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# Fish, Fisheries, and Water Resources: Adapting to Ontario's Changing Climate

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## *FISH SPECIES REFERENCE LIST*

| Common name | Scientific name | OMNR species code | Short or other name | Thermal guild | Assemblage name used here |
|---|---|---|---|---|---|
| Alewife | *Alosa pseudoharengus* | 61 | | cool | |
| Lake trout | *Salvelinus namaycush* | 81 | | cold | |
| Lake whitefish | *Coregonus clupeaformis* | 91 | whitefish | cold | cold-water species |
| Cisco | *Coregonus artedi* | 93 | lake herring | cold | cold-water species |
| Northern pike | *Esox lucius* | 131 | pike | cool | esocid |
| Muskellunge | *Esox masquinongy* | 132 | | cool | esocid |
| Grass pickerel | *Esox americanus vermiculatus* | 133 | | cool | esocid |
| Chain pickerel | *Esox niger* | 135 | | cool | esocid |
| White sucker | *Catostomus commersonii* | 163 | sucker | cool | misc. warm-water species[a] |
| Silver redhorse | *Moxostoma anisurum* | 168 | | cool | misc. warm-water species |
| Shorthead redhorse | *Moxostoma macrolepidotum* | 171 | | cool | misc. warm-water species |
| Greater redhorse | *Moxostoma valenciennesi* | 172 | | cool | |
| River redhorse | *Moxostoma carinatum* | 173 | | cool | |
| Northern redbelly dace | *Phoxinus eos* | 182 | | cool | |
| Lake chub | *Couesius plumbeus* | 185 | | cool | |
| Golden shiner | *Notemigonus crysoleucas* | 194 | | warm | |
| Common shiner | *Luxilus cornutus* | 198 | | warm | |
| Blacknose shiner | *Notropis heterolepis* | 200 | | warm | |
| Mimic shiner | *Notropis volucellus* | 206 | | warm | |
| Bluntnose minnow | *Pimephales notatus* | 208 | | warm | |
| Creek chub | *Semotilus atromaculatus* | 212 | | warm | |
| Fallfish | *Semotilus corporalis* | 213 | | warm | |
| Pearl dace | *Margariscus margarita* | 214 | | warm | |
| Yellow bullhead | *Ameiurus natalis* | 232 | | warm | |
| Brown bullhead | *Ameiurus nebulosus* | 233 | | warm | |
| Channel catfish | *Ictalurus punctatus* | 234 | | warm | |
| Margined madtom | *Noturus insignis* | 238 | | cool | |
| American eel | *Anguilla rostrata* | 251 | eel | warm | |
| Burbot | *Lota lota* | 271 | | cold | |
| Trout-perch | *Percopsis omiscomaycus* | 291 | | cool | |
| White perch | *Morone americana* | 301 | | warm | |
| Rock bass | *Ambloplites rupestris* | 311 | | warm | misc. warm-water species |
| Pumpkinseed | *Lepomis gibbosus* | 313 | | warm | misc. warm-water, sunfish |
| Bluegill | *Lepomis macrochirus* | 314 | | warm | misc. warm-water, sunfish |
| Smallmouth bass | *Micropterus dolomieu* | 316 | bass | warm | basses |
| Largemouth bass | *Micropterus salmoides* | 317 | | warm | basses |
| Black crappie | *Pomoxis nigromaculatus* | 319 | crappie | warm | misc. warm-water species |
| Yellow perch | *Perca flavescens* | 331 | perch | cool | misc. warm-water species[a] |
| Walleye | *Sander vitreus* | 334 | walleye | cool | |
| Johnny darter | *Etheostoma nigrum* | 341 | darter | cool | |
| Logperch | *Percina caprodes* | 342 | | cool | |
| Spoonhead sculpin | *Cottus ricei* | 383 | | cold | |

[a] For year-class comparisons, considered to be included as a miscellaneous warm-water species

## Section 1 Executive Summary

We have researched and reviewed "*Fish, Fisheries, and Water Resources: Adapting to a Changing Climate*" in four subprojects: 1) *Fish and fisheries adapting to a changing climate: Overview*, 2) *Weathering Climate Change: Workshops*, 3) *Economics, consequences, and adaptation: Survey*, and 4) *Water management responses: Modelling and planning* and provided considerable insights concerning sensitivity and response and made recommendations concerning what to expect and how to adapt. Science transfer, policy development, and implementation are urgently needed.

This study draws from Ontario and particularly Lake Ontario, a southern water body in the Great Lakes Basin, as well as Ontario's Mississippi River and watershed, a tributary of the Ottawa River. Changing thermal conditions have been quite well documented in the Great Lakes Basin, particularly in Lake Ontario and specifically the Bay of Quinte, where long-term fisheries data has also been collected and integrated. The full impact of a broad range of changing conditions, such as greater temperature extremes, longer growing seasons, warmer and earlier springs, warmer summers, longer and warmer falls, shorter winters, reduced ice cover and thickness, needs to be explored in relation to fish life history, quite specifically spawning time, location and depth, changes in vertical and spatial distribution, seasonal activity patterns, frequency of winter and summer kills, as well as a range of changes and invasions.

In some watersheds, water regimes and dynamics are well understood, such as in Ontario's Mississippi River watershed. If fish and fisheries in this system are studied in integration with water resources and their dynamics, the response, impacts, and recommendations for adaptation would be uniquely useful, especially if the primary focus was climate change and involved predictive modelling.

Lake Ontario and the Mississippi River and watershed contain a diversity of fish species. Historically, lake trout lakes dominated the watershed, but now only a few lakes in the western sub-watershed continue to be managed as cold-water fisheries, particularly around reservoir use and fall drawdown. The central and lower river and watershed lakes are managed for cool- and warm-water species. Walleye and bass dominate the fisheries. Water levels and flows along the main branch of the Mississippi River are regulated to protect fish spawning, and a detailed management plan was prepared in 2006 and although fish played a dominant role in the plan, climate change was not taken into consideration. This study was initiated in part to address this emerging issue.

The Almonte Communiqué was developed and released. The 150 participants unanimously agreed that there should be a call for action to governments and residents, where possible, to mitigate and adapt to reduce the impact of a changing climate.

Fish, fisheries, and aquatic ecosystems and water resources are sensitive to, and powerful indicators of, climate change. Long-term data from the Laurentian Great Lakes Basin indicate that for the past five decades, inshore surface water temperatures during open water (Apr-Sep) increased 1.5$^{o}$C, evaporation increased 9%, and ice cover decreased, most significantly since the thermal regime shift of the late 1970s. Also it is obvious that water temperature is a far more sensitive indicator of thermal change than is air temperature since it traps solar energy. Water resources and fish are among the best functional indicators of climate change.

The Lake Ontario fish population and communities confirm that with increasing midsummer temperatures, recruitment will increase in warm-water fish (centrarchids; +1$^{o}$C = +2.2×, +2$^{o}$C = + 4.8×, +3$^{o}$C = +10.6×) decrease in cool-water and fall-spawning cold-water fish (lake trout; +1$^{o}$C = -1.5×, 2$^{o}$C = -2.4×, +3$^{o}$C = -20.1 x), the latter negatively affected by increasing fall temperatures (Dec). In Lake Ontario, fish communities in the 1990s started to show changes reflecting a response to these increasing thermal changes. In the Mississippi River watershed, some cold-water coregonids have already been extirpated; expansion and invasion of thermally better-adapted warm-water centrarchids (e.g., black crappie and cool-water esocids (e.g., chain pickerel and grass pickerel) has accelerated. Esocid spawning behaviour is being affected by decreasing spring water levels, resulting in some adaptation and hybridization. With increasing temperature, body growth increases in warm- and cool-water species and decreases in cold-water species (+1$^{o}$C = ±9% to +3$^{o}$C = ±28%).

From our workshop, which focused on the Mississippi watershed in eastern Ontario, participants concluded that: 1) climate, ice cover, water temperature, river flows, local ecosystems, and fisheries are changing in the Mississippi watershed and will continue to do so; 2) there are now and will be future impacts on agriculture, tourism, forestry, fisheries, and other sectors; 3) impacts will be both positive and negative; 4) some but not all of the impacts can be reduced through adaptation; 5) there are barriers to taking action – tradeoffs will be necessary; 6) climate change must be incorporated into all aspects of our planning processes (e.g., health care, fisheries management, infrastructure design, water management, etc); 7) guidelines and toolkits are needed to help at the local level; participants look to all levels of government to provide these; 8) there is a continued need to raise awareness of this issue.

Modelling predicts that over the next 100 years, summer water temperatures will increase 4$^{o}$C; summer flows of rivers will decrease by 44%, lasting 28% longer; and spring discharge will peak 7 weeks earlier and decrease by 33%, negatively affecting walleye recruitment (-24%). Water budget models project increases of 74% in mean annual temperature and a 23% increase in evapotranspiration. Projected decreased summer flows will necessitate providing additional reservoir storage capacity and reducing nutrient loading.

The water budget model projected increases of 74% in mean annual temperature, 10% in precipitation, 20% in rainfall, 23% in potential evapotranspiration, and 144% in deficit. Snowmelt decreased by 25%, surplus by 3%, snow accumulation by 67%, and soil moisture by 12% between the 1985 and 2099 periods.

Results of the reservoir simulations indicated that average annual stream flow will decrease by 10% between the base period (1972-2003) and the future period (2070-2099). In general, stream flows will increase substantially in fall (Oct-Dec) and winter (Jan-Feb) periods by 74% and 70%, respectively, while they will decrease in spring (Mar-May) and summer (Jun-Sep) by 43% and 66%, respectively.

Spring water retention in wetlands can abate lower summer flows. This could be accomplished by using low-head dikes in wetland areas that could flood marshes in spring and facilitate pike spawning. Pike recruitment is negatively affected by reduced spring flooding, which is predicted to become more common. Artificial spawning marshes have been quite successful in enhancing pike recruitment. Strategic water management that retains water in wetlands in spring can not only increase pike production but provide valuable storage of water that can be used to augment flows that are decreasing, and will decrease, in summer. Prototype installations could be constructed and water management protocols developed around these pike-spawning marshes to mitigate reduced spring runoff and enhance cool-water fish production. It is a well-known fact that spring water level is directly related to pike recruitment; this was not apparent in the Mississippi watershed in the historic data because spring water levels are heavily regulated.

Water resource analysis and modelling provided the following recommendations: 1) communicate and transfer new science to all water resource users, stakeholders, general public, and water resource professionals; 2) incorporate new insights and modelling into existing water management plan and begin to manage accordingly; 3) provide additional reservoir storage capacity; 4) reduce and minimize nutrient loading; 5) improve capacity for watershed modelling and assessment; 6) facilitate integrated watershed management by a) involving stakeholders from multiple sectors, b) conducting community outreach; 7) improve watershed resiliency; 8) where possible, manage water resource use and changes to sustain and, where possible, increase fish resources and fisheries – a) maintain wetlands during minimum flows and increase fish passage.

Resource users mostly attributed observed environmental changes to climate change (96.8 ± 3%) but were unwilling to adapt to fish-community changes; they attributed these changes to invasive species, water quality, and exploitation rather than to the effects of climate changes. Only 12.9% of respondents considered an increase in warm-water species to be positive, more so in the Mississippi Valley area, where anglers were already using warm-water species. All this underlines the need for science transfer. As a result, more respondents (18.2%) in the Mississippi Valley area considered an increase in water-water species as positive, estimating few changes in resource use (50.0%) and revenues (53.8) than other areas. To help offset social and economic impacts of climate change, 88.8% of respondents indicated that management actions should be taken that adopt and incorporate environmental and fish-community changes due to climate change. Promotion of underused stocks was encouraged. Respondents considered that any management action needed to be heavily based on science; social and economic concerns were far less important. In addition, 85.6% indicated that a fish policy and management plan should be developed to deal directly with impacts and adaptations to climate change, including participation from all levels of government, academia, non-government organizations, and knowledgeable local resource users and stakeholders.

The survey and its research provided the following recommendations: 1) maintain existing databases and expand where and when possible to analyze long-term trends to determine factors and stressors associated with a changing climate; 2) take advantage of cooperative action, using local resources, users, and volunteer groups; 3) improve science transfer and information to the general public and professionals alike; 4) maintain openness and flexibility in management decisions and regulations; 5) consult with local users and communities in management decisions; 6) management actions deemed most effective in offsetting social and economic impacts of climate change: ordered priority – a) public education, b) regulations, c) promote underused stocking; 7) base management decisions on ordered priority – a) scientific evidence (overwhelming), b) social concerns (distant second), c) economic concerns (very distant third).

Assessing and managing water, fish resources, and fisheries in a changing climate necessitates monitoring more intensively, increasing assessment and research capacity, adapting management to use increasingly abundant warm-water fish while protecting decreasing cold-water species, proactively addressing these controlling, changing environmental factors and shifting baselines and mitigating by making, publicizing, and promoting local fish and fisheries as part of our local "100-mile diet." This proactively will reduce our carbon footprint.

Water resources provide two valuable natural resources: fish for food and recreation and water power for energy. These two resources are equally important but have often been in conflict. Water power, as developed and used in the past, often negatively affected fish and fisheries (Pyzer 2009b). Climate change will alter critically important aspects of water resources that could make these two resources more competitive. Special effort should be taken to make sure that fish and fisheries are not detrimentally affected but remain productive, naturally self-sustaining, and undiminished. Local fish and fisheries provide food and a local "homeland" security, which will become increasingly more valuable because worldwide food production is decreasing, becoming more expensive in a less secure and changing world.

Science transfer was an important goal of the study and has been ongoing since the completion of the research in 2008. Numerous presentations, many by invitation, have been made locally, provincially, nationally, and internationally. The authors of this report have made many of these presentations not only to the science community but to the lay public, and the principal investigator has been invited on numerous occasions to be a keynote speaker on the subject and has drawn heavily on the research of this study and the science emanating from the study. In August 2008, the principal investigator co-convened a one-day special symposium session entitled "*Fish, Fisheries, and Water Resources: Adapting to a Changing Climate*" at the American Fisheries Society Annual Meeting in Ottawa. Three of the presentations in that symposium came directly from this study. The symposium was followed by several invited interviews on CBC national radio.

The science assembled here continues to be expanded upon, and presentations are actively being sought. As recent examples, in 2010 the principal investigator made an invited plenary presentation, "Effects of climate and climate change on freshwater fish and fisheries: Driving environmental factors and shifting baselines," at a St. Lawrence River Institute conference, "*Protecting and Restoring Aquatic Ecosystems Through Government and Community Action*," in Cornwall in May and another in July, "Effects of a changing climate on freshwater fish and fisheries: Driving environmental factors and shifting baselines – what to expect, how to adapt," in the symposium "*Adapting Fisheries for a Changing Climate*" at an international joint meeting of the Fisheries Society of the British Isles, Japanese Society of Fisheries Science, and American Fisheries Society held in Belfast, Northern Ireland. There is considerable proof that the research and science were timely and continue to be eagerly sought.

The changes and challenges are unprecedented and will continue to be so, given the climate changes that are underway and are predicted for the future. Adaptation and mitigation are essential and can even provide positive opportunities if fish and water resources and human endeavours are to be sustained in a changing climate. Now that we know what to expect and have developed recommendations, the question is, How will we adapt to changing fish and fisheries and water resources while trying to mitigate this formidable global problem.

# Section 2 General Introduction

Fish, fisheries, and water resources in the Great Lakes Basin are changing with global climate change. Lake Ontario, the St. Lawrence River, and connecting watersheds such as Ontario's Mississippi River can provide insights into central Canada's vulnerability. Abundance and distribution of aquatic organisms, particularly fish, are changing, and some are adapting to altered environmental conditions. The financial magnitude of these adjustments may become extreme; for example, Great Lakes fisheries, which are 90% recreation based, are worth $5 billion annually, and we need to know how we can adapt to maximize their use sustainably. Water and aquatic resources require attention and research because they will become more precious as global warming continues its projected increase.

Like fish inhabiting newly created environmental niches, we too can take advantage of new resource opportunities if research and development show us the way. This project examines how, when, and where adaptation is possible, including costs and benefits. The research considers the feasibility, acceptability, and willingness associated with adaptation, reviews examples and case histories of adaptive capacity and adaptation, and provides straightforward recommendations that can be immediately and easily used by policy and decision makers.

Impacts and general changes in fish, fisheries, and water resources in relation to adaptation have been generally reviewed in an extensive review of Canada in a changing climate (Chiotti and Lavender 2008), but specifics around these have not been considered or addressed. Considerable data now exists to address adaptation and an integrated study was needed that quite specifically measures the extent of these changes in the future and the degree of adaptation required.

For this reason, a set of four interrelated subprojects was conducted to contribute to an improved understanding of how changing climate and aquatic resources will affect our lives, finances, activities, and interests. We will need to better understand adaptation and adaptive capacity if we are to continue to appreciate the undiminished benefits of these aquatic resources. We brought together engineers, scientists, biologists, stakeholders, policymakers, and resource managers to help us quantify and better understand change, adaptation, and adaptive capacity concerning fish, fisheries, and water resources in Ontario's changing climate.

This study deals directly with five important aspects of a changing climate and adaptation. These involve providing case studies of adaptation, considering actual and perceived risks, evaluating adaptive capacity, assessing economic and social impacts, and considering a changing climate in plans and policy processes.

The first research subproject, *Fish and fisheries: Adapting to a Changing Climate*, provides a complete review with examples of how fish are adapting to changing environmental conditions and how fisheries can be redirected advantageously. This subproject was conducted by the principal investigator and senior author, Dr. John M. Casselman (see Section 3.1, Subproject 1; CV Appendix A2.1). The second subproject, *Stakeholder Outreach and Science Transfer Workshops: Weathering Climate Change*, provided the opportunity to discuss, with assistance of Mississippi Valley Field Naturalists, perceptions of resource users and their willingness to adapt their use of aquatic resources to maximize personal and financial return, yet conserve and sustain them. This subproject was conducted by Paul Egginton and Beth Lavender, with the assistance of Jackie Oblak (see Section 3.2, Subproject 2). This subproject and our third subproject on *Economics, Consequences, and Adapting to Changing Climate* engaged fisheries-resource managers to identify barriers and incentives to adaptation, as well as evaluate the ability of current management plans and policies to address future climate change. This subproject considers financial aspects and draws on a broad comparison with past fish-resource use and value. This subproject was conducted by Lucian Marcogliese (see Section 3.3, Subproject 3, CV Appendix A2.1).The fourth subproject deals with *Water Management Response to Climate Change.* This study was conducted by Mississippi Valley Conservation and examined opportunities and constraints within an integrated watershed hydrologic and hydraulic modelling. A recently completed water-management plan associated with this subproject considered some aspects of fish resources but did not take climate change into account. This science will make it possible to consider climate change and revise the plan and associated policies. This subproject was conducted by Dr. Sobhalatha Kunjikutty and Paul Lehman (see Section 3.4, Subproject 4; CVs Appendix A2.1).The most significant results will be integrated with recommendations in a final research report, "*Fish, Fisheries and Water Resources: Adapting to Ontario's Changing Climate*."

The general objectives of this integrated research were to conduct and interrelate a set of research initiatives to better understand adaptation and adaptive capacity associated with fish, fisheries, and water resources in a rapidly changing environment so that we can minimize risks, develop case studies involving adaptation, and make recommendations so that stakeholders and policy and decision makers can better position themselves at the local and regional levels to take advantage of new opportunities and resources associated with global climate change.

The primary objectives of the subproject on *Fish and Fisheries* were to assemble and research how 1) fish either are not adapting or are showing adaptation to changing environmental conditions, considering, for example, changing spawning time and depth (pike), increased diversity in spawning habitat – shoreline versus river (walleye and others); 2) community structure, production, and fish-resource abundance are changing, switching from cold-water (lake trout, whitefish) and some cool-water (pike) to other cool-water (yellow perch, walleye) and warm-water (basses, panfish, muskellunge) assemblages; 3) stocking cold-water species such as lake trout can circumvent climate-induced recruitment bottlenecks that are starting to occur for cold-water species because of warm falls and winters even though deep, cold-water habitats for growth and production of older life stages persist; 4) fisheries regulations, management, assessment methods, and technology and data collection will need to change to consider climate-induced alterations affecting species composition, habitat, environmental, biological, and physiological differences.

Objectives for the workshops, *Weathering Climate Change*, were to 1) bring together expert, local, and traditional knowledge to develop and scope future interactions and concerns and provide insights by engaging well-informed resource users (Mississippi Valley Field Naturalists), focusing on specific local and well-understood areas; 2) conduct surveys and transfer the science resulting from current research; 3) consider stakeholders' involvement in monitoring programs and obtain case histories.

Objectives of subproject *Economics and Consequences* were to 1) provide a financial measure of economic impacts due to global warming on fish resources, regionally in Ontario and locally in the Mississippi Valley of eastern Ontario; 2) determine whether resource users and managers have the flexibility, willingness, and information to adapt to these impacts; 3) document past and present economic value and social importance of fish resources and forecast future trends based on current attitudes of resource users; 4) make recommendations to resource managers that would promote economic growth and sustainable use of the resource while maintaining its social importance.

Objectives of subproject *Water Management Response* were to 1) evaluate the capacity of the Mississippi River Water Management Plan (2006) and associated reservoir operation policies to address future climate change; 2) provide an important component of a broader, ongoing water-management planning initiative in the Mississippi River watershed; 3) provide an integrated water-management plan to address climate-change impacts at the watershed scale, incorporating fish, fisheries, and sustainable aquatic-resource use. Subsequent phases of this work will use the research to integrate water quality and ecosystem considerations into water-management planning.

An overriding objective was to integrate the research of the subprojects to provide an overview and recommend how fish, fisheries, and water resource use can be adapted in sustainable and optimally productive ways in a changing climate.

The proposed research consisted of four interrelated subprojects. This was a new project (stand-alone) using methods that complement one another and permit an integrated combined analysis. Each subproject focused on some aspect of understanding how fish and humans are adapting or can adapt successfully to Ontario's changing climate.

The first subproject, *Fish and Fisheries*, used fish (10 important, mainly large-bodied species – smallmouth bass, largemouth bass, white perch, yellow perch, American eel, northern pike, walleye, lake trout, lake whitefish) and environmental data (see below) that have been assembled as part of a 50-year community-indexing program in eastern Lake Ontario and the Bay of Quinte. As the data were analyzed and variously published (Casselman 2002, 2006, 2008; Casselman and Scott 2003; Casselman et al. 2002), it became apparent that additional analyses could provide important insights concerning adaptation and adaptive capacity of these fish and their fisheries. Similar data have been acquired from the upper St. Lawrence River and the Mississippi and Ottawa rivers that provide additional insights for eastern Ontario. Analyses are comparative, correlative and, where possible, quantitative to show interrelationships between global warming, climate change, and adaptation. Time-trend and CUSUM analyses were used to quantify and detect change.

Some of the variables used in the analysis that are already affecting, and will increasingly affect, fisheries and fish resources in eastern Lake Ontario, the St. Lawrence River, and associated watersheds are increasing annual temperatures (Casselman 2002), greater temperature extremes, longer growing seasons, warmer and earlier springs (Casselman et al. 2002), longer and warmer falls (Casselman 2008), shorter winters (Egginton et al. 2007), reduced ice thickness and ice-cover periods, fewer extreme cold events, altered precipitation and reduced runoff (Casselman 2006), more extreme discharges and runoff, drier springs and less flooding of wetlands (Casselman 2006). Analysis of how these factors either directly or indirectly affect fish, depending upon thermal habitat and temperature requirements (Casselman 2002) and subsequent adaptation, considered changes in natural mortality, longevity, recruitment (Casselman 2002), growth (Casselman 1996), productivity, abundance, dynamics (Casselman and Scott 2003), interaction and community structure (Casselman 2002), as well as resource use, exploitation (Casselman 1978), total allowable catch, and regulations such as creel limits, size limits (Casselman 2007), and fishing seasons. Fish that adapt or are exposed to more optimum conditions will be more productive. But ill-adapted stocks will be depleted and must be managed and harvested more conservatively (Magnuson 2002). This will require new approaches for management and regulations.

Specific data are available and were assembled from long-term time series, as well as from published and unpublished literature, to analyze a series of research questions associated with fish, fisheries, and adaptation. They are: 1) changes in relative abundance that began after the temperature regime shift of 1977 (Casselman and Scott 2003), spawning time and depth (pike) (Casselman and Lewis 1996; Casselman 2006), types of spawning stocks and habitat – river versus shoreline (walleye), abundance of lotic (river, flowing water) and lentic (lake) forms (walleye) (Pyzer 2009a), vertical and spatial distribution (whitefish, lake trout) (Casselman 2008), seasonal activity (pike) (Casselman 1978), range expansions, contractions, and invasions (numerous species) (Vander Zanden et al. 1999; Shuter et al. 2002; Vander Zanden et al. 2004; Chu et al. 2005); 2) changes in community structure (Casselman et al. 1999; Casselman 2002; Casselman and Scott 2003; Kling et al. 2003; Mills et al. 2003) and productivity – switching from cold-water (lake trout, whitefish) and cool-water (pike, walleye) to warm-water (basses, muskellunge) assemblages, depending upon requirements and changes in thermal habitat (Pyzer 2007); 3) how stocking of cold-water species such as lake trout can circumvent recruitment bottlenecks that are starting to occur because of warmer falls and winters (Casselman 2008), while deep, cold-water habitats persist (Ellis 2007); 4) fisheries regulations, assessment methods, and technologies will need to be re-evaluated and possibly changed (e.g., scale age assessment complicated by increasing temperature and decreasing growth – pike) (Casselman 1996); 5) redirecting exploitation from stressed thermal guilds (cold-water – lake trout) to those better thermally adapted (warm-water – basses) (Casselman et al. 2002; Pyzer 2007).

Adaptation to climate change has commenced, through a shift in policy, to meet energy needs to expand hydro power production. Dams and manipulation of water levels and flows have negatively affected fish production, fish, and fisheries (Pyzer 2009b). These are addressed and quantified to encourage a better appreciation of the value of fisheries resources, which are equally as important and renewable as water resources for hydro power and should not be permanently diminished in the pursuit of what is inappropriately perceived to be “green” power when fish and fish resources are considered (Pyzer 2009b; Helsdon 2010).

Stakeholder workshops (Subproject 2, *Weathering Climate Change*) focused on the Mississippi River watershed and initiated outreach and interactions so that trade-offs could be evaluated. The range of participants was broad. Science transfer was a component, and though certainly not the primary purpose, it was be a first step in examining changing demands on a specific watershed and not only provided information to participants but provided participants with the opportunity to share local knowledge and engage in discussions with experts from several sectors.

The first workshop (May 12, 2007), was held in Lanark on May 12, 2007. It involved local lake stewards and lake association representatives. A speaker opened the day with information on fisheries and climate change, and discussion included how to work within the community to address local issues. The outcome was to establish an organizational capacity to effectively address future issues, facilitate communication with stakeholders on the issues, and encourage continued engagement through gathering local information and implementing appropriate local management responses as adaptation alternatives present themselves. The second set of workshops was held on two days, September 15 and 22, 2007. They allowed 200 to 300 participants, representing local organizations as well as the public, to hear from sector experts. Each day was broken into two key sectors. The workshop engaged public and local sector associations as well as the public. Each morning expert speakers presented one-hour talks on their sectors, and each afternoon featured breakout groups to explore one of the subjects of the morning presentations. The afternoon breakout sessions provided an opportunity for participants to discuss potential impacts and adaptation measures in their areas of interest and provided organizers with an opportunity to gauge the willingness of stakeholders to modify their current practices under certain scenarios. Discussions from the breakout sessions were facilitated and recorded. Results from the sessions, as well as presenters' notes, were compiled to produce a report that will assist in identifying local stakeholder issues and concerns and amalgamate expert and local knowledge on the relevant issue.

Interested stakeholders were also consulted in all four subprojects, and a limited number (15) participated in the Organizational Capacity Working Group assembled to provide ongoing engagement of local organizations and management agencies to facilitate communications, obtain advice, and make recommendations on how to respond to ongoing and future climate-change risks. They were, for example: Queen's University, Mississippi Valley Conservation, University of Guelph, Mississippi Valley Field Naturalists, Ontario Ministry of Natural Resources (relevant departments and sections, Fisheries Branch, Research Section, regional and district offices, e.g., Kemptville and Bancroft), Ontario Federation of Anglers and Hunters, Bait Association of Ontario, Ontario Commercial Fishery Association, Ontario Conservation Authorities, Canada Department of Fisheries and Oceans, Ontario Woodlot Association, Lanark County Maple Syrup Association, Lanark OFA, Christian Farmers Alliance, Lanark Landowners Association, Fruit Growers Association, Nursery Association, Ontario Parks, stewardship groups and councils resort owners, lake/cottage associations, local Native groups.

General methods for Subproject 3, *Economics and Consequences*, involved examining fish resources, users, and managers in Ontario at the macro level, then the scope was narrowed to the micro level by examining specific conditions for the Mississippi River Watershed of eastern Ontario, with the help of the Mississippi Valley Field Naturalists. First, a review of all existing literature and known research on the impacts of global warming on resource users and managers was conducted to acquire the necessary data for analysis. The review focused on documented conditions before and after recent Great Lakes Basin water-temperature warming commenced (Casselman 2002). Second, a survey was conducted that focused on and measure attitudes, adaptability, opinions, and perceptions of resource users and managers. These empirical observations and attributes measureed the social and economic importance of fish resources and the adaptability of users and managers, which will ultimately determine the economic significance of change.

In 1976, before temperatures started to increase dramatically in the Great Lakes Basin (Casselman 2002), a survey was conducted that examined social attitudes of resource users, resource enforcement officers, and politicians toward a sport-fishing licence for Ontario (Marcogliese 1977). The research included a measure of the economic value of Ontario's sport fishery in 1961 and 1970. Where applicable, this present research and survey paralleled the 1976 survey and provided direct comparisons between stable and increasing global temperature conditions. For example, the 1976 survey showed that the highest-priority concerns with regard to Ontario's sport fishery, in descending order of importance, were pollution control, enforcement, regulations and laws (established by fishery managers), biological research of the fish resource, hatchery operations, and public education. Of much less importance were licence fees, water levels, creel census, and research needs of the angler (Marcogliese 1977). Environmental and global climate change were not even envisaged as a problem. We specifically addressed this.

For both the published and unpublished literature and survey, four components were examined concerning economic consequences of global warming. 1) Determine how fish resources and fisheries will be affected by global climate change: a) Environmental changes – temperature, precipitation, duration of ice cover and thickness, floods, low water, and wind; b) Fish-community changes – species and abundance (will incorporate and integrate with Subproject 1 and resource users and managers survey). 2) Resource use – past, present, and future. 3) Economic consequences – users' willingness or unwillingness to adapt. 4) a) Ability of users to adapt – switch species, travel, support a put-and-take fishery (stocking); b) Ability of managers and policy makers to suggest adaptation – publicize and promote new and alternative species, regulations, and decisions; encourage business plans. The primary focus of the analysis in this subproject concerns social aspects and adaptability of resource users and managers to changing fish resources, since they are the primary variables that will determine economic aspects.

Survey results are expressed in terms of ranks and percentages, and statistical tests involved Chi-squared analysis of stakeholders and decision makers attitudes, past and present.

The research in Subproject 4, *Water Management Response*, built on analyses completed for the Mississippi River Water Management Plan (Mississippi River Water Management Plan Steering Committee 2006) to evaluate the capacity of the plan, associated reservoir operation policies, and water-control infrastructure to address climate-change impacts.

The Water Management Plan was a multi-stakeholder initiative to develop a water level and flow management plan for the Mississippi River, which builds on the current operating regime for the river system and integrates environmental and socioeconomic values and considerations. The plan was directed and supported financially by the local water-power producers, Mississippi Valley Conservation, and Ontario Ministry of Natural Resources. The planning process included extensive public consultation and involvement of a Public Advisory Committee to assist in obtaining public input. The plan deals with 12 water-control structures, including five hydroelectric generating facilities and six reservoirs. As part of its long-term management objective, Mississippi Valley Conservation has initiated work to address data and information gaps identified through preparation of the Water Management Plan in 2006.

Climate-change considerations were not addressed in the Mississippi River Water Management Plan (Mississippi River Water Management Plan Steering Committee 2006), although subsequent analyses indicate that seasonal shifts in runoff patterns will have significant implications on socioeconomic and environmental objectives. With the potential impacts of climate change on surface water quantity, quality, and temperature, the effects on aquatic ecosystems will need to be assessed to ensure that the Plan remains responsive to management objectives. The research provided the chance to address future climate-change effects within an integrated plan. The first phase evaluated performance of existing water-control and future climate scenarios, using climate and water-quality data provided by the University of Guelph. Effects of seasonal changes in runoff distribution and increases in evapo-transpiration were evaluated through the use of the deterministic hydrologic Guelph All Weather Sequential-Events Runoff model. Stream flow-time series under various climate scenarios were simulated with the HEC ResSim2.0 reservoir simulation model. This integrated modelling approach investigates the influence of changes in stream discharge and water temperature to determine effects on spawning, growth, and production of fish of different thermal guilds (pike, walleye, bass), their fisheries, and the ecosystem. Field surveys and reservoir operation modelling were used to assess conflict between competing interests such as navigation and reservoir drawdown on success of cold-water fish (lake trout)and fisheries. Based on findings of this phase, opportunities and approaches available to incorporate climate-change considerations into current management plans and regulatory policies were explored with affected stakeholders.

Finally, the results of all four subprojects were amalgamated to provide an overview of our understanding of how fish, fisheries, resource users, economic forces, and water resources and their management are interrelated in Ontario's changing climate. We recommend actions that will minimize conflicts and risks, suggest how adaptation is possible at all levels, and conduct analysis to help quantify the interrelationships and the final recommendations.

This integrated study, "*Fish, fisheries, and water resources: Adapting to Ontario's changing climate* (A1367)," was supported by Climate Change Impacts and Adaptation Directorate, Earth Sciences Sector, Natural Resources Canada, Climate Change Impacts and Adaptation Program (CCIAP) resulting from a call for proposals involving Understanding Adaptation and Adaptive Capacity. The research was initiated in 2007 and completed in 2008.

# Section 3.1 Fish and fisheries: Adapting to a Changing Climate, Subproject 1

### 3.1.1 Introduction

Climate is changing, and there are many far-reaching effects on aquatic ecosystems, fish, and fisheries. Indeed, in the past, fish and fisheries have been fundamental in providing valuable insights and leading the way in documenting and profiling major environmental and aquatic concerns and issues. Over the years, these broad issues have involved 1) overexploitation of fish resources, particularly related to commercial harvest; 2) aquatic ecosystem eutrophication, primarily involving phosphorus loading; 3) bioaccumulation of aquatic contaminants and associated toxicities; 4) acid precipitation and the loss of fish production and species; and, most recently, 5) invasion of exotic species and their negative impacts.

Aquatic systems are particularly sensitive to climate change, so as expected, fish and fisheries are playing and can once again play a primary role in profiling the profound environmental alterations and impacts related to a changing climate. And quite importantly, if studied in detail, it is possible to determine how human activities can be altered to adapt to these changes and even, in the process, contribute to mitigation.

Fish and fish resources have not only documented these major anthropogenic changes and stresses but have been important in initiating solutions and encouraging legislation and then subsequently assessing the success of positive actions.

Increasing temperature conditions and global warming is one of the primary impacts of climate change. Temperature is a major controlling factor affecting all aspects of aquatic production. This shifting baseline will permanently alter environmental conditions and food webs. Changing thermal conditions have been quite well documented in the Great Lakes Basin, particularly in Lake Ontario and specifically the Bay of Quinte, where long-term fisheries data has also been collected and integrated. The full impact of a broad range of changing conditions, such as greater temperature extremes, longer growing seasons, warmer and earlier springs, warmer summers, longer and warmer falls, shorter winters, reduced ice cover and thickness, needs to be explored in relation to fish life history, quite specifically spawning time, location and depth, changes in vertical and spatial distribution, seasonal activity patterns, frequency of winter and summer kills, as well as a range of changes and invasions.

Also, quite important to fish and fish resources, water dynamics and water resources are changing as a result of climate change. With every increase in temperature of $1^{o}$C, evaporation and transpiration increase by 6%. This, along with changing precipitation, will result, for example in the Great Lakes Basin, in reduced runoff, drier springs and reduced spring flooding of wetlands, more extreme discharge, and less snow pack and ice cover. These impacts will be exacerbated if flows and levels are artificially manipulated and regulated. The effects of water regimes and discharge on fish and fisheries, especially as they pertain to spawning time and location and spring flooding, have been fairly well studied for a number of species; e.g., pike and walleye. However, the impacts of a changing climate need to be more thoroughly and precisely quantified if we are to adapt and mitigate.

In some watersheds, water regimes and dynamics are well understood, such as in Ontario's Mississippi River watershed. If fish and fisheries in this system are studied in integration with water resources and their dynamics, the response, impacts, and recommendations for adaptation would be uniquely useful, especially if the primary focus was climate change and involved predictive modelling.

Fish populations and communities are responding to these environmental changes. The literature indicates changes in thermal habitat, temperature adaptation, natural mortality, longevity, recruitment, growth, production, abundance, dynamics, interaction, and community structure. All of this suggests, although they are not well documented, changes in fish community structure, dynamics, and productivity, as well as switches in assemblages from cold-water (e.g., lake trout and whitefish) and cool-water (e.g., pike and walleye) to warm-water (e.g., basses and muskellunge), depending upon thermal requirements and thermal habitat.

There is evidence that these changes are affecting fisheries and should be taken into consideration to better manage fish resources in the Great Lakes Basin in a changing climate. These environmental changes will affect exploitation and resource abundance and allocation and will affect decisions concerning allowable catch, creel limits, size limits, fishing seasons, and associated regulations. Discussions have commenced concerning stocking of cold-water species (e.g., lake trout) and even cool-water species to circumvent recruitment bottlenecks that are starting to appear. In lake trout, these are directly negatively influenced by warmer falls and winters. Nevertheless, deep, cold habitats will still exist and should be used. Quantitative information is becoming available for the Great Lakes Basin that can be used to redirect exploitation from thermally less adapted and more environmentally stressed species (e.g., cold-water lake trout, whitefish, cisco) to those that are better adapted to increasing thermal conditions (e.g., warm-water basses and panfish).

But most importantly, research is needed to examine to examine both response and adaptation to determine how human adaptive capacity and intervention could assist in maintaining valuable fish resources and using them more prudently and more extensively by better management and assessment. Emphasis should be placed on adaptation, because climate change and responses are underway and need to be considered and emphasized. Fish and aquatic resources can be very sensitive indicators of climate change. If these are understood and fisheries are managed proactively, fish and fisheries can provide adaptive opportunities while achieving some degree of mitigation. If response is studied carefully and thoroughly, changes can be predicted, making it possible to recommend how to actively exploit opportunities by managing in an advantageous way to use resources that will increase while restricting harvest and use of those that are contracting and need to be protected to maintain diversity.

Changing environmental conditions will affect productivity and potential use of fish resources. Fisheries management practices will need to be adaptive and reconsidered and altered where necessary. Changing conditions will require a complete re-evaluation of procedures and practices. New approaches that involve protecting declining resources while liberalizing the use of those that are expanding will need to be considered. Climate change is not entirely a negative effect. It is imperative that regulations adapt to restrict in some cases but liberalize in others, where appropriate. All of this will reinforce that it is critically important to monitor and assess more carefully and thoroughly than before in order to detect changing conditions. Sampling techniques and data collection may need to be redesigned to meet changing biotic and abiotic conditions. There is no doubt that environmental conditions will need to be carefully monitored in conjunction with fish sampling and indexing in order to better and more thoroughly understand the changes that are occurring and the causes for them. All too often in the past, fish and fisheries have been adequately monitored but environmental conditions have been overlooked. This was probably more acceptable when conditions were relatively stable, but changing conditions require not only fisheries but more integrated and detailed environmental monitoring.

A detailed review and study of climate change, fish and fisheries, and adaptation is needed. Such a study is assembled here that integrates all aspects, incorporating a literature review and assembling new data and analyses to 1) quantify how aquatic environmental conditions have changed and are predicted to change in the future; 2) document changes in population dynamics and abundance and community structure; 3) examine changes in resource use and fisheries to determine how fish resources can be sustained and even increased through human intervention by using management and regulations to circumvent climate-induced bottlenecks; 4) examine fisheries regulations, management, assessment methods, and technology and data collection to meet changes in species composition, distribution, behaviour, and environmental physiology; 5) determine what types of adaptation are possible and what adaptive capacities exist or can be recommended. It is quite apparent that the subject needs a thorough and in-depth review if challenges created by climate change are to be addressed. The problem seems daunting but well worth the effort if adaptation and some degree of mitigation is achieved.

The study conducted here assembles and updates climate change, fish and fisheries, and the aquatic environment, particularly as it pertains to Ontario’s freshwater ecosystems of the Great Lakes-St. Lawrence River Basin. Specific long-term fish and temperature data for Lake Ontario and the Bay of Quinte provide extensive and strongly quantitative data that is in-depth but also broad in scope. These data are, in part, from the Ontario Ministry of Natural Resources, Glenora Fisheries Station, Fish Community Indexing Program.

In addition, an integrated study was conducted in partnership with Mississippi Valley Conservation on Ontario’s Mississippi River watershed. This was conducted because Mississippi Valley Conservation Authority wanted to consider climate change in the recently completed Water Management Plan, and a review of the plan indicated that fish and fisheries were an important component and considered throughout all aspects. It is rare to see a water management plan with strong fish and fisheries components. In addition, it was known that many assessment surveys had been conducted over the past five decades on the numerous water bodies of this river and watershed. A cursory review indicated that they contained a wealth of data that could be used to examine long-term changes in the fish populations and community, which, if integrated with a collaborative study conducted on water resources, not only could document changing conditions but might also predict future changes. Predictive modelling was planned as part of the water resources component. This would be extremely valuable in guiding recommendations concerning adaptation.

Specific data and methods are detailed that describe the assemblage of long-term (three to seven decades) water and air temperatures for Lake Ontario, Bay of Quinte, and the Mississippi River and its watershed. Similar long-term data on discharge and precipitation are assembled for the St. Lawrence River and the Mississippi River system. In addition, long-term water level information was reviewed for the St. Lawrence River and Lake Ontario. Climate change predictions for the Mississippi watershed were used from Subproject 4 (Water Management Responses). All were reviewed and analyzed in conjunction with long-term fisheries data in association with thermal requirements and changing thermal and water resource conditions and their effect on spawning, recruitment, growth, and production.

Response and adaptation to climate change for fish, populations, and communities are reviewed in terms of the thermal requirements of three major thermal guilds, or groupings: warm-water, cool-water, and cold-water. The effects of changing climate and aquatic environmental conditions on year-class strength, recruitment, and growth are compared and contrasted across thermal guilds. The effects of these on community structure and dynamics are considered, with examples. Distribution and behaviour of species are changing, affecting their availability and use in relation to thermal niche. Changes in community structure and exploitation must take this into consideration when adapting management and regulations to consider changes that are climate-induced.

Lake Ontario, the St. Lawrence River, and the associated watershed of Ontario's Mississippi River provide insights as to how sensitive fish resources are to changing climatic conditions in central Canada, including their response and vulnerability. Abundance and distribution of aquatic organisms, particularly fish, are changing, and some are adapting to altered environmental conditions. We need to understand and quantify this.

The specific objectives of Subproject 1 on *Fish and Fisheries: Adapting to a Changing Climate* were to describe, using where possible long-term data, aquatic changes associated with the Great Lakes, using Lake Ontario, and inland waters, using the Mississippi River watershed, considering 1) water temperature, 2) air temperature, 3) duration of ice cover, 4) global teleconnection with the tropical Pacific, 5) precipitation, and 6) discharge. Also consider general fish responses involving 7) species thermal requirements, 8) changes in recruitment and community structure, and 9) body growth of typical species of the three thermal guilds. Also consider water bodies and fish species of the Mississippi watershed using multiple-year assessment sampling to 10) evaluate year-class strength in relation to annual trends in various environmental conditions, 11) model and predict thermal and water resource changes over the next 100 years, and 12) determine fish sensitivity, response, and adaptation. Indeed, some species are expanding their range and adapting, while others are contracting. The question is, how can humans respond and adapt to these changing resources? The subproject reviews and recommends what can be done to help sustain fish resources and human endeavours in a changing and more variable climate.

Quite importantly, we need to know how humans can adapt to use these valuable resources sustainably as controlling factors and baselines shift. Aquatic resources, especially fisheries, require special consideration because, on both a worldwide and a local scale, wild fish resources are declining, hence their value is increasing and they will become more important and precious as global warming continues to increase, altering food production. Response and adaptation, as measures of sensitivity of fish and fisheries to changing environmental conditions and aquatic resources, can provide valuable insights to help sustain human endeavours if adaptation and adaptive capacity are considered.

Objectives of Subproject 1, ***Fish and fisheries***, were to assemble and research how 1) fish either are or are not showing adaptation to changing environmental conditions, considering, for example, changing spawning time and depth, increased diversity in spawning habitat – shoreline versus river; 2) community structure, production, and fish resource abundance are changing, switching from cold-water and some cool-water to other cool-water and warm-water assemblages; 3) stocking cold-water species such as lake trout can circumvent climate-induced recruitment bottlenecks that are starting to occur for cold-water species because of warm falls and winters even though deep, cold-water habitats for growth and production of older life stages persist; 4) fisheries regulations, management, assessment methods, and technology and data collection will need to change to consider climate-induced alterations affecting species composition, habitat, environmental, biological, and physiological differences.

Climate is changing, affecting aquatic environments, fish, and fisheries worldwide. In the past, fish and fisheries have provided important insights and led the way in documenting major aquatic environmental issues, such as phosphorus loading and bioaccumulation of contaminants, as well as the negative effects of acid precipitation. Fish resources have not only documented these anthropogenic stressors but have been important in encouraging and assessing mitigation. Fish and fisheries are playing, and can once again play, a leading role in profiling climate change and encouraging, through science transfer, a better understanding of response, adaptation, and mitigation.

A detailed study was conducted that assembled and updated knowledge on climate change, fish, fish resources, and the aquatic environment in the Great Lakes Basin, focusing on Lake Ontario and Ontario's Mississippi River watershed. In addition to assembling existing data, new and original analyses were conducted for the Mississippi watershed to determine whether fish and fish resources provide confirmation of change and would, in other ways, quantify this and guide adaptation.

The study was conducted to examine both response and adaptation to determine how human adaptive capacity and intervention could assist in maintaining valuable fish resources and using them more prudently and more extensively by better management and assessment. Adaptation is an important part of the theme of this study, because climate change and responses are underway and need to be considered and emphasized.

The study demonstrated how global climate change is affecting fish, fisheries, and water resources in the Great Lakes Basin. Lake Ontario, the St. Lawrence River, and connecting watersheds such as Ontario's Mississippi River provide insights into central Canada's vulnerability. Abundance and distribution of aquatic organisms, particularly fish, are changing, and some are adapting to altered environmental conditions. We need to know how we can adapt to maximize sustainable use of these valuable resources. Aquatic resources, especially fisheries, require attention and research because of their general worldwide depletion and their increasing value, which will become more precious as global warming continues its projected increase. Response and adaptation, as measures of sensitivity of fish and fisheries to changing environmental conditions and aquatic resources, can provide valuable insights to help sustain human endeavours if adaptation and adaptive capacity are considered.

This subproject assembles literature and data and researches how 1) fish may be adapting to changing environmental conditions; 2) population dynamics and growth, community structure, production, and resource abundance are changing; 3) resource use can be sustained and even increased through human intervention, using management and regulations to help circumvent climate-induced recruitment bottlenecks; 4) fisheries regulations, management, assessment methods, and technology and data collection will need to change to consider climate-induced alterations affecting species composition, habitat, environment, and physiology.

Specific data and methods are detailed that describe the assemblage of long-term (three to seven decades) water and air temperatures for Lake Ontario, Bay of Quinte, and the Mississippi River and its watershed. Similar long-term data on discharge and precipitation are assembled for Lake Ontario, the St. Lawrence River, and the Mississippi River system. In addition, long-term water level information was assembled for the St. Lawrence River and Lake Ontario. Climate change predictions for the Mississippi watershed were used from Subproject 4 (Water Management Responses). All were reviewed and analyzed to evaluate fish responses and adaptations associated with thermal requirements and changing conditions related to spawning, recruitment, growth, and production.

Response and adaptation to climate change for fish, populations, and communities are reviewed in terms of the thermal requirements of three major thermal guilds, or groupings: warm-water, cool-water, and cold-water. Changes in relation to spawning time, temperature, depth, and location are examined. The effects of changing climate and aquatic environmental conditions on year-class strength and recruitment are compared and contrasted across thermal guilds. The effects of these on community structure and dynamics are provided, with examples. Distribution and behaviour of species are changing, affecting their availability and use in relation to thermal niche. All of this affects production and resource abundance and must be taken into consideration, since environmental change is occurring and readily detectable.

Changing environmental conditions will affect productivity and potential use of fish resources. Resource use under changing environmental conditions is reviewed, with examples, and fisheries management practices are considered that should be implemented to protect declining resources and use those that are expanding, or might expand, because of increasing thermal conditions. In conjunction with this, regulations are considered, which not only restrict but also liberalize fisheries and fish resource use. Examples are provided of how monitoring and assessment need to be modified and adapted to address these changing environmental conditions. Fisheries sampling techniques and design are reviewed to show how new technologies and data collection should be changed, emphasizing the need to also monitor and use environmental data (particularly water temperature) as part of routine fisheries assessment indexing and research.

One of the primary aspects of climate change is increasing thermal conditions. This controlling factor greatly affects fish and fish resources. As a prerequisite to the study, an extensive literature review was conducted. The review detailed several aspects of how thermal conditions are changing in the Great Lakes Basin. Some specifics are: greater temperature extremes, longer growing seasons, warmer and earlier springs, warmer summers, longer and warmer falls, increasing thermal units and changes in thermocline, shorter winters, reduced ice cover and thickness, fewer extreme cold events. Some examples of how these affect fish and fisheries are reviewed, such as changes in relative abundance associated with thermal requirements; changes in spawning time and depth (e.g., lake trout); changes in vertical and spatial distribution (e.g., whitefish and lake trout); changes in seasonal activity and behaviour (e.g., northern pike); fewer winterkills, more frequent summer kills (e.g., pike) range changes, expansions, contractions, and invasions (e.g., basses).

In addition, water dynamics and resources are changing with changing climatic conditions. A similar literature review for the Great Lakes Basin indicates altered precipitation and reduced runoff, drier springs and reduced spring flooding of wetlands, wetter falls and winters, extreme discharges and runoff; water management and regulation alterations. There are examples of how these affect fish and fish resources through changes in spawning time and depth (e.g., pike); changes in spawning location and contribution of various spawning stocks (e.g., river versus shoreline, walleye); water level changes affecting spawning timing and location, resulting in increased hybridization (e.g., pikes).

Fish populations and communities are responding to these environmental changes. The literature indicates changes in thermal habitat, temperature adaptation, natural mortality, longevity, recruitment, growth, production, abundance, dynamics, interaction, and community structure. All of this suggests, although they are not well documented, changes in fish community structure, dynamics, and productivity, as well as switches in assemblages from cold-water (e.g., lake trout and whitefish) and cool-water (e.g., pike and walleye) to warm-water (e.g., basses and muskellunge), depending upon thermal requirements and thermal habitat.

There is evidence that these changes are affecting fisheries and should be taken into consideration to better manage fish resources in the Great Lakes Basin. These environmental changes will affect exploitation and resource abundance and allocation and will affect decisions concerning allowable catch, creel limits, size limits, fishing seasons, and associated regulations. Discussions have commenced concerning stocking of cold-water species (e.g., lake trout) and even cool-water species to circumvent recruitment bottlenecks that are starting to appear. In lake trout, these are directly influenced by warmer falls and winters. Nevertheless, deep, cold habitats will still exist and should be used. Quantitative information is becoming available for the Great Lakes Basin that can be used to redirect exploitation from thermally less adapted and more environmentally stressed species (e.g., cold-water lake trout, whitefish, cisco) to those that are better adapted to increasing thermal conditions (e.g., warm-water basses and panfish).

Environmental conditions, using long-term datasets for mean monthly water and air temperature, discharge, and precipitation for Lake Ontario and the Mississippi watershed, are examined in a retrospective analysis to confirm changes in environmental conditions. These are provided, with supporting statistical analyses, and are illustrated in detail, including CUSUM analysis of residuals. It is apparent that water temperature of the Bay of Quinte (Belleville municipal water supply), which has been shown to be typical for the Great Lakes Basin, shows a substantial increase in thermal units, commencing more dramatically in the late 1970s at a time of a thermal regime shift in the northern hemisphere. A similar trend is shown for the open-water period, April to September. For the past seven decades, this change has been associated with a 12% increase in evaporation. This goes hand in hand with a significant increase in duration of the high-temperature period, expressed as number of days that water temperature is $>20^{o}$C. A highly significant increase in summer (June-August) water temperature (approximately 1°C) has occurred for the period but most markedly during the past three decades. The same occurred for midsummer (July-August) temperature conditions in the Bay of Quinte. This warming is in synchrony with a dramatic decrease in ice cover. The average annual duration of 112 days for this entire period has now shortened to 68 to 80 days. All these changes follow global climate change and are exactly the trends, even by decade, that climatologists indicate exemplify broad-scale global warming. These specific environmental data allow us to quantify quite precisely the inter-relationships between climate change and its effects on fish and fisheries.

Quite importantly, El Niño and La Niña conditions in the tropical Pacific can predict climatic conditions in the Bay of Quinte and, more generally, the Great Lakes Basin. Seventy per cent of the El Niño and 90% of the La Niña events are realized as extreme midsummer temperature conditions in the Bay of Quinte. Indeed, temperature conditions in the Bay of Quinte can be predicted from tropical Pacific conditions two to eight months earlier. The major La Niña events are predictable; in fact, all but one in the past seven decades have been expressed in the Bay of Quinte. An additional cold event related to the Mount Pinatubo eruption was expressed in the Bay of Quinte and was so extreme that it overrode the influence of a major warm El Niño event. Interestingly, the La Niña event that is underway this winter (2007-2008), associated with extreme weather conditions and precipitation in the Great Lakes Basin, was entirely predictable, given its earlier development in the tropical Pacific. The discovery of this association and the teleconnection of water temperatures in the tropical Pacific and Bay of Quinte (with appropriate lags) make it possible for us to predict temperature and water resource changes in the Great Lakes Basin more precisely (see Subproject 4).

To further our understanding of changes in thermal conditions and water dynamics and their effects on Great Lakes fish and fisheries, we retrospectively examined long-term datasets for the Mississippi River and watershed, looking at discharge at Appleton and air temperature and precipitation at seven Department of Environment meteorological stations in the watershed. Almost eight decades of mean monthly air temperatures show a very significant increase in spring warming (March-May), as well as a significant increase in summer temperatures (June-August). Quite generally, there is a highly significant increase for the open-water period (April-November), the closed-water period (December-March), and annual monthly means. There is also a significant increase in air temperature in summer (June-August) and midsummer (July-August). Unfortunately, no long-term water temperature data exist for the Mississippi watershed, except for eight years of monthly mean river data at Carleton Place from 1998 to 2005.

A comparison of this eight years of water-to-air temperature indicates that water temperature is much less variable than air temperature and, in spring and summer, is appreciably higher – depending upon month, as much as 1.9 to 10°C above air temperature. This difference is explained by the fact that water traps radiant energy. This is particularly important when trying to understand the effect of temperature on aquatic organisms, particularly fish, and in quantifying specific response. On average, from 1998 to 2005, mean monthly air temperature was three times more variable than water temperature, which was, on average, 4.8°C higher (11.5°C compared with 6.7°C). Air temperature conditions were modelled and used to predict temperature increases up to 2099 (see Subproject 4).

Analysis of long-term air and water temperature data (1950-2006, 57 years) from the Bay of Quinte indicates the same general relationships (summer water temperatures an average of 3.0°C warmer than air); air temperature is twice as variable as water temperature. Water-air temperature relationships are provided on a monthly and seasonal basis. However, it is not easy to convert air temperature to water temperature, so this study encourages the establishment of long-term continuous monitoring of water temperature. Water temperatures more precisely describe aquatic thermal conditions and are particularly important in documenting change and understanding ecosystem response.

Discharge in the Mississippi River system, measured at Appleton, on a monthly and seasonal basis, was assembled and analyzed for a 76-year period (1930-2005) and was also used to predict changing conditions up to 2099 (see Subproject 4). Long-term changes in discharge were examined, and when Bonferroni corrected for multiple correlation analysis, December and January showed a significant increase. As a result, the winter period (December-February), as well as the autumn and winter periods combined (September-February), showed increasing trends that were highly significant. Overall, annual discharge increased significantly over this period, but it was mainly the result of increases in fall and winter. Also, extreme summer pulses are becoming more prevalent (see Subproject 4), producing a flushing that could shift and possibly reduce productivity of some fish species.

The Mississippi watershed is heavily regulated; however, the significant changes in discharge seen here seem to be somewhat independent of this regulation (see Subproject 4). The increased winter discharge does not appear to be related to an overall increase in precipitation but to the form of precipitation – decreased snow and increased thaws and rains. All of this is associated with less winter snow pack. Indeed, an analysis of long-term (76 years) monthly and seasonal precipitation in the Mississippi watershed showed no significant trends when Bonferroni corrections were applied. There is some evidence of a possible increase in fall precipitation. Modelling of predicted changes indicates that spring discharge over time will become earlier and more diminished. This will affect spawning and recruitment of cool-water species such as wetland-spawning pike and river-spawning walleye.

In order to understand how fish species will respond to these changing environmental conditions, specific thermal requirements must be considered, specifically those associated with spawning, growth, and preference. Warm-water fish have very high temperature preferences (> approx. 25°C) and growth optima, cool-water fish require intermediate temperature conditions (approx. 15-25°C), and cold-water fish a lower preference (< approx. 15°C) (see examples, Table 1).

Table 1. Temperature requirements of typical Great Lakes Basin fish of the three major thermal groupings. Means of optimum and preferred temperature are provided.

| Thermal grouping | Species | Temperature (°C) | | | |
|---|---|---|---|---|---|
| | | Spawning | Optimum | Preferred | Mean |
| Warm-water | bluegill | 23.7 | 30.2 | 31.3 | 30.8 |
| | white perch | 20.1 | 28.8 | 29.8 | 29.0 |
| | smallmouth bass | 18.0 | 27.0 | 27.4 | 27.2 |
| | *Mean* | 20.6 | 28.7 | 29.5 | 29.0 |
| Cool-water | yellow perch | 9.3 | 22.5 | 23.3 | 22.9 |
| | walleye | 8.0 | 22.6 | 21.7 | 22.2 |
| | northern pike | 6.9 | 20.0 | 23.5 | 21.8 |
| | *Mean* | 8.1 | 21.7 | 22.8 | 22.3 |
| Cold-water | brook trout | 8.7 | 15.0 | 13.0 | 14.0 |
| | lake whitefish | 5.7 | 15.2 | 11.1 | 13.2 |
| | lake trout | 10.6 | 11.7 | 11.2 | 11.5 |
| | *Mean* | 8.3 | 14.0 | 11.8 | 12.9 |

Long-term recruitment data from Lake Ontario confirm that year-class strength, recruitment, and production of young-of-the-year warm-water fish (e.g., smallmouth bass) are directly correlated with increased thermal conditions best exemplified by July-August water temperatures. Indeed, if temperature increases 1°C, there is a 2.5-fold increase in recruitment; 2°C, 6-fold; 3°C, an increase of almost 15-fold (Table 2). The latter is a slight extrapolation, because for the three-decade period from 1970 to 2000, the temperature deviation was actually ±2.8°C. Most of these predictions come from measured observations and indicate that abundance of bass and other warm-water species should have increased significantly over the past several decades. This is documented with quantitative sampling data from the Bay of Quinte. Over the same three-decade period, recruitment of cool-water fish (e.g., pike) in Lake Ontario has declined at temperatures above the long-term mean. With a 1°C increase, recruitment would decline almost 2.4-fold and 2°C almost 18-fold. The decline is so precipitous that the response to a 3°C increase could not be predicted (Table 2).

A similar analysis of cold-water recruitment was not possible for Lake Ontario, because lake trout, the best assessed cold-water native species, disappeared from the lake in the mid-1950s and the population consists almost entirely of stocked individuals; recruitment is very poor and inadequate to assess quantitative changes. However, an egg/fry incubation study initiated in the late 1980s indicated that if eggs are deposited at high temperature at spawning time in the fall, they hatch prematurely (lake trout require 495 heat units, or °C days, to hatch). If temperatures are low at spawning time, development is slower and hatch is more appropriately delayed until spring, resulting in increased survival and production at time of spring emergence. There is evidence that fall spawning time of lake trout is more associated with the fish strain, water body, and photoperiod than with temperature, whereas temperature seems to be more important for fish that spawn in early spring (cool-water fish) and early summer (warm-water fish) (Table 1). From detailed incubation studies, it has been proven that if temperature at spawning time were 1°C warmer, survival and

Table 2. Changes in recruitment for typical warm-water, cool-water, and cold-water species in the Great Lakes Basin an increasing temperature regime of 1°C to 3°C and the per cent change in community recruitment, assuming initial equal recruitment of the three thermal guilds. Temperatures exceeding 2.8°C require extrapolation.

| Thermal grouping<br>Species | Recruitment change | | | Community structure (%)[b] | | |
|---|---|---|---|---|---|---|
| | +1°C | +2°C | +3°C [a] | 0°C | +1°C | +2°C |
| Warm-water<br>smallmouth bass | +2.5× | +6.0× | +14.7× | 33 | 69[c] | 93[d] |
| Cool-water<br>northern pike | -2.4× | -17.9× | | 33 | 12 | 1 |
| Cold-water<br>lake trout | -1.5× | -2.4× | -20.1× | 33 | 19 | 6 |

[a] Extrapolated
[b] Predicted from Casselman (2002)
[c] Recruitment would increase by 2.1x with 1°C increase
[d] Recruitment would increase by 2.8x with 2°C increase

recruitment of lake trout fry would decrease by almost 1.5-fold, 2°C by 2.4-fold, and at 3°C the decrease would be 20-fold (Table 2). Also, summer temperature conditions are increasing, and there is new evidence that lake surface area in relation to volume affects cooling. This is compounded by the fact that fall and early winter temperatures are increasing. Long-term December water temperatures of the Bay of Quinte document the latter. December temperatures started to increase markedly in the 1990s. Average December temperature for the past seven decades was 1.3°C. Below this temperature, the bay is ice-covered. In recent years, December water temperature has been as high as 3 to 5°C. This dramatically increases thermal conditions, accelerating egg and fry development of fall-spawning cold-water species such as lake trout. The majority of lake trout stocks in the Great Lakes Basin spawn from mid-October to mid-November.

The literature and analyses indicate that, over the past three decades, there has been a steady decline in recruitment of lake trout in a large set of lakes in northeastern Ontario (58) and Quebec (99). Many of these lakes, particularly those in Quebec, are not considered to be heavily fished. This declining recruitment of approximately 50% corroborates the decline and loss of recruitment of cold-water fish over time and with increasing temperature (exemplified by midsummer [July-August] conditions). There is increasing evidence that loss of recruitment of lake trout and other cold-water species in the Great Lakes Basin is directly related to increased warming, probably to some extent resulting in poor development and survival of eggs and fry. Traditional knowledge gleaned from long-time commercial fishers on the Great Lakes associates increased production of lake trout and whitefish with extremely cold falls and severe winters.

Lake trout show some signs of adaptation to environmental conditions and change. For example, the Seneca strain of lake trout, which occupies the southern part of the species range, spawns considerably later and at lower temperature, a possible adaptation to warmer, more southerly fall conditions. When stocked in Lake Ontario, this strain spawned a month later than the more northerly central Ontario and Lake Superior strains. There is also increasing evidence in southern Ontario that lake trout are showing some uniquely different spawning behaviours. There are increasing reports of lake trout spawning much deeper than heretofore (below the thermocline). This trait may be related to certain stocks (e.g., Superior strain); however, this requires careful consideration and different approaches when spawning assessment is being conducted.

A comparison of recruitment changes in relation to temperature for the various thermal guilds indicates that as temperature increases, warm-water species recruitment will increase, while cool- and cold-water species recruitment will decrease (Table 2). Of particular interest is the relative change in recruitment that occurs among these three thermal guilds as temperature increases. For example, if we consider a hypothetical fish community in which each thermal guild initially has equal recruitment with 33% from each, then an increase of 1°C would result in a shift in overall recruitment to 69% for the warm-water guild, a relative increase of 2.1-fold. With a 2°C temperature increase, recruitment of this assemblage would increase to 93%, a 2.8-fold increase. The cool-water, as well the cold-water, guild would also show a relative and marked decline (Table 2). This confirms that climate change can produce a significant community shift to increasing warm-water species recruitment and abundance. Long-term community sampling of the Bay of Quinte confirms that eight centrarchids, primary components of the warm-water fish community, are increasing in abundance, most markedly since the mid- to late 1990s. Similarly, four species of cyprinids, or minnows, smaller and younger members of the warm-water community, have shown increased abundance, which commenced in the early 1990s. This increase would be expected, given that they have a shorter generation time. Their abundance, however, has not continued to increase, since they are primary prey species of the burgeoning centrarchids. Generation time and predator-prey interaction of the warm-water community in the Bay of Quinte provide strong long-term evidence that warm-water species are increasing in abundance in association with increasing thermal conditions, most apparent in the past two decades.

A study of long-term fish population and community dynamics of the Mississippi watershed was conducted, using various sampling studies that have been carried out over the years by the Ontario Department of Lands and Forests and Ministry of Natural Resources offices and personnel. Although these studies do not have the same rigorous annual sampling as do Lake Ontario and the Bay of Quinte, 27 water bodies involving 36 species in the Mississippi watershed have been sampled over a six-decade period. These can be used to examine fish populations and communities and climate change. Reports document that some water bodies, such as Mississippi Lake, have changed from essentially cool-water fish communities, dominated by walleye (although an introduced species), to warm-water fish communities, heavily dominated by such species as pumpkinseed, bluegill, and rock bass. The headwater lakes, which are important reservoir systems in the Mississippi watershed, contain cold-water species such as lake trout, lake whitefish, and cisco, although cool-water species, such as pike and walleye, and warm-water species, such as smallmouth bass and largemouth bass, are abundant throughout most of the river system. A large number of age-frequency datasets (136) were assembled and analyzed to assess relative year-class strength and recruitment for 14 species in nine water bodies. This large set of year-class strength data provided insights concerning the relationship between recruitment and environmental factors, some of which are documenting climate change. There was a highly significant decline in cold-water species over the past three decades; recruitment was negatively correlated with summer surface water temperature, explaining 31.1% of the annual variance in recruitment (Figure 1). In contrast, there was a highly significant increase in warm-water fish recruitment over a somewhat shorter period (past two decades); recruitment was positively correlated with increasing summer water temperatures, explaining 56.6% of the variance. Indeed, changes in relative recruitment of both assemblages was approximately 60%, with a rate of decline of cold-water species of slightly more than 2% per year and an increase in recruitment of warm-water species of almost 3.5% per year (Figure 1). These changes coincided with a three-decade increase in summer surface water temperature of 1°C (21.8°C to 22.7°C—0.9°C). It is apparent that a relatively small increase in temperature is associated with a substantial increase in recruitment of warm-water species and a reduction in recruitment of cold-water species. This analysis of Mississippi watershed data provides additional confirmation that fish community structure and dynamics are changing in association with climate warming.

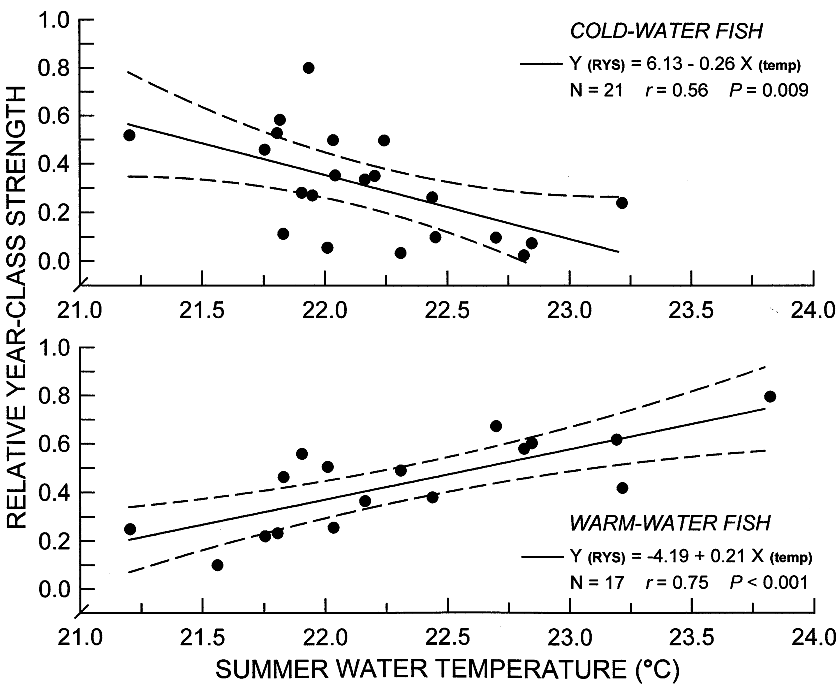



Figure 1. Relative year-class strength of cold- and warm-water species from the Mississippi watershed in relation to summer (Jun-Aug) surface water temperature. Cold-water species data encompass a 27-year period from 1971 to 1997 and come from 4 water bodies and 2 species (lake whitefish, cisco). Warm-water species data encompass a 17-year period from 1983 to 1999 and come from 9 water bodies and 10 species (mainly centrarchids, sunfishes, and basses). Regressions are indicated by solid lines; 95% confidence limits by curved lines, with equations and statistics provided.

Changes in recruitment, production, and abundance are apparent.

An examination of long-term lake sampling records indicates that whitefish and cisco, which were once abundant in headwater lakes of the Mississippi watershed and adjacent systems, are now present only in remnant numbers and that remaining individuals are generally very old (30-40 years). Survey observations confirm the analysis, indicating that recruitment of cold-water species, such as lake trout, has also declined rather dramatically over the past three decades. Some species, such as lake whitefish, may now be on the verge of extirpation in lakes where they were once abundant, and recruitment is becoming increasingly sporadic.

Trends in recruitment of cool-water species are much less clear. Pike recruitment showed no correlations with discharge and precipitation in long-term analysis of recruitment in the Mississippi watershed. This may in part be explained by the fact that the water regime is somewhat regulated and manipulated. The same may be true for walleye. In the few comparisons where discharge and precipitation were correlated with year-class strength, the relationships were negative and difficult to interpret because of the highly significantly inverse relationship between temperature and discharge. An analysis of recruitment of walleye stocks supported by riverine and shoreline spawning gave very few insights concerning the effects of environmental factors even though it has been well documented that spring discharge has a direct positive effect on recruitment in other locales, such as the Bay of Quinte and Georgian Bay. Although walleye recruitment appears to be weakly positively correlated with temperature, particularly in spring, it is apparent that individual species and species assemblages with extreme thermal requirements, such as cold- and warm-water fishes, are showing the most significant changes with changing climatic conditions.

Some in-depth studies are described, which indicate that many examples of species invasions throughout the Great Lakes Basin can be linked with climate change. The rate of dispersal of warm-water species has been linked with increasing summer temperature, particularly associated with El Niño events. It has been well documented that rock bass invasions in lake trout lakes have resulted in the loss of prey fish, substantially reducing growth and ultimate size and resulting in stunting and reduced fecundity of lake trout. There is evidence that these centrarchid invasions have affected walleye and even the large-bodied basses by reducing prey fish abundance. Black crappie, another warm-water centrarchid, is now invading many Ontario watersheds, including the Mississippi, and this will have direct effects on walleye recruitment, since black crappies are known predators of juvenile walleyes. An increase in warm-water fish abundance associated with climate warming can have both a direct effect on cool-water fish, through predation, as well as an indirect effect, through competition. There is considerable evidence that environmental conditions are changing so rapidly in the Great Lakes Basin that species adaptation is precluded if competitors are present that are better adapted to changed conditions and can quickly take advantage of new thermal conditions and niches.

Exotic invaders are often thermally ill adapted and destabilize fish communities, particularly when extreme environmental events occur. Indeed, extreme environmental conditions become more prevalent as global climate changes. Examples associated with alewife and white perch invasions show how climate extremes can dramatically affect abundance, which, in turn, greatly affects fish community dynamics.

Detailed studies of growth of typical species of the warm-water (e.g., white perch), cool-water (e.g., walleye), and cold-water (e.g., lake whitefish) fish communities, using calcified structures, make it possible to quantify growth responses in relation to temperature and climate. These analyses indicate positive annual correlations with summer temperature in warm- and cool-water species and negative correlations in cold-water species (Table 3). By converting calcified structure growth to body growth, length and weight changes of each of the thermal guilds can be quantified in relation to temperature change. This makes it possible to precisely describe growth changes in relation to climate warming, in reference to increasing temperatures of 1, 2, or 3$^{o}$C (Table 3). When this is combined with recruitment responses described in a similar fashion, we have a thorough way of describing population and community changes in terms of structure, dynamics, and production.

Changing thermal conditions affect distribution and behaviour of fish. As an example, midsummer depth distribution and behaviour of cold-water species (e.g., lake trout) are examined in relation to climate warming. Examination of lake thermodynamics and changes in the thermocline provides insights as to how thermal habitat will change. Changes in habitable depth and volume in relation to changing environmental conditions, eutrophication, and oxygen depletion are also important considerations. Winterkill of cool-water species in the Great Lakes Basin will become less prevalent; however, summer kills of cool-water species (e.g., northern

Table 3. Changes in growth of otoliths and body length and weight for typical warm-water, cool-water, and cold-water species in the Great Lakes Basin in an increasing temperature regime of 1.0$^{o}$C to 3.0$^{o}$C. Actual water temperatures pertain to midsummer means (Jul-Aug) for Bay of Quinte-Lake Ontario. Temperatures exceeding 2.8$^{o}$C require extrapolation.

| Thermal grouping Species | Temperature ($^{o}$C) | | Otolith growth (%) | Body change (%) | |
|---|---|---|---|---|---|
| | Mean | Change | | Length | Weight |
| Warm-water | 22.6 | 0 | | | |
| white perch | 23.6 | +1 | +9.6 | +9.4 | +33.3 |
| | 24.6 | +2 | +19.2 | +18.4 | +68.8 |
| | 25.6 | +3 | +28.8 | +28.2 | +93.3 |
| Cool-water | 22.6 | 0 | | | |
| walleye | 23.6 | +1 | +10.1 | +9.1 | +32.8 |
| | 24.6 | +2 | +20.3 | +18.1 | +63.3 |
| Cold-water | 22.6 | 0 | | | |
| lake whitefish | 23.6 | +1 | - 11.0 | - 4.5 | - 14.3 |
| | 24.6 | +2 | - 22.1 | - 9.4 | - 28.1 |
| | 25.6 | +3 | - 33.1 | - 14.4 | - 41.2 |

[a] Extrapolated

pike and yellow perch) will become more common.

The effects of droughts and reduced precipitation and altered discharge are reviewed, with numerous examples for northern pike from long-term data from Lake Ontario and the St. Lawrence River system. Droughts and water-level stabilization have dramatically reduced pike abundance, production, and harvest over the years. This provides evidence of how this cool-water species is responding to a changing water regime. In addition, in-depth studies show alterations in spawning time and depth related to decreased spring flooding of wetlands. Dramatic reductions in winter and spring precipitation in the mid-1960s and late 1980s resulted in deeper and later spawning. In the St. Lawrence River system, this also was associated with spawning overlap (time and niche) of several esocids, which resulted in documented hybridization (pike x muskellunge, pike x grass pickerel).

Declining recruitment of the American eel (a catadromous species that spawns in the Sargasso Sea) in the St. Lawrence River system has been shown to be affected by global climate change through the North Atlantic Oscillation Index (NAOI). At one time, eels were also abundant in the Mississippi watershed, but the decline there is synchronous with the loss of recruitment in the upper St. Lawrence River, documented by eel ladder passage at the Moses-Saunders dam. Recruitment indices for this eel ladder, lagged by age of the recruits, shows a highly significant correlation ($r^2 = 0.73$) with a young-of-the-year index for the European eel in Den Oever, the Netherlands. Up to the mid-1970s, recruitment of both species appeared constant and uniformly similar. After that time, the indices remained in synchrony but became negatively related to the NAOI. This marked difference coincided with declining recruitment and the major temperature regime shift in the northern hemisphere. It is apparent that the American eel is a unique example of a species that is being affected by large-scale global and oceanic effects associated with climate change and that these effects are influencing the freshwater fish community of the lower Great Lakes Basin.

It is clear that climate change is affecting fish and fisheries at various levels. Fisheries managers have found it difficult to consider climate change because it has been perceived that large-scale climatic effects are not considered within their control. Nevertheless, changes are occurring and the effects must be managed properly, regardless of cause and control. Management must respond to changes that are occurring if certain fish resources are to be used appropriately and others sustained and conserved to maintain diversity. Assessment techniques may need to change; for example, rapidly changing thermal conditions can create above-optimum temperatures that alter growth. Age is usually determined from analysis of calcified structure growth. If temperature change is extreme, this can affect growth and the ability to determine age accurately. For instance, there is evidence that scale and bone age assessment of pike in the Great Lakes Basin is becoming much more difficult and probably less accurate because midsummer temperature conditions are increasing, resulting in decreased growth and more frequent production of false annuli, or year marks.

Fisheries assessment, indexing, and sampling of biological data needs to be re-examined carefully as a result of rapidly changing environmental conditions. It is apparent that, throughout the Great Lakes Basin, climate warming is altering temperatures and aquatic resources and this has the potential to affect many aspects of fish and fisheries. The new challenge for fisheries managers will be to assess and manage fish resources in not only changing but also more variable environmental conditions. It is obvious that changing environmental conditions can trigger, and are triggering, fish population and community changes. These need to be monitored and assessed to manage fish resources and fisheries appropriately.

Fish are very sensitive to climate change and are responding and adapting. The question is, how will we respond and adapt to take advantage of these changing and increasingly valuable fish resources? There are many ways that we can respond proactively to these changing environmental and resource conditions. This study emphasizes that, in the Great Lakes Basin, we should promote and more intensively use the increasingly abundant and valuable warm-water fish resources for food and recreation. This will help reduce our carbon footprint, so we should universally encourage the use of local fish and fisheries as an important part of a 100-mile diet and take advantage of resources that are expanding and proliferating, but at the same time, protect those that may be declining and destabilizing.

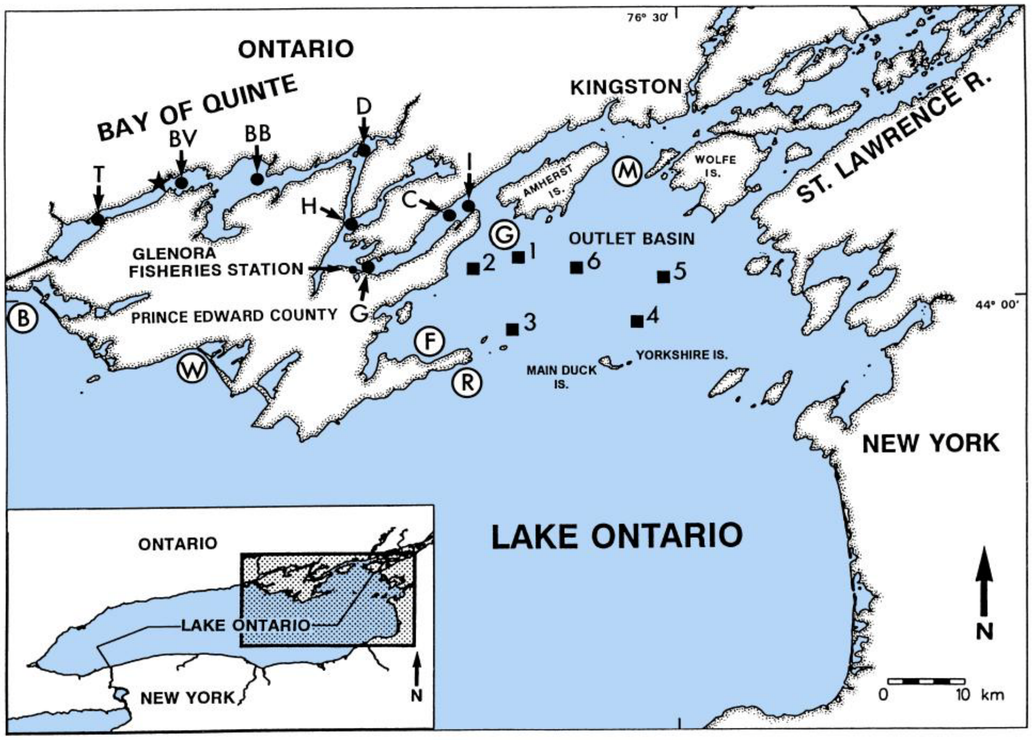



Figure 1.1. Eastern Lake Ontario and the Bay of Quinte showing locations of the long-term index fish sampling sites. Small dark closed circles show sites in the Bay of Quinte; large open circles show nearshore depth-stratified sites; letters indicate names of locations; closed squares with numbers indicate deep sampling sites in Outlet Basin. For complete definition of sites and details, see Casselman (2002) and Casselman and Scott (2003). The Belleville Water Treatment Plant (closed star) shows the location in the Bay of Quinte where daily water temperatures were measured, depth 3.2 m.

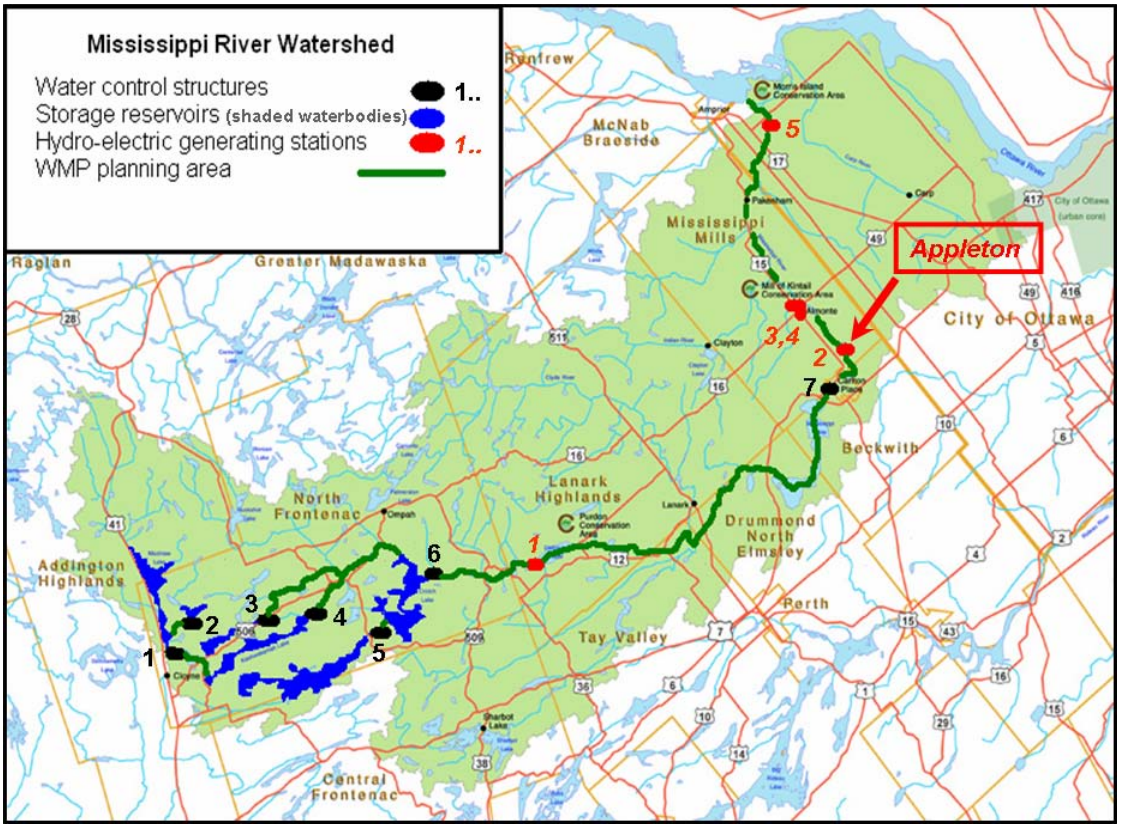



Figure 1.2. Mississippi River watershed (shaded, light green) and Mississippi River system (dark green line) of eastern Ontario, flowing into the Ottawa River just upstream of the city of Ottawa. The main river system is outlined (dark green). The seven water control structures are indicated by ovals and numbers (black), and the storage reservoirs and lakes in the headwater area are outlined (blue). The five onhydroelectric generating stations are indicated by ovals and italicized letters (red). The Appleton site, where long-term water monitoring data have been collected, is marked, just upstream of the Appleton hydroelectric generating stat. The main physio-graphic areas are indicated, along with roadways and villages. For specific details, see the Mississippi River Water Management Plan (2006). The water bodies throughout the watershed are detailed in the plan.

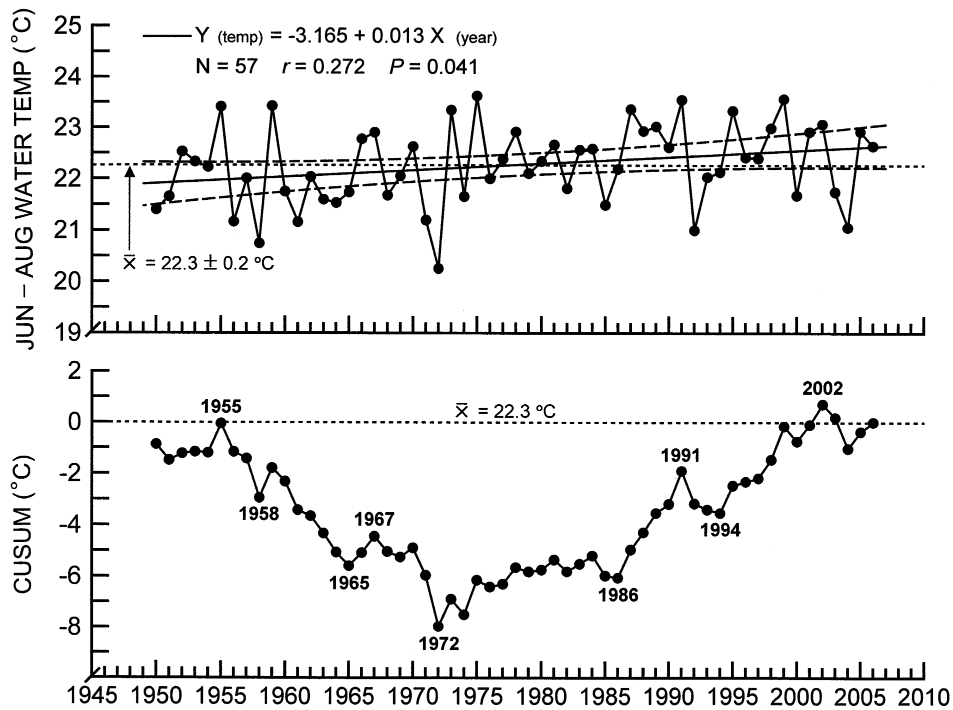



Figure 1.3. Mean monthly summer surface water temperature (Jun-Aug) for the upper Bay of Quinte for a 57-year period, 1950-2006. The accumulated sum of the residuals (CUSUM, °C) about the mean is also provided, indicating the years when dynamic change occurred. The regression line, curved 95% confidence limits, equation, and associated statistics are provided. Water temperature measured in upper bay at the Belleville municipal pumping station for water drawn at approximately 3.2 m. Bay of Quinte water temperatures at this location are homothermous.

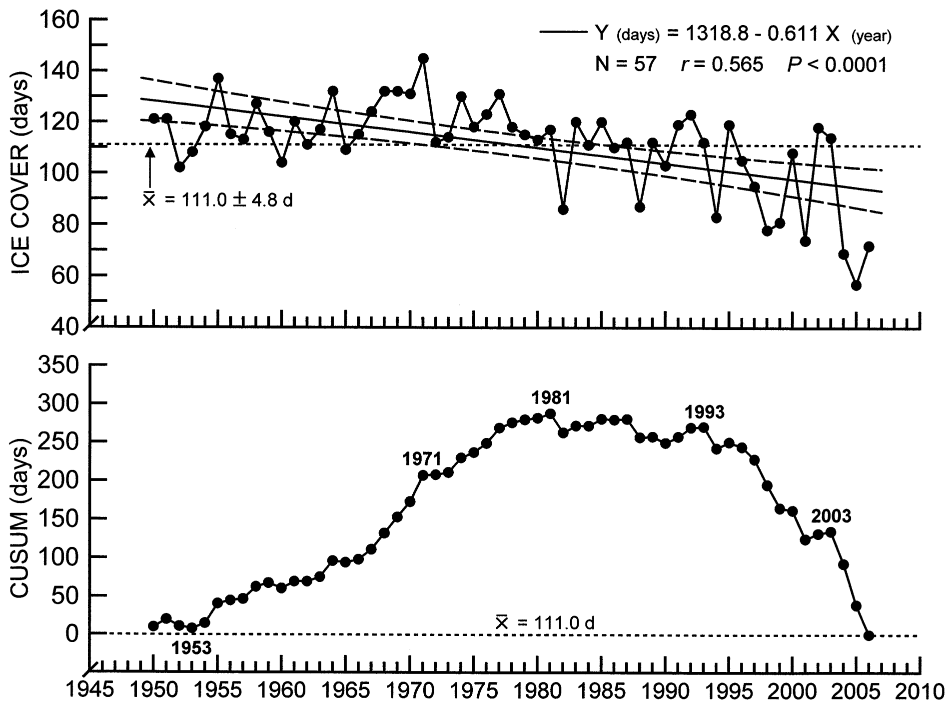



Figure 1.4. Duration of ice cover (days) for the upper Bay of Quinte for a 57-year period, 1950-2006, as indicated for the period of time when bay temperatures were <1.5$^{o}$C. about the mean is also provided, indicating the years when dynamic change occurred. The accumulated sum of the residuals (CUSUM, $^{o}$C) about the mean is also provided, indicating the years when dynamic change occurred. The regression line, curved 95% confidence limits, equation, and associated statistics are provided. Water temperature measured in upper bay at the Belleville municipal pumping station for water drawn at approximately 3.2 m. Bay of Quinte water temperatures at this location are homothermous.

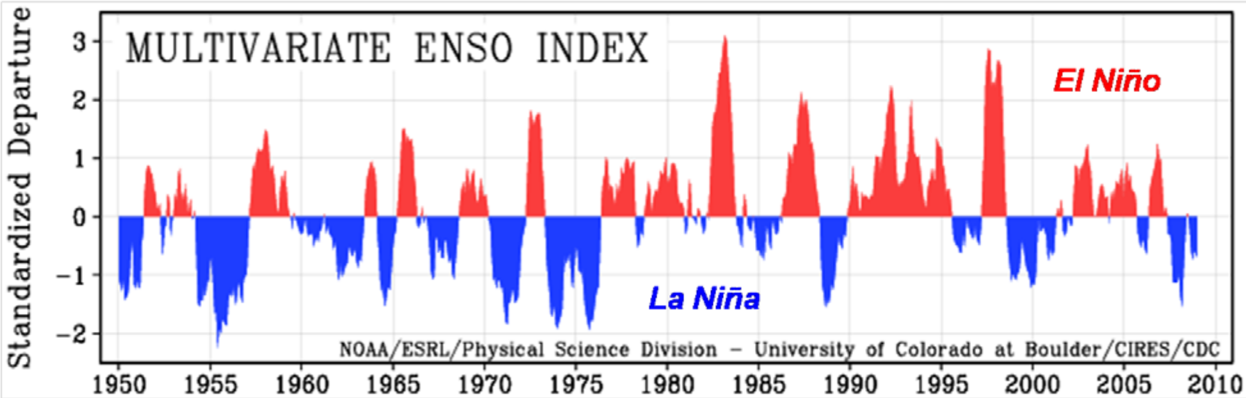



Figure 1.5. Multivariate ENSO index (MEI) for the tropical Pacific, indicating El Niño events (red) and La Niña events (blue) for a 59-year period, 1950-2008. The graph is reproduced by permission of, and from, NOAA/ESRL/Physical Science Division – University of Colorado at Boulder – CIRES/CDC. Downloaded Feb. 27, 2009. Available at website www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/.

Table 1.1. Air temperature by month and season for a 76-yr period, 1930-2005, Ottawa area, Ontario. Mean of seven stations about Appleton (45°19'N 76°11'W) (Department of the Environment). Regressions that show significance when Bonferroni corrections are provided: ** – highly significant, * – significant, blank – not significant.

| Month and season | Temperature (°C) | | | Temporal trends | |
|---|---|---|---|---|---|
| | Mean | 95% C.I. | CV | $r^2$ | *P* |
| Jan | -7.4 | 0.69 | 40.6 | 0.094 | 0.007 |
| Feb | -10.8 | 0.67 | 27.4 | 0.004 | 0.582 |
| Mar | -9.4 | 0.64 | 29.8 | 0.111 | 0.003 |
| Apr | -3.2 | 0.56 | 77.5 | 0.085 | 0.011 |
| May | 5.2 | 0.41 | 34.3 | 0.076 | 0.016 |
| Jun | 12.4 | 0.39 | 13.8 | 0.036 | 0.103 |
| Jul | 17.6 | 0.26 | 6.6 | 0.046 | 0.063 |
| Aug | 20.0 | 0.24 | 5.3 | 0.049 | 0.054 |
| Sep | 18.9 | 0.30 | 6.9 | 0.047 | 0.059 |
| Oct | 14.2 | 0.32 | 9.8 | 0.042 | 0.076 |
| Nov | 7.9 | 0.33 | 18.3 | 0.005 | 0.533 |
| Dec | 1.1 | 0.44 | 181.3 | 0.055 | 0.041 |
| Spring | | | | | |
| Mar-May | -2.5 | 0.40 | 70.9 | 0.169 | <0.001** |
| Summer | | | | | |
| Jun-Aug | 16.7 | 0.21 | 5.4 | 0.090 | 0.009* |
| Fall | | | | | |
| Sep-Nov | 13.7 | 0.20 | 6.4 | 0.065 | 0.026 |
| Winter | | | | | |
| Dec-Feb | -5.7 | 0.41 | 31.5 | 0.081 | 0.013 |
| Open-water period | | | | | |
| Apr-Nov | 11.6 | 0.17 | 6.4 | 0.207 | <0.001** |
| Closed-water period | | | | | |
| Dec-Mar | -6.6 | 0.35 | 23.2 | 0.163 | <0.001** |
| Annual (mean monthly) | 5.5 | 0.19 | 15.0 | 0.270 | <0.001** |

Table 1.2. Comparison of water and air temperatures for Mississippi River watershed. Water temperatures from Carleton Place and air temperature from seven stations in the watershed and vicinity, using monthly means for eight years, 1998-2005. Provided by month and various seasonal and monthly combinations. Means, 95% confidence intervals (C.I.) and coefficient of variation (CV) and differences are provided.

| Month and season | Water temperature (°C) | | | Air temperature (°C) | | | Water-air difference |
|---|---|---|---|---|---|---|---|
| | Mean | 95% C.I. | CV | Mean | 95% C.I. | CV | |
| Jan | 2.2 | 0.67 | 37.0 | -5.4 | 2.45 | 54.3 | 7.6 |
| Feb | 2.4 | 0.88 | 43.7 | -10.2 | 2.72 | 32.0 | 12.6 |
| Mar | 2.8 | 1.06 | 45.4 | -7.2 | 1.95 | 32.4 | 10.0 |
| Apr | 7.3 | 1.57 | 25.7 | -1.8 | 0.45 | 111.1 | 9.1 |
| May | 15.8 | 1.74 | 13.2 | 6.0 | 1.10 | 21.8 | 9.8 |
| Jun | 21.2 | 1.91 | 10.8 | 13.3 | 1.71 | 15.3 | 7.9 |
| Jul | 24.1 | 0.94 | 4.7 | 18.3 | 1.30 | 8.5 | 5.8 |
| Aug | 22.3 | 2.06 | 11.0 | 20.4 | 0.92 | 5.4 | 1.9 |
| Sep | 19.7 | 0.75 | 4.5 | 19.9 | 1.05 | 6.3 | -0.2 |
| Oct | 11.4 | 0.81 | 8.5 | 16.0 | 1.06 | 7.9 | -4.6 |
| Nov | 5.3 | 1.03 | 23.4 | 8.3 | 0.91 | 13.1 | -3.0 |
| Dec | 2.7 | 0.87 | 38.3 | 2.5 | 1.19 | 56.5 | 0.2 |
| Spring | | | | | | | |
| Mar-May | 8.6 | 0.64 | 8.9 | -1.0 | 1.22 | 146.6 | 9.6 |
| Summer | | | | | | | |
| Jun-Aug | 22.5 | 1.12 | 6.0 | 17.4 | 0.89 | 6.1 | 5.1 |
| Fall | | | | | | | |
| Sep-Nov | 15.9 | 0.35 | 2.6 | 14.7 | 0.58 | 4.7 | 1.2 |
| Winter | | | | | | | |
| Dec-Feb | 2.6 | 0.75 | 31.2 | -4.4 | 1.70 | 45.9 | 7.0 |
| Winter/spring | | | | | | | |
| Dec-May | 5.5 | 0.59 | 11.5 | -2.7 | 1.23 | 53.9 | 8.2 |
| Midsummer | | | | | | | |
| Jul-Aug | 23.2 | 1.21 | 6.2 | 19.4 | 0.99 | 6.1 | 3.8 |
| Open-water period | | | | | | | |
| Apr-Nov | 15.9 | 0.35 | 2.6 | 12.6 | 0.45 | 4.3 | 3.3 |
| Closed-water period | | | | | | | |
| Dec-Mar | 2.7 | 0.69 | 27.9 | -5.1 | 1.30 | 30.7 | 7.8 |
| Annual (mean monthly) | 11.5 | 0.30 | 2.8 | 6.7 | 0.58 | 10.5 | 4.8 |

Table 1.3. Comparison of water and air temperatures for Bay of Quinte area. Water temperatures from Belleville and air temperature from Belleville and Trenton, averaged, and Kingston, averaged from Kingston Airport, Kingston Municipal Pumping Station, and Kingston Hydro, using monthly means for eight years, 1998-2005. Provided by month and various seasonal and monthly combinations. Means, 95% confidence intervals (C.I.) and coefficient of variation (CV) and differences are provided.

| Month and season | Water temperature ($^{o}C$) | | | Air temperature ($^{o}C$) | | | Water-air difference |
|---|---|---|---|---|---|---|---|
| | Mean | 95% C.I. | CV | Mean | 95% C.I. | CV | |
| Jan | 0.9 | 0.15 | 19.2 | -6.7 | 2.19 | 39.4 | 7.6 |
| Feb | 1.0 | 0.36 | 45.4 | -3.7 | 1.20 | 38.4 | 4.7 |
| Mar | 1.5 | 0.72 | 58.4 | 0.8 | 1.64 | 242.9 | 0.7 |
| Apr | 7.2 | 1.17 | 19.4 | 7.5 | 1.09 | 17.4 | -0.3 |
| May | 15.0 | 1.85 | 14.8 | 14.3 | 1.59 | 13.3 | 0.7 |
| Jun | 20.2 | 1.13 | 6.7 | 18.7 | 1.32 | 8.5 | 1.5 |
| Jul | 23.6 | 0.97 | 4.9 | 20.7 | 1.09 | 6.3 | 2.9 |
| Aug | 23.6 | 0.86 | 4.3 | 19.6 | 1.09 | 6.7 | 4.0 |
| Sep | 20.4 | 0.62 | 3.6 | 15.1 | 1.73 | 13.7 | 5.3 |
| Oct | 12.4 | 0.73 | 7.0 | 8.2 | 1.28 | 18.8 | 4.2 |
| Nov | 6.2 | 0.95 | 18.4 | 2.6 | 1.87 | 85.8 | 3.6 |
| Dec | 2.5 | 1.07 | 52.2 | -3.6 | 2.68 | 88.9 | 6.1 |
| Spring | | | | | | | |
| Mar-May | 7.9 | 1.02 | 15.5 | 7.5 | 1.11 | 17.6 | 0.4 |
| Summer | | | | | | | |
| Jun-Aug | 22.5 | 0.73 | 3.9 | 19.7 | 0.82 | 5.0 | 2.8 |
| Fall | | | | | | | |
| Sep-Nov | 13.0 | 0.46 | 4.2 | 8.6 | 1.46 | 20.2 | 4.4 |
| Winter | | | | | | | |
| Dec-Feb | 1.3 | 0.44 | 39.0 | -4.6 | 1.51 | 38.9 | 5.9 |
| Winter/spring | | | | | | | |
| Dec-May | 4.6 | 0.55 | 14.2 | 1.5 | 0.67 | 55.3 | 3.1 |
| Midsummer | | | | | | | |
| Jul-Aug | 23.6 | 0.74 | 3.8 | 20.2 | 0.82 | 4.9 | 3.4 |
| Open-water period | | | | | | | |
| Apr-Nov | 16.1 | 0.63 | 4.7 | 13.3 | 0.68 | 6.11 | 2.8 |
| Closed-water period | | | | | | | |
| Dec-Mar | 1.4 | 0.43 | 37.3 | -3.3 | 1.08 | 39.3 | 4.7 |
| Annual (mean monthly) | 11.2 | 0.51 | 5.4 | 7.8 | 0.72 | 11.1 | 3.4 |

Table 1.4. Comparison of water and air temperatures for Bay of Quinte area. Water temperatures from Belleville and air temperatures from Belleville and Trenton, averaged, and Kingston estimated from Kingston Airport, Kingston Municipal Pumping Station, and Kingston Hydro, using monthly means for 57 years, 1950-2006. Provided by month and various seasonal and monthly combinations. Means, 95% confidence intervals (C.I.) and coefficient of variation (CV) and differences are provided.

| Month and season | Water temperature (°C) | | | Air temperature (°C) | | | Water-air difference |
|---|---|---|---|---|---|---|---|
| | Mean | 95% C.I. | CV | Mean | 95% C.I. | CV | |
| Jan | 0.7 | 0.08 | 43.7 | -7.3 | 0.74 | 38.1 | 8.0 |
| Feb | 0.7 | 0.08 | 47.6 | -6.1 | 0.68 | 41.8 | 6.8 |
| Mar | 1.0 | 0.17 | 60.0 | -0.9 | 0.58 | 234.3 | 1.9 |
| Apr | 6.4 | 0.48 | 27.8 | 6.4 | 0.43 | 25.5 | 0 |
| May | 14.3 | 0.41 | 10.9 | 12.6 | 0.47 | 14.0 | 1.7 |
| Jun | 20.2 | 0.29 | 5.5 | 17.7 | 0.35 | 7.4 | 2.5 |
| Jul | 23.5 | 0.26 | 4.2 | 20.6 | 0.28 | 5.0 | 2.9 |
| Aug | 23.1 | 0.29 | 4.7 | 19.7 | 0.32 | 6.2 | 3.4 |
| Sep | 19.3 | 0.29 | 5.6 | 15.2 | 0.40 | 9.9 | 4.1 |
| Oct | 12.3 | 0.31 | 9.4 | 9.0 | 0.40 | 16.8 | 3.3 |
| Nov | 5.7 | 0.32 | 21.1 | 2.9 | 0.43 | 55.1 | 2.8 |
| Dec | 1.3 | 0.21 | 61.9 | -3.9 | 0.77 | 74.1 | 5.2 |
| Spring | | | | | | | |
| Mar-May | 7.3 | 0.26 | 13.7 | 6.0 | 0.38 | 23.7 | 1.3 |
| Summer | | | | | | | |
| Jun-Aug | 22.3 | 0.21 | 3.6 | 19.3 | 0.23 | 4.4 | 3.0 |
| Fall | | | | | | | |
| Sep-Nov | 12.4 | 0.20 | 6.0 | 9.0 | 0.29 | 12.2 | 3.4 |
| Winter | | | | | | | |
| Dec-Feb | 0.9 | 0.10 | 43.6 | -5.8 | 0.44 | 28.4 | 6.7 |
| Winter/spring | | | | | | | |
| Dec-May | 4.1 | 0.15 | 13.9 | 0.1 | 0.32 | 400.8 | 4.0 |
| Midsummer | | | | | | | |
| Jul-Aug | 23.3 | 0.23 | 3.8 | 20.1 | 0.25 | 4.6 | 3.2 |
| Open-water period | | | | | | | |
| Apr-Nov | 15.6 | 0.18 | 4.3 | 13.0 | 0.17 | 4.8 | 2.6 |
| Closed-water period | | | | | | | |
| Dec-Mar | 0.9 | 0.11 | 43.9 | -4.6 | 0.39 | 31.9 | 5.5 |
| Annual (mean monthly) | 10.7 | 0.14 | 4.8 | 7.1 | 0.19 | 9.9 | 3.6 |

Table 1.5. Monthly water to air relationships for Bay of Quinte, Lake Ontario, for a 57-year period, 1950-2006. Provided by month and various seasonal and monthly combinations. Regression coefficients and statistics are provided.

| Month and season | Water (Y) – Air (X) temperature regressions | | | |
|---|---|---|---|---|
| | Intercept | Slope | P | $r^2$ |
| Jan | 0.925 | 0.029 | 0.053 | 0.067 |
| Feb | 0.872 | 0.033 | 0.046 | 0.071 |
| Mar | 1.139 | 0.178 | <0.001 | 0.359 |
| Apr | 1.948 | 0.708 | <0.001 | 0.412 |
| May | 6.675 | 0.607 | <0.001 | 0.479 |
| Jun | 11.521 | 0.492 | <0.001 | 0.342 |
| Jul | 7.937 | 0.753 | <0.001 | 0.643 |
| Aug | 9.216 | 0.708 | <0.001 | 0.614 |
| Sep | 12.860 | 0.427 | <0.001 | 0.356 |
| Oct | 7.550 | 0.531 | <0.001 | 0.486 |
| Nov | 4.596 | 0.378 | <0.001 | 0.260 |
| Dec | 1.673 | 0.104 | 0.003 | 0.151 |
| Spring | | | | |
| Mar-May | 4.405 | 0.473 | <0.001 | 0.459 |
| Summer | | | | |
| Jun-Aug | 7.378 | 0.781 | <0.001 | 0.669 |
| Fall | | | | |
| Sep-Nov | 9.458 | 0.332 | <0.001 | 0.240 |
| Winter | | | | |
| Dec-Feb | 1.599 | 0.124 | <0.001 | 0.286 |
| Winter/spring | | | | |
| Dec-May | 4.035 | 0.344 | <0.001 | 0.524 |
| Midsummer | | | | |
| Jul-Aug | 7.763 | 0.771 | <0.001 | 0.662 |
| Open-water period | | | | |
| Apr-Nov | 5.154 | 0.805 | <0.001 | 0.560 |
| Closed-water period | | | | |
| Dec-Mar | 1.732 | 0.181 | <0.001 | 0.440 |
| Annual (mean monthly) | 6.934 | 0.529 | <0.001 | 0.525 |

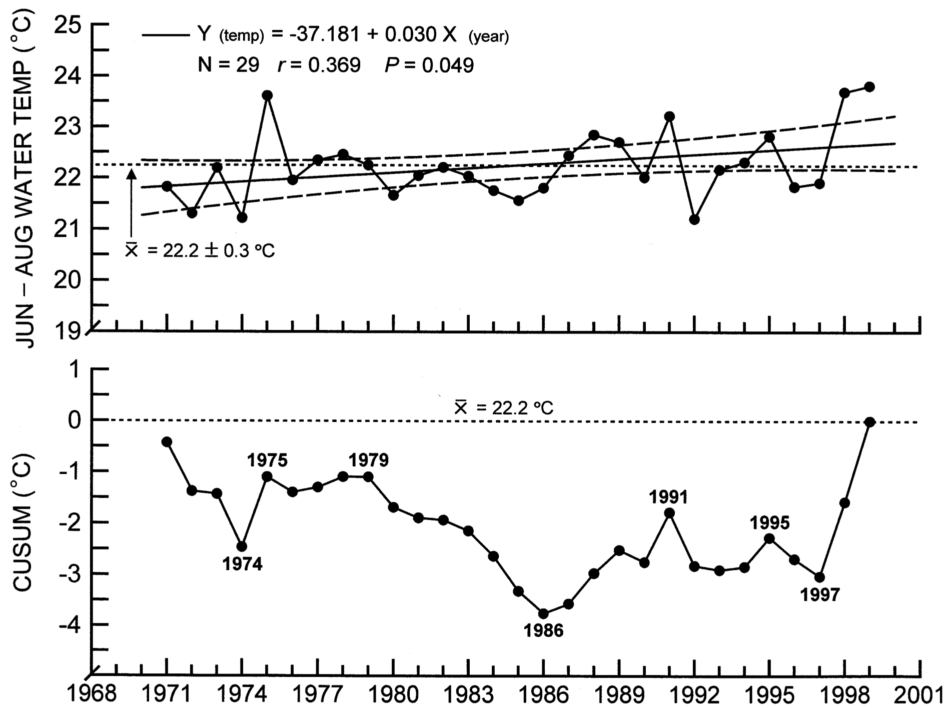



Figure 1.6. Mean monthly summer surface water temperature (Jun-Aug) for the Mississippi River and watershed for a 29-year period, 1971-1999, as estimated from air temperature from seven Environment Canada stations in the watershed and vicinity of Appleton, converted to water temperature, using monthly mean river temperatures for eight years, 1998-2005, measured at Carleton Place. The accumulated sum of the residuals (CUSUM, $^{o}$C) about the mean is also provided, indicating the years when dynamic change occurred. The regression line, curved 95% confidence limits, equation, and associated statistics are provided.

Table 1.6. Precipitation (rain and snow) by month and season for a 76-yr period, 1930-2005, Ottawa area, Ontario. Mean of seven stations about Appleton (45°19'N 76°11'W). Season and mean monthly. No regressions were significant.

| Month and season | Precipitation (mm) | | | Temporal trends | |
|---|---|---|---|---|---|
| | Mean | 95% C.I. | CV | $r^2$ | *P* |
| Jan | 60.7 | 5.23 | 37.7 | -0.001 | 0.852 |
| Feb | 53.4 | 5.54 | 45.4 | -0.001 | 0.760 |
| Mar | 62.4 | 5.92 | 41.6 | -0.007 | 0.468 |
| Apr | 66.4 | 5.93 | 39.0 | 0.001 | 0.778 |
| May | 71.4 | 6.65 | 40.7 | 0.024 | 0.180 |
| Jun | 79.9 | 7.17 | 39.3 | 0.007 | 0.460 |
| Jul | 82.0 | 6.54 | 34.9 | 0.002 | 0.685 |
| Aug | 78.9 | 7.68 | 42.6 | 0.010 | 0.386 |
| Sep | 80.2 | 7.36 | 40.1 | 0.003 | 0.615 |
| Oct | 70.8 | 8.20 | 50.7 | 0.040 | 0.084 |
| Nov | 73.2 | 5.55 | 33.0 | 0.048 | 0.058 |
| Dec | 73.7 | 6.38 | 38.0 | -0.024 | 0.179 |
| Spring | | | | | |
| Mar-May | 66.8 | 4.08 | 26.7 | 0.004 | 0.609 |
| Summer | | | | | |
| Jun-Aug | 80.3 | 4.25 | 23.2 | 0.018 | 0.249 |
| Fall | | | | | |
| Sep-Nov | 74.9 | 4.04 | 23.6 | 0.073 | 0.018 |
| Winter | | | | | |
| Dec-Feb | 62.4 | 3.41 | 23.91 | -0.014 | 0.304 |
| Annual (mean monthly) | 71.1 | 1.91 | 11.7 | 0.037 | 0.096 |

Table 1.7. Discharge Mississippi River by month and season for a 76-yr period, 1930-2005, measured at Appleton (45°19'N 76°11'W). Regressions that show significance when Bonferroni corrections are provided: ** – highly significant, * – significant, blank – not significant.

| Month and season | Discharge ($m^3.s^{-1}$) | | | Temporal trends | |
|---|---|---|---|---|---|
| | Mean | 95% C.I. | CV | $r^2$ | $P$ |
| Jan | 26.9 | 3.91 | 63.1 | 0.172 | <0.001* |
| Feb | 26.2 | 3.16 | 52.9 | 0.101 | 0.005 |
| Mar | 38.3 | 4.38 | 50.0 | 0.069 | 0.022 |
| Apr | 87.6 | 7.40 | 37.0 | -0.002 | 0.736 |
| May | 56.1 | 6.68 | 52.2 | -0.038 | 0.094 |
| Jun | 21.1 | 3.67 | 64.8 | -0.010 | 0.396 |
| Jul | 12.3 | 1.84 | 65.5 | 0.006 | 0.523 |
| Aug | 9.1 | 1.00 | 48.1 | 0.005 | 0.533 |
| Sep | 9.8 | 1.60 | 72.1 | 0.029 | 0.143 |
| Oct | 11.2 | 2.02 | 78.8 | 0.028 | 0.150 |
| Nov | 17.6 | 2.86 | 71.0 | 0.063 | 0.029 |
| Dec | 25.0 | 3.52 | 61.1 | 0.249 | <0.001* |
| Spring | | | | | |
| Mar-May | 60.7 | 4.52 | 32.6 | -0.001 | 0.783 |
| Summer | | | | | |
| Jun-Aug | 15.4 | 1.89 | 53.2 | -0.001 | 0.815 |
| Fall | | | | | |
| Sep-Nov | 12.9 | 1.88 | 63.8 | 0.056 | 0.041 |
| Winter | | | | | |
| Dec-Feb | 25.9 | 3.15 | 53.3 | 0.217 | <0.001** |
| Spring-summer | | | | | |
| Mar-Aug | 38.0 | 2.64 | 30.4 | -0.001 | 0.750 |
| Autumn-winter | | | | | |
| Sep-Feb | 19.4 | 2.00 | 45.3 | 0.227 | <0.001** |
| Annual (mean monthly) | 28.7 | 1.73 | 26.3 | 0.061 | 0.032* |

Table 1.8. Temperature requirements of typical Great Lakes Basin fish of the three major thermal groupings. Means of optimum and preferred temperature are provided.

| Thermal grouping | Species | Temperature (°C) | | | |
|---|---|---|---|---|---|
| | | Spawning | Optimum | Preferred | Mean |
| Warm-water | bluegill | 23.7 | 30.2 | 31.3 | 30.8 |
| | white perch | 20.1 | 28.8 | 29.8 | 29.0 |
| | smallmouth bass | 18.0 | 27.0 | 27.4 | 27.2 |
| | *Mean* | 20.6 | 28.7 | 29.5 | 29.0 |
| Cool-water | yellow perch | 9.3 | 22.5 | 23.3 | 22.9 |
| | walleye | 8.0 | 22.6 | 21.7 | 22.2 |
| | northern pike | 6.9 | 20.0 | 23.5 | 21.8 |
| | *Mean* | 8.1 | 21.7 | 22.8 | 22.3 |
| Cold-water | brook trout | 8.7 | 15.0 | 13.0 | 14.0 |
| | lake whitefish | 5.7 | 15.2 | 11.1 | 13.2 |
| | lake trout | 10.6 | 11.7 | 11.2 | 11.5 |
| | *Mean* | 8.3 | 14.0 | 11.8 | 12.9 |

Table 1.9. Changes in recruitment for typical warm-water, cool-water, and cold-water species in the Great Lakes Basin an increasing temperature regime of 1°C to 3°C and the per cent change in community recruitment, assuming initial equal recruitment of the three thermal guilds. Temperatures exceeding 2.8°C require extrapolation.

| Thermal grouping | Recruitment change | | | Community structure (%)[b] | | |
|---|---|---|---|---|---|---|
| Species | +1°C | +2°C | +3°C [a] | 0°C | +1°C | +2°C |
| Warm-water | | | | | | |
| smallmouth bass | +2.5× | +6.0× | +14.7× | 33 | 69[c] | 93[d] |
| Cool-water | | | | | | |
| northern pike | -2.4× | -17.9× | | 33 | 12 | 1 |
| Cold-water | | | | | | |
| lake trout | -1.5× | -2.4× | -20.1× | 33 | 19 | 6 |

[a] Extrapolated
[b] Predicted from Casselman (2002)
[c] Recruitment would increase by 2.1x with 1°C increase
[d] Recruitment would increase by 2.8x with 2°C increase

Table 1.10. Changes in growth of otoliths and body length and weight for typical warm-water, cool-water, and cold-water species in the Great Lakes Basin in an increasing temperature regime of 1.0°C to 3.0°C. Actual water temperatures pertain to midsummer means (Jul-Aug) for Bay of Quinte-Lake Ontario. Temperatures exceeding 2.8°C require extrapolation.

| Thermal grouping Species | Temperature (°C) | | Otolith growth (%) | Body change (%) | |
|---|---|---|---|---|---|
| | Mean | Change | | Length | Weight |
| Warm-water | 22.6 | 0 | | | |
| white perch | 23.6 | +1 | +9.6 | +9.4 | +33.3 |
| | 24.6 | +2 | +19.2 | +18.4 | +68.8 |
| | 25.6 | +3[a] | +28.8 | +28.2 | +93.3 |
| Cool-water | 22.6 | 0 | | | |
| walleye | 23.6 | +1 | +10.1 | +9.1 | +32.8 |
| | 24.6 | +2 | +20.3 | +18.1 | +63.3 |
| Cold-water | 22.6 | 0 | | | |
| lake whitefish | 23.6 | +1 | - 11.0 | - 4.5 | - 14.3 |
| | 24.6 | +2 | - 22.1 | - 9.4 | - 28.1 |
| | 25.6 | +3[a] | - 33.1 | - 14.4 | - 41.2 |

[a] Extrapolated

Table 1.11. Fish species present in Mississippi River watershed as indicated by Ontario Ministry of Natural Resources (OMNR) survey data presented in Mississippi River Water Management Plan, Final Report, 2006. Water bodies (27) progress from headwaters to middle and lower reaches. Other water bodies exist in the Mississippi watershed; however, species composition is not detailed in the Mississippi River Water Management Plan. Fish species (36) presented in numeric order using OMNR species code. In some cases, water bodies were not thoroughly assessed, so species composition is a minimum estimate. Species with special status are: river redhorse designated provincially and federally as Special Concern; marginated madtom listed federally as Threatened, now downlisted to Data Deficient; American eel recommended provincially as Endangered and recommended federally as Special Concern (July 2008). Amercian eels reported in Mazinaw Lake by Whitfield (1956) and in Big Gull Lake by Roecker (pers. obs. 1971) in Big Gull Lake data files, OMNR Bancroft; spoonhead sculpin reported in Mazinaw Lake, Mazinaw Lake data files, OMNR Bancroft. Occurrences possibly underestimated.

| | | | Water body Mississippi River watershed | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | OMNR Species code | Thermal guild | Shabomeka Lake | Semicircle Lake and Creek | Mazinaw Lake | Marble Lake | Kashwakamak Lake | Mud Lake | Mississagagon Lake | Swamp Creek | Big Gull Lake | Crotch Lake | Kings Lake | Otter Lake | Miller Lake | Stump Lake | Gedde's Rapids | Dalhousie Lake | Dalhousie Lake to Sheridan's Rp. | Sheridan's Rp. to Stepstone Rp. | Stepstone Rp. to Playfairville Rp. | Playfairville Rp. to Fergusons Fl. | Fergusons Fl. to Innisville Rp. | Mississippi Lake | Carleton Place to Appleton | Appleton to Almonte | Almonte to Pakenham | Pakenham to Galetta | Galetta to Ottawa River | Combined |
| Lake trout | 81 | cold | x | x | x | | | | | | | | | | | | | | | | | | | | | | | | | 3 |
| Lake whitefish | 91 | cold | x | | x | x | x | | | | x | x | | | | | | x | | | | | | | | | | | | 7 |
| Cisco | 93 | cold | x | | x | x | x | | x | | x | x | | | | | | x | | | | | | | | | | | | 8 |
| Northern pike | 131 | cool | | x | x | x | x | x | x | x | x | x | x | x | x | x | | x | x | x | x | x | x | x | x | x | x | x | x | 25 |
| White sucker | 163 | cool | x | x | x | x | x | | x | | x | x | | | | | x | x | x | x | x | x | x | x | x | x | x | x | x | 21 |
| Silver redhorse | 168 | cool | | | | | | | | | | | | | | | | | | | | | | | | | x | x | x | 3 |
| Shorthead redhorse | 171 | cool | | | | | | | | | | | | | | | | x | | | | | | | | | x | x | x | 4 |
| Greater redhorse | 172 | cool | | | | | | | | | | | | | | | | | | | | | | | | | | x | | 1 |
| River redhorse | 173 | cool | | | | | | | | | | | | | | | | | | | | | | | | | x | x | x | 3 |
| Northern redbelly dace | 182 | cool | x | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| Lake chub | 185 | cool | | | x | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| Golden shiner | 194 | warm | | | x | x | x | | | | x | x | | | | | | x | | | | | | | | | | | | 6 |
| Common shiner | 198 | warm | | | x | x | x | | | | | | | | | | | | | | | | | | | | | | | 3 |
| Blacknose shiner | 200 | warm | | | | | | | | | | | | | | | | | | | | | | x | | | | | | 1 |
| Mimic shiner | 206 | warm | | | | | | | | | | x | | | | | | | | | | | | | | | | | | 1 |
| Bluntnose minnow | 208 | warm | | | | | | | | | | | | | | | | | | | | | | x | | | | | | 1 |
| Creek chub | 212 | warm | | | | | | | | | | | | | | | | x | | | | | | | | | | | | 1 |
| Fallfish | 213 | warm | | | x | x | x | | | | | x | | | | | | x | | | | | | x | | | | | | 6 |
| Pearl dace | 214 | warm | x | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| Yellow bullhead | 232 | warm | | | | | | | | | | | | | | | | | x | | | x | x | x | | | | | | 4 |
| Brown bullhead | 233 | warm | | | x | x | x | | x | | x | x | | | | | x | x | x | x | x | x | x | x | x | x | | | x | 17 |
| Channel catfish | 234 | warm | | | | | | | | | | | | | | | | | x | | | x | x | | | | | | x | 4 |
| Marginated madtom | 238 | cool | | | | | | | | | | | | | | | | | | | | x | | | | | | | | 1 |
| American eel | 251 | warm | | | x | | | | | | x | | | | | | | x | x | | | x | x | x | | | x | x | x | 9 |
| Burbot | 271 | cold | x | | x | | x | | | | x | x | | | | | | x | | | | | | x | | | | | | 7 |
| Trout-perch | 291 | cool | | | | | | | | | | | | | | | | x | | | | | | | | | | | | 1 |
| Rock bass | 311 | warm | x | x | x | x | x | | x | | x | x | | | | x | | x | x | | | x | x | x | | x | x | x | x | 18 |
| Pumpkinseed | 313 | warm | x | | x | x | x | | x | | x | x | | | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 21 |
| Bluegill | 314 | warm | | | x | | | | | | x | x | | | | x | | x | | | | | | x | | | | | | 6 |
| Smallmouth bass | 316 | warm | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 27 |
| Largemouth bass | 317 | warm | x | x | x | x | x | x | x | x | x | x | x | x | x | | | x | x | | | x | x | x | | x | x | x | x | 22 |
| Black crappie | 319 | warm | | | | | | | | | | | | | | | | x | | | | | | x | | | x | x | x | 5 |
| Yellow perch | 331 | cool | x | x | x | x | x | | x | | x | x | | | | x | | x | x | | | x | x | x | | x | x | x | x | 18 |
| Walleye | 334 | cool | | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 25 |
| Johnny darter | 341 | cool | | | | | | | | | | | | | | | | | | | | | | x | | | | | | 1 |
| Logperch | 342 | cool | | | | | | | | | | x | | | | | | | | | | | | x | | | | | | 2 |
| Spoonhead sculpin | 383 | cold | | | x | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| Combined | | | 12 | 7 | 20 | 14 | 15 | 4 | 10 | 4 | 14 | 17 | 4 | 4 | 4 | 7 | 5 | 20 | 12 | 6 | 6 | 13 | 12 | 19 | 6 | 9 | 13 | 14 | 14 | |

Table 1-12. Species composition in NSCIN index trap net for Mississippi Lake, 1998, and upriver and downriver, 2001. Mississippi Lake catch data for 1998 from Mathers et al. (1998), upriver and downriver from Degner et al. (2001a, b, respectively). Downriver extends from Almonte to Galetta. Upriver is from Innisville to Dalhousie Lake. Species are listed in order of numerical occurrence for Mississippi Lake, and rank order is calculated in relation to CUE. Overall is equally weighted. CUE is number caught per 24-hr set.

| | | Upriver | | | Lake | | | Downriver | | | Overall | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Thermal guild | Rank order | % of catch | CUE | Rank order | % of catch | CUE | Rank order | % of catch | CUE | Rank order | % of catch | CUE |
| Pumpkinseed | warm | 1 | 35.1 | 16.9 | 1 | 54.2 | 70.6 | 2 | 18.8 | 3.3 | 1 | 47.8 | 30.3 |
| Bluegill | warm | | | | 2 | 13.7 | 17.9 | | | | 2 | 9.4 | 6.0 |
| Rock bass | warm | 3 | 12.9 | 6.2 | 3 | 10.6 | 13.8 | 4 | 8.0 | 1.4 | 3 | 8.1 | 5.1 |
| Black crappie | warm | | | | 4 | 6.2 | 8.1 | 14 | 0.6 | 0.1 | 6 | 4.3 | 2.7 |
| Smallmouth bass | warm | 4 | 6.7 | 3.2 | 5 | 3.4 | 4.4 | 1 | 41.5 | 7.3 | 4 | 7.8 | 5.0 |
| Northern pike | cool | 10 | 1.7 | 0.8 | 6 | 3.2 | 4.2 | 10 | 1.1 | 0.2 | 9 | 2.7 | 1.7 |
| Walleye | cool | 8 | 2.7 | 1.3 | 7 | 2.3 | 3.0 | 9 | 2.3 | 0.4 | 10 | 2.5 | 1.6 |
| Brown bullhead | warm | 2 | 22.5 | 10.8 | 8 | 2.2 | 2.9 | 6 | 3.4 | 0.6 | 5 | 7.5 | 4.8 |
| White sucker | cool | 7 | 4.4 | 2.1 | 9 | 1.8 | 2.4 | 5 | 5.1 | 0.9 | 8 | 2.8 | 1.8 |
| Yellow perch | cool | 5 | 6.2 | 3.0 | 10 | 1.2 | 1.6 | 3 | 11.4 | 2.0 | 7 | 3.5 | 2.2 |
| Largemouth bass | warm | 6 | 5.0 | 2.4 | 11 | 0.8 | 1.1 | 11 | 1.1 | 0.2 | 11 | 1.9 | 1.2 |
| American eel | warm | 12 | 0.2 | 0.1 | 12 | 0.1 | 0.1 | 12 | 0.6 | 0.1 | 15 | 0.2 | 0.1 |
| Yellow bullhead | warm | 9 | 2.5 | 1.2 | 13 | 0.1 | 0.1 | | | | 12 | 0.7 | 0.4 |
| Shorthead redhorse | cool | | | | | | | 7 | 2.8 | 0.5 | 14 | 0.3 | 0.2 |
| Silver redhorse | cool | | | | | | | 8 | 2.8 | 0.5 | 13 | 0.3 | 0.2 |
| River redhorse | cool | | | | | | | 13 | 0.6 | 0.1 | 16 | 0.1 | <0.1 |
| Channel catfish | warm | 11 | 0.2 | 0.1 | | | | | | | 17 | 0.1 | 0.1 |
| Warm-water species | | | 85.0 | 40.9 | | 91.4 | 119.0 | | 73.8 | 13.0 | | 87.9 | 55.6 |
| Cool-water species | | | 15.0 | 7.2 | | 8.6 | 11.2 | | 26.1 | 4.6 | | 12.1 | 7.7 |
| Total | | | 100 | 48.1 | | 100 | 130.2 | | 100 | 17.6 | | 100 | 63.3 |

Table 1.13. Age-frequency datasets (136) for the period 1945-2007 used to calculate and hindcast relative year-class strength for nine water bodies in the Mississippi River watershed for 14 species of warm-, cool-, and cold-water fish. Number of datasets is shown, with superscripts indicating method of sampling and years sampled. x indicates species present but age data either not available or inadequate to calculate indices of relative year-class strength. Data come from FWIN sampling provided by G. Morgan, Laurentian University – 1997, 1998, 2000, 2001; trap-netting and creel data provided by T. Haxton, OMNR Kemptville – 1996, 1999, 2001; S. Smithers, OMNR Kemptville – 2003, 2007; R. Whitfield, Ontario Department of Lands and Forests Kemptville, 1957; H. Cooper, Ontario Department of Lands and Forests Tweed, 1970; Degner et al., 2001a, b; Mathers et al. 1998; Kerr (1997, 1998, 1999). Fish species presented in numeric order using OMNR species code. [a] gill net, FWIN; [b] 2000; [c] 2001; [d] 1998; [e] 1957, 1970; [f] 1997; [g] trap net, NSCIN recent years; [h] 1978, 1983, 1990, 1994; [i] 1959, 1966, 1972, 1978, 1983, 1990, 1994; [j] 1975, 1980, 1987, 1992, 1997; [k] 1975, 1987, 1992, 1997; [l] 1998, 2003; [m] creel census; [n] 1977, 1981, 1985, 1990, 1991, 1994, 1998; [o] 1996, 1999; [p] 1961, 1977, 1981, 1985, 1990, 1991, 1994, 1998, 2001, 2003, 2007.

| | | | Water body Mississippi River watershed | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | OMNR species code | Thermal guild | Kashwakamak Lake | Mississagagon Lake | Big Gull Lake | Crotch Lake | Bennett Lake | Dalhousie Lake | Upriver of Mississippi Lake. | Mississippi Lake | Downriver of Mississippi Lake | Combined |
| Lake whitefish | 91 | cold | x | | 2[a,d,e] | x | x | | | | | 2 |
| Cisco | 93 | cold | 1[a,b] | 1[a,c] | 1[e] | x | | 1[a,c] | | | | 4 |
| Northern pike | 131 | cool | 1[a,b] | 1[a,c] | 1[a,d] | 1[a,f] | 1[a,c] 4[g,h] | 1[a,c] 4[g,i] | 1[g,c] | 1[a,c] 2[g,l] 7[g,n] | x | 25 |
| White sucker | 163 | cool | x | x | x | x | x | x | 1[g,c] | 2[g,l] | 1[g,c] | 4 |
| Silver redhorse | 168 | cool | | | | | | | | | 1[g,c] | 1 |
| Shorthead redhorse | 171 | cool | | | | | x | | | | 1[g,c] | 1 |
| Rock bass | 311 | warm | x | x | x | x | x | x | 1[g,c] | 2[g,l] | 1[g,c] | 4 |
| Pumpkinseed | 313 | warm | x | x | x | x | x | x | 1[g,c] | 2[g,l] | 1[g,c] | 4 |
| Bluegill | 314 | warm | | | x | x | | x | | 2[g,l] | | 2 |
| Smallmouth bass | 316 | warm | 1[a,b] | 1[a,c] | 1[a,d] | 1[a,f] | 1[a,c] 4[g,h] | 1[a,c] 4[g,k] | 1[g,c] | 1[a,c] 2[g,l] 7[g,n] | 1[g,c] | 26 |
| Largemouth bass | 317 | warm | x | 1[a,c] | 1[a,d] | 1[a,f] | 1[a,c] 4[g,h] | 1[a,c] 4[g,k] | 1[g,c] | 2[g,l] 7[g,n] | 1[g,c] | 24 |
| Black crappie | 319 | warm | | | | | x | | | 2[g,l] | x | 2 |
| Yellow perch | 331 | cool | x | x | x | x | x | x | 1[g,c] | 1[g,d] | x | 2 |
| Walleye | 334 | cool | 1[a,b] | 1[a,c] | 1[a,d] | 1[a,f] | 1[a,c] 7[h,i] | 1[a,c] 5[g,j] | 1[g,c] | 1[a,c] 2[m,o] 12[g,p] | 1[g,c] | 35 |
| Combined | | | 4 | 5 | 7 | 4 | 23 | 22 | 8 | 55 | 8 | 136 |

Table 1.14. Relationships between species and species assemblages, relative year-class strength (RYS), and various annual temperature and precipitation conditions in relation to periods and seasons for the Mississippi River watershed, 1945-2003, and Georgian Bay Moon River walleye, 1955-1968. Lentic and lotic refer to spawning stock. Some lentic spawning stocks also have some lotic spawning, unquantified but considered to be less important; populations with lotic spawning stocks are primarily associated with this condition. Months associated with periods and seasons are: open water – Apr-Nov; summer – Jul-Aug; fall – Sep-Oct; winter – Dec-Feb; spring – Mar-May; midsummer – Jul-Aug. For Georgian Bay data from Winterton, relative year-class strengths were recalculated to conform to current methods and regressions tested for homogeneity of variance, which necessitated a log relationship with discharge. Moon River discharge x $10^8 m^3$ for spawning period, 4.5-15.0 C. Temperature (°C), precipitation (cm), discharge $m^3 \cdot s^{-1}$. Relative year class based on strongest annual year class equal to 1 and other year-classes in relation to this, providing number of years (N), intercept and slope of the regression (negative relationships are indicated), and probability (*P*) and correlation coefficient ($r^2$). Regressions that showed significant relationships are provided, and when multiple correlations were examined, significance involving Bonferroni corrections are provided: ** – highly significant, * – significant, blank – not significant. [a] Years for which data exist, 1983-1999.

| | Variables | | | | | | |
|---|---|---|---|---|---|---|---|
| Comparison | Y | X | N | Intercept | Slope | *P* | $r^2$ |
| Mississippi River watershed relationships, 1945-2003 | | | | | | | |
| Fish interrelationships | RYS lentic walleye | RYS lotic walleye | 16 | -0.073 | 1.052 | 0.045* | 0.258 |
| | RYS warm-water species[a] | RYS cold-water species | 14 | 0.601 | -0.693 | <0.001** | 0.767 |
| Smallmouth bass | Relative year-class strength | Open-water temperature | 35 | -0.581 | 0.088 | 0.021* | 0.152 |
| | | Summer temperature | 35 | -0.938 | 0.082 | 0.004* | 0.222 |
| | | Midsummer temperature | 35 | -1.292 | 0.092 | 0.001* | 0.281 |
| Largemouth bass | Relative year-class strength | Summer temperature | 39 | -1.607 | 0.121 | 0.001** | 0.258 |
| | | Midsummer temperature | 39 | -1.660 | 0.110 | 0.002* | 0.235 |
| | | Winter-spring precipitation | 39 | 0.936 | -0.008 | 0.008* | 0.176 |
| | | Annual discharge | 39 | 0.773 | -0.012 | 0.012* | 0.158 |
| | | Spring-summer discharge | 39 | 0.757 | -0.009 | 0.004** | 0.208 |
| | | Summer discharge | 39 | -0.602 | -0.013 | 0.006* | 0.188 |
| | | Spring discharge | 39 | 0.648 | -0.004 | 0.032 | 0.119 |
| | | Midsummer discharge | 39 | 0.546 | -0.012 | 0.013 | 0.156 |
| Bass combined | Relative year-class strength | Summer temperature | 38 | -1.169 | 0.096 | <0.001** | 0.344 |
| | | Midsummer temperature | 38 | -1.360 | 0.095 | <0.001** | 0.363 |
| | | Summer discharge | 38 | 0.546 | -0.080 | 0.050 | 0.099 |
| Misc. warm-water spp. | Relative year-class strength | Year | 17 | -101.360 | 0.051 | <0.001** | 0.689 |
| | | Summer temperature | 17 | -3.087 | 0.206 | 0.006* | 0.400 |
| | | Jul-Aug temperature | 17 | -2.611 | 0.158 | 0.031 | 0.274 |
| | | Spring precipitation | 17 | 1.449 | -0.015 | 0.002* | 0.496 |
| | | Winter-spring precipitation | 17 | 1.370 | -0.015 | 0.041 | 0.250 |
| Warm-water species[a] | Relative year-class strength | Year | 17 | -51.345 | 0.026 | 0.002** | 0.483 |
| | | Summer temperature | 17 | -4.191 | 0.210 | 0.001** | 0.565 |
| | | Midsummer temperature | 17 | -2.062 | 0.130 | 0.001** | 0.504 |
| | | Winter-spring precipitation | 17 | 1.129 | -0.011 | 0.011* | 0.360 |
| | | Spring precipitation | 17 | 1.050 | -0.009 | 0.002* | 0.477 |
| Lotic walleye | Relative year-class strength | Year | 59 | -8.692 | 0.005 | 0.001** | 0.185 |
| | | Annual temperature | 59 | 0.010 | 0.071 | 0.034* | 0.076 |
| | | Open-water temperature | 59 | -0.628 | 0.089 | 0.011* | 0.107 |
| | | Summer temperature | 59 | -1.017 | 0.086 | <0.001** | 0.196 |
| | | Midsummer temperature | 59 | -0.972 | 0.074 | 0.004* | 0.139 |
| | | Fall precipitation | 59 | 0.209 | 0.003 | 0.043 | 0.070 |
| Lentic walleye | Relative year-class strength | Annual temperature | 16 | -0.745 | 0.186 | 0.016* | 0.347 |
| | | Open-water temperature | 16 | -1.795 | 0.177 | 0.012* | 0.370 |
| | | Winter-spring temperature | 16 | 0.763 | 0.116 | 0.030 | 0.295 |
| | | Summer temperature | 16 | -2.787 | 0.185 | 0.009* | 0.399 |
| Northern pike | Relative year-class strength | Fall discharge | 37 | 0.525 | -0.005 | 0.024 | 0.137 |
| Cold-water species | Relative year-class strength | Year | 21 | 37.511 | -0.019 | 0.004** | 0.363 |
| | | Summer temperature | 21 | 6.134 | -0.263 | 0.009* | 0.311 |
| | | Midsummer temperature | 21 | 3.450 | -0.165 | 0.006* | 0.333 |
| | | Annual precipitation | 21 | -0.822 | 0.015 | 0.040* | 0.204 |
| | | Spring-summer discharge | 21 | -0.147 | 0.012 | 0.034 | 0.215 |
| Georgian Bay, Moon River spawning walleye population, 1955-1968 | | | | | | | |
| Lotic walleye | Relative year-class strength | May temperature | 14 | 0.214 | 0.059 | 0.048 | 0.287 |
| | Log relative year-class strength | Discharge at spawning time | 14 | -1.434 | 0.034 | 0.002** | 0.565 |

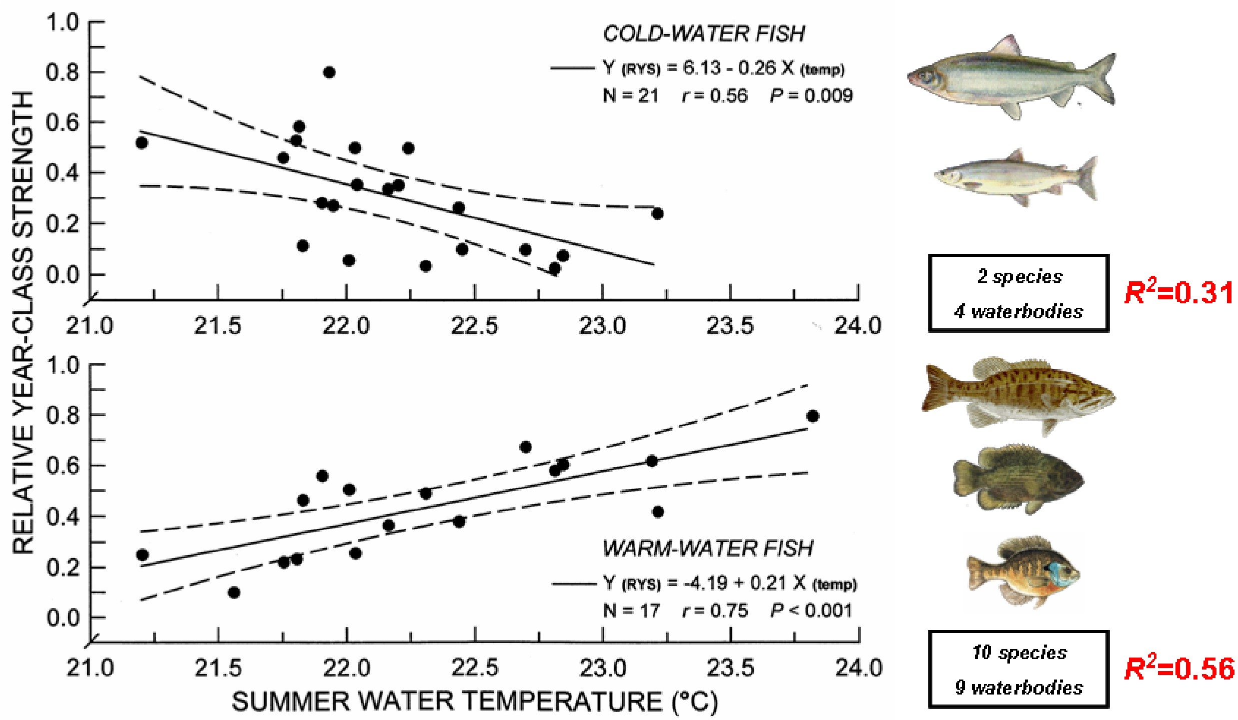
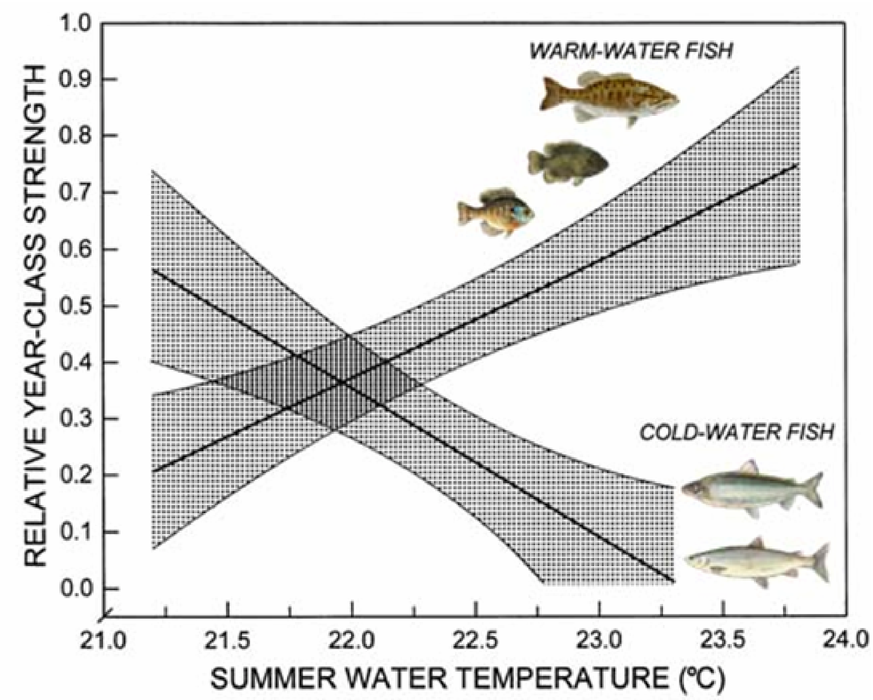



Figure 1.7. Relative year-class strength of cold- and warm-water species from the Mississippi watershed in relation to summer (Jun-Aug) surface water temperatures. Cold-water species data encompass a 27-year period from 1971 to 1997 and come from 4 water bodies and 2 species (lake whitefish, cisco). Warm-water species data encompass a 17-year period from 1983 to 1999 and come from 9 water bodies and 10 species (mainly centrarchids, sunfishes, and basses). Regressions are indicated by solid lines; 95% confidence limits by curved lines, with equations and statistics provided.




**Over two decades a 60% increase; rate of increase–3.4% a year**

**Over three decades a 60% decrease; rate of decrease–2.2% a year**

Figure 1.8. General relationships between recruitment and summer water temperature for warm-water and cold-water fishes in the Mississippi River watershed in Ontario. Means (solid line) and 95% confidence limits (light curves and shaded) are provided, using data from Figure 1.6. Extrapolation of the relationships indicates that, on average, recruitment would cease for warm-water species below 20.2°C and for cold-water species above 23.3°C and would be maximal for warm-water species at 25.1°C and for cold-water species at 19.5°C.

Table 1.15. Predicted changes in relative year-class strength of two centrarchids, smallmouth bass and rock bass, from mean, regressed, and model-predicted Mississippi River watershed summer surface water temperatures. Estimated and extrapolated using relative year-class strength and midsummer water temperature relations from Lake Ontario. Predicted air temperature from modelling in Water Resources section (Subproject 4) of "Fish, Fisheries, and Water Resources: Adapting to Ontario's Changing Climate". Water temperature converted from air temperature, summer (Jun-Aug), midsummer (Jul-Aug). Optimum temperature for growth – smallmouth bass 27.0°C and rock bass 26.0°C

| Time period | | Water temperature | | | | Year-class strength | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Smallmouth bass | | Rock bass | | Combined | |
| Period | Year | Source | Summer | Deviation | Mid-summer | Relative | Fold change | Relative | Fold change | Relative | Fold change |
| 1970-2000 | 1985[a] | mean | 22.2 | 0 | 23.2 | 2.05 | 0 | 1.56 | 0 | 1.75 | 0 |
| | 1970 | regressed | 21.8[b] | -0.4 | 22.8 | 1.45 | -0.71 | 1.19 | -0.77 | 1.32[c] | -0.73 |
| | 2000 | regressed | 22.7[b] | +0.5 | 23.7 | 3.15 | +1.54 | 2.15 | +1.39 | 2.65[c] | +1.47 |
| 2000-2009 | 2005[a] | interpolated | 23.2 | +1.0 | 24.2 | 4.85 | +2.36 | 2.98 | +1.93 | 3.92 | +2.18 |
| 2010-2039 | 2025[a] | predicted | 24.2 | +2.0 | 25.1 | 11.47 | +5.59 | 5.74 | +3.71 | 8.60 | +4.78 |
| 2040-2069 | 2055[a] | predicted | 25.2 | +3.0 | 26.1 | 27.12 | +13.23 | 11.05 | +7.13 | 19.09 | +10.61 |
| 2070-2099 | 2085[a] | predicted | 26.2 | +4.0 | 27.0 | 64.15 | +31.28 | 21.27 | +13.73 | 42.71 | +23.73 |
| | 2100 | predicted | 27.0 | +4.8 | 27.8 | 127.71 | +62.28 | 35.92 | +23.19 | 81.82 | +45.46 |

[a] Median year for the period
[b] Summer surface water temperatures increased from 1970 to 2000 by 0.9°C.
[c] The predicted increase in recruitment for this increasing temperature would be 100%; however, the actual change in recruitment over this temperature range was 62% – the observed was slightly more than half the predicted.

Table 1.16. Examination of changes in peak discharge in the Mississippi River system, as predicted from climate change modelling (Subproject 4), in relation to walleye recruitment. A relationship exists between recruitment and spring discharge for river-spawning walleye, best documented for the Moon River, Georgian Bay, 1955-1968, (Winterton 1975). A reassessment of the Moon River data indicates the following equation:

$$\mathit{Log}\ X_{\text{(walleye RYS)}} = 0.856 + 0.0034\ Y_{\text{(DISC cms)}}$$

$$N = 14 \qquad r = 0.752 \qquad P = 0.0019$$

Relative year-class strength – RYS; discharge – DISC. Applying this Moon River recruitment-discharge relationship to the predicted changes in the Mississippi River discharge in relation to the reference period (1974-2002), the estimated changes in walleye recruitment are provided.

| Time period | | Peak discharge | | | | Walleye recruitment | |
|---|---|---|---|---|---|---|---|
| Period | Median year | Date | Days earlier | Flow (cms) | % change | Relative year-class strength | % change |
| 1974-2002 | 1985 | Apr 27 | | 107.4 | | 1.00 | |
| 2010-2039 | 2025 | Apr 8 | 19 | 103.3 | - 3.8 | 0.97 | - 3 |
| 2040-2069 | 2055 | Mar 27 | 31 | 78.6 | - 26.8 | 0.80 | - 20 |
| 2070-2099 | 2085 | Mar 11 | 47 | 72.0 | - 33.0 | 0.76 | - 24 |

# Section 3.2 Weathering Climate Change: Stakeholders Outreach and Science Transfer Workshop, Subproject 2

## 3.2.1 Introduction

"*Fish, Fisheries, and Water Resources: Adapting to Ontario's Changing Climate*" deals with both regional-scale issues and, by means of a specific case study, a local watershed. The rationale for this approach has been discussed in the introduction.

For the case study of the Mississippi River watershed, it was immediately apparent that a special effort was needed to engage the local population. From the perspective of the overall project goals, it was necessary to alert residents and watershed users that the study on climate change and adaptation was underway and that there are, and will be, implications from climate change, including changes to water quantity and quality and to fish stocks. As well, there was a desire to seek the views of watershed users about current and future concerns around fish, fisheries, and water resources and adaptive capacity. Lastly, there was a need to encourage participation in a survey of the economics of fish resources and use in the watershed. The survey (see Section 3.3, Subproject 3) was designed to engage a broad range of users from casual fishers to fish-resource professionals: residents and recreational users of the watershed needed to be alerted and engaged.

The project researchers were also keenly aware that although stream flow regulation can help offset some changes to the flow regime and some potential changes to fish stocks, there will be changing demands for water as various sectors adapt to changing climate conditions. It is unlikely that all concerns can be addressed; trade-offs will be necessary. Thus, there is a need for a more balanced view of the choices that will be made as to how we use water and aquatic resources (the focus of this study) and also how various sectors adapt more broadly to changing climate in the watershed (also the subject of ongoing discussion).

For all the above reasons and with the limited timeframe available for this project, it was decided that the best approach, both for public engagement and information exchange, was a formal workshop based in the Mississippi River watershed.

## 3.2.2 Outreach and Science Transfer Workshop

The workshop "Weathering the Change: Adapting to Climate Change in the Mississippi Valley" ran for two days on consecutive Saturdays, September 15 and 22, 2008, at R. Tait Mackenzie Public School in Almonte, Ontario. The workshop was sponsored by Mississippi Valley Conservation (MVC) in collaboration with Mississippi Valley Field Naturalists (MVFN), which provided in-kind funding, important to the success of the overall study on aquatic resources, adaptation, and adaptive capacity.

Approximately 150 people attended the sessions. Morning presentations by experts in the field were followed by breakout sessions in the afternoons, each of which focused on specific issues associated with climate change. A broad range of aspects was considered, including fish, fisheries, and water resources. This thorough overview was necessary to put the multitude of issues into context. The various presentations were posted on the MVC website (www.mvc.on.ca/program/ccindex.html) and links. Presenters attended the breakout sessions and offered comments, observations, and advice. Although the workshops covered a wide range of issues, this report will focus only on those most relevant to fish, fisheries, and the primary theme of this study "Fish, fisheries, and water resources: Adapting to Ontario's changing climate."

The co-sponsors of the workshops, MVC and MVFN, organized and conducted the events. Without the input of MVFN and numerous local volunteers, the workshops would not have been the success that participants thought they were. A report (Egginton and Lavender 2009, manuscript report, see www.mvc.on.ca, 2009) captures the key points and concerns for the region for all areas of discussion and acts as a catalyst for future discussions. The report was made available to the community at large. Quite generally, the key overall results, as they pertain to the present study, were:

1. Climate, ice cover, water temperature, river flows, ecosystems, and fisheries are changing in the Mississippi River watershed and will continue to do so.
2. There are sectoral impacts now and will be in future (e.g., on agriculture, tourism, forestry, fisheries, etc.).
3. Some, but not all, of the impacts can be reduced through adaptation actions.
4. All sectors and areas of our economy and our environment will be affected in both positive and negative ways.
5. There are barriers to taking action — trade-offs will be necessary.
6. Climate change should be incorporated into all aspects of our planning processes (e.g., health care, fisheries management, infrastructure design, water management, etc.)
7. Guidelines and tool kits are needed to help at the local level, and residents and local agencies alike look to senior levels of government to provide these.
8. Participants prepared and released "The Almonte Communiqué," which calls for action by governments and residents to adapt to a changing climate.

***The Almonte Communiqué***

*Released by delegates of "Weathering the Change"*
*a two-day workshop co-sponsored by MVC and MVFN*

*Many important economic and social decisions are being made today on long-term projects and activities in our watershed based on the assumption that past climate change data are a reliable guide to the future. This is no longer a good assumption.*

*We believe that all levels of government are key players in this issue and must raise awareness and incorporate climate change into planning, decision making and leadership.*

The two-day workshop was particularly relevant, since it provided valuable insights for other subprojects in the study into the effects of climate change on fish, fisheries, and water resources. Local watershed residents and users were both alerted to, and became engaged in, other aspects of the study, in part as a result of the outreach workshop. Subproject leads were, in turn, made aware of local issues and concerns.

The workshop provided a venue for announcing and explaining the economic survey that was planned in support of the study. The workshop made it possible to explain the relevance and various aspects of the survey, which have provided an in-depth understanding of the economics and consequences of adapting to climate change (see Section 3.3, Subproject 3). The highly successful response to the survey was in part due to the publicity provided by the workshop.
Given the limited duration of the present study and the objectives of the subprojects, workshop sessions dealing with fish and fisheries are most directly relevant at this time, but a summary for all sectors has been assembled by Egginton and Lavender (2009, manuscript report, see www.mvc.on.ca).

Impacts and implications of climate change and possible adaptation options have been identified (Egginton and Lavender, [2009, manuscript report, see www.mvc.on.ca]). These have been prepared in a succinct tabular form and also draw extensively from Section 3.1, Subproject 1 and Section 4.1, Subproject 4 of the present study (Table 2.1).

### 3.2.3 Future Directions

Adaptation is not without cost, and it will have to be dealt with in considerable detail: significant analysis (cost benefit analysis) will be required in some instances. In some cases, possible adaptation actions could involve other sectors or areas of the community. For example, expressed concerns over water quality, including increased use of salt as winters become increasingly mild with more ice, may need to be addressed by roads and maintenance departments at the local and regional level and not by those directly involved in the water sector.

In many cases, the options identified may simply be short-term solutions and buy time. This is still important, given the uncertainties, but their long-term effectiveness will need to be evaluated. For example, some potential options for dealing with decreases in cool- and cold-water fisheries include: i) put-and-take programs using hatchery-raised fish to move around the fall thermal bottleneck (i.e., induce recruitment) in a specific lake when conditions get too warm; ii) encourage trout to spawn deeper in cooler lake water through, for example, the provision of suitable deeper (and cooler) spawning beds; iii) inducing fish to spawn in lakes rather than rivers; iv) long-term replacement of current lake stocks. Lake trout stocks in some lakes, through evolutionary development (over long timeframes), spawn deeper and up to a month later than those in lakes in Mississippi watershed (see Section 3.1, Subproject 1,). Such stocks may be useful for stocking/rehabilitation programs in the Mississippi watershed as conditions continue to warm with time. With significant warming, as is envisaged over the next 100 years, even this range of options may be of limited long-term use. Warm-water species are becoming more prevalent and, with increasing temperatures, will continue to do so. See Section 3.1, Subproject 1 for a more thorough discussion of fish and fisheries issues.

It is not too surprising that water emerged as a key cross-cutting issue in the workshop (Egginton and Lavender, [2009, manuscript report, see www.mvc.on.ca]). Adequate water supply is crucial for all sectors in the Mississippi River watershed, including fisheries. As Egginton and Lavender indicate, today it is perhaps arguable that in general we have the water supply that we require. That is, we have adapted *grosso modo* to the water levels and flows that we have. However, even today we are experiencing extreme low summer flow in some years. Each sector may have a specific seasonal need for a given water level or water volume. It is clear that if summer flows continue to decline, conflicts will arise as the various sectors adapt to these conditions and require/demand a larger share of the remaining resource. Some of the potential sectoral conflicts are illustrated in Figure 2.1 and are detailed in Section 3.4, Subproject 4 of the present study.

The present study and the associated analyses have necessarily focused upon fish, fisheries, and water resources and the development of some management options. They represent a good start; however, further analysis and consideration of other sector interests, some of which have been identified in other sector reports (in writing), will be required for future overall watershed management.

The Egginton and Lavender report (Egginton and Lavender, [2009, manuscript report, see www.mvc.on.ca]) has already informed further discussion within the watershed. For example, since January 2008, MVC has engaged local agencies and councillors in ongoing discussions and has started to incorporate climate change scenarios in the water management plans, which was the primary impetus for the present study. For further updates and ongoing progress, see the MVC website (www.mvc.on.ca, 2009) and links.

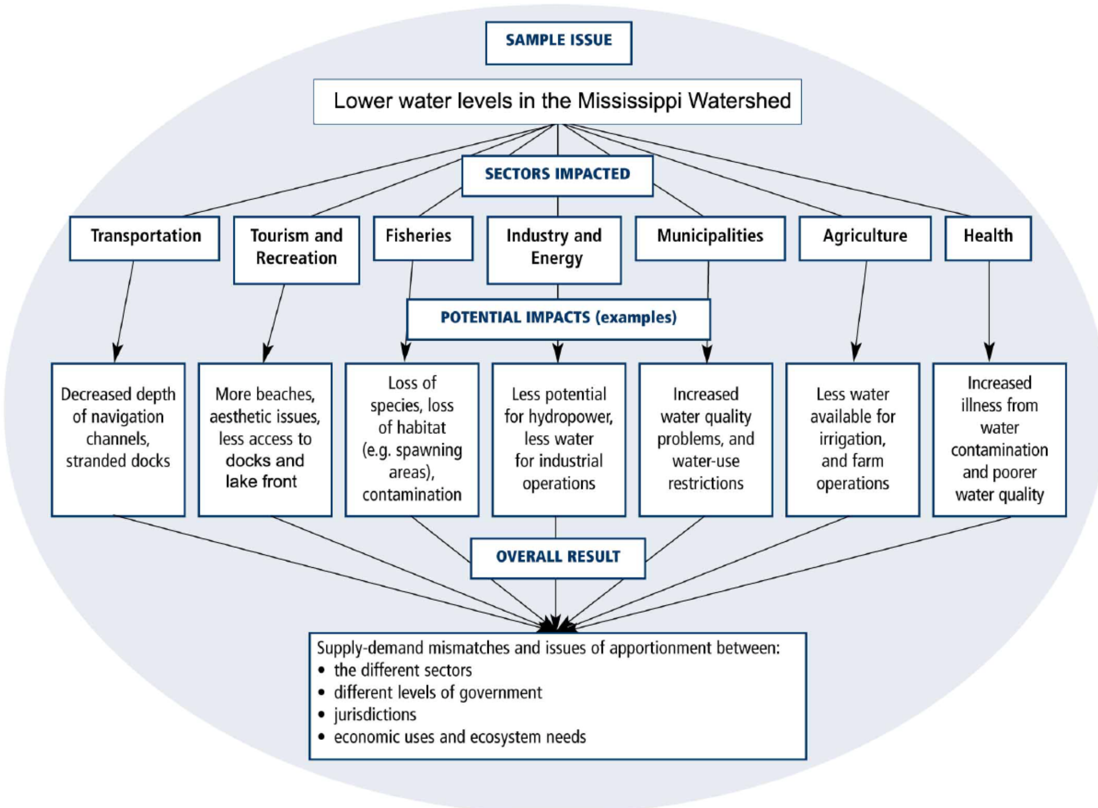



Figure 2.1. Sectors affected by lower water levels in the Mississippi River watershed and the potential impacts ([Egginton and Lavender [2009, manuscript report[, see www.mvc.on.ca], modified from Lemmen et al. 2008 modified).

Table 2.1. Egginton and Lavender ([2009, manuscript report], see www.mvc.on.ca) provided a summary of the fisheries sensitivities, impacts, and concerns for the Mississippi watershed, which was assembled from presentations in the workshop and Section 3.1, Subproject 1, provided here.

| Variable | Impacts/Implications | Possible Adaptation |
|---|---|---|
| ***Air temperature***<br>• higher annual, summer, winter temperatures<br>• more heat waves, longer growing season | • recreational patterns change, spring and fall more amenable to on-water activities<br>• switch in fishing pressure, less in winter more in summer<br>• demand for higher summer lake and flow levels<br>• increased aquatic plant growth | • start to promote summer fishery<br>• warm-water fish will be better adapted to changing conditions |
| ***Precipitation***<br>• more rain in winter<br>• more droughts<br>• more heavy rain events<br>- flash rains and runoff more extreme and common | • water quantity and quality in some years and areas poor, impact on fish quality<br>• potential for pollutants to be washed into river system during extreme events<br>• water level fluctuation may be too extreme for some species<br>• increased sedimentation, particulate matter in water column, and scouring | • monitor fish quality<br>• source water protection<br>• improve quality of urban effluent<br>• encourage better manure/fertilizer management plans<br>• develop riparian buffer zones<br>• wetland protection and maintenance<br>• encourage revegetation/ naturalization of shorelines) |
| ***Evaporation and Evapotranspiration***<br>• open-water evaporation rates likely higher, increasing by about 6% for each degree C increase<br>• increased emergent aquatic vegetation and associated evapotranspiration | • greater surface water loss,<br>• less inflow from shallow ground-water sources; they may dry up and streams may become more ephemeral and/or warmer | • encourage reforestation where possible (helps to maintain summer groundwater inflow) |
| ***Wind***<br>• more variable, higher gusts | • ice formation affected | • monitor change and possible impacts |

| | | |
|---|---|---|
| ***Water temperature***<br>• increasing throughout the season<br>• longer open-water periods, shorter ice-cover periods<br>• large, deep lakes develop (have) greater thermal inertia (see Section 3.1, Subproject 1) | • ice cover not as safe as in past, shorter duration<br>• winter sports fishery at risk<br>• potentially less fish winter kill<br>• aquatic plants and algae expand with longer aquatic growing season<br>• changes in depth of thermocline upward or, with increased wind action, downward<br>• summer oxygen levels likely lower<br>• increased summer kills (see Section 3.1, Subproject 1)<br>• conditions move to favour warm-water fish<br>• expect average yearly recruitment to increase in warm-water species (e.g., bass) to double by 2020 and increase by 15 times by 2050; expect a decrease in cool- and cold- water fish recruitment (e.g. pike) and cold-water fish (e.g. lake trout) by similar amounts<br>• conditions will be more conducive to invasive (warm-water) species,<br>• expect outbreaks/fish deaths associated with toxic-producing strains of bacteria such as *Columnaris* | • raise awareness of changing fishing conditions, risk of invasive species, target schools, sports fishers, cottage associations, public, government, etc.<br>• use stocking programs to minimize thermal bottlenecks for cold water fish (e.g., trout)<br>• take actions to maximize and promote potential and use of summer fishery and warm-water species<br>• long-term monitoring: changing water conditions and species with time; response will be species-specific<br>• consider viability of options such as only catch and release of valued species, change in start/end of season, etc.<br>• protect key feeding/spawning areas<br>• assess potential to use water management to flush river/lake system, moderate temperatures<br>• promote full use of (removal) warm-water fish, in cool-/cold-water lakes through catch and keep, derbies, commercial fishing<br>• awareness – fish eating quality is high<br>• manage rivers and lakes to protect cold-water species recruitment<br>• keep water quality high |
| ***River flows, lake levels, ground water***<br><br>• down in some seasons/years<br>• more frequent flooding | • low or changing water levels and/or loss of wetlands, shallows will affect spawning<br>• competition for remaining water flow in time of drought<br>• flooding – peak floods may occur in any season and affect fry through increased scouring and flushing | • assess potential to use water management to regulate flow and water levels for fish<br>• keep wetlands wet<br>• assess the need for more water storage in the basin to moderate floods and to enhance flow during droughts<br>• examine trade-offs and choices in maintaining sensitive species.<br>• reforest where possible |

# Section 3.3 Impacts, Adaptive Capacity, and Socio-economic Consequences of Climate Change on Fish Resource Use and Management in Ontario: A Survey of Resource Users, Businesses, and Professionals, Subproject 3

### 3.3.1 Introduction

Global warming and climate change have been well documented for the past several decades (Intergovernmental Panel on Climate Change 2007), and global action is required (European Union 2007). Local changes can be variable across regions, from extreme air temperatures to flooding or drought due to changes in precipitation, which in turn can affect water temperature, flow, runoff, and ice cover. In addition, the historical timing of these environmental events is being altered. In the Lake Ontario region, for example, warmer temperatures have delayed lake cooling, fall turnover, and winter ice cover, while lack of winter precipitation and snow buildup have reduced spring runoff and flow (see Section 3.1, Subproject 1).

While relatively new, the scientific literature is growing and indicates that as global climate change and warming progress, warm-water species will become more abundant, while cold-water species will decline (Casselman et al. 2003; see Section 3.1, Subproject 1). Some species will most likely be lost to local communities, especially cold-water species in the southern portion of their range (Environmental Protection Agency 1999). Even subtle changes in environmental conditions can result in significant changes in fish resources. Different fish species have evolved to specific environmental conditions for growth, maturity, reproductive success, and survival, which, if altered, could affect not only abundance but community structure (see Section 3.1, Subproject 1; Natural Resources Canada 2004). For example, in water bodies that traditionally contained cool-water species such as walleye (optimum temperature for growth [OTG] 23°C), warm-water species such as smallmouth bass (OTG 26°C), could become more prevalent (Wismer and Christie 1987). Adaptation by the fish community will occur, but the degree of change in any given water body will be local and site-specific.

More uncertain are the changes and adaptations of fish resource users and managers. Their adaptability could have significant positive or negative social and economic impacts caused by changing fish resources. Some areas in Ontario will undoubtedly experience social and economic loss due to these changes, while other areas could experience a net gain. Anticipating and recognizing these changes will aid in offsetting or minimizing any negative impacts. Working with and understanding the willingness of resource users to adapt will provide the cornerstone for planning and implementation. However, resource managers must be willing to adapt, work cooperatively with resource users, and be flexible. There are no guidelines for managing fish resources during times of global warming and uncertain changes. Traditional regulations involving seasons, creel limits, size limits, etc. may no longer apply in changing environmental conditions, spawning periods, migrations, community structure, species abundance, and growth.

A survey was conducted to measure attitudes, adaptability, opinions, and perceptions of resource users and managers. These empirical observations and attributes provide a measure of the social importance of the fish resource and the adaptability of users and managers, which will ultimately determine the economic impacts of change. Thus, the objectives of the study were to: (1) document observational knowledge, impacts, and adaptability of fish resource users and professionals; (2) determine the economic and social value and impacts and forecast future trends based on current attitudes; (3) integrate with other water resource uses and the management plan for the Mississippi Valley Watershed; and (4) make recommendations that promote economic growth and sustainable use of fish resources while maintaining its social importance.

Climate change, especially change in water conditions, is changing fish communities in Ontario (see Section 3.1, Subproject 1). Hydrological modelling (see Section 3.4, Subproject 4) forecast changes in water conditions that can be expected in the Mississippi Valley watershed to 2099. Use of fish resources is a large component of the multi-purpose uses within this watershed. Any changes to fish communities will have social and economic impacts, either positive or negative, that will require adaptation by fish resource users and managers. The survey helped document current resource use and adaptation to fish community changes, which will allow informed planning and promoting of the positive aspects of change. Enhancing efforts to address adaptation is one of the eight building blocks of an effective framework to avoid dangerous climate change (European Union 2007).

### 3.3.2 Methodology

#### 3.3.2.1 Survey Background

In May 2007, a workshop arranged by Mississippi Valley Conservation (MVC) took place in Lanark, Ontario, in the Mississippi Valley watershed. It was attended by 15 to 20 local stewards representing lake, cottage, and property-owner associations. The workshop was a precursor to the current study and had several purposes: it was an information session in which recent scientific data about impacts of global climate change on fish resources were presented (see Section 3.1, Subproject 1), it introduced the concept of a fish resource survey in the context of climate change, and it gauged local interest by providing the opportunity for extended discussion and feedback. This proved to be extremely insightful and helped in designing the survey.

#### 3.3.2.2 Survey Design

A literature review of the impacts of global climate change on fish resource use and management was conducted to provide background information and to aid in design of the survey. The review was to focus on documented conditions before and after impacts caused by climate change, but documented and published reports pertaining to impacts and adaptation to changing fish resources are scarce or nonexistent, a strong indication that the current project is in the forefront on these issues. However, the few documents found provided useful information on socio-economic value and costs of environmental and fisheries resources (Adams 1994; Solomon et al. 2002; Weithman and Haas 1982).

The survey focused on fish resource issues in the context of climate change, observed changes in the environment and fish community, and impacts, adaptations, and economic consequences. To accomplish this, the survey had to measure attitudes, adaptability, opinions, and perceptions of resource users and managers. These empirical observations and attributes would measure the social importance of the fish resource and the adaptability of users and managers, which would ultimately determine the economic impacts of change. Of particular help in designing the survey was a survey conducted in 1976 as part of a master’s thesis, University of Waterloo. In 1976, pre global warming, Marcogliese (1977) conducted a survey that examined social attitudes of resource users, resource enforcement officers, and politicians toward a sport fishing licence for Ontario. Where applicable, the current survey was designed to parallel the 1976 survey, which provided comparisons pre and post global warming.

The survey was designed to solicit information from fish resource users and managers from across Ontario and to examine responses on a regional basis. The three regions included northern and southern Ontario (delineated by the Ontario Ministry of Natural Resources [OMNR] regional boundary), and the Mississippi Valley area (MVA) located in southeastern Ontario (Figure 3.1). While the overall study centred on the Mississippi Valley watershed (MVW) and incorporating climate change into their water management plan, the provincial and regional approach was taken for comparative purposes and to determine whether the results would be generally applicable. The MVW could be viewed as a case study and used as a model for other watersheds. In addition, the provincial approach paralleled the 1976 study, in which northern and southern Ontario regions were examined (Marcogliese 1977).

The layout of the survey followed a logistical sequence so as not to bias participants in the context of climate change. Following the same format, surveys were designed for each targeted fish resource group, including anglers, baitfish operators, businesses (lodges, resorts, guides, etc.), commercial fishers, First Nations, and professionals (managers, technicians, conservation officers, etc.). Preliminary feedback indicated that many potential participants, mainly anglers, businesses, and professionals, belonged to more than one of these targeted groups and many wanted to respond for all groups they were associated with. A compilation survey was designed that had 10 sections and targeted three groups associated with fish resources, anglers, businesses, and professionals. The compilation survey was the same survey, but longer and with more sections because sections pertaining to three groups were included. The sections of the compilation survey were:

*Section 1—Issues of Concern*
Participants were asked to rank, in order of importance, four issues from a list of 15 that they considered to have the

highest priority regarding fish resources in Ontario. The issues paralleled the 1976 survey (Marcogliese 1977) and provided the opportunity to understand and put in context the effects of climate change and where it stood as an issue today. Unfortunately, climate change was not considered or listed in 1976; thus, we made some modifications and updated the list by removing three issues that were of middle to low importance, two of which pertained directly to the 1976 study, and adding climate change effects, habitat, and invasive species. The latter two issues were based on feedback from the precursor workshop (May 2007). While these


Figure 3.2. Map of Ontario showing boundaries of the three areas in which the climate change survey was conducted. Areas 1 (northern) and 2 (southern) follow the Ontario Ministry of Natural Resources Regional Boundary. Area 3 (Mississippi Valley Area) was extended (hatched area—right arrow) to include the surrounding area of the Mississippi Valley watershed (white open area in hatched area—left arrow). Not to scale.

modifications, and a slightly different targeted group (1976 survey—anglers, conservation officers, politicians) prevent a direct comparison with the 1976 survey, the list required updating and would still provide a strong indication of whether issues had changed over the past 32 years, especially if changes were substantial. The 15th issue listed in both surveys was “Other”, which allowed participants to include an issue important to them that was not on the list.

*Section 2—Participant Group and Species*
Participants indicated which of the fish resource groups they belonged to and were asked to rank in order the four fish species they targeted most often (anglers), their customers attempted to catch (businesses), or were considered most important in their area of work (professionals).

*Section 3—Participant Profile*
Designed to collect demographic data of participants, including gender, age group, residency (Ontario or out of province), general location and years at residence, and area of residency in relation to the designated regions of Ontario within this study. In addition, participants were asked to provide their name and contact information for quality control purposes and to help prevent duplicate submissions. All surveys were confidential and anonymous,

and personal information was restricted to this researcher.

*Section 4—Observational Knowledge, Changes, and Effects*
Participants documented their observations with regard to the environment and fish community. First, they were asked if they had noticed any changes in the environment or fish community and, if so, to rank from a list (13 environmental, nine fish community), all changes they had noticed from the most to least noticeable, to indicate the year or time period they first noticed the change, and to describe how conditions had changed. Several types of time periods were allocated for when the change was first noticed, including a single year, a specific range of years, a decade, early part of a decade, and late part of a decade. Thus, the following method was followed to assign a year to time periods: the first year in a specific range, the midpoint of a decade, the first numbered year (1) for early part of decade, and last year (9) for the late part of a decade.

Participants were asked if any of the environmental or fish community changes they listed had affected their fishing (anglers), their customers' fishing (businesses), or their work in fisheries (professionals). If yes, respondents were asked whether the effect was positive, negative, or neutral and, for positive and negative effects, to comment on how the change affected them.

At this point in the survey, a few simple questions about climate change were first asked that addressed whether respondents knew of any examples of how global climate change had affected fish communities, whether they felt climate change had affected the use of fish resources, and whether they attributed any of those environmental or fish community changes to climate change.

*Section 5—Angler Profile*
Designed specifically for anglers to document current use of fish resources for themselves and their families. Data collected included specific details about their fishing experience, number of people within their household who fish, locations, seasonal effort (open water and ice cover), and annual household expenditures by season (open water and ice cover). Capital costs were not to be included in expenditures. Any item indicated as a capital cost or item listed >$1,000 was not included in the analysis. Thus, only direct angling costs were included and analyzed. Household expenditures and anglers were used to calculate individual expenditures. For analysis, data were $\log_{(10)}$ transformed and geometric means were calculated and presented.

To ensure that participants represented the general population, anglers were asked if they belonged to a club or association and, if so, to list their memberships. To ensure that responses were widely distributed throughout the three regions of Ontario, anglers were also asked to provide the names of the three water bodies in which they fished most often. This helped to verify the region they fished most often. Finally, to help determine the importance of angling in Ontario's society today, anglers were asked to rank in order of importance, from a list of 13, all reasons why they fish.

*Section 6—Business Profile*
Designed specifically for fish resource businesses and followed a format similar to the angler profile, but questions were geared toward experience in the fish resource industry and their customer base. These data included location of business in relation to the regions in this study and the percent of business, number of operating days, customers, and origin of customers by season (open water or ice cover). Four categories were defined for origin of customers: local (within 100 km or 1-hr drive), regional Ontario residents (100-200 km or 1-to-2-hr drive), provincial Ontario residents (>200 km or 2-hr drive), and non-Ontario residents. In addition, businesses were asked to estimate daily customer expenditures that were directly related to the services they provide. As with anglers, to help verify their location and area within this study, fish resource businesses were asked to provide the names of up to two water bodies at which their business operates.

*Section 7—Professional Profile*
Designed specifically for fish resource professionals and dealt specifically with years of experience, which included professional, Ontario, and experience in the region where they currently work (northern or southern Ontario, MVA).

*Section 8—Adaptation and Impacts to Environmental and Fish Community Changes*
A brief introduction of global climate change effects on the environment and fish communities was presented, based on accredited science that documents long-term changes in eastern Ontario (see Section 3.1, Subproject 1). It

included the classifications of warm-, cool-, and cold-water species on the basis of their thermal requirements and how subtle environmental changes can result in significant changes in fish resources by affecting growth, maturity, reproductive success, survival, and abundance. As global climate change and warming progresses, warm-water species are adapting better and becoming more abundant, while cool- and cold-water species are diminishing, ultimately resulting in changes in the structure of fish communities. Participants were then presented with a list of 25 common species in Ontario, which were categorized as warm-, cool-, or cold-water on the basis of their thermal requirements (Wismer and Christie 1987).

Sub-section 8A posed a series of 10 statements to estimate the adaptive capacity of anglers to changes in the environment and fish communities attributed to global climate change and warming. More specifically, the statements dealt with seasonal changes in effort and timing, as well as changes in fishing patterns, techniques, depths, habitat, and location. Participants were asked to indicate on a scale ranging from 1 (agree) to 9 (disagree) with the statement (5 was the midpoint of the scale, indicating indifferent or neutral). Lastly, participants were asked if they considered an increase in warm-water species a positive change, negative, or both.

Sub-section 8B was designed for anglers and estimated their adaptive capacity to increased abundance of warm-water species with regard to annual effort in terms of fishing trips and frequency. Anglers were asked to indicate their number of annual fishing trips by duration (day, weekend, week) and by season (open water and ice cover). For analysis, data were $\log_{(10)}$ transformed and geometric means were calculated. In addition, anglers were asked to indicate how an increase in warm-water species would affect their fishing trips (increase, decrease, no change). These data were separated and examined according to those who indicated the changes would be positive or both and those who indicated changes would be negative or both (Sub-section 8A). The latter group was asked to indicate whether they were more likely to change locations or target different species that were more abundant and, for the latter group, whether they would get as much satisfaction from catching a different species.

Sub-section 8C was designed for all fish resource groups and attempted to estimate overall impacts on fish resource use and revenue. Specifically, participants were asked to indicate whether they felt future changes in the environment and fish communities due to global climate change would increase, decrease, or not change; how often they went fishing; their annual expenditures (anglers); the impacts on their customer base and business income (businesses); and the impacts on resource use and revenue in their work area (professionals).

*Section 9—Adaptive Management Actions*
Designed for all fish resource groups to determine whether management actions should be taken in an attempt to help offset social and economic impacts of environmental and fish community changes due to global climate change. A list of possible management actions was presented that included public education (information transfer, value of all fish resources), promotion (encourage use of more abundant species and discourage use of less abundant species), removal of more abundant species (programs, harvest, derbies), stocking (support existing, put-and-leave, put-grow-and-take), and regulations (adaptable, flexible, site-specific, real time, more liberal or restrictive, promote value). Participants were asked to indicate which management actions they would support and to rank the actions they believed would be most effective in offsetting social and economic impacts. In addition, if management actions were taken, participants were asked to indicate the basis for the action (economic, scientific, social, or all) and to rank which (among economic, scientific, and social) would be most important.

*Section 10—Water Management and Multi-Purpose Use*
In regulated watersheds, water management and multi-purpose use will be even more challenging (see Section 3.4, Subproject 4). Participants were asked to rank in order of importance, from a list of 11 water uses, which should have the highest priority during periods of low water levels. It was recognized that participants in this survey were a targeted group and the results would most likely favour fisheries uses, but they should provide a better understanding of the level of concern from fish resource groups and indicate non-fisheries priorities, since most people have multi-purpose uses for water (i.e., consumption, homes and cottages, hydro, etc.).

In all sections, items were listed in alphabetical or chronological order to prevent bias. Also, in each list the last item was “Other”, which allowed participants to specify an item or issue important to them that was not on the list.

#### 3.3.2.3 Survey Distribution and Promotion

To encourage participation in the survey, it was intensively promoted, including participation in three Climate Change Workshops, two formally within the overall project (Section 3.2, Subproject 2) and the precursor workshop (May 2007—Section 3.1.1). At Workshops II and III (September 2007), time was allotted to give a short presentation about the fisheries survey and elicit volunteers to participate. In addition to the workshops, a presentation was made at the 6th Annual Lake Links Workshop, Perth, Ontario (October 2007). This workshop was attended by representatives of lake and cottagers associations, conservation authorities, stewardship groups and councils, Parks Canada, and Ontario Ministry of Natural Resources from eastern Ontario. Also, articles and ads were written in local newspapers in the Mississippi Valley that informed residents of the overall study and survey. To obtain participants from outside the Mississippi Valley watershed (northern and southern Ontario), the Ontario Federation of Anglers and Hunters (OFAH) was contacted; the OFAH has the largest membership (>80,000) of any organized fish and game club in Ontario. A letter was sent to their board of directors in November 2007, and it was arranged for members of our research team to present our climate change study and survey at their Fish Committee meeting being held in late November 2007 in Toronto. The survey was fully endorsed, and we received offers to promote it, including a posting on their website with a downloadable version of the survey (www.ofah.org) . Permission was also granted to the Temagami Stewardship Council to post a notice on their website (www.temagamistewardship.ca) linking it to the OFAH website.

An extensive list of resource professionals was compiled from the government of Ontario online information and services website (www.infogo.gov.on.ca). Occupations ranged from upper management to field staff. Before distributing the survey to them, it was essential and ethical that we inform them of the study and gain their support, which would help increase their participation rate. A meeting was arranged with senior management of the OMNR, including representatives of three of four districts that encompass the Mississippi Valley watershed (Bancroft, Pembroke, Peterborough). The meeting occurred in December 2007 in Peterborough, at which members of our research team presented our climate change study and survey. The survey was discussed in detail and was well received and supported; OMNR employees were encouraged to participate. Also, we arranged for a posting on the OMNR Employees Bulletin Board and OMNR website (www.mnr.gov.on.ca) linking it to the MVC website (www.mvc.on.ca) where the overall project and downloadable version of the survey were posted. While OMNR has the most fisheries professionals in Ontario, the survey was also distributed to professionals employed by Ontario's conservation authorities and some members of DFO and consulting firms.

In addition, the Bait Association of Ontario, the Ontario Commercial Fishery Association and First Nations within the Mississippi Valley were contacted and sent copies of the survey, which they were asked to distribute among their members. Participation was low, however, and they were not represented in any further analysis or results within this study. A more extensive study should be considered, because all groups were interested and it is widely believed participation would increase greatly if they were directly involved. Their observational knowledge and perceptions would have been extremely valuable to this study.

The survey was distributed between late December 2007 and mid-January 2008 as support and approvals were obtained from different agencies. The survey was in circulation for a 5-to-7-week period, with a deadline date of February 21, 2008, for submissions. Finally, to help encourage participation, a local lodge owner located in the Mississippi Valley graciously donated a two-night stay at his lodge. The winner was randomly drawn from all survey submissions.

#### 3.3.2.4 Data Management and Analysis

In sections specifically designed for anglers and businesses (Sections 5 and 6), participants were asked to indicate the percent of their fishing or business operations that occurred in each region in Ontario (northern, southern, MVW). Discrepancies arose mainly for anglers located in southeastern Ontario, near the MVW. The majority of their fishing occurred in or near the MVW, but the watershed was not always known or correctly identified. To assign them correctly to a region, the list of water bodies they fished most often was checked against a list of water bodies within the MVW. While most discrepancies could be resolved concerning watersheds, it was not known how the percent of angling in each region was affected by this reassignment. The best way to resolve this problem was to expand the area of the MVW and rename it the Mississippi Valley area in southeastern Ontario (Figure 3.1). The MVA included watersheds located in the OMNR Districts of Kemptville (excluding the St. Lawrence River), Pembroke, and the eastern portion of Bancroft, because these three districts encompass most of the MVW. This realignment resulted in 11 anglers being assigned to the expanded MVA without direct angling experience in the

MVW. For consistency, businesses and professionals were also assigned to the expanded Mississippi Valley area in southeastern Ontario. Several professionals (N=12) had provincial jurisdiction, thus they were assigned to one of the three regions of Ontario on the basis of their work location and/or residency unless they indicated specific knowledge within a region (southern Ontario N = 7, MVA N = 5).

Sections 1 and 4 of the compilation survey were common to all fish resource groups. For these sections, responses were replicated if a participant responded for more than one fish resource group (i.e., angler, business). Sections 8A, 9, and 10, also common, contain replication only if the resource group was not identified.

Several sections (1, 2, 4, 9, and 10) asked participants to rank items in order of importance. Prior to analysis, all ranks were weighted following the same procedure. A rank of 1 was assigned a weighted score equal to 100. Subsequent ranks were assigned a continual decreasing score. The incremental decrease between consecutive ranks was calculated as

100 / the number of items that potentially could be ranked within a question.

The denominator was restricted by the number of items listed or the number of items the participants were asked to rank. Thus, the incremental decrease between consecutive ranks was evenly distributed within a question but varied among questions. For example, the weighted score for a question with four items to rank would have an incremental decrease between consecutive ranks equal to 25, while a question with five items would have an incremental decrease equal to 20.

Several different situations were encountered concerning ranks that were dealt with in a consistent method. They were:

- If no items were ranked, it was treated as missing data or blanks.
- If one or more items were ranked, they were assigned a weighted score and the unranked items were assigned a score equal to 0.
- If more items were ranked than were asked for, only the number of items that were asked for were assigned a weighted score. The rest were assigned a score equal to 0.

If the same rank was used more than once (i.e., 1, 1) the position of the ranks was determined (i.e., 1, 2), the sum of the weighted scores for those positions was calculated (i.e., 175), divided by the number of items with the same rank. (i.e., 2), and assigned to each item with the same rank (i.e., weighted score = 87.5 each)

For presentation and analysis, questions with scales ranging from 1 (agree), to 5 (indifferent), to 9 (disagree) were rescaled and assigned categories: -4 = strongly disagree, -3 = disagree, -2 = moderately disagree, -1 = somewhat disagree, 0 = indifferent, 1 = somewhat agree, 2 = moderately agree, 3 = agree, 4 = strongly agree.

Analysis was conducted by area and groups within areas. Descriptive statistics, frequencies, frequency distributions, and geometric means were calculated and presented. Frequency (N) varied among questions and can be greater than the number of participants when multiple responses were requested or less when only participants who responded Yes were to proceed to the next question or because participants did not answer all questions.

Statistical testing included parametric and non-parametric ANOVA, multiple range and comparison of means (alpha=0.05).

All statistical tests were conducted with Statistix Analytical Software (2003).

### 3.3.3 Results

#### 3.3.3.1 Survey Response and Participant Profile

In total, 686 surveys were distributed directly to potential participants belonging to at least one of the targeted fish resource groups (angler, business, professional). The list of potential participants was compiled through the promotion process of the survey and from lists of resource professionals from several government and non-government agencies. Of the distributed surveys, 156 were returned (23%). An additional 63 surveys were downloaded and returned from either the MVC or OFAH websites for a known total of 749 distributed and 219 returned (29%). It is not known how many surveys were downloaded from the websites and not returned, but there was a total of 952 viewings of the survey page from both websites (MVC = 429, OFAH = 523). Thus, distribution of the survey and website viewings equalled 1,638, some of which would have undoubtedly been duplicates since people would have been accessing the websites to read about the overall project. Distribution was considered extensive, however, because all regions in Ontario were well represented and a few survey submissions came from the province of Quebec and the states of New York and Pennsylvania (Table 3.1). An additional 88 responses were submitted from participants who belonged to more than one fish resource group, which increased the total number of responses to 307.

Table 3.1. Total number of survey participants by residency and age group, and total number of survey responses by fish resource group, fishing area, business location, and work jurisdiction, 2007. Responses outnumber participants, since many participants belonged to, and responded to, more than one fish resource group (*N* = 88). Ang.–anglers; Bus.–fish resource businesses; Pro.–fish resource professional.

| | Participants by residency and age group (yr) | | | | | | | | | Responses by group | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | *N* | < 20 | 20-29 | 30-39 | 40-49 | 50-59 | 60-69 | 70-79 | 80 > | *N* | Ang. | Bus. | Pro. |
| Northern Ontario | 43 | | 4 | 6 | 13 | 17 | 2 | 1 | | 70 | 32 | 4 | 34 |
| Southern Ontario | 123 | | 7 | 19 | 38 | 41 | 16 | 2 | | 139 | 59 | 8 | 72 |
| Mississippi Valley area[a] | 48 | | 2 | 3 | 7 | 13 | 16 | 5 | 2 | 98 | 70 | 7 | 21 |
| Other[b] | 5 | | 1 | 2 | 1 | | | | | | | | |
| Combined | 219 | | 14 | 30 | 59 | 71 | 34 | 8 | 2 | 307 | 161 | 19 | 127 |

[a] Age group significantly older ($P<0.0001$).
[b] Includes province of Quebec (*N* = 2), states of New York (*N* = 1) and Pennsylvania (*N* = 1), and missing data (*N* = 1).

The modal age group of participants for the northern and southern regions was 50 to 59 years and for the MVA 60 to 69 years. More participants from the MVA were in the older age groups, while younger participants were from the northern and southern areas (Table 3.1). The mean age group of participants was significantly older in the MVA ($P<0.001$, Kruskal-Wallis non-parametric AOV). Males comprised 90.4% of all participants and females 9.6%; they represented 67 different counties, townships, municipalities, and districts (north). Participants listed 222 different water bodies they fished most often (anglers), or where their business operations were located, which were referenced 471 times. By area, this included 53, 100, and 69 water bodies in the north, south, and MVA, respectively.

### 3.3.3.2 Angler Profile

Anglers were well represented from all regions of Ontario (N = 161) (Table 3.1) and had a vast amount of angling experience (40 ± 2.3 yr, mean ± 95% confidence interval (CI)). On the basis of annual angling days, the range of days (2-160) indicated that survey responses were submitted from casual to avid anglers and were likely representative of the general public (Table 3.2). Slightly more than half (52.3%, N=149) were members of an organized club or association; 51 different clubs or associations were listed, including fish and game clubs (68.0%), lake/cottage/property owners associations (14.6%), naturalists/conservation associations (13.6%), councils/professional associations (2.9%), and tourism associations (1.0%).

*Effort*

All anglers indicated they fished during the open-water season, while 72% fished during the ice-cover season. Angling effort, however, was heavily concentrated during the open-water season (83.1%) compared with the ice-cover season (16.9%) (Table 3.2). The north had slightly more effort during the ice-cover season than other areas.

Table 3.2. Years of angling experience, daily annual use of fish resources, and effort indicated by per cent of anglers who fish the open-water and ice-cover seasons, and mean per cent of time fishing each season, by area and areas combined, Ontario, 2007. CI–95% confidence interval; CV–coefficient of variation, %; MVA–Mississippi Valley area; *N*–number of responses.

| | Experience (yr) | | | | Number of days annually | | | | | Open-water effort (%) | | | | | Ice-cover effort (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | *N* | Mean | CI | CV | *N* | Mean | CI | CV | Range | *N* | % | Mean | CI | CV | % | Mean | CI | CV |
| Northern | 30 | 43 | 4.4 | 27.4 | 30 | 42 | 15.7 | 100.5 | 3–160 | 30 | 100 | 78.7 | 6.6 | 22.5 | 90 | 21.3 | 6.6 | 82.8 |
| Southern | 55 | 37 | 3.9 | 38.8 | 56 | 34 | 7.5 | 83.1 | 4–125 | 56 | 100 | 86.5 | 4.5 | 19.5 | 64 | 13.5 | 4.5 | 125.3 |
| MVA | 68 | 42 | 3.7 | 36.9 | 68 | 40 | 8.4 | 88.0 | 2–150 | 67 | 100 | 82.3 | 5.3 | 26.1 | 70 | 17.7 | 5.2 | 121.6 |
| Combined | 153 | 40 | 2.3 | 36.1 | 154 | 38 | 5.4 | 89.9 | 2–160 | 153 | 100 | 83.1 | 3.1 | 23.2 | 72 | 16.9 | 3.1 | 114.4 |

*Annual Expenditures*

Most anglers were residents of Ontario (97.5%), thus expenditures were calculated and classified as direct resident expenditures per year; sport fishing licences and capital costs were not included. The mean number of anglers per household was similar for all areas (2.4) (Table 3.3). Annual household expenditures varied greatly, however, ranging from $40 to $11,100, a strong indication they represented casual to avid anglers. Seasonally, open-water expenses exceeded ice-cover expenses for all areas. Overall, the lowest expenditures occurred in the MVA (mean = $746), while the highest were from southern Ontario (mean = $1,174), but there were no significant difference among areas (ANOVA, alpha=0.05); in this section, all references to mean expenditures are geometric mean values. Northern anglers spend more during the ice-cover season than anglers from the south or MVA, likely related to increased effort.

Table 3.3. Mean number of anglers per household and household expenditures by season (open-water, ice-cover) and annually, by area and areas combined, Ontario, 2007. L95–lower 95% confidence limit; U95–upper 95% confidence limit; MVA–Mississippi Valley area; *N*–number of responses.

| | Anglers | Open-water expenditures per household ($) | | | | | Ice-cover expenditures per household ($) | | | | | Total annual expenditures per household ($) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | Mean | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range |
| Northern | 2.5 | 29 | 837.3 | 543.0 | 1,291.5 | 40-7,000 | 23 | 337.1 | 206.2 | 551.2 | 30-2,650 | 29 | 1,119.4 | 727.9 | 1,721.9 | 40- 8,700 |
| Southern | 2.4 | 55 | 1,065.1 | 795.6 | 1,425.9 | 50-9,000 | 35 | 220.9 | 141.3 | 345.1 | 10-2,100 | 56 | 1,173.5 | 864.2 | 1,593.3 | 50-11,100 |
| MVA | 2.3 | 65 | 660.4 | 483.3 | 902.6 | 30-7,250 | 41 | 170.4 | 107.4 | 270.3 | 05-2,500 | 68 | 746.4 | 547.3 | 1,018.4 | 50- 7,250 |
| Combined | 2.4 | 149 | 825.1 | 681.2 | 999.5 | 30-9,000 | 99 | 218.8 | 167.2 | 286.4 | 05-2,650 | 153 | 951.3 | 783.2 | 1,155.3 | 40-11,100 |

We used a two-step approach to calculate individual expenditures from household expenditures and the number of people within the household who fish (Table 3.3). This approach was used because it provided an estimate of annual expenditures for all residents who fish in Ontario. The estimate included dependents under 16 years, who are not required to purchase a resident sport fishing licence, and because the survey was not restricted to just licensed anglers, the estimate included seniors and non-licensed anglers.

Since the mean number of anglers per household was nearly identical among areas, the general results were the same as for household expenditures; only the values have changed (Table 3.4). Expenses ranged from $10 to $11,100, with an annual mean equal to $472 (lower and upper 95% confidence limits (CL)—$384-$580). Expenditures were lowest in the MVA (mean = $386, 95% CL—$279-$533) and highest in southern Ontario (mean = $575, 95% CL—$404-$819) (Table

Table 3.4. Mean angler expenditures by season (open-water, ice-cover) and annually, by area and areas combined, Ontario, 2007. L95–lower 95% confidence limit; U95–upper 95% confidence limit; MVA–Mississippi Valley area; *N*–number of responses.

| | Open-water expenditures per angler ($) | | | | | Ice-cover expenditures per angler ($) | | | | | Total annual expenditures per angler ($) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range |
| Northern | 29 | 385.3 | 255.6 | 580.8 | 40-4,000 | 23 | 145.4 | 81.4 | 260.0 | 6- 825 | 29 | 515.1 | 339.6 | 781.4 | 40- 4,325 |
| Southern | 55 | 530.9 | 379.1 | 743.2 | 10-9,000 | 35 | 102.3 | 64.4 | 162.4 | 5-2,100 | 56 | 575.3 | 403.9 | 819.4 | 10-11,100 |
| MVA | 65 | 344.0 | 250.0 | 473.3 | 30-6,020 | 41 | 77.0 | 48.2 | 122.9 | 3-2,500 | 68 | 385.8 | 279.2 | 533.2 | 10- 6,020 |
| Combined | 149 | 412.8 | 337.6 | 504.7 | 10-9,000 | 99 | 98.7 | 74.5 | 130.7 | 3-2,650 | 153 | 471.7 | 383.6 | 580.0 | 10-11,100 |

3.4). This difference may be related to local responses within the MVA, since individual expenses in the north were similar to the south (mean = $515, 95% CL—$340-$781), but overall, there were no significant differences among areas (ANOVA, alpha = 0.05).

Unfortunately, we were unable to obtain an estimate of the total number of resident anglers in Ontario (licensed and non-licensed), which was needed to estimate total resident expenditures. The calculated estimate equalled $360.6 million (95% CL—$293.2-$443.3 million) by using the number of active licensed anglers in Ontario for 2005 (N = 764,374) (Department of Fisheries and Oceans 2007). This assumes that the number of active, licensed anglers remained constant and is a conservative estimate because it does not include non-licensed anglers, resident sport fishing licences, and capital costs. If direct non-resident expenditures and direct major purchases for all anglers from 2005 were added (Department of Fisheries and Oceans 2007), all direct angling expenditures would be estimated at approximately $1.67 billion annually.

*Angling Importance*
The reasons why anglers fish and the importance of fishing were similar across Ontario (Table 3.5). In 2007, angling was very much a recreational and social activity in Ontario. In order of mean weighted scores (subsequently referred to as score order) the top four positions were enjoyment (85.0), relaxation (66.4), outdoor lifestyle (55.6), and family time (46.0), while fishing for a source of food was in fifth position (41.4). The score order of the latter two, family time and food, was reversed in the north. Enjoyment, the number one reason for fishing, far exceeded the next four reasons; however, mean scores decreased noticeably afterwards (Table 3.5).

#### 3.3.3.3 Business Profile

The response from fish resource businesses was lowest among all groups (Table 3.1), which led to a high degree of variability, but some important trends can be seen in these data. In total, responses were submitted by 19 businesses (north N = 4, south N = 8, MVA N = 7), representing six types of fish resource businesses in the customer service industry. Total representation (N = 23) was greater than responses because some operated multiple businesses. They included camp operator (N = 2), charter operator/guide (N = 8), lodge/resort operator (N = 5), outfitter/tourist

Table 3.5. Reasons why anglers fished, listed in descending order of importance based on weighted mean scores, by area and areas combined, 2007. Bold type indicates top four ranks. Total number of responses was 54 (northern Ontario *N* = 30, southern Ontario *N* = 56, Mississippi Valley area *N* = 68). MVA–Mississippi Valley area.

| | Ontario combined | | | Northern Ontario | | | Southern Ontario | | | MVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Category | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order |
| Enjoyment | **139** | **85.0** | **1** | **25** | **79.2** | **1** | **53** | **88.6** | **1** | **61** | **84.7** | **1** |
| Relaxation | **122** | **66.4** | **2** | **24** | **62.9** | **3** | **43** | **64.1** | **2** | **55** | **70.0** | **2** |
| Outdoor lifestyle | **102** | **55.6** | **3** | **25** | **68.8** | **2** | **37** | **55.3** | **3** | **40** | **50.1** | **3** |
| Family time | **84** | **46.0** | **4** | 20 | 53.7 | 5 | **28** | **43.9** | **4** | **36** | **44.3** | **4** |
| Food | 86 | 41.4 | 5 | **22** | **55.7** | **4** | 28 | 37.2 | 5 | 36 | 38.5 | 5 |
| Sport | 62 | 28.0 | 6 | 11 | 23.7 | 8 | 23 | 29.7 | 6 | 28 | 28.6 | 6 |
| Socialize | 62 | 28.0 | 7 | 16 | 35.7 | 6 | 22 | 27.0 | 8 | 24 | 25.5 | 7 |
| Challenge | 50 | 24.4 | 8 | 10 | 22.7 | 9 | 21 | 28.6 | 7 | 19 | 21.8 | 8 |
| Tradition | 42 | 18.4 | 9 | 11 | 27.9 | 7 | 13 | 13.5 | 10 | 18 | 18.3 | 9 |
| Culture/heritage | 32 | 13.7 | 10 | 7 | 16.6 | 10 | 14 | 16.8 | 9 | 11 | 9.9 | 11 |
| Right to fish | 17 | 6.4 | 11 | 3 | 4.3 | 12 | 4 | 2.4 | 12 | 10 | 10.5 | 10 |
| Competition | 18 | 6.2 | 12 | 4 | 9.7 | 11 | 8 | 6.5 | 11 | 6 | 4.3 | 12 |
| Other | 0 | | 13 | 0 | | 13 | 0 | | 13 | 0 | | 13 |

operator (N = 4), baitfish operator (N = 3, responded to the business survey), and marina owner (N = 1). Overall, business experience was high (21.6 ± 8.2 yrs, mean ± 95% CI).

Number of operating days, customers, and daily customer expenditures by season suggested that most business occurs during the open-water season (Table 3.6), consistent with when anglers fish most often. Examination of total annual means, however, suggested a longer operating period (N = 93 d) and more customers (N = 1,167) in the MVA compared with the north and south areas, but customer expenditures were lowest (N = $179). This suggests that angling during the ice-cover season may contribute significantly to resource use in the MVA.

The most obvious difference was in the origin of customers among areas (Table 3.7). The mean percent of customers attending southern businesses in the open-water season is fairly evenly split among local (23.8%), regional (19.4%), provincial (22.3%) and out of province (31.3%). In the north and MVA, the majority of customers are from out of province (83.5% and 61.0%, respectively), with only 5.0% local customers in the north. In the ice-cover season, there is a definite shift to local customers in the southern area (53.3%) and the MVA (86.0%). While only 33.3% of businesses operate during the ice-cover season, it is local residents who sustain them.

Table 3.6. Mean annual days of operation, customers, and daily expenditures at fish resource businesses by season (open-water, ice-cover) and seasons combined (total) and by area and areas combined, Ontario, 2007. CI–95% confidence interval; CV–coefficient of variation, %; MVA–Mississippi Valley area; *N*–number of responses.

| | Open water | | | | | Ice cover | | | | | Total | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Annual number of operating days*** | | | | | | | | | | | | | | | |
| Area | *N* | Mean | CI | CV | Range | *N* | Mean | CI | CV | Range | *N* | Mean | CI | CV | Range |
| Northern | 4 | 125 | 83 | 41.9 | 60-180 | 1 | 12 | | | | 4 | 128 | 82 | 40.2 | 60-180 |
| Southern | 8 | 127 | 111 | 104.5 | 7-329 | 3 | 53 | 152 | 116.4 | 1-120 | 8 | 147 | 113 | 91.9 | 7-365 |
| MVA | 6 | 163 | 78 | 45.7 | 65-256 | 2 | 92 | | 26.4 | 75-110 | 6 | 193 | 124 | 60.9 | 65-365 |
| Combined | 18 | 139 | 49 | 71.2 | 7-329 | 6 | 59 | 53 | 85.1 | 1-120 | 18 | 158 | 56 | 71.5 | 7–365 |
| ***Annual number of customers*** | | | | | | | | | | | | | | | |
| Area | *N* | Mean | CI | CV | Range | *N* | Mean | CI | CV | Range | *N* | Mean | CI | CV | Range |
| Northern | 4 | 654 | 1,022 | 98.2 | 100-1,500 | 1 | 10 | | | | 4 | 656 | 1,017 | 97.4 | 110-1,500 |
| Southern | 7 | 157 | 128 | 88.4 | 40- 400 | 3 | 72 | 255 | 143.4 | 5- 190 | 7 | 188 | 124 | 71.1 | 45- 400 |
| MVA | 6 | 792 | 1,223 | 147.2 | 45-3,000 | 2 | 1,125 | | | 750-1,500 | 6 | 1,167 | 1,877 | 153.3 | 45-4,500 |
| Combined | 17 | 498 | 398 | 155.4 | 40-3,000 | 6 | 413 | 635 | 146.6 | 5-1,500 | 17 | 644 | 581 | 175.6 | 45-4,500 |
| ***Daily customer expenditures ($)*** | | | | | | | | | | | | | | | |
| Area | *N* | Mean | CI | CV | Range | *N* | Mean | CI | CV | Range | *N* | Mean | CI | CV | Range |
| Northern | 4 | 212.5 | 221.4 | 65.5 | 90-410 | 1 | 275.0 | | | | 4 | 281.3 | 434.2 | 97.0 | 90-685 |
| Southern | 6 | 161.7 | 146.9 | 86.6 | 25-380 | 1 | 80.0 | | | | 6 | 175.0 | 143.4 | 78.1 | 25-380 |
| MVA | 6 | 102.8 | 97.5 | 90.3 | 30-223 | 2 | 36.0 | | 43.2 | 25- 47 | 6 | 114.8 | 91.6 | 76.0 | 32-223 |
| Combined | 16 | 152.3 | 65.8 | 81.1 | 25-410 | 4 | 106.8 | 182.1 | 107.2 | 25-275 | 16 | 179.0 | 89.3 | 93.7 | 25-685 |

Table 3.7. Mean number of years fish resource businesses have operated, open-water and ice-cover business (%), and origin of customers by travel distance (%), by season, area, and areas combined, Ontario, 2007. CI–95% confidence interval; CV–coefficient of variation, %; MVA–Mississippi Valley area; *N*–number of responses.

| | | | | | Open-water fish resource business | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Customer travel distance (%) | | | | | | | | | | | | |
| | | Years in business | | | Business (%) | | | Local (< 1hr) | | | Regional (1-2 hr) | | | Provincial (> 2 hr) | | | Out of province | | | |
| Area | *N* | Mean | CI | CV | % | CV | *N* | Mean | CI | CV | Mean | CI | CV | Mean | CI | CV | Mean | CI | CV | |
| Northern | 4 | 25.8 | 34.9 | 85.2 | 97.5 | 5.1 | | 5.0 | 6.5 | 81.7 | 3.8 | 7.6 | 127.7 | 7.8 | 14.8 | 120.3 | 83.5 | 28.3 | 21.3 | |
| Southern | 8 | 20.8 | 9.9 | 57.0 | 88.1 | 31.5 | | 23.8 | 21.3 | 107.2 | 19.4 | 15.7 | 97.0 | 25.6 | 22.3 | 104.0 | 31.3 | 24.6 | 94.0 | |
| MVA | 6 | 19.8 | 21.6 | 103.9 | 90.8 | 15.7 | | 22.8 | 41.7 | 173.9 | 6.0 | 12.5 | 198.6 | 6.0 | 8.3 | 131.2 | 61.0 | 46.1 | 72.0 | |
| Combined | 18 | 21.6 | 8.2 | 76.6 | 91.1 | 21.8 | | 19.3 | 14.0 | 146.3 | 11.4 | 7.8 | 136.8 | 15.1 | 10.2 | 135.6 | 52.8 | 18.9 | 72.0 | |
| | | | | | Ice-cover fish resource business | | | | | | | | | | | | | | | |
| Northern | 4 | | | | 2.5 | 200.0 | 1 | 5.0 | | | 5.0 | | | 40.0 | | | 50.0 | | | |
| Southern | 8 | | | | 11.9 | 233.8 | 3 | 53.3 | 125.0 | 94.4 | 6.7 | 28.7 | 173.2 | 38.3 | 134.0 | 140.7 | 1.7 | 7.2 | 173.2 | |
| MVA | 6 | | | | 9.2 | 155.9 | 2 | 86.0 | | 18.1 | 10.5 | | 128.0 | 3.0 | | 94.3 | 0.5 | | 141.4 | |
| Combined | 18 | | | | 8.9 | 223.8 | 6 | 56.2 | 46.3 | 78.5 | 7.7 | 10.2 | 126.9 | 26.8 | 40.7 | 144.6 | 9.3 | 21.0 | 214.5 | |

#### 3.3.3.4 Professional Profile

Fish resource professionals were well represented in all areas of Ontario (N = 127) (Table 3.8). Representation from the MVA was an initial concern because of the smaller geographic size, thus fewer professionals within the area, but many responded (N = 21). Professional experience in fisheries was highest in the MVA (22.9 ± 4.8 yrs) and lowest in the north (16.9 ± 2.8 yrs), Overall, Ontario experience (18.2 ± 1.7 yrs) and current work area experience (15.1 ± 1.7 yrs) decreased slightly, all of which suggests initial placements of younger professionals in the north and some movement prior to settling in one area. There were no significant differences in professional, Ontario, or current work area experience among areas (ANOVA, alpha = 0.05).

Table 3.8. Years of experience for fish resource professionals, including experience in Ontario and current work area, by area and areas combined, Ontario, 2007. CI–95% confidence interval; CV–coefficient of variation, %; MVA–Mississippi Valley area; *N*–number of responses.

| | Professional experience (yr) | | | | | Ontario experience (yr) | | | | | Current work area experience (yr) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | *N* | Mean | CI | CV | Range | *N* | Mean | CI | CV | Range | *N* | Mean | CI | CV | Range |
| Northern | 34 | 16.9 | 2.8 | 47.4 | 2-28 | 34 | 16.7 | 2.8 | 47.3 | 2-28 | 33 | 15.0 | 2.8 | 52.8 | 2-28 |
| Southern | 71 | 18.8 | 2.3 | 51.2 | 2-35 | 71 | 17.9 | 2.4 | 55.4 | 1-35 | 70 | 15.0 | 2.3 | 63.9 | 1-35 |
| MVA | 21 | 22.9 | 4.8 | 46.0 | 5-44 | 21 | 21.5 | 5.1 | 52.4 | 4-44 | 21 | 15.8 | 5.3 | 73.5 | 1-40 |
| Combined | 126 | 19.0 | 1.7 | 50.1 | 2-44 | 126 | 18.2 | 1.7 | 53.5 | 1-44 | 124 | 15.1 | 1.7 | 62.6 | 1-40 |

#### 3.3.3.5 Issues of Concern

Overall, climate change has become one of the top issues of concern regarding fish resources in Ontario (26.6, mean score), although it was positioned fourth, slightly behind water conditions (27.9) and ahead of enforcement services (26.2). The top two issues of importance were invasive species (45.2) and habitat (44.7) (Table 3.9). After these five issues, mean scores decreased considerably. Issues of importance in southern Ontario were very similar to the overall but contained only the top four issues before an obvious decrease in mean scores occurred. Both northern Ontario and MVA were very different, having more issues in which there was a gradual decrease in mean scores (Table 3.9). In the north, the additional issues included regulations/laws (19.8), public education (18.4), and research/biological aspects (15.0). In the MVA, additional issues included pollution control (22.5) and regulations/laws (20.8). The most obvious differences among areas occurred in the north. Instead of invasive species or habitat being in the top position, the highest score recorded in the north was enforcement services (43.5); climate change occupied sixth position (19.4).

Table 3.9. Issues of concern regarding fish resources, listed in descending order of importance on the basis of weighted mean scores, by area and areas combined, 2007. Bold type indicates top four ranks. Total number of responses was 303 (northern Ontario $N = 68$, southern Ontario $N = 137$, Mississippi Valley area $N = 98$). $N$–number of times issue was listed; MVA–Mississippi Valley area.

| | Ontario combined | | | Northern Ontario | | | Southern Ontario | | | MVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Issue | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order |
| Invasive species | **205** | **45.2** | **1** | **40** | **41.7** | **2** | **107** | **54.7** | **1** | **58** | **34.5** | **2** |
| Habitat | **200** | **44.7** | **2** | **36** | **33.8** | **3** | **105** | **53.7** | **2** | **59** | **39.7** | **1** |
| Water conditions | **143** | **27.9** | **3** | **27** | **21.8** | **4** | **74** | **33.1** | **3** | 42 | 24.9 | 5 |
| Climate change | **138** | **26.6** | **4** | 25 | 19.4 | 6 | **76** | **30.8** | **4** | **37** | **25.6** | **4** |
| Enforcement services | 116 | 26.2 | 5 | **39** | **43.5** | **1** | 39 | 17.3 | 5 | **38** | **26.7** | **3** |
| Regulations–laws | 79 | 14.5 | 6 | 25 | 19.8 | 5 | 21 | 7.4 | 9 | 33 | 20.8 | 7 |
| Pollution control | 66 | 13.6 | 7 | 13 | 9.6 | 10 | 19 | 9.3 | 8 | 34 | 22.5 | 6 |
| Research: biological aspects | 79 | 13.5 | 8 | 19 | 15.0 | 8 | 43 | 15.2 | 6 | 17 | 9.9 | 10 |
| Public education | 76 | 13.5 | 9 | 21 | 18.4 | 7 | 28 | 11.2 | 7 | 27 | 13.1 | 9 |
| Hatchery operations–stocking | 40 | 7.9 | 10 | 4 | 5.0 | 12 | 14 | 5.1 | 10 | 22 | 13.9 | 8 |
| Other[a] | 32 | 6.3 | 11 | 12 | 9.9 | 9 | 8 | 3.6 | 11 | 12 | 7.6 | 11 |
| Administrative powers to clubs | 24 | 4.3 | 12 | 7 | 5.1 | 11 | 6 | 2.2 | 13 | 11 | 6.6 | 12 |
| Research: needs of the user | 11 | 1.9 | 13 | 6 | 4.7 | 13 | 3 | 1.5 | 14 | 2 | 0.7 | 14 |
| Lamprey control | 10 | 1.8 | 14 | 0 | 0 | 15 | 8 | 3.6 | 12 | 2 | 0.6 | 15 |
| Landowner–user relations | 10 | 1.7 | 15 | 3 | 2.5 | 14 | 2 | 0.5 | 15 | 5 | 2.8 | 13 |

[a] Consists of nine issues: harvest levels (over-fishing, exploitation, poaching, access–31.2%), dams and hydro facilities (15.6%), municipal planning and regulatory control (12.6%), Native fishing rights (12.5%), double-crested cormorant impacts (9.4%), under-valued fish resource (9.4%), virus mortalities (3.1%), fin clipping and marking (3.1%), and changes in fish species abundance (3.1%).

Examination of the top four issues by fish resource groups indicated some very different results within northern Ontario and the MVA, but not in southern Ontario (Table 3.10). In the north, the top issues were nearly identical for anglers and professionals (enforcement services, invasive species, habitat), with the only difference occurring in the fourth position (Table 3.10). For businesses, however, the top two scores were very different and included public education (31.3) and administration powers to clubs and associations (29.7). In the MVA, all resource groups scored habitat and invasive species in their top four issues, but in different order. The MVA differences occurred mainly between anglers and businesses, which favoured enforcement services and regulations, while professionals favoured climate change and water conditions. In southern Ontario, climate change was obviously an important issue, because all groups scored it in their top four issues. Outside of southern Ontario, however, climate change was not viewed as being nearly as important; only professionals in the MVA scored it in their top four most important issues (Table 3.10).

Over the past three decades, issues concerning fish resources in Ontario have changed significantly (Figure 3.2). In 1976, the four most frequently listed issues of importance (1976-1980) in descending order were pollution control, enforcement services, regulations and laws,

Table 3.10. Top four issues of concern regarding fish resources, listed in descending order based on mean weighted scores, by fish resource group and area, Ontario, 2007. Total number of responses was angler 159, businesses 19, and professionals 125 (northern Ontario $N = 31$, $N = 4$, $N = 33$; southern Ontario $N = 58$, $N = 8$, $N = 71$; Mississippi Valley area $N = 70$, $N = 7$, $N = 21$, respectively). $N$–Frequency issue was listed; Admin.–Administration.

| Anglers | | | | Fish resource businesses | | | | Fish resource professionals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Issue | *N* | Mean score | Rank order | Issue | *N* | Mean score | Rank order | Issue | *N* | Mean score | Rank order |
| ***Northern Ontario*** | | | | | | | | | | | |
| Enforcement services | 17 | 40.7 | 1 | Public education | 2 | 31.3 | 1 | Enforcement services | 20 | 50.0 | 1 |
| Invasive species | 17 | 39.1 | 2 | Admin. powers–clubs | 3 | 29.7 | 2 | Invasive species | 22 | 46.2 | 2 |
| Habitat | 17 | 33.9 | 3 | Regulations–laws | 2 | 29.7 | 3 | Habitat | 19 | 37.9 | 3 |
| Regulations–laws | 11 | 20.2 | 4 | Water conditions | 3 | 29.7 | 4 | Water conditions | 14 | 22.7 | 4 |
| ***Southern Ontario*** | | | | | | | | | | | |
| Invasive species | 45 | 52.7 | 1 | Habitat | 6 | 56.3 | 1 | Invasive species | 56 | 56.8 | 1 |
| Habitat | 44 | 51.8 | 2 | Invasive species | 6 | 50.0 | 2 | Habitat | 55 | 55.0 | 2 |
| Water conditions | 32 | 36.3 | 3 | Water conditions | 5 | 37.5 | 3 | Climate change | 44 | 33.5 | 3 |
| Climate change | 29 | 29.3 | 4 | Other[a] | 2 | 25.0 | 4 | Water conditions | 37 | 30.0 | 4 |
| ***Mississippi Valley area*** | | | | | | | | | | | |
| Habitat | 40 | 37.7 | 1 | Regulations–laws | 4 | 50.0 | 1 | Habitat | 16 | 51.2 | 1 |
| Invasive species | 40 | 33.3 | 2 | Enforcement services | 4 | 42.9 | 2 | Invasive species | 14 | 41.7 | 2 |
| Enforcement services | 29 | 30.2 | 3 | Invasive species | 4 | 25.0 | 3 | Climate change | 11 | 38.1 | 3 |
| Pollution control | 28 | 25.8 | 4 | Habitat | 3 | 25.0 | 4 | Water conditions | 9 | 26.2 | 4 |

[a] Consists of two issues; doubled-crested cormorant impacts (50%) and fish resources being undervalued (50%).

and biological research of the resource (Marcogliese 1977). In 2007, these issues were replaced by invasive species (67.7%), habitat (66.0%), water conditions (47.2%), and climate change (45.5%). Of the top four issues today, water conditions was the only issue common to both surveys and, in 1976, was listed in 11th position (10.4%). While this is not a direct comparison with the 1976 survey (see Survey Design, Section 3.22), the very high frequency of top four issues of 2007 far exceeds the frequencies of the issues that were removed from the 1976 list because of updating (creel census 19.9%, licence fees 17.5%, and licence fees/non-resident 8.0% [Marcogliese 1977]). The high support for today's top four issues was the result of a shift from issues that were common to both surveys.

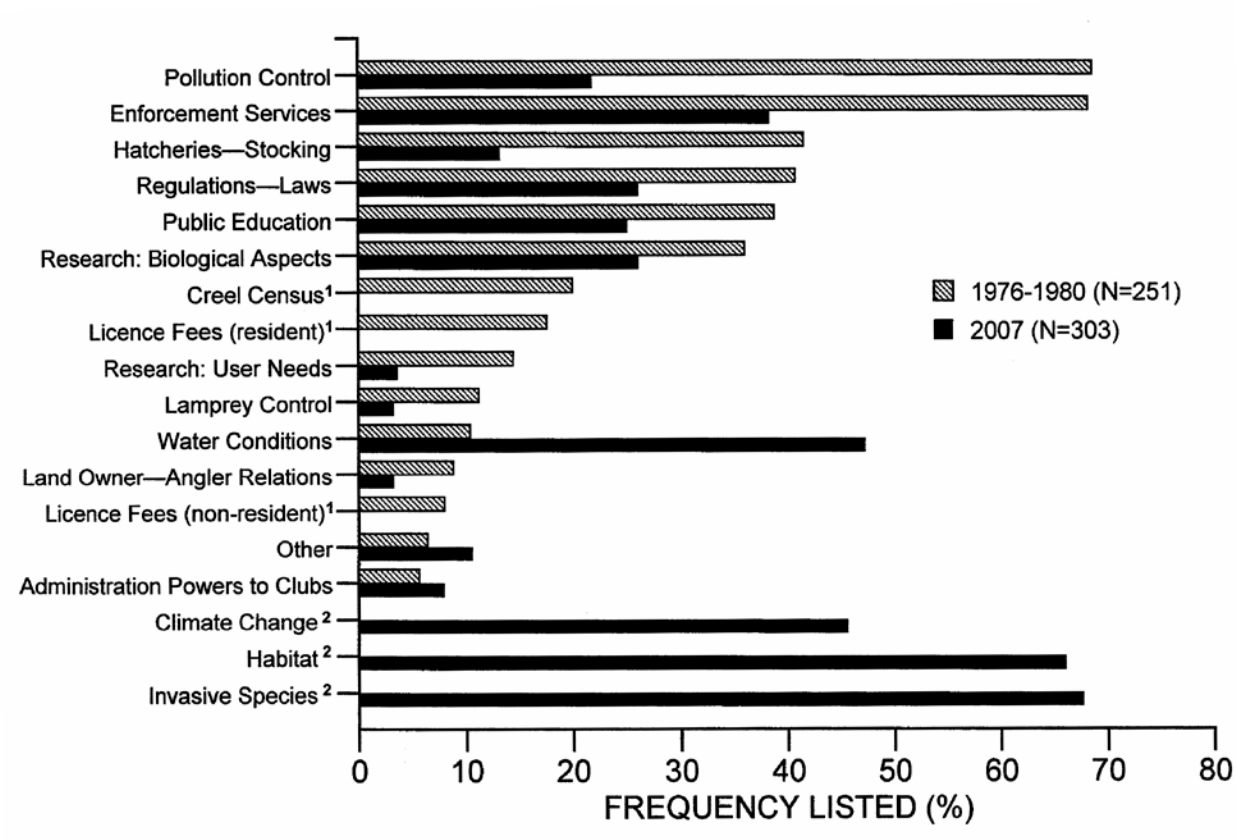



Figure 3.2. Frequency distributions of issues concerning fish resources in Ontario, 1976 (Marcogliese 1977–hatched bars) and 2007 (current survey–solid black bars), areas and fish resource groups combined. Issues are listed in descending order of frequency from the 1976 survey for those considered to be of concern over the next five years (1976-1980). Superscript one ([1]) indicates issues listed in 1976 survey only, and superscript two ([2]) indicates issues listed in 2008 survey only.

### 3.3.3.6 Fish Species of Importance

In Ontario, fish species most often targeted by anglers and customers of fish resource businesses and considered most important by professionals within their jurisdiction were cool- and cold-water (Table 3.11). Walleye, a cool-water species, was unanimously the species with the highest mean score (MS=56.9). Two cold-water species, lake trout (34.3), and brook trout (21.2), occupied the second and fourth positions. Of the top 12 species, smallmouth bass and largemouth bass were the only warm-water species, occupying the third (28.9) and fifth (19.9) positions, respectively. Warm-water species dominated the bottom portion of the list, occupying seven of the bottom ten positions of least targeted or important (Table 3.11)

In northern Ontario, the same cool- and cold-water species (walleye, lake trout, and brook trout) were the most often targeted or important as indicated by all fish resource groups, with northern pike, *Esox lucius*, being added to the list (Table 3.12). The only warm-water species in the top

Table 3.11. Fish species most often targeted by anglers and fish resource business customers and considered most important by fish resource professionals in their jurisdiction, combined, listed in descending order on the basis of weighted mean scores, by area and areas combined, 2007. Bold numbers indicate top four ranks, whereas for species bold and italics indicates warm-water species and non-bold type indicates cool- and cold-water species. Total number of responses was 284 (northern Ontario *N* = 64, southern Ontario *N* = 128, Mississippi Valley area *N* = 92). *N*–frequency species was listed; MVA–Mississippi Valley area.

| | Ontario combined | | | Northern Ontario | | | Southern Ontario | | | MVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order |
| Walleye | **204** | **56.9** | **1** | **56** | **76.2** | **1** | **80** | **47.4** | **1** | **68** | **56.8** | **1** |
| Lake trout | **145** | **34.3** | **2** | **51** | **50.0** | **2** | **54** | **30.1** | **3** | **40** | **29.3** | **4** |
| ***Smallmouth bass*** | **138** | **28.9** | **3** | 13 | 10.5 | 5 | **69** | **32.1** | **2** | **56** | **37.2** | **3** |
| Brook trout | **92** | **21.2** | **4** | **39** | **38.3** | **3** | 39 | 20.2 | 5 | 14 | 10.6 | 6 |
| ***Largemouth bass*** | 84 | 19.9 | 5 | 2 | 1.6 | 16 | 34 | 15.7 | 6 | **48** | **38.4** | **2** |
| Northern pike | 93 | 17.3 | 6 | **25** | **20.3** | **4** | 28 | 10.4 | 9 | 40 | 24.7 | 5 |
| Yellow perch | 62 | 13.0 | 7 | 4 | 2.3 | 12 | **43** | **21.5** | **4** | 15 | 8.6 | 7 |
| Rainbow trout | 50 | 9.0 | 8 | 9 | 7.0 | 7 | 35 | 14.0 | 7 | 6 | 3.4 | 9 |
| Whitefish | 32 | 7.0 | 9 | 8 | 7.4 | 6 | 21 | 10.5 | 8 | 3 | 1.9 | 13 |
| Salmon | 28 | 5.9 | 10 | 4 | 2.7 | 9 | 21 | 10.4 | 10 | 3 | 1.9 | 15 |
| Muskellunge | 29 | 5.1 | 11 | 3 | 2.0 | 14 | 17 | 5.7 | 12 | 9 | 6.5 | 8 |
| Brown trout | 20 | 4.8 | 12 | 0 | 0.0 | 19 | 17 | 9.3 | 11 | 3 | 1.9 | 14 |
| Other[a] | 18 | 3.4 | 13 | 5 | 2.7 | 10 | 9 | 4.9 | 13 | 4 | 1.9 | 12 |
| ***Sunfish*** | 16 | 2.7 | 14 | 1 | 1.6 | 15 | 8 | 3.3 | 15 | 7 | 2.7 | 10 |
| ***Crappie*** | 17 | 2.6 | 15 | 2 | 1.2 | 17 | 9 | 3.3 | 14 | 6 | 2.7 | 11 |
| Lake sturgeon | 9 | 2.0 | 16 | 5 | 5.9 | 8 | 4 | 1.6 | 17 | 0 | 0.0 | 21 |
| ***White perch*** | 6 | 0.9 | 17 | 2 | 0.8 | 18 | 4 | 1.6 | 16 | 0 | 0.0 | 22 |
| Cisco (herring) | 5 | 0.9 | 18 | 2 | 2.0 | 13 | 3 | 1.0 | 19 | 0 | 0.0 | 23 |
| ***Carp*** | 5 | 0.8 | 19 | 0 | 0.0 | 20 | 4 | 1.1 | 18 | 1 | 0.8 | 16 |
| Sauger | 3 | 0.7 | 20 | 2 | 2.3 | 11 | 0 | 0.0 | 23 | 1 | 0.5 | 18 |
| ***Rock bass*** | 5 | 0.5 | 21 | 0 | 0.0 | 21 | 4 | 0.9 | 20 | 1 | 0.3 | 20 |
| ***Channel catfish*** | 3 | 0.4 | 22 | 0 | 0.0 | 22 | 2 | 0.4 | 21 | 1 | 0.8 | 17 |
| ***Brown bullhead*** | 2 | 0.2 | 23 | 0 | 0.0 | 23 | 1 | 0.2 | 22 | 1 | 0.3 | 19 |

[a] Consists of one hybrid, one family, and four species: splake (44.4%), minnow family (Cyprinidae–27.8%), American eel (11.1%), longnose gar (5.6%), alewife (5.6%), and Aurora trout (5.6%).

Table 3.12. Top four fish species most often targeted by anglers, fish resource business customers, and considered most important by fish resource professionals in their jurisdiction, listed in descending order on the basis of weighted mean scores, by area, 2007. Bold type indicates warm-water species and non-bold indicates cool- and cold-water species. Total number of responses was anglers 151, businesses 17, and professionals 116 (northern Ontario $N = 30$, $N = 4$, $N = 30$; southern Ontario $N = 54$, $N = 7$, $N = 67$; Mississippi Valley Area $N = 67$, $N = 6$, $N = 19$, respectively). *N*–Frequency species was listed.

| Anglers | | | | Fish Resource Businesses | | | | Fish Resource Professionals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | *N* | Mean score | Rank order | Species | *N* | Mean score | Rank order | Species | *N* | Mean score | Rank order |
| ***Northern Ontario*** | | | | | | | | | | | |
| Walleye | 29 | 80.8 | 1 | Walleye | 3 | 75.0 | 1 | Walleye | 24 | 71.7 | 1 |
| Lake trout | 21 | 44.2 | 2 | Northern pike | 2 | 37.5 | 2 | Lake trout | 28 | 59.2 | 2 |
| Brook trout | 19 | 40.8 | 3 | Lake trout | 2 | 25.0 | 3 | Brook trout | 20 | 40.8 | 3 |
| Northern pike | 9 | 17.5 | 4 | **Smallmouth bass** | 2 | 25.0 | 4 | Northern pike | 14 | 20.8 | 4 |
| ***Southern Ontario*** | | | | | | | | | | | |
| Walleye | 34 | 42.6 | 1 | **Smallmouth bass** | 7 | 53.6 | 1 | Walleye | 43 | 52.1 | 1 |
| **Smallmouth bass** | 35 | 42.6 | 2 | Walleye | 3 | 39.3 | 2 | Lake trout | 35 | 41.1 | 2 |
| **Largemouth bass** | 22 | 27.7 | 3 | Northern pike | 4 | 32.1 | 3 | Brook trout | 27 | 25.7 | 3 |
| Yellow perch | 19 | 22.2 | 4 | **Largemouth bass** | 2 | 17.9 | 4 | Yellow perch | 23 | 22.0 | 4 |
| ***Mississippi Valley area*** | | | | | | | | | | | |
| Walleye | 48 | 53.7 | 1 | Walleye | 4 | 62.5 | 1 | Walleye | 16 | 65.8 | 1 |
| **Largemouth bass** | 40 | 43.8 | 2 | **Largemouth bass** | 4 | 50.0 | 2 | Lake trout | 14 | 56.6 | 2 |
| **Smallmouth bass** | 46 | 41.7 | 3 | **Smallmouth bass** | 4 | 45.8 | 3 | Brook trout | 8 | 27.6 | 3 |
| Northern pike | 37 | 31.0 | 4 | Muskellunge | 2 | 25.0 | 4 | **Smallmouth bass** | 6 | 18.4 | 4 |

four positions was smallmouth bass, as indicated by businesses. In southern Ontario and the MVA, walleye still occupy the top position, but smallmouth bass and largemouth bass are much more important to anglers and businesses, both listed in the top four. Conversely, the only warm-water species positioned in the top four for professionals was smallmouth bass (4th) in the MVA (MS = 18.4). All other species listed by professionals in these two regions were cool- and cold-water (Table 3.12).

### 3.3.3.7 Observational Knowledge, Changes and Effects

*Environmental Observations*

In Ontario, the vast majority of respondents have observed environmental changes (89.8%, N = 305) (MVA 83.7%, N = 98), and 78.1% (N = 302) indicated these changes have affected the use of fish resources (MVA 69.1%, N = 97). In order of mean scores, the top four observed changes included ice-cover duration (51.4), water levels (50.9), air temperature (49.4), and snowfall (47.1) (Table 3.13). These changes were consistent in southern Ontario and the MVA, but in a slightly different order. In northern Ontario, noticeable differences included ice-cover duration positioned sixth (28.6) and rainfall positioned much higher (fourth—38.4). Observed environmental changes in the north were fairly consistent among anglers, businesses, and professionals, with an obvious absence of changes in both duration and thickness of ice cover (Table 3.14). Instead, observed changes in snowfall and rainfall scored in the top four. In contrast, changes in duration and thickness of ice cover have been observed more often in

Table 3.13. Observed meteorological-related environmental changes listed in descending order based on weighted mean scores, by area and areas combined, 2007. Bold type indicates top four ranks. Total number of responses was 272 (northern Ontario *N* = 61, southern Ontario *N* = 130, Mississippi Valley area *N* = 81). *N*–frequency of observed environmental change; MVA–Mississippi Valley area.

| | Ontario combined | | | Northern Ontario | | | Southern Ontario | | | MVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Environmental change | *N* | Mean score | Rank order | *N* | Mean Score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order |
| Ice cover (duration) | **165** | **51.4** | **1** | 21 | 28.6 | 6 | **93** | **60.9** | **1** | **51** | **53.1** | **2** |
| Water levels | **160** | **50.9** | **2** | **38** | **53.9** | **2** | **78** | **52.0** | **2** | **44** | **46.6** | **4** |
| Air temperature | **151** | **49.4** | **3** | **36** | **56.4** | **1** | **66** | **43.6** | **4** | **49** | **53.4** | **1** |
| Snowfall | **148** | **47.1** | **4** | **34** | **50.2** | **3** | **67** | **44.2** | **3** | **47** | **49.6** | **3** |
| Drought | 101 | 30.7 | 5 | 20 | 27.0 | 8 | 51 | 39.9 | 5 | 20 | 18.6 | 9 |
| Rainfall | 96 | 29.2 | 6 | **28** | **38.4** | **4** | 47 | 29.5 | 7 | 21 | 21.6 | 7 |
| Water temperature | 97 | 28.1 | 7 | 16 | 20.0 | 9 | 48 | 29.2 | 8 | 33 | 32.4 | 5 |
| Ice cover (thickness) | 95 | 26.0 | 8 | 12 | 14.1 | 10 | 52 | 29.9 | 6 | 31 | 28.6 | 6 |
| Winds | 82 | 22.4 | 9 | 21 | 28.6 | 5 | 38 | 20.1 | 9 | 23 | 21.5 | 8 |
| Spring runoff | 69 | 18.8 | 10 | 19 | 27.2 | 7 | 32 | 16.2 | 11 | 18 | 16.8 | 10 |
| Water flow | 52 | 13.6 | 11 | 7 | 8.9 | 11 | 34 | 18.6 | 10 | 11 | 9.1 | 11 |
| Flooding | 29 | 7.9 | 12 | 3 | 4.4 | 12 | 29 | 10.3 | 12 | 7 | 6.6 | 12 |
| Other[a] | 6 | 1.0 | 13 | 1 | 1.3 | 13 | 2 | 0.8 | 13 | 3 | 1.1 | 13 |

[a] Consists of four observed changes: air quality (33.3), electrical storms and storms (33.3%), cloud cover (16.7%), and extreme weather (16.7%).

southern Ontario and the MVA, but overall, changes were more variable among groups within these areas (Table 3.14). Changes in water level, however, were observed consistently in all areas by all fish resource groups. On average, changes in the environment were first noticed from 1995 to 2000, and there was very high agreement as to the types of changes most frequently noticed (84.3 ± 7.7%, mean ± 95% CI, CV = 15.1, range = 50.0-98.0%, N = 13). For example, the most frequently listed change for ice cover (duration) was shorter, as indicated by 93% of responses (N = 152), and for water levels was decreasing (88%, N = 134) (Table 3.15). The vast majority of responses, ranging from 53 to 100% (78.2 ± 7.4%), considered all environmental changes to have negative affects. For the most part, the negative changes can be grouped into four categories that include decreased angling opportunities, decreased quantity and quality of catch, increased difficulty in angling, and increased stress on fish populations. Some responses, although relatively few, considered these changes to be positive (Table 3.15).

*Fish Community Observations*

As with environmental changes, the vast majority of respondents have observed fish community changes (86.6%, N = 306) (MVA 80.4%, N = 97) and 73.4% (N = 301) indicated that these changes have affected the use of fish resources (MVA 70.1%, N = 97). In order of mean scores, the top four observed changes included invasive species (60.8), species abundance (55.1), species type (34.8), and water clarity (32.6) (Table 3.16). Both invasive species and species abundance scored in the top two positions for all areas, but differences were evident in positions

Table 3.14. Top four most observed meteorological (weather) related environmental changes listed in descending order based on mean weighted scores, by fish resource group and area, 2007. Total number of responses was anglers 139, businesses 15, and professionals 118 (northern Ontario $N = 27$, $N = 3$, $N = 31$; southern Ontario $N = 55$, $N = 8$, $N = 67$; Mississippi Valley area $N = 57$, $N = 4$, $N = 20$, respectively). $N$–frequency of observed environmental change.

| Anglers | | | | Fish resource businesses | | | | Fish resource professionals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Environmental change | *N* | Mean score | Rank order | Environmental change | *N* | Mean score | Rank order | Environmental change | *N* | Mean score | Rank order |
| ***Northern Ontario*** | | | | | | | | | | | |
| Air temperature | 15 | 53.3 | 1 | Air temperature | 3 | 92.2 | 1 | Water levels | 21 | 58.8 | 1 |
| Water levels | 16 | 50.6 | 2 | Water levels | 1 | 33.3 | 2 | Air temperature | 18 | 55.7 | 2 |
| Snowfall | 15 | 50.1 | 3 | Snowfall | 1 | 30.8 | 3 | Snowfall | 18 | 52.3 | 3 |
| Rainfall | 11 | 34.4 | 4 | Winds | 1 | 30.8 | 4 | Rainfall | 17 | 45.6 | 4 |
| ***Southern Ontario*** | | | | | | | | | | | |
| Ice cover (duration) | 39 | 60.0 | 1 | Snowfall | 6 | 63.3 | 1 | Ice-cover (duration) | 39 | 63.0 | 1 |
| Water levels | 36 | 58.3 | 2 | Water temperature | 5 | 55.7 | 2 | Air temperature | 40 | 52.1 | 2 |
| Snowfall | 30 | 47.1 | 3 | Ice cover (duration) | 5 | 52.8 | 3 | Water levels | 38 | 47.3 | 3 |
| Drought | 26 | 40.2 | 4 | Ice cover (thickness) | 5 | 50.8 | 4 | Drought | 33 | 41.4 | 4 |
| ***Mississippi valley area*** | | | | | | | | | | | |
| Ice cover (duration) | 34 | 50.6 | 1 | Air Temperature | 3 | 71.1 | 1 | Snowfall | 18 | 74.1 | 1 |
| Water levels | 32 | 48.7 | 2 | Water levels | 3 | 59.5 | 2 | Air temperature | 16 | 70.7 | 2 |
| Air temperature | 30 | 46.1 | 3 | Ice cover (thickness) | 2 | 43.2 | 3 | Ice cover (duration) | 15 | 63.7 | 3 |
| Snowfall | 28 | 42.8 | 4 | Winds | 2 | 42.2 | 4 | Water levels | 9 | 38.0 | 4 |

three and four. In the north, changes in species type and size of fish were most noticeable, while in the south, changes in habitat were most notable (water clarity and submerged plants). In the MVA, the third and fourth positions were a mixture of fish and habitat changes (species type and submerged plants) (Table 3.16). Invasive species and species abundance were observed by nearly all fish resource groups from all areas (Table 3.17). The third and fourth positions, however, varied considerably within the same area; some groups observed more fish-related changes, while others observed habitat changes.

Observed changes in fish communities were first noticed in the mid-1990s, mainly 1996 and 1997, and unlike the environmental changes, there was considerable more variability and less agreement in the types of changes most frequently noticed (48.0 ± 17.8%, mean ± 95% CI, CV = 48.3, range = 23.0-84.0%, N = 9) (Table 3.18). For example, zebra mussuels, *Dreissena polymorpha*, were the most frequently listed change for invasive species although listed by only 29% of responses (N=261) (Table 3.18). Several other changes were listed, but the next three most frequently listed were round goby, *Neogobius melanostomus* (26%); new species range expansion (10%); and warm-water fish expansion (8%). For species abundance, increased warm-water species (23%) was listed most often (N = 297) (Table 3.18), followed by a decrease in cool-water species (22%) and cold-water species (13%). Most of these fish community changes were considered to have negative effects, but not overwhelmingly (58.9 ± 6.3%, range = 48 to 74%). The negative changes can be grouped into one main category with three components:

Table 3.15. Observed meteorological (weather) related environmental changes listed in descending order based on weighted mean scores, areas and fish resource groups combined, Ontario, 2007. Includes mean year in which change was first observed, type of effect (P–positive, N–negative, NE–no effect), type of change most frequently listed (*N*, %), and two most frequently listed positive and negative affects (*N*, %). Total number of responses indicating effects of environmental changes was 236 (northern Ontario *N* = 53; southern Ontario *N* = 116; Mississippi Valley area *N* = 67). *N*–Number of responses (includes multiple responses for type of change); CI–95% confidence interval.

| | Year observed | | | Type of effect | | | | Type of change | | | Two most frequently listed effects | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observed change | *N* | Mean | CI | *N* | %P | %N | %NE | *N* | Most frequent listing | % | *N* | Positive effect | % | *N* | Negative effect | % |
| Ice cover (duration) | 141 | 1997 | 1.3 | 136 | 8 | 84 | 8 | 152 | Shorter | 93 | 8 | Reduced fishing pressure | 38 | 79 | Shorter season | 71 |
| | | | | | | | | | | | | Longer open-water season | 38 | | Unsafe ice conditions | 20 |
| Water levels | 127 | 1998 | 1.2 | 122 | 7 | 87 | 6 | 134 | Decreasing | 88 | 4 | Fish more predictable | 75 | 65 | Reduced access | 29 |
| | | | | | | | | | | | | Increased vegetation to fish | 25 | | Behaviour changes–fish | 23 |
| Air temperature | 129 | 1996 | 1.3 | 86 | 15 | 70 | 15 | 146 | Warmer–hotter | 89 | 10 | Longer open-water season–field work easier | 50 | 39 | Too hot to fish–work | 28 |
| | | | | | | | | | | | | Increased bass populations | 30 | | Alters habitat–thermocline | 13 |
| Snowfall | 131 | 1995 | 1.4 | 80 | 15 | 61 | 24 | 136 | Decreasing–less accumulation | 88 | 9 | Easy access to lakes | 78 | 28 | Reduced access to lakes | 50 |
| | | | | | | | | | | | | Longer open-water season | 11 | | Reduced spawning | 18 |
| Drought | 91 | 1998 | 1.3 | 76 | 7 | 84 | 9 | 87 | Increasing | 98 | 5 | Predictable fishing locations | 60 | 36 | Loss of habitat–sites | 47 |
| | | | | | | | | | | | | Considered good weather | 40 | | Decreased recruitment | 19 |
| Rainfall | 86 | 2000 | 1.1 | 69 | 9 | 76 | 15 | 88 | Decreasing–more extreme events | 78 | 3 | Increased days on water | 33 | 28 | Fishing–sampling difficulty[1] | 39 |
| | | | | | | | | | | | | Species dependent recruitment | 33 | | Reduced catch[a] | 29 |
| Water temperature | 83 | 1998 | 1.8 | 80 | 11 | 78 | 11 | 89 | Warmer–hotter | 96 | 10 | Changes in fish behaviour | 40 | 39 | Changes in fish behaviour | 28 |
| | | | | | | | | | | | | Fish predictable | 20 | | Alters habitat–thermocline | 18 |
| Ice cover (thickness) | 76 | 1995 | 2.1 | 75 | 3 | 88 | 9 | 86 | Thinner | 93 | 0 | None | 0 | 54 | Unsafe ice conditions | 52 |
| | | | | | | | | | | | | | | | Shorter season | 42 |
| Winds | 73 | 1999 | 1.5 | 64 | 3 | 81 | 16 | 80 | Stronger–more frequent | 84 | 0 | None | 0 | 36 | Too rough–dangerous | 47 |
| | | | | | | | | | | | | | | | Decreased use–activity | 39 |
| Spring runoff | 57 | 1998 | 1.6 | 54 | 13 | 72 | 15 | 61 | Decreasing–earlier | 79 | 4 | Earlier open-water season | 50 | 21 | Shorter spawning run | 67 |
| | | | | | | | | | | | | Easier work conditions | 25 | | Spawners vulnerable | 14 |
| Water flow | 39 | 1998 | 2.5 | 40 | 3 | 83 | 14 | 43 | Decreasing–more variable | 88 | 1 | Increased catch | 100 | 21 | Reduced spawning run | 48 |
| | | | | | | | | | | | | | | | Stagnant water | 14 |
| Flooding | 22 | 1997 | 2.7 | 15 | 0 | 53 | 47 | 25 | Increasing–flash flooding | 72 | 0 | None | 0 | 4 | Water quality–runoff | 100 |
| Other[b] | 5 | 1998 | 9.4 | 1 | 0 | 100 | 0 | 6 | Increasing | 50 | 0 | None | 0 | 0 | None | 0 |

[a] Negative effects of decreasing snowfall related to lower water levels.
[b] Includes two environmental changes: air quality-pollution (66.7%) and cloud cover (33.3%).

increased difficulty catching desired species due to altered habitat and community structure, displaced or relocated desired species, and access problems due to increased weed growth. The positive effects belonged to two basic categories: new and increased angling opportunities and increased and improved habitat to fish (Table 3.18).

*Observational Changes and Climate Change*

In Ontario, fewer than half of the respondents (45.4%, N = 291) indicated that they knew of examples of climate change effects on fish communities. Slightly fewer (44.2%, N = 301) felt that climate change had affected the use of fish resources, 16.6% felt that it had not, and a fairly large portion (39.2%) did not know. Half of the respondents, however, attributed at least one of their observed environmental or fish community changes to climate change (50.2%, N = 291), while 19.9% did not and 29.9% did not know.

In the MVA, the relationship between observational changes and climate change was similar to the overall results, but with some differences. Fewer than half of the respondents (43.8%, N = 96), indicated they knew of examples of climate change effects on fish communities, while 43.9% (N = 98) felt that climate change had affected use of fish resources. There was an increase

Table 3.16. Observed fish community changes listed in descending order based on weighted mean scores, by area and areas combined, 2007. Bold type indicates top four ranks. Total number of responses was 264 (northern Ontario $N = 57$, southern Ontario $N = 129$, Mississippi Valley area $N = 78$). $N$–Frequency fish community change was listed; MVA–Mississippi Valley area.

| | Ontario combined | | | Northern Ontario | | | Southern Ontario | | | MVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish community change | $N$ | Mean score | Rank order | $N$ | Mean score | Rank order | $N$ | Mean score | Rank order | $N$ | Mean score | Rank order |
| Invasive species | **177** | **60.8** | **1** | **25** | **38.8** | **2** | **104** | **74.5** | **1** | **48** | **54.1** | **2** |
| Species abundance | **168** | **55.1** | **2** | **35** | **55.8** | **1** | **76** | **48.9** | **2** | **57** | **65.0** | **1** |
| Species type | **113** | **34.8** | **3** | **23** | **35.3** | **3** | 56 | 33.2 | 5 | **34** | **37.2** | **3** |
| Water clarity | **113** | **32.6** | **4** | 14 | 20.1 | 6 | **66** | **38.3** | **3** | 33 | 32.3 | 5 |
| Submerged plants | 106 | 31.5 | 5 | 12 | 17.2 | 8 | **62** | **35.7** | **4** | **32** | **35.0** | **4** |
| Species size | 102 | 30.1 | 6 | **21** | **30.0** | **4** | 53 | 31.4 | 6 | 28 | 27.8 | 6 |
| Introduced species | 86 | 26.3 | 7 | 15 | 24.2 | 5 | 48 | 30.2 | 7 | 23 | 21.2 | 7 |
| Protruding plants | 65 | 17.4 | 8 | 13 | 17.9 | 7 | 33 | 16.5 | 8 | 19 | 18.7 | 8 |
| Other[a] | 13 | 3.6 | 9 | 1 | 1.6 | 9 | 6 | 4.0 | 9 | 6 | 4.4 | 9 |

[a] Consists of six observed changes: fish kills (38.5%), forage base declines (15.4%), improved water quality and habitat (15.4%), secchi disc readings (15.4%), decline in aquatic insects (7.7%), and viruses and botulism (7.7%).

Table 3.17. Top four most observed fish community changes listed in descending order on the basis of weighted mean scores, by fish resource group and area, 2007. Total number of responses was anglers 135, businesses 15, and professionals 114 (northern Ontario $N = 27$, $N = 3$, $N = 27$; southern Ontario $N = 55$, $N = 7$, $N = 67$; Mississippi Valley area $N = 53$, $N = 5$, $N = 20$, respectively). $N$–frequency fish community change was listed.

| Anglers | | | | Fish resource businesses | | | | Fish resource professionals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish community change | $N$ | Mean score | Rank order | Fish community change | $N$ | Mean score | Rank order | Fish community change | $N$ | Mean score | Rank order |
| ***Northern Ontario*** | | | | | | | | | | | |
| Species abundance | 16 | 53.9 | 1 | Species size | 3 | 77.8 | 1 | Species abundance | 17 | 56.4 | 1 |
| Invasive species | 13 | 43.6 | 2 | Species abundance | 2 | 66.7 | 2 | Invasive species | 12 | 38.3 | 2 |
| Species type | 11 | 35.4 | 3 | Emergent plants | 1 | 33.3 | 3 | Species type | 11 | 36.2 | 3 |
| Species size | 11 | 33.3 | 4 | Water clarity | 1 | 29.6 | 4 | Introduced species | 7 | 24.7 | 4 |
| ***Southern Ontario*** | | | | | | | | | | | |
| Invasive species | 43 | 71.7 | 1 | Invasive species | 4 | 54.0 | 1 | Invasive species | 57 | 78.9 | 1 |
| Species abundance | 33 | 51.0 | 2 | Species abundance | 4 | 50.8 | 2 | Species abundance | 39 | 46.9 | 2 |
| Submerged plants | 29 | 39.1 | 3 | Species size | 3 | 30.2 | 3 | Water clarity | 36 | 39.5 | 3 |
| Water clarity | 28 | 38.3 | 4 | Water clarity | 2 | 27.0 | 4 | Species type | 33 | 37.3 | 4 |
| ***Mississippi Valley area*** | | | | | | | | | | | |
| Species abundance | 38 | 64.3 | 1 | Species abundance | 4 | 75.6 | 1 | Invasive species | 17 | 74.5 | 1 |
| Invasive species | 28 | 46.5 | 2 | Invasive species | 3 | 53.3 | 2 | Species abundance | 15 | 64.5 | 2 |
| Submerged plants | 23 | 38.5 | 3 | Water clarity | 3 | 46.7 | 3 | Species type | 9 | 41.1 | 3 |
| Species size | 23 | 37.1 | 4 | Species size | 3 | 46.7 | 4 | Introduced species | 10 | 38.9 | 4 |

Table 3.18—Observed fish community changes listed in descending order on the basis of weighted mean scores, areas and fish resource groups combined, Ontario, 2007. Includes mean year change was first observed, type of effect (P–positive, N–negative, NE–no effect), type of change most frequently listed (*N*, %), and two most frequently listed positive and negative effects (*N*, %). Total number of responses indicating effects of fish community changes was 221 (northern Ontario *N* = 45, southern Ontario *N* = 108, Mississippi Valley area *N* = 68). *N*–number of responses (includes multiple responses for type of change); CI–95% confidence interval.

| | Year observed | | | Type of effect | | | | Type of change | | | Two most frequently listed effects | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observed change | *N* | Mean | CI | *N* | %P | %N | %NE | *N* | Most frequent listing | % | *N* | Positive effect | % | *N* | Negative effect | % |
| Invasive species | 159 | 1996 | 1.6 | 138 | 11 | 74 | 15 | 261 | Zebra mussels | 29 | 2 | Increased programs | 50 | 40 | Habitat altered–fish relocate | 40 |
| | | | | | | | | | | | | Fishing easier | 50 | | Increased programs | 15 |
| Species abundance | 145 | 1996 | 1.2 | 135 | 36 | 59 | 5 | 297 | Increase warm-water species | 23 | 24 | Increased fishing opportunities | 50 | 12 | Native community altered, desired species displaced | 50 |
| | | | | | | | | | | | | New fishing opportunities | 29 | | Decreased desired catch | 17 |
| Species type | 91 | 1996 | 1.7 | 79 | 28 | 64 | 8 | 132 | Shift to warm-water species | 42 | 15 | Fun to catch alternative species | 40 | 21 | Decreased opportunities, quality of desired catch | 43 |
| | | | | | | | | | | | | New fishing opportunities | 33 | | Native community altered | 29 |
| Water clarity | 91 | 1997 | 1.7 | 71 | 16 | 50 | 34 | 109 | Increased clarity | 49 | 6 | Increased fishing opportunities | 67 | 16 | Fishing more difficult–reduced catch | 50 |
| | | | | | | | | | | | | New fishing opportunities | 33 | | Habitat altered–decreased opportunities | 25 |
| Submerged plants | 93 | 1996 | 2.0 | 79 | 28 | 64 | 8 | 97 | Increased growth–density | 84 | 18 | Habitat increased–improved | 83 | 33 | Fishing more difficult–avoid | 36 |
| | | | | | | | | | | | | Under utilized–less pressure | 17 | | Limits navigation–access | 21 |
| Species size | 81 | 1997 | 1.8 | 78 | 34 | 53 | 13 | 118 | Decrease size cool-cold-water species | 36 | 1 | Increased desired catch | 100 | 12 | Decreased quality of catch | 42 |
| | | | | | | | | | | | | | | | Desired community altered | 17 |
| Introduced species | 74 | 1993 | 3.1 | 66 | 43 | 48 | 9 | 115 | Unauthorized–intentional | 24 | 3 | New fishing opportunities | 100 | 11 | Native species displaced | 36 |
| | | | | | | | | | | | | | | | Management issues | 27 |
| Emergent plants | 53 | 1997 | 2.3 | 46 | 17 | 63 | 20 | 50 | Increased growth–density | 78 | 3 | Under utilized–less pressure | 67 | 19 | Limits navigation–access | 32 |
| | | | | | | | | | | | | Habitat increased–improved | 33 | | Fishing more difficult–avoid | 21 |
| Other | 13 | 1996 | 6.0 | 11 | 36 | 55 | 9 | 11 | Increased fish kills | 67 | 0 | None | 0 | 2 | Social–environmental Impacts | 100 |

in those who felt it had not affected use (20.4%) and a slight decrease in the portion who did not know (35.7%). There was a slight increase, however, for those who attributed at least one of their observed environmental or fish community changes to climate change (52.7%, N = 93), while 20.4% did not and 26.9% did not know.

Observed environmental changes were overwhelmingly attributed to climate change (96.8 ± 3.0%, range = 86.9-100.0%), but fish community changes were not (46.0 ± 15.5%, range=18.2-72.9%) (Figure 3.3). Fish community changes that were attributed to something other than climate change (N = 0240) can be grouped into four main categories: invasive species—authorized/unauthorized/inadvertent introduction, expansion (39.7%); water—uses, quality, condition (18.4%); harvest—overfishing, regulations, enforcement (17.1%); and stocking—inadequate, overstocking, non-native (8.8%).

### 3.3.3.7 Adaptation and Impacts to Environmental and Fish Community Changes

*Behavioural Adaptations--Angling*

The majority of respondents agreed that environmental and fish community changes due to climate change would alter angling behaviour (Table 3.19). Most (54%, N=280) either agreed or strongly agreed that there would be decreased time and effort ice-fishing. Opinions differed most for this statement, however, since a small group strongly disagreed (19%). For the remaining statements, the strongest agreement was on how angling effort would change compared with when effort would occur. In order of decreasing magnitude of agreement, these included changes in fishing depths, patterns and techniques, habitat, and sites within a water body (Table 3.19).

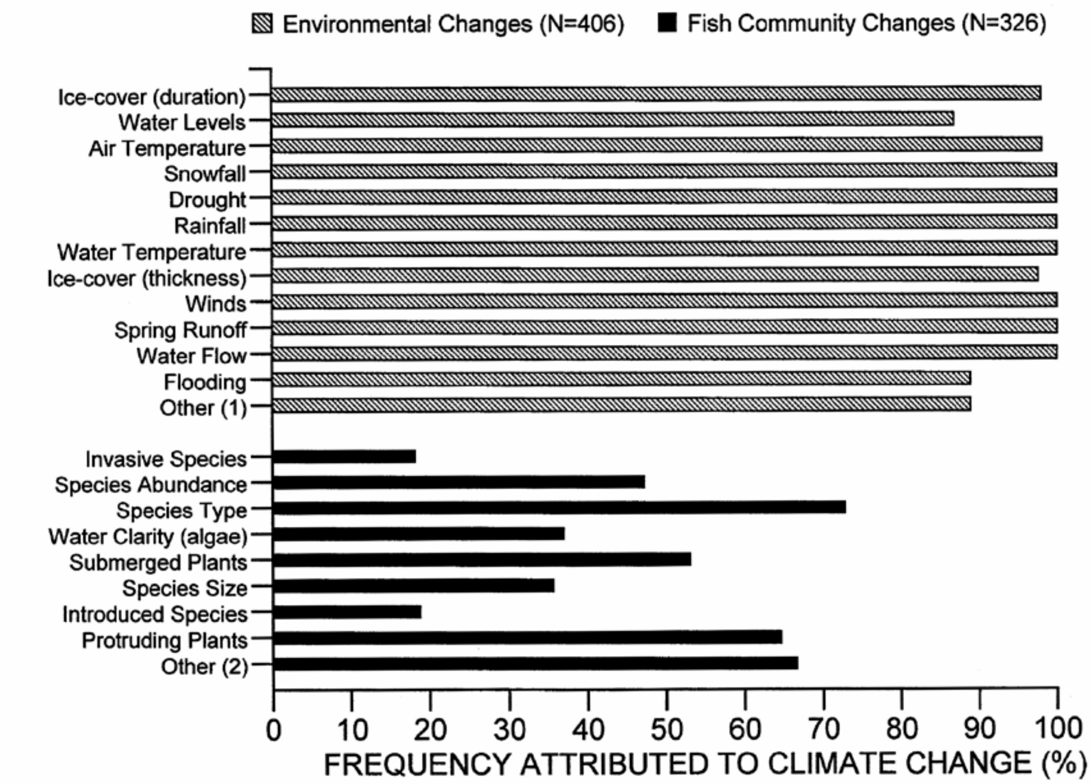



Figure 3.3. Frequency distributions of observed environmental (hatched bars) and fish community changes (solid black bars) that were attributed to climate change, areas and fish resource groups combined, Ontario, 2007. Observed changes are listed in descending order based on weighted mean scores. Total number of responses is indicated (*N*), which includes multiple listings from participants, environmental changes (*N* = 150), and fish community changes (*N* = 157).

Most agreement for timing of effort was for altering dates on which fishing trips were booked to coincide with the weather, but there was a high level of indifference (mode, 21%). There was somewhat to moderate agreement on increased night effort and open-water fishing effort, but the level of agreement was shifting toward indifferent. A decrease in day fishing was the only response that leaned toward disagreement, but again, there was a high level of indifference (median and mode, 26%).

*Behavioural Adaptations—Angling Trips*

Overall, most anglers (50%) go on day-long fishing trips, followed by weekend (31%), and week-long trips (19%) (Table 3.20). Assuming one day for day trips, two days for weekend, and seven days for week, day trips accounted for 18.6 days annually (mean), weekend trips for 11.4 days (mean = 5.7), and week-long trips for 13.3 days (mean=1.9). By duration, the mean number of open-water trips exceeded ice-cover trips for all areas, except week-long ice-cover trips in southern Ontario. Far fewer anglers make week-long ice-cover trips (N = 3), compared with open-water trips (N = 16).

Table 3.19. Behavioural adaptations of anglers to environmental and fish community changes due to climate change, listed from least to most symmetrical distribution (skew, 0=symmetry), in either positive or negative direction, areas and fish resource groups combined, Ontario, 2007. Total number of responses (*N*) is indicated. Frequency (*N*, %) listed for agreement, disagreement, and indifferent responses to the statement indicated in parentheses. Categories for the statement included: agreement categories, 1–somewhat, 2–moderate, 3–agree, 4–strong; disagreement categories: -1–somewhat, -2–moderate, -3–disagree, -4–strong; and 0–indifferent. For overall distribution, median and mode are indicated by category number, and parentheses indicate frequency (%). A negative skew favours agreement, and a positive skew favours disagreement with the statement. The larger the skew in either direction from symmetry (0) increases the level of agreement or disagreement. Bold indicates that the skew favours disagreement.

| | | Agree | | | Disagree | | | Indifferent | | | Overall distribution | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Statement | *N* | *N* | % | Rank order | *N* | % | Rank order | *N* | % | Rank order | Median (%) | Mode (%) | Skew | Rank order |
| Decreased time, effort, ice-fishing | 280 | 202 | 72 | 5 | 45 | 16 | 6 | 33 | 12 | 6 | 3 (19) | 4 (35) | -1.16 | 1 |
| Change fishing depths | 285 | 236 | 83 | 2 | 29 | 10 | 8 | 20 | 7 | 9 | 2 (19) | 4 (26) | -1.11 | 2 |
| Change fishing patterns, techniques | 283 | 235 | 83 | 1 | 34 | 12 | 9 | 14 | 5 | 10 | 2 (28) | 2 (28) | -1.08 | 3 |
| Change habitat fished | 284 | 222 | 78 | 4 | 35 | 12 | 10 | 27 | 10 | 7 | 2 (25) | 2 (25) | -0.93 | 4 |
| Locate new fishing sites | 281 | 221 | 79 | 3 | 41 | 14 | 7 | 19 | 7 | 8 | 2 (20) | 4 (26) | -0.78 | 5 |
| Change trip dates–weather related | 275 | 174 | 63 | 6 | 57 | 21 | 3 | 44 | 16 | 5 | 2 (18) | 0 (21) | -0.66 | 6 |
| Shorter, intense ice-fishing season | 278 | 158 | 57 | 8 | 54 | 19 | 4 | 66 | 24 | 3 | 2 (15) | 4 (20) | -0.53 | 7 |
| Increased open-water fishing | 283 | 172 | 61 | 7 | 48 | 17 | 5 | 63 | 22 | 4 | 1 (15) | 0,3 (17) | -0.50 | 8 |
| Decreased day fishing | 284 | 74 | 26 | 10 | 74 | 26 | **2** | **136** | **48** | **1** | **0 (26)** | **0 (26)** | **0.20** | **9** |
| Increased night fishing | 282 | 82 | 29 | 9 | 106 | 38 | 1 | 94 | 33 | 2 | 0 (38) | 0 (38) | -0.14 | 10 |

Table 3.20. Mean number of angling trips by season (open-water, ice-cover), by duration, area, and areas combined, Ontario, 2007. L95–lower 95% confidence limit; U95–upper 95% confidence limit; MVA–Mississippi Valley area.

| | Open-water days | | | | | Open-water weekends | | | | | Open-water weeks | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range |
| Northern | 24 | 13.5 | 9.2 | 19.7 | 3- 96 | 15 | 3.5 | 2.5 | 5.0 | 1-10 | 8 | 1.2 | 0.9 | 1.6 | 1-2 |
| Southern | 43 | 15.3 | 11.0 | 21.3 | 1- 80 | 27 | 5.7 | 3.8 | 8.8 | 1-40 | 16 | 1.7 | 1.3 | 2.2 | 1-5 |
| MVA | 49 | 16.1 | 11.7 | 22.2 | 1-150 | 32 | 4.6 | 3.4 | 6.2 | 1-25 | 21 | 2.0 | 1.5 | 2.8 | 1-8 |
| Combined | 116 | 15.2 | 12.5 | 18.5 | 1-150 | 74 | 4.7 | 3.8 | 5.8 | 1-40 | 45 | 1.7 | 1.4 | 2.1 | 1-8 |

| | Ice-cover days | | | | | Ice-cover weekends | | | | | Ice-cover weeks | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range |
| Northern | 21 | 2.6 | 2.1 | 3.1 | 2-60 | 7 | 1.5 | 0.8 | 3.0 | 1- 5 | 0 | | | | |
| Southern | 26 | 2.5 | 2.2 | 2.8 | 1-30 | 12 | 2.6 | 1.5 | 4.6 | 1-12 | 3 | 2.4 | 0.2 | 27.9 | 1-7 |
| MVA | 34 | 2.8 | 2.5 | 3.1 | 1-50 | 21 | 2.6 | 1.7 | 4.1 | 1-25 | 3 | 1.6 | 0.6 | 4.3 | 1-2 |
| Combined | 81 | 2.6 | 2.4 | 2.8 | 1-60 | 40 | 2.4 | 1.8 | 3.2 | 1-25 | 6 | 2.0 | 0.9 | 4.1 | 1-7 |

| | Combined days | | | | | Combined weekends | | | | | Combined weeks | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range | *N* | Mean | L95 | U95 | Range |
| Northern | 27 | 17.3 | 12.0 | 25.0 | 3-156 | 16 | 3.9 | 2.7 | 5.6 | 1-15 | 8 | 1.2 | 0.9 | 1.6 | 1- 2 |
| Southern | 44 | 17.8 | 12.8 | 24.5 | 1-100 | 28 | 6.5 | 4.3 | 9.8 | 1-40 | 16 | 1.9 | 1.3 | 2.8 | 1-12 |
| MVA | 52 | 20.0 | 14.5 | 27.7 | 1-180 | 33 | 6.2 | 4.5 | 8.5 | 1-50 | 22 | 2.2 | 1.6 | 2.9 | 1- 8 |
| Combined | 123 | 18.6 | 15.3 | 22.6 | 1-180 | 77 | 5.7 | 4.6 | 7.0 | 1-50 | 46 | 1.9 | 1.5 | 2.3 | 1-12 |

A very high percentage of anglers (81.0%, N = 657) indicated that they would not change number or duration of their angling trips because of an increase in warm-water species. However, 13.9% would decrease their fishing trips, while only 5.2% would increase their trips, a difference of -8.7%. The percent of anglers who would increase their fishing trips was evenly split between open-water and ice-cover trips (5.0% and 5.5% increase, respectively), but not for anglers who would decrease their fishing trips (11.9% and 17.3% decrease, respectively). For the latter, the highest percent decrease was for day trips (16.5%, N = 345), a 14.1 % decrease in the open-water season (N = 205) and a 20.0% decrease during the ice-cover season (N = 140).

*Impacts*

Overall, an increase in warm-water species was considered to be a positive change by only 12.9% of respondents, while almost half (48.6%) considered it a negative change (Table 3.21). The MVA had the highest percentage of responses indicating the change would be positive (18.2%) and the lowest percentage indicating negative (40.9%). Southern Ontario was divided between those who felt there would be an increase (31.7%) and a decrease (50.4%) in resource use and resource revenue (increase 29.8%, decrease 44.6%), with by far the fewest feeling there would be no change (use 17.9%, revenue 25.6%). In northern Ontario and the MVA, more than half of the responses indicated there would be no change in either resource use or revenues and estimated a much lower decrease for both compared with the south (Table 3.21).

**Table 3.21. Frequency (%) of responses indicating type of effect an increase in warm-water fish species would have and frequency (%) estimating the type of impacts on fish resource use and revenue, resource groups combined, by area and areas combined, 2007. *N*–number of responses, Pos.–positive, Neg.–negative, Both–positive and negative, Inc.–increased, Dec.–decreased, NC–no change.**

| | Warm-water species increase (%) | | | | Impacts on resource use (%) | | | | Impacts on resource revenue (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Category | *N* | Pos. | Neg. | Both | *N* | Inc. | Dec. | NC | *N* | Inc. | Dec. | NC |
| Northern Ontario | 63 | 11.1 | 60.3 | 28.6 | 62 | 21.0 | 27.4 | 51.6 | 62 | 19.4 | 29.0 | 51.6 |
| Southern Ontario | 129 | 10.1 | 48.1 | 41.9 | 123 | 31.7 | 50.4 | 17.9 | 121 | 29.8 | 44.6 | 25.6 |
| Mississippi Valley area | 88 | 18.2 | 40.9 | 40.9 | 94 | 13.8 | 36.2 | 50.0 | 93 | 18.3 | 28.0 | 53.8 |
| Combined | 280 | 12.9 | 48.6 | 38.6 | 279 | 23.3 | 40.5 | 36.2 | 276 | 23.6 | 35.5 | 40.9 |

Examining the positive aspect of change, a combined 59.5% of respondents felt there would be no change, or even an increase, in resource use, while even more (64.5%) felt the same about resource revenues (Table 3.21). The majority of anglers (58.8%) who felt an increase in warm-water species was negative or both negative and positive (N = 131) indicated they would not change locations to fish their desired species, but instead would target different species that were more abundant. Only 38.9% would get as much satisfaction from catching a different species (warm-water). This could have social implications.

The positive aspect of change was higher in the MVA, where a combined 63.8% indicated they felt there would be no change, or even an increase, in resource use, while an even greater percent (72.1%) felt the same for resource revenues (Table 3.21). A higher percentage of anglers (64.8%) who felt an increase in warm-water species was negative or both negative and positive (N=91) would target more abundant species instead of changing locations, and slightly more (42.9%) would get as much satisfaction from catching a different species (warm-water). These results suggest that some adaptation may already be occurring in the MVA and that anglers are utilizing warm-water species.

### 3.3.3.8 Adaptive Management Actions

To help offset social and economic impacts, 88.8% (N = 297) of responses (MVA 81.7%, N = 95) indicated that management actions should be taken to adopt and incorporate environmental and fish community changes due to climate change. Overall, public education (MS = 84.1) and regulations (MS = 74.2) were in the top two positions for all areas of Ontario, followed by promotion (MS = 52.9) and stocking (MS = 51.4) (Table 3.22). In the MVA, stocking occupied the third position instead of the fourth. Both removal and harvest programs (MS = 16.9) and no management action (MS = 5.0) scored very low (Table 3.22).

Table 3.22. Management actions believed would be most effective in offsetting social and economic impacts of climate change and a changing fish resource, listed in descending order on the basis of weighted mean scores, by area and areas combined, 2007. Bold type indicates top four ranks. Total number of responses was 276 (northern Ontario *N* = 63, southern Ontario *N* = 122, Mississippi Valley area *N* = 91). *N*–frequency management action was listed; MVA–Mississippi Valley area.

| | Ontario combined | | | Northern Ontario | | | Southern Ontario | | | MVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Management action | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order |
| Public education | **253** | **84.1** | **1** | **56** | **80.9** | **2** | **116** | **87.9** | **1** | **81** | **81.2** | **1** |
| Regulations | **252** | **74.2** | **2** | **61** | **81.8** | **1** | **111** | **72.8** | **2** | **80** | **70.8** | **2** |
| Promotion | **199** | **52.9** | **3** | **50** | **59.2** | **3** | **92** | **54.3** | **3** | **57** | **46.6** | **4** |
| Stocking | **194** | **51.4** | **4** | **51** | **55.3** | **4** | **82** | **48.5** | **4** | **61** | **52.6** | **3** |
| Removal—harvest programs | 180 | 16.9 | 5 | 15 | 12.2 | 5 | 37 | 18.7 | 5 | 28 | 17.7 | 5 |
| No management | 23 | 5.0 | 6 | 7 | 4.5 | 6 | 8 | 3.4 | 7 | 8 | 7.5 | 6 |
| Other[a] | 11 | 3.4 | 7 | 2 | 3.0 | 7 | 7 | 5.5 | 6 | 2 | 0.8 | 7 |

[a] Consists of six management actions: increase and improve habitat (36.4%), increase enforcement presence in the field (18.2%), maximize watershed resilience (18.2%), research (9.1%), First Nations fishing rights (9.1%), and Fish Community Management Plans (9.1%).

The top four issues were the same for all areas of Ontario, but there were distinct differences in score orders between anglers, businesses, and professionals (Table 3.23). In all areas, both anglers and businesses scored stocking higher than professionals and promotion lower. Businesses in the north and south areas scored stocking the highest, which was different from

Table 3.23. Top four management actions that would be considered most effective in offsetting social and economic impacts of climate change and a changing fish resource, listed in descending order based on weighted mean scores, by fish resource group and area, 2007. Total number of responses was anglers 144, businesses 16, and professionals 116 (northern Ontario $N = 29$, $N = 2$, $N = 32$; southern Ontario $N = 52$, $N = 7$, $N = 63$; Mississippi Valley area–$N = 63$, $N = 7$, $N = 21$, respectively). $N$–frequency with which management action was listed.

| Anglers | | | | Fish resource businesses | | | | Fish resource professionals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Management actions | *N* | Mean score | Rank order | Management actions | *N* | Mean score | Rank order | Management actions | *N* | Mean score | Rank order |
| ***Northern Ontario*** | | | | | | | | | | | |
| Regulations | 27 | 79.8 | 1 | Stocking[a] | 2 | 85.7 | 1 | Public education | 30 | 87.0 | 1 |
| Public education | 25 | 76.3 | 2 | Regulations[a] | 2 | 85.7 | 2 | Regulations | 32 | 83.5 | 2 |
| Stocking | 24 | 58.6 | 3 | Public education | 1 | 50.0 | 3 | Promotion | 28 | 64.7 | 3 |
| Promotion | 21 | 55.2 | 4 | Promotion | 1 | 28.6 | 4 | Stocking | 25 | 50.4 | 4 |
| ***Southern Ontario*** | | | | | | | | | | | |
| Public education | 48 | 84.1 | 1 | Stocking | 5 | 85.7 | 1 | Public education | 61 | 92.3 | 1 |
| Regulations | 46 | 70.9 | 2 | Regulations | 7 | 83.7 | 2 | Regulations | 58 | 73.2 | 2 |
| Stocking | 39 | 56.0 | 3 | Public education | 7 | 77.5 | 3 | Promotion | 47 | 55.3 | 3 |
| Promotion | 40 | 54.9 | 4 | Promotion | 5 | 40.8 | 4 | Stocking | 36 | 38.1 | 4 |
| ***Mississippi Valley area*** | | | | | | | | | | | |
| Public education | 56 | 80.0 | 1 | Public education | 6 | 75.5 | 1 | Public education | 19 | 86.4 | 1 |
| Regulations | 56 | 70.7 | 2 | Regulations | 6 | 67.3 | 2 | Regulations | 18 | 72.1 | 2 |
| Stocking | 46 | 57.8 | 3 | Stocking | 4 | 51.0 | 3 | Promotion | 14 | 50.3 | 3 |
| Promotion | 39 | 46.2 | 4 | Promotion | 4 | 38.8 | 4 | Stocking | 11 | 37.4 | 4 |

[a] Mean score of management actions were tied, listed in order of lowest variability.

both anglers and professionals. In the MVA, there was consensus among groups about the top two scores, public education and regulations.

Science was overwhelmingly the number one basis for any management action (MS = 95.0). Management actions based on social (MS = 48.6) and economic issues (MS = 46.6) were a very distant second and third (Table 3.24). Even by fish resource group, science was overwhelmingly the number one basis for management decisions, but anglers in southern Ontario and the MVA positioned economic concerns ahead of social concerns (Table 3.25). Somewhat surprisingly, businesses scored economics last in the north and south and tied with social concerns in the MVA.

To deal with impacts and adaptations to climate change, 85.6% (N = 288) of respondents (MVA 86.3%, N = 91) indicated that a fish policy and management plan should be developed. A few comments indicated that separate documents were not necessary but could be incorporated into Ontario's existing policy and plan. Participation should come from all levels of government, science, academia, non-government organizations, and knowledgeable local stakeholders.

Table 3.24. Basis for management actions that would be considered most effective in offsetting social and economic impacts of climate change and a changing fish resource, listed in descending order based on weighted mean scores, by area and areas combined, 2007. Bold type indicates highest rank. Total number of responses was 219 (northern Ontario *N* = 58, southern Ontario *N* = 96, Mississippi Valley area *N* = 65). *N*–frequency basis for management action was listed; MVA–Mississippi Valley area.

| | Ontario combined | | | Northern Ontario | | | Southern Ontario | | | MVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Basis for management action | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order |
| Scientific | **216** | **95.0** | **1** | **55** | **95.7** | **1** | **95** | **95.3** | **1** | **63** | **93.8** | **1** |
| Social | 158 | 48.6 | 2 | 37 | 45.7 | 2 | 79 | 52.8 | 3 | 42 | 45.0 | 2 |
| Economic | 159 | 46.6 | 3 | 34 | 36.2 | 3 | 80 | 54.1 | 2 | 45 | 44.6 | 3 |

Table 3.25. Basis for management actions that would be considered most effective in offsetting social and economic impacts of climate change and a changing fish resource, listed in descending order based on weighted mean scores, by fish resource group and area, 2007. Total number of responses were: anglers 110, businesses 14, and professionals 95 (northern Ontario *N* = 27, *N* = 4, *N* = 27; southern Ontario *N* = 40, *N* = 5, *N* = 51; Mississippi Valley area *N* = 43, *N* = 5, *N* = 17, respectively). *N*–frequency basis for management action was listed.

| Anglers | | | | Fish resource businesses | | | | Fish resource professionals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Basis for management actions | *N* | Mean score | Rank order | Basis for management actions | *N* | Mean score | Rank order | Basis for management actions | *N* | Mean score | Rank order |
| ***Northern Ontario*** | | | | | | | | | | | |
| Scientific | 27 | 97.2 | 1 | Scientific | 4 | 93.8 | 1 | Scientific | 27 | 94.4 | 1 |
| Social | 17 | 46.3 | 2 | Social | 3 | 62.5 | 2 | Social | 17 | 42.6 | 2 |
| Economic | 15 | 33.3 | 3 | Economic | 4 | 56.3 | 3 | Economic | 15 | 36.1 | 3 |
| ***Southern Ontario*** | | | | | | | | | | | |
| Scientific | 40 | 96.3 | 1 | Scientific | 5 | 90.0 | 1 | Scientific | 50 | 95.1 | 1 |
| Economic | 33 | 54.4 | 2 | Social | 5 | 80.0 | 2 | Economic | 42 | 53.8 | 2 |
| Social | 32 | 51.3 | 3 | Economic | 5 | 55.0 | 3 | Social | 42 | 51.4 | 3 |
| ***Mississippi Valley area*** | | | | | | | | | | | |
| Scientific | 42 | 94.8 | 1 | Scientific | 4 | 70.0 | 1 | Scientific | 17 | 98.5 | 1 |
| Economic | 30 | 47.1 | 2 | Economic[a] | 3 | 45.0 | 2 | Social | 13 | 55.9 | 2 |
| Social | 26 | 40.7 | 3 | Social[a] | 3 | 45.0 | 3 | Economic | 12 | 38.2 | 3 |

[a] Mean scores were tied and of equal variability, therefore were listed in alphabetical order.

### 3.3.3.9 Water Management and Multi-Purpose Use

During periods of low water levels, fisheries concerns were the most important across Ontario (Table 3.26). In order of priority, fish spawning areas (MS = 82.1), nursery habitat (MS = 72.9), and environmentally sensitive areas (ESA) (MS = 65.8) were in the top three positions throughout Ontario. This was not unexpected, because survey respondents were specifically

**Table 3.26. Assigning priority to water use when managing levels and flows during periods of decreased water abundance, listed in descending order based on weighted mean scores, by area and areas combined, 2007. Bold type indicates top four ranks. Total number of responses was 295 (northern Ontario *N* = 68, southern Ontario *N* = 130, Mississippi Valley area *N* = 97). *N*–frequency water use was listed; MVA–Mississippi Valley area.**

| | Ontario combined | | | Northern Ontario | | | Southern Ontario | | | MVA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Use | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order | *N* | Mean score | Rank order |
| Fish spawning areas | **272** | **82.1** | **1** | **63** | **84.6** | **1** | **122** | **83.0** | **1** | **87** | **79.0** | **1** |
| Fish nursery habitat | **261** | **72.9** | **2** | **60** | **73.7** | **2** | **119** | **75.2** | **2** | **82** | **69.2** | **2** |
| Environmental sensitive areas | **244** | **65.8** | **3** | **50** | **55.6** | **3** | **116** | **72.5** | **3** | **78** | **64.0** | **3** |
| Consumption | **209** | **51.4** | **4** | 46 | 50.7 | 5 | **98** | **54.3** | **4** | **65** | **48.4** | **4** |
| Hydro generation | 215 | 44.1 | 5 | **53** | **51.6** | **4** | 100 | 44.1 | 6 | 62 | 38.8 | 7 |
| Homes and cottages | 219 | 41.6 | 6 | 51 | 46.7 | 6 | 99 | 38.3 | 8 | 69 | 42.6 | 5 |
| Navigation/transportation | 213 | 41.0 | 7 | 48 | 40.4 | 7 | 102 | 42.6 | 7 | 63 | 39.4 | 6 |
| Agriculture | 208 | 39.4 | 8 | 39 | 29.4 | 8 | 105 | 48.9 | 5 | 64 | 33.7 | 8 |
| Water sports and recreation | 195 | 23.5 | 9 | 41 | 19.9 | 9 | 97 | 24.1 | 9 | 57 | 25.1 | 9 |
| Historical or traditional Sites | 159 | 19.9 | 10 | 35 | 19.1 | 10 | 82 | 22.7 | 10 | 42 | 16.9 | 10 |
| Other[a] | 3 | 1.0 | 11 | 0 | 0.0 | 11 | 2 | 1.5 | 11 | 1 | 0.9 | 11 |

[a] Consists of three water uses: biodiversity (33.3%), wastewater treatment (33.3%), and developmental planning (33.3%).

targeted from groups associated with fish resources. Some differences started to occur at the fourth position, where southern Ontario and the MVA scored consumption, whereas in the north,
the fourth position was occupied by hydro generation; hydro generation was seventh in the MVA (Table 3.26). The other noticeable differences occurred in the north, where agriculture was considered the fifth highest priority (MS = 48.9), although it was only eighth overall (MS=39.4), and in the MVA, where homes and cottages (MS = 42.6) was positioned higher than the overall.

Anglers, businesses, and professionals all positioned fish spawning areas, nursery habitat, and ESAs in their top four priorities of water use, but in different score order. There was little agreement on the fourth highest priority use (Table 3.27). Consumption was considered important by anglers and professionals in the MVA, but not by businesses. All businesses considered homes and cottages, and navigation and transportation, as one of their top priority uses, but no other group did.

### 3.3.4 Discussion

Environmental and fish community changes are occurring across the province of Ontario, and people associated with fish resources, anglers, businesses, and professionals are noticing these changes. Science has documented the changes, some of which include earlier springs and later falls, delayed lake cooling and fall turnover, decreased duration of winter ice cover, lack of winter precipitation, and reduced spring runoff and flow (see Section 3.1, Subproject 1). As global climate change progresses, hydrologic modelling in the Mississippi Valley watershed to 2099 forecasts continued changes, which will stress and limit water resources Some of these

Table 3.27. Assigning priority to water use when managing levels and flows during periods of decreased water abundance, listed in descending order on the basis of weighted mean scores, by fish resource group and area, Ontario, 2007. Total number of responses was anglers 155, businesses 18, and professionals 122 (northern Ontario $N = 32$, $N = 4$, $N = 32$; southern Ontario $N = 54$, $N = 7$, $N = 69$; Mississippi Valley area $N = 69$, $N = 7$, $N = 21$, respectively). $N$–frequency water use was listed; ESA–Environmentally Sensitive Areas.

| Anglers | | | | Fish resource businesses | | | | Fish resource professionals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water use | *N* | Mean score | Rank order | Water use | *N* | Mean score | Rank order | Water use | *N* | Mean score | Rank order |
| ***Northern Ontario*** | | | | | | | | | | | |
| Fish spawning areas | 29 | 83.8 | 1 | Fish spawning areas | 4 | 93.2 | 1 | Fish spawning areas | 30 | 84.4 | 1 |
| Fish nursery habitat | 27 | 72.3 | 2 | Homes and cottages | 4 | 79.5 | 2 | Fish nursery habitat | 30 | 76.4 | 2 |
| Hydro generation | 24 | 51.4 | 3 | ESA | 4 | 65.9 | 3 | ESA | 25 | 60.5 | 3 |
| ESA | 21 | 49.3 | 4 | Fish nursery habitat | 3 | 63.6 | 4 | Consumption | 24 | 56.8 | 4 |
| ***Southern Ontario*** | | | | | | | | | | | |
| Fish spawning areas | 48 | 78.7 | 1 | Fish spawning areas | 7 | 81.2 | 1 | Fish spawning areas | 67 | 86.5 | 1 |
| ESA | 47 | 70.5 | 2 | Fish nursery habitat | 7 | 76.0 | 2 | Fish nursery habitat | 66 | 79.4 | 2 |
| Fish nursery habitat | 46 | 69.6 | 3 | Navigation/transportation | 6 | 52.0 | 3 | ESA | 64 | 76.1 | 3 |
| Consumption | 43 | 60.0 | 4 | ESA | 5 | 52.0 | 4 | Agriculture | 57 | 50.7 | 4 |
| ***Mississippi Valley area*** | | | | | | | | | | | |
| Fish spawning areas | 60 | 76.2 | 1 | Fish spawning areas | 7 | 92.2 | 1 | Fish spawning areas | 20 | 84.0 | 1 |
| Fish nursery habitat | 57 | 66.9 | 2 | ESA | 6 | 68.8 | 2 | Fish nursery habitat | 20 | 80.1 | 2 |
| ESA | 54 | 61.8 | 3 | Fish nursery habitat | 5 | 58.4 | 3 | ESA | 18 | 69.7 | 3 |
| Consumption | 45 | 47.0 | 4 | Navigation/Transportation | 5 | 48.1 | 4 | Consumption | 16 | 53.0 | 4 |

changes include shifts to earlier spring runoff, increases in evapotranspiration, extended summer dry period, and increased water temperature (see Section 3.4, Subproject 4). These changes will stress current fish populations, since even subtle environmental changes can result in significant changes in growth, maturity, reproductive success, survival, and abundance, which will ultimately change the structure of fish communities because some species, especially warm-water species, adapt more readily to these changes (see Section 3.1, Subproject 1). However, environmental changes can be variable across regions, and the degree and type of change in any given water body is local and species-dependent. This was documented through the survey, since many observed changes were common across Ontario, but others were more area-specific with varying degrees of importance.

Over the past three decades, many changes have already occurred as issues concerning fish resources in Ontario have changed significantly. In 1976, the four most frequently listed issues were pollution control, enforcement services, hatcheries and stocking, and regulations and laws (Marcogliese 1977). In 2007, these four issues decreased in importance, now occupying positions from five to nine. They were replaced by three new issues not even considered in 1976—invasive species, habitat, and climate change, and one issue, water conditions, which had a 4.6-fold increase in importance (Figure 3.2). While climate change has become the fourth top issue across Ontario, the level of importance has regional differences (Table 3.9 and 3.10). It was scored (mean weighted score) highest in southern Ontario by professionals and anglers and in the MVA by professionals. In northern Ontario, however, it was not in the top four for any group and was positioned sixth overall; the top issue in the north was enforcement services.

Issues concerning fish resources in Ontario strongly reflect changes observed by people associated with fish resources. Most (89.8%; MVA 83.7%) have noticed environmental changes, and 78.1% (MVA 69.1%) indicated that these changes have affected the use of fish resources. In order of most noticeable change, the four top observations include shorter duration of ice cover, decreasing water levels, increasing air temperature, and decreasing snowfall and accumulation (Tables 3.13 and 3.14). These four observations were constant in southern Ontario and the MVA, but there were differences in northern Ontario: ice cover was not a top four observation, but decreasing rainfall with more extreme events was. These changes are consistent with documented changes attributed to global climate change. On average, most environmental changes were first noticed between 1995 to 2000 and were considered by most to have negative effects (78.2 ± 7.4%, overall mean ± 95% CI), which included decreased angling opportunities, decreased quantity and quality of catch, increased difficulty angling, and increased stress on fish populations.

Most (86.6%, MVA 80.4%) have noticed fish community changes, and 73.4% (MVA 70.1%) indicated that these changes have affected the use of fish resources. In order, the four most noticeable changes were increased invasive species, increased abundance of warm-water species, species type shifting to warm-water species, and increased water clarity (Tables 3.16-3.18). Under species abundance, the most frequently listed change was increased abundance of warm-water species (23%), which was followed by decreases in cool- and cold-water species (22% and 13%, respectively), all of which are consistent with documented changes attributed to climate change. The relationship with the other two observed changes, however, may not be as direct. For invasive species, zebra mussels (29%) and gobies (26%) were listed most often. Invasive species were not limited to exotic introductions but included range expansion of new species (10%), and warm-water fish (8%). Species require favourable conditions to expand ranges; thus increased water clarity, which was mainly attributed to zebra mussels, may be related to range expansions. Most fish community changes were first noticed in the mid-1990s and were considered by most to have negative affects, but not overwhelmingly (58.9 ± 6.3%, overall mean ± 95% CI). The negative effects can be grouped into one main category which is increased difficulty catching desired species due to altered habitat and community structure, displaced or relocated desired species, and access problems due to increased weed growth. Some viewed these changes as positive, however, which included new and increased angling opportunities and increased and improved habitat. Positive or negative effects all depended on desired species.

By examining fish species most often targeted or most important, it is easy to understand why the observed environmental and fish community changes are seen as predominately negative. Of the top 12 species, 10 are either cool- or cold-water, while seven of the bottom 10 species least often targeted are warm-water (Table 3.11). The only two warm-water species in the top 12 are smallmouth bass and largemouth bass, which are positioned third and fifth, respectively. Fortunately, both species are high in importance for anglers and businesses in southern Ontario and the MVA (Table 3.12). Their use and importance in northern Ontario, however, is mostly nonexistent, since cool- and cold-water species dominate. This is the same for professionals from all areas; the only warm-water species to be scored in the top four were smallmouth bass in the MVA. The rest were cool- and cold-water species.

Knowledge about climate change and fish resources was limited, since fewer than half (45.4%) knew of any effects or examples. This lack of knowledge likely resulted in only 44.2% of responses indicating that climate change had affected the use of fish resources. By comparison, in a poll released in September 2007, 68% of Ontarians said they had personally experienced climate change (Harris-Decima, www.cbc.ca/news). The large percent difference supports the notion that climate change effects have not been broadly related to fish resources. Only half (50.2%) attributed at least one of their observed changes to climate change, but it was environmental changes mostly attributed to climate change, not fish community changes (Figure 3.3). Fish community changes were attributed mostly to issues related to invasive species (39.7%), water (18.4%), harvest (17.1%), and stocking (8.8%).

Fish are a valuable resource in Ontario, with direct resident expenditures of $472 (95% CL—$384-$580) per angler annually (Table 3.4). Using data from 2005 (Department of Fisheries and Oceans 2007) on active licensed anglers, non-resident anglers, and major purchases (capital, land, etc.), a conservative estimate of expenditures attributed directly to recreational angling is $1.67 billion annually. This should not be confused with the value of the fishery, which is much more difficult to assess (Solomon 2003). Placing a value on a fishery would require a benefit:cost analysis, which monetarily would be considerably higher than expenditures. This would take into consideration values such as replacement cost of fish and the value of the fishery to anglers and the local economy (Weithman and Haas 1982). Some would argue, however, that benefit:cost analysis tries to do the impossible, because it implies that a cash value can be placed on everything, including the existence value of environmental resources (Adams 1994), while others cite the difficulties in placing a value on angler enjoyment (Solomon 2003).

It is difficult to measure the exact impacts of fish community changes consistent with climate change effects, but there will be some redistribution of fish resource use and revenue, since anglers are somewhat reluctant to adapt. Most anglers agree that adaptations will have to be made in angling effort, including changes in fishing depths, habitat, patterns and techniques, sites, and those imposed by changing environmental conditions (shorter ice-cover season) (Table 3.19). On the basis of their documented observations and impacts, many are already making these adaptations, but these are mostly attempts to continue catching their desired species, which are predominately cool- and cold-water. Only 12.9% considered an increase in warm-water species to be a positive change, while almost half

(48.6%) considered it a negative change (Table 3.21). Somewhat encouraging is that most (59.5%) indicated there would be an increase or no change in fish resource use, and 58.8% of those who felt the changes would be negative would adapt by targeting different species instead of relocating. There would be a degree of social impact, however, since only 38.9% would get as much satisfaction from fishing a different species. This is related to the reasons why people fish. In Ontario today, angling is very much a recreational and social activity, playing an important personal role in enjoying oneself, relaxing, lifestyle, and family time (Table 3.5). Similarly, 64.5% indicated that there would be an increase or no change in resource revenues, but for both revenue and use, 36 to 41% of responses indicated a decrease. The largest decrease was estimated for southern Ontario.

While only 13.9% of anglers indicated that they would change the number and duration of their fishing trips, the initial impacts would be felt locally. The highest decreases were documented for day trips, a 14.1% decrease in open-water day trips and a 20.0% decrease in ice-cover day trips. These decreases could prove to be significant since most angling effort occurs locally, within a one-hour or 100-km drive (Table 3.2). Conversely, non-resident anglers strongly support fish resource businesses during the open-water season, especially in the north (83.5%) and MVA (61.0%); thus impacts are not known, since 97.5% of responses were from resident anglers. This trend has not changed over the past three decades; Marcogliese (1977) reported that almost 60% of non-resident angling was done in the north. It is reasonable to assume that non-resident trips to the north and the MVA are longer than one day, thus potentially lessening the initial impacts. This may not be the case during the ice-cover season, however, as southern Ontario (53.3%) and the MVA (86.0%) recorded a shift to local anglers during this season. Thus they would not be immune to the impacts; data were scarce for ice-cover customers in the north. Scott et al. (2002) estimated a 30 to 34% economic loss to the recreational ice-fishing industry in Lake Simcoe, Ontario, by the 2020s because of a shorter season due to climate change.

Some adaptation to warm-water species is already occurring in the MVA. Compared with northern and southern Ontario, more anglers in the MVA considered an increase in warm-water species as positive (18.2%), and half to slightly more than half felt there would be no change in resource use and revenue (50.0% and 53.8%, respectively) (Table 3.21). Examination of the species targeted most often indicated that anglers in the MVA are using warm-water species, because both smallmouth and largemouth bass were in their top four species.

While adaptation in the MVA is encouraging, a scenario appears to be developing that would see social and economic impacts on fish resource use in Ontario. Many observational changes are consistent with documented science in that warm-water species are increasing in abundance, but most warm-water species are underutilized and predominately viewed as negative. The types and levels of impacts will be based on two issues—the degree of site-specific changes and the ability and willingness of those associated with fish resources to adapt to a changing situation.

To help offset social and economic impacts of changing fish resources, 88.8% (MVA 81.7%) of responses indicated that management actions should be taken. The most effective actions, in order, were deemed to be public education, regulations, promotion, and stocking (Table 3.22), all of which have several associated issues. Removal and harvest programs, as well as no management actions, were scored so low that they were not considered viable options. Interestingly, prior to the brief introduction about climate change, public education—the number one scored management action—was only the ninth most important issue concerning fish resources in Ontario today (Table 3.9). This is a strong indication that there is a thirst for knowledge, and new science and information has not been widely distributed to all fish resource groups. Overwhelmingly, all groups from all areas want management actions to be based on science; social and economic concerns were a very distant second and third (Tables 3.24 and 3.25). Several comments were that if we take care of the fishery on the basis of science, social and economic issues will take care of themselves.

Managers face challenging decisions in light of environmental and fish community changes in the context of climate change. Not unexpectedly, fisheries issues were given the highest priority when managing water resources, and most groups associated with fish resources are passionate about these issues. Other priorities, however, included homes and cottages, navigation and transportation, and consumption (Table 3.26 and 3.27).

### 3.3.5 Summary and Conclusions

The survey dealt with fish resource issues in the context of climate change, observed changes in the environment and fish community, and impacts, adaptations, and economic consequences. In December 2007 and January 2008, 749 surveys were distributed, targeting anglers, fish resource businesses, and professionals in Ontario, of which 219 were returned, for a total of 307 responses. Analysis indicated that 90% of respondents have observed environmental changes, most of which they attribute to climate change (96.8 ± 3.0%); most changes were perceived as having negative effects (78.2 ± 7.4%). Conversely, 87% have observed fish community changes that include invasive species and changes in fish abundance and size, but <50% attributed any of these changes to climate, nor do they know the possible effects of climate on fish resources. Fish community changes are perceived to be caused by introductions, overfishing, enforcement, water, and stocking issues.

Angling has become a very social and recreational activity; only 56% indicated they fished for food, and it was not considered an important reason for fishing. Some warm-water fish are obviously responding to increasing climate conditions; anglers seem slightly more reluctant to change and adapt. There will likely be a redistribution of use and fishing-related revenues from anglers who would relocate to continue fishing preferred species, but responses indicated a general tendency not to change; 77 to 79% of anglers (open-water and ice-cover) would not change locations or were willing to travel only locally (1 hr, 100 km) to fish their preferred species.

Responses from all groups supported management actions (89%) and the development of science-based fish policies that incorporate climate change (99%), which should include participation from all levels of government, science, academia, non-government organizations, and knowledgeable local stakeholders.

Over the course of this study, while talking with many people and from the very detailed comments they provided in the survey, the following is recommended:

1. Maintain existing databases and expand where and when possible to analyze long-term trends. This is needed either to factor out other stressors that could be causing changes or to attribute them to climate change. Long-term data will also provide a better understanding of limitations being imposed by the natural environment.

2. Take advantage of local resources. Local residents are more than willing to help, but they need and want guidance from professionals.

3. Vastly improve science transfer and information, not only to the general public but to professionals.

4. Maintain openness and flexibility in management decisions, especially regulations.

5. Directly involve local communities in management decisions. There will always be opposition to management actions, even if they are based on sound science, but recommendations # 2 and 3 will help obtain a better level of acceptance of management decisions that may be negative or controversial in some people's view.

6. Include the human dimension in management objectives and decisions. They are part of the ecosystem, and their impacts must be evaluated to determine the best objectives for specific areas or water bodies.

Taking these into consideration will go a long way to making fisheries more adaptable to climate change and in mediating the impact on fish and fisheries, not only in various regions of Ontario and the Mississippi Valley area but elsewhere.

# Section 3.4 Water Management Response to Climate Change, Subproject 4

## 3.4.1 Introduction

The Mississippi River watershed is located in eastern Ontario and is made up of a complex network of rivers, streams, and lakes. The Mississippi River has a drainage area of 3,750 km from its headwaters in Kilpecker Creek, in the Township of Addington Highlands, to its outlet at the Ottawa River in the City of Ottawa. The river is 212 km in length and drops 252 m toward the east to an elevation of 73 m at its confluence with the Ottawa River.

The Mississippi River watershed is divided into three sub-watersheds (Fig. 4.1): the western and central sub-watersheds lie on the Canadian Shield, and the eastern sub-watershed lies off the Shield to the west of the Ottawa River. The western sub-watershed is speckled with deep, glacial lakes, whereas the eastern sub-watershed is dominated by riverine systems, which is a reflection of its topography and surficial geology. The central sub-watershed is a combination of both the western and eastern sub-watersheds and may be considered a transitional zone between ecological land types and communities.

The Mississippi River system contains both cold- and warm-water fish species. Historically, lake trout lakes dominated the watershed, but now only a few lakes in the western sub-watershed continue to be managed as cold-water fisheries. The central and eastern sub-watershed lakes are managed as warm-water, walleye and bass dominated fisheries. Water levels and flows along the main branch of the Mississippi River are regulated to support a variety of interests. The watershed has many natural heritage features, including several locally and provincially significant wetlands, rare species and species at risk, other significant natural features such as wild rice, a migratory bird sanctuary and Areas of Scientific and Natural Interest (ANSIs), provincial parks, conservation reserves, and Crown land.

Development of the Mississippi River began in the 1800s to transport large timbers from Mazinaw Lake downstream to sawmills along the river and in Quebec. A series of dams were built at strategic points along the river to store water, and slides were built to carry logs past falls and rapids (Mississippi Valley Conservation Report, 1970). Other dams, such as Mazinaw, Crotch, Big Gull and Kashwakamak Lake, were originally built solely for timber transport.

The lower river system through towns such as Carleton Place, Almonte, Pakenham, and Appleton thrived with textile and gristmills as the river provided a useful source of water power. In the early 1900s, a group of business interests representing mill owners and the Ontario Hydroelectric Commission acquired and reconstructed six of the upstream water control structures to augment stream flows in the lower river system for water power. The management regime utilized the large storage capacity behind these dams to store excess runoff during the spring freshet, providing a source of water to augment stream flows during the dry summer months. By the mid-1900s, recreational and tourism development along the shores of these storage reservoirs resulted in pressure to stabilize water levels during the summer months, restricting their use for downstream water supply during this period.

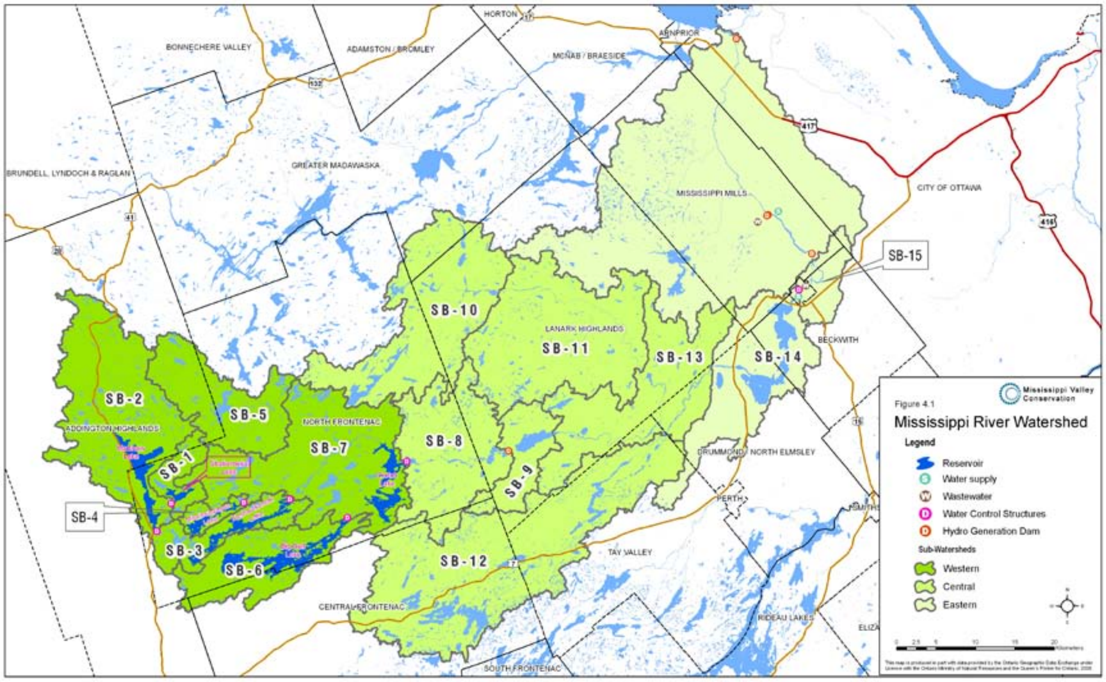



Figure 4.1. Mississippi River watershed (shaded), showing sub-watersheds (western, shaded darkest; central, shaded moderately; eastern, shaded lightest) and numbered sub-basins. Reservoirs, water supply, wastewater, water control structures, and hydro generating dams are indicated, along with townships.

The largest and most downstream reservoir, located at Crotch Lake, was not subjected to these water level restrictions and was subsequently utilized to provide low flow augmentation during the summer months and then used to store water in the fall when the upper reservoirs could be drawn down. This water could then be used to augment stream flows over the winter period. All six storage reservoirs would therefore be at their lowest level prior to the next spring freshet, providing a measure of flood protection to downstream communities as water was again stored in the reservoirs. This semi-annual management cycle of reservoir storage and release has been successfully implemented since that time.

Today, the six upstream storage reservoirs are managed by the Mississippi Valley Conservation Authority (MVC) and Ontario Power Generation in consultation with MVC. Including these six reservoir dams and five hydro generation facilities, a total 23 dams and water control structures are maintained within the Mississippi River watershed.

Water use within the watershed is not significant at present. There are four current water-taking permits issued for the Mississippi River with a total maximum allowed taking or extraction of approximately 14,000 cubic metres of water per day, which is equivalent to 0.16 cubic metres per second (cms). The most notable of these is for the municipal water supply at Carleton Place, which has a maximum taking of water at 12,000 cubic metres of water per day.

There are two municipal sewage treatment facilities, which discharge effluent to the Mississippi River; Mississippi Mills (Almonte), with a population of 4600, and Carleton Place, with a population of 9,300.

At Appleton, the mean seven-day drought estimate, with a 20-year return period, is approximately 4 cms. At present, there have been no reports of significant surface water shortages that have affected either municipal supply or effluent requirements, although water-quality monitoring along the lower reaches of the Mississippi River suggest that total phosphorous levels may begin to exceed provincial water-quality objectives. Other water takings within the watershed are from either off-line surface or groundwater sources, which are not directly influenced by stream flow conditions in the Mississippi River (Golder Associates 2003).

In 2006, the Mississippi River Water Management Plan (Mississippi River Water Management Plan Steering Committee 2006) was finalized, which confirmed the current management regime for the Mississippi River and established flow and water-level objectives for the major water-control structures along the river. In the course of completing the hydro-technical analyses for the Water Management Plan, MVC noted trends in the stream flow conditions that could present difficulties for water managers to satisfy the established Water Management Plan objectives, particularly related to fish and aquatic habitat, if these trends were to persist. Further investigation of these findings suggested that they were consistent with recent research on water resource impacts from climate change.

In the event that the apparent changes in stream flow are attributable to climate change, it will become important for water managers to understand the extent to which these changes may progress and to determine the capacity of the existing infrastructure to respond to these changes and manage the associated risks in an integrated manner.

#### 3.4.1.1 Objectives

The specific objectives of this research study include:

- downscale future climate predictions (precipitation and temperature) of the Coupled Global Climate Model (CGCM2) to the Mississippi Valley watershed;
- generate future climatic data based on historic trends and CGCM2 projections;
- quantify the potential effect of climate change on the watershed water budget components;
- calibrate and validate a rainfall-runoff (RR) model for the Clyde River at the Gordon Rapids stream gauge (WSC 02KF013);
- simulate future runoff and stream flow for periods (2010-2099) with the validated RR model;
- conduct reservoir and hydraulic modelling to simulate stream flows and water levels at reservoir sites and the downstream gauge site on the Mississippi River at Appleton (WSC 02KF006)

## 3.4.2 Methodology

### 3.4.2.1 Global Climate Change Models

General circulation models (GCMs) (sometimes referred to as global circulation models) are physically based, complex, three-dimensional climate models that integrate as many factors as possible that could influence climate to simulate the global climate system. Since GCMs are essentially the only viable tools for simulating regional patterns of climate change, their outputs have been widely used to assess climate change impacts. Several GCMs have been recognized for their ability to represent reasonably well the main features of the global distribution of basic climate parameters (Lambert and Boer 2001) including, CGCM2 (The Second Generation Coupled Global Climate Model Developed by the Canadian Centre for Climate Modelling and Analysis), the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia's national science agency, the U.S. National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory (GFDL), and Met Office, Hadley Centre for Climate Change, United Kingdom (Hadley).

In 1996, the Intergovernmental Panel on Climate Change (IPCC) distributed a set of greenhouse gas emission scenarios called the Special Report on Emissions Scenarios (SRES), based on developments in different social, economic, technological, environmental, and policy dimensions, and named A1, A2, B1 and B2 scenarios. The A1 scenario describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. The A2 scenario describes a very heterogeneous world with themes of self-reliance and preservation of local identities. The B1 scenario describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, reductions in material intensity, and the introduction of clean and resource-efficient technologies. The B2 scenario describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability.

Prior to this study, four different GCM models (CGCM2, CSIRO, GFDL, and Hadley) were tested with Mississippi River watershed data using these four scenarios (A1, A2, B1, and B2). For this study, the Second Generation Coupled Global Climate Model CGCM2 model of the Canadian Centre for Climate Modelling and Analysis (CCCma) and the A2 scenario, where self-reliance and preservation of local identities are of more importance, is being used. The daily climate data are downloaded from the Environment Canada website www.cccma.bc.ec.gc.ca/data/cgcm2/cgcm2_a2.shtml for the Mississippi River watershed grid (Lat. 46.36˚ N, Long. 75.00˚W). Each grid is about 300 km x 300 km. The increase in mean monthly precipitation and air temperature obtained using CGCM2 for the Mississippi River watershed were similar to the results obtained by Booty et al. (2005) for the Duffins Creek watershed near Toronto using the same model.

#### 3.4.2.2 Downscaling CGCM2 Data to Mississippi River Watershed

The main advantage of using a GCM is that it is the only tool that estimates changes in climate due to increased greenhouse gases for a large number of climate variables in a physically consistent manner. However, GCM simulations of current regional climate can often be inaccurate, and the output from GCMs is usually produced at a coarse temporal and spatial resolution; therefore a downscaling technique is needed to calibrate and refine the resolution of the GCM model data required for impact studies (Carter et al. 1999; Xu 1999; Prudhomme et al. 2002). Also downscaling is necessary to link GCM predictions to actual measured data at climate stations. Downscaling can be dynamic or statistical. Dynamic downscaling is a computer-intensive task, while statistical downscaling is based on relationships among regional and local scale variables. There are three categories of statistical downscaling methods: estimating relationships using parametric, nonparametric, linear and nonlinear methods, using weather generators, and weather typing by linking GCM, regional outputs, and local variables. Weather generators are numerical algorithms able to generate weather data with given statistical characteristics. Weather generator parameters of the local climate station for the future periods are updated with a relative change function between the GCM base and future grid data.

In order to assess climate change impacts regionally, daily time series of historic data for the Mississippi River watershed were analyzed statistically. To produce future climate change scenarios, a set of baseline climatology and GCM patterns are used. To conform with the World Meteorological Organization (WMO), standard values are derived from a 30-year period of record.

Climate data for the base period (1970-2000) and future period (2010-2099) were downloaded from the Environment Canada website for the grid that includes the Mississippi River watershed area and processed with the ClimGen model to create a climate parameter file (.LOC) for each period. The future period (2010-2099) is split into three 30-year windows, denoted as I for 2010-2039, II for 2040-2069, and III for 2070-2099. The relative change in climate parameters between the baseline period and future periods (I, II and III) from the grid data is subsequently applied to the Mississippi River watershed baseline period to obtain the future periods (I, II, and III) climate parameters. Observed data from the Drummond Centre Climate station, located in the watershed, is processed with the ClimGen model to create a local climate parameter file. The relative change in climate parameters derived from the grid data were applied to the local climate parameter file to create local climate parameter files for the future periods. These updated parameter files are then processed with the ClimGen to generate future climate data for the I, II, and III periods. The statistical summary (mean and standard deviation) of the generated climate data was also calculated using the ClimGen software (www.bsyse.wsu.edu/climgen/).

*ClimGen Model*

A weather generator is a computer algorithm that uses an existing meteorological record to produce a long series of synthetic daily weather data. The statistical properties of the generated data are expected to be similar to those of the actual data for a specified station. ClimGen

(Stöckle et al. 1999) was selected for this study from numerous weather generators developed since 1984. Castellvi et al. (2002), Stöckle et al. (2004), and McKague et al. (2006) showed that ClimGen has produced promising results regarding the generation of weather data for various climatic data. In most cases, an excellent agreement between actual and generated weather data was found.

ClimGen provides utilities for computing all required generation parameters and statistical summaries from existing daily weather records. ClimGen generates precipitation, daily maximum and minimum temperature, solar radiation, air humidity, and wind speed. The program requires the input of a daily series of these variables to calculate parameters used in the generation process. Because all generation parameters are calculated for each site of interest, ClimGen can be applied to any world location with enough information to parameterize.

The weather data generated by ClimGen is stored in a universal environment database (UED) format. All the parameters are stored in a location file with an extension of LOC. Stored in this location file are the parameters used for weather data ge.eration, such as the monthly mean maximum and minimum temperature and their standard deviation; monthly mean solar radiation and its standard deviation; monthly mean precipitation, the monthly fraction of wet days, the mean and deviation of solar radiation, maximum temperature, and minimum temperature for wet days and dry days; the values of A, B matrix; as well as the values of alpha and beta for precipitation and wind speed generation. The GCM patterns are then used in this LOC file to downscale the global climate change scenario to the local spatial resolution, with projected time series from the baseline to the future based on the Intergovernmental Panel on Climate Change emissions scenarios.

#### 3.4.2.3 Water Budget Model

The Modified Thornthwaite Water Budget Model from Environment Canada was used to estimate the water budget components. The model was run with the actual climate data from the Drummond Centre climate station to verify the program and subsequently run with the future climate data to estimate future water budget components.

### 3.4.2.4 Rainfall-Runoff Model

MIKE 11, a Danish Hydrologic Institute software for river and channel modelling, has different modules, including hydrodynamic, rainfall-runoff, sediment transport, advection-dispersion, ECOLab, flood forecast, data assimilation, etc. Rainfall and runoff are often key issues when modelling river systems. The rainfall-runoff (RR) module can either be applied independently or used to represent one or more contributing catchments that generate lateral inflows to the hydrodynamic module for river routing. This module contains a number of different approaches to estimate catchment runoff, such as:

1. NAM: The Danish NedbØr-AfstrØmmings-Model, meaning precipitation-runoff model, which was developed by the Department of Water Resources at the Technical University of Denmark (Nielsen and Hansen 1973). It is a lumped, conceptual rainfall-runoff model simulating overland flow, interflow and base flow as a function of the water storage in each of four mutually interrelated storages representing the storage capacity of the catchment. The NAM method can take into account manmade interventions in the hydrological cycle such as irrigation and groundwater pumping.

2. UHM: The UHM module simulates the runoff from single storm events based on the unit hydrograph technique. This method is useful in areas where no stream flow records are available or where the unit hydrograph technique is well proven.

3. SMAP: A monthly soil moisture accounting model is particularly useful when only monthly input data are available.

4. URBAN: Runoff methods specifically tailored to urban environments.

5. FEH: Catchment runoff estimation based on the UK Flood Estimation Handbook developed by CEH, Wallingford.

6. DRiFt: Semi-distributed rainfall-runoff - geomorphological approach.

Among these, NAM, a more suitable approach to the Mississippi River watershed was selected for this study. The NAM model is a well proven engineering tool that has been applied to a number of catchments around the world, representing many different hydrological regimes and climate conditions (MIKE11 Reference Manual, 2004). The NAM hydrological model simulates the rainfall-runoff processes occurring at the catchment scale. The NAM model has different applications, such as general hydrologic analysis, flood forecasting, extension of stream flow records, and prediction of low flows. In this study, NAM was applied to general hydrologic analysis to estimate runoff distribution in the catchment area. The NAM model represents various components of the rainfall-runoff process by continuously accounting for the water content in four different, mutually interrelated storages that represent different physical elements of the catchment, including snow storage, surface storage, lower or root zone storage, and groundwater storage. Based on the meteorological data input, NAM produces catchment runoff as well as other information, such as the temporal variation of the evapotranspiration, soil moisture content, groundwater recharge, and groundwater levels. The generated runoff is conceptually split into overland flow, interflow, and base-flow components.

*Rainfall-Runoff (NAM) Model Set-Up*

The NAM model was set up for the Clyde River at the Gordon Rapids catchment area. The Gordon Rapids discharge data are not affected by upstream controls and were therefore chosen for this study. The NAM model for rainfall-runoff estimation requires model parameters, initial conditions, meteorological data (rainfall and potential evapotranspiration), and temperature for snow modelling as input files. Snow accumulation and melt are important hydrological processes in river basins where the snow pack acts as storage in which precipitation is retained during the cold season and subsequently released as melt water during the warmer periods of the year.

Daily precipitation data are sufficient in many cases, though rapidly responding catchments require precipitation data at a finer resolution to represent peak flows accurately. The NAM model will interpolate the precipitation data for the simulation time step. The precipitation data are treated as an accumulated total, and so the precipitation at any particular time is the precipitation accumulated since the previous time step. Temperature data are required, since snow accumulation and melt are included in the simulation. During the snow season, the time increments in the temperature data reflect the length of time step in the simulation. The temperature data at a given time represent the average temperature since the previously entered data. Daily precipitation and temperature data from the Drummond Centre climate station in the Mississippi River watershed area were used as input to the model.

Monthly potential evapotranspiration values are sufficient when daily time steps are used. The potential evapotranspiration data estimated by the Modified Thornthwaite Water Budget Model were used as an input to the NAM model. Similar to the precipitation data, the potential evaporation data was also treated as accumulated totals, and so the potential evapotranspiration at any particular time is the potential evapotranspiration since the previously entered data.

Observed discharge data at the catchment outlet are required to compare the simulated runoff for model calibration and validation. The observed discharge at Gordon Rapids at Clyde River (WSC 02KF012) was used as input to the model. Similar to the temperature data, the discharge at a given time represents the average discharge since the previously entered data. The major surface and root zone parameters to the NAM model are maximum water content in surface storage ($U_{max}$), maximum water content in root zone storage ($L_{max}$), overland flow runoff coefficient (CQOF), time constant for interflow (CKIF), time constant for routing interflow and overland flow ($CK_{12}$), root zone threshold value for overland flow (TOF), and root zone threshold value for interflow (TIF). Groundwater model parameters are base-flow time constant ($CK_{BF}$), root zone threshold value for groundwater recharge (TG), recharge to lower groundwater storage ($CQ_{LOW}$), time constant to routing lower baseflow ($CK_{low}$), ratio of groundwater catchment to topographical catchment area ($C_{area}$), maximum groundwater depth causing baseflow ($GWL_{BF0}$), specific yield ($S_y$), and groundwater depth for unit flux ($GWL_{FL1}$). The snow module model parameters are degree-day coefficient, base temperature, radiation coefficient, and rainfall degree-day coefficient. Initial water content in the surface and root zone storages and initial values for overland flow, interflow, and base flow are required by the NAM model as initial conditions. Values of the model parameters and initial conditions will be described in the model calibration section.

*Calibration, Validation, and Simulation of NAM Model*

The main objectives of the model calibration process are to obtain;

i. good agreement between the average simulated and observed runoff;

ii. good overall agreement of the shape of the hydrograph;

iii. good agreement of the peak flows with respect to timing, rate, and volume;

iv. good agreement for low flows.

Compromises exist between these objectives, and so the parameter values that provide a very good simulation of peak flow might result in poor low flow simulations, and vice versa. Although equal importance was given initially to all four objectives, higher priority was given to low flow simulation at a finer level of calibration. Both graphical and numerical performance measures were applied to the calibration process. The graphical evaluation includes comparison of observed and simulated hydrographs and comparison of observed and simulated accumulated runoff. The numerical evaluations include the overall water balance error (difference between the average simulated and observed runoff) and a measure of the overall shape of the hydrograph based on the coefficient of determination. The goodness of fit of the calibrated model is affected by errors in meteorological input data, recorded observations, errors and simplification inherent in the model structure, and the use of non-optimal parameter values. Only the last error can be minimized in the calibration process.

Both automatic and manual calibration options are available. The auto-calibration tool in the NAM model can be used to speed up the calibration of the model. Based on up to four objectives (water balance, overall hydrograph shape, peak flows, and low flows), the auto-calibration tool will find the best fit between simulated and observed hydrographs. A global optimization routine called the Shuffled Complex Evolution (SCE) algorithm takes care of the actual parameter optimization. It will optimize nine different model parameters, including maximum water content in surface storage ($U_{max}$), maximum water content in root zone storage ($L_{max}$), overland flow runoff coefficient (CQOF), time constant for interflow (CKIF), time constant for routing interflow and overland flow ($CK_{12}$), root zone threshold value for overland flow (TOF), root zone threshold value for interflow (TIF), baseflow time constant ($CK_{BF}$), and root zone threshold value for groundwater recharge (TG). Manual calibration can also be applied to the above nine different parameters within the permissible minimum and maximum values (Table 4.1). The stopping criterion for the model optimization is the maximum number of evaluations that depend on the number of parameters and model complexity. The maximum number of evaluations in the range of 1000-2000 normally ensures an efficient calibration, and 2000 were taken for this study.

**Table 4.1. NAM model – auto or manual calibration model parameter ranges.**

| Parameter | Unit | Range | Parameter | Unit | Range |
|---|---|---|---|---|---|
| $U_{max}$ | mm | 5-35 | TOF | | 0-0.9 |
| $L_{max}$ | mm | 50-400 | TIG | | 0-0.9 |
| CQOF | | 0 | TG | | 0-0.9 |
| CKIF | hours | 200-2,000 | $CK_{BF}$ | hours | 500-5,000 |
| $CK_{12}$ | hours | 3-72 | | | |

The model was initially run with auto-calibration; and finer level calibration was done with an objective to match low flows. After the auto-calibration, the model was manually calibrated first to adjust overall water balance in the system. The total evapotranspiration over the period is then compared to the difference in accumulated precipitation and runoff. The peak runoff events are caused by large quantities of overland flow, and can be adjusted by changing the CQOF, where the shape of the peak depends on $CK_{12}$. The amount of base flow is affected by overland flow or interflow. A decrease in the overland flows or interflows results in higher base flows, and vice versa. The shape of the base flow recession is a function of the base flow time constant ($CK_{BF}$); if the base flow recession changes to a slower recession after a certain time, a lower groundwater reservoir should be added, including calibration of $CQ_{low}$ and $CK_{low}$. Since the objective of the finer level manual calibration was an overall water balance and base flow match, the above-mentioned parameters were adjusted by trial and error until satisfactory results were obtained.

The NAM m/del was calibrated with observed runoff at the Clyde River at the Gordon Rapids stream gauge (WSC 02KF013) for 21 years from January 1, 1973, to December 31, 1993. The parameters for the well calibrated model are given in Table 4.2. The satisfactory calibrated NAM model was validated with 10 years of data (1994-2003) by keeping the same calibration parameters in the model. The well calibrated and validated NAM model was then used to simulate runoff for future periods from 2010-2099. Generated future climate data, along with potential evapotranspiration, was used as input files to simulate the future runoff data for the Clyde River at Gordon Rapids sub-watershed area.

### 3.4.2.5 Transposing and Validation of Reservoir Inflows

Table 4.2. NAM model – calibration and initial conditions parameters.

| Surface-Rootzone | | Groundwater | | Snowmelt | | Initial conditions | |
|---|---|---|---|---|---|---|---|
| Parameter | Value | Parameter | Value | Parameter | Value | Parameter | Value |
| $U_{max}$ | 19.8 | $CK_{BF}$ | 1,605 | $C_{snow}$ | 2 | $U/U_{max}$ | 0 |
| $L_{max}$ | 298 | $C_{area}$ | 1 | $T_o$ | 0 | $L/L_{max}$ | 0 |
| CQOF | 0.513 | $S_y$ | 0.1 | | | QOF | 0 |
| CKIF | 751.8 | $GWL_{BF0}$ | 10 | | QIF | 0 | |
| CK12 | 47.7 | $GWL_{BF1}$ | 0 | | | BF | 0.5 |
| TOF | 0.874 | $CQ_{low}$ | 0 | | | | |
| TIF | 0.874 | $CK_{low}$ | 10,000 | | | | |
| TG | 0.58 | | | | | | |

Daily water level and water control structure operation records are available for each reservoir site since 1993, providing estimates of reservoir inflow, outflow, and change in reservoir storage. Because of errors associated with estimating reservoir inflow based on water level records, which are typically recorded to an accuracy of +/- 1.0 cm, calibration of the NAM model for each reservoir site was not considered feasible for the present study.

Estimating reservoir inflows on the basis of transposed stream flow records from an adjacent hydrologically similar basin is recognized as a useful approach where stream flow records are not available. MVC has transposed stream flow records from the Clyde River at the Gordon Rapids stream gauge (WSC 02KF013) as an estimate of reservoir inflow, based on relative drainage area, for the subject reservoir sites in previous studies and has found these to provide a reasonable estimate.

The resulting stream flow projections were subsequently transposed to the local drainage basin for each reservoir and intermediate sub-watershed along the Mississippi River to the Mississippi River at Appleton stream gauge site (sub-watershed details are given in Table 4.3 and Fig. 4.1). Reservoir simulation was conducted with the Mississippi River Watershed Model (MRWM),

Table 4.3. Mississippi River sub-watershed delineation.

| ID | Sub-watershed–reservoir | Drainage area (km$^2$) |
|---|---|---|
| SB1 | Shabomeka Lake Reservoir | 40.32 |
| SB2 | Mazinaw Lake Reservoir | 298.60 |
| SB3 | Kashwakamak Lake Reservoir | 42.60 |
| SB4 | Buckshot Creek | 172.70 |
| SB5 | Mississagagon Lake Reservoir | 22.00 |
| SB6 | Big Gull Lake Reservoir | 141.40 |
| SB7 | Crotch Lake Reservoir | 298.10 |
| SB8 | High Falls G.S. | 202.67 |
| SB9 | Dalhousie Lake | 78.86 |
| SB10 | Clyde River at Gordon Rapids | 287.80 |
| SB11 | Clyde River at Lanark | 326.20 |
| SB12 | Fall River | 427.30 |
| SB13 | Mississippi River at Ferguson Falls | 215.90 |
| SB14 | Mississippi Lake | 209.40 |
| SB15 | Mississippi River at Appleton | 63.10 |

which is an in-house reservoir operation model developed by MVC. This model was used to route reservoir inflow hydrographs through each reservoir using the storage-indication method, based on calibrated structure rating curves and reservoir stage-storage relationships. The model allows the user to adjust dam settings at each time step of the simulation. The resulting discharge hydrograph is subsequently routed to the next downstream reservoir using the Muskingum Method and then added to local basin inflows. The Muskingum routing parameters were calibrated through trial and error based on historical water level and available stream flow records (Table 4.4). This process was continued through the river system, incorporating each storage reservoir and intermediate sub-watershed inflow to simulate the stream flow at the Appleton stream flow gauge (Mississippi River at Appleton – WSC 02KF006)

Table 4.4. Muskingum routing parameters.

| Routing Reach | K | X |
|---|---|---|
| SemiCircle Creek | 6 | 0.2 |
| Marble Lake | 15 | 0.2 |
| Farm Lake | 42 | 0.2 |
| Swamp Creek | 9 | 0.2 |
| Ardoch | 42 | 0.2 |
| Gull Creek | 9 | 0.2 |
| Snow Road | 18 | 0.2 |
| High Falls | 6 | 0.2 |
| Sheridans Rapids | 17 | 0.2 |
| Clyde | 12 | 0.2 |
| Ferguson Falls | 12 | 0.2 |
| Mississippi Lake | 12 | 0.1 |
| Appleton | 6 | 0.2 |

### 3.4.3 Results and Discussion

### 3.4.3.1 Present Climate at Mississippi Watershed

Generally, the climate of eastern Ontario can be described as humid continental (Ontario Ministry of Natural Resources 2005). The Great Lakes exert the major influence on the climate in the Great Lakes-St. Lawrence region, promoting cold winters and warm summers due to humidity changes. Precipitation in the region is also caused by cold polar air from the north and warm moist air from the United States. The mean annual precipitation in the region ranges from 800 mm to 1,000 mm (Ontario Ministry of Natural Resources 2005). According to Canadian Forestry Service study the annual precipitation for the region ranges from 840 to 1,000 mm (McKenney et.al. 2006).

An inventory of all climate stations in the region found four active stations in the Mississippi Valley. In addition to these stations, there are eight rain gauge stations operated by Mississippi Valley Conservation Authority All the active stations have rainfall, snowfall, precipitation, and temperature records. There are only 12 years (1994-2005) of data available in common for the active stations in the region (Table 4.5). Generally, there is no pattern in the precipitation in the region from west to east or south to north. However, the highest precipitation (945 mm) was observed in the southwest and the lowest (870 mm) in the middle of the region. There is an increase in mean temperature from southwest to northeast of the region. The southwest region is 1°C cooler than the northeast region (Table 4.5).

For the climate pattern discussion, 56-year mean values of precipitation (including rainfall and snowfall) and temperature at a centrally located climate station, Drummond centre (Drummond centre and Chatsfalls station data combined provide 56 years of data) data was used (Table 4.6).

**Table 4.5. Mean annual precipitation and temperature at active climate stations at in the Mississippi watershed (1994-2005).**

| Station name | Mean annual precipitation (mm) | Mean annual temperature (°C) |
|---|---|---|
| Ompah | 944.8 | 5.3 |
| Ompah-seiz | 924.7 | 6.1 |
| Drummond Centre | 870.0 | 6.4 |
| Appleton | 869.1 | 6.3 |

Snowfall and rainfall account for 20% and 79% of the annual total precipitation in the region. The highest snowfalls occur in December through February (48, 42, and 41 mm. The wettest months are May to November, with only 27 mm variability in monthly precipitation. The lowest precipitation is observed in February (57 mm). The highest precipitation without snowfall was observed in August (88 mm). Observed average annual precipitation of 880 mm is in accordance with the values obtained from the Hydrological Atlas of Canada (1978) and studies done by the

Ontario Ministry of Natural Resources (1984), Moin and Shaw (1985), and Canadian Forestry Service (McKenney et al. 2006). The temperature in the region ranges from a minimum of -29°C (January) to maximum of 33°C. Although the precipitation is evenly distributed throughout the year, there is a deficit in precipitation amounts in the summer months (May through August), when potential evapotranspiration rates are high.

**Table 4.6. Summary of climate data for Drummond centre (1950-2005). Precipitation is measured as mm, temperature as °C.**

| | Month | | | | | | | | | | | | Mean annual total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| **Precipitation** | | | | | | | | | | | | | |
| Total | 69 | 57 | 59 | 62 | 75 | 72 | 81 | 88 | 85 | 71 | 82 | 80 | 881 |
| Rain | 27 | 16 | 33 | 54 | 75 | 72 | 81 | 88 | 85 | 69 | 66 | 32 | 698 |
| Snow | 42 | 41 | 26 | 8 | 0 | 0 | 0 | 0 | 0 | 2 | 16 | 47 | 183 |
| **Temperature** | | | | | | | | | | | | | |
| Mean | -11 | -10 | -2 | 7 | 13 | 17 | 19 | 18 | 14 | 9 | 2 | -8 | 5 |
| Maximum | 6 | 7 | 15 | 23 | 29 | 31 | 33 | 32 | 29 | 24 | 16 | 9 | 21 |
| Minimum | -29 | -28 | -20 | -10 | -3 | 2 | 6 | 4 | -2 | -6 | -13 | -24 | -10 |
| **Potential ET** | 0 | 1 | 6 | 33 | 82 | 116 | 135 | 112 | 71 | 34 | 10 | 1 | 602 |

*Precipitation Pattern at Mississippi*

Precipitation varies with changes in climatic cycles, geographic location, and elevation. Figure 4.2 shows annual total precipitation, rainfall, and snowfall occurring at the Drummond Centre for a period of 56 years (1950-2005). For the last 56-year period, there was no observed pattern in rainfall, snowfall, and precipitation occurrences; however, there does appear to be a decrease in the amount over the past 10 years. The driest period took place between 1957 and 1970, and the wettest between 1971 and 1987. The maximum and minimum precipitation occurrences in Mississippi are shown in Table 4.7. Monthly distributions of precipitation occurring at Drummond Centre for the period of 1950-2005 is given in Figure 4.3. The histogram shows the contribution of rainfall and snowfall to total monthly precipitation. Maximum precipitation occurs in the summer months, when all appears as rainfall, and in winter, when 20 to 72% of the total precipitation is in the form of snow.

*Temperature Patterns at Mississippi*

Similar to precipitation, temperature also varies with change in climate cycles and geographic locations. Figure 4.4 shows the annual minimum, maximum, and mean temperatures occurring at Drummond Centre for a period of 56 years (1950-2005). It is observed that there has been a warming pattern over the past 10 years (1995-2005). Over the 56-year period, the maximum mean daily temperature of 38°C occurred at Drummond centre in 1955, whereas, the minimum daily temperatures of -37°C occurred in 1981.

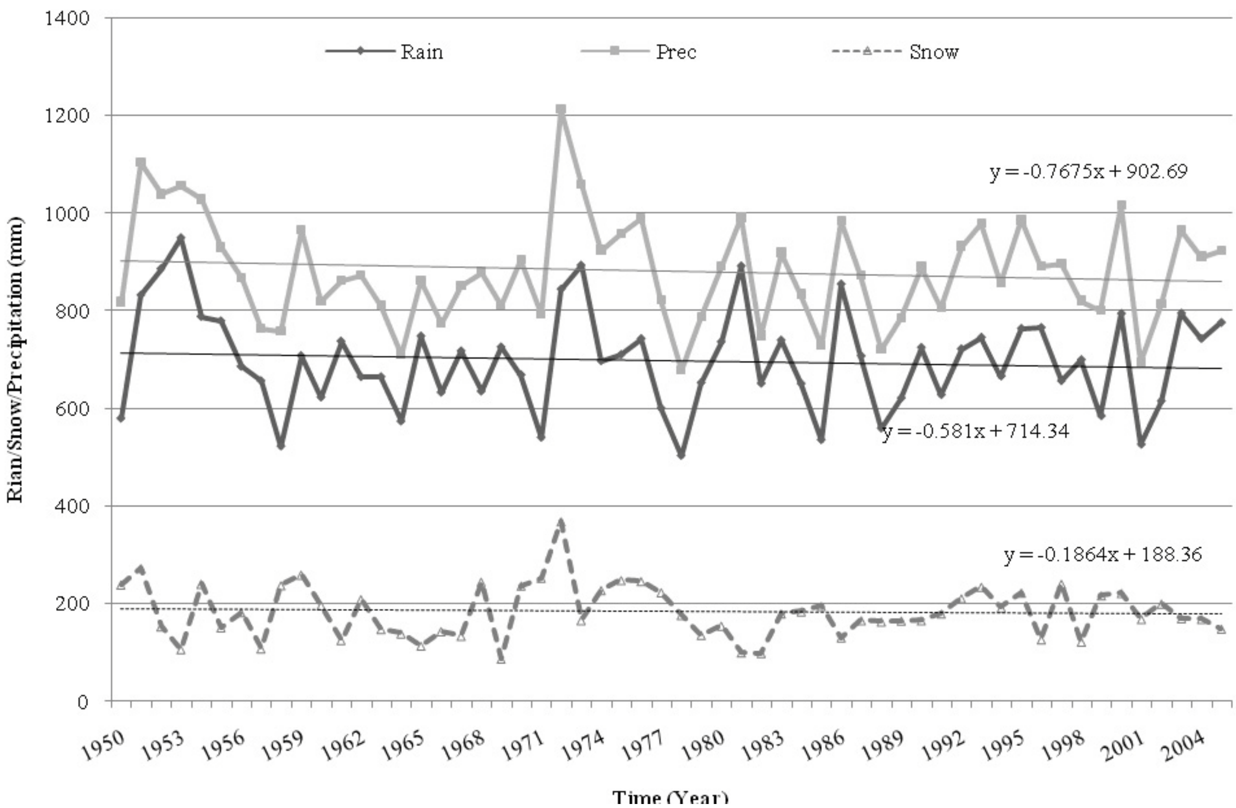



Figure 4.2. Annual average precipitation (rain and snow) in the Mississippi watershed (1950-2005).

Table 4.7. Maximum and minimum precipitation occurrences in the Mississippi watershed.

| Parameter | Amount and year |
|---|---|
| Maximum annual precipitation | 1,211 mm (1972) |
| Maximum snowfall | 368 mm (1972) |
| Maximum rainfall | 949 mm (1953) |
| Minimum annual precipitation | 678 mm (1978) |
| Minimum snowfall | 86 mm (1969) |
| Minimum rainfall | 502 mm (1978) |

**Average Monthly Precipitation in the Mississippi Watershed**

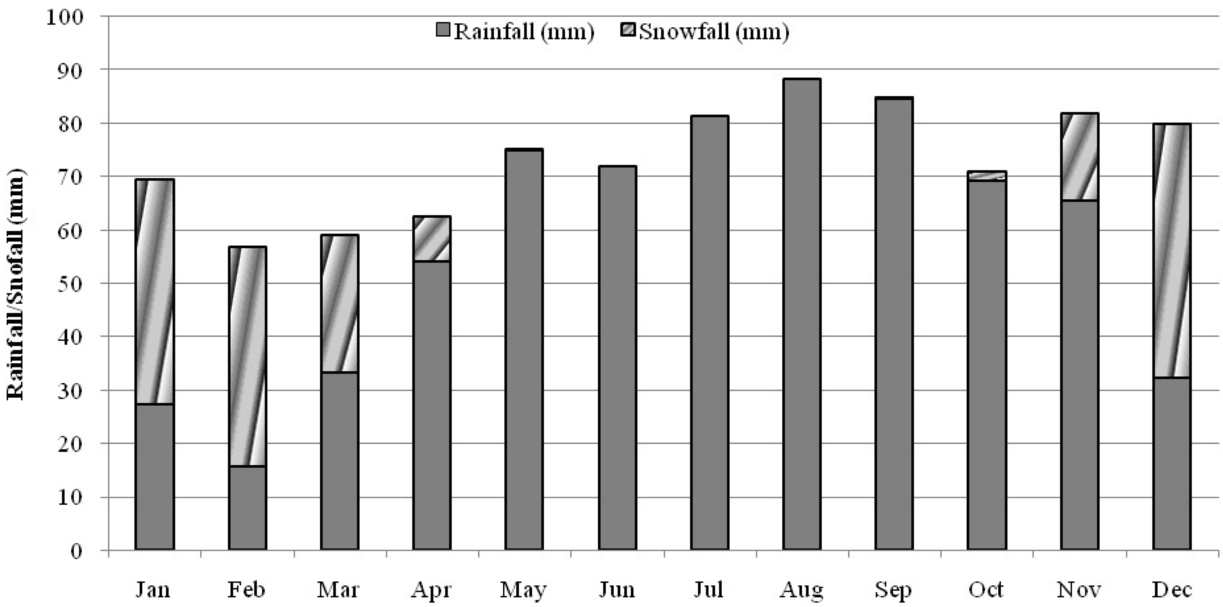



Figure 4.3. Average monthly precipitation in the Mississippi watershed.

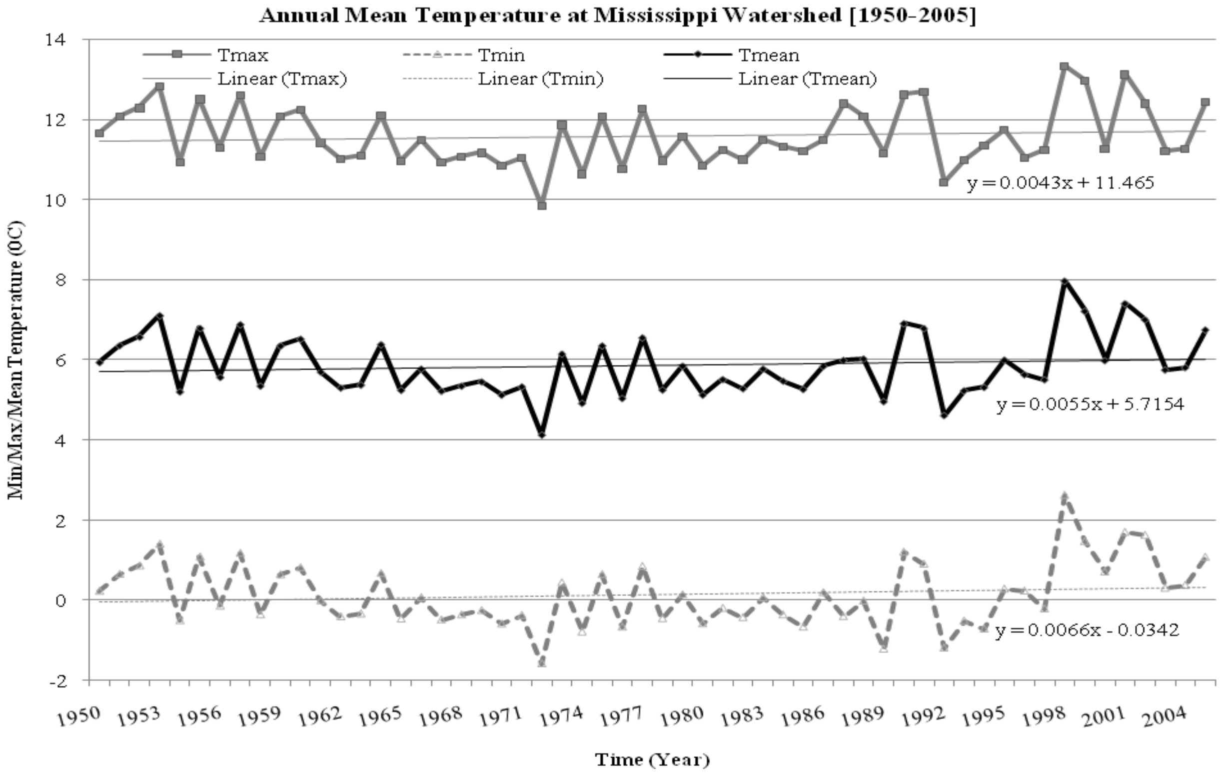



Figure 4.4. Annual temperature pattern at Drummond Centre-Mississippi (1950-2005).

Monthly distributions of average daily minimum, maximum, and mean temperatures at the Drummond Centre are shown in Figure 4.5. Maximum temperatures (>10$^{o}$C) occur between mid-March and mid-November and begin to decrease significantly in late August. Minimum

### 3.4.3.2 Projected Future Climate Data with Downscaled CGCM2 Data to Mississippi River Watershed

Projections of mean monthly minimum and maximum temperature and precipitation for the future periods (I, II and III) in the Mississippi River watershed were derived by applying the relative changes in climate parameters to data from the Drummond Centre Climate station for 1985-2003 (baseline period). These projections were compared with the actual baseline data and are shown in Figures 4.6, 4.7, and 4.8. Table 4.8 shows the rate of change in the CGCM2 projected mean monthly maximum and minimum temperature ($^{o}$C/yr), and precipitation (mm/yr) in the Mississippi River watershed for the period 1984-2000.

**Average Monthly Temperature in the Mississippi Watershed**

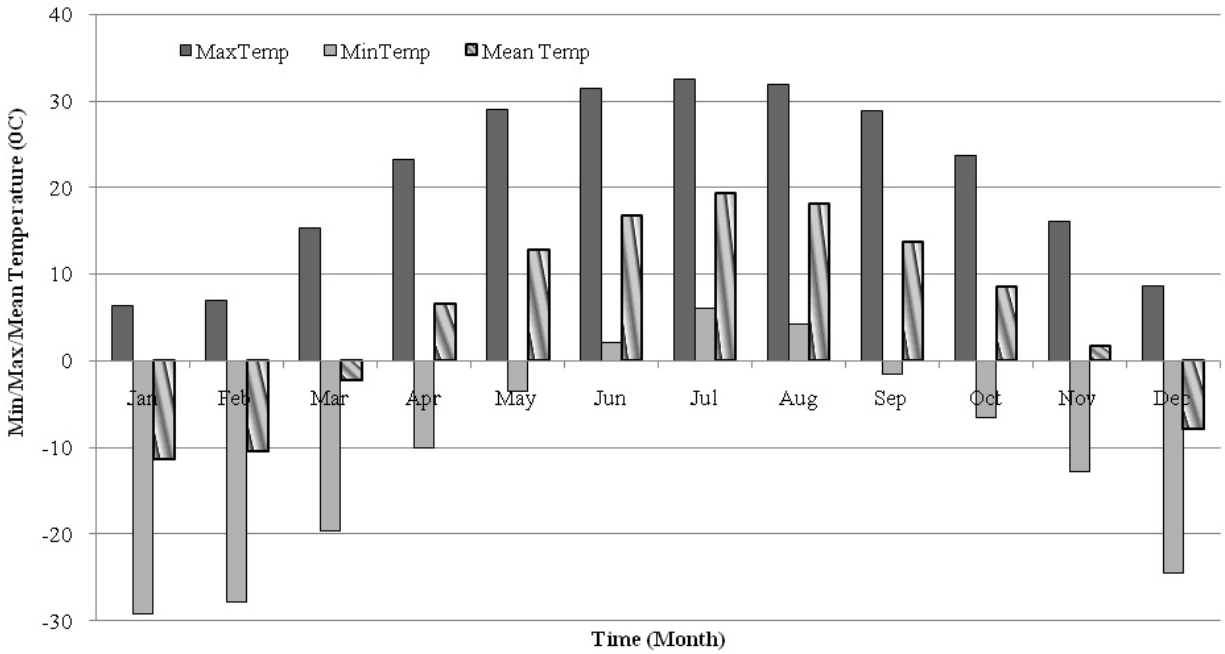



Figure 4.5. Monthly temperature at Drummond Centre-Mississippi.

Mean maximum temperature has been increasing in almost all months except December and March; however, mean minimum temperature has been increasing significantly for all months of the year (Fig. 4.6 and 4.7). Winter minimum temperatures are significantly increasing (especially in January through March) for the 2010 to 2099 periods. Winter and summer maximum temperatures are significantly increasing for the 2010 to 2099 periods. The highest rate of change was observed in minimum temperature, which rose in the months of January and February (0.06 to 0.17$^{o}$C/yr) for the 2010 to 2099 periods (Table 4.8). It is evident that in the winter months of December and January through March, precipitation has been decreasing, while in the summer months and particularly in the months of September, October and November, precipitation has been increasing (Fig. 4.8). Wetter fall conditions are predicted; however, winter conditions are more or less the same as the baseline period.

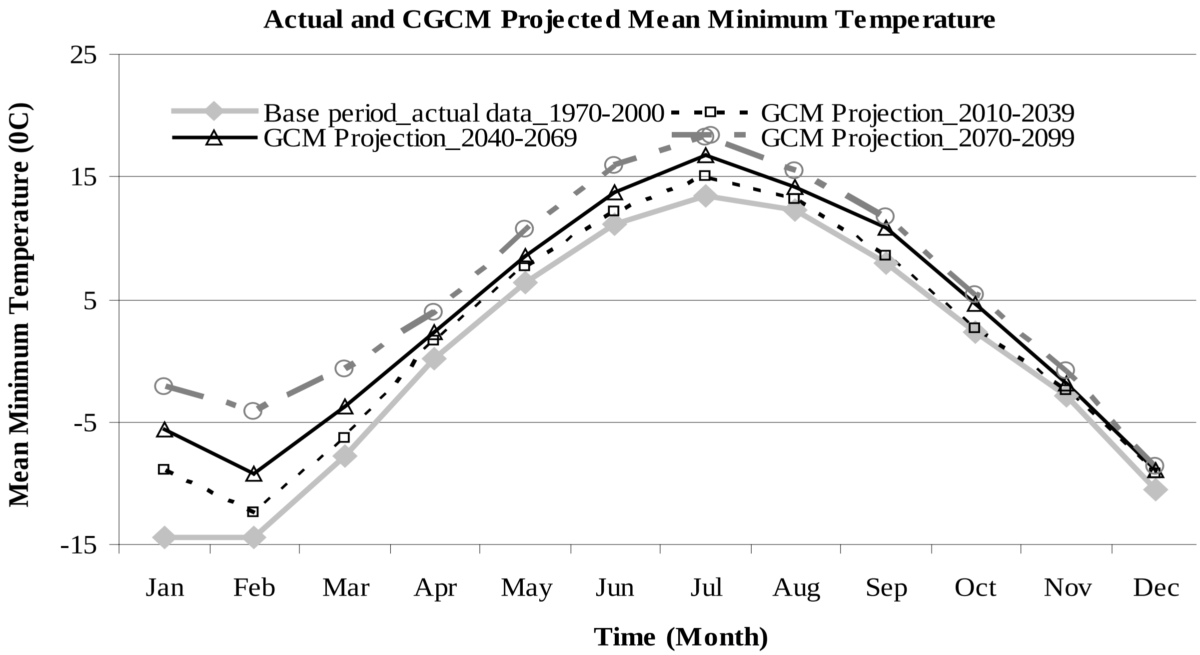



Figure 4.6. Actual (1984-2000) and CGCM2 projected mean minimum temperature for 2010-2039, 2040-2069, and 2070-2099.

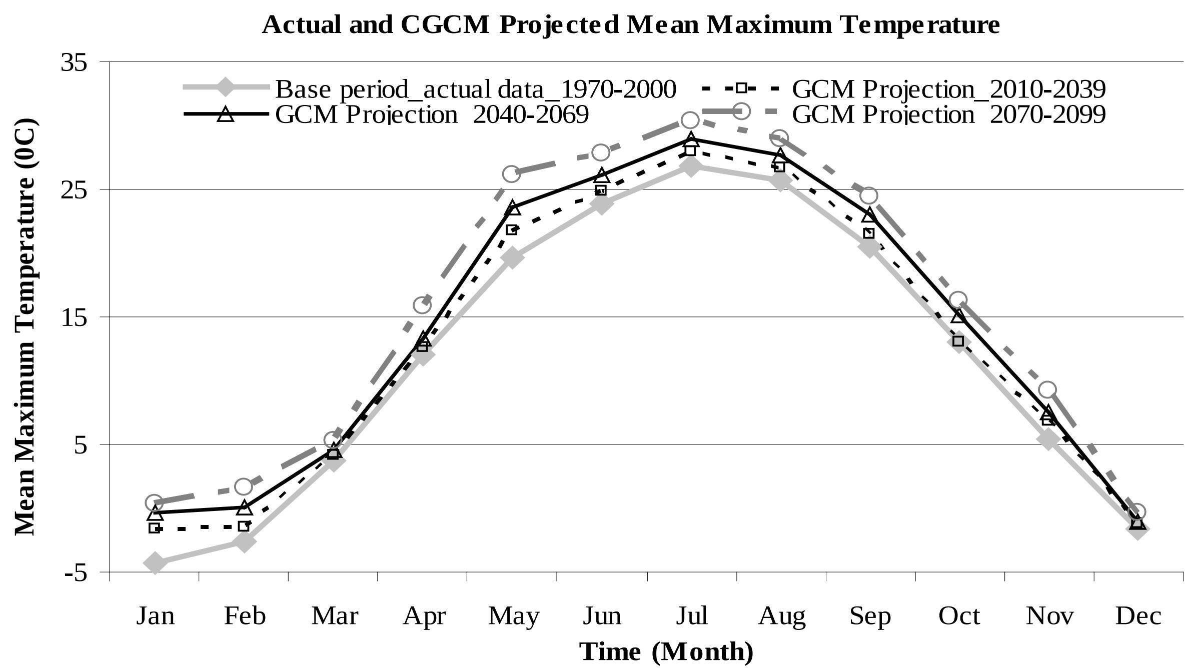



Figure 4.7 Actual (1984-2000) and CGCM2 projected mean maximum temperature for 2010-2039, 2040-2069, and 2070-2099.

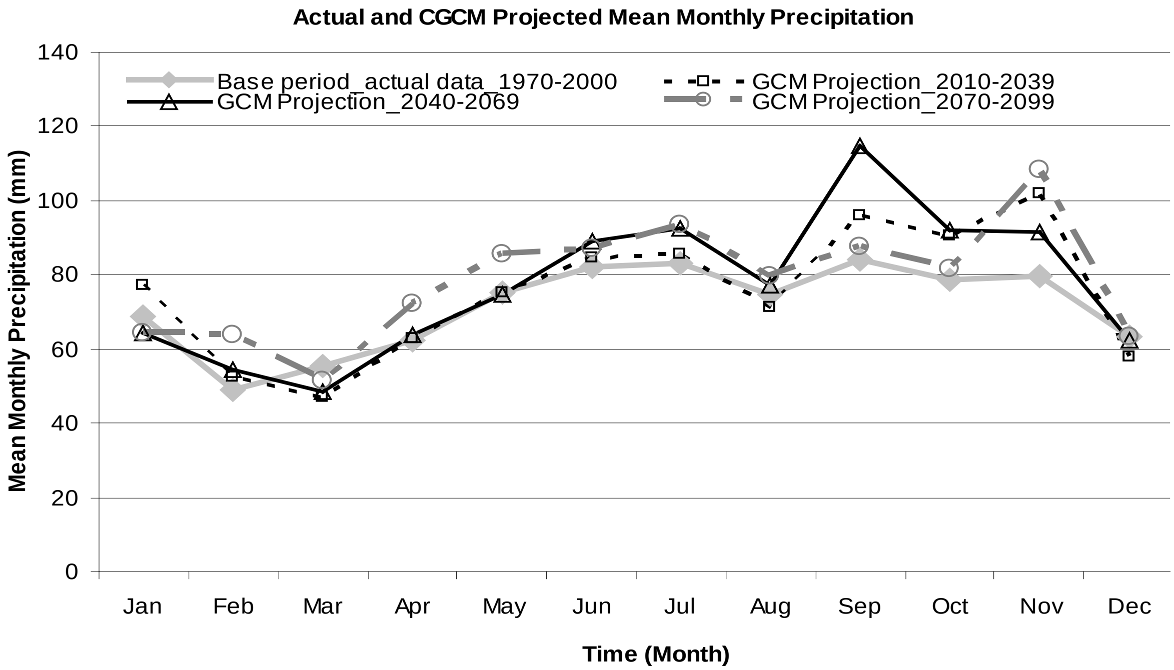



Figure 4.8. Actual (1984-2000) and CGCM2 projected precipitation for 2010-2039, 2040-2069, and 2070-2099.

Table 4.8. CGCM2 projected precipitation and temperature change rates from base period (1984-2003).

| | Rate of change | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Maximum temperature (°C•yr$^{-1}$) | | | Minimum temperature (°C•yr$^{-1}$) | | | Precipitation (mm•yr$^{-1}$) | | |
| Month | 2010-2039 | 2040-2069 | 2070-2099 | 2010-2039 | 2040-2069 | 2070-2099 | 2010-2039 | 2040-2069 | 2070-2099 |
| Jan | 0.08 | 0.06 | 0.05 | 0.17 | 0.14 | 0.13 | 0.26 | -0.07 | -0.04 |
| Feb | 0.03 | 0.04 | 0.05 | 0.06 | 0.08 | 0.11 | 0.10 | 0.09 | 0.16 |
| Mar | 0.01 | 0.01 | 0.02 | 0.05 | 0.06 | 0.08 | -0.26 | -0.11 | -0.04 |
| Apr | 0.02 | 0.02 | 0.04 | 0.05 | 0.03 | 0.04 | 0.00 | 0.02 | 0.10 |
| May | 0.07 | 0.06 | 0.07 | 0.04 | 0.03 | 0.05 | -0.01 | 0.00 | 0.11 |
| Jun | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.05 | 0.08 | 0.11 | 0.05 |
| Jul | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.08 | 0.15 | 0.11 |
| Aug | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | -0.11 | 0.04 | 0.05 |
| Sep | 0.03 | 0.04 | 0.04 | 0.02 | 0.05 | 0.04 | 0.36 | 0.49 | 0.04 |
| Oct | 0.00 | 0.03 | 0.04 | 0.01 | 0.04 | 0.03 | 0.36 | 0.21 | 0.03 |
| Nov | 0.04 | 0.03 | 0.04 | 0.01 | 0.02 | 0.02 | 0.69 | 0.19 | 0.31 |
| Dec | 0.02 | 0.01 | 0.01 | 0.04 | 0.02 | 0.02 | -0.16 | -0.02 | 0.00 |

#### 3.4.3.3 Climate Data Generation for Future Periods for Mississippi Watershed

The Drummond Centre Climate Station .LOC files updated with estimated per cent changes for future I, II and III periods were run with ClimGen to generate future climate data for Mississippi watershed. The generated mean monthly minimum and maximum temperatures and precipitation data for I, II, III periods were compared with the actual data (1984-2000) (Fig. 4.9, 4.10, 4.11). Table 4.9 shows the per cent change rate in generated mean maximum, minimum, and precipitation rates of change in mean maximum and minimum temperatures ($^{o}$C/yr), and in precipitation (mm/yr) for the Mississippi River watershed for the period 1984-2000.

Similar to CGCM2 model projection, ClimGen-generated winter and summer maximum temperatures for the Mississippi River watershed are increasing significantly for the 2010 to 2100 periods (Fig. 4.10). Similarly, CGCM2 projections and ClimGen predictions were showing significant increases in winter minimum temperatures (especially in January through March) for the 2010 to 2100 periods (Fig. 4.9). Although the ClimGen-generated precipitation is also similar to the CGCM2 projections where wetter fall conditions were predicted, there is more variability in precipitation generation than that of minimum or maximum temperatures (Fig. 4.11). Therefore, not only mean precipitation and mean temperature data have to be considered, but also their standard deviation among the data. Table 4.10 shows the mean monthly precipitation and temperature and their standard deviation for the 2010-2039, 2040-2069, and 2070-2099 periods (see Appendices 4-A1 and 4-A2). The statistical analysis results of future climate data from CimGen are given in Appendices 4-A3, 4-A4, and 4-A5 for the 2010-2039, 2040-2069, and 2070-2099 periods, respectively.

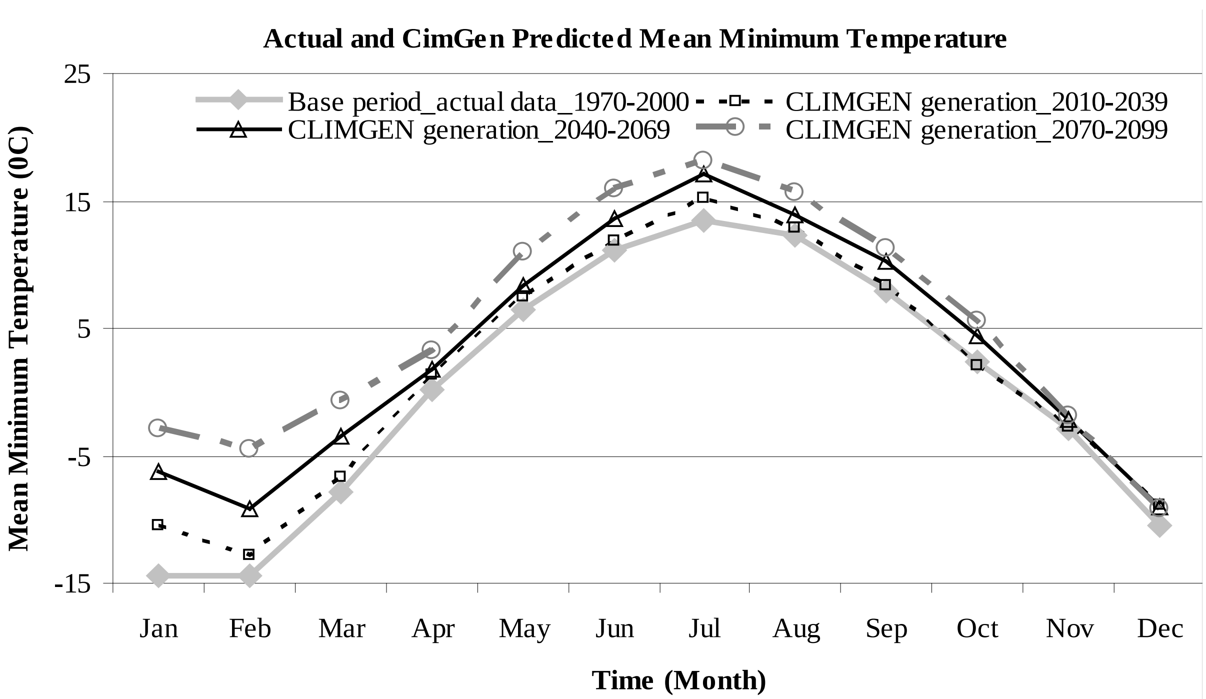



Figure 4.9. Actual (1984-2000) and ClimGen generated mean minimum temperature for 2010-2039, 2040-2069, and 2070-2099.

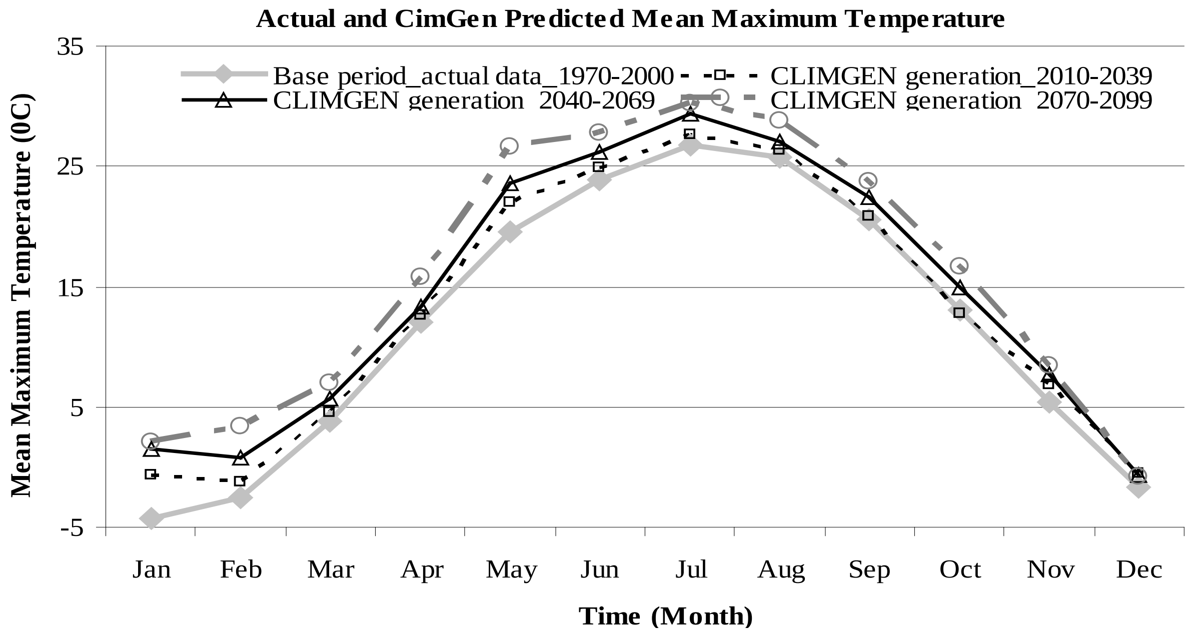



Figure 4.10. Actual (1984-2000) and ClimGen generated mean maximum temperature for 2010-2039, 2040-2069, and 2070-2099.

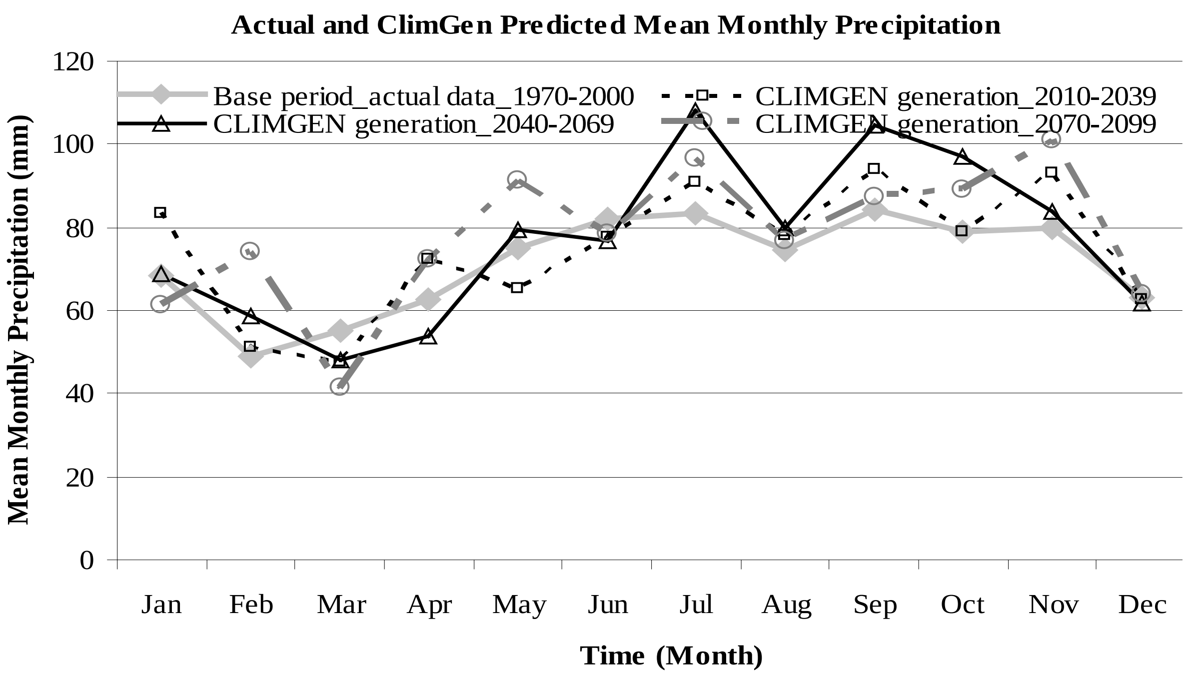



Figure 4.11. Actual (1984-2000) and ClimGen generated mean precipitation for 2010-2039, 2040-2069, 2070-2099 periods

Table 4.9. ClimGen generated precipitation and temperature change rates from base period.

| | Rate of change | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Maximum temperature ($^oC \cdot yr^{-1}$) | | | Minimum temperature ($^oC \cdot yr^{-1}$) | | | Precipitation ($mm \cdot yr^{-1}$) | | |
| Month | 2010-2039 | 2040-2069 | 2070-2099 | 2010-2039 | 2040-2069 | 2070-2099 | 2010-2039 | 2040-2069 | 2070-2099 |
| Jan | 0.11 | 0.09 | 0.07 | 0.12 | 0.13 | 0.13 | 0.47 | 0.00 | -0.08 |
| Feb | 0.04 | 0.05 | 0.06 | 0.05 | 0.08 | 0.11 | 0.07 | 0.16 | 0.27 |
| Mar | 0.03 | 0.03 | 0.03 | 0.03 | 0.07 | 0.08 | -0.24 | -0.11 | -0.15 |
| Apr | 0.02 | 0.02 | 0.04 | 0.04 | 0.02 | 0.03 | 0.30 | -0.14 | 0.10 |
| May | 0.07 | 0.06 | 0.08 | 0.03 | 0.03 | 0.05 | -0.30 | 0.07 | 0.18 |
| Jun | 0.03 | 0.04 | 0.04 | 0.02 | 0.04 | 0.05 | -0.14 | -0.09 | -0.04 |
| Jul | 0.03 | 0.04 | 0.04 | 0.05 | 0.06 | 0.05 | 0.24 | 0.40 | 0.15 |
| Aug | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 0.04 | 0.11 | 0.08 | 0.02 |
| Sep | 0.01 | 0.03 | 0.04 | 0.01 | 0.04 | 0.04 | 0.30 | 0.33 | 0.03 |
| Oct | -0.01 | 0.03 | 0.04 | -0.01 | 0.03 | 0.03 | 0.00 | 0.29 | 0.11 |
| Nov | 0.05 | 0.04 | 0.03 | 0.01 | 0.01 | 0.01 | 0.41 | 0.06 | 0.23 |
| Dec | 0.04 | 0.02 | 0.01 | 0.05 | 0.02 | 0.01 | -0.01 | -0.03 | 0.01 |

The mean temperature of 6$^oC$ in the baseline period increased to 10.5$^oC$ in 2099 with a standard deviation range of 1.3 to 1.7$^oC$ over a year for future periods compared with 1.9$^oC$ for the baseline period (Table 4.10). Large variations in mean temperature occurred from November to April. The average annual precipitation of 849 mm increased to 907 mm in 2099, while standard deviation varied from 32 to 34 mm over a year for the future periods, with a 31-mm variation for the baseline period. The variation in precipitation was small from November through May. This variation might be due to drier winter conditions. No significant trend was observed in the actual or predicted precipitation data (

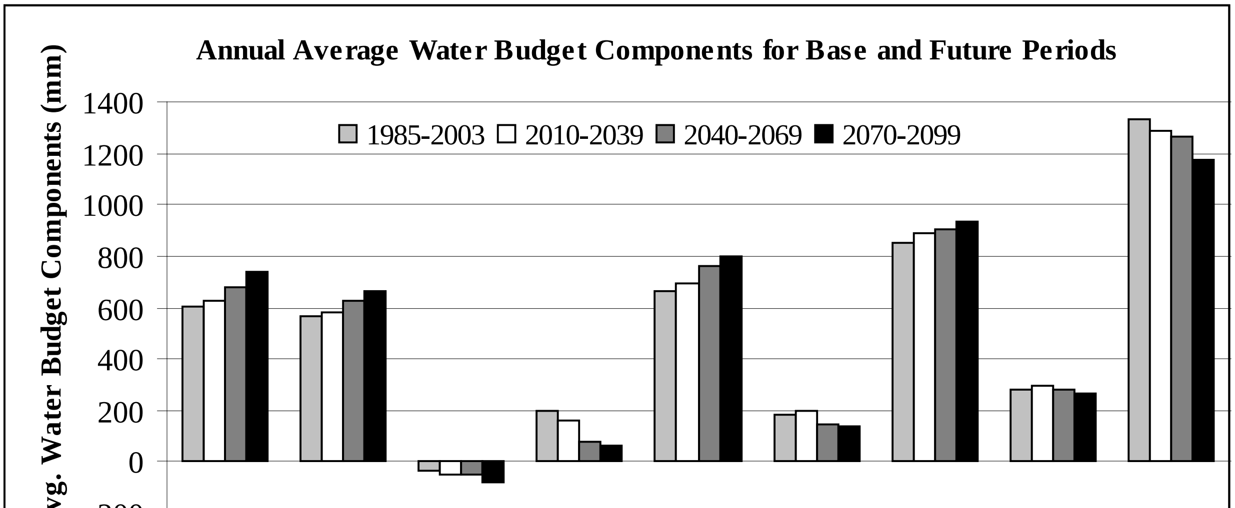
Table 4.10. Mean and standard deviation of actual and ClimGen generated future temperature and precipitation.

| | Mean temperature ($^oC$) | | | | Standard deviation mean temperature ($^oC$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | 2010-2039 | 2040-2069 | 2070-2099 | Actual | 2010-2039 | 2040-2069 | 2070-2099 |
| Jan | -9.7 | -5.5 | -2.3 | -0.4 | 3.2 | 2.3 | 1.4 | 1.5 |
| Feb | -8.6 | -7 | -4.3 | -0.5 | 2.6 | 2 | 1.2 | 1.9 |
| Mar | -2.1 | -1 | 1 | 3.1 | 2.1 | 2.3 | 1.5 | 2 |
| Apr | 5.9 | 7 | 7.6 | 9.6 | 1.6 | 1.6 | 1.7 | 2 |
| May | 12.8 | 14.7 | 15.9 | 18.7 | 1.5 | 1.4 | 1.3 | 1.5 |
| Jun | 17.6 | 18.3 | 19.8 | 21.8 | 1.3 | 1.4 | 0.8 | 1.7 |
| Jul | 20.1 | 21.4 | 23.2 | 24.2 | 1.2 | 1.1 | 0.6 | 1 |
| Aug | 19 | 19.6 | 20.4 | 22.3 | 1.2 | 1.4 | 1 | 1.4 |
| Sep | 14.4 | 14.6 | 16.3 | 17.5 | 1.3 | 1.4 | 1.4 | 1.7 |
| Oct | 7.6 | 7.4 | 9.7 | 11 | 1.3 | 1.4 | 1.3 | 1.8 |
| Nov | 1.2 | 2.1 | 2.7 | 3.3 | 1.7 | 1.9 | 1.7 | 2 |
| Dec | -6.1 | -4.6 | -4.8 | -4.9 | 3.4 | 1.8 | 1.5 | 1.4 |
| Mean | 6.0 | 7.3 | 8.8 | 10.5 | 1.9 | 1.7 | 1.3 | 1.7 |

| | Mean precipitation (mm) | | | | Standard deviation precipitation (mm) | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | 2010-2039 | 2040-2069 | 2070-2099 | Actual | 2010-2039 | 2040-2069 | 2070-2099 |
| Jan | 68 | 82 | 68 | 61 | 34 | 29 | 29 | 23 |
| Feb | 51 | 50 | 59 | 75 | 21 | 17 | 22 | 32 |
| Mar | 53 | 48 | 48 | 42 | 28 | 18 | 22 | 24 |
| Apr | 61 | 73 | 54 | 72 | 33 | 37 | 33 | 27 |
| May | 76 | 66 | 77 | 91 | 26 | 27 | 49 | 44 |
| Jun | 80 | 76 | 73 | 77 | 40 | 36 | 37 | 46 |
| Jul | 85 | 90 | 108 | 98 | 30 | 43 | 48 | 36 |
| Aug | 75 | 78 | 80 | 78 | 33 | 40 | 32 | 29 |
| Sep | 88 | 94 | 102 | 87 | 33 | 49 | 38 | 36 |
| Oct | 78 | 77 | 96 | 89 | 35 | 31 | 41 | 37 |
| Nov | 76 | 93 | 82 | 100 | 33 | 35 | 32 | 36 |
| Dec | 58 | 63 | 60 | 63 | 27 | 25 | 24 | 23 |
| Total | 849 | | | | | | | |
| Mean | | 890 | 907 | 933 | 31 | 32 | 34 | 33 |

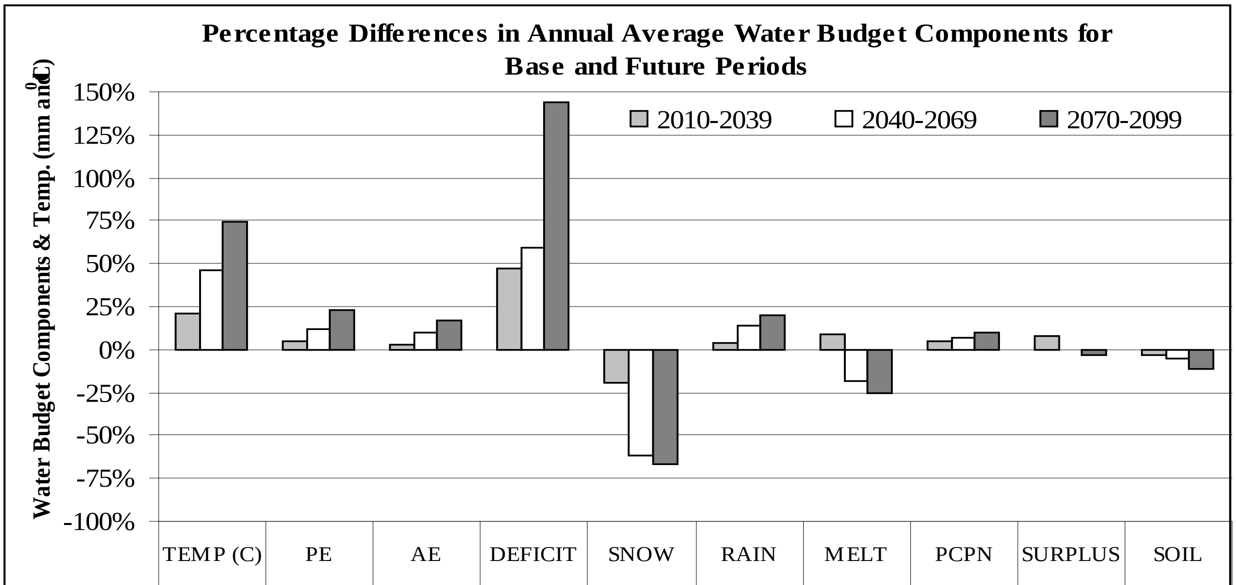
#### 3.4.3.4 Water Budget Modelling

The comparison of water budget components between baseline and future periods showed a 17% increase in annual actual evapotranspiration (663 mm vs. 569 mm) in the III period from the baseline period (Fig. 4.12 and 4.13). Even with a 10% increase in precipitation in the III period, a 74% increase in the temperature with a 23% increase in the potential evapotranspiration will result in a 144% deficit (Fig. 4.13). This is because the estimated runoff (P-ET) reduced by 53 mm with 193 mm increase in ET due to 4.5$^{o}$C increase in the temperature and 154 mm reduction in soil moisture content. Though the rain will increase from 667 mm to 798 mm in the III period, the snow will decrease from 206 mm to 66 mm during that period (Fig. 4.12). While the precipitation is continuously increasing from the baseline to III period, the snow is decreasing with the most significant decrease shown in the II period (Fig. 4.13). Temperature increased significantly from the baseline in all three future periods.




| | PE | AE | DEFICIT | SNOW | RAIN | MELT | PCPN | SURPLUS | SOIL |
|---|---|---|---|---|---|---|---|---|---|
| 1985-2003 | 603 | 569 | -32 | 201 | 667 | 181 | 849 | 277 | 1332 |
| 2010-2039 | 630 | 583 | -47 | 163 | 691 | 197 | 890 | 299 | 1288 |
| 2040-2069 | 677 | 626 | -51 | 77 | 758 | 147 | 907 | 277 | 1266 |
| 2070-2099 | 740 | 663 | -78 | 66 | 798 | 135 | 933 | 269 | 1178 |

Figure 4.12. Annual average water budget components for base and future periods.




| | TEMP (C) | PE | AE | DEFICIT | SNOW | RAIN | MELT | PCPN | SURPLUS | SOIL |
|---|---|---|---|---|---|---|---|---|---|---|
| 2010-2039 | 21% | 4% | 2% | 47% | -19% | 4% | 9% | 5% | 8% | -3% |
| 2040-2069 | 46% | 12% | 10% | 59% | -62% | 14% | -19% | 7% | 0% | -5% |
| 2070-2099 | 74% | 23% | 17% | 144% | -67% | 20% | -25% | 10% | -3% | -12% |

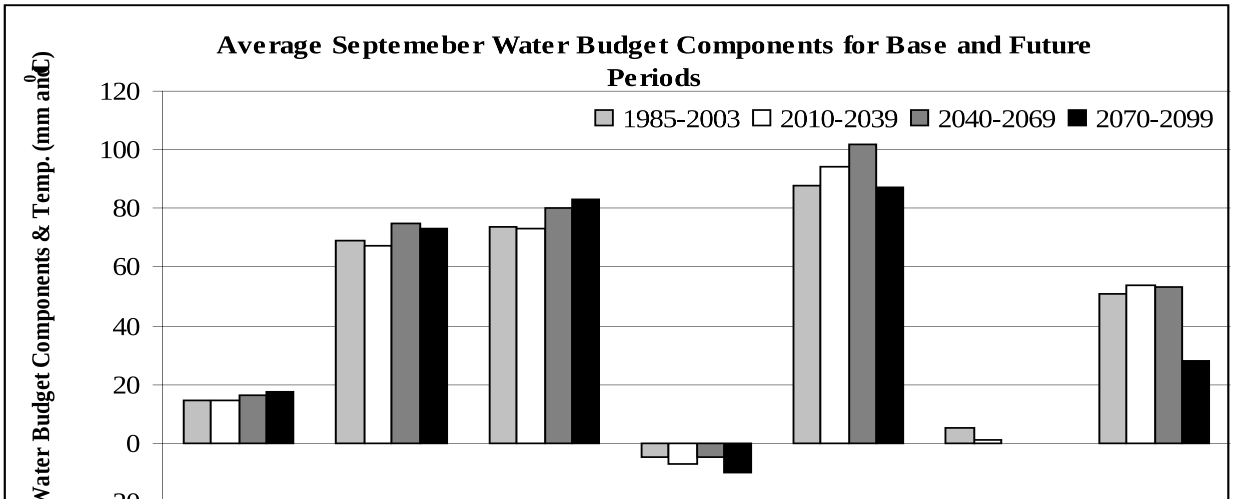
Figure 4.13. Percentage differences in annual average water budget components of base and future periods.

From the recent Source Water Protection-Tier I Water Budget study (Mississippi-Rideau Source Protection Region), the highest water demand in the watershed upstream of Appleton (for Carleton Place surface water taking) was observed in September, a low flow month (unpublished CA-MNR draft document). Therefore, the water budget components in September were analyzed to determine the effect of future water takings. There might be an increase of 3.1°C in the temperature (22% from the base period) by the III period (Fig. 4.14 and 4.15). In the II period, the variation in the actual and potential evapotranspiration was less (9% vs. 8%), with a 16% increase in precipitation, hence no deficits (Fig. 4.15). However, there will not be any surplus water (100% decrease). A 22% increase in temperature increased 12% of the actual evapotranspiration in the III period. Precipitation may also decrease by 1%, so the deficit will increase and surplus will decrease by 100% (Fig. 4.15). Though soil moisture decreased continuously from I to III periods, a significant decrease (-45% vs. 4-6%) was observed in the III period. This is due to reduced runoff (10 mm), soil moisture (23 mm), increased ET (9 mm) and no surplus in the III period.

In general, with respect to the baseline period conditions, temperature is continuously increasing at 1 to 22%; surplus is decreasing at -80 to <-100%; and soil moisture content is also decreasing at 6 to -45%. Though there was a decrease in potential or actual evapotranspiration in the I period, the values observed will increase in the II and III periods. Similarly, although the precipitation observed will increase in the I and II periods, it will decrease in the III period. The deficit will be in the range of 0-100% within the three periods. So even with some increase in precipitation, increase in the ET along with higher temperatures continuously increased the deficit and reduced the surplus. Therefore, more studies and/or better water management options should be implemented to meet -water demand, especially in low flow periods.

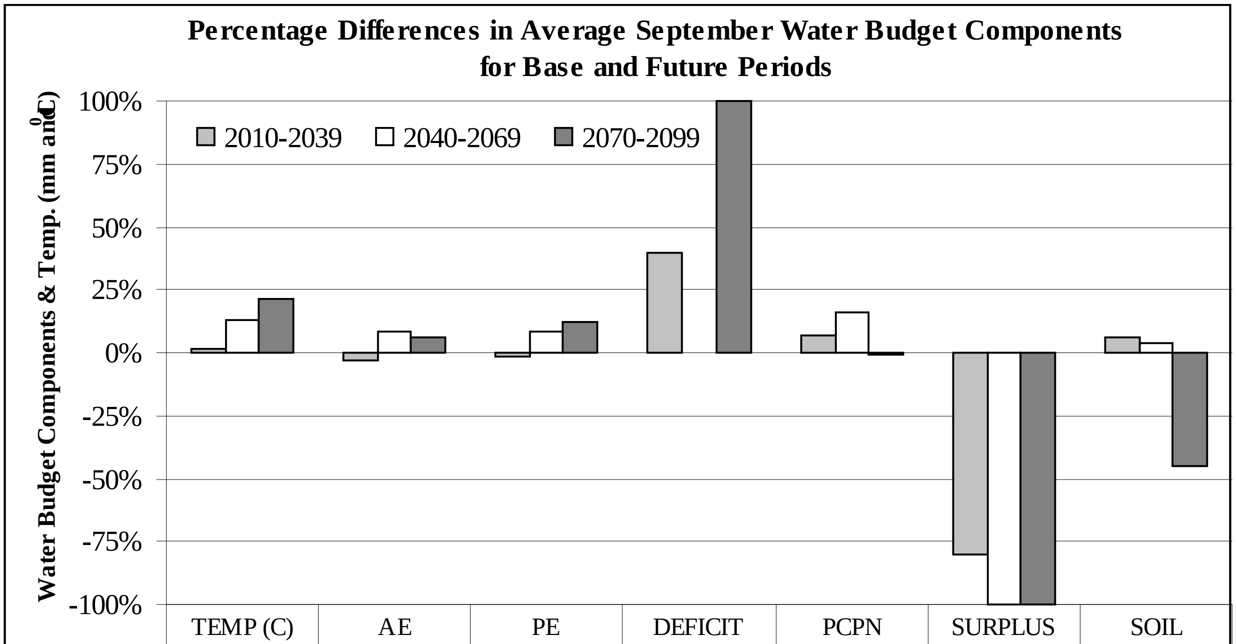
### 3.4.3.5 Calibration of NAM Model

The NAM model was calibrated with observed runoff at Gordon Rapids for 21 years, from January 1, 1973, to December 31, 1993. The simulated and observed runoff (hydrograph) and simulated and observed accumulated runoff for the period 1973-1993 are shown in Figure 4.16. Simulated and observed flows match well, and their accumulated flows also compared well with each other. A higher coefficient of determination of 0.72 was obtained for observed and simulated flow, and the difference between the average annual observed and simulated flow was 25 mm/yr (Fig. 4.16).




| | TEMP (C) | AE | PE | DEFICIT | PCPN | SURPLUS | SOIL |
|---|---|---|---|---|---|---|---|
| 1985-2003 | 14.4 | 69 | 74 | -5 | 88 | 5 | 51 |
| 2010-2039 | 14.6 | 67 | 73 | -7 | 94 | 1 | 54 |
| 2040-2069 | 16.3 | 75 | 80 | -5 | 102 | 0 | 53 |
| 2070-2099 | 17.5 | 73 | 83 | -10 | 87 | 0 | 28 |

Figure 4.14. Average September water budget components for base and future periods.




| | TEMP (C) | AE | PE | DEFICIT | PCPN | SURPLUS | SOIL |
|---|---|---|---|---|---|---|---|
| 2010-2039 | 1% | -3% | -1% | 40% | 7% | -80% | 6% |
| 2040-2069 | 13% | 9% | 8% | 0% | 16% | -100% | 4% |
| 2070-2099 | 22% | 6% | 12% | 100% | -1% | -100% | -45% |

Figure 4.15. Percentage differences in average September water budget components for base and future periods.

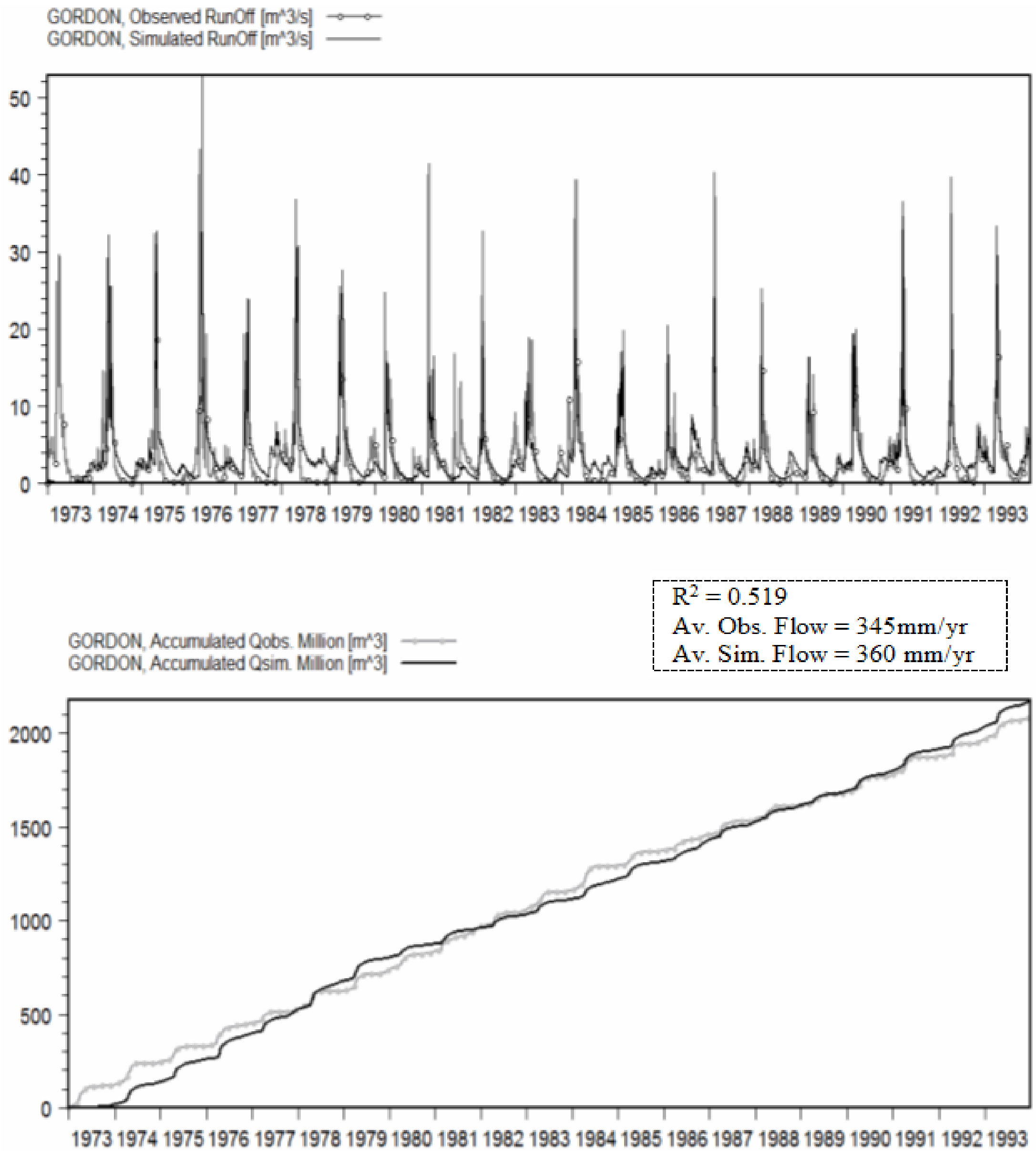



Figure 4.16. NAM model calibration – runoff hydrograph and accumulated runoff of observed and simulated flows at Gordon Rapids for 1973-1993.

### 3.4.3.6 Validation of NAM Model

The calibrated NAM model was validated with 10 years (1994-2003) of observed runoff at Gordon Rapids. Figure 4.17 shows a good comparison between simulated and observed runoff (hydrograph). Accumulated runoff of simulated flows is well matched from 2000 onwards; a coefficient of determination of 0.743 and less difference (10 mm/yr) in accumulated observed and simulated flows are good for the modem validation.

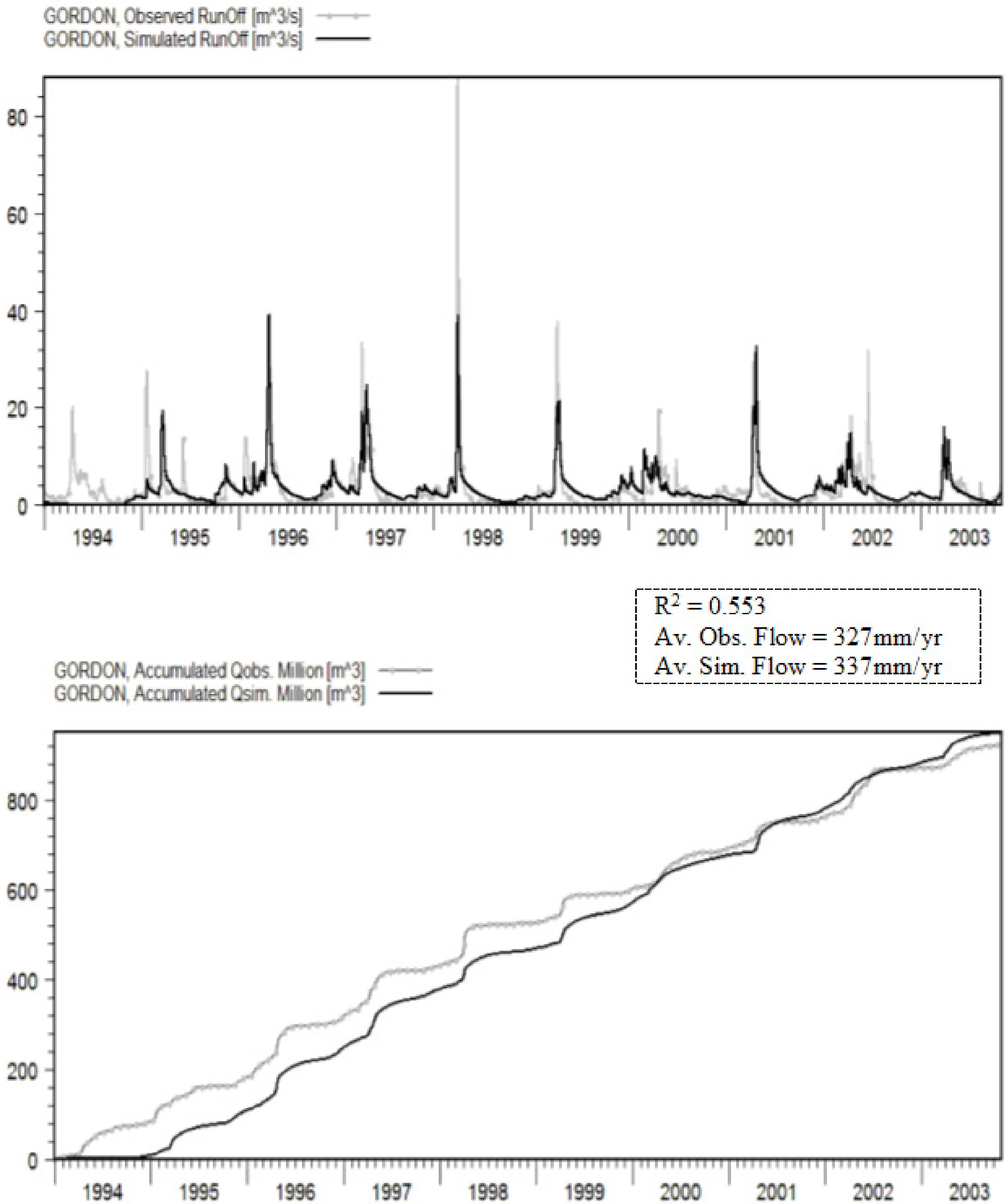
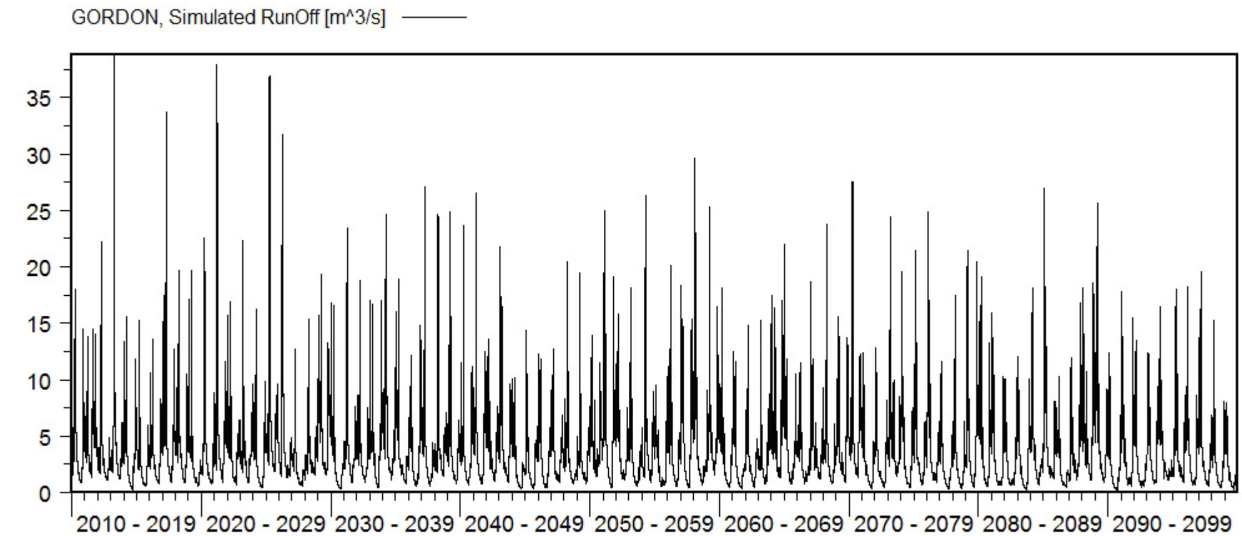



Figure 4.17. NAM model validation – runoff hydrograph and accumulated runoff of observed and simulated flows at Gordon Rapids for 1994-2003.

#### 3.4.3.7 Simulation of Runoff for Future Periods

The well calibrated and validated NAM model was used to simulate runoff for future periods from 2010-2099. The simulated and accumulated runoff flows (hydrograph) for 2010-2099 periods are shown in Figure 4.18.



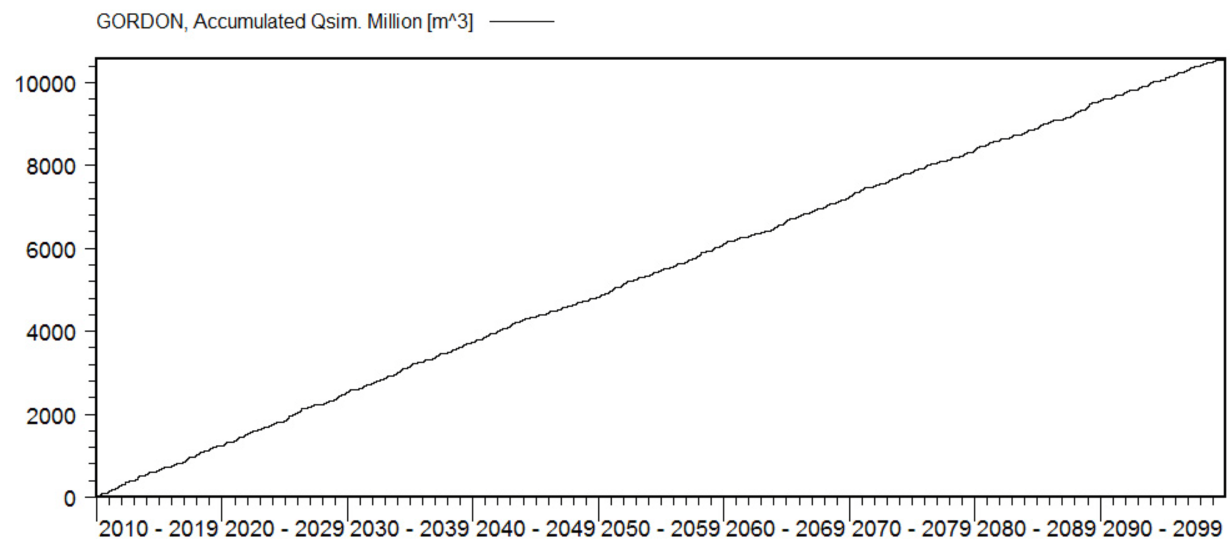




Figure 4.18. Runoff hydrograph and accumulated simulated runoff at Gordon Rapids for 2010-2099.

### 3.4.3.8 Adjusted Simulated Flows

Although much effort was taken to match low flows and overall water balance in model calibration, the model overestimated flows in June to October. Since this difference was observed in the summer months, it might be due to the evapotranspiration data used in the model calibration. The ET data were taken from the source protection study, where the ET was generated by a GIS-based Thornthwaite Model, which took into account soil, slope, land use, and

water-holding capacity. The model was primarily run with climate data from the Ottawa station; therefore it might have some differences when applied to the Mississippi watershed area.
In order to correct the difference while keeping the simulation for other months the same, a ratio of observed and simulated flows for each month was estimated and applied to daily simulated data. Figure 4.19 shows the average daily flows of observed, adjusted simulated, and original simulated flows. The adjusted simulated flows match well with the observed flows for all months. Therefore, the ratios were similarly applied to the simulated daily flows for the future periods (2010-2099).

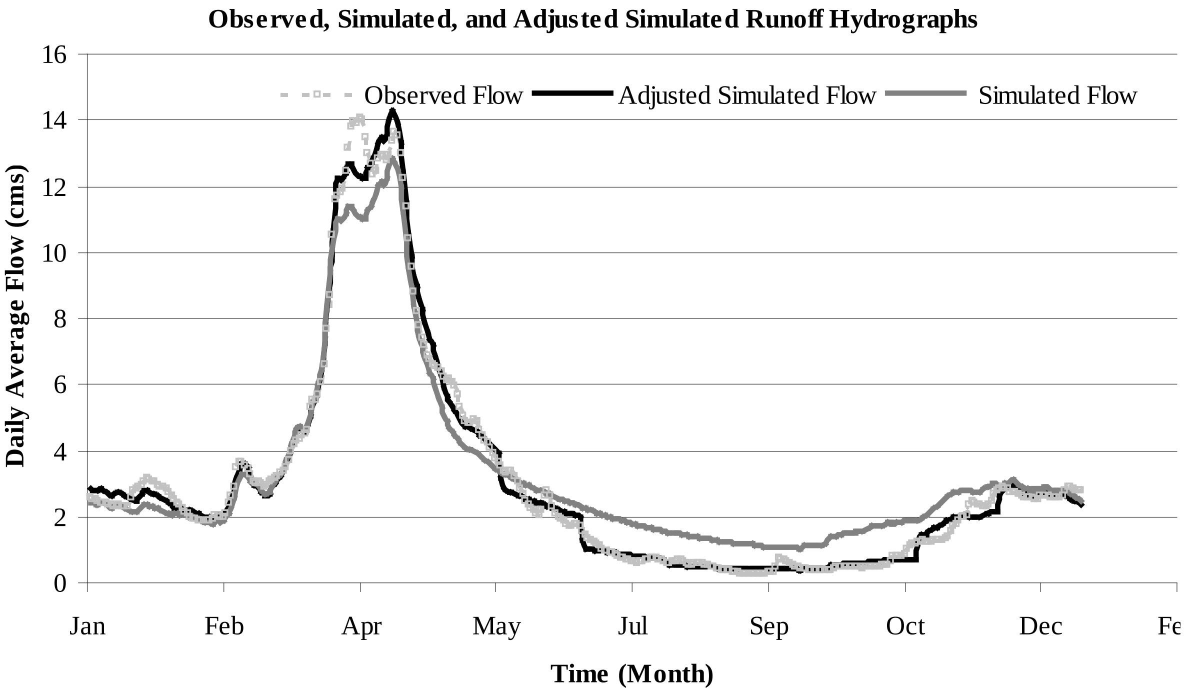



Figure 4.19. Average daily runoff hydrograph of observed, adjusted simulated, and simulated flows at Gordon Rapids.

### 3.4.3.9 Validation of Mississippi River Watershed Model (MRWM)

Calibration of the Mississippi River Watershed Model (MRWM) was previously completed as part of the Mississippi River Water Management Plan and is not presented as part of this report. Since the MRWM is principally a hydrologic routing algorithm, calibration essentially consists of the following components:

- Structure stage/discharge and stage/storage relationships
- Muskingum routing parameters
- Estimates of lake evaporation

Three years (1997, 1999, and 2001) were selected from the base periods (1974-2002) for which structure operating records are available to validate the MRWM for the present study. Figure 4.20 provides a comparison of simulated versus observed stream flows at the Appleton stream gauge site for 1999; 1997 and 2001 are shown in Appendices 4-A9 and 4-A10, respectively.
As can be seen, the model provides a good representation of the observed hydrograph, particularly as it relates to timing, and further provides a good ability to model reservoir influences. The principal error introduced by the model is a result of the reservoir inflows and sub-watershed contributions being derived from transposed stream flows. This error, however, is minimized by the significant storage and lag introduced by the reservoirs.

### 3.4.3.10 Water Resources Implications and Response

*Overview of Current Management Strategy*
Reservoir regulation involves the strategic storage and release of water over varying time periods to achieve a range of water management objectives. These objectives are established to address a variety of social, environmental, and economic interests within the constraints imposed by the physical characteristics of the watershed and reservoir system under consideration.
Within the Mississippi River watershed, the water management objectives are defined by the Mississippi River Water Management Plan (2006) and reflect the management regime that has evolved over the past 90 years in response to development, resource use, and climate conditions experienced in the watershed.

The mean annual stream flow hydrograph (Fig. 4.21) from the Mississippi River at the Appleton stream gauge record (WSC 02KF006) demonstrates the typical response of this relatively large rural watershed to climate conditions in the region.

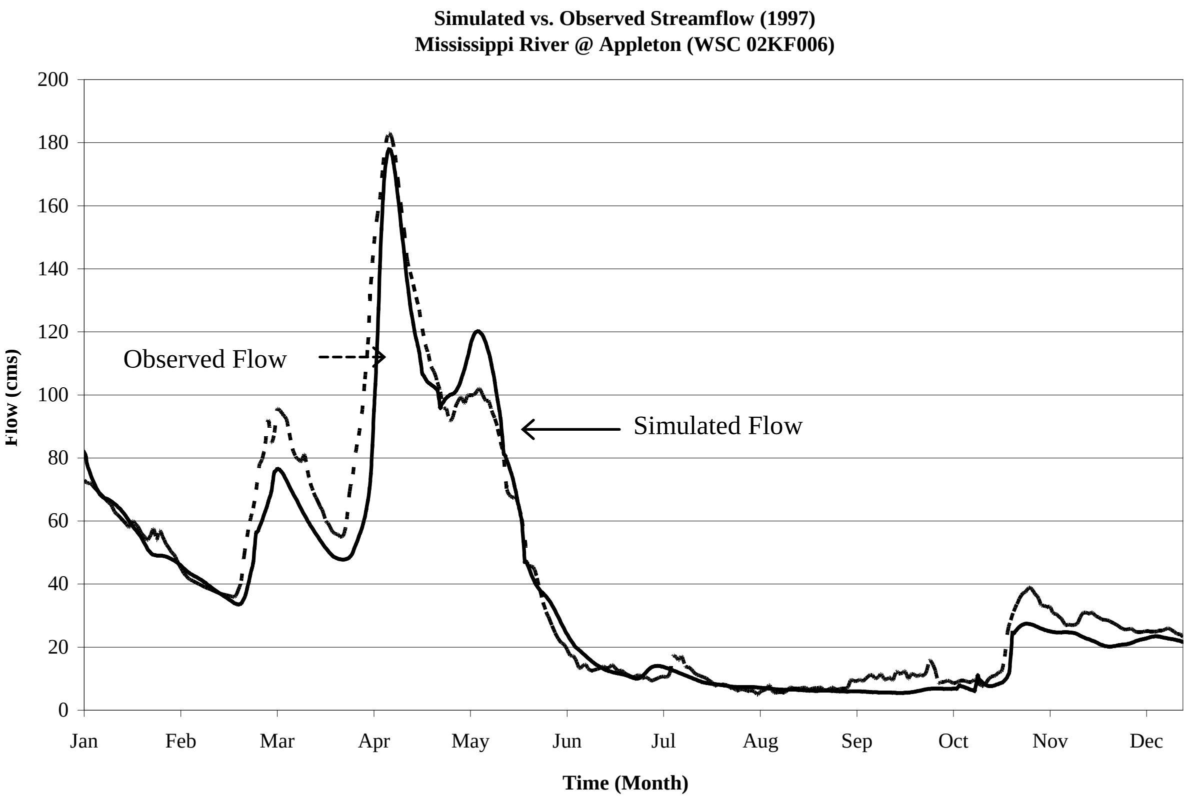


Figure 4.20. Simulated vs. observed stream flow of the Mississippi River at the Appleton gauge.

This response generally reflects accumulation of the snow pack over the winter months with relatively stable stream flows. By mid-March, stream flows begin to increase as warmer temperatures begin melting the snow pack, followed by a spring freshet where stream flows are typically at their highest level by mid- to late April as a result of snowmelt and rainfall. Over the months of May and June, stream flows recede as runoff from the freshet drains from the upland areas reaching their lowest levels by early September. While the Mississippi River stream flows reflect the influence of reservoir storage, this annual cycle is characteristic of most rural streams in eastern Ontario.

The water management regime implemented on the Mississippi River utilizes the existence of several large natural lakes in the upper reaches of the watershed to store water in times of excess runoff and then release it during drier periods when stream flow conditions are less reliable. The total storage available in these reservoirs (Table 4.11) is approximately 13,300 ha-m, or 47 mm of runoff when expressed as an average depth across the drainage area upstream of the Appleton stream gauge site.

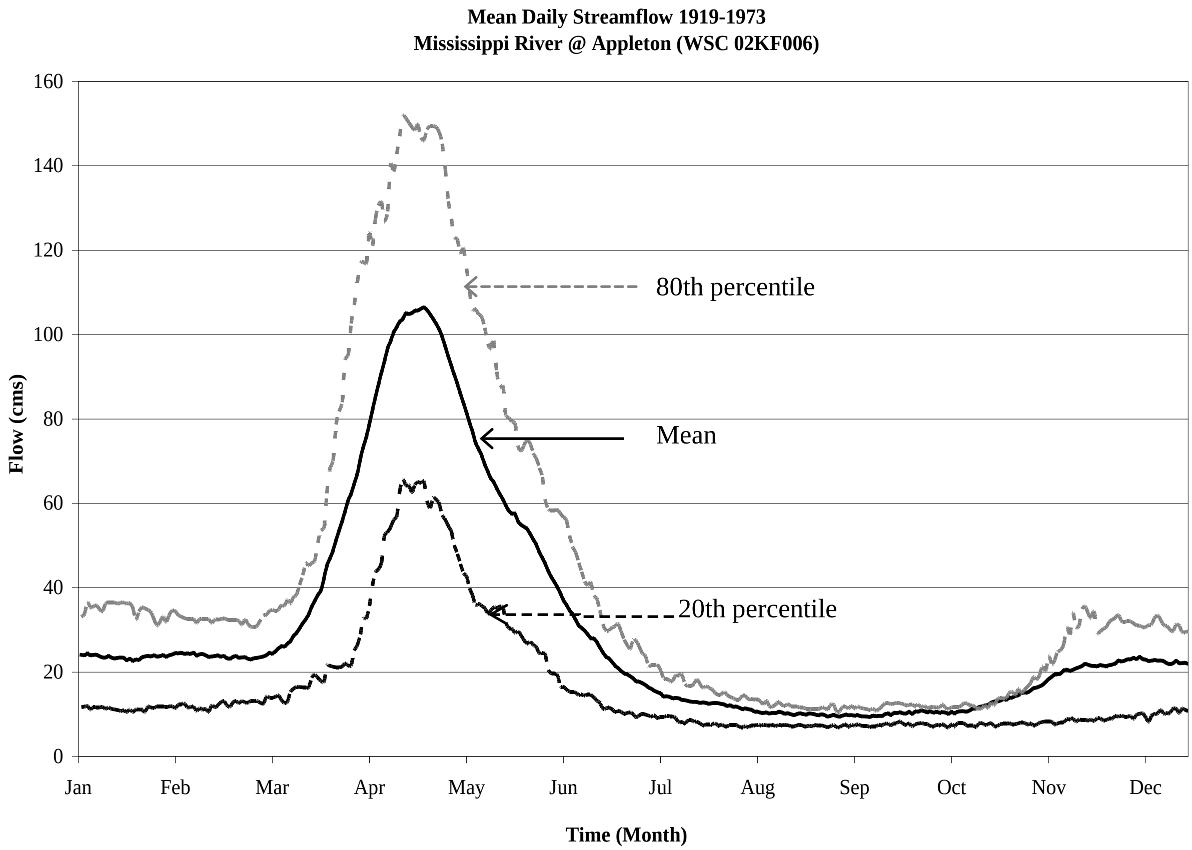



Figure 21. Mean daily stream flow of the Mississippi River at the Appleton gauge for 1919-1973.

**Table 4.11. Reservoir storage.**

| Reservoir | Storage (ha-m) |
|---|---|
| Shabomeka Lake | 428 |
| Mazinaw Lake | 1,956 |
| Kashwakamak Lake | 2,038 |
| Mississagagon Lake | 273 |
| Big Gull Lake | 1,778 |
| Crotch Lake | 6,836 |

To augment the available storage for stream flow regulation, the reservoir system utilizes a semi-annual drawdown regime of the main reservoir at Crotch Lake. Following the spring freshet, all six reservoirs are filled to their maximum operating levels. The upper five reservoirs are maintained within a tight operating band of +/- 0.1 m over the summer months to support tourism, recreation, and navigational interests. In contrast, the Crotch Lake reservoir is gradually drawn down over this period to release storage and augment stream flows in the lower river system. The available storage in Crotch Lake is typically depleted by mid-October when the reservoir reaches its minimum level.

By this point, storage from the upper five reservoirs is released and retained in the Crotch Lake reservoir for subsequent release to the lower river system over the winter period. All six reservoirs reach their lowest levels by the end of March, providing the maximum capacity to store excess runoff from the spring freshet. This provides a degree of flood protection to downstream communities while replenishing the reservoirs. Figures 4.22 and 4.23 describe this semi-annual management approach.

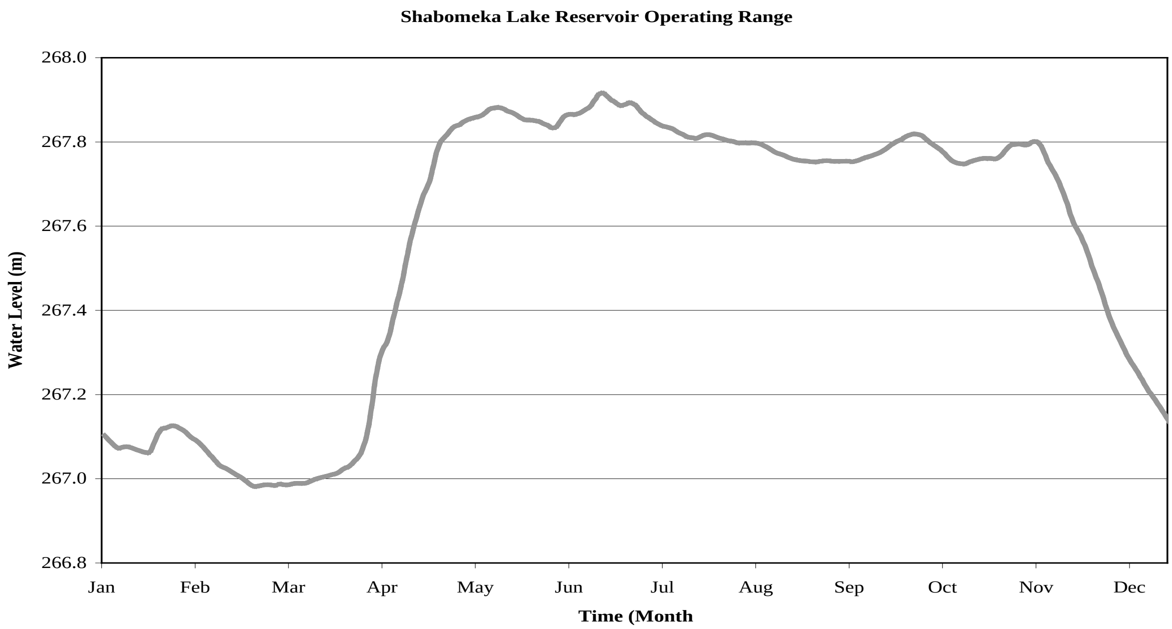



Figure 4.22. Shabomeka Lake reservoir operating regime.

The current strategy capitalizes on the historic runoff patterns to maximize available reservoir capacity and provide a variety of water management benefits, including:

- Flood reduction during spring freshet
- Stream flow augmentation for water supply, hydropower, waste assimilation, and aquatic ecosystems
- Stable water levels to support recreation, tourism, and navigation
- Maintaining fish and aquatic habitat

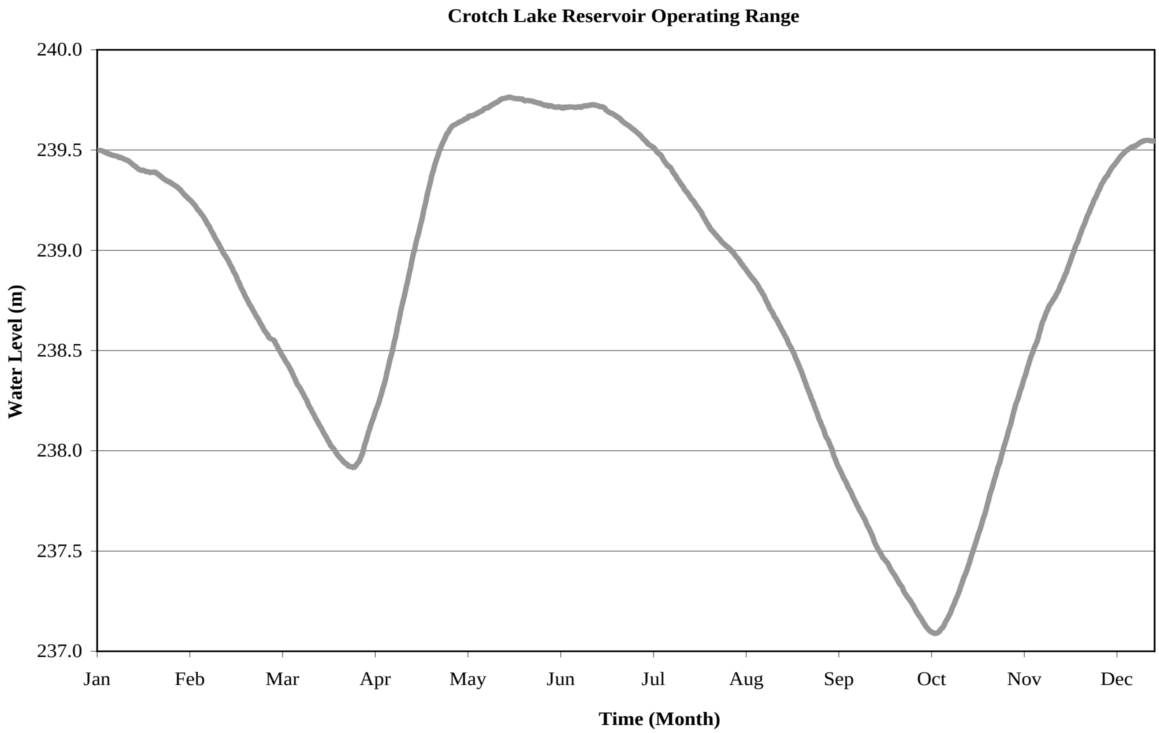



Figure 4.23. Crotch Lake reservoir operating regime.

*Implications of Changes in Stream flow Characteristics*

As mentioned previously, the existing infrastructure and present management regime are largely dependent on the continuation of historic runoff patterns within a degree of natural variability. In addition, development within the watershed and other resource management objectives for fisheries and water quality protection are premised on the present management regime being maintained.

A review of the stream flow record from the Appleton stream gauge (WSC 02KF006), which dates back to 1919, provides some insight into the potential implications of changing climate conditions. The stream flow record indicates a shift in average streamflow conditions between the periods 1919-1973 and 1974-2002 (Fig. 4.24). The spring freshet occurs approximately 10 days earlier in the later period, with an increase in fall/winter stream flows of approximately 43%.

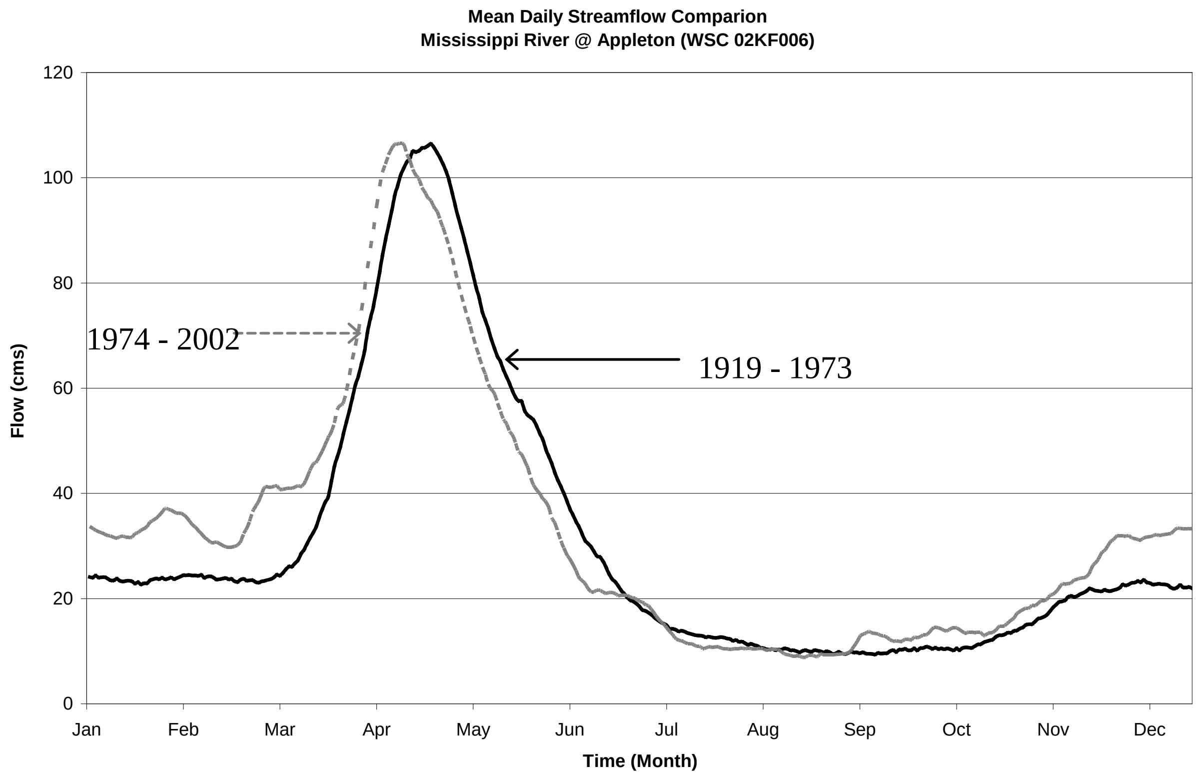



Figure 4.24. Comparison of mean daily stream flow of the Mississippi River at the Appleton gauge for 1919-1973 and 1974-2002.

Further insight can be gained by examining changes in seasonal stream flow characteristics. The Mann-Kendall test was applied to the seasonal stream flow series to test for statistically significant trends in the data set. Mean annual stream flow at Appleton over the period of record (Fig. 4.25) is approximately 30 cms and does not demonstrate any statistically significant trend (Table 4.12). However, mean stream flows for January and February over the period of record (Fig. 4.26) demonstrate a statistically significant increase (• • • • • • •••• ••• • •••••••• variability (Table 4.12).

In contrast, Figure 4.27 shows a trend toward lower minimum stream flows expressed as a 7-day mean for the period

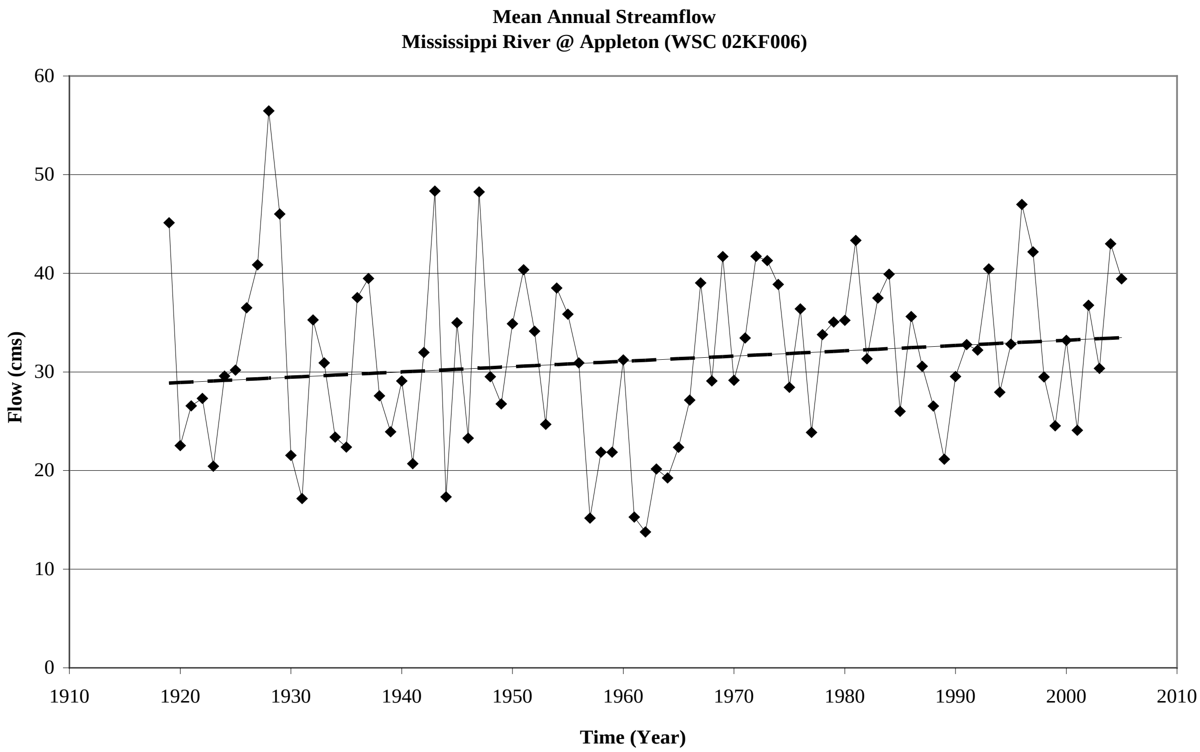



Figure 4.25. Mean annual stream flow of the Mississippi River at the Appleton gauge (1919-2005).

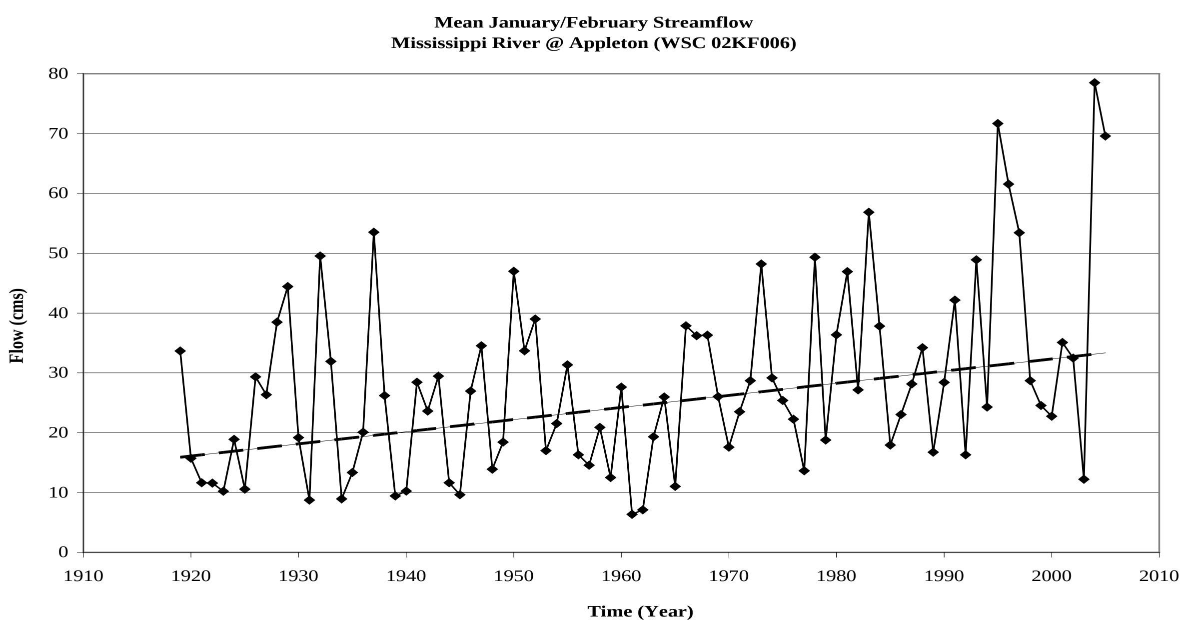



Figure 4.26. Mean stream flow (Jan/Feb) of the Mississippi River at the Appleton Gauge (1919-2005).

Table 4.12. Regression and Mann-Kendall statistics.

| | | | Mann-Kendall statistics | |
|---|---|---|---|---|
| Data period | Regression equation | Coefficient of determination (*r*) | Z value | Significant level (α) |
| ***1919-2005 Flow at Appleton*** | | | | |
| Mean annual flow | Y = 0.053T - 73.81 | 1 | 1.4 | >0.1 |
| Mean winter flow | Y = 0.203T - 373.6 | 1 | 3.32 | 0.001 |
| Min. summer flow | Y = -0.032T + 70.02 | 1 | -3.45 | 0.001 |
| ***1972-2003 Flow at Gordon Rapids*** | | | | |
| Mean annual flow | Y = 0.1437T + 28.685 | 0.16 | -0.18 | >0.1 |
| Mean winter flow | Y = 0.0255T + 1.5494 | 0.00 | 0 | >0.1 |
| Min. summer flow | Y = -0.0022T + 0.6267 | 0.10 | 0 | >0.1 |
| Max. summer flow | Y = 0.0055T + 2.3047 | 0.04 | 0.57 | >0.1 |
| ***2010 - 2099 Simulated Flow at Gordon Rapids*** | | | | |
| Mean annual flow | Y = -0.0641T + 23.354 | 0.00 | -1.24 | >0.1 |
| Mean winter flow | Y = 0.0009T + 4.489 | 0.00 | -0.26 | >0.1 |
| Min. summer flow | Y = -.0072T + 1.0415 | 0.21 | -2.16 | 0.05 |
| Max. summer flow | Y = -0.0137T + 3.6061 | 0.22 | -1.95 | 0.1 |
| ***Model Calibration Validation 1975 - 2003 Flow at Gordon Rapids*** | | | | |
| Mean annual observed flow | Y = -0.013T + 3.294 | 0.01 | -0.66 | >0.1 |
| Mean annual simulated flow | Y = 0.009T + 2.939 | 0.22 | -0.43 | >0.1 |

*Other Factors Affecting Stream Flow*

Operating records for the reservoir system prior to 1950 are sparse; however, based on records that are available, it appears that operation of the Crotch Lake reservoir has largely remained unchanged. Available information and anecdotal evidence indicate that the upper reservoirs may have been subjected to some restrictions in their use for stream flow augmentation during the summer months. It is not expected that these restrictions can fully account for the trends being noted, although they may be an aggravating factor.

Large-scale changes in land cover and drainage patterns can also \ influence the stream flow characteristics of a watershed. Forest cover within the Mississippi River watershed upstream of Appleton is presently 70%, with mixed deciduous and coniferous forest. Active forest harvesting has occurred, particularly in Lanark and Frontenac counties, although this resource has been actively harvested over the past century and forest cover continues to be the dominant land use in the watershed.

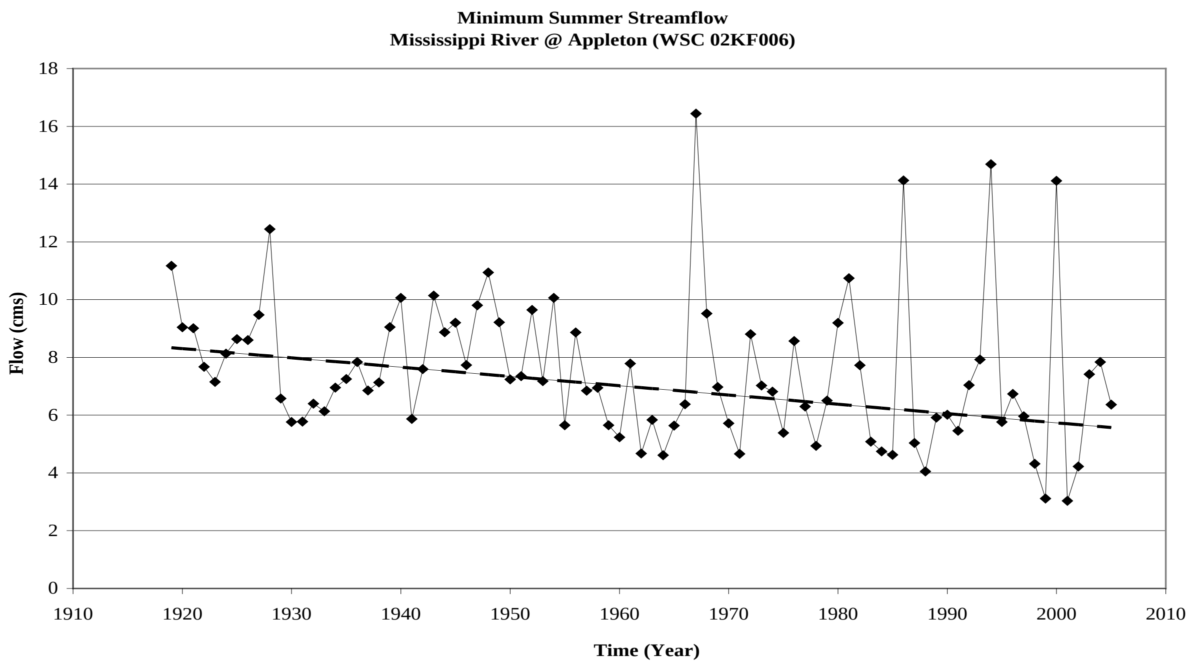



Figure 4.27. Mean stream flow (Jul-Oct) of the Mississippi River at the Appleton Gauge (1919-2005).

No large-scale drainage projects or wetland loss have been noted over the period of record that could account for changes in stream flow.

*Water Resource Implications*

In an effort to investigate the potential for climate change to influence the stream flow characteristics of the Mississippi River, the present study was undertaken to assist in quantifying the impact that projected climate scenarios may have on stream flow conditions and the ability of existing water control infrastructure and management plans to respond to those conditions.

As discussed previously, the methodology used in the present study was to generate a synthetic stream flow series for the Mississippi River under projected climate scenarios to the year 2099. The stream flow series was subsequently applied as inflows to the reservoir system to assess the performance of the water control infrastructure in satisfying the water management objectives as established through the Mississippi River Water Management Plan.

The synthetic stream flow series generated from the climate modelling provided a continuous time series of stream flows for the Clyde River at Gordon Rapids for the period 1974 to 2099. As discussed previously, this series was subdivided into four subsets representing 1974-2002, 2010-2039, 2040-2069, and 2070-2099. The 1974-2002 subset provided a base period on which to evaluate the impact of climate projections over successive periods relative to the base period.

Each period was initially described by the mean daily stream flow hydrograph for the period, then transposed to the adjacent sub-basins and subsequently routed through the watershed and reservoirs to the Mississippi River at Appleton based on current water management objectives. The resulting average stream flow conditions at Appleton are shown in Figure 4.28.

The changes in projected stream flow conditions are consistent with observed changes occurring in the actual stream flow record between 1919 and 2002. Results of the reservoir simulations indicate that average annual stream flow will decrease by 10% between the base period (1972-2002) and the future period (2070-2099). In general, stream flows will increase substantially in fall (Oct-Dec) and winter (Jan-Feb) periods by 74% and 70%, respectively, while they will decrease in spring (Mar-May) and summer (Jun-Sep) by 43% and 66%, respectively. On average, spring freshets will occur 6 to 7 weeks earlier in the 2070-2099 period than in the 1972-2002 base period and will be approximately 33% lower in peak stream flow. Minimum summer flows will decrease by approximately 44% and will persist 28% longer.

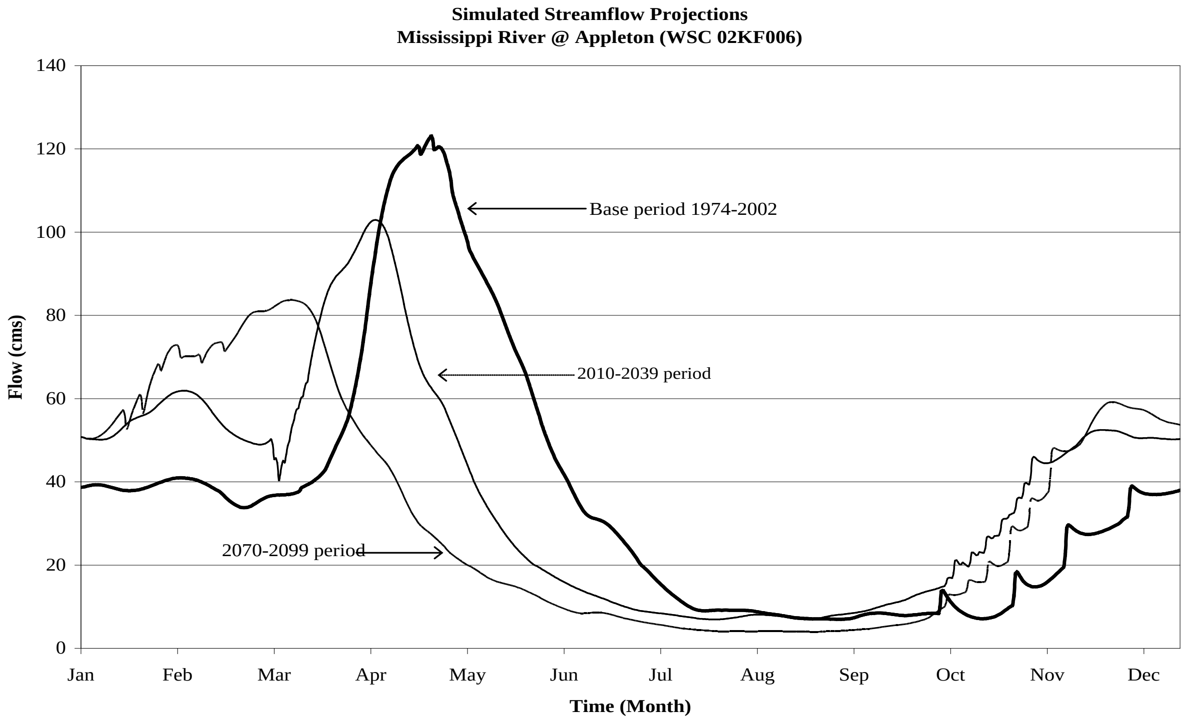



Figure 4.28. Simulated stream flow projections for the Mississippi River at the Appleton gauge for 2010-2039, 2070-2099.

Clyde River at Gordon Rapids stream flow projections (Fig. 4.29) suggest that maximum annual stream flow will tend to decrease, while the variability of summer maximum stream flows (Fig. 4.30) • • • • • • • • • • • • • • • • • • Table 4.12). This will require further research to assess the potential implications of high-intensity rainfall events on factors such as flood risk and nutrient loading from non-point sources.

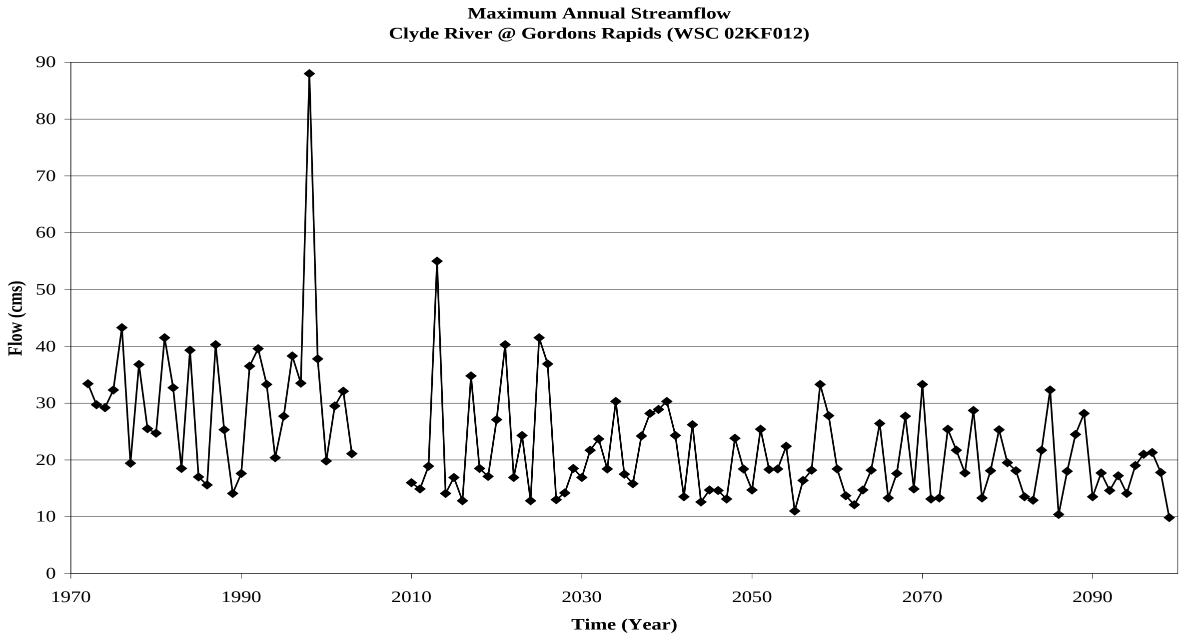



Figure 4.29. Maximum annual stream flow of the Clyde River at Gordon Rapids (1975-2100).

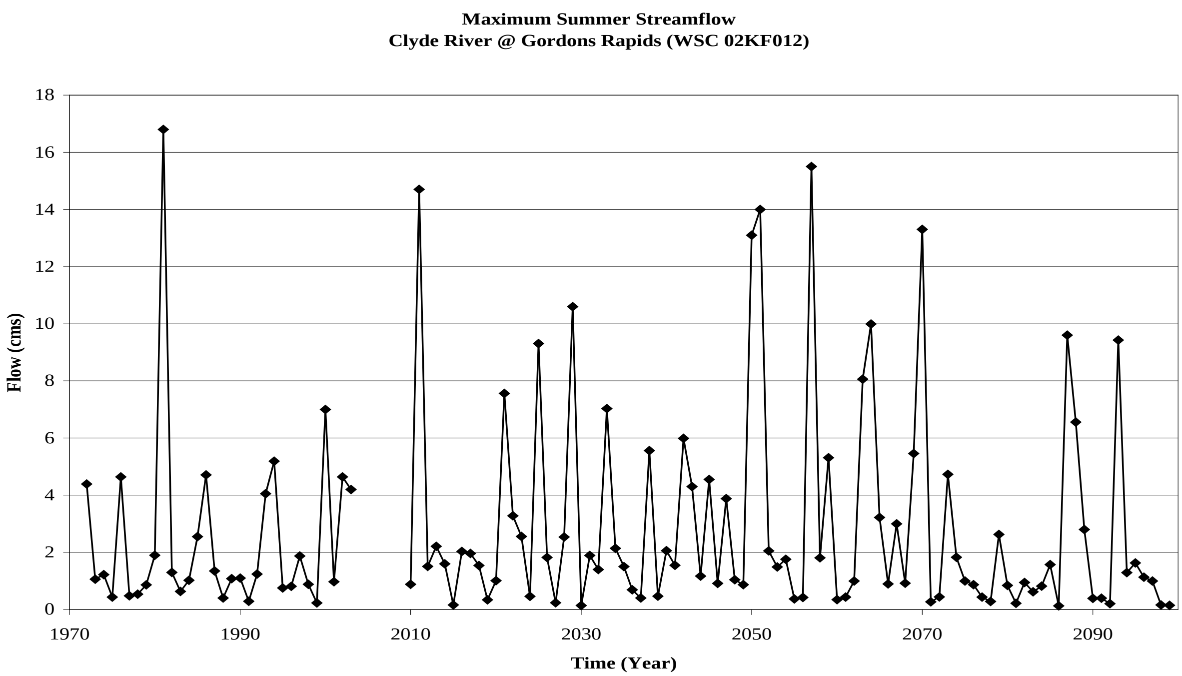



Figure 4.30. Maximum summer stream flow of the Clyde River at Gordon Rapids (1975-2100).

Low flow conditions on the Mississippi River are expected to become more frequent and severe in the later periods. While these will be moderated through stream flow augmentation, the capacity of the reservoir system to satisfy current stream flow objectives will be insufficient. The reservoir capacity is insufficient to meet current objectives under extreme low flow conditions as experienced in 1999. Low flow events on the Mississippi River are expected to become more prolonged (Fig. 4.31). Minimum stream flows in 1999 were 2.5 cms as compared to 2.4 cms and 1.7 cms in 2030 and 2083, respectively.

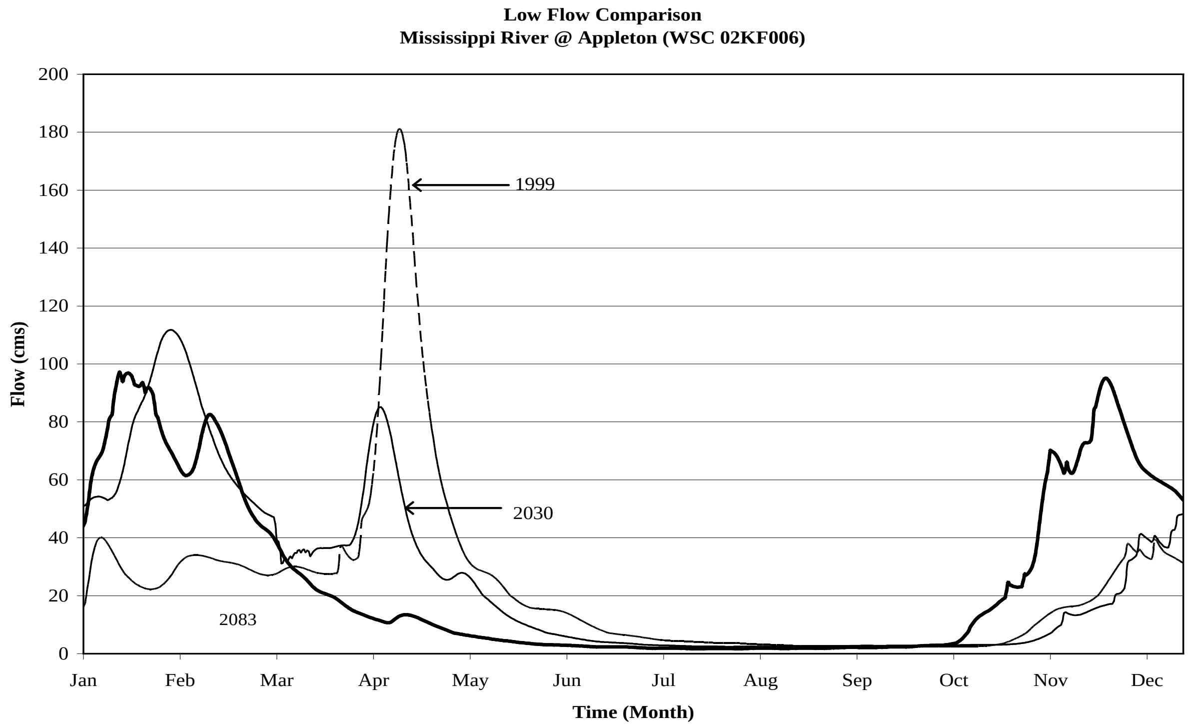



Figure 4.31. Low flow comparison for the Mississippi River at the Appleton gauge.

*Reservoir Operation and Capacity*

The most significant effect of the projected change in climate conditions for the Mississippi River will be a shift in the temporal distribution of runoff (Fig. 4.28), which will be incompatible with current reservoir operation policies. The existing reservoir system addresses multiple water management objectives, such as flood reduction, low flow augmentation, maintaining fish habitat, and supporting recreation and tourism.

While, in general, recreational interests can be satisfied in the upper reservoirs, existing reservoir capacity is insufficient to meet downstream low flow augmentation objectives under extreme conditions. To satisfy these objectives, additional reservoir volumes of 2,000 to 3,500 ha-m will be required.

The current strategy of reservoir drawdown in the fall will present risks for flood and erosion damage, since stream flow conditions are expected to be on average 74% higher during the drawdown period. The mean projected stream flow rates (for all future periods) will be sufficient to place flood-susceptible areas of the watershed near flood stage for much of the fall and winter periods. Restricting drawdown of the reservoirs to lessen the risk in the fall may subsequently place the same flood-prone areas at risk from spring snowmelt should accumulation of a snow pack occur. Likewise, flood susceptibility and risk of erosion on reservoir lakes will increase with higher reservoir levels over the winter. There is a high degree of uncertainty associated with this risk as mean monthly temperatures approach 0°C during the winter months and snow accumulation becomes more variable, particularly in the 2070-2099 period.

*Water Resource Impacts and Response Summary*

Table 4.13 provides a summary of water resource implications for the Mississippi River as a result of projected changes in climate conditions and potential response measures that may be considered to assist in adaptation. While the direct impacts of the projected changes in climate are significant to the water resources of the basin, the indirect or secondary effects on existing infrastructure and resource management policies are more difficult to assess.

The projected changes in climate and associated runoff patterns in the Mississippi River watershed are expected to create conflicts among competing interests for the basin's water resources. More severe and prolonged low flow conditions, when coupled with higher surface water temperatures and the potential for higher nutrient loading, will also result in substantial stress on the aquatic ecosystem. Resource management policies and related infrastructure, which have been developed based on our past experience and expectations of climate norms, will require modification to address a range of social and environmental impacts. At the local level, addressing these will be more difficult, given our current administrative structures, which are not conducive to integrated planning and decision making.

Table 4.13. Water resource impacts and response summary.

| Objective | Water Resource Impact | Potential Response |
|---|---|---|
| Low flow augmentation<br>Water supply<br>Hydro generation | More severe and prolonged low flow conditions;<br>Reservoirs will be insufficient to satisfy current low-flow targets;<br>Municipal water supply requirements;<br>Will be fully dependant on reservoir supplies;<br>Hydro generation potential will be reduced in summer low flow periods. | Increased reservoir storage by 2000 to 3500 ha-m required to meet current objectives;<br>Continued maintenance and reconstruction of water control infrastructure;<br>Minimize water use and consumption. |
| Fish habitat | Lower stream flows during typical walleye spawning periods;<br>Loss of traditional pike spawning habitat due to lower water levels during spawning period. | Identify and protect significant spawning areas;<br>Develop opportunities for fish passage around structural barriers. |
| Flood protection | Generally lower risks from spring snowmelt/rainfall events;<br>Greater risk of fall/winter flood conditions coupled with reservoir drawdown. | Discontinue/reduce fall drawdown regime;<br>Assess implementation of risk-based reservoir management strategy;<br>Assess alternative flood damage reduction measures. |
| Tourism/recreation | Generally capable of achieving recreational water level targets on reservoirs;<br>Lower stream flows will be insufficient to maintain recreational levels within current objectives. | Assess efficacy of lower and broader operating targets on recreational lakes, including the provision for flood reserves. |
| Water quality protection | Lower stream flows in summer will reduce flushing rates and waste assimilation capacity;<br>Higher intensity rainfall events will increase nutrient loading to the river system;<br>Total phosphorous levels currently approaching limit of provincial water quality objective for Policy 2 streams;<br>Greater risk for low dissolved oxygen levels. | Quantify nutrient loading;<br>Reduce point and non-point loading;<br>Minimize disruption and alteration to natural stream corridors and shore lands. |

### 3.4.4 Summary and Conclusions

The CGCM2 climate projections and the CLIMGEN-generated future climate data for the Mississippi River watershed projects an increase in minimum and maximum temperatures throughout the year, except for maximum temperatures in December. Winter (Jan through Mar) minimum temperatures, winter maximum temperatures, and summer minimum temperatures increase considerably over the 2010 to 2099 periods. The highest percentage rate change was observed in minimum temperature, which increased in January and February by $0.05^{0}$C/yr to $0.13^{o}$C/yr for the 2010 to 2099 periods. Wetter fall conditions are predicted; however, winter conditions are more or less the same as the base period (1984-2000). There is more variability in both the actual and generated precipitation data than in minimum or maximum temperatures. The base period average annual precipitation of 849 mm, with a standard deviation of 31 mm, increases to 907 mm by 2099, with a standard deviation varying between 32 to 34 mm. The water budget model projects increases of 74% in mean annual temperature, 10% in precipitation, 20% in rainfall, 23% in potential evapotranspiration, and 144% in deficit. Snowmelt decreases by 25%, surplus decreases by 3%, snow accumulation decreases by 67%, and soil moisture decreases by 12% between the 1985 and 2099 periods.

The NAM model calibrated with 21 years (Jan. 1, 1973-Dec. 13, 1993) of actual flow data for the Clyde River at the Gordon Rapids stream gauge. Simulated and observed stream flows match well with a coefficient of determination of 0.72, and their accumulated flows also compared well with each other. Good agreement was observed between the simulated and observed runoff, with a higher coefficient of determination of 0.74 for NAM model validation with 10 years (1994-2003) of actual flow data.

Results of the reservoir simulations indicate that average annual stream flow will decrease by 10% between the base period (1972-2003) and the future period (2070-2099). In general, stream flows will increase in the fall (Oct-Dec) and winter (Jan-Feb) periods by 74% and 70%, respectively, while they will decrease in spring (Mar-May) and summer (Jun-Sept) by 43% and 66%, respectively. On average, spring freshets will occur 6 to 7 weeks earlier in the 2070-2099 period than in the 1972-2003 period and will be approximately 33% lower in peak stream flow. Minimum summer flows will decrease by approximately 44% and will persist 28% longer.

# Section 4 General Discussion and Recommendations

We have researched and reviewed "*Fish, Fisheries, and Water Resources: Adapting to a Changing Climate*" in four subprojects: 1) *Fish and fisheries adapting to a changing climate: Overview*, 2) *Weathering Climate Change: Workshops*, 3) *Economics, consequences, and adaptation: Survey*, and 4) *Water management responses: Modelling and planning* and provided considerable insights concerning sensitivity and response and made recommendations concerning what to expect and how to adapt. Science transfer, policy development, and implementation are urgently needed.

Fish, fisheries, and aquatic ecosystems and water resources are sensitive to, and powerful indicators of, climate change. Long-term data from the Laurentian Great Lakes Basin indicate that for the past five decades, inshore surface water temperatures during open water (Apr-Sep) increased 1.5$^{o}$C, evaporation increased 9%, and ice cover decreased, most significantly since the thermal regime shift of the late 1970s. Also it is obvious that water temperature is a far more sensitive indicator of thermal change than is air temperature, since it traps solar energy. Water resources and fish are among the best functional indicators of climate change.

Modelling predicts that over the next 100 years, summer water temperatures will increase 4$^{o}$C; summer flows of rivers will decrease by 44%, lasting 28% longer; and spring discharge will peak 7 weeks earlier and decrease by 33%, negatively affecting walleye recruitment (-24%). Water budget models project increases of 74% in mean annual temperature and a 23% increase in evapotranspiration. Projected decreased summer flows will necessitate providing additional reservoir storage capacity and reducing nutrient loading.

The Lake Ontario fish population and communities confirm that with increasing midsummer temperatures, recruitment will increase in warm-water fish (centrarchids; +1$^{o}$C = +2.2×, +2$^{o}$C = + 4.8×, +3$^{o}$C = +10.6×) decrease in cool-water and fall-spawning cold-water fish (lake trout; +1$^{o}$C = -1.5×, 2$^{o}$C = -2.4×, +3$^{o}$C = -20.1 x), the latter negatively affected by increasing fall temperatures (Dec). In Lake Ontario, fish communities in the 1990s started to show changes reflecting a response to these increasing thermal changes. In the Mississippi River watershed, some cold-water coregonids have already been extirpated; expansion and invasion of thermally better-adapted warm-water centrarchids (e.g., black crappie) and cool-water esocids (e.g., chain pickerel and grass pickerel) has accelerated. Esocid spawning behaviour is being affected by decreasing spring water levels, resulting in some adaptation and hybridization. With increasing temperature, body growth increases in warm- and cool-water species and decreases in cold-water species (+1$^{o}$C = ±9% to +3$^{o}$C = ±28%).

Resource users mostly attributed observed environmental changes to climate change (96.8 ± 3%) but were unwilling to adapt to fish-community changes; they attributed these changes to invasive species, water quality, and exploitation rather than to the effects of climate changes. Only 12.9% of respondents considered an increase in warm-water species to be positive, more so in the Mississippi Valley area, where anglers were already using warm-water species. All this underlines the need for science transfer. As a result, more respondents (18.2%) in the Mississippi Valley area considered an increase in water-water species as positive, estimating few changes in resource use (50.0%) and revenues (53.8) than other areas. To help offset social and economic impacts of climate change, 88.8% of respondents indicated that management actions should be taken that adopt and incorporate environmental and fish-community changes due to climate change. Promotion of underused stocks was encouraged. Respondents considered that any management action needed to be heavily based on science; social and economic concerns were far less important. In addition, 85.6% indicated that a fish policy and management plan should be developed to deal directly with impacts and adaptations to climate change, including participation from all levels of government, academia, non-government organizations, and knowledgeable local resource users and stakeholders.

Assessing and managing water, fish resources, and fisheries in a changing climate necessitates monitoring more intensively, increasing assessment and research capacity, adapting management to use increasingly abundant warm-water fish while protecting decreasing cold-water species, proactively addressing these controlling, changing environmental factors and shifting baselines and mitigating by making, publicizing, and promoting local fish and fisheries as part of our local "100-mile diet." This proactively will reduce our carbon footprint.

Water provides two valuable natural resources: fish for food and recreation and water power for energy. These two resources are equally important but have often been in conflict. Water power, as developed and used in the past, often negatively affected fish and fisheries (Pyzer 2009b). Climate change will alter critically important aspects of water resources that could make these two resources more competitive. Special effort should be taken to make sure that fish and fisheries are not detrimentally affected but remain productive, naturally self-sustaining, and undiminished. Local fish and fisheries are especially valuable because they provide food and a local, or homeland, security, which will become increasingly more important in a less secure and changing world. Worldwide food production is declining and increasing in value, underlining the increasing value of local fish and fisheries.

The workshops of Subproject 2, *Weathering Climate Change*, demonstrated that a change in climate is already visible, both globally and in Canada. However, as recently as 2005, little local information was readily available to the public that was specific to the Mississippi watershed; as a result, few residents/users of the watershed were aware that climate is already changing here.

Warming of the climate system is unequivocal, and recent warming is very likely due to humans. Climate is changing, and will continue to change, irrespective of initiatives to reduce greenhouse gas emissions: even if global emissions could be capped tomorrow at 2000 levels, an additional global warming of 0.6 C would still occur. The best estimates of projected increases in global mean annual temperatures by 2100 range from 1.8 to 4.0 C. The Intergovernmental Panel on Climate Change (IPCC 2007) indicates that we need to both reduce emissions (to stop or slow the rate of climate change) and adapt to the changes that are now occurring and will occur in the future. Adaptation is not an option but a necessity.

In the Mississippi watershed and much of eastern Ontario, mean annual temperature can be expected to increase above 1960-1990 values by about 1.5 C by 2020, 3.5 C by 2050, and 5.0 C by 2080.

Climate change is often cited as a key environmental issue. Indeed, it is; however, such a formulation misses the fact that it is also a key social and economic issue. There will be impacts on all sectors of the local economy. Such impacts can be minimized and opportunity maximized by proactive adaptation. Local strategies for action need to be developed.

For this to occur, the public, local agencies, and municipal governments need to begin a discussion of the implications of climate change for the watershed as a whole. With this in mind, Mississippi Valley Field Naturalists and Mississippi Valley Conservation, in September 2007, convened a two-day workshop, "Weathering the Change," in Almonte, Ontario. About 150 people attended. Ten speakers, all with sectoral and climate change expertise, gave overview talks and helped animate the discussions in sector breakout sessions.

The main goals of the workshop were to: 1) engage the public and experts in a discussion of climate change and identify some of the key impacts on the region; 2) start a discussion of potential adaptation options – including water and fish management issues; 3) recognize the limitations of adaptation; 4) explore some of the barriers to taking action and start to raise awareness of the tradeoffs involved; 5) capture key issues and concerns for our region as a point of departure for future discussions and actions.

Participants and presenters considered the workshops to be highly successful. An evaluation of approximately 50 respondents considered the breakout sessions as highly useful (90%), the appropriateness of the presentations 92%, and the recommendation to colleagues and friends 94%.

Participants concluded that: 1) climate, ice cover, water temperature, river flows, local ecosystems, and fisheries are changing in the Mississippi watershed and will continue to do so; 2) there are now and will be future impacts on agriculture, tourism, forestry, fisheries, and other sectors; 3) impacts will be both positive and negative; 4) some but not all of the impacts can be reduced through adaptation; 5) there are barriers to taking action – tradeoffs will be necessary; 6) climate change must be incorporated into all aspects of our planning processes (e.g., health care, fisheries management, infrastructure design, water management, etc); 7) guidelines and toolkits are needed to help at the local level; participants look to all levels of government to provide these; 8) there is a continued need to raise awareness of this issue.

The release of the Almonte Communiqué expresses the 150 participants' call for action to governments and residents to adapt to a changing climate.

## *The Almonte Communiqué*

*Released by delegates of "Weathering the Change"*
*a two-day workshop co-sponsored by MVC and MVFN*

> *Many important economic and social decisions are being made today on long-term projects and activities in our watershed based on the assumption that past climate change data are a reliable guide to the future. This is no longer a good assumption.*
>
> *We believe that all levels of government are key players in this issue and must raise awareness and incorporate climate change into planning, decision making and leadership.*

There is a need for follow-up meetings and discussions around the sectors identified in the report to provide vertical integration among various levels of government and the public. There is a need for the establishment of a process for horizontal integration (e.g., using one or more regional coordination committees or existing bodies) to develop local adaptation strategies.

The Subproject 3, Economics, Consequences, Adaptation survey of fish resource users, businesses, and professionals was conducted to understand the social and economic impacts of changing fish resources in a changing climate to assess perceptions, attitudes, adaptive capacity, social importance, and economic impacts.

The survey indicated that in Ontario, issues concerning fish resources have changed significantly over the past three decades, from pollution control, enforcement services, regulations and laws, and biological research to invasive species, habitat, water conditions, and climate change. In 2007, issues strongly reflected observational knowledge: 89.8% of survey respondents had observed environmental changes and 86.6% had observed fish community changes. Most observations were first noticed in the mid- to late 1990s, and 78.1% (environment) and 73.4% (fish community) indicated these changes had affected the use of fish resources; most changes were perceived as negative.

Environmental changes were mostly attributed to climate change (96.8 ± 3.0%), but not fish community changes (46.0 ± 15.5%). Fish community changes were attributed mostly to issues regarding invasive species, water quality, harvest, and stocking. Fewer than half (45.4%) knew of examples of climate change effects on fish communities, and 44.2% did not feel that climate change had affected the use of fish resources.

Fish community changes consistent with climate change effects will result in some redistribution of fish resource use and revenue, since anglers are somewhat reluctant to adapt. Angler behaviours are showing signs of adaptations to fishing depths, habitat fished, and fishing patterns and techniques, but these are reactions to observed changes and an attempt to continue catching desired species, which were predominately cool- and cold-water. Only 12.9% of respondents considered an increase in warm-water species to be a positive change, while 48.6% considered it to be negative. Associated with these changes would be a degree of social impact, since only 38.9% of those who would adapt to fishing a different, more abundant species would get as much satisfaction. This is related to the reason anglers fish, and enjoyment was the top reason. For both fish resource revenue and use, 36 to 41% of responses indicated a decrease; the largest decrease was estimated for southern Ontario.

More adaptation appears to be occurring in the MVA, where anglers are already using warm-water species (smallmouth and largemouth bass). As a result, more responses from the MVA considered an increase in warm-water species as positive (18.2%), estimating fewer changes in resource use (50.0%) and revenues (53.8%) than other areas.

Not including capital costs or major purchases, direct fishing expenditures of resident anglers was $472 annually (95% CL—$384-$580). Most resident angling is local, within one hour, or a 100-km drive (81.2%), and this is where the largest economic impacts will occur. While only 13.9% of anglers indicated they would decrease their number of annual fishing trips, the highest decreases were documented for day trips: a 14.1% decrease in open-water day trips and a 20.0% decrease in ice-cover day trips. Non-resident anglers strongly support fish resource businesses in the open-water season, especially in the north (83.5%) and MVA (61.0%). Thus, these impacts are unknown, since only 2.5% of responses were from non-resident anglers. Local anglers, however, sustain businesses that operate in the ice-cover season, especially in southern Ontario (53.3%) and the MVA (86.0%).

To help offset social and economic impacts, 88.8% of responses indicated that management actions should be taken that adopt and incorporate environmental and fish community changes due to climate change. In order, public education, regulations, promotion, and stocking were the four management actions thought to be the most effective. Any management action needed to be heavily based on science; social and economic concerns were far less important. In addition, 85.6% indicated that a fish policy and management plan should be developed to deal with impacts and adaptations to climate change that would include participation from all levels of government, science, academia, non-government organizations, and knowledgeable local stakeholders.

The survey and its research provided the following recommendations: 1) maintain existing databases and expand where and when possible to analyze long-term trends to determine factors and stressors associated with a changing climate; 2) take advantage of cooperative action, using local resources, users, and volunteer groups; 3) improve science transfer and information to the general public and professionals alike; 4) maintain openness and flexibility in management decisions and regulations; 5) consult with local users and communities in management decisions; 6) management actions deemed most effective in offsetting social and economic impacts of climate change: ordered priority – a) public education, b) regulations, c) promote underused stocking; 7) base management decisions on ordered priority – a) scientific evidence (overwhelming), b) social concerns (distant second), c) economic concerns (very distant third).

Subproject 4, considering *Water Management and Responses: Modelling and Planning*, used the Ontario Mississippi River and its watershed and recently completed water management plan as a case history to examine sensitivity, responses, and adaptation to a changing climate.

The Mississippi River is 212 km in length and drops 252 m toward the east to an elevation of 73 m at its confluence with the Ottawa River just upstream of the city of Ottawa. The watershed is divided into three sub-watersheds: the western and central sub-watersheds lie on the Canadian Shield, and the eastern sub-watershed lies off the shield to the west of the Ottawa River. The western sub-watershed is speckled with deep, glacial lakes, whereas the eastern sub-watershed is dominated by riverine systems, which is a reflection of its topography and surficial geology. The central sub-watershed is a combination of both the western and eastern sub-watersheds and may be considered a transitional zone between ecological land types and communities.

Originally, dams were constructed for timber transport (Mazinaw, Crotch, Big Gull, Kashwakamak lakes). The towns on the lower river system thrived with textile and gristmills since the river provided a useful source of water power. In the early 1900s, a group of business interests representing mill owners and the Ontario Hydroelectric Commission acquired and reconstructed six of the upstream water control structures to augment stream flows in the lower river system for water power. The management regime used the large storage capacity behind these dams to store excess runoff during the spring freshet, providing a source of water to augment stream flows during the dry summer months. Development along the shores of these storage reservoirs resulted in pressure to stabilize water levels during the summer months, restricting their use for downstream water supply during this period.

The largest reservoir, located at Crotch Lake, was not subject to these water level restrictions and was subsequently used to provide low flow augmentation during the summer months and to store water in fall when the upper reservoirs could be drawn down. This water could then be used to augment stream flows over the winter period. All six storage reservoirs would therefore be at their lowest level prior to the next spring freshet, providing a measure of flood protection to downstream communities as water was again stored in the reservoirs. This semi-annual management cycle of reservoir storage and release has been successfully implemented since that time.

The Mississippi Valley Conservation Authority (MVC) manages the five upstream storage reservoirs, while Ontario Power Generation, in consultation with MVC, manages the Crotch Lake reservoir. Including these six reservoir dams, and five hydro generation facilities, a total 23 dams and water control structures are maintained within the Mississippi River watershed.

In 2007, the Mississippi River Water Management Plan was finalized. It confirmed the current management regime for the Mississippi River and established flow and water level objectives for the major water control structures along the river. In the course of completing hydro-technical analyses for the plan, MVC noted trends in stream flow conditions that could present difficulties for water managers to satisfy the established plan objectives, particularly related to fish and aquatic habitat, if these trends were to persist. Further investigation of these findings suggested that they were consistent with recent research on climate change impacts to water resources.

The specific objectives of the water resource research and modelling study conducted here involved: 1) applying future climate predictions (precipitation and temperature) of the Canadian Global Climate Model (CGCM2) to the Mississippi Valley watershed; 2) generating future climatic data based on historic trends and CGCM2 projections; 3) quantifying the potential effect of climate change on the watershed water budget; 4) calibrating and validating a rainfall-runoff model; 5) simulating future runoff and stream flow for periods from 2010 to 2099 with the validated rainfall-runoff model; 6) conducting reservoir and hydraulic modelling to simulate stream flows and water levels at reservoir sites and the downstream gauge site on the Mississippi River at Appleton.

The Global Climate Models (GCMs) provided estimates of changes in climate due to increased greenhouse gases for a large number of climate variables in a physically consistent manner. However, GCM simulations of *current regional climate* can often be inaccurate and the output from GCMs is usually produced at a *coarser temporal and spatial resolution*; therefore, a downscaling technique was needed to calibrate and refine the resolution of the GCM model data required for impact studies. Hence, the CGCM2 data downloaded from the Environment Canada website for the grid including the Mississippi River watershed was used to downscale the climate projections to the Mississippi River watershed based on historic trends at a local climate station. CLIMGEN, a weather generating model, was used to generate future climate data for the Mississippi River watershed. The Thornthwait model was used to quantify the water budget component for the period of available climate data (1984-2000) and future projections for the period (2010-2099). The actual evapotranspiration data from this model was used as an input to the rainfall-runoff modelling.

The six storage reservoirs of concern are located in the upper reaches of the Mississippi River watershed with limited stream flow records on which to calibrate a hydrologic model. A stream flow record from the adjacent Clyde River watershed, with similar topography, exists from 1972. The Nedbør-Afstrømmings-Model (NAM), a rainfall-runoff model, was used to simulate future runoff and stream flows at the Clyde River gauge site.

The resulting stream flow projections were subsequently transposed, based on relative drainage area, to the local drainage basin for each reservoir and intermediate sub-watershed along the Mississippi River to the Appleton gauge site. Reservoir simulation was conducted with the in-house Mississippi River watershed-reservoir operation model to route reservoir inflow hydrographs through each reservoir using the storage-indication method, based on calibrated structure rating curves and reservoir stage-storage relationships. The model allows the user to adjust dam settings at each time-step of the simulation. The resulting discharge hydrograph was subsequently routed to the next downstream reservoir, using the Muskingum Method, and then added to local basin inflows. The Muskingum routing parameters were calibrated through trial and error based on historical water level and available stream flow records. This process was continued through the river system, incorporating each storage reservoir and intermediate sub-watershed inflow to simulate the stream flow at the Appleton stream flow gauge.

Because of the manual effort required to manipulate the required dam setting at each time-step of the simulation, reservoir simulation was undertaken for the following scenarios: 1) a mean annual hydrograph for each period of interest (1974-2002, 2010-2039, 2070-2099) used to represent the average stream flow response for the period; 2) a year that represented a high mean stream flow rate during the summer for each period; 3) a year that represented a low mean stream flow rate during the summer for each period. This approach allowed both typical and extreme events for each period to be assessed under current reservoir operation policies.

The CGCM2 climate projections and the CLIMGEN generated future climate data for the Mississippi River watershed projected an increase in the minimum and maximum temperatures throughout the year, except for the maximum temperatures in December and March. Winter (Jan-Mar) minimum temperatures, winter maximum temperatures, and summer maximum temperatures increase considerably over 2010 to 2099. The highest percentage rate change was observed in the minimum temperature, which increased in the months of January and February by 0.06$^{o}$C/yr to 0.17$^{o}$C/yr for 2010 to 2099. Wetter fall conditions are predicted, however, winter conditions are more or less the same as the base period (1984-2000). There was more variability in both actual and generated precipitation data than in minimum or maximum temperatures. The base period average annual precipitation of 849 mm, with a standard deviation of 31 mm, increased to 907 mm by 2099, with a standard deviation varying between 32 and 34 mm.

The water budget model projected increases of 74% in mean annual temperature, 10% in precipitation, 20% in rainfall, 23% in potential evapotranspiration, and 144% in deficit. Snowmelt decreased by 25%, surplus by 3%, snow accumulation by 67%, and soil moisture by 12% between the 1985 and 2099 periods.

The NAM model was calibrated for 21 years (1973-1993) based on actual flow data for the Gordon's Rapids at Clyde River stream gauge. Simulated and observed stream flows matched well with a coefficient of determination of 0.72, and their accumulated flows also compared well. The calibrated NAM model was validated with 10 years (1994-2003) of actual flow data. Good agreement was observed between the simulated and observed runoff, with a higher coefficient of determination of 0.74.

Results of the reservoir simulations indicated that average annual stream flow will decrease by 10% between the base period (1972-2003) and the future period (2070-2099). In general, stream flows will increase substantially in fall (Oct-Dec) and winter (Jan-Feb) periods by 74% and 70%, respectively, while they will decrease in spring (Mar-May) and summer (Jun-Sep) by 43% and 66%, respectively. On average, spring freshets will occur 6 to 7 weeks earlier in the 2070 to 2099 period than in the 1972 to 2003 period and will be approximately 33% lower in peak stream flow. Minimum summer flows will decrease by approximately 44% and will persist 28% longer.

Spring water retention in wetlands can abate lower summer flows. This could be accomplished by using low-head dikes in wetland areas that could flood marshes in spring and facilitate pike spawning. Pike recruitment is negatively affected by reduced spring flooding, which is predicted to become more common. Artificial spawning marshes have been quite successful in enhancing pike recruitment. Strategic water management that retains water in wetlands in spring can not only increase pike production but provide valuable storage of water that can be used to augment flows that are decreasing, and will decrease, in summer. Prototype installations could be constructed and water management protocols developed around these pike-spawning marshes to mitigate reduced spring runoff and enhance cool-water fish production. It is a well-known fact that spring water level is directly related to pike recruitment; this was not apparent in the Mississippi watershed in the historic data because spring water levels are heavily regulated.

Water resource analysis and modelling provided the following recommendations: 1) communicate and transfer new science to all water resource users, stakeholders, general public, and water resource professionals; 2) incorporate new insights and modelling into existing water management plan and begin to manage accordingly; 3) provide additional reservoir storage capacity; 4) reduce and minimize nutrient loading; 5) improve capacity for watershed modelling and assessment; 6) facilitate integrated watershed management by a) involving stakeholders from multiple sectors, b) conducting community outreach; 7) improve watershed resiliency; 8) where possible, manage water resource use and changes to sustain and, where possible, increase fish resources and fisheries – a) maintain wetlands during minimum flows and increase fish passage.

Science transfer was an important goal of the study and has been ongoing since the completion of the research in 2008. Numerous presentations, many by invitation, have been made locally, provincially, nationally, and internationally. The authors of this report have made many of these presentations not only to the science community but to the lay public and the principal investigator has been invited on numerous occasions to be a keynote speaker on the subject and has drawn heavily on the research of this study and the science emanating from the study. The pivotal role and funding support of the Climate Change Impacts and Adaptation Directorate of Natural Resources Canada has always been acknowledged in relation to the transfer of this science and a number of symposia on the subject have been involved. In fact, in 2008, he co-convened a one-day special symposium session entitled "*Fish, Fisheries, and Water Resources: Adapting to a Changing Climate*" at the American Fisheries Society Annual Meeting in August 2008, in Ottawa. Three of the presentations in that symposium came directly from this study (Subprojects 1, 3, and 4), with the presentations being made by the principal investigator and two co-investigators. The symposium was followed by several invited interviews on CBC national radio. The symposium was, quite appropriately and enthusiastically, sponsored by the Canadian Aquatic Resources Section of the American Fisheries Society.

The science assembled here continues to be expanded upon, and presentations are actively being sought. As recent examples, the principal investigator will make an invited plenary presentation "Effects of climate and climate change on freshwater fish and fisheries: Driving environmental factors and shifting baselines" at a St. Lawrence River Institute conference "*Protecting and Restoring Aquatic Ecosystems Through Government and Community Action*" in Cornwall in May 2010 and another invited presentation in July, "Effects of a changing climate on freshwater fish and fisheries: Driving environmental factors and shifting baselines – what to expect, how to adapt," in the symposium "*Adapting Fisheries for a Changing Climate*" at a joint meeting of the Fisheries Society of the British Isles, Japanese Society of Fisheries Science, and American Fisheries Society to be held in Belfast, Northern Ireland. This is ample proof that the research and science were timely and continue to be eagerly sought.

The changes and challenges are unprecedented and will continue to be so, given the climate changes that are underway and are predicted for the future. Adaptation and mitigation are essential and can even provide positive opportunities if fish and water resources and human endeavours are to be sustained in a changing climate. Now that we know what to expect and have developed recommendations, the question is, How will we adapt to changing fish and fisheries and water resources while trying to mitigate this formidable global problem.

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