Potential Effects of Climate Change-Induced Low Water Levels on Rural Communities in the Upper Credit River Watershed

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Preface

In the water sector, the persistence of human impacts and associated costs of climate events point clearly to the need to identify strategies for coping with climate variability and change, and to develop an enhanced capacity to respond effectively (Hofmann *et al*., 1998). Rural communities – especially those in the rural-urban fringe – are challenged by the need to balance human uses (e.g., rural industry, recreation, municipal water supply) and ecosystem protection (e.g., maintenance of base flow to support fisheries, protection of wetlands that depend on shallow groundwater aquifers). Key stakeholders comprising rural communities in the rural-urban fringe include municipal water managers, rural residents and industries, farmers, golf course operators, anglers, and conservation groups. Not only are these people and groups experiencing increasing conflict and competition over water, particularly groundwater (Kreutzwiser and de Loë, 1998), but also they must cope with capacity-related challenges. Two issues are particularly important:

- First, not much is known about the impacts of climate-induced water shortages on rural communities in Canada and the ecosystems upon which they depend (Climate Change Action Fund, 1998; Hofmann *et al*., 1998).
- Second, in Ontario, recent reductions in provincial support for water management and land use planning (Kreutzwiser, 1998) have had serious implications for rural communities. For many rural communities, the capacity to mount effective climate change adaptation strategies is in question.

Our *Climate Change Action Fund* research project # A258 assessed the capacity of rural communities in the upper Credit River watershed in southern Ontario to adapt to climate-induced water shortages. The research effort was organized around three objectives:

1. Identify the actual and potential impacts of climate-induced variability on hydrologic systems in the upper Credit River watershed.
2. Identify adaptation responses and determine and assess factors that facilitate and constrain the ability of rural communities to balance human uses of water and ecosystem protection under increasing climate variability.
3. Recommend strategies to enhance the capacity of rural communities to adapt to climate-induced variability in hydrologic systems.

Four documents were created to summarize the findings of the research:

- This document, *Potential Effects of Climate Change-Induced Low Water Levels on Rural Communities in the Upper Credit River Watershed*, addresses Objective 1,
- *Climate Change, Water Resources, and Rural Community Capacity to Adapt: Workshop Session on Adapting to Low Water Levels in the Upper Credit River Watershed* is a reference document prepared as background information for participants of a workshop held in Orangeville in April 2001 to address objectives 2 and 3,
- *Adapting to Low Water Levels in the Upper Credit River Watershed – Workshop Summary* summarizes the findings of the workshop, and

- *Strengthening Rural Community Capacity for Adaptation to Low Water Levels* summarizes the findings of objectives 2 and 3, including a case study on subwatersheds 16/18 and 19 of the Credit River watershed.

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1.0 Climate change and drought

Southern Ontario has a modified continental climate, moderated by the presence of the Great Lakes, and protected from Atlantic storms by the Appalachian mountains (Phillips, 1990). At a regional level climate is affected by latitude, air masses, storm movement, altitude, and topography (Phillips, 1990). High and low pressure systems pass over southern Ontario every few days, making weather variable, and weather extremes typically short-lived (Phillips, 1990). The upper Credit River watershed lies above the Niagara Escarpment, one of the most prominent features of southern Ontario topography (Figure 1). The escarpment provides some protection for the lower portion of the watershed by dissipating clouds and precipitation, inhibiting winds, and warming air masses as they descend the eastern side of the escarpment (Phillips, 1990). While the upper Credit River watershed lies to the northwest of the City of Toronto, and experiences less of the moderating effects on temperature of Lake Ontario and large urban areas, Toronto climatic conditions are indicative of the general characteristics of the climate of the area. Average mid-afternoon temperatures in Toronto range from –2.5°C in January to 26.8°C in July (Phillips, 1990). The frost-free period lasts an average of 149 days, from May 8 to October 5 (Phillips, 1990). On average, Toronto experiences 99 days of rain, and 47 days of snow each year, culminating in an average of 637.2 mm of rain and 131.2 cm of snow (total precipitation of 761.5 mm) (Phillips, 1990). Total precipitation is generally evenly distributed throughout the year.

Climate change due to increased concentrations of atmospheric CO_2 is likely to result in changes to the temperature and hydrologic regimes of southern Ontario (Hofmann *et al*., 1998). In addition to changes in average climatic conditions (e.g., air temperature, annual precipitation), increased climatic variability could lead to more frequent and severe extreme climatic events (e.g., droughts, heat waves, and floods). Although estimates of future changes in climatic conditions are subject to uncertainty, increases in air temperature and evapotranspiration, and changes in the amount and distribution of precipitation are likely (Lavender *et al*., 1998). These conditions could result in an increase in the incidence and duration of low water conditions in southern Ontario in general, and in the Credit River watershed in specific (Hofmann *et al*., 1998).

Low water levels already have implications for the management of human (e.g., agriculture, municipal water use) and natural (e.g., aquatic and terrestrial ecosystems) systems dependent on water. Gabriel and Kreutzwiser (1993) note in their study of Ontario drought impacts that dry periods lasting a minimum of 7 days occur at least once a month during the growing season, while droughts lasting over 4 weeks occur once every 3 years. In the past, droughts have occurred in Ontario in 1973, 1978, 1983, 1988, and 1989 (Phillips, 1990). Low water conditions are of recent concern in the Credit River watershed. Annual rainfall levels approached 30 year lows in 1997 and 1998 (Credit Valley Conservation, 1999b). An increase in the incidence and duration of drought due to climate change will impact upon the nature and management of human and natural systems in the upper Credit. If water supplies in the watershed become more variable, water use conflicts, in particular between natural and human systems, could become more common and severe.

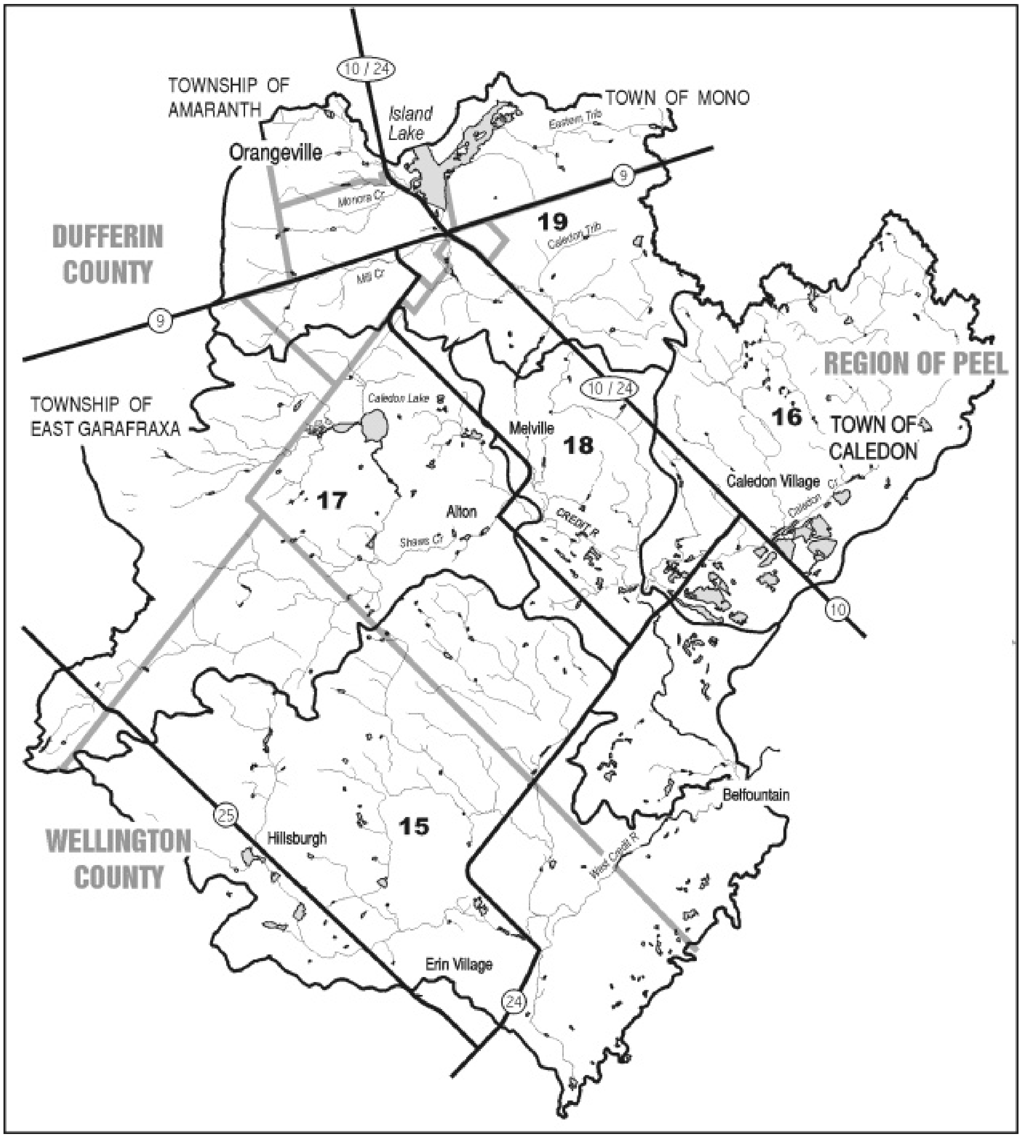

Figure 1: The upper Credit River watershed

The purpose of this report is to summarize the possible impacts of climate-induced water shortages on water-dependent resources and activities in subwatersheds 16/18 and 19 of the upper Credit River watershed. Of particular concern regarding natural systems are the cold water fisheries and wetland resources of the Credit watershed. Human systems likely to be affected by drought include municipal and rural domestic water supplies, agriculture, commercial and industrial water uses, and recreation and tourism. Data sources included watershed and subwatershed reports, municipal and conservation authority documents, peer-reviewed literature, and interviews with watershed stakeholders. While the impacts on human and natural systems will be treated separately, it is acknowledged that human and natural systems interact, and are largely dependent on one another. Hence, impacts on one system may exacerbate or moderate impacts on another. A key concern for rural municipalities in the upper Credit River watershed will be balancing the water needs of natural systems against those of human systems.

2.0 Human water uses

The total permitted water taking in the Credit River watershed, under the Ontario Ministry of the Environment's Permit to Take Water (PTTW) program, is approximately 400 million Lday^{-1} (Credit Valley Conservation, 1999a). Of the 241 permits issued in the watershed, 105 are for over 1 million Lday^{-1} (Credit Valley Conservation, 1999a). Large water users include gravel pits and municipal water suppliers, as well as water bottlers, agriculture, golf courses, and industrial/commercial water users (Triton Engineering Services Ltd. *et al*., 1991). Since 1962, there has been a five-fold increase in the permitted volume of water withdrawals (Credit Valley Conservation, 1999a).

2.1 Municipal and rural domestic water use

Municipal water use accounts for 50% of the total permitted water taking from the entire Credit River watershed (Credit Valley Conservation, 1999a). Current and expired permits for municipal water takings in the upper Credit River watershed total 218,631,207 Lday^{-1}. Groundwater is supplied to upper watershed residents by the Region of Peel, the Town of Erin, and the Town of Orangeville (Table 1). The Region of Peel operates and maintains the water supply systems for the villages of Alton and Caledon, the Town of Erin for the former Village of Erin, and the Town of Orangeville for its residents. Other small communities and rural residents draw their drinking water from private wells. Of the 6,675 wells in the Credit River watershed, 88% are used for domestic and livestock watering purposes, and 2.5% are municipal wells (Beak Consultants Ltd. *et al*., 1992).

The low water levels and high air temperatures associated with drought result in higher demand for water, and a reduction in the amount of water available for use. Impacts on municipal water supply of increased incidence or duration of droughts include:

- Increased conflict with other water users due to competition for limited water supplies, or interference from higher pumping rates,

- Increased costs to develop additional pumping and storage capacity, or to develop new water sources, and
- More extensive wastewater treatment to ensure appropriate dilution of wastes in surface water systems.

Rural residents may be affected by conflict with other water users and increasing costs for well drilling and maintenance, cisterns for water storage, and water quality testing.

Table 1: Municipal water supply systems in subwatersheds 16/18 and 19 of the upper Credit River watershed

Water supply	Town of Orangeville	Region of Peel	
		Village of Caledon	Village of Alton
Water sources	13 wells in 9 wellfields (8 wells in Amabel aquifer, 2 in Guelph aquifer, 3 in overburden aquifers)[2]	3 wells (2 in overburden aquifers, 1 in Amabel aquifer)	4 wells (all in overburden aquifers)
Total weighted maximum daily available supply ($m^3 day^{-1}$)	20,153[3]	3,667.5[4] (1995)	2,782[4] (1995)
Average annual day demand ($m^3 day^{-1}$)	10,126 (5,832 residential sector)[1] (1997)	627.8 (1997)	521.2 (1998)
Maximum day demand ($m^3 day^{-1}$)	16,408[2] June 13, 1999	2,320 June 22, 1997	2,223.9 August 3, 1998

Sources: [1] REIC Consulting Ltd. *et al*., 1998; [2] Town of Orangeville Public Works Department, 2000a; [3] Town of Orangeville Public Works Department, 2000b; [4] Schiller, 1996; in Troyak, 1996.

Town of Orangeville

Conflicts have arisen between municipal water supply for the Town of Orangeville and water requirements for fish habitat. For instance, groundwater pumping from a number of Orangeville wells has, in the past, interfered with surface water systems and fish habitat (wells 2A, 5/5A, 8) (Gartner Lee Limited, 1998; Tupling, 2001, Pers. Comm.). Twenty years ago, pumping from the Town's #5 well resulted in cessation of flow in the upper reach of Mill Creek (above Monk Pond), and subsequent damage to the vegetation along the banks of the Creek (Gartner Lee Limited 1998, 33). More recently, pumping from some municipal wells has reduced groundwater upwellings serving as baseflow in local streams (Aquafor Beech Ltd. *et al*., 1997).

Credit Valley Conservation's (CVC) the Subwatershed 19 Study recommended reduced pumping from wells 5/5A to restore baseflow to Mill Creek (Aquafor Beech Ltd. *et al*., 1997). The Permits to Take Water issued by the Ontario Ministry of the

Environment for wells 2A, 8A/8B/8C, and 9A/9B have special conditions requiring the Town to engage in monitoring programs to determine impacts on streams and fish habitat (Town of Orangeville Public Works Department, 2000b). The permits for wells 2A and 10 require reduced or stopped pumping seasonally (Town of Orangeville Public Works Department, 2000b).

The Town of Orangeville has experienced difficulty in meeting demand for water due to limited pumping and storage capacity. This situation may be complicated by the findings of a recent consulting study indicating that five of Orangeville's municipal wells show some interference with each other (Gartner Lee Limited, 1998). Concerns exist regarding the adequacy of water supplies and pumping capacity to meet future demands, especially in regard to new development (REIC Consulting Ltd. *et al*., 1998). The Town's existing capacity of 20,672 m^3day^{-1} is projected to be reached in 2012 (REIC Consulting Ltd. *et al*., 1998). The Town's Growth Management Study (1996) estimated that the Town's population could eventually reach 55,000, requiring annexation of additional lands and development of water supplies (Town of Orangeville Public Works Department, 2000b). A class environmental assessment recommended that additional supplies be developed through a variety of methods, including water conservation (Town of Orangeville Public Works Department, 2000b).

The Town of Orangeville has incurred costs in order to respond to concerns regarding low water levels. In the past five years, the Town has commissioned:

- a Water Efficiency Study, funded by a $90,000 allocation in 1997 (Town of Orangeville Public Works Department, 2000b), estimated to cost $640,101 to implement between 1998 and 2015 (REIC Consulting Ltd. *et al*., 1998),
- a Phase 1 Class Environmental Assessment report to develop new water sources (Town of Orangeville Public Works Department, 2000b),
- a Groundwater Management Plan, funded initially by a $100,000 allocation approved in 1997 (Town of Orangeville Public Works Department, 2000b), and
- a Groundwater Resource and Contamination Assessment Study, estimated to cost $200,000, 25.97% of which will be funded by the Provincial Water Protection Fund (Town of Orangeville Public Works Department, 2000b).

Costs may also be incurred in order to maintain water quality during low water conditions. The Town of Orangeville owns a Water Pollution Control Plant, which is operated by the Ontario Clean Water Agency (REIC Consulting Ltd. *et al*., 1998). Outflow from the plant is released into the Credit River south of the Town. During periods of low water, water quality in the Credit River may be degraded due to a lack of dilution of sewage outflow. The Town's water efficiency study determined that, under the present capacity rating of 14,400 m^3day^{-1}, wastewater flows will exceed capacity by 2002 (REIC Consulting Ltd. *et al*., 1998). The plant may be able to be re-rated to a capacity of 18,000 m^3day^{-1}, which would meet needs until 2014 (REIC Consulting Ltd. *et al*., 1998). By implementing the water efficiency program, capacity at the water treatment plant may not be exceeded until 2015 (REIC Consulting Ltd. *et al*., 1998). However, it seems likely that in order to accommodate growth, the Town of Orangeville will have to take additional steps to ensure surface water quality during low flow conditions.

Town of Caledon

Recent low water conditions have been a problem for rural residents with private wells in the southwest corner of the Town of Caledon (Peel Agricultural Advisory Working Group, 1999; Schiller, 2001, Pers. Comm.; Thompson, 2001, Pers. Comm.). Water shortages have prompted residents to drill new wells, install cisterns, and truck in water (Thompson, 2001, Pers. Comm.). As a temporary solution to the problem, the Region of Peel constructed a pumping station at the Snelgrove water tower to allow residents to fill tanks for water supply (Peel Agricultural Advisory Working Group, 1999; Schiller, 2001, Pers. Comm.). There is some support for municipal servicing as a long-term solution, but concerns exist regarding costs and development pressures ensuing from servicing (Peel Agricultural Advisory Working Group, 1999). Other concerns have included the impacts of municipal takings on the water level of Green Lake, and on private wells (Schiller, 2001, Pers. Comm.).

Between 1991 and 1996, the Town of Caledon’s population grew by 14.1% (Statistics Canada, 2001b). By 2021, the Town’s population is projected to increase to 84,000 (Regional Municipality of Peel, 1998). While much of the growth is expected to occur in the urban areas of Bolton and Mayfield West, the populations of Alton, Caledon Village, Cataract, Belfountain, and Brimstone are expected to increase by more than 30% by 2011 (Town of Caledon, 1991; in Troyak, 1996).

The Region of Peel has incurred costs to address issues of water supply. For instance, in 2000, the Region budgeted $800,000 for pumping station expansions, $100,000 for water quality and conservation studies, $15,000 for a groundwater monitoring program, and $150,000 for CVC’s water monitoring program, as well as additional funds for CVC’s subwatershed studies and water quality strategy (Region of Peel, 2000a). In order to address water supply concerns, the Region of Peel undertook a study to determine the feasibility of interconnecting municipal water systems in the Town of Caledon (Region of Peel, 1997).

Rural communities in the upper Credit River watershed, and elsewhere, are likely to face challenges in public and private domestic water supply as a result of an increased incidence or duration of drought events. Increased conflict with other human and ecological water uses, as well as increased costs for water supply planning, operations, and infrastructure can be expected. In areas where rural communities are growing, in particular in the rural-urban fringe, population growth and development may place additional stress on public water supply systems.

2.2 Agricultural water use

Roughly 30% of the land area of most subwatersheds in the upper Credit River is being used for intensive agriculture (i.e., cultivated fields, nurseries, orchards, etc.), while 6-12% is used for non-intensive agriculture (i.e., fields that have not been recently cultivated, pasture/grazing areas) (Table 2) (Credit Valley Conservation, 1998a). In the upper Credit, the agricultural sector is composed of a mixture of crop and livestock farming (Table 3). In 1996, the Town of Caledon contained 490 farms, covering an area of 36,247 ha, 69% of which was in crops (Statistics Canada, 1996). The Town of Erin had 276 farms, covering 15,904 ha of land, 58% of which was in crops (Statistics Canada, 1996). The most common agricultural crops are alfalfa and corn, while cattle farms, hobby farms, and poultry farms make up most of the livestock in the area.

Table 2: Intensive vs. non-intensive agriculture in upper Credit subwatersheds

Subwatershed	Intensive agriculture		Non-intensive agriculture	
	ha	%	ha	%
15	3,503	33.2	1,090	10.3
16	1,765	33.9	445	8.6
17	2,691	37.4	440	6.1
18	1,188	30.3	481	12.3
19	1,417	23.7	398	6.7

Source: Credit Valley Conservation, 1998a.

Of the 6,675 wells in the Credit River watershed, 88% are for livestock watering or domestic use, and 9% are for irrigation, industrial, and commercial uses (Beak Consultants Limited *et al*., 1992). Irrigation is minimal in the upper Credit River area. Only 0.7% of the total land reported in crops in the Town of Caledon in 1996 was irrigated (Statistics Canada, 1996). In the Town of Erin, only 0.4% of cropped land was reported to be irrigated (Statistics Canada, 1996). Current and expired permits for agricultural irrigation in the upper Credit River watershed total 1,448,335 $Lday^{-1}$, while aquaculture accounts for 4,667,376 $Lday^{-1}$. Agricultural water use is likely to be highest for livestock drinking water, and water used for washing and cooling animals, barns, and equipment (Ivey, 1998). An Environment Canada study estimated that groundwater resources were worth between $1,070,118 and $2,080,237 annually in the Town of Caledon for livestock watering alone (Troyak, 1996).

Table 3: Agriculture in the upper Credit River watershed

	Town of Caledon	Town of Erin
Crops (% land area)		
Alfalfa and alfalfa mixtures	28	38
Corn for grain	17	13
Soybeans	15	7.7
Wheat	9.1	8.6
Other tame hay and fodder crops		9.0
Mixed grains		6.9
Livestock (# of farms)		
Cattle and calves	234	133
Horses and ponies	123	97
All types of poultry farms	102	67
Goats	31	
Sheep and lambs	30	21

Source: Statistics Canada, 1996.

In a review of the impacts of drought on a variety of resource sectors, Gabriel and Kreutzwiser (1993) found that agriculture can be affected by drought through reduced crop productivity, increased soil erosion, and water and temperature stress on livestock. Productivity of cereal crops, hay, and pasture is adversely affected by early summer drought, while corn and pasture productivity is affected by late summer drought (Brown *et al*., 1968; in Gabriel and Kreutzwiser, 1993). Gabriel and Kreutzwiser's (1993) review of drought impacts notes that soybean, grain, corn, potato, hay, and fruit crops in Ontario were impacted by droughts between 1960 and 1989. The upper Credit watershed's dominant crops, alfalfa, corn, soybeans, wheat, and hay could be particularly susceptible to future growing season droughts. As irrigation is rare in the area, and expensive to install, it is unlikely that lower precipitation levels will be offset by irrigation.

Livestock producers use water for animal consumption, washing, and cooling (Ivey, 1998). Low water levels and high air temperatures could tax barn cooling and ventilation systems, and result in feed shortages (Gabriel and Kreutzwiser, 1993). Where crops are not insured, droughts could result in significant drops in farm income, a potentially important source of income in rural communities.

2.3 Commercial and industrial water use

The municipalities in subwatersheds 16/18 and 19 of the upper Credit watershed are primarily rural, with the only significant urban industrial area located in the Town of Orangeville. There are approximately 125 industrial and commercial, and 25 institutional sites on public water supply in the Town of Orangeville (REIC Consulting Ltd. *et al*., 1998). Industrial, commercial, and institutional water use makes up 19.7% of Orangeville's annual average day demand, using about 1,995 $m^3 day^{-1}$ in 1997 (REIC Consulting Ltd. *et al*., 1998).

Major commercial and industrial water uses reliant on private water supplies in the upper Credit River watershed include aggregate mining and processing, golf course irrigation and water bottling (Table 4). Aggregate mining is one of the most prevalent industries in the upper watershed, in particular in the Town of Caledon (Table 5). In 1997, the Town of Caledon was the 3rd highest aggregate producing municipality in the province (Planning and Engineering Initiatives Ltd. *et al*., 1999). In 1983, gravel pits held water taking permits equivalent to 30% of the total permitted water withdrawal in the watershed (Triton Engineering Services Ltd. *et al*., 1991). "Below-water extraction operations, especially those with dewatering such as is typical with quarries, has the potential for changes to: the water table in wetlands, the ground water flow system, and stream baseflow with its associates implications for stream flow and aquatic resources" (Planning and Engineering Initiatives Ltd. *et al*. 1999, 11). CVC's *Water Backgrounder* document states that golf courses in the watershed are permitted to use approximately 25 million $Lday^{-1}$, while bottled water companies are permitted for 1.6 million $Lday^{-1}$ (Credit Valley Conservation, 1999a). An Environment Canada study estimated the annual value of groundwater resources in the Town of Caledon to industrial/commercial/institutional use to be between $3,969,929 and $13,010,229 (Troyak, 1996).

Table 4: Active and expired industrial/commercial permits to take water in subwatersheds 15-19 (2001)

Water Use	Permitted Withdrawal ($Lday^{-1}$)
Aquaculture	4,667,376
Dewatering	21,097,830
Golf course irrigation	11,289,600
Aggregates	133,430,046
Industrial	53,391,677

Table 5: Aggregate extraction in the upper Credit River watershed

Location	Number of aggregate/quarrying sites
Town of Caledon	22
Erin Township	4
Amaranth Township	1
East Garafraxa Township	8
Mono Township	4

Source: Beak Consultants Ltd. *et al*., 1992.

Strong public concern in the Town of Caledon exists regarding the impacts of aggregate extraction on surface and groundwater resources (Planning and Engineering Initiatives Ltd. *et al*., 1999). Specific concerns relating to impacts on stream baseflow and fisheries have been noted for aggregate resource areas west of Alton, south of Melville, the southwest portion of subwatershed 18, and the southern portion of subwatershed 16 (Planning & Engineering Initiatives Ltd. *et al*., 1999).

As is the case for municipal water use, the warm dry conditions common during summer droughts often serve to increase demand for water among many commercial and industrial water users (e.g., golf course irrigation, fish hatcheries). However, withdrawals by other commercial and industrial businesses may remain constant (e.g., water bottling), or even be reduced (e.g., quarry dewatering), in the face of low water conditions. Insufficient water supplies could result in conflict with other human or ecological water uses, and loss of profits for commercial and industrial businesses dependent on water for the development of products or provision of services.

2.4 Recreation and tourism

Water-related recreational activities in the watershed include fishing, hiking, swimming, camping/picnicking, skiing, and golfing (Beak Consultants Limited *et al*., 1992). Recreational activities take place in public conservation areas owned by CVC, the province, and municipalities, as well as on private land. As of 2001, current and expired permits to take water totaling 3,266,775 $Lday^{-1}$ are for recreational uses.

CVC owns 13 conservation areas in the Credit River watershed (Beak Consultants Ltd. *et al*., 1992). About 125,000 people visit CVC conservation areas each year (Puddister, 1995). The Belfountain and Orangeville Reservoir conservation areas are managed for intensive recreational use (Beak Consultants Ltd. *et al*., 1992). In these areas, facilities exist for swimming, fishing, hiking, and picnicking. Camping and skiing are allowed in the Orangeville Reservoir Conservation Area. Provincial lands in the upper Credit watershed include the Forks of the Credit Provincial Park, and the Alton Integrated Resource Management Area. The Forks of the Credit park allows intensive recreational activities such as fishing, camping, hiking, and picnicking, while the Alton park is used for passive activities like picnicking, hiking, and skiing (Beak Consultants Ltd. *et al*., 1992).

Angling is a popular sport in the upper Credit River watershed, both for residents and visitors to the area. Much of the Credit River and its tributaries in the upper Credit are managed as a cold-water fishery, where fly fishing is popular, and brown and brook trout are the key species. An Environment Canada study estimated that groundwater resources were worth about $1,326,956 annually to recreational cold-water fishing in the Town of Caledon (Troyak, 1996). Other areas of the watershed are managed as warm-water fisheries (e.g., Orangeville Reservoir), where largemouth bass and northern pike are popular sport fish. Fishing also occurs in the winter season at the Orangeville Reservoir. In wetland areas, bird watching, and waterfowl and deer hunting occur.

Watershed residents and visitors swim in the river at Belfountain Conservation Area and in other informal locations. Swimming is also popular at the Orangeville Reservoir, Caledon Lake (private), and Roman Lake (private). Canoeing, kayaking, and tubing occur on the river and its tributaries, and a rowing club operates at the Orangeville Reservoir.

Hiking is a common activity in the watershed, in particular along the Bruce Trail, which follows the Niagara Escarpment. Winter activities include snow-mobiling on rail trails, cross-country skiing, and downhill skiing (one ski hill in upper watershed).

In general, low water levels can be expected to have both beneficial and harmful effects on recreational activities in Ontario. Hot, sunny, dry, summer weather encourages water-related activities such as camping, boating, and swimming. Low water levels can increase the size of beaches and aid in beach maintenance (Gabriel and Kreutzwiser, 1993). However, extreme low water levels can lead to reduced water quality and beach closures, dredging and modification of docks and other infrastructure, and negative impacts on the aesthetic quality of some beaches and wetlands (Allsopp *et al*., 1981; Gabriel and Kreutzwiser, 1993). During the dry summer of 1999, the Orangeville Reservoir was drained earlier in the season than usual, possibly resulting in impacts on boating activities, and reduced recreation revenues for CVC (Worte, 2001, Pers. Comm.).

A number of local recreation-related issues could be exacerbated by drought conditions. In particular, concerns exist regarding impacts of low water levels and increased demand for water on fish resources. Threats to the cold-water fishing industry could have implications for tackle shops, outfitters, and the bed and breakfast industries, which support fish-related tourism (Morris, 2000, Pers. Comm.). Low water levels could also prohibit boating activities, such as canoeing, rowing, and kayaking. Concerns exist about water quality in the river and in lakes and reservoirs. Both Belfountain and Orangeville Reservoir conservation area beaches have been posted at times with warnings for bacterial contamination (Beak Consultants Ltd. *et al*., 1992). Low water levels could exacerbate poor water quality conditions, making swimming unsafe. Low water levels in wetlands could result in temporary reductions in the numbers of waterfowl and other wildlife in wetlands, affecting hunting and wildlife watching activities (Wall, 1998). An increase in demand for water-related activities in summer months, due to warm, dry conditions, could result in high volumes of visitors to recreation lands, possibly resulting in degradation of natural areas.

Low water levels can also affect winter activities, by reducing the amount of snow for snow-mobiling and skiing (Gabriel and Kreutzwiser, 1993). However, downhill ski resorts with snowmaking capabilities could mitigate the effects of low snowfall if temperatures are sufficiently low.

3.0 Ecological water use

Average climatic conditions and the incidence of extreme climatic events affect the size, distribution, and success of populations of both flora and fauna. In the upper Credit watershed, an increased incidence or duration of drought will have implications for aquatic and terrestrial ecosystems.

3.1 Terrestrial ecosystems and wildlife

The upper Credit watershed is located in the Huron-Ontario section of the Great Lakes-St. Lawrence Forest Region, which is dominated by sugar maple and beech tree species (Aquafor Beech *et al*., 1997). Eastern hemlock, white pine, and balsam fir are common in upland areas of the upper Credit, while eastern white cedar is common in the lowlands (Aquafor Beech *et al*., 1997). Upland areas provide recharge for local and regional aquifers, and affect surface water flows. Lowland and valley areas are characterized by wetlands, areas of groundwater discharge, that are important for flood control and water quality (Credit Valley Conservation, 1998b). A variety of types of forested and non-forested, upland and lowland habitats exist within the upper Credit watershed, some of which are natural, others have been disturbed by human activity (e.g., cultural land uses) (Table 6). The percent area of natural forested land in upper Credit subwatersheds ranges from 8-15%. Plantations cover between 3 and 6 percent of the subwatersheds' areas, while other cultural land uses cover between 14 and 24%. Upland areas are preferred habitat for a number of amphibian, reptile, bird, and mammalian species, some of which are provincially rare (Tables 7 and 8).

Increasing air temperatures and changes in precipitation amounts and patterns will affect the size and distribution of ecosystems. For instance, the ranges of sugar maple, beech, and eastern hemlock, common tree species in the upper Credit, are anticipated to move 500 km to the north in the next century, under a doubling of atmospheric carbon dioxide (Smith *et al*., 1998). However, if climate change occurs faster than species can adapt or migrate, species could be threatened with extinction. For example, the species migration rates of sugar maple and beech are estimated at between 10 and 40 km/hundred years, while their range could shift north by as much as 500 km over the next century (Smith *et al*., 1998). Migration can also be impeded by habitat fragmentation, increased susceptibility to fire and pests, human development, increased competition from exotic species, inefficient seed dispersal mechanisms, and limited suitable habitat (e.g., soil conditions) (Smith *et al*., 1998). As habitat in the upper Credit watershed is already highly fragmented, migration of species could face significant obstacles (Aquafor Beech Ltd. *et al*., 1997; Credit Valley Conservation, 1998b).

Table 6: Land use in upper Credit River subwatersheds (1996)

Land use type	Subwat. 15	Subwat. 16	Subwat. 17	Subwat. 18	Subwat. 19
	% land area				
Intensive agriculture	33.2	33.9	37.4	30.3	23.7
Non-intensive agriculture	10.3	8.6	6.1	12.3	6.7
Urban/roads	6.5	5.0	4.9	3.4	19.1
Rural development	2.4	0.0	1.5	0.2	2.0
Active/inactive aggregate	1.2	11.0	1.1	7.0	1.1
Forest [1]	12.1	11.0	8.4	15.5	7.9
Plantation [2]	6.1	3.0	5.0	5.6	4.2
Cultural [3]	14.8	15.2	18	15.9	24.3
Wetlands [4]	10.0	7.9	15.5	4.7	5.6
Aquatic	0.9	3.7	1.2	1.3	3.2
Total area (ha)	**10,556**	**5,198**	**7,204**	**3,919**	**5,982**

Source: Credit Valley Conservation, 1998a.

Table 7: Wildlife species of Credit River watershed upland areas

Wildlife type	Upland forested habitat	Upland non-forested habitat
Herpetofauna	Jefferson *, silvery, Tremblay's, northern redback salamanders Wood frog Tetraploid grey treefrog Northern brown snake Northern redbelly snake	Striped chorus, northern leopard frogs Blue-spotted salamander Eastern milk snake Smooth green snake Red eared slider (exotic)
Mammals	Masked, smoky, pygmy, water, northern short-tailed shrews Hairy-tailed mole Little brown, silver-haired, eastern red bats Eastern cottontail Eastern chipmunk Gray, Red, northern flying, southern flying ** squirrels White-footed, deer, woodland jumping mouse White-tailed deer Bobcat **	Little brown bat Eastern cottontail European hare (exotic) Woodchuck Ermine Woodland jumping mouse

Source: Puddister, 2000.

Note: * Provincially very rare, ** Provincially rare to uncommon

Changes in the distribution and size of vegetation communities will result in changes in the distribution and size of wildlife populations. Climate change, resulting habitat loss, and increased habitat fragmentation will affect the productivity, survival, timing and success of breeding, and migration patterns of wildlife populations (Smith *et al*., 1998). Some wildlife species may not be able to migrate successfully through the transitional habitats that will be created by shifting vegetation communities. Provincially rare and uncommon species (e.g., Jefferson salamander), especially those that are specialists or sensitive to human disturbances, could be at particular risk. Transitional habitats may favour the proliferation of exotic, generalist, or opportunistic species (e.g., purple loosestrife, red eared slider, European hare) already present in the upper Credit watershed (Peters, 1992; Credit Valley Conservation, 1998b).

Changes in the amount and distribution of habitat increase the dangers of species extinction due to catastrophic events (e.g., severe droughts and floods). Species that are presently rare or endangered (e.g., southern flying squirrel, Jefferson salamander, many bird species) will be at greater risk of local extinction. As wildlife populations migrate at different rates, new predator/prey interactions and interspecies competition are likely to occur, which will also affect the success of species' populations (Peters, 1992; Smith *et al*., 1998).

An increased incidence of drought could also affect the assemblages of species in any given area. In addition to being sensitive to average climatic conditions, plants and animals are affected by the prevalence and duration of extreme climatic conditions, such as drought. More common low water conditions could encourage the establishment of drought tolerant species, and discourage the establishment of species poorly adapted to withstand dry conditions.

Natural areas (e.g. ESAs) presently protected in order to preserve valued ecosystems may no longer be able to support the vegetation and wildlife communities they were originally intended to protect. Climate change and increased climatic variability may also lead to changes in human land use and management, which may place both protected and unprotected natural areas at further risk. Credit Valley Conservation's goal in managing its conservation areas is "To protect the Credit River Watershed's significant and representative ecosystems, and offer sustainable natural heritage appreciation and recreational benefits to its residents and visitors" (Credit Valley Conservation 1994, 2). The authority's goal is further defined by three objectives, the most important of which is "To protect significant and representative natural heritage features through selective acquisition and resource management" (Credit Valley Conservation 1994, 3). Changes in the characteristics of conservation areas, due to climate change, will affect CVC's ability to successfully meet its goals and objectives relating to management of natural areas.

Table 8: Bird species of conservation concern in Credit River watershed lowlands

Upland forested habitat	Upland non-forested habitat
Turkey vulture, Hooded merganser Sharp-shinned, Cooper's, red-shouldered, Broad-winged hawk Northern goshawk, Ruffed grouse Wild turkey Barred, long-eared, northern saw-whet owl Common nighthawk, Whip-poor-will Red-headed, hairy, pileated woodpecker Eastern wood pewee, Least flycatcher Yellow-throated, blue-headed vireo Red-breasted nuthatch, Brown creeper Winter wren, Golden-crowned kinglet Blue-gray gnatcatcher, Veery Wood thrush, Gray catbird Brown thrasher Blue-winged, Brewster's, golden-winged, Nashville, chestnut-sided, magnolia, yellow-rumped, black-throated green, blackburnian, pine, cerulean, black-and-white, mourning, Canada warbler American redstart, Ovenbird Northern waterthrush Scarlet tanager Eastern towhee White-throated sparrow Common grackle Purple finch Red crossbill Pine siskin	Northern harrier Red-shouldered, sharp-shinned, Cooper's hawk Northern goshawk, Common moorhen American coot, Killdeer Wild turkey, Upland sandpiper Common snipe, Yellow-billed cuckoo Common nighthawk Red-headed, hairy, pileated woodpecker Whip-poor-will, Chimney swift Belted kingfisher, Eastern wood pewee Alder, least flycatcher Eastern kingbird Yellow-throated, blue-headed vireo Horned lark Bank, Cliff, Barn swallow Sedge wren, Purple martin Red-breasted nuthatch, Gray catbird Northern mockingbird, Brown thrasher Blue-gray gnatcatcher, Eastern bluebird Veery Blue-winged, Brewster's, golden-winged, Nashville, chestnut-sided, yellow-rumped, black-and-white, mourning, Canada warbler American redstart, Scarlet tanager Eastern towhee Clay-colored, vesper, savannah, grasshopper, Henslow's, white-throated sparrow Bobolink, Eastern meadowlark Common grackle, Orchard oriole Purple finch, Pine siskin

Source: Puddister, 2000.

3.2 Wetlands

There are a number of wetland complexes in the headwater area of the upper Credit watershed. In general, they consist of swamps, which are treed wetlands characterized by shrub thickets and coniferous and deciduous forest stands; and marshes, which are characterized by emergent vegetation such as reeds, rushes, and sedges (Beak Consultants Ltd. *et al*., 1992). Wetlands have formed where soils of low permeability have allowed water to pond and where groundwater discharges occur, in particular along the Credit River and its tributaries. Wetlands in the upper Credit are hydrologically important, providing baseflow to streams, releasing stored water during low flow conditions, providing storage for floodwaters, and filtering contaminants from the water (Beak Consultants Ltd. *et al*., 1992). In addition to their hydrologic role, wetlands provide habitat for fish, reptiles, amphibians, invertebrates, birds, and mammals (Credit Valley Conservation, 1998b). Upper Credit wetlands are home to a variety of wildlife species, some of which are provincially rare (Tables 9 and 10, List 1).

In the event of climate change, higher air temperatures and low water conditions could become more common in the watershed. These conditions could affect wetland systems in a variety of ways. For instance, higher air temperatures are likely to result in increased rates of evapotranspiration from wetland vegetation. If not offset by increases in precipitation, higher rates of evapotranspiration could exacerbate low water levels.

Table 9: Wildlife species in upper Credit watershed lowland areas

Wildlife type	Lowland forested habitat	Lowland non-forested habitat
Herpetofauna	Jefferson *, silvery, tremblay's, four-toed, spotted salamanders Pickerel frog	Red-spotted newt Four-toed salamander Northern spring peeper Striped chorus, northern leopard, pickerel, mink frog Red eared slider (exotic) Northern ribbon snake
Mammals	Virginia opossum Masked, smoky, pygmy shrews Little brown, silver-haired bats Eastern cottontail Snowshoe hare, Red squirrel White-footed mouse Mink Bobcat ** White-tailed deer	Masked, pygmy, water, northern short-tailed shrews Star-nosed mole Little brown, silver-haired bats Eastern cottontail, Snowshoe hare Meadow vole, Muskrat Meadow jumping, woodland jumping mouse Ermine, Long-tailed weasel, Mink

Source: Puddister, 2000.

Note: * Provincially very rare, ** Provincially rare to uncommon

Table 10: Bird species of conservation concern in Credit River watershed lowlands

Lowland forested habitat	Lowland non-forested habitat
American bittern, Great blue heron Hooded merganser, Northern harrier Sharp-shinned, Red-shouldered hawk Ruffed grouse, Wild turkey Common snipe Barred, Northern saw-whet owl Hairy woodpecker, Alder flycatcher Yellow-throated vireo Red-breasted nuthatch Brown creeper, Winter wren Golden-crowned kinglet Blue-gray gnatcatcher Veery, Wood thrush Blue-winged, Golden-winged, Cerulean, Black-and-white warbler Northern, Louisiana waterthrush Mourning, Canada warbler	Pied-billed grebe American, Least bittern Great blue heron, Gadwall American black duck, Green-winged teal Northern harrier, Sharp-shinned hawk Common moorhen, American coot Black tern Barred, Long-eared, Northern saw-whet owl Alder flycatcher, Purple martin Winter, Sedge, Marsh wren Veery Golden-winged, Nashville warbler Northern waterthrush Mourning warbler Savannah, Henslow's sparrow Bobolink Common grackle

Source: Puddister, 2000.

Box 1: Wetland plant species considered rare in the Credit River watershed and Peel Region

Water foxtail Sedge Yellow sedge Tuckerman's sedge Bottle-shaped sedge Deserving hornwort Calyxed leatherleaf Small's spikerush Purple-veined willow-herb Water horsetail Small floating manna-grass Greenland labrador-tea Star duckweed Red cardinal-flower Lily-of-the-valley Mountain holly Alder-leaved buckthorn Common bladderwort

Source: Oldham *et al.*, 1995.

Wetland systems are characterized by fluctuating water levels. However, changes in the degree and permanence of water level variations could adversely affect wetlands. Lower water levels in wetlands could result in lower maximum water levels, a reduction in the extent of wetlands, isolation of wetlands previously open to a water body, changes to the ratio of emergent cover to open water in wetlands, and changes to seasonal wet/dry cycles (Hofmann *et al*., 1998; Smith *et al*., 1998). Wetlands exclusively reliant on surface water sources may be more vulnerable to low water levels than those at least partially reliant on groundwater sources (Winter, 2000). In addition to a general drying out of wetlands, wetland distribution is likely to be affected by climate change. In some areas of the upper Credit River watershed, wetlands may dry out, while in other areas (e.g., abandoned aggregate pits in the Caledon area) lower water levels could result in improved conditions for wetland creation (Morris, 2000, Pers. Comm.).

While higher atmospheric CO_2 concentrations may encourage plant growth and productivity, higher air temperatures and lower water levels will have implications for wetland vegetation (Burkett and Kusler, 2000). Wetland vegetation communities develop in response to the environmental conditions and variability of the present and recent past. Despite their reliance on variable water levels, changes in the incidence and duration of droughts will affect wetland vegetation. Changes in air and water temperature, and water availability, will affect vegetation communities' distribution and composition. Lower water levels will stimulate growth of emergent vegetation, while higher water levels will stimulate growth of submergent vegetation (Mortsch, 1990).

Under some conditions, emergent and submergent vegetation communities may be able to migrate following their preferred water level conditions (Mortsch, 1998). Annual vegetation may be better able to migrate than perennials (Mortsch, 1998). The exposed edges of wetlands may become vulnerable to invasion by exotic plant species (e.g., purple loosestrife). Exposed mudflats are likely to result in faster establishment of seedlings, resulting in an increase in heavy emergent vegetation. More emergent vegetation could mean fewer open water areas.

Changes in vegetation community distribution and composition, and the ratio of emergent vegetation to open water, will result in changes in the amount, type, and distribution of habitat for wetland fauna. Waterfowl, for example, prefer wetlands with 50% open water for breeding, a condition which may become less common with lower water levels and more vegetative cover (Mortsch, 1990). Additionally, lower water levels could reduce access to spawning and nursery habitat, the amount of spawning and nursery habitat, and survival of young for some fish species (Mortsch, 1990).

Increases in air temperature and lower water levels will affect wetland chemistry, and mineral and nutrient cycling. For instance, wetlands dependent on groundwater discharges, isolated from surface water bodies, could experience an increase in salinity due to lower surface runoff and precipitation, and higher evapotranspiration. Water quality could suffer from lower water velocity and depth, high sedimentation, less dilution of contaminants, and increased water temperature (Mortsch, 1990). Reductions in water quality and quantity could render wetlands less able to filter pollutants from human sources (e.g., effluents from Orangeville's sewage treatment plant). Furthermore, changes in water quality could affect the quality of habitat for fish, waterfowl, and other wetland fauna.

Climate change could alter the balance between photosynthesis and decomposition in wetland soils. Higher CH_4 production is encouraged by higher air temperatures, longer growing seasons, high water levels, and higher rates of photosynthesis and anaerobic decomposition (Burkett and Kusler, 2000). In contrast, low water levels encourage higher rates of aerobic decomposition, resulting in increased production of CO_2 and reduced production of CH_4 (Burkett and Kusler, 2000). The complexities of carbon cycling in wetland ecosystems makes predicting changes in CO_2 and CH_4 emissions very difficult.

The impacts of increased climatic variability on wetlands have implications for human systems, and vice versa. For instance, changes to wetland hydrology may make them less able to release water during low flow conditions, or to retain water during flood conditions. Changes in water levels, plant communities, and habitat may affect the recreational opportunities provided by wetland ecosystems (see Wall, 1998). For example, changing water levels may necessitate modifications to the location and extent of visitor access to wetlands. Nature trails, angling, hunting and trapping, and nature watching could all be impacted by changes in the composition, distribution, and extent of wetlands. Conversely, human-made alterations to wetland environments (e.g., dikes, channelisation of watercourses, and fragmentation) may make them more vulnerable to the impacts of increased climatic variability.

Changes in the types and distribution of vegetation communities in existing wetlands could affect their protection status. Provincially significant wetlands, those wetlands classed by the Ministry of Natural Resources as class 1, 2, or 3, are protected by municipalities under provincial policy statements relating to the *Planning Act*. Low water levels could result in changes to the physical, hydrological, and biological characteristics of a wetland. Developers potentially could request re-evaluation of a wetland by MNR, possibly resulting in downgrading of its class, and removing its protection under the *Planning Act*. It is unknown to what extent more frequent or severe dry periods could threaten the development status of wetlands in the upper Credit River watershed.

3.3 Aquatic ecosystems

The main branch of the Credit River flows through the upper portion of the watershed as do its tributaries, the west branch of the Credit, Caledon Creek, and Shaw's Creek (Triton Engineering Services Ltd. *et al*., 1991). Groundwater discharges constitute a major source of baseflow to the streams in the area (Credit Valley Conservation, 2000a). "At Orangeville, Alton, Erin, Cataract, and Boston Mills, groundwater baseflow is estimated to be 73 to 76 per cent of streamflow" (Region of Peel 1996, 6). Groundwater quality is generally good, except in the Orangeville Reservoir, downstream of the Orangeville sewage treatment plant, and near areas of mineral extraction (Credit Valley Conservation, 2000a).

Fish species found in the upper Credit watershed include brook trout, northern pike, and largemouth bass (Table 11). Other exotic, introduced, or naturalized species found in the area include brown trout, salmon, and white perch. The Credit River watershed is also home to a number of provincially rare fish species, such as the redside dace, lake sturgeon, and the American brook lamprey. In order to maintain the commercially valuable brook trout and brown trout populations, much of the upper Credit watershed is managed as a cold-water fishery. However, some stretches of the upper watershed are managed for mixed warm/cool- and warm-water communities (Credit Valley Conservation, 2000a). The watershed's riparian, riverine, and lacustrine habitats are also home to a variety of reptilian, amphibian, mammalian, and avian species (Tables 12 and 13).

Table 11: Fish of the Credit River watershed

Prevalence	**Riverine habitats**	**Lacustrine habitats**
Common to very common	Gizzard shad Atlantic salmon Brook trout Northern pike White, northern hog sucker Northern redbelly, blacknose, longnose, pearl dace Brassy minnow Hornyhead, river, creek chub Common, blacknose, spottail, rosyface, spotfin, mimic, redfin shiner Bluntnose, fathead minnow Brown bullhead Channel catfish Stonecat American eel Brook, threespine stickleback Rock, smallmouth bass Pumpkinseed Rainbow, Iowa, fantail, johnny darter Mottled, slimy sculpin	Bowfin Gizzard shad Rainbow smelt Northern pike Central mudminnow White sucker Northern redbelly, finescale, pearl dace Brassy minnow Hornyhead, creek chub Golden, emerald, spotfin shiner Fathead minnow Brown bullhead Brook, threespine stickleback Trout-perch White, rock, smallmouth, largemouth bass Pumpkinseed Black crappie Yellow perch Iowa darter Freshwater drum Mottled , slimy sculpin
Rare to uncommon	American brook lamprey Lake sturgeon Redside dace	Lake sturgeon
Exotic	Sea lamprey Pink, Coho, Chinook salmon Rainbow, Brown trout Common carp	Sea lamprey Alewife Pink, Coho, Chinook salmon Rainbow trout Goldfish Common carp White perch

Source: Puddister, 2000.

Table 12: Wildlife of the aquatic habitats of the Credit River watershed

Species type	Lacustrine/shoreline	Riverine/riparian
Herpetofauna	Mudpuppy Red-spotted newt Jefferson salamander * Silvery, tremblay's, blue-spotted, spotted salamander Northern spring peeper Tetraploid grey treefrog Pickerel, mink frog Bullfrog Common snapping turtle Midland painted turtle ** Red eared slider (exotic) Blanding's, common map turtle Northern water snake	Mudpuppy Jefferson salamander * Silvery, tremblay's salamander Pickerel, green, mink frog Midland painted turtle ** Red eared slider (exotic) Common map turtle Northern water snake
Mammals	Virginia opossum Northern short-tailed shrew Star-nosed mole Beaver Meadow vole Muskrat Woodland jumping mouse Raccoon Ermine Long-tailed weasel Mink River otter	Virginia opossum Water, northern short-tailed shrew Star-nosed mole Beaver Meadow vole Woodland jumping mouse Raccoon Ermine Long-tailed weasel Mink River otter

Source: Puddister, 2000.

Note: * Provincially very rare, ** Provincially rare to uncommon

At each life stage, different fish species require different environmental conditions for survival and for reproductive success. Important parameters affecting suitability of habitat are water level, water temperature, and water quality (e.g., dissolved oxygen) (Meisner *et al*., 1987; Sinokrot *et al*., 1995).

In the event of increased climatic variability, low water levels could become more common in the watershed. Low surface water and groundwater levels could impact fish and fish habitat in a variety of ways. For example, high spring water levels in wetlands and shoreline areas have been associated with success of northern pike, yellow perch, and largemouth bass young (Meisner *et al*., 1987). Reduced spring runoff from snow melt could result in lower survival rates of the young of some fish species. Low surface and groundwater levels could result in some presently permanent streams becoming intermittent. Increased incidence of temporary streams could reduce the amount of fish habitat, impede migration, and reduce access to necessary resources (e.g., food, spawning

Table 13: Birds of the aquatic habitats of the Credit River watershed

Lacustrine/shoreline	Riverine/riparian
Pied-billed grebe, Least bittern	Least bittern
Great blue, green heron	Great blue, green heron
Canada goose	Canada goose
Wood, American black duck	Wood, American black duck
Gadwall, Mallard	Gadwall, Mallard
Blue-winged, green-winged teal	Blue-winged, green-winged teal
Hooded, common merganser	Hooded, common merganser, Northern harrier
Northern harrier	Cooper's, red-shouldered hawk
Red-shouldered hawk	Ruffed grouse, Virginia rail, Sora
Ruffed grouse, Virginia rail	Common moorhen, American coot, Killdeer
Sora, Common moorhen	Spotted sandpiper, Common snipe
American coot, Killdeer	American woodcock, Herring gull
Spotted sandpiper	Caspian, common, black tern, Yellow-billed cuckoo
Common snipe	Eastern screech, great horned, barred, long-eared owl
Herring, great black-backed	Belted kingfisher
gull	Red-headed, downy, hairy woodpecker
Caspian, common, black tern	Yellow-bellied sapsucker
Barred, long-eared owl	Alder, willow flycatcher
Belted kingfisher	Eastern phoebe, Eastern kingbird, Warbling vireo
Alder, willow flycatcher	Purple martin
Eastern phoebe, Purple martin	Tree, bank, cliff, barn, northern rough-winged
Tree, bank, cliff, barn, northern	swallow
rough-winged swallow	Black-capped chickadee
Black-capped chickadee	Winter, marsh wren
Winter, marsh wren	Veery, Gray catbird, Cedar waxwing
Veery, Gray catbird	Blue-winged, brewster's, golden-winged, Nashville,
Cedar waxwing, Yellow	yellow, cerulean, black-and-white, Canada warbler
warbler	American redstart
American redstart	Northern, Louisiana waterthrush
Northern waterthrush	Common yellowthroat, Eastern towhee
Common yellowthroat	Clay-coloured, henslow's, swamp sparrow
Clay-coloured, song, swamp	Northern cardinal
sparrow	Rose-breasted grosbeak
Rose-breasted grosbeak	Indigo bunting
Indigo bunting	Red-winged blackbird
Red-winged blackbird	Orchard, Baltimore oriole
Orchard oriole	American goldfinch

Source: Puddister, 2000.

areas, etc.). An overall reduction in stream water levels could result in changes to localized thermal environments. For example, groundwater seeps feed cold water into streams, creating cold-water refuges for some fish species (Sinokrot *et al*., 1995). "A reduction in stream flow will…reduce the length of any transient stream temperature reach below a dam or groundwater source" (Stefan and Sinokrot 1993, 373). A reduction in cold-water habitat could adversely affect the reproductive success of some fish species reliant on cold-water for spawning (e.g., brook trout) (Meisner *et al*., 1988). In general, diminishing water levels will lead to a reduction of aquatic habitat, resulting in reduced fish productivity (Meisner, 1990). In addition to changes in water levels, changes in channel structure and sediment regime, as a result of climate change, could also affect fish habitat (Worte, 2000, Pers. Comm.).

The temperature of water in streams is affected by air temperature, source water temperature (e.g., groundwater, reservoir releases, etc.), heat exchange with the streambed, and the topography and geography of specific watersheds (Meisner *et al*., 1988; Sinokrot *et al*., 1995). Groundwater temperature is directly related to mean annual air temperature (Meisner *et al*., 1987). Increasing mean annual air temperatures will lead to increases in groundwater temperatures. An increase in groundwater temperature will likely have the effect of retracting downstream limits of cold-water habitat (i.e., habitat for brook trout and brown trout) towards headwater areas (Meisner *et al*., 1988). Areas downstream of groundwater discharges act as cold-water refuges for some fish species. The downstream extent of groundwater refuges will likely shrink in the event of increased groundwater temperatures (Meisner *et al*., 1988; Meisner, 1990). Overall, this could result in the loss of cold-water habitat supporting brook and brown trout. Simulations of the impact of increased water temperature on cold-water habitat have concluded that loss of cold-water habitat is likely in the Rouge and Humber Rivers east of the Credit River (Meisner, 1990), and in Minnesota (Sinokrot *et al*., 1995). Stream water warming due to climate change could exacerbate existing warming trends in the Credit River. For instance, rising temperatures have been recorded at a stream water monitoring station located above Belfountain in the Town of Caledon over the period 1982-1992 (Region of Peel, 1996).

In addition to reductions in specific thermal habitats, increased water temperatures are likely to result in changes in species composition, and increased competition (Meisner *et al*., 1987). For example, in the event of increasing water temperatures, cool-water and warm-water fish species are likely to invade what is presently cold-water habitat, increasing competition between brook trout and other fish species (Meisner *et al*., 1987). Higher water temperatures could also promote the survival of exotic fish species released into aquatic environments through escapes from hatcheries and private ponds, and dumping of bait buckets by anglers. Water temperature increases are also likely to affect thermal structure of lakes, ponds, and reservoirs (Meisner *et al*., 1988). Changes in thermal stratification will change the volumes of thermal habitats, and will likely affect different species' production (Meisner *et al*., 1988). Longer, warmer growing seasons could increase the population of some fish species, resulting in changes in species composition and increased competition.

Warmer groundwater temperatures could also negatively impact water quality. For example, "Elevated groundwater temperatures may depress dissolved oxygen concentrations in groundwater discharge due to decreased oxygen solubility and increased rates of microbial oxidation of dissolved organic matter" (Meisner *et al*. 1988, 7). Some fish species require high dissolved oxygen concentrations for spawning (e.g., trout), and could experience declines in reproductive success due to relatively small decreases in dissolved oxygen (Meisner *et al*., 1988). Higher water temperatures could result in increased algae production. In addition to water quality concerns related to increased water temperature, low stream levels could result in increased concentrations of all types of pollutants in aquatic ecosystems. Discharges from Orangeville's sewage treatment plant have already been identified as a source of water contamination in subwatershed 19 (Credit Valley Conservation, 2000a). A variety of other urban (e.g., rural estate development), industrial (e.g., aggregate extraction, landfills), and rural (e.g., agriculture, septic systems) sources of contamination have been identified in the upper Credit subwatersheds (Beak Consultants Ltd. *et al*., 1992). Low water levels and higher water temperatures could exacerbate water quality problems relating to sewage and other discharges. Furthermore, changing water conditions could increase the risk of disease among fish populations. An interview with CVC staff revealed that there is some anecdotal evidence for increased black spot disease among brook drought during the dry summer of 1999 (Morris, 2001, Pers. Comm.).

Increased climatic variability could also affect the riparian vegetation of streams (Stefan and Sinokrot, 1993). Vegetation, like fish, has specific environmental requirements. Changes in air temperature and precipitation due to climate change could result in changes in watershed vegetation over time (Stefan and Sinokrot, 1993). A reduction in bank vegetation could result in less shading of streams, and further increases in water temperature (Stefan and Sinokrot, 1993). Higher water temperatures and lower water levels could promote weed growth (Morris, 2000, Pers. Comm.).

Changes in water levels, water quality, and water temperature are likely to result in changes in the extent and distribution of thermal environments in the streams and lakes of the upper Credit watershed. Cold-water fish species (e.g., brook trout) may be in danger of increased competition from cool-water and warm-water species (e.g., northern pike). Changes in populations of fish species could have implications for recreation (e.g., anglers) in the upper Credit watershed. In addition to impacts on game species, climate change could affect minnow species, creek chub, and rock bass (Morris, 2000, Pers. Comm.). Anecdotal evident from key informant interviews suggest that despite the low water conditions of the summers of 1998 and 1999, water temperatures remained low enough to prevent fish kills, although young of the year populations of brook trout were reduced (Imhof, 2001, Pers. Comm.; Morris, 2001, Pers. Comm.).

Fish habitat, defined as "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend, directly or indirectly, to carry out their life processes" (Department of Fisheries and Oceans 1995, 2), are protected under the federal *Fisheries Act*, administered by conservation authorities in Ontario. However, Estrin and Swaigen (1993) note that in court cases, fish habitat has variously been required to satisfy all, or just one of the above conditions for protection. Changes to some of the characteristics of existing fish habitat due to climate-induced low water levels could result in changes to the protection status of the habitat. Credit Valley Conservation's *Fishery Management Plan* identifies habitat degradation and protection as "the most important issue facing the Credit's aquatic ecosystems" (Credit Valley Conservation 2000a, 4-2). Future climate change could exacerbate existing threats to the upper Credit's cold-water fishery from urbanization, aggregate extraction, and water takings (Morris, 2000, Pers. Comm.).

4.0 Summary of findings

The surface and ground waters of the upper Credit River watershed are a resource shared by many different economic sectors, from domestic water use and recreation, to agriculture and industry. Reliable access to clean water is a necessity for individuals and businesses in the watershed. However, as well as fulfilling human needs, water is necessary for many of the valued natural systems in the area. The streams, rivers, and groundwater of the watershed support cold-water fisheries and wetlands, along with upland habitats. A key challenge for future management of the watershed will be striking a balance between utilization of water resources for human purposes, and protection of natural systems. This challenge is magnified by existing and expected climate variability and change.

Low water levels in 1998/1999 brought concerns about insufficient water supply to the attention of residents of southern Ontario. In 1998, the Credit River watershed experienced the lowest total annual precipitation recorded in 38 years (Credit Valley Conservation, 1999b). Anticipated climate change is likely to cause changes in the temperature and hydrologic regimes of southern Ontario. For example, a recent study suggests that climate change could result in higher temperatures and evapotranspiration, and lower precipitation, runoff, net basin supply, and soil moisture in the Great Lakes-St. Lawrence Basin (Lavender *et al*., 1998). In addition to changes in average climatic conditions (e.g., temperature, precipitation), increased climatic variability could lead to more frequent and severe extreme events (e.g., droughts, heat waves, and floods). Low water conditions may be exacerbated by development pressures, resulting in high demand for water.

Changes in rain and snow patterns, higher temperatures and evaporation, and less runoff could result in more frequent or severe droughts in the Credit River watershed. At present, dry periods lasting a minimum of 7 days occur at least once a month during the growing season in Ontario, while droughts lasting over 4 weeks occur once every 3 years (Gabriel and Kreutzwiser, 1993). In recent decades, droughts have occurred in Ontario in 1973, 1978, 1983, 1988, and 1989 (Phillips, 1990). In 1997 and 1998, annual rainfall in the Credit River watershed approached 30 year lows (Credit Valley Conservation, 1999b). An increase in the number and severity of droughts due to climate change will have implications for the nature and management of human and ecological systems in the upper Credit (Table 14). Low water levels could result in poor water quality and reduced water supplies for rural and urban domestic use, as well as commercial, industrial and agricultural water uses. Drought may also impact the environment by changing the distribution of habitat and wildlife populations, and encouraging the invasion of exotic species.

Table 14: Selected impacts of drought on human and ecological water uses

Use Sector	Uses of Water	Impacts of Drought
Municipal	• Drinking water • Waste disposal and dilution • Industrial, commercial, institutional water supply • Recreation • Fire fighting • Watering lawns and gardens	• Higher demand for water coupled with reduced supply from surface and ground water sources • Higher pumping rates may result in interference with other wells • Increased costs due to need to develop new wells • Lack of pumping and/or storage capacity to meet demand for water • Increased wastewater treatment costs as water quality decreases • Increased conflict with other water uses
Rural domestic	• Drinking water • Washing and cleaning • Watering gardens	• Insufficient water supply • Increased costs to deepen shallow wells • Increased conflict with other water uses
Agriculture	• Irrigation • Washing and cleaning • Livestock watering, cooling • Waste disposal • Spraying of chemicals	• Increased demand for irrigation, livestock watering, and cooling, coupled with reduced supplies • Lower production, higher animal stress • Increased soil erosion • Increased conflict with other water uses
Industrial & commercial	• Cooling, processing • Waste disposal, cleaning • Water bottling • Fish hatcheries • Aggregate processing	• Reduced supplies • Increased demand for water (e.g., fish hatcheries) • Loss of profits • Increased conflict with other water uses
Recreation and tourism	• Beach/swimming • Canoeing and boating • Fishing and hunting • Hiking, nature watching • Golfing • Skiing, snow-mobiling • Aesthetic	• Poor water quality from higher temperatures and less dilution may restrict activities • Lower water levels impede navigation of rivers and streams • Temporary changes in distribution of habitat and fish and wildlife populations • Loss of profits for related industries (e.g., ski hills, outfitters, etc.) • Increased demand for water (e.g., golf course irrigation) • Increased conflict with other water uses
Ecological	• Terrestrial ecosystems • Wetlands • Aquatic ecosystems • Fisheries • Wildlife	• Invasion of exotic species (e.g., purple loosestrife) • Temporary changes in distribution of habitat and fish and wildlife populations • Increased competition and conflict with human water uses (e.g., development of wetlands in dry years) • Warming of surface waters affecting thermal habitat (e.g., cold-water to warm-water), reduced spawning success • Impeded migration of fish and wildlife • Poor water quality resulting from higher temperatures, less dilution • Permanent streams becoming intermittent, lower water levels result in loss of habitat

5.0 References

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