edge species, patches with both 100 and 200 metre buffers are required. Larger patches are also more likely to contain a higher diversity of community and species types as well as increased potential for uncommon or rare species and habitats. Accordingly, the largest natural forest patches should be maintained to provide the greatest diversity of habitats possible within the Subwatershed.

Research reviewed by Environment Canada and others (1998) highlight the interdependent relationships that exist between forest cover and wildlife habitat. Using the indicator of forest birds, researchers have documented a significant reduction in forest-dependant species when cover is reduced below 30 per cent. In an effort to
maintain or enhance species diversity within the subwatershed a target of 30% forest cover is recommended.

5.3.5 Stream Morphology Objectives

Upon completion of the impact assessment for the interim and ultimate scenarios, potential impacts to channel form and function were identified. Through a review of these results, various objectives were identified. These objectives should support the vision and goals of the subwatershed. Although no visions or goals have been explicitly identified for the watercourses, several objectives can be identified. These objectives strive to maintain or enhance channel functions to promote channel stability and to benefit aquatic resources. To be useful, the objectives need to be measurable, realistic and achievable. For the watercourses situated within Subwatershed 11, the following objectives have been identified:

- No reduction in channel length.
- No exacerbation of erosion in highly sensitive channels.
- Target migration rates of < 10 cm/yr.
- Naturalize previously altered channels (i.e., develop planform, cross-section, profile configuration suitable for flow and sediment regimes).
- Wherever possible, no alteration in flow or sediment regimes for highly sensitive channels (i.e., gullies, wetland channels).
- Maintain an entrenchment ratio of > 2.5 to enable larger than bankfull flows to spill onto a floodplain and dissipate flow energy.
- Reduce the excessive accumulation of fine sediment.
- Define a river corridor that enables natural migration tendencies to occur (i.e., the belt width).
- Minimize increase in stream power.

5.3.6 Water Quality Objectives

As part of CVC’s overall Water Quality Strategy, 9 objectives for water quality have been identified for the Credit River watershed (CVC et al., 2000 and Heathcote, 2002). The following 9 objectives outline general water quality objectives that either help to ensure good water quality or are an indicator of good water quality.

- Maintain adequate and clean groundwater upwellings
- Maintain stable stream form
- Minimize toxicity to aquatic biota
- Maintain aesthetics in and around watercourses
- Maintain safe swimming conditions
- Maintain healthy temperature regime
- Maintain healthy dissolved oxygen regime
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- Maintain healthy fish habitat
- Maintain adequate assimilative capacity

Maintaining adequate and clean groundwater upwellings should be accomplished through maintaining adequate infiltration and minimizing contaminant loadings from septic systems, road salting and agricultural practices, into the groundwater systems. Where possible, nitrate and chloride levels in groundwater upwellings should be below 2.5 mg/L and 250 mg/L, respectively.

Maintaining a stable stream form is crucial for minimizing detrimental loadings of suspended solids, and their associated contaminants (i.e. metals and phosphorus) to watercourses. Adequate riparian vegetation and stormwater controls are particularly important in maintaining a stable stream form. Given the low observed levels of suspended solids in the Silver Creek system, the suspended solids should not increase by 25 mg/L above background levels for high flows or 5 mg/L during low flows.

Toxicity to aquatic biota should be minimized through minimizing inputs of trace metals, un-ionized ammonia, nitrite and nitrate, from urban runoff, CSDS flows and contaminated groundwater upwellings. All metal levels should be under their respective PWQOs but copper and zinc are good representative metals as they have known toxic effects on aquatic biota and are also known to be found in urban runoff. The PWQO for copper is 5 ug/l, given the hardness of the water in Silver Creek, and the PWQO for zinc is 20 ug/l. Given their current low levels, un-ionized ammonia and nitrite should be maintained well under the PWQO of 20 ug/l and 0.06 mg/L CCME guideline, respectively. Where possible, both groundwater upwellings and watercourse concentrations of nitrate and chloride should be below 2.5 mg/L and 250 mg/L, respectively, which impacted aquatic biota in the literature (Rouse et al., 1999 and Environment Canada, 2001).

Although maintaining aesthetics around watercourses is a qualitative objective, this objective can be related to maintaining a natural channel form, enhancing riparian vegetation and maintaining low turbidity in watercourses. The objective for clear water flow (i.e. dry weather) is that the maximum increase of suspended solids is 5 mg/L for a time period greater than a day. Therefore, flows from any potential CSDSs should not increase suspended solids concentration to above 5 mg/L under the 7Q20 scenario.

Although Silver Creek does not have any official swimming beaches, maintaining safe swimming conditions is important for safe recreational uses of the watercourse. *E. coli* and turbidity, from suspended solids, are the primary parameters, which cause unsafe swimming conditions. Any effluent from the potential CSDSs in the subwatershed should have non-toxic tertiary treatment, which includes disinfection by ultra-violet radiation or ozonation. Seasonal geometric means, particularly for the summer, should be under the PWQO of 100 counts/100ml for recreational contact with the water.

Turbidity in Silver Creek should not increase to levels that will change the natural Secchi disc reading by more than 10 percent for background conditions (MOE, 1999).
The PWQO for water temperature states that the “natural thermal regime of any body of water shall not be altered so as to impair the quality of the natural environment. In particular, the diversity, distribution and abundance of plant and animal life shall not be significantly changed. Maximum temperatures should kept under the native coldwater fishery guideline of 20°C and minimum water temperatures should not go below freezing for potential or existing spawning areas. The guideline of 23°C for a self-sustaining coldwater fishery may be more appropriate for some subcatchments, which have maximum water temperatures currently above this guideline because of off-line and on-line ponds.

A healthy dissolved oxygen regime can be maintained by avoiding excessive nutrient (nitrogen and phosphorus), BOD, SOD, and NOD loadings from stormwater inputs, CSDS loadings and agricultural runoff. Since excessive nutrient loadings, particularly phosphorus (PWQO is 0.03 mg/L), may cause excessive aquatic plant growth, which in turn, can deplete dissolved oxygen levels during the night. Additional factors for maintaining a healthy dissolved oxygen regime include minimizing reductions in baseflow that could reduce flow velocities, which in turn, will reduce reaeration rates and maintaining a healthy temperature regime, since increases in water temperature will reduce the amount of dissolved oxygen that the water can hold.

Maintaining a healthy fish habitat is an integrative objective of the above water quality objectives, which support adequate and clean groundwater upwellings, stable stream form, healthy water temperature and dissolved oxygen regime, and non-toxic conditions for fish. Additional objectives for a healthy fish habitat are outlined below.

### 5.3.7 Benthics Objectives

Benthic macroinvertebrates can be used to monitor changes in environmental quality over time. Measurable objectives are listed in Table 4.8.1 above. Generally, those indices used to characterize the existing conditions (i.e., number of taxa, HBI, WQI, etc.,) can be used for monitoring. Here, the objectives for each subcatchment are set on the basis that an unimpaired condition will be maintained or achieved. Alternatively, a generic objective for each subcatchment might be no negative change from the existing condition, as determined by the baseline data collected in 2001. For example, there should be at least 20 distinct taxa at any site, with a minimum of 3 taxa that are mayflies, stoneflies or caddisflies (i.e. EPT taxa). The percent of the fauna as EPT should be > 10%, while oligochaete worms should comprise < 30% of the fauna, chironomids (midge) should account for between 10 and 40%, and isopods should account for < 5% of the fauna. Diversity (H’) would ideally exceed 3, while Hilsenhoffs Biotic Index would be < 6 and the BioMAP Water Quality Index would be > 9.

### 5.3.8 Aquatic Objectives

Goals and objectives related to the protection and enhancement of fisheries are derived from a number of complimentary policy documents with public input.
The Federal Fisheries Act legislates that there be no destruction or degradation of fish habitat without a permit or compensation agreement. The policy of no net loss further encourages that fish habitat and productivity be improved. The Credit River Water Management Strategy also sets the objectives of maintaining and improving fish habitat throughout the watershed. The Credit River Fisheries Management Plan 2002 has established goals and objectives in partnership with the Federal Department of Fisheries and Oceans, the Ministry of Natural Resources, Credit Valley Conservation and several stakeholder groups and the public. The goal endorsed from the Strategic Plan for Ontario Fisheries is “healthy aquatic ecosystems that provide sustainable benefits, contributing to society’s present and future requirements for a high quality environment, wholesome food, employment and income, recreational activity, and cultural heritage” (MNR 1992).

The stated objectives include:
- protect healthy aquatic ecosystems;
- rehabilitate aquatic ecosystems; and
- improve cultural, social and economic benefits from the aquatic resources of the Credit River.

At a more local level a Focus Group was also formulated for this subwatershed study that further endorses the protection, maintenance and enhancement of fishery resources with particular emphasis on the self-sustaining coldwater fishery.

Consistent with the above objectives, those for this subwatershed study utilize the similar terminology of maintenance and improvement. In cases, minimizing impacts can be permissible since there would be no anticipated impacts on a fish community either because no fish are present or the community is not sensitive to such changes.

Specific measurable targets have also been provided in order to measure the success of implementing actions to achieve set objectives. These targets are stipulated under the objectives column in Appendix I and relate directly to the three primary habitat requirements of each fish community classification documented throughout the subcatchments and discussed in section 4.7.

In summary the objectives and targets are as follows for each fish community and have been taken from the Credit River Water Management Strategy (Beak et al. 1992) or as cited from other disciplines within this study:

**Watertable**
- maintain watertable elevations as related to refuge pools, wetlands and discharge zones along stream corridors.

**Baseflow and Runoff**
- Coldwater: maintain or improve with a target of > 35 % total flow
- Mixed Coldwater: maintain or improve with a target of > 20 % total flow
- Small Warmwater: maintain with a target of > 10 % total flow
• Maintain seasonality of baseflow (including spring hydroperiod of intermittent streams)
• Maintain runoff component as related to fluvial geomorphology

**Fluvial Geomorphology**
• Maintain flow and sediment regime responsible for a quasi-equilibrium in channel shape, substrate, pool-riffle morphology and sinuosity (no excess erosion or sedimentation).

**Water Temperature**
• Coldwater: maintain or improve with a target of summer maximum < 20°C
• Coolwater/Redside Dace: maintain with a target of summer maximum < 23°C
• Warmwater: minimize with a target of summer maximum < 25°C
• Tolerant Warmwater: minimize with a target of summer maximum < 28°C

**Total Phosphorous**
• <0.06 mg/l to prevent excess plant growth and oxygen depletion

**Unionized Ammonia**
• < 2.5 mg/l to prevent potential effects on fish eggs (and amphibians)

**Riparian Cover**
• Maintain or enhance buffered stream length with minimum widths of 30m (15+15) on Warmwater streams and 60m (30+30) on Coldwater and Mixed Coldwater streams.

**Wetlands**
• Maintain wetland hydrology and enhance area to 10% catchment.
6.0 ALTERNATIVE MANAGEMENT SOLUTIONS

6.1 INTRODUCTION

This chapter endeavors to develop a set of management options that allow for alternative ways of dealing with the proposed land use changes for the Silver Creek subwatershed. In essence, these options will identify techniques used to offset the impacts of future land use changes.

6.1.1 Types of Options

It is important that options are clearly defined and easily understood by all involved in the process in order to obtain consensus and buy in. The following represents the identified options available for implementation:

**Do Nothing Approach**
This approach acknowledges that there will be future land use changes and chooses not to intervene with offsetting mitigative actions. It should be acknowledged that this approach is not acceptable and does not meet the vision, goals and objectives for the subwatersheds.

**Structural Measures**
This approach acknowledges that there will be future land use changes and allows for change with the intent of utilizing various technological solutions or structural measures to offset impacts.

**Non-Structural Measures**
This approach acknowledges that there will be future land use changes and allows for changes while utilizing management solutions which calls for changes to human behaviour and management practices.

**Avoidance**
This approach does not acknowledge that there will be future land use changes and therefore supports status quo conditions. It should be noted that this option is not realistic given the commitment to some degree of land use change in these subwatersheds.

Upon review of the above options, it becomes clear that the implementation of structural and non-structural options are the most viable. The following discusses the application of these approaches to all study components.
6.2 HYDROLOGY

6.2.1 Do Nothing

The main objective for the Silver Creek subwatershed is to maintain existing streamflow rates and volumes. For the interim scenario, the Do Nothing alternative would see significant site level impacts, but less significant subwatershed impacts. The Do Nothing alternative for the ultimate land use scenario would see significant site, tributary, and subwatershed impacts.

6.2.2 Structural Approach

Structural approaches to maintaining existing streamflow rates and volumes would include site best management (infiltration basins, detention basins, retention basins, etc.) and watercourse modifications. Structural approaches would most likely be conducted at the site level rather than at the tributary or subwatershed level. A large portion of the Silver Creek subwatershed is under private ownership. Any Stormwater management facilities for separate adjacent properties would have to be completed at an early planning stage. Property owners have the right to receive runoff in a natural state both in quantity and quality.

If tributary level structure could be constructed it would probably necessitate the enlargement of road crossing conveyance capacities and storage capacity enlargement of existing ponds. In addition, easements to contain flood waters would have to be acquired.

6.2.3 Non-structural Approach

Non-structural approaches include policies and regulations. Existing CVC policies and regulations would be enforced. Changes (increases/decreases) to water levels and the duration of flooding on private property will not be allowed. Large portions of the Silver Creek subwatershed are under private ownership. Development allowed under non-structural approaches may require site easements and adjacent property damage payments.

6.2.4 Combination

A combination of structural and non-structural approaches will be required to allow development within the Silver Creek subwatershed. Structural approaches would probably be conducted at the site level unless a large block was to be developed at the same time. Development would probably require the conveyance of easements and the construction of best management practices. Adjacent developments could construct joint facilities. Planning for joint facilities would have to conclude at an early stage.
6.3 HYDROGEOLOGY

Based on the hydrogeological impact assessment, the impacts to the groundwater system resulting from land use changes and increased pumping include:

1. Measurable reductions in groundwater discharge (baseflow) in areas that are developed;
2. Reduced recharge and baseflow above the escarpment (e.g. Ballinafad);
3. Measurable but small reduction in groundwater discharge resulting from local reduction of recharge from land use changes alone in Georgetown.
4. Significant reduction in groundwater discharge below the escarpment from cumulative effects of proposed land use changes and increase pumping;
5. Potential for significant reduction in baseflow below escarpment from land use changes in Subwatershed 10;
6. Local changes in water table elevation and groundwater flow direction near pumping wells with increased pumping (e.g. subcatchment 1117);
7. Reduced groundwater flow from Subwatershed 11 to adjacent Subwatersheds (6, 9, 12, 14), which could result in impacts in those areas; and
8. Potential for groundwater quality degradation in high vulnerability areas.

Management solutions to mitigate potential impacts on hydrogeological system must consider areas beyond the boundary of the subwatershed and seek to protect source/recharge areas. In considering all areas and focusing mitigation on protecting areas of significant groundwater recharge and discharge, changes in the water table elevation, groundwater flow direction and groundwater discharge (baseflow) may be minimized.

There are three major land uses within the Subwatershed 11: settled, natural, and agricultural. The proposed land use changes would convert natural and agricultural areas to settled areas. The following highlights the various potential management solutions related to the land uses increased water demand. A discussion of the preferred management options is presented at the end of the section.

6.3.1 Do Nothing

The do nothing approach recognizes that development and increased pumping will occur and the impacts will not be mitigated. Adoption of this approach contradicts objectives defined for the subwatershed and would result in a reduction in groundwater discharge, a degradation of groundwater quality and overall degradation of the health of the subwatershed.

The amount of water available is finite. The system has the ability to adapt to some level of land use and still maintain water table elevation, groundwater flow and groundwater discharge at current conditions. However, the cumulative effects of development and increased pumping are likely to exceed the capacity of the system. The greatest impacts from increased pumping are expected below the escarpment, while the greatest impacts
from reduction in recharge are expected above the escarpment in areas where development will occur on higher permeability materials.

Currently the Ontario Ministry of the Environment (MOE), Permit To Take Water (PTTW) program regulates the amount of water taken from large surface and groundwater takings. For groundwater takings, the permitted volume is based on an assessment of well efficiency, aquifer capacity, and surface water connections and other well interferences. This system provides one level of protection to the groundwater system but does not consider the water budget of the system and the cumulative effects of land use changes on recharge.

The CVC also currently reviews individual development applications to ensure that they conform to CVC’s policies and also to determine if there would be a potential Harmful, Alteration, Disruption or Destruction (HADD) of fish habitat associated with the development, on behalf of Fisheries and Oceans, Canada (DFO). As part of the CVC review, the effects of local land use changes on the ecosystem are considered. However, this review is conducted for individual sites and assessing the potential larger scale and cumulative impacts of these developments is difficult.

### 6.3.2 Structural Approach

The structural approach recognizes that development and increased pumping will occur and the impacts may be mitigated through technological solutions or structural measures. The approach mitigating the predicted impacts is the same whether agricultural or natural land is being changed to settled land. In both situations, recharge will be reduced without mitigative measures. The following structural solutions are typical of many developments and could be employed to reduce impacts from land use changes:

- Construct stormwater management structures such as infiltration galleries to capture runoff from settled areas in order to compensate for the loss of recharge through the increase in impervious cover;
- A less common and more expensive option may be artificial aquifer recharge with source of water being drawn from areas with “excess” capacity;
- Construction of regional sewer lines or the use of communal systems with enhanced treatment systems to service new developments reduces potential for contamination from septic systems, that are typical of dense developments (below escarpment);
- Alternative de-icing agents should be investigated for areas expected to be impacted by road salt.

The impact from increased pumping may be mitigated through technologies that allow for accurate simulation of the groundwater system that include investigations of the buried bedrock valleys and provide estimates of “sustainable yield” which can be used to limit water takings to with the PTTW.

Impacts from increased pumping may also be mitigated by adopting water conservation techniques (such as a municipally sponsored program promoting water efficient shower...
heads and toilets), limiting water use (e.g. lawn watering bans) or by satisfying the increased demand with a water source from outside the system (e.g., pipeline from Lake Ontario).

### 6.3.3 Non-structural Approach

The non-structural approach recognizes that development and increased pumping will occur and the impacts may be mitigated through changes in human behaviour and management practices.

These following mitigative solutions are likely to be the most effective and still allow for proposed development and associated increase in pumping:

- Limit development to areas of low permeability surface materials (e.g. Till in Georgetown) due to low vulnerability and
- Protect recharge areas by limiting development in these areas to protect the source quantity and quality. This includes area within and outside Subwatershed 11.
- Limit road density in recharge areas to minimize impermeable surfaces;
- Promote water conservation and limit water use (e.g. water meters);
- Limit high groundwater use activities (e.g. irrigation, process water);
- Impose development density restrictions where septic systems must be employed for wastewater treatment (e.g. above escarpment);
- Encourage high density housing to limit the “impermeable surface footprint”;
- Limit groundwater use to the capacity that can be supplied by the buried valley in the Georgetown area without adversely affected the health of the environment; and
- Limit activities with a potential to contaminate groundwater to low vulnerability areas.

### 6.3.4 Combination

The non-structural measures proposed are the most financially viable solutions for implementation, but the most difficult to employ as they have societal implications. Structural mitigation measures are more easily accepted, as they do not involve modification of human behaviour or expectations, only an increase in development costs.

The most appropriate mitigative measures are the ones that allow the objectives for the subwatershed to be achieved. Structural measures can be imposed through local laws and the costs can be passed on through the development. However, these measures will not address all of the objectives. Non-structural measures can be implemented through education of people and companies in the local area.

The sensitivity of groundwater system of Subwatershed 11 and the connection with Subwatershed 10 through the buried bedrock valley requires a combination of structural and non-structural approaches. The greatest challenge with respect to groundwater will be to mitigate the effects of the additional municipal pumping that may be required as a
result of ongoing development. Conservation measures are preferred to obtaining a source from outside the area as it forces a local solution and is more ecologically sound for the larger area. Such a solution is likely to be a combination of structural and non-structural mitigation measures.

6.4 HYDRAULICS

6.4.1 Do Nothing

The Do Nothing alternative will see minor impacts for the interim land use scenario upstream of Georgetown. Downstream through Georgetown the impacts will be significant. For the ultimate land use scenario, impacts will be significant throughout the Silver Creek watershed.

6.4.2 Structural Approach

Assuming best management practices are not constructed to maintain existing streamflow rates and volumes, then structural approaches will be required to maintain existing water levels and flow velocities. The measures will involve enlarging existing road / rail crossings, channelization, and dyking. For interim land use scenarios, the measures would be constructed downstream of 22nd Sideroad or through Georgetown. For the ultimate land use scenario works would have to be constructed throughout the Silver Creek watershed.

The majority of road crossings are under the jurisdiction of regional, municipal, and provincial agencies. Enlarging road crossings should not be a difficult undertaking. Channelization will involve the acquisition of private lands to enlarge the watercourse. Property owners have the right to receive runoff in a natural state both in quantity and quality. Therefore acquisition of private lands will be required. In addition, the cooperation of private corporations will be required to enlarge rail crossings. The cost and level of effort will be significant for channelization and rail crossing enlargement.

Structural approaches are not the preferred method of mitigating hydraulic impacts due to urban development. The costs and environmental impacts are significant. Preferred approaches are to maintain existing streamflow rates and volumes.

6.4.3 Non-structural Approach

Non-structural approaches are not applicable to maintaining existing water levels and flow velocities. Non-structural approaches such as easement and property acquisition will ensure new development is located outside the Regulatory Flood Plain. However, in developed areas the number of buildings in the Regulatory Flood Plain will probably be increased.
6.4.4 Combination

Without best management practices, combinations of structural and non-structural measures, to maintain existing water levels and flow velocities, will be extremely difficult and costly to implement.

6.5 Terrestrial

The Silver Creek Subwatershed represents a fragmented and disturbed landscape. Considerable evidence exists to illustrate that the terrestrial systems are under a variety of ecological stresses. As a result, and in keeping with the Vision and Goals for the Subwatershed, the remaining natural areas should be protected to the greatest extent possible and efforts should be made to create and/or enhance terrestrial communities where practical.

6.5.1 Do Nothing

As noted above, if the Study is to effectively address the Vision and Goals for the Subwatershed, the do nothing alternative is not really tenable. Silver Creek is an especially important tributary to the Credit River system. While showing evidence of previous land use changes, the system continues to support important terrestrial features and functions. If proactive management of the Subwatershed does not occur, these significant attributes will be threatened in the future as land use changes continue.

6.5.2 Structural Approach

There are a number of ‘structural’ measures, or improvements, that should be considered to enhance the remaining natural areas and to improve their resilience to the anticipated changes within the Subwatershed:

1. planting of stream banks and adjacent lands in areas where land uses have encroached within the recommended riparian zone widths
2. carrying out reforestation around the perimeter of disturbed woodland communities to reduce the amount of edge habitat and provide enhanced interior area
3. enhancing or re-establishing corridors to link upland natural areas
4. restore wetlands and promote the use of wetland-type storm water quality control ponds in urbanizing areas to increase the amount and diversity of wetland communities within the subwatershed
5. increase the amount of natural area around wetlands through planting or naturalization to achieve the recommended targets
6. increase total forest cover within the Subwatershed to achieve the recommended target of 30% (an increase of 8.5%).

6.5.3 Non-structural Approach

A series of existing or enhanced programs and policies can also be effective in protecting or improving the remaining natural system within the Silver Creek Subwatershed:

1. protect all high priority terrestrial communities through municipal planning documents (i.e. official plans and zoning by-laws)

2. require the preparation of Environmental Impact Statements for changes in land use, which may affect important terrestrial communities, either directly or indirectly

3. target key rural properties for the preparation of Conservation Plans to encourage long term stewardship

4. encourage the exchange of information and educational opportunities for landowners through a variety of approaches such as workshops and printed materials

5. for targeted properties, provide financial incentives to those landowners who are prepared to carryout stewardship projects on their properties for the benefit of the subwatershed (a maximum of one-half of project cost to be covered by public funding and/or services in kind)

6. encourage members of the local community to volunteer their time to work with CVC and other groups and agencies to promote the stewardship, restoration and monitoring of the terrestrial communities within the Subwatershed (i.e. services in kind)

7. promote opportunities for passive outdoor recreation and nature appreciation through the use acquisition and protection of important greenlands, which complement the existing public open spaces within the settled areas and along the Niagara Escarpment, thereby connecting parks and nearby conservation areas.

6.5.4 Combination

In reality, a combined and comprehensive approach will be required to most effectively protect and enhance the terrestrial systems within the Silver Creek Subwatershed. When specific areas within the Subwatershed are identified for management, a range of both structural and non-structural approaches will likely form the preferred approach. For example, while reaches of a tributary stream may be targeted for restoration, the owners of these same lands will also be encouraged to practice good land and water stewardship.
6.6 **STREAM MORPHOLOGY**

6.6.1 **Do Nothing**

In headwater channels, alteration of land use will cause more frequent and flashy flows. Due to the often low grade of these watercourses and the vegetative control, the impact may not be substantial. Nevertheless, it is anticipated that widening and planform development is anticipated. Channels flowing through wetland areas are sensitive to changes in flow and sediment regimes.

Channels that are situated along the main channel of the drainage network can experience significant impacts from changes in flow and sediment regimes that occur due to alterations in land use. The impact is cumulative in the downstream direction and hence downstream channels may be more impacted. In all channels significant enlargement is expected predominantly through the process of widening. Extensive erosion and planform adjustments are anticipated, especially in the areas receiving runoff from urban areas. Sediment from bank and valley wall erosion, in conjunction with fine sediments entering the channel from roads, can cause an increase in fine-sediment which could alter substrate composition in such a way as to be detrimental to the survival of fish eggs. Excess sediment would be temporarily stored in lower gradient reaches; this could cause further channel widening and planform development. Increases in flows will cause an increase in the stress exerted on the channel bed and in sediment transport potential which can lead to incision and loss of channel bed stability through the frequent mobilization of large sediment.

6.6.2 **Structural Approach**

To off-set impacts of alterations in flow and sediment regimes, various approaches can be taken. Areas in which extensive erosion occurs can be remediated through natural channel design, and the application of bank restoration treatments such as bio-engineering or, where necessary, harder engineering solutions. Catchment pools can be created downstream of roads to capture sediment from road runoff, thereby reducing the impact to spawning gravels. In-stream structures can be created to reduce flow-energy and therefore sediment transport potential. Natural channel design approaches could be used to naturalize channel sections. Incorporating structural solutions for mitigating land use change effects.

6.6.3 **Non-structural Approach**

Various management solutions can be used to accommodate the alterations in flow and sediment regime that accompany land use changes. Defining and setting aside a river corridor in which meandering tendencies of the watercourses can occur (i.e., the meander belt) is one solution that allows channel adjustment processes to continue while protecting private property. Management of storm water runoff to reduce peak flows and
the rate of excess volume release will reduce the impact of changing flow regime on the channel. As a result, the magnitude of channel adjustments would be reduced (i.e., enlargement, erosion, sedimentation etc.). Careful consideration of storm sewer outfall locations will minimize impact to sensitive channels and gullies.

6.6.4 Combination

From a geomorphologic perspective, the form, function, and processes of watercourses are best protected when changes to the flow regime resulting from changing land use are mitigated. The goals and objectives of the Subwatershed plan are best achieved by incorporating both structural and non-structural approaches to mitigating the impacts of changing land use on the physical form of watercourses.

6.7 WATER QUALITY

6.7.1 Do Nothing

The ‘do nothing’ approach would allow development and aggregate activity to occur without any controls to offset severe impacts to in-stream water quality as outlined in Table C. This would result in unacceptable water quality conditions for nearly all the subcatchments in the subwatershed.

6.7.2 Structural Approach

The following structural approaches would aid in the attenuation of the unacceptable water quality impacts from the degree of development and aggregate activity presented in the interim and ultimate scenarios:

- require high levels of treatment for wastewater to be provided by the Georgetown WPCP, such as:
  - consideration of denitrification /nitrification treatment
  - ‘best available technology’ for total phosphorus removal (0.15 mg/L in effluent)
- upgrade existing and any future individual septic systems for treatment of nitrate
- upgrade existing settled areas to provide stormwater quality treatment, where feasible
- require stormwater quality treatment for all future development
- require sediment fences and traps during construction
- multiple pits with walls between them to maximize baseflow for benthic invertebrates.
6.7.3 Non-structural Approach

The following non-structural approaches would further aid in the attenuation of the unacceptable water quality impacts from the degree of development and aggregate activity presented in the interim and ultimate scenarios:

- encourage best management practices for agriculture activity through Environmental Farm Plans, including:
  - proper manure management (storage and application)
  - fencing livestock out of watercourses
  - planting of riparian vegetation
  - proper application of fertilizers and pesticides
  - adopting integrated pest management
- encourage municipalities to develop Salt Management Plans that minimize the use of road salt
- encourage minimal fertilizer and pesticide use in rural and settled areas
- educate septic systems owners on proper operation and maintenance of their systems
- do not carry out aggregate extraction below water table
- avoid extracting aggregate areas where baseflows will be impacted
- enhance riparian areas by planting native trees and shrubs

6.7.4 Combination

Neither a purely structural or non-structural approach to attenuating water quality impacts is likely to result in acceptable water quality conditions of this subwatershed therefore a combination of all these approaches are recommended.

6.8 Benthics

Because the benthos are sensitive to changes in suspended solids, nutrients, and persistent organic and inorganic chemicals that runoff from urban surfaces, any activity or structure that minimizes or mitigates chemicals in surface runoff will be beneficial. Further, any activity that enhances or maximizes groundwater infiltration, and that will ensure/maintain baseflows and stream temperatures should be incorporated into a subwatershed management plan.

6.8.1 Do Nothing

The do-nothing approach would use traditional designs and would result in the impacts as predicted.

6.8.2 Structural Approach
There are a variety of structural mitigation actions that can be used to offset potential impacts to benthic macroinvertebrates. Stormwater ponds can reduce nutrients and suspended solids loads, and can increase groundwater infiltration to ensure baseflow contributions and thus cool stream temperatures. Sediment traps/fences are also recommended for construction phases of development to reduce sediment entering streams.

### 6.8.3 Non-structural Approach

Buffer strips along streams can be used to keep streams cool, to maintain allochthonous food supplies (i.e., leaf litter, terrestrial insects) for invertebrates, and to maintain channel integrity. Buffer zones also act as sediment traps and nutrient filters for overland flows, and prevent streambank erosion. To protect sensitive and cold-water fauna, buffer strips of at least 30 m width (on each side of the channel) are recommended.

Controlling the amount and development of hardened surface area can minimize runoff. Infiltration can also be enhanced by directing stormwater runoff over land instead of to hardened surfaces (driveways, roads, culverts) that lead to streams.

Chemical contamination can be minimized if the use of chemical pesticides and fertilizers are minimized.

Hardened stream sides do not facilitate the development and growth of benthic macroinvertebrates. Natural channel designs should, therefore, be encouraged where possible to ensure that stream sides are as natural as possible, and to enhance the production/growth of benthos in those areas.

### 6.8.4 Combination

Both structural and non-structural (passive) technologies can be used to enhance/maintain healthy invertebrate communities. Sediment traps/fences can be used during construction phases to limit the amount of sediments entering streams. Settling ponds can be developed within urban areas to remove chemicals from stormwater runoff. Riparian zones can be maintained or allowed to develop to provide shade for streams, and to act as filtering mechanisms for overland runoff. Within the developments themselves, it is important to limit the impervious area, and to maintain or enhance infiltration by directing runoff to permeable substrates.

### 6.9 AQUATICS

Since fish are considered to be integrative indicators or a product of the forms and processes within the subwatershed and that the other disciplinary studies are promoting alternative management solutions that ultimately affect the fisheries, only those additional management options specific to fish require discussion here.
6.9.1 Do-Nothing

The do-nothing alternative is not acceptable if it results in habitat degradation. However it is acceptable elsewhere as degraded habitats over time will become stable or improve through natural succession (e.g. buffers).

6.9.2 Structural Approach

There are a variety of structural options to improve aquatic habitat:
- riparian plantings or soil bioengineering (for fish cover only);
- cover structures (lunkers, reefs, woody cover) to improve habitat in streams;
- wetland creation, shoreline reconfiguration, adding woody cover and reefs in rehabilitated pits would provide aquatic habitat;
- beaver dam and log jam management removal or management;
- dam removal.

Alternative management solutions discussed in other components that directly benefit fisheries include: stormwater best management practices (BMPs); wetland creation; vegetative plantings in recharge and riparian areas; livestock fencing from watercourses; groundwater BMP’s such as limiting depth of excavation and proximity to watercourses, and the control of water tables by not removing land barriers between ponds; as well as flood, erosion and siltation controls.

6.9.3 Non-structural Approach

Non-structural approaches to address aquatic recommendations are:
- fish stocking or control of undesirable species;
- special harvest and seasonal fishing regulations;
- other management solutions recommended as non structural such as policies and regulations and in particular, the Federal Fisheries Policy, along with stewardship programs will be the most effective in maintaining or improving fish and fish habitat; and
- appropriate land use planning policies.

6.9.4 Combination

Given that a combination of alternative management solutions from all study components are required to manage fish and fish habitat, a combination of structural and non structural methods are recommended.
7.0 IMPLICATION FOR ADAPTIVE MANAGEMENT & MONITORING

7.1 INTRODUCTION

The principles of adaptive environmental management (AEM) have been fully described in the Phase I report. As outlined previously, the key to AEM is the concept of learning and adapting. Figure 7.1.1, a conceptual model that describes the process of AEM, shows the importance of monitoring as a means of learning and making appropriate adjustments with the knowledge gained. The purpose of this chapter is to provide a continuous thread on AEM through the subwatershed planning process, as it will be key in following through on implementation issues.

7.2 MONITORING PHILOSOPHY

Traditionally monitoring has been associated with legal compliance issues. Under the AEM approach, focusing on learning and adapting, helps to bring purpose and direction to monitoring (Bormann et al. – unpublished document). It is therefore essential that the questions to be answered must first be developed. Monitoring efforts need to be shared amongst those involved in the process, namely, scientists, managers and residents so that each group is given the opportunity to learn. It is however important to utilize scientific methods that maximizes the opportunity to detect differences and trends efficiently and at the same time minimizing biases (Bormann et al. – unpublished document). Evaluation of monitoring results is important in comparing forecasted versus actual outcomes. This is

Figure 7.1.1  Conceptual Model of Adaptive Management
essential, as it will alert implementers when sufficient monitoring is achieved or when some pre-identified threshold is reached and another type of action and monitoring approach is needed.

7.3 PARTNERSHIPS

The AEM approach recognizes the need to involve the interaction between scientists, managers, proponents for change and local residents. In times of shrinking budgets and the need to develop monitoring protocols that are relevant, repeatable and simple allows for more opportunities to get volunteers from local interest groups, schools and residents, who live close to selected monitoring locations, involved in a meaningful fashion. This approach allows scientists, proponents for change and managers to interact with local residents with mutual benefits gained with the joint learning by all parties resulting in holistic views on desired conditions (Bormann et al. – unpublished document).
8.0 FUTURE WORK

This concludes the work, analyses and findings carried out under the Phase II Impact Assessment work program. The next steps would involve selection of a preferred option and developing a defined implementation strategy. This analysis will be covered in a separate report that will summarize Phase III of the subwatershed process namely, Implementation.
REFERENCES


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