Adapting to the Impacts of Climate Change and Variability in the Grand River Basin: Surface Water Supply and Demand Issues

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Apologies for any that have been overlooked.

Chuck Southam

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List of Acronyms and Abbreviations

$1xCO_2$	present atmospheric carbon dioxide concentration
$2xCO_2$	double the present atmospheric carbon dioxide concentration
ADF	Average Daily Flow
AE	Associated Engineering Limited
BOC	Basis of Comparison
CA	Conservation Authority
CCC	Canadian Climate Centre
CCC GCM II	Canadian Climate Centre's Second Generation General Circulation Model
CO_2	Carbon Dioxide
deg C	refers to temperature difference in Celsius
FCCC	Framework Convention on Climate Change
g/ac/d	Imperial Gallons per Acre per Day
gpcd	Imperial Gallons per Capita per Day
GRIC	Grand River Implementation Committee
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographic Information System
GISS	Goddard Institute of Space Sciences
GLERL	Great Lakes Environmental Research Laboratory
GLSLB	Great Lakes-St. Lawrence Basin
GRB	Grand River Basin
GRCA	Grand River Conservation Authority
HELP	Hydrologic Evaluation of Landfill Performance
IAS	Impact-assessment Scenario
ICI	Industrial-Commercial-Institutional
kW	Kilowatt
l/c/d	Litres per Capita per Day
m	Metre
m^3/s or m^3/s	Cubic Metres per Second
m^3/d or m^3/d	Cubic Metres per Day
MCC	Midwestern Climate Center
MES	Model-evaluation Scenario
MIG	Million Imperial Gallons
MIGD	Million Imperial Gallons per Day
Mm^3/yr	Million Cubic Metres per Year
mm	Millimetre

MOE	Ontario Ministry of Environment
MUD'91	1991 Municipal (Water) Use Database
MUD'94	1994 Municipal (Water) Use Database
NAPCC	Canada's National Action Plan on Climate Change
NRC	National Research Council
NWRI	National Water Research Institute
OAC	Ontario Agricultural College
OMAF	Ontario Ministry of Agriculture and Food
OMOF	Ontario Ministry of Finance
RBA	River Basin Authority
RMOW	Regional Municipality of Waterloo
STP	Sewage Treatment Plant
Tri-City(s)	Kitchener, Waterloo and Cambridge
WID	Water Issues Division
WUAM	Water Use Analysis Model

EXECUTIVE SUMMARY

The surface water component of the Grand River Basin (GRB) Study is one of several theme-based climate impact and adaptation studies initiated as part of the Great Lakes-St. Lawrence Basin (GLSLB) Project. Building from past research, the study addressed surface water supply, water use and management issues in the GRB. In terms of analysis, the work:

- examined the impacts of climate change and variability on surface water supplies, and
- identified strategies for adapting to possible impacts.

The assessment of climate impacts and development of adaptive strategies requires an interdisciplinary and participatory approach (Mortsch and Mills, 1996). Involvement by those who may be affected, either by climate variability and change impacts or adaptive measures, is essential. Throughout the course of this study, close liaison was maintained with staff at the Grand River Conservation Authority (GRCA). GRCA staff provided local knowledge and expertise to help ensure that the Grand River system was adequately modelled. This liaison also permitted direct involvement in *The Grand Strategy for Shared Management of the Grand River Watershed* (*The Grand Strategy*; GRCA, 1996) which is designed to develop and implement a shared management plan for the Grand River watershed. Communication with GRCA staff and other participants in *The Grand Strategy* provided valuable information for the study and presented a unique opportunity to increase the awareness of GRB stakeholders to climate change, potential impacts and response strategies.

Study Approach

To determine impacts and develop adaptation strategies, the first four steps--*Define objectives, Specify important climatic impacts, Identify adaptation options* and *Examine constraints*--of the seven-step approach described by Carter *et al.* (1994) were carried out. Recommendations based on study results are made in an effort to provide a foundation for steps five through seven--*Quantify measures and formulate alternative strategies, Weight objectives and evaluate trade-offs* and *Recommend adaptation measures*--to be addressed by others.

Basin Management Objectives

A literature and policy review was conducted to establish which issues and aspects of GRB management are sensitive to climate and to define the context and scope of the impact and adaptation assessment.

The GRB contains one of the healthiest river systems in North America situated in a heavily populated area. Since the 1930s, the water quality of the watershed has improved significantly due to more effective urban wastewater treatment, storm water management and rural land management practices. The improved watershed health has been accompanied by a revitalized sport fishery, increased recreational use of the river system and a greater appreciation of the river's natural and human heritage. Several major watershed management issues have, however, been identified as part of *The Grand Strategy*. The large and growing population of the central portion of the basin places high demands and stresses on the natural resources of the watershed, particularly surface and groundwater resources through water extraction and wastewater discharge activities.

A shared vision for the Grand River watershed has been developed and endorsed by all participants in *The Grand Strategy*. *The Vision* (GRCA, 1996) encapsulates the overall objectives of the current shared management plan for the Grand River watershed. The objectives defined by *The Vision* were therefore adopted into this study for impact and adaptation evaluation purposes.

Determination of Important Climatic Impacts

Previous research initiatives (Sanderson, 1993) describe climate change impacts on GRB water resources which may affect whether the watershed objectives defined in *The Vision* can be met. The potential impact of climate change on streamflow was selected as the primary focus of the impact analysis summarized in the following pages. It is the key climate-sensitive element in the GRB affecting almost every activity and goal identified in *The Vision*. Implications for these water-based activities were drawn from streamflow impacts determined through the analysis.

Flows in the Grand River can be highly variable, both from season to season and year to year. The observed flows reflect the varying degree of regulation throughout the system over time as well as changes in land use, water use and operating policies at system reservoirs. Low flow augmentation and flood control are presently provided by a system of multipurpose dams and reservoirs operated by the GRCA. Although most of the basin population is serviced by groundwater, the Regional Municipality of Waterloo and the City of Guelph are relying more heavily on water supplies taken from the Grand and Eramosa Rivers. Brantford and Six Nations depend exclusively on water taken from the Grand River. All of the cities and towns discharge their treated wastewater to the Grand River or one of its tributaries.

Any streamflow impact assessment must recognize and take into account the current and potential roles streamflow regulation and water use play throughout the system. The Water Use Analysis Model (WUAM; Kassem, 1992) was selected to determine the impacts of changes in surface water supply considering these two factors. WUAM is a relatively new approach to supply-demand balance modelling. Its use of water demand as a point of departure contrasts with the more traditional supply-side focus of other models. WUAM deals exclusively with water quantity aspects and has three principal components: water use; water supply; and, water balance.

Study Area and WUAM Network

The study area covered the portion of the GRB above the Environment Canada streamflow gauge on the Grand River at Brantford. The lack of long-term streamflow data prevented the incorporation of areas downstream of Brantford. Eleven study subbasins were modelled using a network of 15 nodes (or study points). Three existing major reservoirs (Belwood, Conestogo and Guelph), key low flow augmentation target sites (Doon, Hanlon and Brantford) and the potential reservoir site at West Montrose were modelled. The five primary urban serviced areas (Guelph, Kitchener, Waterloo, Cambridge and Brantford) were each assigned to separate nodes. Multiple nodes were defined at the outlets of three subbasins to adequately model abstractions from, or wastewater discharge to, the river system above or below the target flow sites noted.

Surface Water Supply

In order to evaluate the potential impact on streamflows and facilitate discussions about adaptive strategies, surface water supplies based on time-series of monthly unregulated river discharges at key points throughout the watershed were constructed for base case (1951-88) and seven potential changed-climate conditions.

The base case flows represent the streamflows throughout the system which would have occurred if system flows had not been regulated. The base case flows were also projected forward into the future without modification as a surface water supply scenario. The uncertainty associated with predictions of regional climate change precluded the use of just one climate scenario. Five changed-climate scenarios specified by the GLSLB Project were used, one based on the Canadian Climate Centre's Second Generation General Circulation Model (CCC GCM II; Louie, 1991) and the remaining four on climate data transposed from areas south, southeast and southwest of the Great Lakes Basin by the Midwest Climate Center (MCC) (Scenarios1-4; Croley *et al.*, 1995). Changed-climate surface water supply scenarios, consistent with the base case flows, were established by modifying the output from climate change analyses conducted by the U.S. National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory (GLERL) on the hydrology of Great Lakes watersheds. Arbitrary 20% and 50% linear reductions in the base case flows were also added as sensitivity-testing scenarios. The resulting surface water supply scenarios are compared to the base case in Table 1.

Table 1 - Surface Water Supply Scenarios

Scenario Name	Percentage Change Relative to Base Case (1951-88 unregulated flows)			Standard Deviation in Annual Flows at Galt (in m^3/s)
	Basin-wide*	Range for all Subbasin outlet points	At Galt	
Base Case	0%	0%	0%	9.6
GLSLB Project Specified				
CCC GCM II	-51%	-56% to -47%	-53%	5.6
Transposition MCC1	-2%	-11% to +3%	-5%	14.0
Transposition MCC2	-19%	-28% to -14%	-22%	8.7
Transposition MCC3	+13%	-1% to +21%	+8%	15.5
Transposition MCC4	+14%	+2% to +22%	+10%	11.8
Arbitrary				
Base Case - 20% (linear)	-20%	-20%	-20%	7.7
Base Case - 50% (linear)	-50%	-50%	-50%	4.8

** Basin-wide percentage change value also used as a reference to identify a scenario throughout this document*

Clearly, the temporal averaging scale and the point of interest selected can have an important effect on the detail of information provided. A long-term basin-wide percentage change value, often used as a reference to identify a supply scenario, does not adequately describe its characteristics. Long-term percentage changes vary significantly throughout the basin and a small overall change can be the result of a highly variable flow sequence. Even with the wide range in impacts indicated for the GLSLB Project scenarios, on average, they all produced an earlier spring freshet and lower summertime supplies throughout the GRB than the base case.

Groundwater Supply

Only ad hoc procedures were used to model groundwater supplies. WUAM's application required base-year data on the proportion of the total water use at each node which is supplied from groundwater sources. The model applies the same proportions for future years, provided that the total groundwater withdrawal does not exceed a user-defined maximum. Additional or alternate supplies may be required in the future and climate change may negatively impact basin groundwater supplies. Given the lack of specific information on groundwater limits and the range in future surface water scenarios adopted, groundwater supplies were assumed available for the future water requirements for modelling purposes.

System Operation (reservoir configuration and operation)

Like the base case, the changed-climate surface water supply scenarios developed represent uncontrolled runoff from the basin. Regulation goals and capabilities would affect the actual streamflows experienced under these supply conditions. Past studies have been criticized for not incorporating some degree of adaptive response in assessing the potential impacts of climate change (Smit, 1993). It is unlikely that local water managers and others engaged in climate-sensitive activities would fail to adjust their operations to accommodate the changing supply conditions identified in Table 1. Historically, many adjustments can be at least partially attributed to observed climate and supply (drought and flood) conditions, particularly the development of the system reservoirs. Therefore, "state-of-nature" (i.e., reservoir outflow equals inflow), current and modified reservoir operating rules were defined for the Belwood, Conestogo and Guelph reservoirs and the potential reservoir at West Montrose to permit the modelling of different combinations of reservoir configuration and operation.

Water Use

WUAM was set up to simulate current (1991) and estimated future (2021) withdrawal water use for each of the eleven subbasins defined in the study area. Withdrawal water uses modelled included urban (domestic, industrial, commercial and institutional), rural (domestic) and agricultural (irrigation and livestock watering). With the exception of irrigation, withdrawal water use estimates were based on current and future estimates of activity level (e.g., population) and coefficients of water use per unit activity level. Future water use coefficients were not adjusted to reflect the potential impact of climate change on demand due to the large uncertainties in growth projections and the range in climate-change scenarios used. WUAM's standard input and diversion options were adapted to correctly account for the unique supply (groundwater or surface water) and wastewater flow (continuous-flow wastewater system, timed-output lagoon system or private septic system) conditions in each subbasin. Irrigation values for the years 1978 and 2031 presented in the Grand River Implementation Committee report (GRIC, 1982) were adopted to represent current and future conditions, respectively.

Current and future non-withdrawal (or in-stream) water uses, including water quality and recreation, were dealt with as constraints on streamflow based on current minimum flow requirements. The target flows vary seasonally and represent volumes of water which the GRCA strives to maintain or exceed to ensure an acceptable level of water quality.

Application Scenarios

In total, 24 WUAM application scenarios were run. Each scenario was constructed using a combination of current or future conditions for three components: surface water supply; system operation (reservoir configuration and operation); and, water use.

Model-evaluation Scenarios

In order to evaluate the water balance performance of WUAM, three model-evaluation scenarios (MES) were run for the 1951-88 study period using base case surface water supplies. MES1 represents current basin conditions as it assumed 1991 withdrawal and non-withdrawal water use and the current reservoir configuration and operation. MES2 and MES3 used the same water use conditions as the MES1; however, MES2 assumed "state-of-nature" system operation. The West Montrose reservoir was added to the current reservoir configuration for MES3.

MES1-simulated levels and outflows for the Belwood, Conestogo and Guelph reservoirs and streamflows at Brantford compared well with measured values for the period January 1984 to December 1988, the portion of the study period when measured reservoir levels and releases were available. Generally, the model followed the rule curves more rigidly than the actual reservoir operation. In all cases, the annual redistribution of flow at each site suggested adequate model operation.

MES1 summertime (June to September) streamflow target satisfaction on a monthly basis at Doon, Hanlon and Brantford ranged from 82%-89%, 71%-92% and 92%-100%, respectively. While well below 100% and lower than results achieved by others using the GRCA reservoir yield model assuming similar conditions (Paragon Engineering Limited, 1994), comparisons between the results for MES1, MES2 and MES3 indicated that WUAM adequately routes supplies for comparison purposes. Model limitations with respect to time step and reservoir simulation capabilities are acknowledged and should be kept in mind when drawing conclusions about climate change impacts. Relative differences between scenarios should be considered, not their specific monthly values.

Impact-assessment Scenarios

Twenty-one impact-assessment scenarios (IAS) were run to gauge system response. Each IAS assumed 2021 basin conditions with respect to withdrawal water use and assumed current streamflow targets at Doon, Hanlon and Brantford. Scenario differences related to the surface water supply and system operation conditions specified.

Streamflow impacts were evaluated based on target flow satisfaction at Doon, Hanlon and Brantford. Since MES1 represents current basin conditions with respect to water supply, water use and system operations, it was selected as the Basis of Comparison (BOC) for impact assessment purposes. The impact-assessment scenarios were divided into three groups based on the assumed system operation conditions for discussion purposes.

- *Current reservoir configuration assuming current reservoir operation.*

Without some form of action, conditions under all combinations of future surface water supply and water use fall below current conditions as represented by the BOC at all three target flow sites. Modest, moderate or severe impacts on streamflow are experienced depending on the surface water supply scenario assumed.

- *Current reservoir configuration assuming modified reservoir operations.*

By modifying the existing reservoir rule curves, all scenarios assuming a non-linear change in surface water supplies improve with respect to the BOC. Conditions improve more at Doon and Hanlon where reservoir releases represent a higher percentage of the summertime flow.

- *Current reservoir configuration plus the West Montrose reservoir assuming current* or *modified reservoir operation as required by the selected surface water supply scenario.*

While conditions with respect to the BOC are significantly improved at Doon and Brantford by the combination of modified reservoir rule curves (as required) and the West Montrose reservoir, these modifications do not significantly improve the conditions under either the CCC GCM II (-51%) or the Arbitrary Base Case - 50% linear supply scenario. The addition of the West Montrose reservoir does not improve conditions at Hanlon, located on the Speed River.

Adaptation Strategies

The scenarios modelled in this study produce a wide range of impacts on streamflows. All scenarios suggest increased difficulties meeting current minimum targets specified for water quality purposes. These changes would have an impact on water management in the Grand River system and affect the realization of the watershed objectives as defined in *The Vision*. For the scenarios modelled, three distinct conditions (modest, moderate and severe changes in streamflow) and response options (eliminate, reduce or accept the impacts) emerged.

- *Modest change in streamflows - Eliminate impacts*

As shown by the simulation results, rule curve modifications can partially accommodate changes in surface water supply volume, variability and seasonal distribution. Modification of reservoir operation is currently used by the GRCA to deal with short-term changes in supply and some of this operating flexibility could be used to address climate change impacts. Purposeful adaptive measures such as the management of water abstractions and the ones provided in the two policy packages presented in de Loë and Mitchell (1993) could also be considered to deal with the residual changes in streamflow. Many of the measures identified in the packages are already under discussion in other contexts and make good water resource management sense regardless of whether or not streamflows decrease due to climate change. The measures that would have to be adopted under a modest change condition would not be controversial; would have high levels of support; and, would be the easiest ones to implement. While still achievable, the flow conditions and the requisite adaptation measures will complicate the process of implementing the shared vision for the watershed.

- *Moderate change in streamflows - Reduce impacts*

The measures necessary to respond to a moderate change in streamflow conditions may be more controversial in nature; have varying degrees of support; and, may be difficult to implement due to political, economic and environmental barriers. While the addition of the West Montrose reservoir was modelled in this study, another measure (or group of measures) may provide the same adaptation capacity. The 30 measures which were "clearly supported" at the 20% flow reduction level by participants in the de Loë and Mitchell (1993) study may be reasonable candidates. The remaining measures which were not supported until much larger reduction levels (if at all) may also need to be considered. Even with adaptation, it will be difficult to meet the objectives of the shared watershed vision as a whole and the adaptation decisions required may conflict with the goals of individual interests.

- *Severe change in streamflows - Accept impacts*

A severe change in streamflow conditions, such as projected using the CCC GCM II scenario, would have major impacts on all water-based activities. Achieving the current vision objectives for the river system may not be a realistic goal. The changes in supply experienced will require a shift in thinking, away from trying to eliminate or reduce the impact of climate change on flows to actually accepting the conditions as the new "operating environment". Accepting these changes may be particularly difficult since water users are often buffered from the effects of short-term climate change by existing water management practices such as augmentation of low summer flows.

Table 2 - Summary of Streamflow Impacts and Response Strategies

Impact on Streamflows	**Response Strategy**	**Adaptation Measures**	**Considerations**	**Implications for Watershed *Vision***
Modest	Eliminate Impacts	Modify reservoir operations plus modest purposeful measures	• Would not be controversial • Have high levels of support • Easiest ones to implement	• Still achievable • Implementation process more complicated
Moderate	Reduce Impacts	Above measures <u>plus</u> large (or numerous) purposeful adaptation measure(s)	• More controversial in nature • Have varying degrees of support • May be difficult to implement	• Difficult to meet as a whole • Adaptation may conflict with goals of individual interests
Severe	Accept Impacts	Shift in thinking, away from trying to eliminate or reduce the impacts to accepting conditions as the new "operating environment"	• May be difficult since water users are often buffered from the effects of short-term climate change by water management capabilities	• Achievement may not be a realistic goal

Constraints

Water managers in the Grand River system have some capacity to cope with change and variability in river supplies. Nevertheless, the expected adaptive capacity of the system may not materialize under climate change conditions due to conflicting uses or new uses which develop over time.

The vision statement for the Grand River watershed provides a ruler against which adaptive strategies can be gauged. The goal of a single or group of adaptive measure should be consistent with the watershed objectives. However, *The Vision* can also become a constraint to adaptation. As people accept it and invest time, effort and money into its implementation, it may become more difficult to adjust to external forces.

Adaptation raises questions of equity, sustainable development and conflict resolution. A logical adaptive strategy to one interest may appear intrusive to another. The potential impacts of adaptive measures proposed within the GRB on geographic areas and interests outside the basin must also be considered. Many adaptive measures can be adopted; however, whether they should and will is a matter of social and political preference (Mortsch and Mills, 1996).

Study Findings and Recommendations

The changed-climate scenarios used in this study produce a wide range of impacts on surface water supplies. For the impact-assessment scenarios modelled in this study, three distinct conditions (modest, moderate and severe changes in streamflows) and response options (eliminate, reduce or accept the impacts) present themselves. Although the potential impacts and responses are not limited to these three situations, they do provide a way to address the issue in the absence of certainty about the degree of change and its timing. GRB residents (water users), agencies (water managers) and other stakeholders may need to adapt to changes in streamflow regime which will affect their ability to achieve the current shared vision for the watershed. The organizational structure of *The Grand Strategy* provides an excellent opportunity for further discussion.

- **It is recommended that the investigation into the impacts and associated costs of a modest, moderate and severe change in streamflows be included as action items in the Grand River Watershed Management joint work plan.**

- **It is recommended that Environment Canada continue its direct involvement in *The Grand Strategy* helping participants address the issue of climate change and variability.**

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1.0 INTRODUCTION

1.1 The Issue of Climate Change

Over the past fifteen years, potential climate change has emerged as one of the most important global environmental issues. There is scientific consensus that human activities have increased the concentration of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere. Recently, the Intergovernmental Panel on Climate Change (IPCC, 1995), an international body of scientists, stated that: ***"The balance of evidence suggests that there is a discernible human influence on global climate."***

There is approximately 30% more CO_2 in the atmosphere now than in pre-industrial times (IPCC, 1995). Scientific experiments using General Circulation Models (GCMs) of the climate system suggest that the atmospheric concentration of greenhouse gases has risen enough to induce a 0.4-1.3 deg C warming (Environment Canada, 1995). Observed temperatures over the past century have increased globally by 0.5 deg C, nationally by 1.0 deg C and by 0.6 deg C in the Great Lakes-St. Lawrence region.

If current levels of greenhouse gas emissions are not reduced, a doubling will be realized and passed within the next century and a tripling is not impossible. Increasing concentrations of these radiatively active gases will lead to an "enhanced" greenhouse effect and a warmer and wetter global climate. The global mean temperature is expected to rise 1.5-3.5 deg C by the end of the next century (IPCC, 1995) while temperatures in Ontario could rise by 3-8 deg C (Mortsch and Burton, 1992). Global precipitation is also expected to increase, although some mid-latitude regions may experience drier summers. Changes in the frequency, distribution and intensity of extreme events are likely (Mortsch, 1995).

Response to the climate change issue has been slow relative to remedial actions which targeted other atmospheric issues such as ozone depletion and acid rain, largely due to the global nature of both the problem and potential solutions. The international recognition of the significance of climate change was conferred in the signing of the Framework Convention on Climate Change (FCCC) in 1992 which committed nations to begin limiting greenhouse gas emissions (UNEP, 1993). Canada's National Action Program on Climate Change (NAPCC) is designed to meet Canada's commitments under the FCCC (Canadian Energy and Environment Ministers, 1995). The NAPCC also strongly supports improving the science of climate change and variability, increasing knowledge of potential climate impacts and developing adaptation strategies to reduce society's vulnerability to climate change.

1.2 Great Lakes-St. Lawrence Basin Project

The Great Lakes-St. Lawrence Basin (GLSLB) Project on adapting to the impacts of climate change and variability is an Environment Canada research initiative involving federal, provincial, local agency and private industry partners (Mortsch and Mills, 1996). The GLSLB was chosen as a demonstration site for this research due to the economic and ecological importance of the region. Moreover, the area is known for its institutional complexity with numerous bi-national, federal, state, provincial and municipal agencies sharing responsibility for managing basin resources.

The GLSLB Project was initiated to improve our understanding of the complex interactions between climate, environment and society so that regional adaptation strategies could be developed in response to potential climate change and variability. In meeting this objective, research focuses on four climate-sensitive theme areas: land use and management, ecosystem health, human health and water management.

To facilitate integrating results from the various theme-based studies, the period 1951-88 has been specified as the base case climate period representing present conditions. This period was also used for the International Joint Commission Phase II study on fluctuating Great Lakes water levels (IJC, 1993). Five possible future climate scenarios were developed for the GLSLB Project, one using output from the Canadian Climate Centre's Second Generation General Circulation Model (CCC GCM II; Louie, 1991) and four climate transposition scenarios representing warm and dry; warm and wet; very warm and dry; and, very warm and wet basin-wide conditions (Scenarios 1-4; Croley *et al.*, 1995). The transposition scenarios were constructed by the Midwestern Climate Center (MCC) using historical climate data from regions to the south, southeast and southwest of the GLSLB and are referred to as scenarios MCC1-4 throughout this report. Socio-economic scenarios have not been developed for the GLSLB Project as a whole although some future socio-economic scenarios have been prepared as part of individual Project studies.

1.3 Grand River Basin Study

1.3.1 Study Objectives

The Grand River Basin (GRB) Study is one of the several theme-based climate impact and adaptation studies contributing to the GLSLB Project. This study contributes to the understanding of the potential impacts of global warming on water quantity issues in the Lake Erie/St. Clair Basin by addressing water resource issues in the GRB. The objectives of the GRB Study can be summarized as follows:

1. address the impacts of climate change and variability on water supplies and demand in a representative watershed;

2. identify strategies for adapting to possible impacts;

3. involve and encourage multiple disciplines and stakeholders to take part in the research; and,

4. increase awareness about climate variability and change, impacts and possible adaptation responses.

The Grand River Basin was selected for this study because:

- it is heavily populated and is experiencing significant growth;
- the Grand River and its tributaries are extensively used as a source of drinking water, as a medium for tourism and recreation activities and as a receiving stream for treated wastewater;
- it has a diverse economic and social character;
- it has an historic sensitivity to climate (e.g., flooding and water shortages);
- previous studies suggest climate change may significantly affect water resources and decision-making within the basin; and,
- the existing watershed management structure and research community facilitate the exchange of information and the communication of results.

1.3.2 Surface Water Component

Scope and Methodology

This component of the GRB Study deals with the impact of climate change on surface water supplies and the attendant impacts on water-based activities. A separate study component focuses on the impacts of climate change on groundwater resources. The groundwater study is a collaborative initiative of the Water Issues Division (WID), Environmental Services Branch-Ontario Region, Environment Canada; the National Water Research Institute (NWRI), Environment Canada; and, the Grand River Conservation Authority (GRCA).

To determine impacts and develop adaptation strategies, the first four steps--*Define objectives, Specify important climatic impacts, Identify adaptation options* and *Examine constraints*--of the seven-step approach described by Carter *et al.* (1994) in the ***IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*** were carried out. Recommendations based on study results are made in an effort to provide a foundation for steps five through seven--*Quantify measures and formulate alternative strategies, Weight objectives and evaluate trade-offs* and *Recommend adaptation measures*--to be addressed.

The development of adaptive strategies requires an interdisciplinary and participatory approach (Mortsch and Mills, 1996). Since the adaptive process is an interactive and dynamic learning exercise, involvement by those who may be affected, either by climate variability and change impacts or the adaptation measures selected, is essential. Throughout the course of this study, close liaison was maintained with staff at the GRCA. As the organization responsible for managing flows in the river, the GRCA will be directly affected by climate change impacts. The GRCA staff also provided local knowledge and expertise to help ensure that the Grand River system was adequately modelled. This liaison also permitted study team involvement in *The Grand Strategy for Shared Management of the Grand River Watershed* (GRCA, 1996a) which is designed to develop and implement a shared management plan for the Grand River watershed. Close liaison was also maintained with other researches involved in related projects.

Figure 1.1 provides an outline of the methodology used for the impact and adaptation assessment and identifies specific communication activities carried out to meet the objectives specified for GRB Study.

The GRCA, Paragon Engineering Limited, the Great Lakes Environmental Research Laboratory (GLERL) and Environment Canada provided the streamflow data adapted for use in this study. The GRB and its subwatershed boundaries plus streamflow gauge locations were provided in digital form by the Monitoring and Systems Branch - Ontario Region of Environment Canada. Necessary political boundaries were digitized from 1:50,000 Natural Resources Canada (NRC) maps by the Geomatics Unit, Environmental Services Branch - Ontario Region of Environment Canada.

IMPACT AND ADAPTATION ASSESSMENT

1) DEFINE OBJECTIVES

Basin Context and Issue Scoping

- Basin Management Objectives
- Literature review
  - current issues
  - potential climate change issues

↓

2) DETERMINE IMPORTANT CLIMATIC IMPACTS

Formal Simulation Model Selection and Set-up

- Water Use Analysis Model (WUAM) network design
- Data Preparation
  - water supply
  - system operation
  - water use
- Application Scenarios
  - 3 model-evaluation scenarios
  - 21 impact-assessment scenarios

Impact Assessment

- Interpretation of system response(streamflow impacts)
  - target flow satisfaction
  - flow frequency distribution
- Attendant impacts relative to Basin Objectives

↓

3) DEFINE ADAPTATION OPTIONS

↓

4) EXAMINE CONSTRAINTS TO ADAPTATONS

↓

5) QUANTIFY MEASURES AND FORMULATE ALTERNATIVE STRATEGIES
6) WEIGHT OBJECTIVES AND EVALUATED TRADE-OFFS
7) RECOMMEND ADAPTATION MEASURES

COMMUNICATION ACTIVITIES

Preliminary Discussions with Grand River Conservation Authority (GRCA) Water Management Staff

Liaison with Researchers Involved in Related Projects

- University of Waterloo Tri-Council Eco-research project
- Water Network study on climate change
- University of Guelph Rural Water Supply and Climate Change study
- GRB Study Groundwater component

Presentations to Grand Strategy Committees and Technical Working Groups (TWG):

- Grand Strategy Coordinating Committee
- Water Quality/Water Managers TWG
- Hydrology/Groundwater TWG
- Growth and Economic Development TWG

Participation on Grand Strategy Technical Working Groups

- Hydrology/Groundwater TWG

Other Presentations:

- Canadian Association of Geographers annual conference (June 1995)
- Ontario Ministry of Natural Resources/GRCA Hydrological Modelling and Issues workshop (May 1996)
- International Association of Great Lakes Research annual conference (May 1996)

Discussion Paper and Stakeholder Questionnaire (108-person distribution)

- Grand Strategy Coordinating Committee
- Water Quality/Water Managers TWG
- Hydrology/Groundwater TWG
- Fisheries Management TWG
- Growth and Development TWG
- Heritage, Tourism and Recreation TWG

Participation in the Following Meetings:

- Grand River Fisheries Open House/issue workshop (January 1996)
- University of Waterloo Tri-Council Eco-research project Grand River Forum (April 1996)
- Grand Strategy Joint Working Group Meetings (August 1996, February 1997)
- Binational Symposium on Adapting to Climate Change and Variability in the Great Lakes-St. Lawrence Basin (May 1997)

Figure 1.1 Impact and Adaptation Assessment Methodology - Communication Activities

2.0 IMPACT AND ADAPTATION ANALYSIS

2.1 Define Objectives

Any analysis of adaptation must be guided by some agreed upon overall goals and evaluation principles (Carter *et al.,*1994). Specific objectives must be defined that compliment the goals. The context and scope of an impact and adaptation assessment is largely a function of the current and potential issues within the study area under examination.

2.1.1 Basin Management Objectives

In 1990 the Grand River and its for major tributaries, the Nith, Conestogo, Speed and Eramosa Rivers (Figure 2.1) were nominated to the Canadian Heritage Rivers System. The designation as a Canadian Heritage River was accepted in 1994 due to the watershed's abundant human heritage and recreational features. A management plan called *The Grand Strategy for Managing the Grand River as a Canadian Heritage River* (GRCA, 1994), was facilitated by the GRCA and developed as part of the Canadian Heritage River designation process. The work originally focused on the management of heritage and recreational resources and was later broadened to include the development of a shared management plan for the watershed. The organizational structure for *The Grand Strategy for Shared Management of the Grand River Watershed* (*The Grand Strategy*) includes a coordinating committee and technical and community working groups.

The Grand Strategy advocates a management philosophy built on shared beliefs and values, community involvement and cooperation. It provides a mechanism for a joint work program among individuals, groups, municipalities and government agencies. As part of this effort, a shared vision for the Grand River watershed has been developed and endorsed by all participants in *The Grand Strategy. The Vision* (GRCA, 1996a), provided in Appendix A, is written as a "State of the Grand River Watershed" address to watershed residents in the year 2021 and represents the overall objectives of the current shared management plan for the basin. *The Vision* therefore also defines the watershed objectives necessary for the analysis of climate impacts and adaptation strategies in the GRB. Table 2.1 presents specific objective statements drawn from *The Vision.*

2.1.2 Context

Study Area

The GRB is the largest watershed in Ontario south of the Canadian Shield, draining an area of approximately 6790 square kilometres into Lake Erie (GRIC, 1982). The watershed is located in southwestern Ontario, west of Metropolitan Toronto. Its headwaters originate in the Dundalk Highlands at an elevation of 526 metres above sea level, and the river falls some 352 metres during the 290 kilometre journey over its course to Lake Erie (Nelson and O'Neill, 1990). Land cover within the basin is dominated by agriculture (78%) and natural or semi-natural uses (19%) while urban areas constitute the remaining 3% of land (Nelson and O'Neill, 1990).

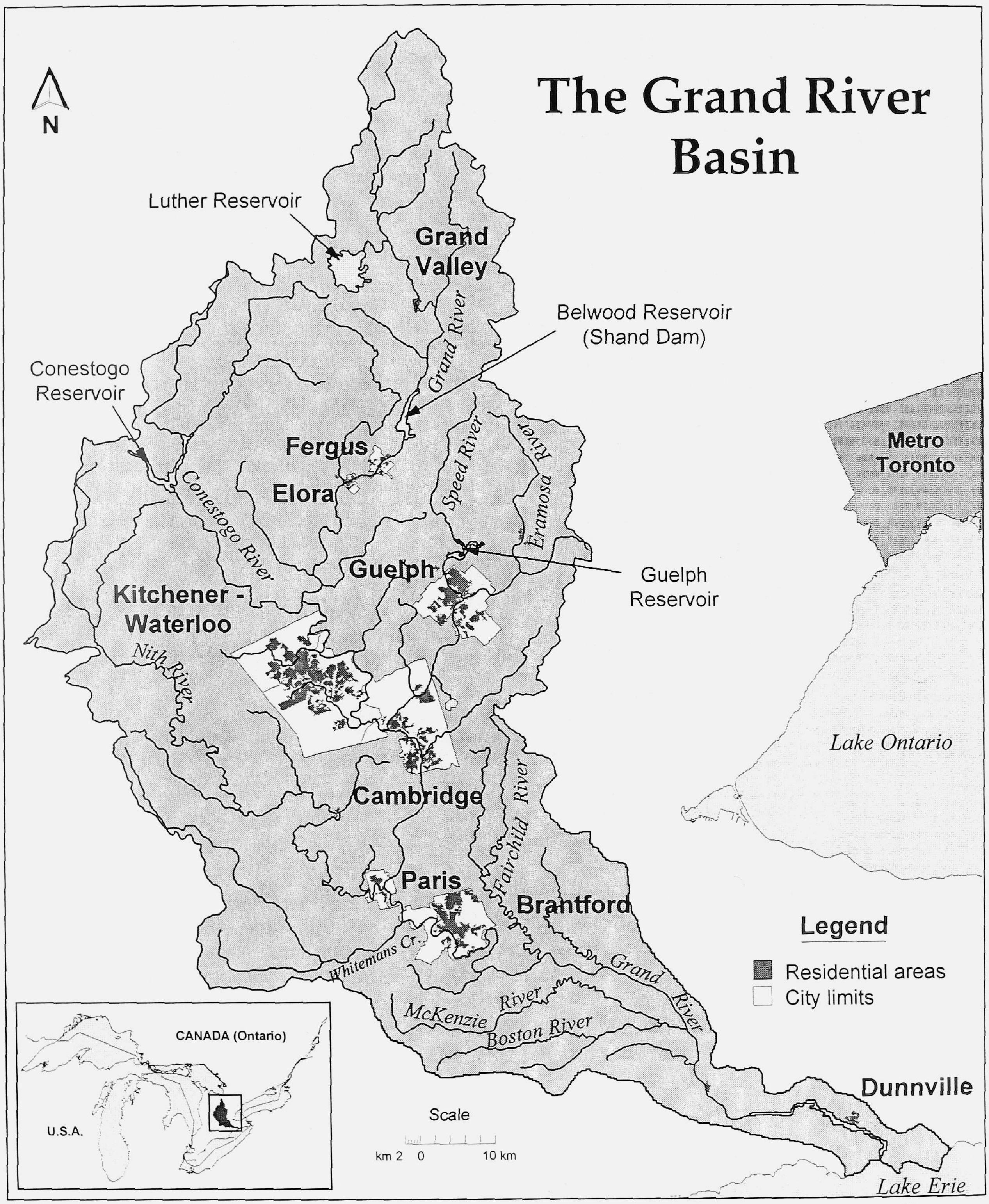


Figure 2.1 - The Grand River Basin

Table 2.1 - VISION 2021[1.]

Water Quantity	• Water supply meets both current and future needs, including municipal, domestic, commercial, industrial, recreational and agricultural. • Surface and groundwater is used wisely to ensure sufficient future water supplies for domestic, commercial, industrial, recreational, agricultural and environmental uses. • Watershed residents value and protect water and the quality of water.
Water Quality	• Water quality is satisfactory for various uses. There is a clean, potable water supply for urban and rural residents at reasonable cost. We can boat and swim in the river throughout the entire system without health concerns. We can safely eat the fish. Water quality supports a diversity of excellent recreational experiences. Water quality supports a healthy aquatic and terrestrial resource.
Flooding	• There is no increase in flood damage potential. Flood potential is reduced.
Growth	• Growth is nurtured and supports economic and social development and environmental protection so that it benefits future generations. • The quality of life and a strong sense of place are maintained.
Business Development	• New technical, manufacturing and service industries are attracted to the watershed as a preferred area in which to invest and entice prospective employees. Business development that benefits communities is encouraged in all sectors. • Business development reflects the values we uphold in the watershed. • A vital rural economy that supports and sustains the rural communities. • Tourism based on the heritage and recreational resources of the watershed provides significant benefits for rural and urban communities.
Natural Areas and Biodiversity	• Healthy aquatic and terrestrial habitats support viable self-sustaining populations of naturally-occurring species. We do not lose any more naturally-occurring species. • Landowners value the natural heritage resources and understand the management requirements of the resources on their land.
Human Heritage	• The human heritage resources of the watershed are acknowledged and valued, and are protected and interpreted on a watershed basis.
Outdoor Recreation	• Outdoor recreation, essential to the health and well-being of our communities, is managed on a watershed basis. • Recreationalists follow a code of ethics which respect others. • Watershed visitors are attracted by the diversity and excellent quality of watershed experiences which are offered in the Grand River watershed. • The entire Grand River system is recognized as a world-class fishery.

Note:

1. Source: Coordinating Committee for the Grand Strategy (1997)

Based upon land use characteristics and other features, the basin can be divided into three units: upper, middle and lower. Land use in the upper basin is largely rural with natural and semi-natural areas interrupting the dominant agricultural landscape. Population is the key feature distinguishing the middle basin from the upper and lower units. The Cities of Kitchener, Waterloo, Cambridge, Guelph and Brantford, all situated in the middle basin, have a combined population of over 450,000 and contain the bulk of the GRB's economic activity. The average grade of the Grand River in the upper and middle basins is 1.6 metres per kilometre while below Brantford the grade lessens to 0.4 metres per kilometre on the flat terrain characteristic of the lower basin (Chapman and Putnam, 1984). As in the upper basin, human settlement in the lower basin is dispersed across the rural landscape with the exception of a few small urban centres. Agriculture is the primary land use though its development was initially hampered by areas of marsh and unproductive agricultural land in the extreme south (GRIC, 1982). The population of the entire basin is expected to exceed one million by the year 2021 (GRCA, 1997).

There are 34 water control structures in the Grand River system, ranging from small weirs to large multi-purpose dams and reservoirs (GRCA, 1996b). The Shand (1942), Luther (1952), Conestogo (1958) and Guelph (1976) dams are operated by the GRCA to reduce peak flows, particularly during the spring freshet. During the summer, water stored in the reservoirs behind the dams is released to augment low flows and maintain adequate water quality. The effects of the Luther and Guelph dams are mainly local on the upper Grand and Speed Rivers, respectively. The Shand, which created the Belwood reservoir, and Conestogo dams have major impacts both locally and on the middle and lower Grand River. Figure 2.2 shows the average breakdown (in percentage of total flow) between flow released from reservoirs and streamflow without reservoir augmentation at selected points of interest throughout the system for the July to September, 1993 period. Although percentage values vary from year to year, the degree of summer streamflow augmentation is clearly significant.

Fifty-four municipalities, in whole or in part, within 11 Regions or Counties are contained in the GRB. The large and growing population of the middle basin places high demands and stresses on the natural resources of the watershed, particularly surface and groundwater resources through water extraction and wastewater treatment activities (GRIC, 1982). Although most of the basin population is serviced by groundwater, the Regional Municipality of Waterloo and the City of Guelph are relying more heavily on water supplies taken from the river system while Brantford and Six Nations depend exclusively on the river. All of the cities and towns, collectively representing approximately 600,000 people, discharge their treated wastewater into the Grand River or one of its major tributaries through 26 sewage treatment plants (STP). Wastewater from the major cities is treated and discharged continuously. Discharge from smaller communities is either on a continuous or intermittent basis. In 1993, wastewater discharge to the system averaged approximately 3.9 m^3/s (OMOE, 1993). Figure 2.3 provides a further breakdown of the total flow at the selected points of interest, including the percentage of total flow which is treated wastewater.

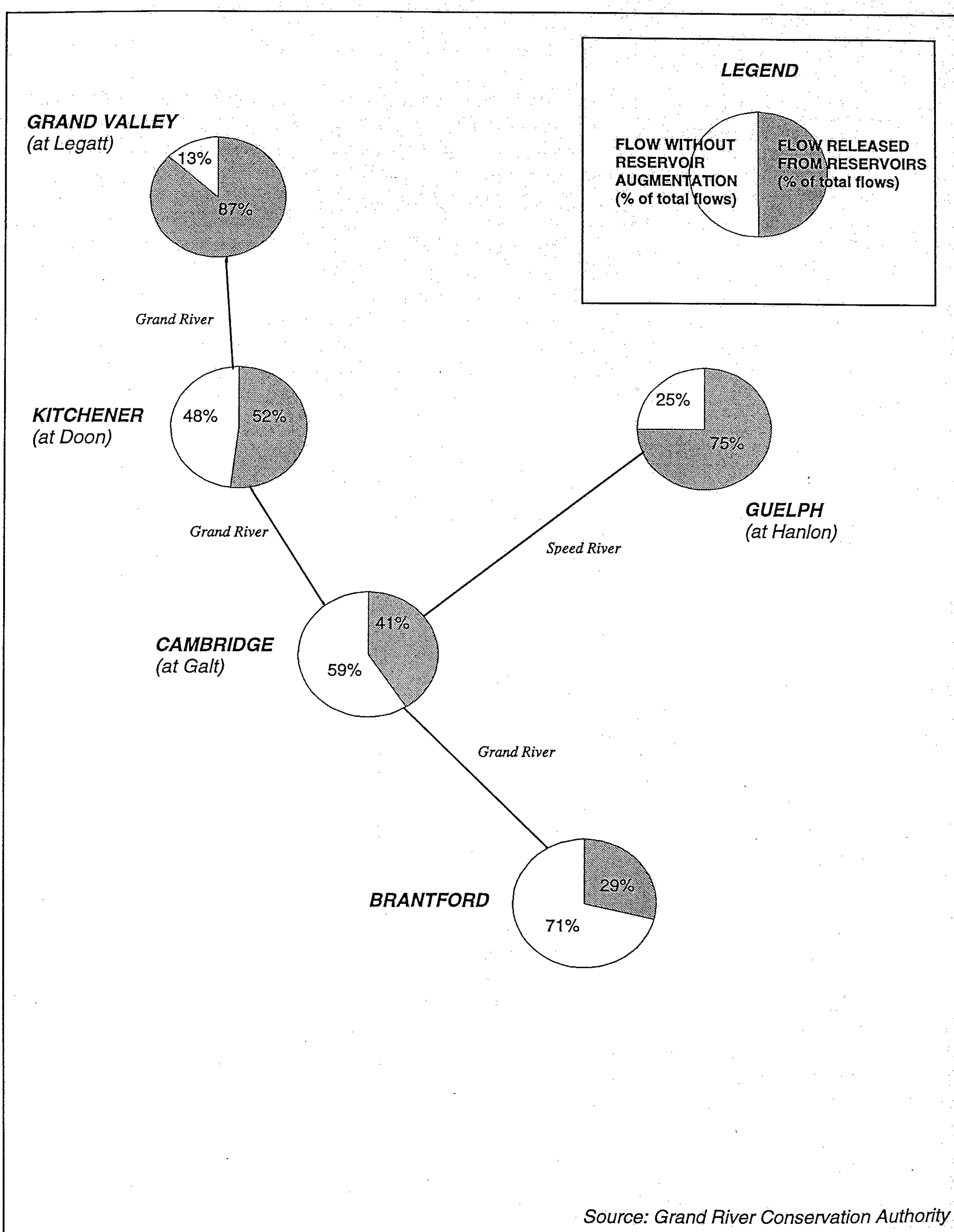


Figure 2.2 - Two-way Breakdown of Summer (July-Sept) 1993 Streamflows

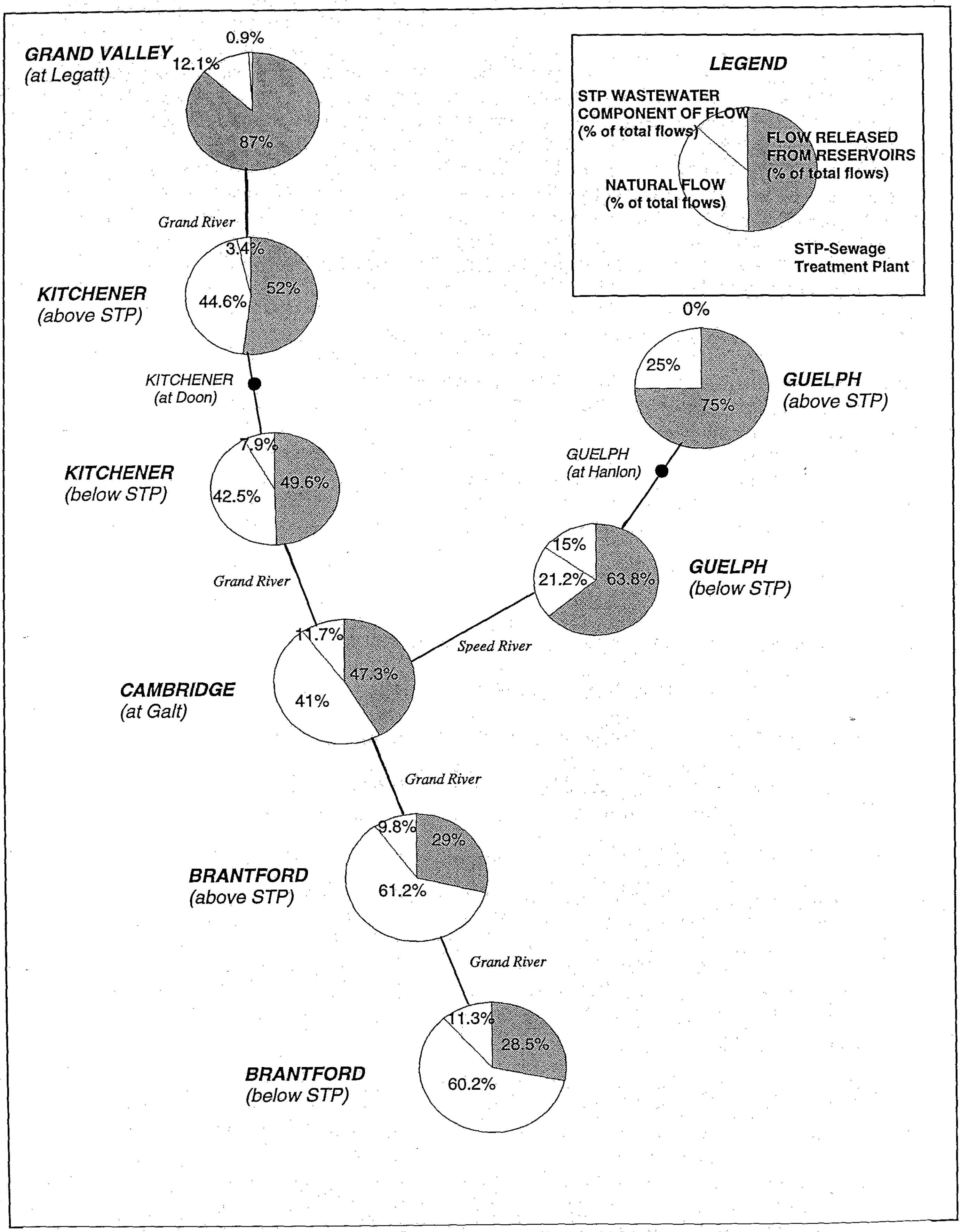


Figure 2.3 - Three-way Breakdown of Summer (July-Sept) 1993 Streamflows

Current Issues

Today, the GRB contains one of the healthiest river systems in North America in a heavily populated area (GRCA, 1996a). Since the 1930s, the water quality of the watershed has improved significantly due to more effective urban wastewater treatment, storm water management and rural land management practices. The improved watershed health has been accompanied by a revitalized sport fishery, increased recreational use of the river system and a greater appreciation of the river's natural and human heritage. Several major watershed management issues have, however, been identified as part of *The Grand Strategy* (GRCA, 1996a). These include:

- keeping the watershed healthy while accommodating growth;
- developing a viable tourism industry while protecting the resources upon which it is based;
- improving water quality using a cost effective balance between cleaning-up urban wastewater and controlling rural sources of pollution;
- water supply and water allocation;
- reducing flooding and erosion damages using a mix of structural and non-structural approaches;
- conserving the natural environment and biodiversity; and,
- conserving heritage and a sense of place.

How Might Climate Change Affect Water Resources in the Grand River Basin

Several research initiatives have examined how climate change might impact on water resources in the GRB.

The Water Network Study

The Water Network, a multi-disciplinary research team, investigated the possible impacts of climate change on water resources in the GRB (Sanderson, 1993). The climate change scenarios used in the studies were based on outputs from General Circulation Models (GCMs). The GCMs used were the Goddard Institute of Space Sciences (GISS; Hansen *et al.*, 1981), Geophysical Fluid Dynamics Laboratory (GFDL; Manabe and Wetherald, 1980) and the Canadian Climate Centre (CCC; Boer, 1990). Selected results from several investigations are summarized below.

Sanderson and Smith (1993) reviewed the basin's annual water balance under present (1951-80) and $2xCO_2$ climates for each GCM output. Their work indicated that the three climate change scenarios considered will affect the basin's hydrology by causing significant decreases in surface runoff, groundwater recharge rates and surface water flows. For the CCC model scenario, water surplus, the part of precipitation that does not evaporate, decreases some 36% across the basin. A significant decrease in surface runoff to the Grand River and its tributaries, and in the rate of aquifer recharge can thus be expected. Less water will be available to supply municipalities and to dilute wastewater. The changes determined by Sanderson and Smith (1993) represent long-term averages. Should climatic variability also increase, short-term fluctuations in supply could be even more severe than the predicted averages.

Smith and McBean (1993) used the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder, 1984) to evaluate the impact of climate change on surface water. This model estimates the daily water balance of an area by simulating both surface and subsurface hydrologic phenomena. Since most of the Grand River and its major tributaries have regulated flows, the analysis of model performance on a monthly basis was limited to the drainage area above Dundalk which has natural outflows but represents less than 1% of the total GRB area. Since no water is stored from year to year, recorded annual flows can be used for calibration purposes for regulated portions of the basin. Using annual flows, the model was applied to the GRB upstream of the Cambridge (Galt) gauging station which represents approximately 52% of the entire basin. On a year-to-year basis the annual modelled water balance did not correspond well with the measured results. The model did, however, successfully simulate the average annual water balance of the study area over the 1980-89 period. Although the HELP model did not accurately simulate specific annual flows, its application does suggest what may happen to the average flow in the Grand River at Cambridge under climate change. For the three future climate scenarios considered, surface water runoff and base flows were expected to decrease by 12% to 23% and 20% to 43%, respectively, resulting in streamflow reductions at Cambridge of between 19% and 40%.

McLaren and Sudicky (1993) used the 15% to 35% drops in surplus water determined by Sanderson and Smith (1993) as a basis for estimating the impact of climate change on groundwater recharge. A model was developed for a study area bounded on the east by the Grand and Conestogo Rivers and to the west by the Nith River. The model predicted that a reduction in the rate of recharge of 15% to 35% would result in a maximum impact (drawdown) at existing municipal well fields in the order of 5 m to 20 m, respectively. In northern regions of the study area, which are generally dependant upon individual wells, drawdowns ranged from 2 m to 7 m. The model also predicted that the 15% groundwater recharge rate reduction scenario would translate into a 17% decline in groundwater discharge to the rivers while the 35% reduction in groundwater recharge rate resulted in a 39% decline in discharge.

Martinello and Wall (1993) investigated the current values of Luther Marsh, located near the northern tip of the GRB, and examined the potential form and functions of the wetland in the event of climatic warming. They concluded that climate change could enhance or degrade the functions and value of Luther Marsh. Multiple use conflicts are likely to increase, and more intensive and extensive wetland management will be necessary to maintain the wetland given stresses associated with climate change as well as agricultural and urban expansion.

FitzGibbon *et al.* (1993) concluded that climate change will have a noticeable effect on the water quality regime of the system. Altered streamflows will affect the concentration of contaminants, and in conjunction with water temperature changes, will affect levels of dissolved oxygen and oxygen demand and thus influence the chemical and biological processes which take place in the water column. These changes will affect life in the aquatic system as well as the use of the river for water supply and wastewater disposal.

Robinson and Creese (1993) determined that climate change will cause important changes in the municipal water supply and wastewater systems of the Tri-Cities (Kitchener, Waterloo and Cambridge). Impacts on water supply and wastewater systems were assessed assuming that the current socio-economic conditions will remain relatively unchanged in the future. The study found that the water supply subsystem will be more affected on the supply side than the demand side. Annual maximum daily use will increase marginally compared to the study's Basis-of-Comparison (BOC) climate scenario. The effect of climate change on demand is small and the uncertainty in forecasting future population is enough to obscure it. The Mannheim recharge scheme (a plan to use treated river water to artificially recharge the Mannheim surficial aquifer) will be significantly impacted by a reduction in streamflow in the Grand River and by changes in water quality brought on by climate change. The quantity of wastewater treated will be affected by climate change through reduced inflow and infiltration into sanitary sewers, due to a lower groundwater table and reduced surface runoff.

The policy implications of climate change for water management in the GRB were assessed by de Loë and Mitchell (1993). The purposes of their work were to identify potential problems created by anticipated changes to surface and groundwater supply patterns and to identify alternative strategic responses. The goal of the two-stage survey used in the study was to engage respondents from each of the following categories: municipal politicians and staff, provincial politicians, provincial bureaucrats, consultants, academics, and environmental and user groups. Forty-eight respondents participated in round one, while 35 took part in the second round. Municipal staff and consultants with engineering or geography/planning/resource management backgrounds constituted the majority of respondents to both surveys.

In round one, respondents were asked to indicate what steps should be taken today to respond to a future 20%, 40% and 60% decreases in stream discharge as measured at a central city in each of three basin areas[northwest, central, southeast]. Respondents were also asked to specify their reasons for selecting these steps. In total, 301 suggestions were generated by respondents to the round-one survey.

For the round-two survey, the 301 suggestions from round one were generalized into 72 unambiguous options by survey organizers. Respondents were asked to rate each of the 72 options plus two "no action" statements on a four-point scale (strongly support, weakly support, weakly oppose or strongly oppose) in the context of a 20%, 40% and 60% decrease in streamflow. The group clearly opposed the "no-action" options. The study organizers grouped the remaining measures by type and determined each measure's levels of consensus and support. Measures which received high consensus on strong or weak-to-strong support were considered "clearly supported" by the report authors.

As a final step, a workshop was organized where participants (in two groups) selected 10 measures from a list of 30 which were "clearly supported" by round two respondents at the 20% decrease in streamflow level. The two policy packages defined by the workshop are provided in Table 2.2.

Emerging most clearly from the policy delphi survey and the workshop used in the study was a strong consensus that it is better to be proactive than reactive. At the same time, it was clear that participants did not support implementing restrictive regulatory measures or constructing major supply works in the near future. The two sets of measures which were identified make good environmental and economic sense, regardless of whether or not streamflows decrease due to climate change.

Table 2.2 - Groups 1 and 2 Policy Packages

Group One's Policy Package (Table 9.3 in de Loē and Mitchell, 1993)		
Measure	**Implementing Agency(s)**	**Rationale**
Legislate water efficient technology for urban and rural uses	Province | Municipal/Regional	• Effective
Full metering, full-cost pricing and maintenance/leak reduction	Regional Municipality, Local Municipality, Public Utilities Commission	• Efficiency (cost)
Conservation, through education/incentives, appropriate vegetation and ponds/cisterns	Province | \ RBA Regional/Local Municipalities	• Comprehensive approach
Regulation of point and non-point source pollution	Province (MOE) | RBA	• Comprehensive approach
Wetlands conservation and restoration	Province | RBA	• Comprehensive approach

Note: RBA: River Basin Authority. MOE: Ontario Ministry of Environment

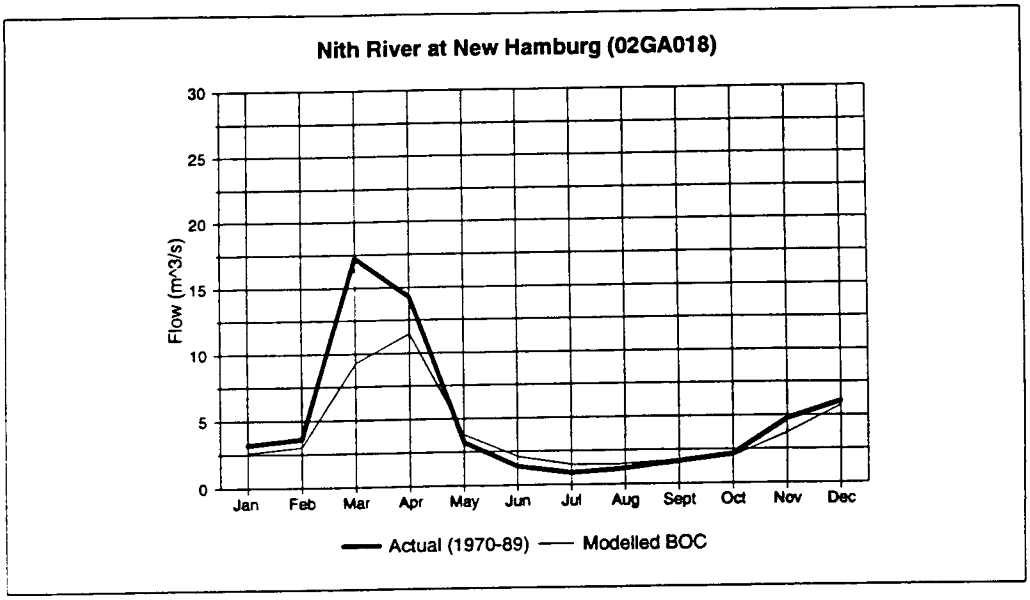
Group Two's Policy Package (Table 9.4 in de Loē and Mitchell, 1993)		
Measure	**Implementing Agency(s)**	**Rationale**
Metering of all uses, combined with more inventory and monitoring of uses	Municipalities, MOE, OMAF	• Comprehensive • Jurisdiction
Increase inventory of surface and groundwater supplies	CA, MOE	• Jurisdiction • Required by regional nature of large aquifers
Leak reduction program	Municipality	• Jurisdiction
Conservation education	Municipal, Provincial, Federal agencies	• Will depend on client and focus
Promote low water using vegetation	Municipality	• Jurisdiction
Full cost pricing	Municipal and/or other delivery agency	• Jurisdiction
Limit urban and agricultural development in wetlands	Municipalities, CA	• Local administration • Watershed overview
Better control of urban runoff (includes use of municipal drains to promote groundwater recharge)	Municipalities and Province	• Jurisdiction • Need for enabling legislation
Better control of agricultural runoff (includes more control of agricultural drainage to promote infiltration)	Municipalities and Province	• Jurisdiction • Need for enabling legislation
Watershed planning	Interjurisdictional (would require a lead agency?)	• Multiple interests to be represented

Note: CA: Conservation Authority. OMAF: Ontario Ministry of Agriculture and Food.

Other Work

Creese and McBean (1996) extended the work of Smith and McBean (1993). Historical climate data for the 20-year period 1970-89, inclusive, was chosen to represent the BOC ($1xCO_2$) scenario. The Nith River, which is the largest unregulated tributary of the Grand River and accounts for 15% of the GRB area, was selected for modelling purposes. Initial intentions were to continue and refine the approach used previously by Smith and McBean (1993) for monthly flows. The approach was eventually abandoned due to difficulty in calibrating all the HELP model parameters. A two-part hydrological and statistical river flow model was created instead. The model was calibrated at two sites on the Nith River, at New Hamburg and near Canning. Although model results were considered good, the 1970-89 long-term modelled BOC flows were approximately 19% and 11% lower than actual values with March and April flows averaging well below recorded (see Figure 2.4). The calibrated model was then run using the changed-climate temperature and precipitation values corresponding to the GISS, GFDL and the CCC GCMs. Relative to the calibrated flows, annual impacts comparable to the 19% to 40% drop in streamflow estimated by Smith and McBean (1993) for the river above Galt were obtained.

As part of the Regional Municipality of Waterloo (RMOW) Long Term Water Strategy study, Paragon Engineering Limited (1994) investigated the impact of climate change on the Grand River as a source of water. In Paragon's assessment, the potential impact of climate change on the reliability of a Grand River supply option was evaluated through a series of Reservoir Yield Model (GRIC, 1982) simulations carried out with all the river discharge inputs reduced. The analysis included linear reductions of 5%, 10% and 20% in all daily river discharges throughout the system. The simulations indicated that although the reliability of achieving specified target discharges decreases progressively with the 5%, 10% and 20% reductions in flows, there is still a relatively high reliability of achieving streamflow targets at Doon, even with a 20% reduction in flows (96% reliability compared to the current 100%). The study's authors concluded that periods of shortage would increase under the assumed climate change flow conditions. Robinson and Creese (1996) suggest that given the non-linear reductions in flow suggested by Creese and McBean (1996), water supply shortages, particularly in the fall, may be greater than those indicated by the Paragon study.



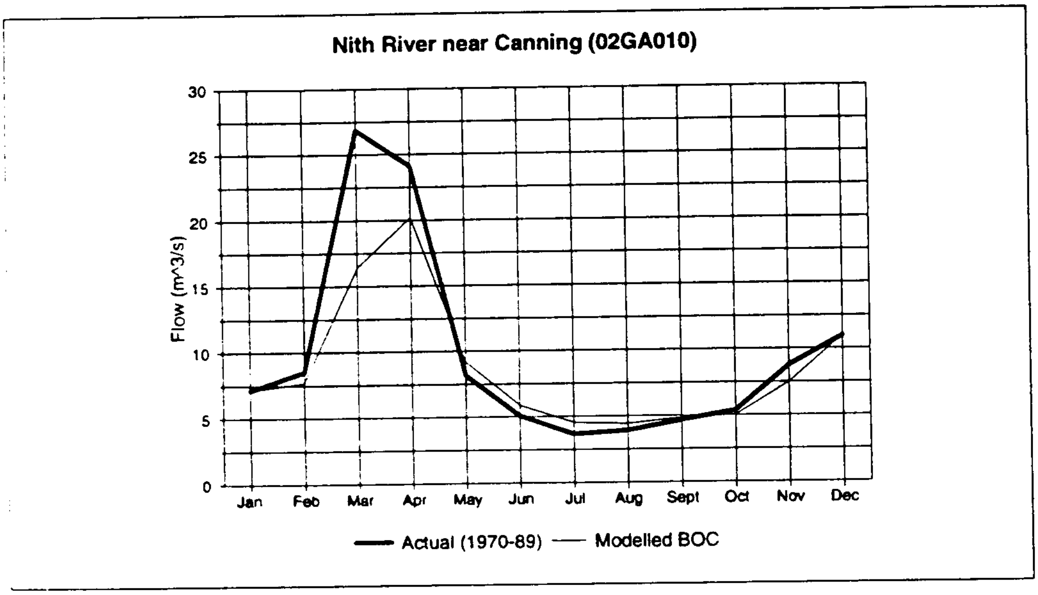


Figure 2.4 - Creese and McBean (1996) Model Calibration Results

2.2 Determination of Important Climatic Impacts

2.2.1 Approach

Impact analyses generally fall into two categories (Mortsch and Mills, 1996): (1) historical analogues, the use of known historical situations to determine possible representative responses to a changed climate situation; and (2) formal simulation, the use of simulation models to estimate system response under a changed climate and test possible adaptive measures.

Streamflow is the key climate-sensitive element in the GRB, affecting almost every activity and goal identified in *The Grand Strategy* vision statement. Adequate surface water quality and quantity are the issues of greatest concern. Like many other factors, such as population growth, climate change and variability acts as a stressor on the river system. As such, climate change may affect whether the watershed objectives as defined by the vision statement can be met.

Any streamflow impact assessment in the GRB must recognize and take into account the current and potential roles streamflow regulation and water use play throughout the system. Due to the existence and purpose of basin dams and reservoirs and the potential for population growth, it was concluded that the formal simulation approach was necessary for study purposes.

2.2.2 Streamflow Conditions

Since the potential impact of climate change on streamflows was selected as the primary focus of the impact analysis, the following sections provide a brief review of flow conditions in the GRB.

General

The flow regime of the Grand River is highly variable. A review of the 1914-94 recorded data indicates a long-term average flow in the Grand River at Galt (the gauge with the longest continuous period of record in the system) of 36.0 m^3/s (Environment Canada, 1994). A maximum daily flow of 1140 m^3/s occurred on October 16, 1954, while a minimum daily flow of 0.736 m^3/s was recorded on August 9, 1936. It is notable that the average flow for the entire month of August 1936 was only 1.33 m^3/s while July and September of that year had average flows of just 1.56 m^3/s and 2.59 m^3/s, respectively. The maximum peak instantaneous discharge was recorded on May 17, 1974 at 1550 m^3/s. The GRCA has calculated that under natural flow conditions, a maximum instantaneous flow of 1642 m^3/s would have occurred at Galt during April 1975 but this flow was reduced to approximately 852 m^3/s by reservoir operations (GRIC, 1982). Figure 2.5 shows the variation in monthly streamflow for the Grand River at Galt.

The observed flows reflect the varying degree of regulation throughout the system over time as well as changes in land use, water use and operating policies at system reservoirs. The Shand (1942), Conestogo (1958) and Guelph (1976) dams are operated to reduce peak flows, particularly during the spring freshet. During the summer, water stored in the reservoirs behind the dams is released to maintain flows above minimum targets, specified at Doon (in Kitchener), Hanlon (below Guelph) and Brantford, to maintain adequate water quality in the system (Table 2.3). In order to fully discuss Grand River flow characteristics it is necessary to determine the streamflows the river would have experienced without regulation or water use impacts.

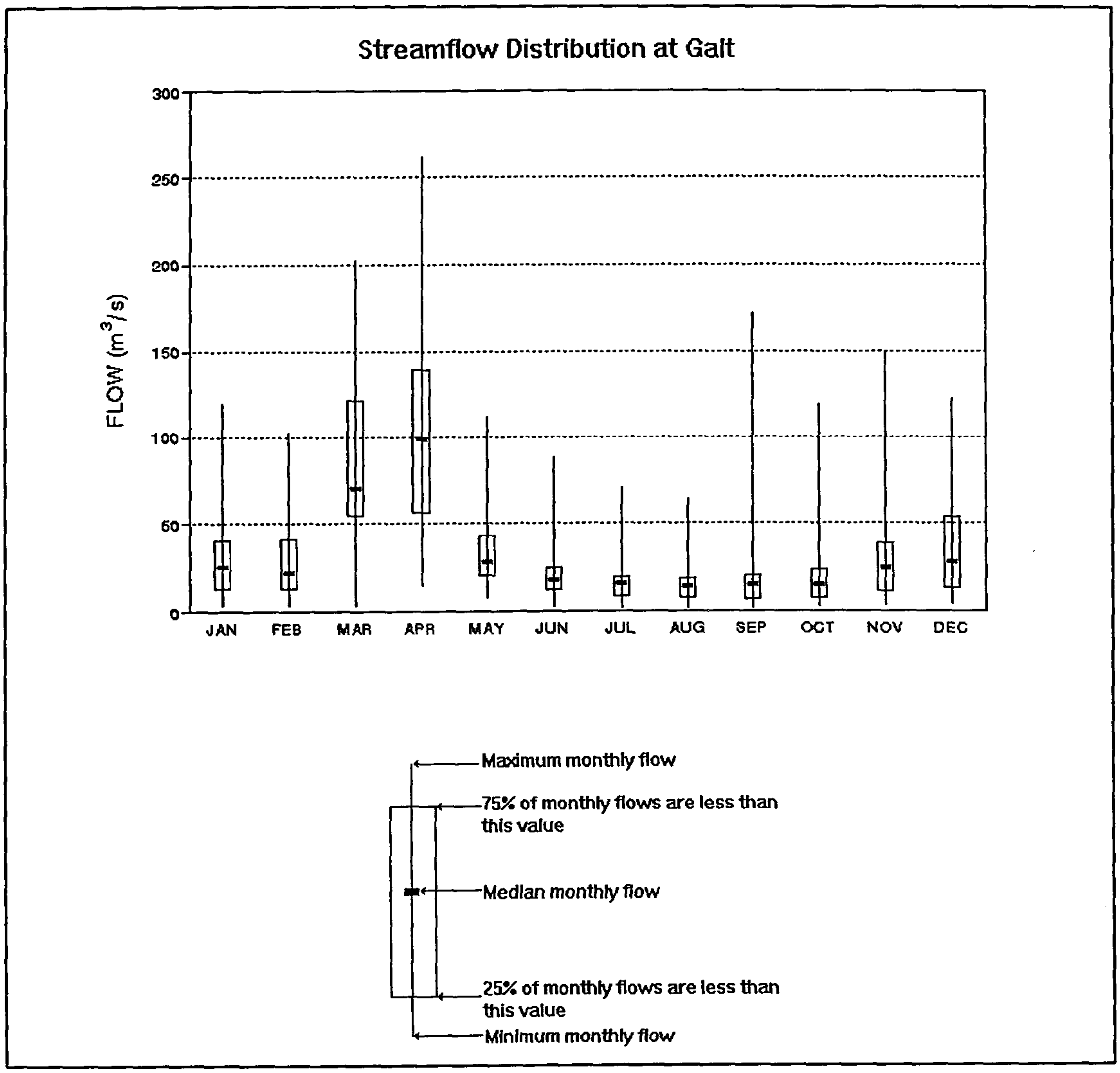


Figure 2.5 - Monthly Streamflow Distribution at Galt (1914-94)

Table 2.3 - Current Streamflow Targets

Location	Daily Flow Targets (m^3/s)		
	Jan. - Apr.	May - Oct.	Nov. - Dec.
Grand River at Doon (in Kitchener)	2.8	9.9	7.1
Speed River at Hanlon (below Guelph)	--	1.7	--
Grand River at Brantford	--	17.0	--

Unregulated Flows

Figure 2.6 shows the location of seven streamflow measurement sites and their related subcatchments. The recorded streamflow at any selected site is the result of contributions from upstream subcatchments. For example, Subcatchments 4 and 5 contribute to flows recorded at the Speed River gauge below Guelph, while all seven subcatchments contribute to the streamflows recorded at the Grand River gauge at Brantford.

Flows from the seven subcatchments shown in Figure 2.6 can be divided into two categories (Paragon Engineering Limited, 1994). Currently, outflows from Subcatchments 1, 2 and 4 are controlled by reservoir operations while outflows from Subcatchments 3, 5, 6 and 7 are not. Uncontrolled, or local, discharges are required for all seven subcatchments to determine unregulated streamflows at each of the seven gauge sites shown. Unregulated streamflows represent the flows that would have occurred throughout the system if they had not been modified by reservoir operations.

The GRCA provided 1950-90 daily local discharges for each of the seven subcatchments above the Brantford gauge. This database, originally developed by the GRCA for the GRIC study, was updated through to 1990 by Paragon Engineering Limited (1994) on behalf of the Regional Municipality of Waterloo as part of their master water supply study. Monthly average local discharges were determined for each subcatchment and summed as required to produce monthly unregulated streamflows at each of the sites for the 1951-88 study period. The initial data were modified after a number of problems were identified in the resulting streamflow values during the reduction and verification process. This exercise was not the subject of a regional analysis, but of theoretical calculations based on replacing incorrect records by either simply prorating adjacent gauges in relation to their drainage area or using regression analysis to determine inter-station correlation coefficients.

In managing Grand River flows, the GRCA does not tend to store water inter-annually. Therefore, on an annual basis there is no difference between the recorded and unregulated flows, except for small surface gains or losses to the atmosphere at the reservoirs. Figure 2.7 provides a comparison between the annual recorded and estimated unregulated flows at Galt. The differences between recorded and unregulated flows shown for Galt are likely the result of estimation errors. Throughout the effort to generate monthly unregulated flows it was felt that if the long-term (1951-88) recorded and estimated unregulated average flows differed by less than plus or minus 1.0 m^3/s at Galt and Brantford they would be considered adequate. While this target has been met, individual annual differences can be greater. For example a maximum difference of -2.9 m^3/s occurs for 1985 at both the Galt and Brantford gauges. Even if the long-term and annual averages match it does not mean the month-by-month unregulated flow values are correct.

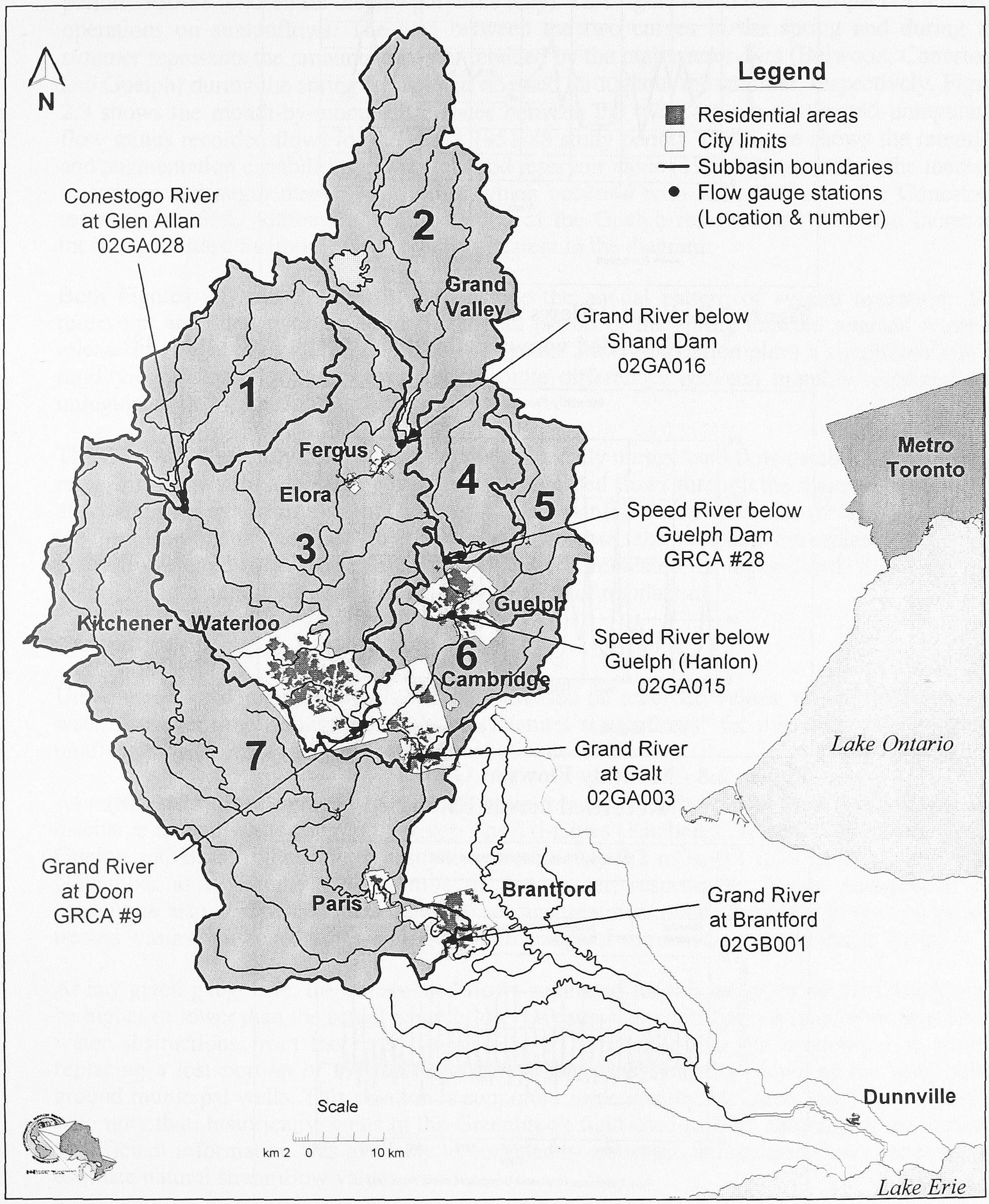


Figure 2.6 - Seven Streamflow Measurement Sites and Their Related Subcatchments

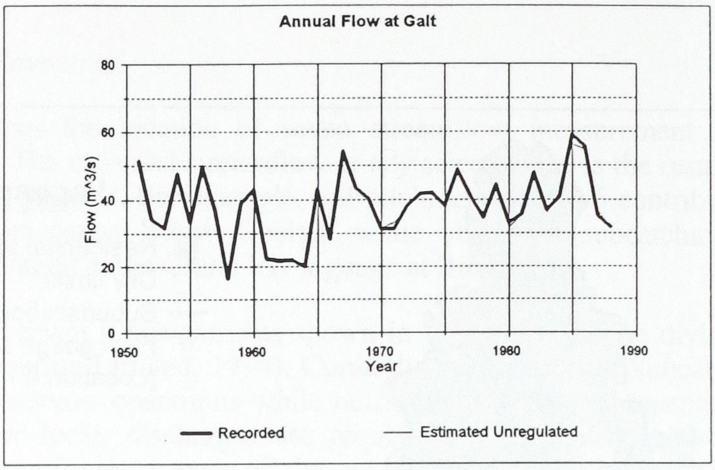


Figure 2.7- Annual Flows at Galt:
Recorded versus Estimated Unregulated (1951-88)

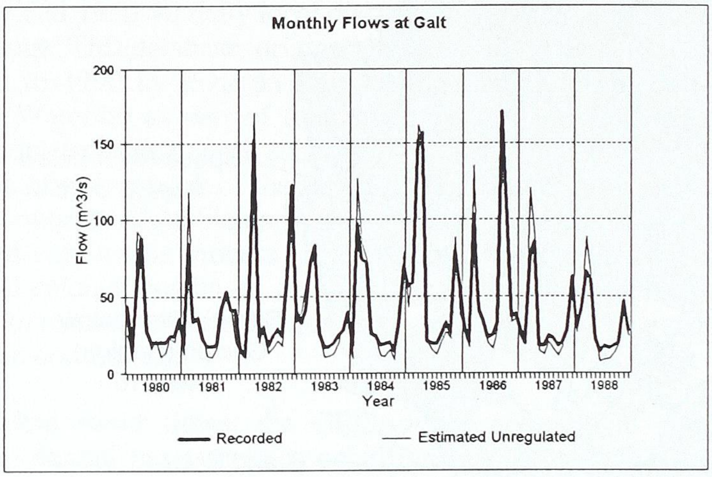


Figure 2.8 - Monthly Flows at Galt:
Recorded versus Estimated Unregulated (1980-88)

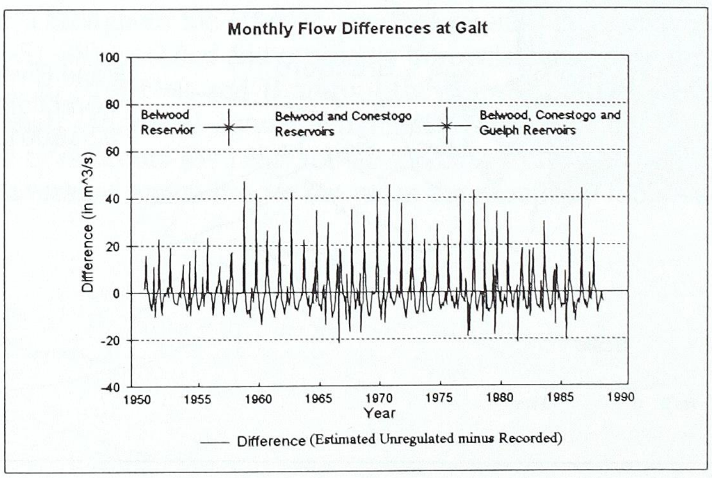


Figure 2.9 - Monthly Flow Differences at Galt:
Estimated Unregulated minus Recorded (1951-88)

Figure 2.8 provides a plot of monthly recorded and estimated unregulated flows at Galt for the period 1980-88 (chosen for display purposes only). This figure illustrates the impact of reservoir operations on streamflows. The area between the two curves in the spring and during the summer represents the amounts of water retained by the major reservoirs (Belwood, Conestogo and Guelph) during the spring freshet and released throughout the summer, respectively. Figure 2.9 shows the month-by-month differences between the two data sets (estimated unregulated flow minus recorded flow) for the entire 1951-88 study period. The figure shows the retention and augmentation capabilities of the Belwood reservoir alone (1951-57), as well as the increase in storage and augmentation capabilities which occurred with the addition of the Conestogo reservoir in 1958. Although the introduction of the Guelph reservoir in 1976 also increases these capabilities, its impact is not readily apparent in the diagram.

Both Figures 2.8 and 2.9 clearly demonstrate the annual pattern of system operation. The reservoirs are filled over a one to two-month period in the spring and the retained water is released throughout the summer period to augment flow. Regulation plays a significant role in modifying system flows; however, the absolute differences between monthly regulated and unregulated flows are small.

The GRCA has recently completed a review of its daily unregulated flow database, determining reservoir inflows for all years by back-routing recorded flows through the major reservoirs and accounting for evaporation from the reservoir and rainfall on the reservoir surface. Because of the back-routing method use to develop the database, the resulting unregulated flows are generally referred to as deregulated flows. These unregulated, or deregulated, flows are also described as "natural" flows referring to the absence of regulation.

Natural Flows

Unregulated, or deregulated flows, which are based on recorded values, reflect the impact of water use over time throughout the basin. "Natural streamflows" for this study refer to flows unaffected by either regulation or the impact of water use.

As noted, most of the municipalities in the basin rely on groundwater for their water supply and discharge treated wastewater to the river. The Tri-Cities (Kitchener, Waterloo and Cambridge), Guelph and Brantford currently abstract approximately 0.2 m^3/s, 0.1 m^3/s (mid-April to mid-November as required), and 0.5 m^3/s of river water, respectively. Water abstractions for agriculture also occur. As noted earlier, 26 sewage treatment plants discharge to the system and treated wastewater constitutes a significant percentage of summer flow in the Grand River.

At any given gauge site, the unregulated flows generated for this study, or by the GRCA, may be higher or lower than the actual natural flows. Wastewater contributions may more than offset water abstractions from the river. Conversely, it is possible that the wastewater is simply replacing a lost portion of the river's base flow resulting from drawdown of the water table around municipal wells. This position is supported somewhat by McLaren and Sudicky (1993) who note that, historically, wells in the Greenbrook field used to flow naturally at the surface. Insufficient information was available to confidently adjust the unregulated flows generated to estimate natural streamflow values.

Trends Observed in Flows

When the 1914-92 annual recorded flows at Galt are plotted, an increasing trend with time is apparent (Figure 2.10). Precipitation records (averaged) for the Kitchener, Waterloo-Wellington airport and Guelph Ontario Agricultural College (OAC) climate stations, for the 1921-92 time period, suggest similar trends in precipitation (Figure 2.11).

Figure 2.12 shows the recorded monthly flows at Galt for the period 1914-88. It is evident that minimum flows increased following the introduction of the major reservoirs; consistent with system operation goals. However, Figure 2.13 indicates that minimum estimated unregulated flows for the period 1951-88 were also higher than minimum flows recorded during the natural flow condition period of 1914-41, suggesting regulation was not responsible for all of the increase in flows in the latter years. A gap in the plot exists from 1942-50 as monthly unregulated flows through this time period were not developed for this study. Figure 2.14, generated by GRCA staff using their updated deregulated daily flows, also shows the increasing trend in minimum "natural" (i.e., uncontrolled) flows with time. In addition to increases in precipitation, factors such as urbanization, wastewater discharge and reforestation may have contributed to the apparent increase in minimum flows.

Figure 2.15 provides the seasonal distribution for the 1914-41 recorded (natural conditions) and the 1951-88 estimated unregulated flows. Note that the annual average flow for the 1914-41 period is approximately 20% less than the 1951-88 period and that the largest differences are found in autumn.

The evidence presented suggests that minimum uncontrolled flows have been higher in recent years. If this is true, then it is reasonable to assume that these higher flows have increased the ability of water managers to maintaining the required target streamflows. Should annual precipitation return to the historical lows of the mid-1930s, the late 1940s or the mid-1960s, with the attendant effect on river flows (even with augmentation), many would perceive this as a change in climate. If the system operation and use have developed based on more recent averages or climate conditions, the adjustment necessary to deal with lower flows may be difficult to make.

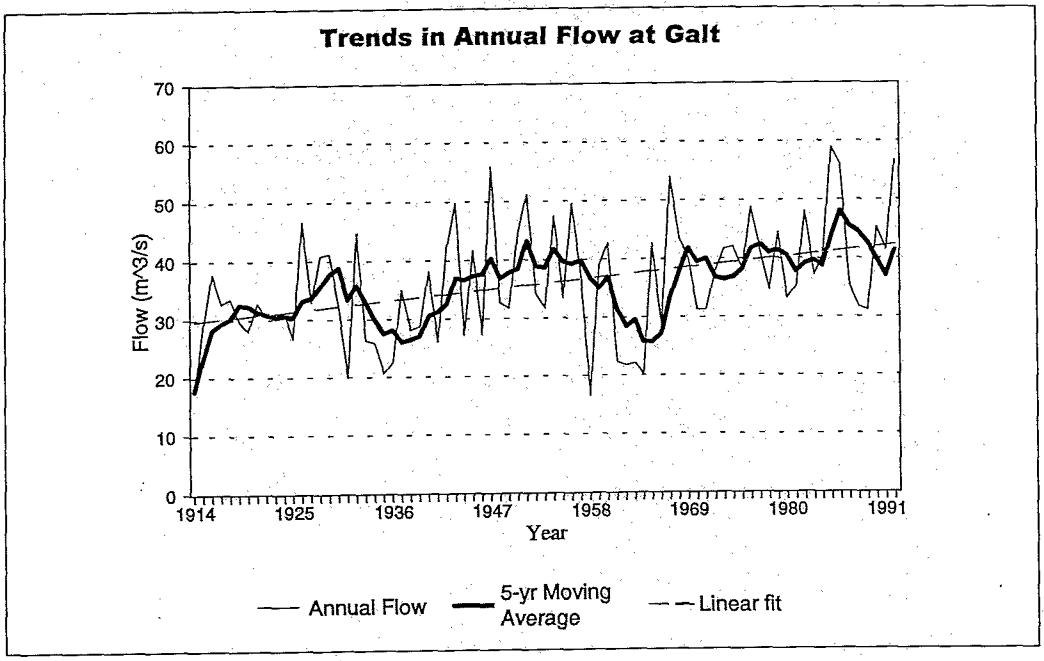


Figure 2.10 - Trends in Annual Flow: Grand River at Galt (1914-92)

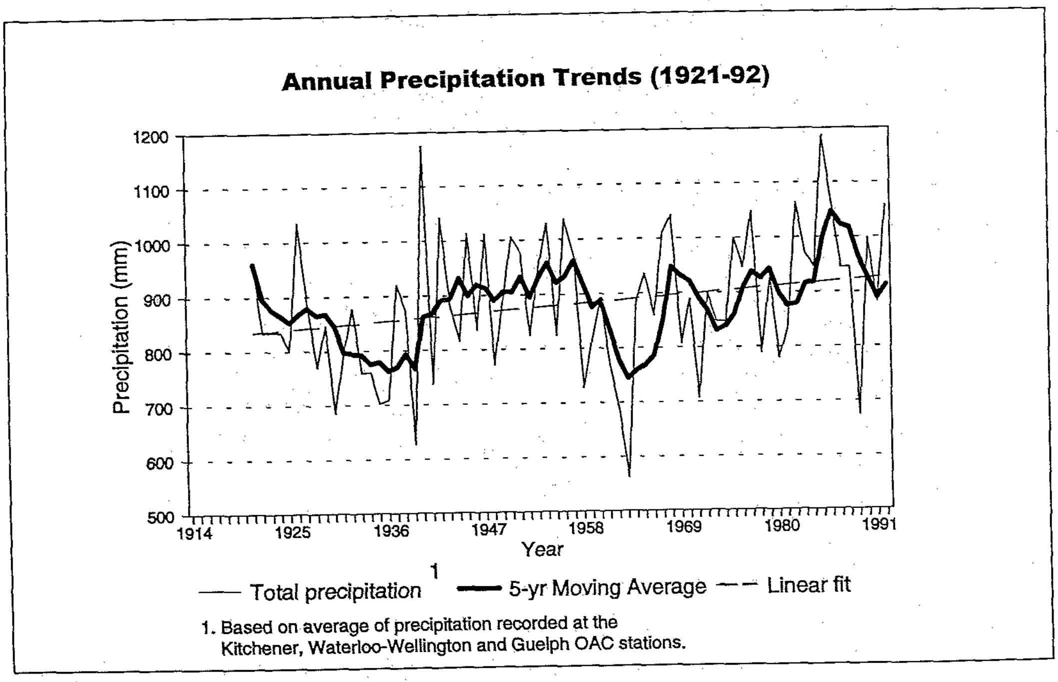


Figure 2.11 - Trends in Annual Precipitation: Average from Kitchener, Waterloo-Wellington and Guelph OAC Stations (1921-92)

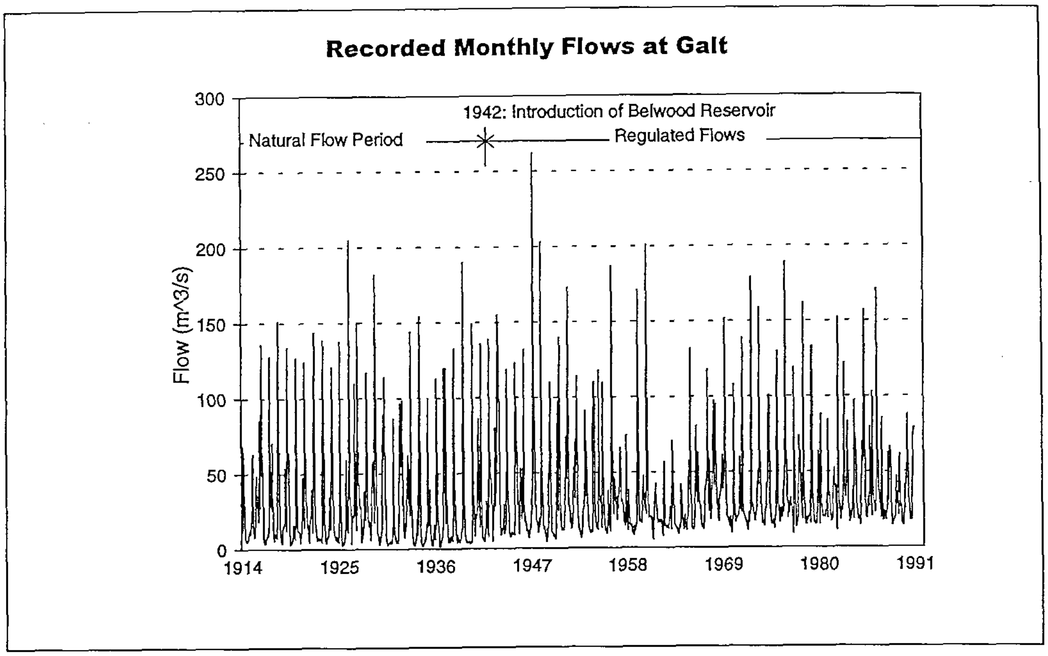


Figure 2.12 - Recorded Monthly Flows: Grand River at Galt (1914-88)

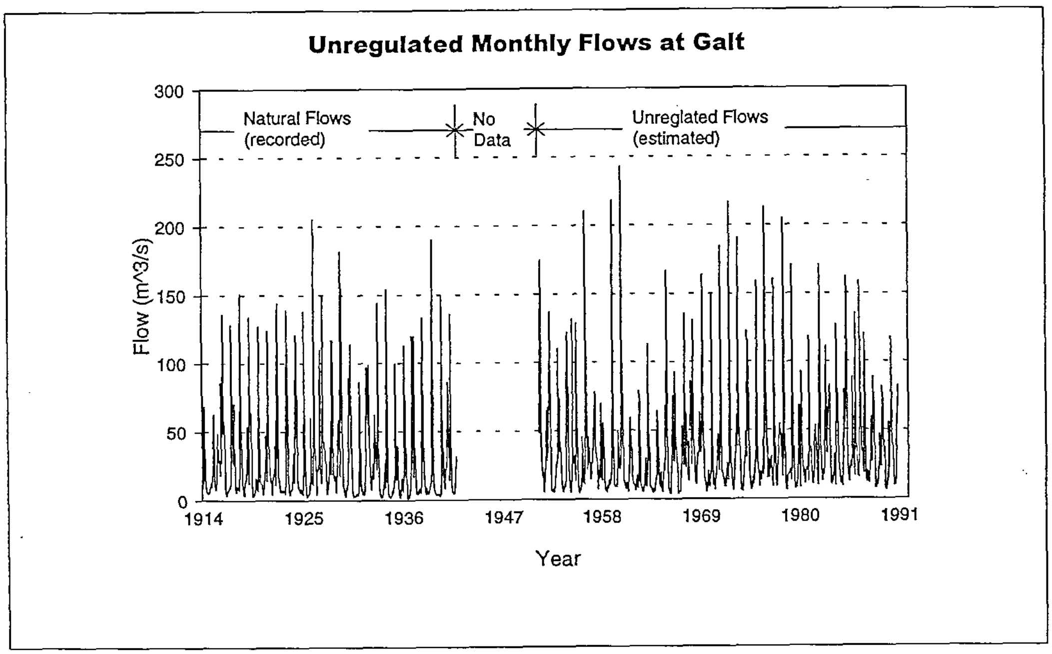


Figure 2.13 - Unregulated Monthly Flows: Grand River at Galt (1914-41, 1951-88)

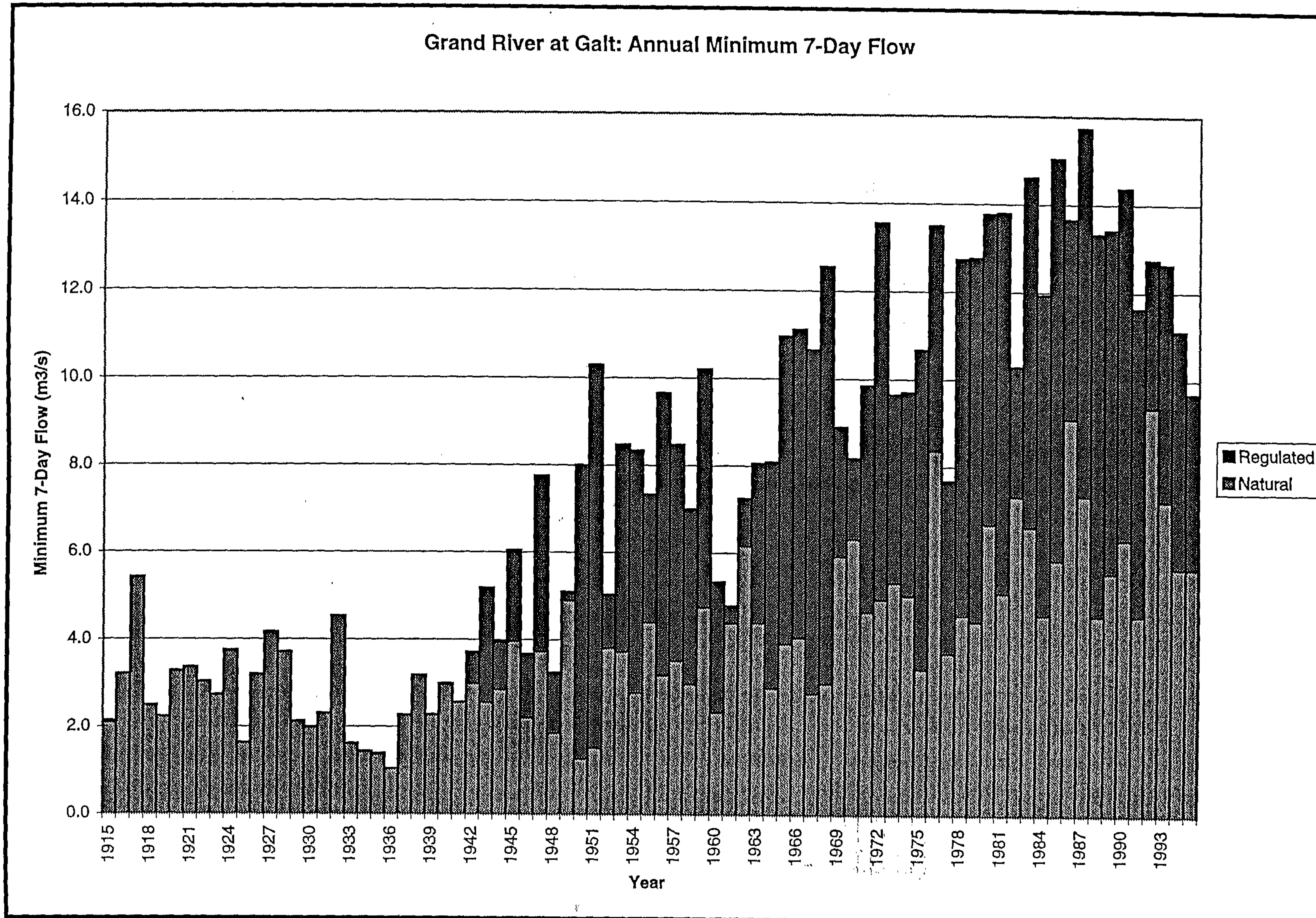


Figure 2.14 - Annual Minimum 7-Day Flow at Galt

Source: D. Boyd, GRCA

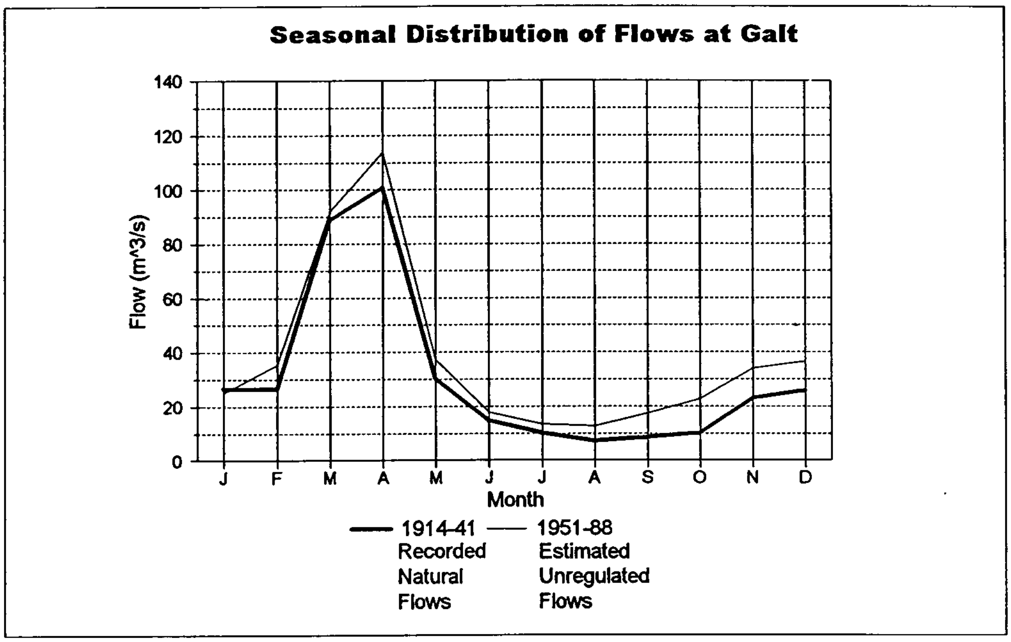


Figure 2.15 - Seasonal Distribution of Flows at Galt: 1914-41 Recorded (Natural) and 1951-88 Estimated Unregulated

2.2.3 Simulation Model Selection

Two simulation models were considered for use in this study: the Grand River Reservoir Yield Model (GRIC, 1982) and the Water Use Analysis Model (WUAM) (Kassem, 1992; Kassem *et al.*, 1994)

The Grand River Reservoir Yield Model is used by the GRCA to simulate various reservoir operating procedures and determine flows throughout the GRB using a daily time step. It has also been used to investigate specific water use questions such as the impacts of increased water abstraction by the Regional Municipality of Waterloo (Paragon Engineering Limited, 1994). However, the model was not selected for this study as it does not have a water use simulation component.

WUAM is a relatively new approach to supply-demand balance modelling. Its use of water demand as a point of departure contrasts with the more traditional supply-side focus of previous models (Kassem, 1992). Figure 2.16 provides a conceptual overview of the model which deals exclusively with water quantity aspects and has three principal components: (a) water use, (b) water supply and (c) water balance.

Water use forecasting is the primary focus of the model. Water uses include withdrawal (or consumptive) and non-withdrawal (or in-stream). Surface water supplies are simulated based on time-series of natural streamflows. Only ad hoc procedures are used for groundwater supplies. A reservoir modelling subcomponent simulates regulation effects on streamflows. A maximum of four reservoirs can be defined for a study area. The final component of the model is an algorithm that compares projected water use against available supplies. Water quality issues can be addressed when considering WUAM output to assist in management decisions.

WUAM depicts a river basin as a dendritic network of nodes (representing tributaries and subbasins) and arcs (representing the flow path between nodes). Water use projections and water balance calculations are carried out at each node (Figure 2.17). WUAM can be used to simulate all of the sources and withdrawals of water within a basin. The model can be used to monitor these variables under different modifications to the system (e.g., changes in climate, population or water use practices) and provide information on water shortages that may have developed.

The reservoir simulation subcomponent of WUAM, which is operated in conjunction with water uses, simulates regulation effects on water availability. While the reservoir routing model contained in WUAM does not mirror all of the operating procedures used at the system reservoirs, it was considered adequate for this study.

While WUAM utilizes a monthly time step and lacks some of the reservoir routing sophistication of the Reservoir Yield Model, it was felt that the model could be used to answer a wider range of "what if" questions concerning multi-sectoral water uses, social and economic effects, and the water balance of the basin under climate change. Nevertheless, it was necessary to adapt WUAM in ways not originally anticipated. For example, the existence of sewage lagoons for wastewater treatment with non-continuous discharge could not be modelled directly by WUAM. Alternative methods were required to adequately address this and other issues. As a result, many of the model's output tables and graphs, developed by the water balance component, were invalidated. Nevertheless, model outputs related to minimum flow target satisfaction were adequate to address the impact of climate change on streamflows.

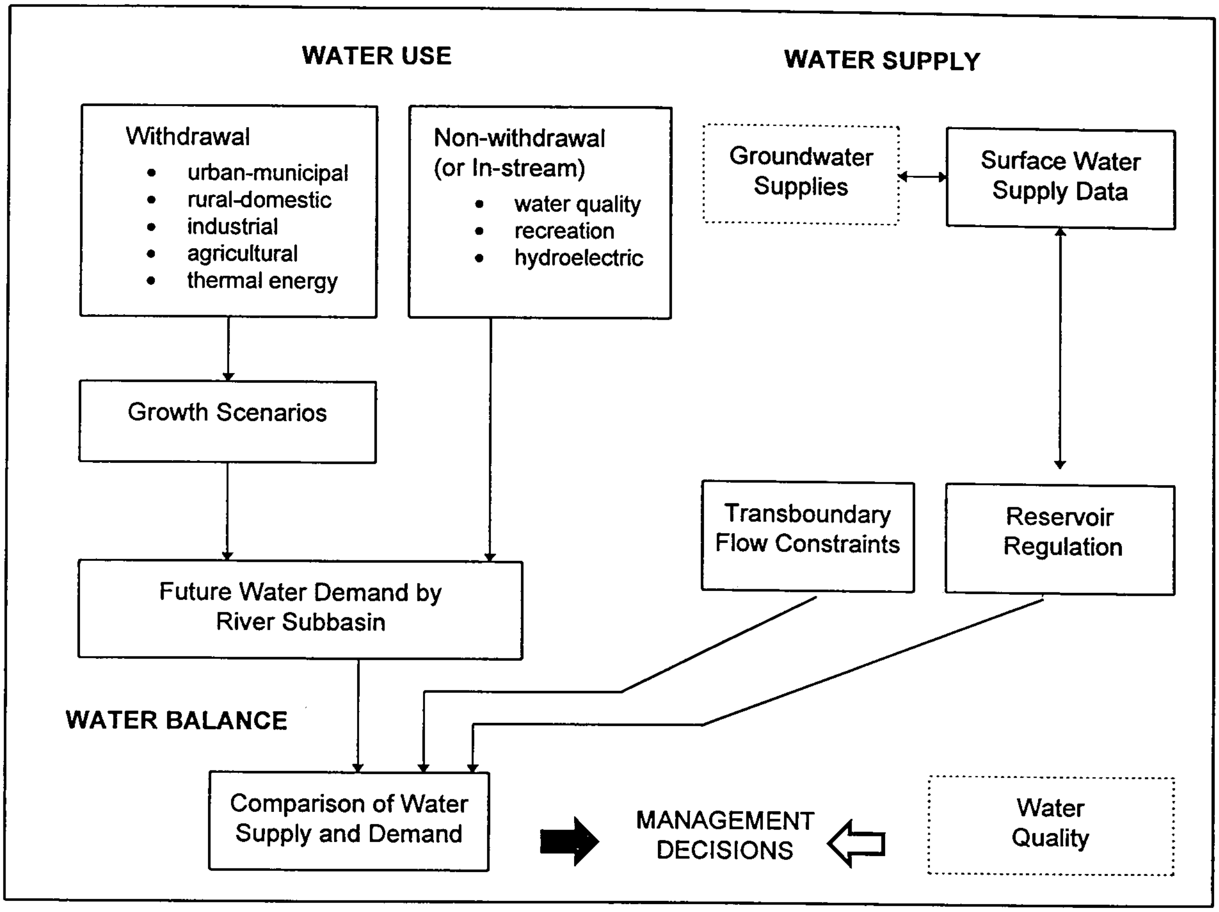


Figure 2.16 - Conceptual Overview of the Water Use Analysis Model (WUAM)

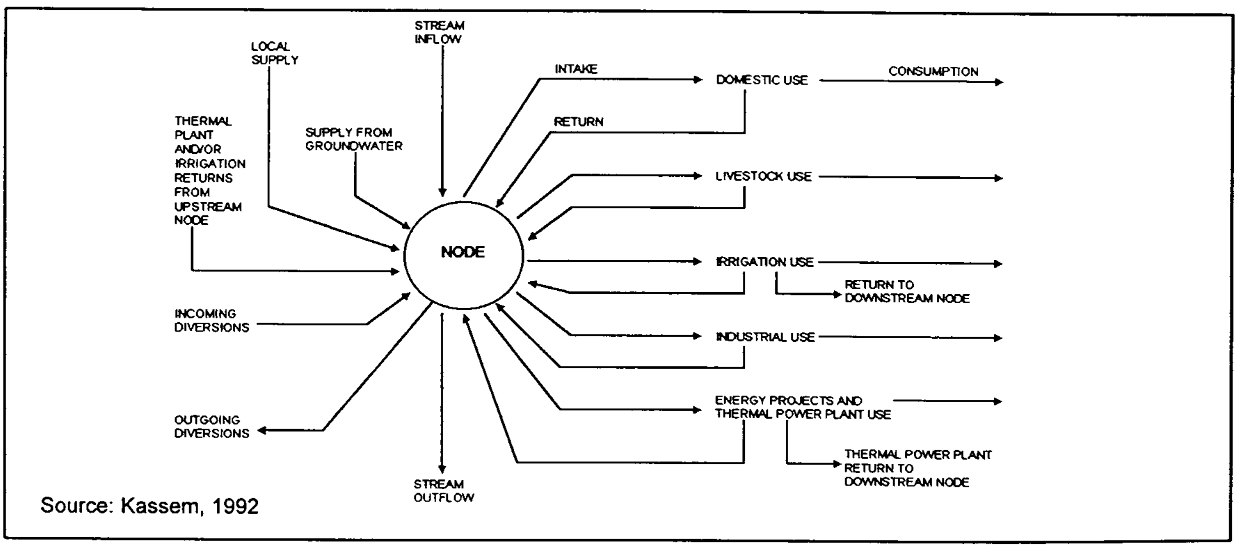


Figure 2.17 - Calculation Detail at Each Node

2.2.4 Model Set-up for the Grand River Basin

All WUAM applications have three main steps:

- dividing the basin into subbasins;
- creating the database for the model; and,
- developing and running scenarios.

These steps are described below as they apply to the study area.

2.2.4.1 Study Area and WUAM Network

The first step in applying WUAM is the division of the basin into subbasins through the selection of study points where water use projections and water balance results will be produced. Key points should be represented in the model; these may include flow gauge sites, subbasin boundaries, reservoirs (current or future) and locations where water diversions or significant water developments exist or are proposed. The information is translated into a network for input into WUAM.

The study area consists of the GRB above the Environment Canada streamflow gauge on the Grand River at Brantford. The lack of long-term flow data downstream of Brantford led to the decision to limit the WUAM application to this area. The streamflow gauges located at the outlets to the seven subwatersheds shown earlier in Figure 2.6 were each selected as study points. Additional study points were added at streamflow gauges located at West Montrose on the Grand River, at New Hamburg and near Canning on the Nith River and near Mount Vernon on Whitemans Creek bringing the total number of study subbasins to 11 (Subbasins A through K in Figure 2.18). The corresponding WUAM network of 15 nodes and their attendant links is presented in Figure 2.19. This configuration respects the drainage system of the Grand River and includes all main tributaries (above Brantford). The three existing major reservoirs (Belwood, Conestogo and Guelph), key low flow augmentation target sites (Doon, Hanlon and Brantford) and the potential reservoir site at West Montrose are modelled. The five primary urban serviced areas (Guelph, Kitchener, Waterloo, Cambridge and Brantford) are assigned to separate nodes. Multiple nodes were defined at the outlets of subbasins **D**, **F** and **K** to adequately model abstractions from or wastewater discharge to the river system above or below the target flow sites noted above.

2.2.4.2 Data Preparation

WUAM's application to the GRB required defining present and future water supply and water use conditions throughout the basin. Although reservoir regulation is generally considered under water supply (see Figure 2.16), given its role in managing GRB flows, current and potential reservoir configuration and operation conditions were defined separately under "system operation".

- Water Supply
  - surface water
  - groundwater
  - diversions

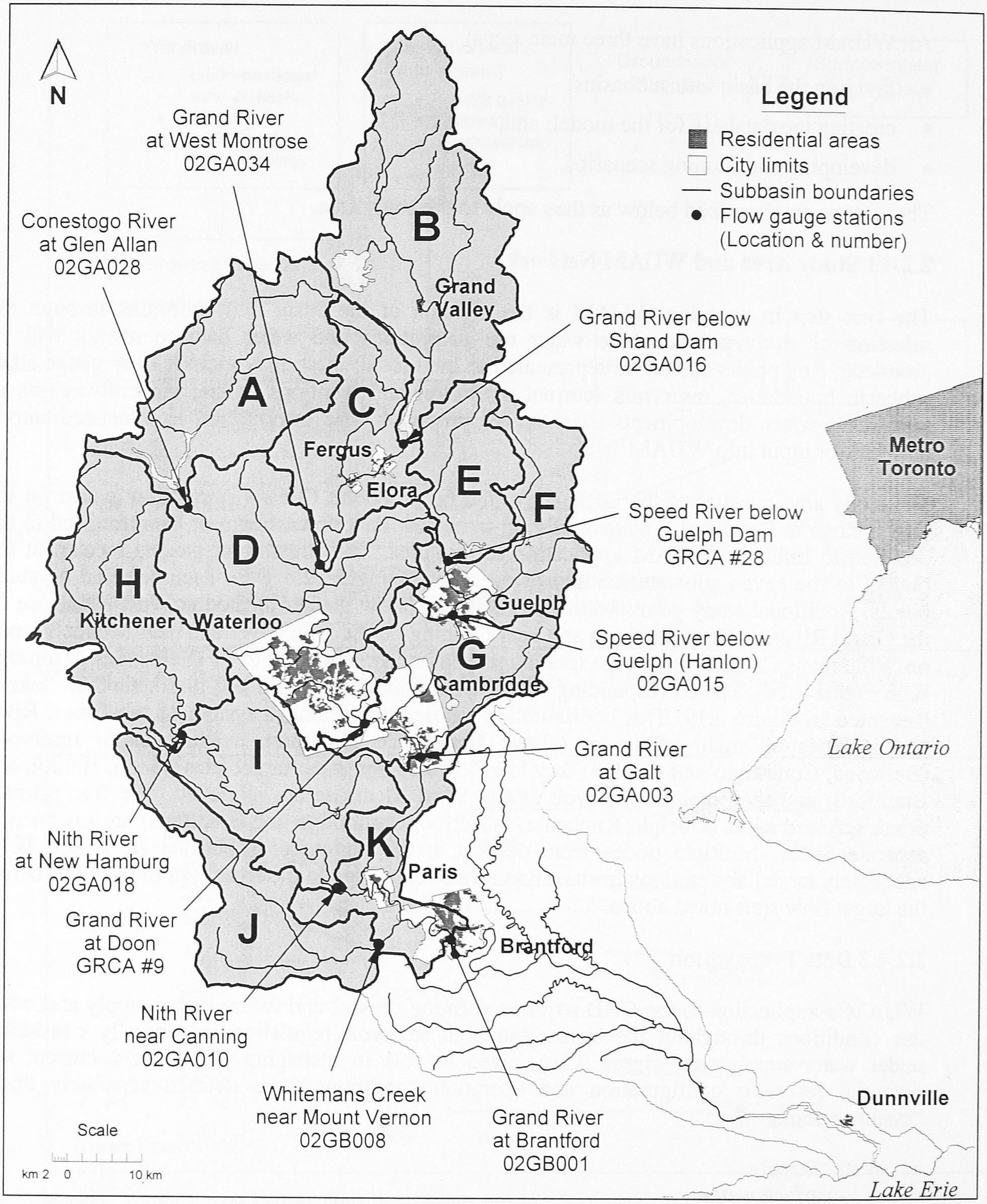


Figure 2.18 - Study Area Subbasins and Outlet Gauges

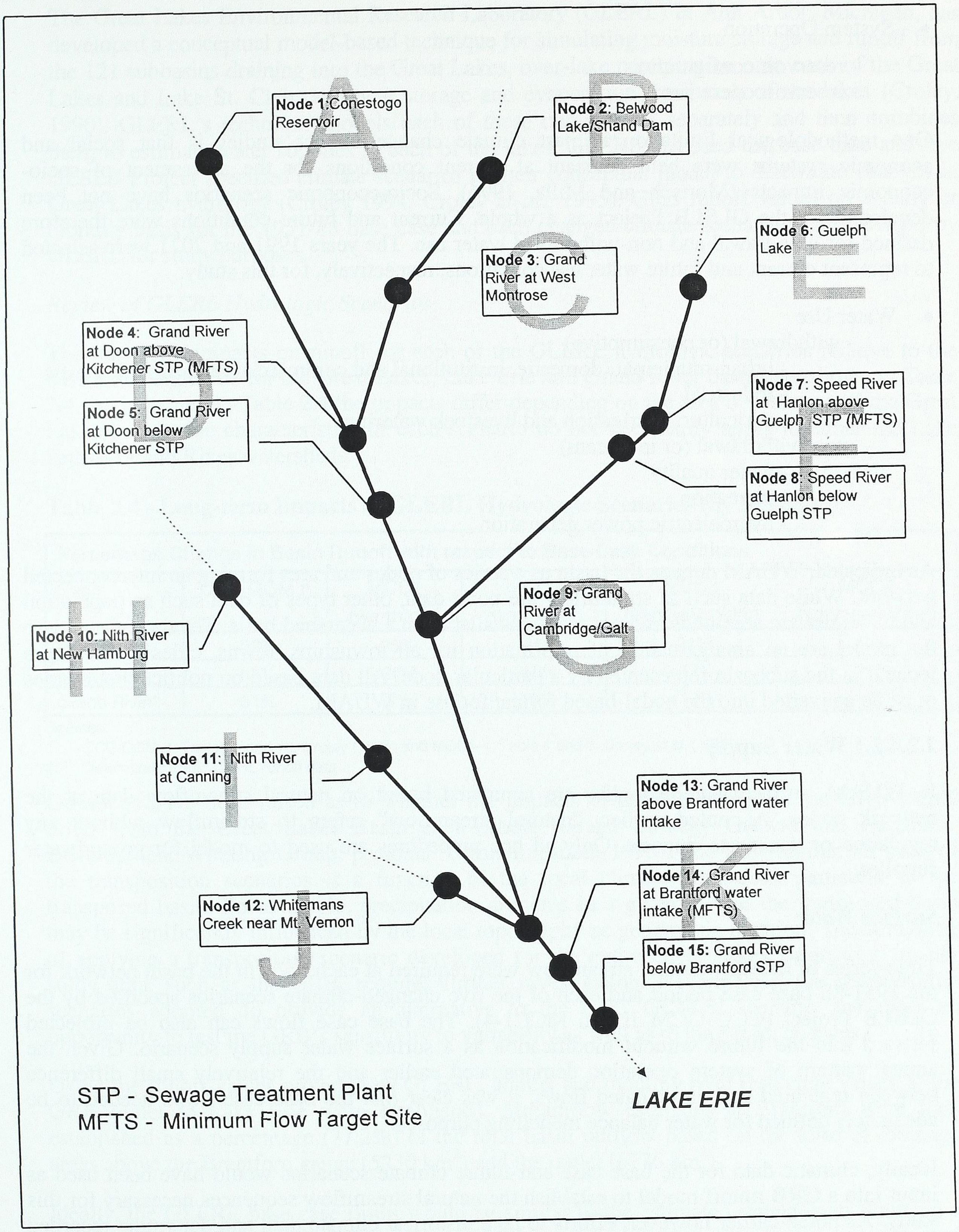


Figure 2.19 - WUAM Network

- System Operation
    - reservoir configuration
    - reservoir operation

One methodological limitation in past climate change impact studies is that social and economic systems were held constant at current conditions for the assessment of socio-economic impacts (Mortsch and Mills, 1996). Socio-economic scenarios have not been developed for the GLSLB Project as a whole. Current and future conditions were therefore defined for withdrawal and non-withdrawal water use. The years 1991 and 2021 were selected to represent current and future water use conditions, respectively, for this study.

- Water Use
    - withdrawal (or consumptive)
        - urban-municipal (domestic, institutional and commercial) and rural-domestic
        - industrial
        - agricultural (irrigation and livestock watering)
    - non-withdrawal (or in-stream)
        - water quality
        - recreation
        - hydroelectric power generation

As indicated, WUAM depicts the basin as a series of nodes and arcs forming an interconnected network. While data such as streamflow are point data, other types of data such as population and water use are area-wide and not readily available on a watershed basis. The data placed into the model are an amalgamation of information for all townships, towns, cities and villages located in the subbasin represented by a particular node. All data based on political boundaries must be converted into the nodal-based format for use in WUAM.

2.2.4.2.1 Water Supply

In WUAM, surface water supplies are simulated based on natural streamflow data at the network nodes. As noted earlier, "natural streamflow" refers to streamflow without any regulation or water use impacts. Only ad hoc procedures are used to model for groundwater supplies.

Surface Water

Time-series of monthly natural streamflow were required at each node in the basin network for the 1951-88 base case period and each of the five changed-climate scenarios specified by the GLSLB Project (CCC GCM II and MCC1-4). The base case flows can also be projected forward into the future without modification as a surface water supply scenario. Given the annual pattern of system operation demonstrated earlier and the relatively small difference between regulated and unregulated flows, it was clear that the base case flows needed to be adequately defined for water balance modelling purposes.

Ideally, climatic data for the base case and future climate scenarios would have been used as input into a GRB runoff model to establish the natural streamflow sequences necessary for this study. As noted earlier however, efforts to take historical climate data and determine recorded Grand River flows directly at selected sites have only had limited success. A hydrologic simulation model under development by the GRCA was not yet operational for continuous long-term simulation of flows using climatic input.

The Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan, has developed a conceptual model-based technique for simulating moisture storage and runoff from the 121 subbasins draining into the Great Lakes, over-lake precipitation onto each of the Great Lakes and Lake St. Clair, and heat storage and evaporation from each of the lakes (Croley, 1990). GLERL's technique models each of these components separately and then combines them to estimate water supplies to each of the lakes. GLERL has used the base case and five GLSLB Project specified climate scenarios in their conceptual model to determine changes in Great Lakes hydrology (Croley 1994; Croley *et al.*, 1995). GRB runoff values on a daily or monthly basis for the 1951-88 base case and each changed-climate scenario were provided by GLERL for study purposes.

Review of GLERL Hydrologic Scenarios

The long-term impacts on runoff for each of the GLERL hydrologic scenarios relative to the base case conditions for the Great Lakes, Lake Erie and Grand River basins are shown in Table 2.4. As indicated in Table 2.4 the impacts differ depending on the area of interest and the Great Lakes basin-wide characteristics of each scenario do not necessarily apply to either the Lake Erie or Grand River watersheds.

Table 2.4 - Long-term Impacts of GLERL Hydrologic Scenarios (by Region)

Percentage Change in Basin Runoff with respect to Base Case Conditions					
Basin	CCC GCM II	MCC1 (warm/dry)	MCC2 (warm/wet)	MCC3 (very warm/dry)	MCC4 (very warm/wet)
Great Lakes[1]	-32%	-25%	-1%	-21%	+2%
Lake Erie[1]	-54%	+26%	+48%	+17%	+36%
Grand River[2]	-51%	-3%	-19%	+13%	+14%

Sources:
1. CCC GCM II: Tables 9 and 10, Croley (1994) and MCC1-4: Table 1 and 3, Croley *et al.* (1995)
2. Determined from GLERL runoff data

Questions have been raised as to whether the impacts of climate change in the GRB would differ from the Great Lakes Basin as a whole (Grand Strategy Growth and Economic Development Working Group, personal communication, 1996). The flow regime for each of the transposition scenarios is a function of the local climate conditions particular to the transposed basin. For example, precipitation amounts in a given part of the transposed basin may be significantly influenced by the local topography or geographic location. The suitability of applying a transposition scenario developed for the entire Great Lakes Basin to a smaller study area, such as the GRB, requires further investigation. Nevertheless, the transposition scenarios adopted do provide an alternative to the CCC GCM II scenario and offer an opportunity to test the GRB's sensitivity to variability as well as to long-term changes.

Using the runoff values provided by GLERL, annual and monthly river discharge values at the GRB outlet to Lake Erie were established. Streamflow estimates at Brantford were then established as a percentage (77.2%) of the total basin outflow based on the ratio of drainage areas above the Brantford gauge (5230 km^2) and the outlet (6776 km^2).

Ideally, the GLERL base case flows would be similar to the estimated unregulated flows on a monthly basis. However, given that the GLERL model basin runoff values were calibrated using recorded data for each Great Lake subbasin, it was expected that they would more closely resemble the recorded flows. On an annual basis, the GLERL base case flows match the recorded (and estimated unregulated) flows at Brantford reasonably well, although some significant differences exist (Figure 2.20) As indicated by Figures 2.21 and 2.22, however, the GLERL base case flows do not compare well with either the unregulated or regulated streamflow sets on a monthly basis. Given the known pattern of system operation, routing the monthly GLERL base case flows using WUAM would not produce meaningful results.

The basin-wide runoff figures generated by GLERL were, however, the only flow scenarios readily available for the five changed-climate scenarios specified for the GLSLB Project. Therefore, in lieu of an adequate Grand River hydrology model and recognizing the need to adequately define base case flows for water balance and discussion purposes, the study team opted to select the estimated unregulated flows as the base case flows and develop changed-climate scenario flows based on the differences between the GLERL model base case and changed-climate scenario flows. As such, all streamflow scenarios used, base case and changed-climate, reflect historical water use impacts to some degree.

Incorporation of GLERL Changed-Climate Scenario Characteristics

Since the GLERL base case flows did not conform to the WUAM base case flows, the GLERL future flow scenarios could not be used directly for comparison purposes. Meaningful representation of the GLERL future scenarios, consistent with the WUAM base case, were required. Climate impact researchers have formulated alternative methods to create climate change scenarios (Carter *et al.*, 1992; Cohen, 1993) which have been adopted for the GLSLB Project. In deriving the CCC GCM II climate change scenario for annual average temperature, the difference between model's the $1xCO_2$ and $2xCO_2$ output values were added to the base case. In the case of total precipitation, the ratio between $2xCO_2$ and $1xCO_2$ values were applied to the base case to produce the final scenario. The first attempt to develop WUAM future scenario streamflows used a "difference" method:

$$Q_{WUAM\ Scenario} = Q_{WUAM\ Base\ Case} + (Q_{GLERL\ Scenario} - Q_{GLERL\ Base\ Case}) \quad (1)$$

Where Q represents the specified scenario monthly streamflow at Brantford.

A comparison between the GLERL base case and CCC GCM II scenario (Figure 2.23) suggests flows will decrease significantly and there will be an earlier spring freshet. Since the GLERL base case flows generally resembled recorded flows and have higher summertime flows, the "difference" method produced negative flows for the WUAM CCC GCM II scenario and was therefore rejected. Secondly, a "ratio" method was applied:

$$Q_{WUAM\ Scenario} = Q_{WUAM\ Base\ Case} * (Q_{GLERL\ Scenario} / Q_{GLERL\ Base\ Case}) \quad (2)$$

This approach appeared to produce an adjusted CCC GCM II scenario consistent with the WUAM base case while maintaining the impact characteristics of the GLERL CCC GCM II scenario.

The ratio method was also applied to each of the four MCC transposition scenarios. The adjustment method used was reviewed and found acceptable by GLERL staff (T. Croley, GLERL, written communication, 1995). While the manipulation maintained the overall impact between the base case and the changed-climate scenarios (Table 2.5), the WUAM scenario year-by-year and month-by-month flows can differ significantly from those originally provided.

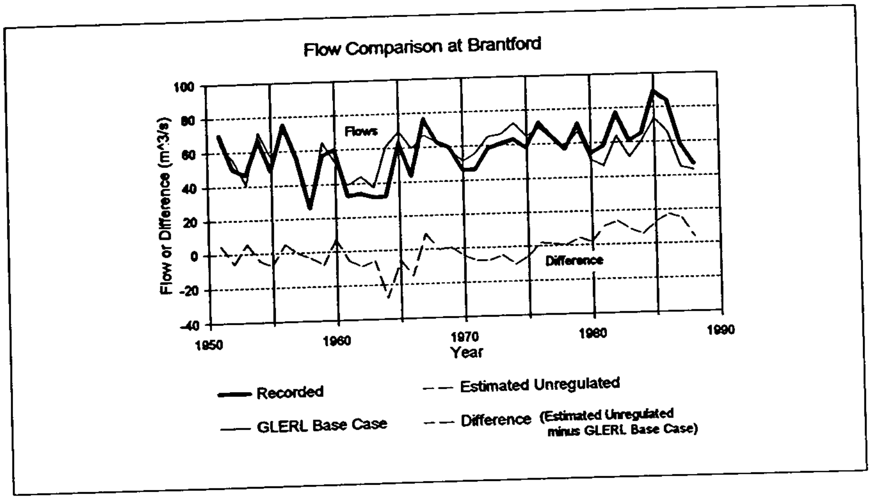


Figure 2.20 - Comparison Between Annual Average Flows at Brantford

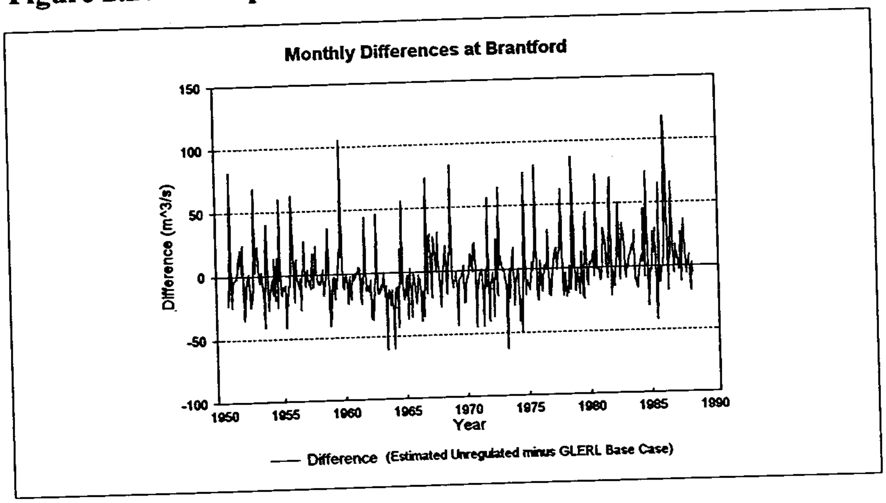


Figure 2.21 - Monthly Flow Differences at Brantford: Estimated Unregulated minus GLERL Base Case

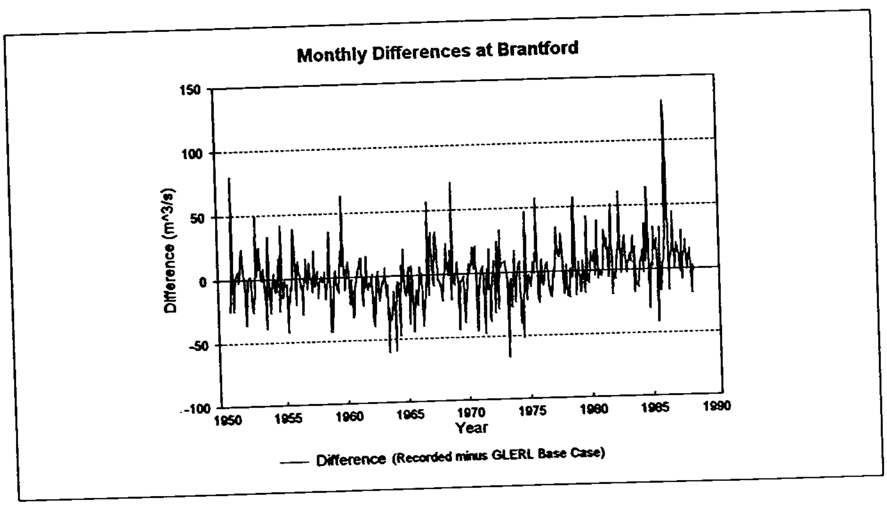


Figure 2.22 - Monthly Flow Differences at Brantford: Recorded minus GLERL Base Case

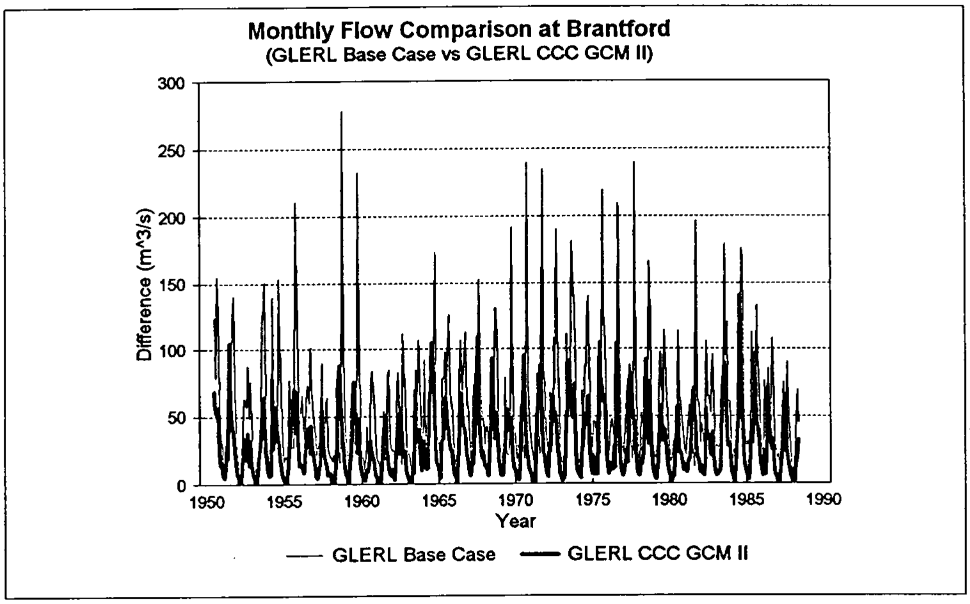


Figure 2.23 - Comparison Between GLERL Base Case and GLERL CCC GCM II Scenario: Flows at Brantford

Table 2.5 - Comparison Between Original and Modified Hydrologic Scenarios

Percentage Change in Basin Runoff with respect to Appropriate Base Case Scenario					
Scenario	CCC GCM II	MCC1 (warm/dry)	MCC2 (warm/wet)	MCC3 (very warm/dry)	MCC4 (very warm/wet)
Original (GLERL)	-51%	-3%	-19%	+13%	+14%
Modified (WUAM)	-51%	-2%	-19%	+13%	+14%

Changed-climate scenario streamflows were also required at the outlets of each of the remaining 10 subbasins in the study area. As a first step it was necessary to complete the unregulated streamflow database by establishing flows for the four study sites added to complete the WUAM network. Unregulated streamflows at West Montrose were established by either adding local flows between West Montrose and the Shand dam to the Shand dam unregulated flows or using linear regression between flows at adjacent gauges. Recorded flows for the Nith River and Whitemans Creek were used unmodified since neither tributary is regulated. The Whitemans Creek streamflow data was extended to match the 1951-88 study period using linear regression.

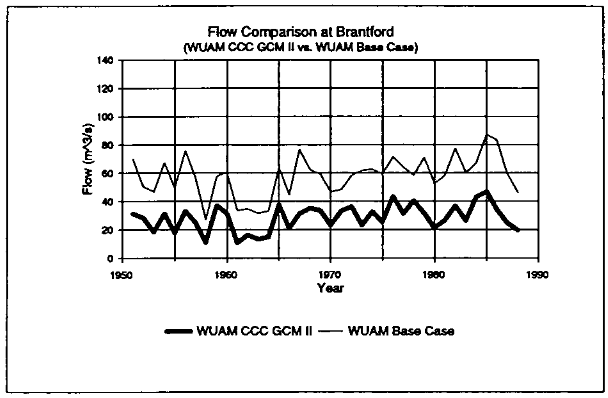
The month-by-month adjustment ratios established for the entire basin were then assumed and Equation (2) applied to determine changed-climate scenario streamflows at the outlet nodes of each subbasin. Recall that multiple nodes are defined at the outlets of subbasins **D**, **F** and **G**. Table 2.6 summarizes the impact of each scenario on streamflow by node site. Since seasonal streamflow characteristics differ from node to node, this method causes a different long-term impact at each node. Flows throughout the system differ significantly from those at Brantford (Nodes 13, 14 and 15) which was assumed to have the same reduction as the at the basin outlet. With only one exception, the resulting scenario streamflows at the existing reservoir sites (Nodes 1, 2 and 6) and at the potential reservoir site at West Montrose (Node 3) decrease more or increase less (depending on the direction of long-term change) than at Brantford.

Table 2.6 - Long-term Impacts of Modified Hydrologic Scenarios on Streamflow (by Node)

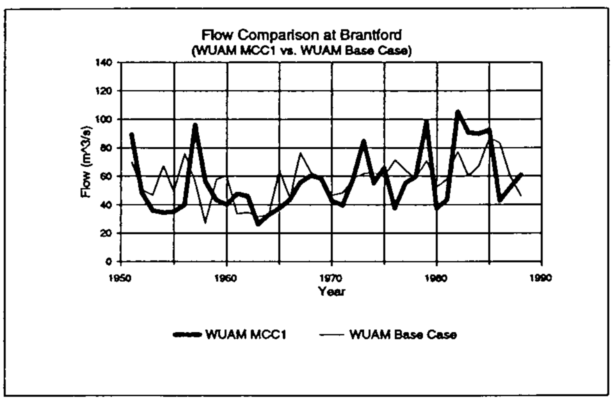
Percentage Change in Unregulated Streamflow with respect to Base Case Scenario					
Node (Subbasin)[1.]	CCC GCM II	MCC1 (warm/dry)	MCC2 (warm/wet)	MCC3 (very warm/dry)	MCC4 (very warm/wet)
1 (A)	-55%	-9%	-27%	0%	+3%
2 (B)	-56%	-11%	-28%	-1%	+2%
3 (C)	-56%	-9%	-27%	+1%	+4%
4 & 5 (D)	-53%	-6%	-23%	+6%	+8%
6 (E)	-51%	-4%	-20%	+12%	+13%
7 & 8 (F)	-51%	-3%	-18%	+14%	+14%
9 (G)	-53%	-5%	-22%	+8%	+10%
10 (H)	-52%	-5%	-25%	+8%	+8%
11 (I)	-49%	0%	-18%	+17%	+17%
12 (J)	-47%	+3%	-14%	+21%	+22%
13, 14 & 15 (K)	-51%	-2%	-18%	+13%	+14%

Note:
1. See Figures 2.18 and 2.19 for node locations

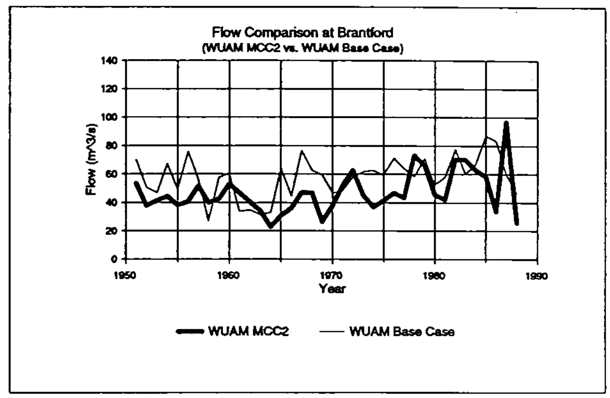
Streamflows for the adjusted WUAM CCC GCM II and MCC1-4 transposition scenarios are compared with the WUAM base case data at Brantford, on an annual and monthly average basis, in Figures 2.24 and 2.25. These plots indicate that the long-term change values in Table 2.6 for Brantford (Nodes 13, 14 and 15) do not adequately describe the impacts on river flows that occur on either an annual or monthly basis at that site. For example, the -2% change in long-term supplies for the MCC1 scenario results from a combination of flows which are higher and lower than those of the base case. Although the MCC3 and MCC4 have similar long-term changes, +13% and +14% respectively, they have significantly different annual and monthly flow sequences.



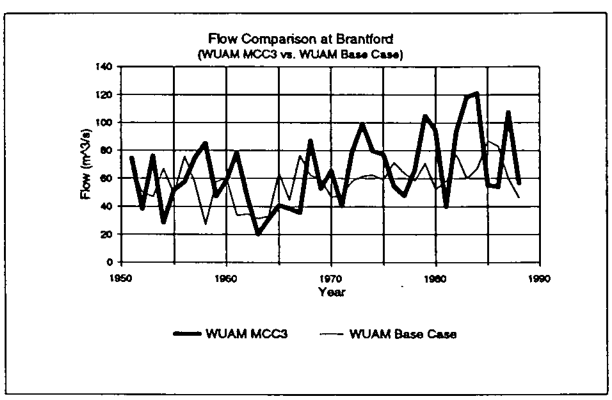
(a) CCC GCM II vs. Base Case



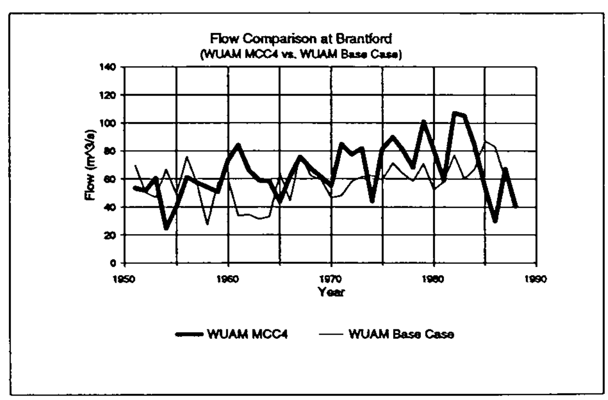
(b) MCC1 vs. Base Case



(c) MCC2 vs. Base Case

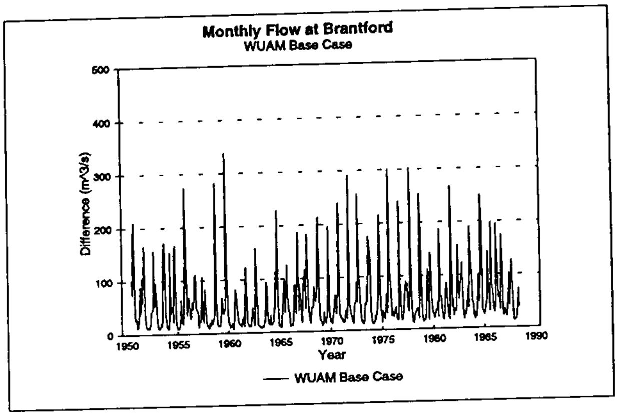


(d) MCC3 vs. Base Case

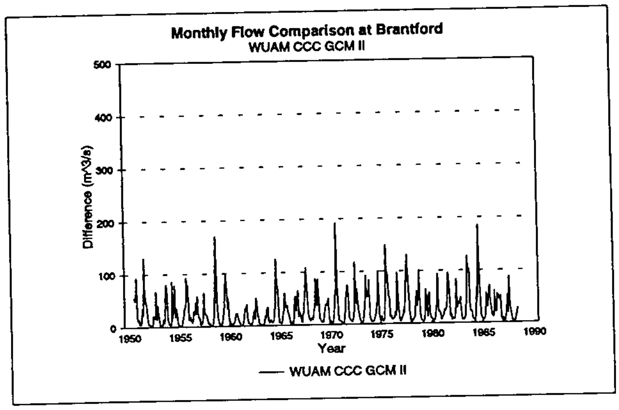


(e) MCC4 vs. Base case

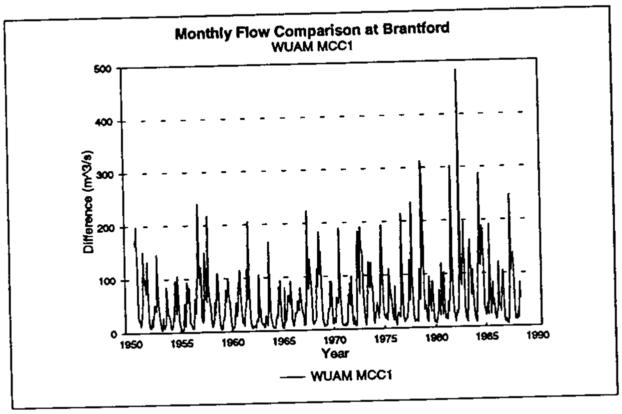
Figure 2.24 - Annual Flow Comparison at Brantford:
WUAM Changed-Climate Sceanrios vs. WUAM Base Case



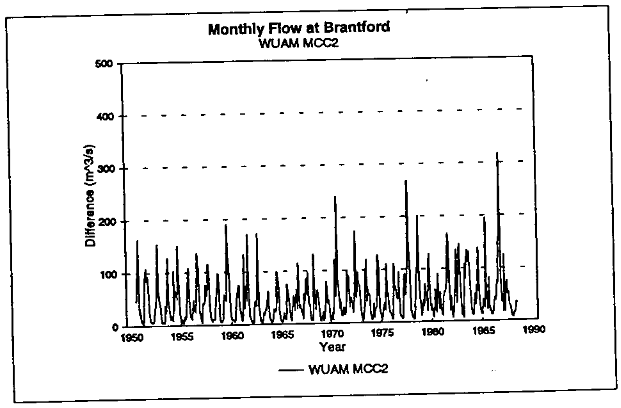
(a) Base Case



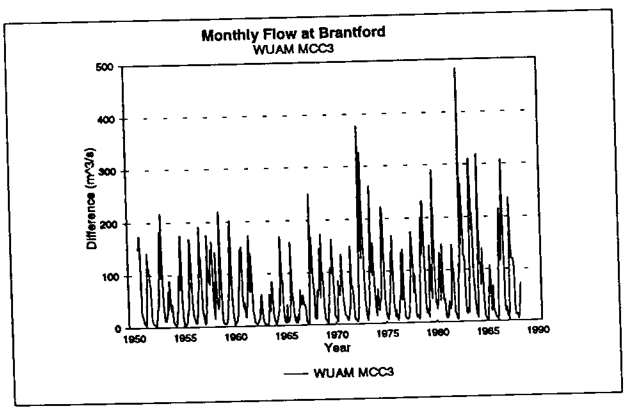
(b) CCC GCM II



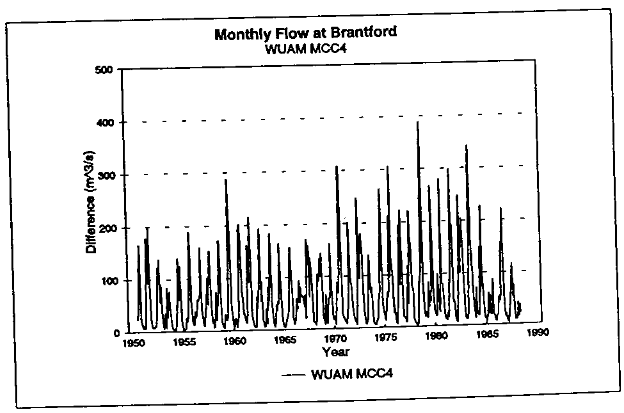
(c) MCC1



(d) MCC2



(e) MCC3



(f) MCC4

Figure 2.25 - Monthly Flow Comparison at Brantford: WUAM Changed-Climate Sceanrios vs. WUAM Base Case

While the annual plots might indicate an increase or decrease in flow for one or more years, the monthly plots suggest other climate change impacts including a change in the seasonal distribution of water supply, lower average summer supplies and some years with little or no water to fill the reservoirs. A plot of the seasonal distribution of flow for the scenarios at Brantford (Figure 2.26) also indicates that, on average, all changed-climate scenarios produce a shift in the spring freshet and lower summertime supplies. Clearly, the temporal averaging scale selected can have an important effect on the detail or level of information provided. Again, overall (long-term average) percentage change values do not adequately describe the impact of a changed-climate scenario on streamflow.

The scenario flow sequences shown in the figures represent uncontrolled runoff from the basin; however, regulation goals and capabilities would affect the actual streamflows experienced. Assessment of the potential impact of the changed-climate surface water scenarios requires routing their unregulated flow sequence assuming current or modified system operations using WUAM.

The CCC GCM II and MCC1-4 surface water supply scenarios represent non-linear month-by-month changes with respect to historic supplies. Two additional "Arbitrary" linear-change supply scenarios (based on 20% and 50% linear reductions in base case streamflows at each node) were generated to complement the GLSLB Project specified scenarios and help assess system response. The Base Case - 20% (linear) scenario is comparable to the maximum reduction applied in the Paragon Engineering Limited (1994) study.

Table 2.7 provides a summary of scenario impacts including the standard deviation in annual flows at Galt. The mean, maximum, minimum, range, and standard deviation in streamflows at Galt, on a monthly and annual basis, for all scenarios used in the study plus the 1914-41 natural flow condition period are provided in Appendix B. The MCC2 (-19%) and Base Case - 20% (linear) supply scenarios have long-term average flows at Galt similar to the 1914-41 period, approximately 20% less than the 1951-88 base case period; however, their seasonal flow distributions differ significantly.

Table 2.7 - Surface Water Supply Scenario Summary

Scenario Name	Percentage Change Relative to Base Case (1951-88 unregulated flows)			Standard Deviations in Annual Flows at Galt (in m^3/s)
	Basin-wide[1.]	Range for all Subbasin outlet points	At Galt	
Base Case	0%	0%	0%	9.6
GLSLB Project Specified				
CCC GCM II	-51%	-56% to -47%	-53%	5.6
Transposition MCC1	-2%	-11% to +3%	-5%	14.0
Transposition MCC2	-19%	-28% to -14%	-22%	8.7
Transposition MCC3	+13%	-1% to +21%	+8%	15.5
Transposition MCC4	+14%	+2% to +22%	+10%	11.8
Arbitrary				
Base Case - 20% (linear)	-20%	-20%	-20%	7.7
Base Case - 50% (linear)	-50%	-50%	-50%	4.8

Note:
1. Basin-wide percentage change value also used as a reference to identify a scenario throughout this document.

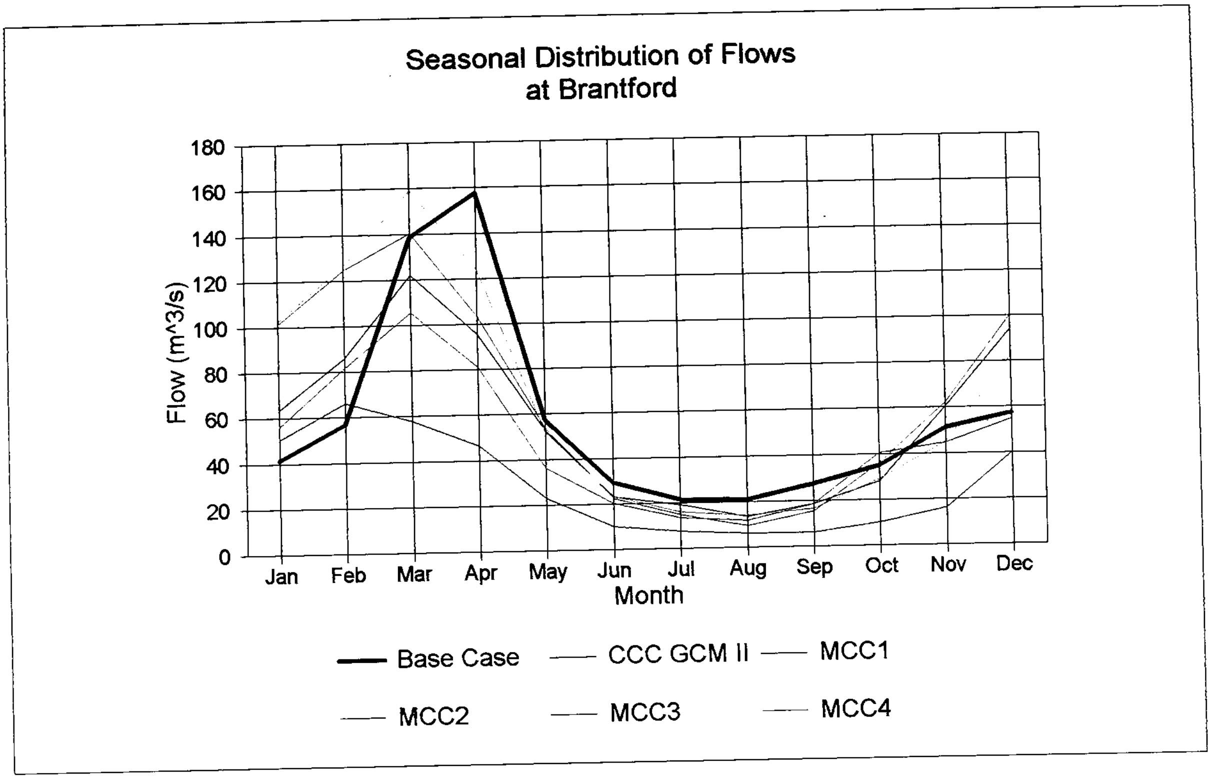


Figure 2.26 - Seasonal Distribution of Flow at Brantford: WUAM Changed-Climate Scenarios vs. WUAM Base Case

Groundwater

Most of the GRB's population is serviced by groundwater. Traditionally, groundwater was the sole source of water for the City of Guelph and the Tri-Cities of Kitchener, Waterloo and Cambridge in the Regional Municipality of Waterloo. With increasing concerns related to the ability of groundwater supplies to meet demand, the City of Guelph and the Regional Municipality of Waterloo are relying more heavily on water supplies taken from the Grand River system.

In addition to being a source of potable water, groundwater is an essential component of the hydrologic cycle which provides base flow--the major fraction of surface water flow in dry weather. Climate change may significantly affect groundwater supplies in the GRB (McLaren and Sudicky, 1993). Efforts to better understand the current and future status of groundwater resources in the basin have been initiated as part of *The Grand Strategy* and through the groundwater component of the GRB Study.

WUAM requires base-year data on the proportion of the total water use at each node which is supplied from groundwater sources. The model applies the same proportions for future years, provided that the total groundwater withdrawal does not exceed a user-defined maximum (if specified). Additional or alternate supplies may be required in the future and climate change may negatively impact groundwater supplies and base flows throughout the basin. However, given the lack of specific information on groundwater limits and the range in and uncertainty related to the future surface water scenarios adopted, groundwater supplies were assumed available for the future water requirements for modelling purposes.

Diversions

A diversion option is available in WUAM to simulate the transfer of water into or out of the study area or between study network nodes. While no diversions have been defined at this point, additional water supplies, such as a Great Lakes pipeline, designed to supply municipal water or augment river flow (Associated Engineering Limited, 1994; Paragon Engineering Limited, 1994) can be simulated using the diversion option.

2.2.4.2.2 System Operation

As noted, reservoir operation plays a major role in the management of streamflows in the GRB. The Shand (1942), Luther (1952), Conestogo (1958) and Guelph (1976) dams are operated by the GRCA to reduce peak flows, particularly during the spring freshet. During the summer, water stored in the reservoirs behind the dams is released to augment low flows and maintain adequate water quality.

Reservoir Configuration and Operation

The three major reservoirs currently in the system (Belwood, Conestogo and Guelph) and a potential reservoir at West Montrose, studied in other contexts (GRIC, 1982; Paragon Engineering Limited, 1994) were modelled. The Luther reservoir was not modelled due to the WUAM limits on reservoir definition. The West Montrose reservoir was included to assess its capabilities to deal with altered supply conditions and to gauge system response. The inclusion of the West Montrose reservoir here does not imply that it should be constructed.

Daily operating rules for the four reservoirs selected were converted to a monthly format for WUAM. The operating rules were set without regard to power generation requirements at the reservoirs. Data sets were also developed at each reservoir node without reservoir operating information to permit the simulation of "state-of-nature" system operation, which routes surface water supplies through the system unmodified (i.e., reservoir outflow equals inflow).

WUAM requires user-specified monthly reservoir target releases. Target releases are important for the successful use of the WUAM reservoir model since they are essentially the driving force for reservoir operation. During dry years, these targets will be too large and the reservoir will fall toward the minimum desirable reservoir level. During wet years, the opposite will happen, with the reservoir levels moving toward the maximum desirable level. Target releases were initially set equal to the actual 1983-92 average monthly releases which were considered representative of current operations. Due to the monthly time step of the model and the relatively small size of the reservoirs, it was necessary to lower the monthly targets to help fill the reservoirs by the end of the spring freshet each year. Maximum and minimum reservoir outflows were set equal to the daily or instantaneous (channel capacity) values used by the GRCA. Target flows and maximum and minimum releases for the West Montrose dam were established by increasing the Shand dam values by 50%, approximating the increase in drainage area from the Shand dam to West Montrose reservoir site.

Past studies have been criticized for not incorporating some degree of adaptive response in assessing the potential impacts of climate change (Smit, 1993). It is unlikely that local water managers and others engaged in climate-sensitive activities would fail to adjust their operations in an effort to accommodate the changing supply conditions identified earlier. Historically, many adjustments can be at least partially attributed to observed climate and supply changes including the development of system reservoirs; reforestation activities; and, improvements to urban storm water management. Accordingly, the ability to modify reservoir management operations was assumed for this exercise since the reservoirs are currently used to deal with drought or flood conditions. For the changed-climate supply scenarios, current operating rule curves and target outflows for each reservoir were modified to reflect the general change in the seasonal distribution of supplies suggested in Figure 2.26. This modification was necessary to help the reservoirs fill during the earlier spring freshet and is consistent with GRCA operating procedures. Figure 2.27 provides the current and changed-climate rule curves for the Conestogo reservoir as an example. The modification adopted does not include significant changes in operating procedures such as year-to-year storage. Given the variability demonstrated by the scenarios, this assumption will limit the system's ability to cope.

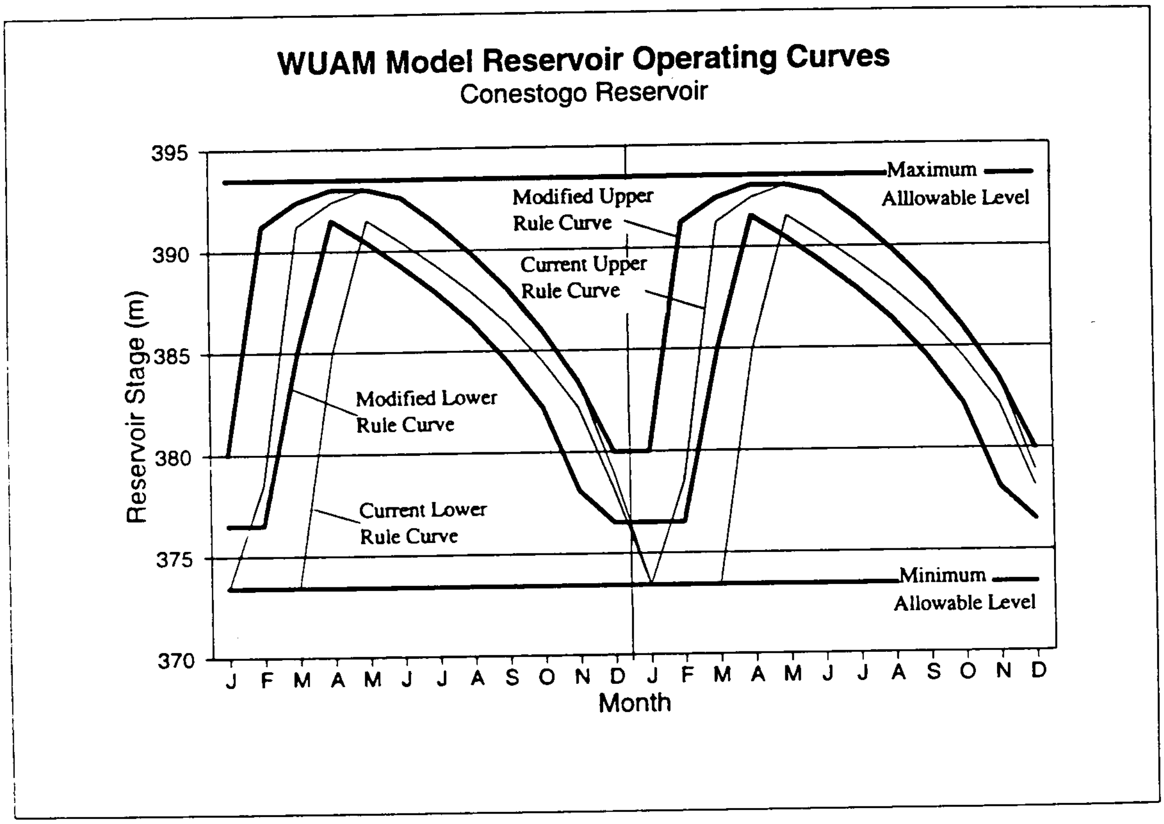


Figure 2.27 - Reservoir Rule Curve Modification

2.2.4.2.3 Water Use

Withdrawal Water Use

Urban-Municipal, Rural-Domestic and Industrial Water Use

Urban-municipal (domestic, commercial and institutional) and rural-domestic water intake are simulated by WUAM using current and forecasted nodal population figures and water intake coefficients (Kassem, 1992). Industrial demand may be included in the calculation of urban-municipal water use, or it can be simulated within the industrial water use component of WUAM as a function of the current and forecasted activity level of industry in the study area.

As demand increases with time, supplies from surface water and groundwater sources are allocated in proportion to the current (1991) breakdown. Based on the monthly water intake and the specified consumption factors, return flow (or wastewater volume) is determined and discharged to the river at each node.

Initial efforts to define the GRB's urban-municipal and industrial water use followed WUAM's standard input and calculation procedures. This approach was subsequently modified due to:

- limitations in available water use and forecast data;
- orders of magnitude differences in water use both within and between sectors throughout the basin;
- the existence of sewage treatment lagoons in the upper portion of the basin with seasonal or proportional discharge; and,
- the existence of fixed limits on river abstractions by the Regional Municipality of Waterloo and the City of Guelph.

Alternate approaches were taken in the study to adequately model current and future municipal water intake (or demand), supply sources and return flow.

Water Intake (or Demand)

Urban-municipal and industrial water intake was incorporated into WUAM using two different methods dependent on the characteristics of the subbasin. For the large urban centres of the Tri-Cities, Guelph and Brantford, it was possible to determine the intake for urban-domestic and the industrial, commercial and institutional (ICI) sectors separately. For the urban-domestic component, water intake was calculated in standard fashion, based on current and forecasted population and water intake coefficients. WUAM's industrial subcomponent was adapted to model the ICI components. Instead of estimating water intake by individual industrial sectors, three sectors representing each of the ICI components were defined. ICI land use projections (Table 2.8) specified for the Tri-Cities (Associated Engineering Limited, 1994) were adopted to estimate future ICI demand for the Tri-Cities. The Tri-City growth rates were also applied to the Cities of Guelph and Brantford.

Sufficient data were not available to separate urban-domestic and ICI components of intake for smaller urban centres in the basin. Instead, the ICI component of urban-municipal water demand was "loaded" on the domestic (or residential) population and the ICI component of demand was assumed to grow with population. This assumption was based on the premise that since much of the ICI development occurs to service the residential population, there is an inherent link between population and ICI growth. It is recognized that this assumption has limitations, particularly when considering a one- or two-industry town.

Rural-domestic water intake was determined based on current and forecasted nodal population figures and estimated rural water intake coefficients.

Table 2.8 - Tri-City 1991[1.] and 1996-2021[2.] Projected Land Use (in Acres)

LAND USE		1991	1996	2001	2006	2011	2016	2021	Percentage Change (1991 - 2021)
Industrial	Kitchener	2,726	2,547	2,586	2,731	2,873	2,974	3,027	+11%
	Waterloo	1,171	1,094	1,111	1,173	1,234	1,278	1,301	+11%
	Cambridge	2,529	2,363	2,399	2,533	2,665	2,758	2,808	+11%
	Tri-City Total	6,426	6,004	6,096	6,437	6,772	7,010	7,136	+11%
Commercial	Kitchener	942	1,327	1,466	1,613	1,749	1,873	1,972	+109%
	Waterloo	343	483	533	587	636	681	717	+109%
	Cambridge	469	661	730	803	871	933	982	+109%
	Tri-City Total	1,754	2,471	2,729	3,003	3,256	3,487	3,671	+109%
Institutional	Kitchener	791	976	1,022	1,049	1,061	1,082	1,109	+40%
	Waterloo	875	1,079	1,130	1,159	1,173	1,196	1,226	+40%
	Cambridge	477	589	616	632	640	652	669	+40%
	Tri-City Total	2,143	2,644	2,768	2,840	2,874	2,930	3,004	+40%

Source:
1. 1991 data from Table 2-6: Tri-City Land Use (1991), Associated Engineering Limited (1994).
2. 1996-2021 data from Table 2-8: 'Base' Tri-City Sub-Aggregate Land Use Projections, Associated Engineering Limited (1994).

Population Estimates

The single largest determinant of municipal water use is population (Robinson and Creese, 1993). "Urban" (serviced by municipal water supply and wastewater treatment systems) and "rural" (not serviced by municipal water supply or wastewater systems) population, by subbasin, for the 1991 base year and the 2021 future forecast year were determined for water intake calculation purposes.

The 1991 Census (Statistics Canada, 1993) provided population figures for lower-tier municipalities (incorporated townships, cities, towns and villages) in the GRB. Population projections up to the year 2021 for upper-tier municipalities (counties, districts and regional municipalities) in the GRB were obtained from the Ontario Ministry of Finance (OMOF, 1994). Table 2.9 provides the population forecast figures utilized.

To account for 1991 Census undercount and to permit the use of the OMOF population projections for future water use calculations, the 1991 Census lower-tier population figures were adjusted to reflect differences between the 1991 Census and 1991 OMOF upper-tier population figures. Since many of the GRB rural townships contain unincorporated urban communities (e.g., Elmira, St. Jacobs, New Hamburg), the populations of these lower-tier municipalities were divided into estimated urban and rural components to facilitate estimating subbasin populations for water use calculation purposes. The entire population of all urban communities was assumed serviced.

Population projections for the GRB were developed using a proportional allocation or constant share/ratio model. The constant share model assumes a lower-tier (or local) population will retain its last observed share of the upper-tier (or parent) population by a projection of the parent population. Limitations on growth, such as water supply or wastewater treatment plant capacity, in specific communities were not considered in this analysis but could be accounted for in future studies.

Table 2.9 - Preliminary[1.] OMOF Population Projections (in Thousands)

County/District or Regional Municipality	Current		OMOF Projections		
	1991[2.]	1991[3.]	2001	2011	2021
Brant	111	114	128	145	159
Dufferin	40	41	50	61	70
Grey	84	86	97	102	108
Oxford	93	95	103	110	121
Perth	70	71	77	87	91
Waterloo	378	393	485	554	609
Wellington	160	165	191	218	247
Halton	313	324	427	539	655

Notes:
1. Final Ministry of Finance projections and Statistics Canada's estimates of net undercount at the census division level were not available at the time of this work (Source: OMOF, 1994).
2 Census count rounded to the nearest 1000 (Source: Statistics Canada Catalogue No. 93-309).
3 Census counts plus OMOF estimate of net undercount.

Population by Subbasin

Municipal and watershed boundaries in the GRB do not coincide, therefore, it was necessary to assign the urban (serviced) and rural (unserviced) population figures to their appropriate subbasin. While some sharing of water supply and wastewater treatment plants occurs, particularly within the Tri-Cities, the population of all major urban areas (Kitchener-Waterloo, Cambridge, Guelph and Brantford) were assigned to a single subbasin. The estimated urban population components of rural townships were assigned to the appropriate subbasin or dropped from the calculation if the township's urban centres were situated outside of the study area. The remaining rural component of each rural township was distributed based on the percentage of the township's area within each subbasin. The populations of the smaller serviced communities (such as Grand Valley) identified in the 1991 Census were also assigned to the appropriate subbasin.

Table 2.10 provides the total population, by subbasin, in ten-year increments from 1991 to 2021. The estimated 2021 study area population represents a 51% increase over the 1991 population total, consistent with the increase estimated as part of *The Grand Strategy*, for the entire GRB (GRCA, 1997). Table 2.10 also identifies the subbasin growth rates for the period 1991-2021. Estimated growth differs significantly from subbasin to subbasin, reflecting the trends in the OMOF projections. Significant growth is projected for the subbasins containing the Tri-Cities and Guelph.

The estimated 1991 and 2021 urban and rural populations, by subbasin and node, are provided in Table 2.11. The projections were based on the 1991-2021 subbasin growth rates from Table 2.10. In most cases, the entire subbasin population was assigned to the outlet node directly. However, multiple nodes were defined at the outlets of Subbasins **D**, **F** and **K** to facilitate modelling target flow sites at Doon, Hanlon and Brantford, respectively. The urban and rural populations of these subbasins were allocated to nodes to replicate water intake and wastewater production characteristics. For example, for the 278,114 people residing in Subbasin **D**, the entire rural population (16,106) was assigned to Node 4, while the total urban population (262,008) was divided between Nodes 4 and 5. Node 4, representing the City of Waterloo and the urban component of Woolwich Township contains 90,578 people, while the remaining 171,430 people, representing Kitchener, were assigned to Node 5.

Table 2.10 - Estimated 1991 and Projected 2001-21 Total Population (by Subbasin)

Subbasin (Node #)	1991	2001	2011	2021	Percentage Increase (1991 to 2021)
A (1)	9,632	11,147	12,722	14,411	49.6%
B (2)	10,950	13,126	15,571	17,648	61.2%
C (3)	19,099	22,147	25,288	28,635	49.9%
D (4 & 5)	278,114	342,890	391,668	430,744	54.9%
E (6)	5,626	6,544	7,519	8,531	51.6%
F (7 & 8)	102,884	119,364	136,503	154,889	50.5%
G (9)	99,334	122,237	139,627	153,700	54.7%
H (10)	19,702	23,437	26,696	29,007	47.2 %
I (11)	13,408	15,873	17,796	19,553	45.8%
J (12)	7,588	8,370	9,207	10,091	33.0%
K (13, 14 & 15)	97,966	110,112	124,729	136,778	39.6%
Study Area	664,303	795,247	907,326	1,003,987	51.1%

Table 2.11 - Estimated 1991 and Projected 2021 Total, "Urban" and "Rural" Population (by Subbasin and Node)

Subbasin (Node #)	Estimated 1991 Population Distribution			Estimated 2021[1] Population Distribution		
	Total	"Urban"	"Rural"	Total	"Urban"	"Rural"
A (1)	9,632	3,304	6,328	14,411	4,944	9,467
B (2)	10,950	3,274	7,676	17,648	5,277	12,371
C (3)[2]	19,099	11,201	7,898	28,635	16,793	11,842
D[2]	-	-	-	-	-	-
(4)	106,684	90,578	16,106	165,233	140,287	24,946
(5)	171,430	171,430	0	265,511	265,511	0
E (6)	5,626	0	5,626	8,531	0	8,531
F[3]	-	-	-	-	-	-
(7)	7,057	0	7,057	10,621	-	10,621
(8)	95,827	95,827	0	144,268	144,268	0
G (9)	99,334	93,530	5,804	153,700	144,719	8,981
H (10)	19,702	8,985	10,717	29,007	13,228	15,779
I (11)	13,408	3,167	10,241	19,553	4,618	14,935
J (12)	7,588	0	7,588	10,091	0	10,091
K[4]	-	-	-	-	-	-
(13)	13,501	8,848	4,653	18,848	12,354	6,494
(14/15)[5]	84,465	84,465	0	117,930	117,930	0
Study Area	664,303	574,609	89,694	1,003,987	869,929	134,058

Notes

1. Population estimates established by increasing 1991 values using 1991-2021 percentage increase values from Table 2.10.
2. Total population for Subbasin D assigned to Nodes 4 and 5.
3. Total population for Subbasin F assigned to Nodes 7 and 8.
4. Total population for Subbasin K assigned to Nodes 13 and 14/15.
5. The same "Urban" population is assigned to Nodes 14 and 15 for modelling purposes. The percentage consumption values at each node were set to properly model water intake and wastewater return conditions at Brantford.

1991 Water Intake (or Use) Coefficients

The Regional Municipality of Waterloo's Long Term Water Strategy Phase 1 report (Associated Engineering Limited, 1994) and Environment Canada's 1991 Municipal (Water) Use Database (MUD'91) were selected as the primary source of water use data for this study. Information in the 1994 Municipal (Water) Use Database (MUD'94) was also used.

The Regional Municipality of Waterloo report provided 1991 serviced population and unit water use (or intake) coefficients[1] (average day demand per capita) for residents of the Tri-Cities as well as 1991 Tri-City land use (area in acres) and related water use coefficients (average demand per unit area) for each ICI sector. MUD'91 contains water use and wastewater production data for all municipalities with populations over 1000 which are serviced with municipal water and wastewater treatment. All data is specified by municipality rather than by individual water or sewage treatment plants. For the purposes of this study the reported 1991 municipal population, 1991 populations serviced with water and wastewater treatment, Average Daily Flows (ADF) for water and wastewater, percentage water use by sector (Domestic, Commercial & Institutional, Industrial, and "Other") and consumption data were of interest.

Serviced population figures for each community in MUD'91 were adjusted to reflect differences between the reported 1991 municipal population and the updated 1991 population figures established in the previous section. Equivalent unit water intake coefficients were then generated for each community by dividing the reported ADF for water by the updated 1991 serviced population figures. Serviced population figures for the Regional Municipality of Waterloo were also adjusted to reflect the updated 1991 population figures; however, the water use coefficients were adopted without adjustment. Total Tri-City 1991 water use by each ICI sector was determined in Million Cubic Metres per year (Mm^3/yr) for use in WUAM's industrial component. The report also provided equivalent unit water intake coefficients which include non-residential components (i.e., ICI) of demand "loaded" on the residential population for Woolwich, Wilmot, Wellesley and North Dumfries townships.

Water demand in Guelph and Brantford was broken down into urban-domestic and ICI sectors using the percentage-use-by-sector values provided in MUD'91 after they were verified by municipal officials. Unit water intake coefficients, expressed in litres per capita per day (l/c/d), were established for the urban-domestic component of each city. The reported Commercial & Institutional water use was split evenly between the two sectors. Water use reported as "Other" was then shared equally between each of the three ICI components. Total 1991 water use for each ICI sector, in Mm^3/year, was then determined for input to WUAM.

Tables 2.12 and 2.13 provide the updated population and water intake coefficients used in this study (shown in bold print). ADF values for the Regional Municipality of Waterloo are compared with MUD values where possible. Since the information presented in MUD'91 is rather general, and is primarily aimed at the production of aggregate and summary statistics, caution is required when extracting municipality-specific data. Municipal officials were consulted to correct a small number of discrepancies found between Regional Municipality of Waterloo, MUD'91 and MUD'94 data. MUD database managers were notified of the errors.

[1] Referred to as Water Consumption Factors in Phase 1 Report

Table 2.12 - Population and Water Use Factors (by Municipality)

MUNICIPALITY	MUD '91 [1] "Present" [2] Population	MUD '91 Population Served w/ Water	MUD '91 Population Served w/ Wastewater Treatment	MUD '91 ADF [3] Water (m^3/d)	MUD '91 ADF Treated Sewage (m^3/d)	1991 Census Population	Updated 1991 Population	RMOW [4] 1991 Serviced Population	Updated 1,991 Population Served w/ Water	Updated [5] Water Use Factor (w/ ICI "loaded" on Residential) (l/c/d)
GRAND VALLEY	1,178		860		384	1,517	1,559		219 [6]	228 [6]
GUELPH TWP	3,288	300	300	173	150	3,288	3,288		300	577
GUELPH CITY	85,000	85,000	85,000	49,900	47,000	87,976	93,367		93,367	534 [7]
ERAMOSA TWP	5,700	2,070	2,090	652	780	5,949	5,949		2,160	302
FERGUS	7,657	7,500	7,500	4,523	4,273	7,940	7,940		7,777	582
ELORA	3,000	3,000	3,000	1,600	1,650	3,261	3,261		3,261	491
DRAYTON	1,181					1,181	1,181		1,181 [8]	357 [8]
ARTHUR	2,000	2,000	2,000	996	1,053	2,123	2,123		2,123	469
BRANTFORD TWP	6,509	418		700		6,509	6,697		430	1,628
BRANTFORD CITY	78,582	78,582	77,000	44,400	50,200	81,997	84,361		84,361	526 [9]
PARIS	8,500	8,500	7,225	5,578	2,437	8,600	8,848		8,848	630
NORTH DUMFRIES TWP	6,500	2,000	2,000	635	748	6,821	6,877	2,298	2,317 [10]	For
CAMBRIDGE	89,950	79,000	80,000	44,701	49,924	92,772	93,530	92,772	93,530 [11]	RMOW
KITCHENER	155,000	155,000	155,000	72,177	70,547	168,282	171,430	170,041	171,430 [11]	values
WATERLOO	80,000	80,000	80,000	31,323	46,661	71,181	82,141	81,475	82,141 [11]	see
WOOLWICH TWP	16,000	14,000 [12]	8,800	4,696	3,864	17,365	17,507	8,369	8,437 [10]	Table 2.13
DUNDALK	1,530	1,450	1,400	632	1,104	1,677	1,715		1,625	389
MILVERTON	1,604	1,604	1,604	364	623	1,664	1,688		1,688	216

Notes:
1. 1991 Municipal (Water) Use Database
2. Present Population - provided by the municipality or (if non-respondent) from most recent census
3. Average Daily Flow
4. Source: Regional Municipality of Waterloo(RMOW) Working Paper: Water Demand and Supply Forecast (Associated Engineering Limited, 1993)
5. Equals A.D.F. Water divided by Updated 1991 Population served w/ water
6. Based on 1994 Municipal (Water) Use Database (MUD'94) data (Present Pop. = 1517, Serviced Pop. = 213, ADF Water = 50 m^3/d))
7. City of Guelph Water Use by Sector: 50% Domestic; 16% Commercial-Institutional; 24% Industrial; 10% "Other" (MUD'91)
8. Full servicing assumed w/ Water Use Factor based on MUD'94 data (Serviced population of 1260 w/ ADF Water =450 m^3/d)
9. City of Brantford Water Use by Sector: 60% Domestic; 5% Commercial-Institutional; 25% Industrial; 10% "Other" (MUD'91 modified)
10. Based on RMOW 1991 Seviced Population not MUD'91 values
11. Full servicing assumed.
12. Apparent error in MUD'91 database. RMOW 1991 value = 8369 and MUD'94 value = 9500

Table 2.13 - Regional Municipality of Waterloo Population and Water Use Factors

MUNICIPALITY	Water Use Sector	1991 [1.] Serviced Population	1991 ICI [2.] Land Use (in Acres)	Water Use [3.] Factors (Average Day) (in gpcd or g/ac/d)	Water Use Factors (Average Day) (in l/c/d)	Calculated ADF [4.] Water (m^3/d)		MUD '91 ADF Water (m^3/d)		MUD '91 ADF Tr. Sewage (m^3/d)
KITCHENER	Residential	171,430		51.9 gpcd	235.9	40,448				
	Industrial		2726	2,077.0 g/ac/d		25,740				
	Commercial		942	759.2 g/ac/d		3,251				
	Institutional		791	910.4 g/ac/d		3,274				
	TOTAL					72,712	vs.	72,177	and	70,547
WATERLOO	Residential	82,141		48.0 gpcd	218.2	17,924				
	Industrial		1171	1,441.6 g/ac/d		7,674				
	Commercial		343	730.3 g/ac/d		1,139				
	Institutional		875	902.1 g/ac/d		3,588				
	TOTAL					30,326	vs.	31,323	and	46,661
						N.B. MUD'94 =		31,323	and	34,095
CAMBRIDGE	Residential	93,530		58.5 gpcd	265.9	24,874				
	Industrial		2529	1,979.7 g/ac/d		22,761				
	Commercial		469	1,055.1 g/ac/d		2,250				
	Institutional		477	1,457.9 g/ac/d		3,161				
	TOTAL					53,046	vs.	44,701	and	50,200
WOOLWICH TWP	TOTAL	8,437 [5.]		115.6 gpcd	525.5	4,434	vs.	4,696	and	3,864
WILMOT TWP	TOTAL	5,986 [5.]		75.6 gpcd	343.7	2,057				
WELLESLY TWP	TOTAL	1,311 [5.]		26.6 gpcd	120.9	159				
NORTH DUMFRIES TWP	TOTAL	2,317 [5.]		48.7 gpcd	221.4	513	vs.	635	and	748

Notes:
1. See Table 2.12
2. Tri-City Land Use, Table 2-6, Associated Engineering Limited (1994)
3. Source: Adjusted Consumption Factors, page 2-17, Associated Engineering Limited (1994)
4. Average Daily Flow
5. ICI component of demand "loaded" on residential population.

Most rural-domestic water demand is supplied from private groundwater wells. Generally, these wells are not metered; thus an average daily per capita water use rate could not be determined in the same manner as for the serviced municipalities. A base year average intake rate of 159 l/c/d was assumed to apply throughout the entire GRB (D. Tate, Environment Canada, personal communication, 1994).

Monthly Distribution in Water Demand

Water demand varies over a given year with demand being greater in summer than the winter. Regional Municipality of Waterloo 1990-93 monthly water use data were used to calculate a representative seasonal water use distribution (Table 2.14) for domestic demand (both urban and rural) throughout the GRB.

Table 2.14 - Monthly Distribution[1.] in Domestic Water Use

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.00	0.95	0.96	1.01	1.04	1.08	1.05	1.01	1.00	1.00	0.96	0.95

Note:
1. Normalized monthly distribution factor (i.e., average month = 1.00).

Industrial use seldom exhibits the same seasonal pattern as domestic use. Where industrial demand was modelled separately from domestic uses (i.e., the Tri-Cities, Guelph and Brantford) it was assumed that ICI consumers do not exhibit seasonal consumption patterns, and all summer peaks are caused by the residential sector. While certain ICI consumers may have seasonal peak demands, others may have staggered demand which tends to balance the seasonal effect (Associated Engineering Limited, 1994). For nodes where the ICI demand was loaded on the domestic population, the seasonal water use pattern was applied to industrial use as well.

Future (2021) Water Intake Coefficients

Many factors influence levels of water demand. Long-term use is controlled by population and demographic change, characteristics of dwellings, fluctuations in water supply or sewage treatment charges, adoption of water conservation technology and the state of the local economy, particularly through the addition or loss of large industrial users (Robinson and Creese, 1993; Akuoko-Asibey *et al.*, 1993; Miaou, 1990).

As noted, population and ICI growth have been assumed for each subbasin. The adoption of water conservation measures, such as plumbing fixture retrofits, is strongly encouraged and supported in the GRB's large urban communities. In preparing its long-term strategy, the Regional Municipality of Waterloo was more confident in the certainty of reduced water use for initiatives that target plumbing fixtures than with initiatives that rely on changes in consumer usage habits (Associated Engineering Limited, 1994). It was assumed that public education would remain a mandatory element of any water use efficiency strategy, albeit with no allowance for any demand reductions. The Region's long-term strategy assumed a 25% reduction in use for new growth (25% savings * 100% market saturation) and an 18.75% reduction for existing users (25% savings * 75% market saturation) resulting from plumbing code modification and fixture replacement, respectively. Water managers for the Cities of Guelph and Brantford indicated that similar overall savings are possible although methods used may differ from those proposed for the Tri-Cities. (T. Hearn, personal communication, 1995; T. Eyre, personal communication, 1995). Therefore, the 1991 water intake coefficients were adjusted using these reduction rates to estimate future urban-domestic unit water intake factors for the Tri-Cities, Guelph and Brantford.

Although there may be opportunities for additional water use reductions in the ICI sectors, it was assumed that most companies that can cost-effectively implement water efficiency measures would have already done so. The preliminary review of past ICI water use efficiency efforts in the Regional Municipality of Waterloo (Associated Engineering Limited,1994) seems to support this position. Therefore, for future scenario runs in WUAM, water use reductions were not applied to the ICI sectors for the Tri-Cities, Guelph or Brantford. However, this does not mean that more aggressive water use efficiency measures cannot be adopted in the future.

In the smaller serviced communities, where the ICI use was loaded on domestic water use, and equivalent unit intake coefficients specified, only the 25% reduction in per capita water use for future growth was assumed. Although fixture replacement or other water efficiency programs may be introduced to residences in these smaller communities, future reductions for existing users were not applied due to the inclusion of the ICI component in the base year daily water use factors. The 1991 assumed rural-domestic water use rate was not modified for future scenario runs.

With respect to the direct effect of climate change on water use, most of the impacts are expected to be short-term. Increases in average and maximum temperature have been associated with increased water use, while greater total rainfall and an increased number of days with rainfall have been related to reduced levels of water use (Akuoko-Asibey *et al.*, 1993; Miaou, 1990). Other variables such as potential evapotranspiration, moisture deficit and degrees above a certain threshold temperature have also been examined (Cohen, 1987; Robinson and Creese, 1993). With respect to climate change, Cohen (1987) assessed the implications of two global warming scenarios on monthly municipal water use for several Great Lakes Basin municipalities. Using regression analysis, he projected that summer (May-September) water use could increase by approximately 5-6% once an equilibrium climate has been reached. Climate change is likely to be a significant factor in changing the peak demand of a water supply and distribution system and others are examining this issue (Mills, 1996). Although climate change may also affect future unit demand values and seasonal use distribution factors, the 1991 values for each were not adjusted for climate change effects given the uncertainty in population forecasts and range in future climate scenarios specified for this study.

Incorporation into WUAM

Normally, municipal water intake at each node would be calculated by WUAM based on the current and forecasted levels of population and ICI activity and their related water demand coefficients. The fraction of water intake supplied either from groundwater or surface water would be calculated based on a defined ratio. Then, using specified consumption factors for each sector, WUAM would determine the return flow (wastewater) at each node, assuming continuous discharge from wastewater treatment facilities. The existence of fixed abstraction rates for the Regional Municipality of Waterloo and the City of Guelph and sewage treatment lagoons in the upper basin, with seasonal or proportional-to-streamflow discharges, required further manipulation of the model and its input to adequately simulate municipal water use in the GRB.

It was concluded that the best way to satisfy the purpose of this study was to estimate 1991 and 2021 urban demand outside of the model. These figures were then incorporated into WUAM in a manner that accounted for the supply (groundwater or surface water) and return flow (continuous-flow wastewater system or timed-output lagoon system) conditions in each subbasin. In 1991, some communities in the GRB had only partial servicing or differing levels of service with respect to water supply or wastewater treatment. For water use modelling purposes it was assumed that the entire population of each community was serviced with both water and wastewater treatment.

Based on the updated 1991 urban population figures, daily unit water intake coefficients and total annual ICI demand figures, established earlier, the total annual 1991 water use for each community and total urban water intake by subbasin node was determined. Weighted average 1991 nodal urban-domestic unit intake rates were also established for subbasins with more than one municipality. Estimates for year 2021 water intake by community and by node were then calculated using the 1991-2021 subbasin population growth rates (Table 2.10), ICI growth rates (Table 2.8) and the water conservation factors described earlier. This data is summarized in Table 2.15. While the estimated study area population growth is approximately 50%, the attendant total water use increase is only about 25% due to smaller increases in use assumed for the ICI components of major centres.

Water consumption rates reflect the percentage of water which is consumed and not returned to the system. Different sectors (e.g., domestic, ICI) have different rates of consumption. Specific values are presented in the MUD database; however, based on a review of the ADF values for water supply and wastewater production provided in MUD, it appears that when the majority of a municipality's population is serviced with water and wastewater facilities, the ADF of treated wastewater often exceeds the ADF of water supplied to the system. This may be due in part to leakage of groundwater into the sanitary system and perhaps illegal hookups of storm water collection systems to the sanitary system. To ensure that current wastewater volumes were maintained for water balance purposes, a theoretical zero net consumption value was assumed for urban-domestic and ICI water use at all nodes. In other words, the 1991 annual water intake values in Table 2.15 were assumed to represent current wastewater contributions for study purposes.

Wastewater volumes may be reduced in the future through efforts to reduce leakage and illegal hookups. Climate change may also decrease the amount of leakage by lowering the water table (Robinson and Creese, 1993). However, given the uncertainty in population forecasts and future water use per capita values, zero net consumption was also adopted for future conditions and the 2021 water intake values provided in Table 2.15 were assumed to equal the wastewater production at that time.

Rural-domestic water intake at each node was calculated by WUAM based on the current and forecasted levels of population and the assumed rural-water demand coefficient.

Water Supply Sources

WUAM requires base-year data on the proportion of urban-domestic, ICI and rural-domestic water use at each node which is supplied from groundwater sources. The remainder of water intake is assumed to come from surface water supplies. The same proportions are assumed to apply for future years, provided that the total groundwater withdrawal does not exceed a user-defined maximum (if specified). In order to adequately model current and future municipal surface water abstractions, an alternate approach was required. Only existing abstraction sites for the Regional Municipality of Waterloo and the Cities of Guelph and Brantford were modelled. Additional or alternate abstraction sites were not considered.

Table 2.15 - Estimated 1991 and 2021 Urban-Municipal and ICI Water Use

				Assummed 1991 and 2021 Conditions										
Node Number Community Name (Wastewater Discharge Type)	Updated 1991 Population Served w/ water	Updated Water Intake Factor by Community & Weighted Avg (l/c/d)	Data Source	Total 1991 "Urban" Population	Water Intake Factor by Community & Weighted Avg (l/c/d)		1991 (Base Year) Annual Water Intake (Mm^3/yr)	1991-2021 Population or ICI Growth Rate (%)	Estimated Total 2021 "Urban" Population	Water Conservation Factors (% reduction)	Weighted Water Conservation Factor (% reduction)	2021 Water Use (l/cap/day)		2021 Annual Water Intake (Mm^3/yr)
NODE 1: Conestogo River at Glen Allan (below Conestogo Dam)														
Arthur (Spring and Fall)	2,123	469.1	(MUD '91)	2,123	469.1		0.36	49.6%	3,177	-25% for new growth	8.3%	430.2		0.50
Drayton (November and December)	1,181	357.1	(MUD '94)	1,181	357.1		0.15	" "	1,767	" "	" "	327.5		0.21
Node Total	3,304	429.1		3,304	429.1		0.52		4,944			393.5		0.71
NODE 2: Grand River Below Shand Dam														
Dundalk (Seasonal)	1,625	388.8	(MUD '91)	1,715	388.8		0.24	61.2%	2,764	-25% for new growth	9.5%	351.9		0.36
Grand Valley (Continuous)	219	228.3	(MUD '94)	1,559	228.3		0.13	" "	2,513	" "	" "	206.6		0.19
Node Total	1,844	369.7		3,274	312.4		0.37		5,277			282.7		0.54
NODE 3: Grand River at West Montrose														
Fergus (Continuous)	7,777	581.6	(MUD '91)	7,940	581.6		1.69	49.9%	11,904	-25% for new growth	8.3%	533.2		2.32
Elora (Continuous)	3,261	490.6	(MUD '91)	3,261	490.6		0.58	" "	4,889	" "	" "	449.6		0.80
Node Total	11,038	554.7		11,201	555.1		2.27		16,793			508.9		3.12
NODE 4: Grand River at Doon (above Kitchener STP)														
Waterloo Residential Intake only, Woolwich w/ ICI loaded on Residential														
Waterloo (Continuous)	82,141	218.2	(AE, 1994)	82,141	218.2		6.54	54.9%	127,220	-25% for new growth plus -18.75% for existing	21.0%	172.5		8.01
Woolwich (Continuous)	8,437	525.5	(AE, 1994)	8,437	525.5		1.62	" "	13,067		" "	415.4		1.98
Sub-total	90,578	246.8		90,578	246.8	Sub-total	8.16		140,287			195.1	Sub-total	9.99
ICI Intake based on Associated Engineering (994)														
Industrial							2.80	11.0%		No reductions applied to ICI components	0.0%			3.11
Commercial							0.42	109.0%			" "			0.88
Institutional							1.31	40.0%			" "			1.83
Node Total							12.69							15.81
NODE 5: Grand River at Doon (below Kitchener STP)														
Residential Intake only														
Kitchener (Continuous)	171,430	235.9	(AE, 1994)	171,430	235.9	Sub-total	14.76	54.9%	265,511	-25% for new growth plus -18.75% for existing	21.0%	186.4	Sub-total	18.07
Kitchener ICI Intake based on Associated Engineering (994)								ICI Growth (AE, 1994)						
Industrial							9.39	11.0%		No reductions applied to ICI components	0.0%			10.42
Commercial							1.19	109.0%			" "			2.49
Institutional							1.19	40.0%			" "			1.67
Node Total							26.53							32.64

Table Continued on next page

Table 2.15 (Continued) - Estimated 1991 and 2021 Urban-Municipal and ICI Water Use

Community Name (Wastewater Discharge Type)	Updated 1991 Population Served w/ water	Updated Water Intake Factor by Community & Weighted Avg (l/c/d)	Data Source	Assummed 1991 and 2021 Conditions: Total 1991 "Urban" Population	Water Intake Factor by Community & Weighted Avg (l/c/d)		1991 (Base Year) Annual Water Intake (Mm^3/yr)	1991-2021 Population or ICI Growth Rate (%)	Estimated Total 2021 "Urban" Population	Water Conservation Factors (% reduction)	Weighted Water Conservation Factor (% reduction)	2021 Water Use (l/cap/day)		2021 Annual Water Intake (Mm^3/yr)
NODE 6: Speed River at Victoria Road (below Guelph Dam)				0			0.00	51.6%	0		N/A			0.00
NODE 7: Speed River below Guelph (at Hanlon above Guelph STP)				0			0.00	50.5%	0		N/A			0.00
NODE 8: Speed River below Guelph (at Hanlon below Guelph STP)														
Guelph Residential Only, Eramosa and Guelph Twp s w/ ICI loaded on residential														
Guelph City (Continuous)	93,367	267.3	(MUD '91)	93,367	267.3		9.11	50.5%	140,564	-25% for new growth	20.6%	211.5		10.65
Eramosa Twp (Continuous)	2,160	301.8	(MUD '91)	2,160	301.8		0.24	• •	3,252	plus	• •	238.9		0.28
Guelph Twp (Continuous)	300	576.7	(MUD '91)	300	576.7		0.06	• •	452	-18.75% for existing	• •	456.5		0.08
Sub-total	95,827	269.0		95,827	269.0	Sub-total	9.41		144,266			212.9	Sub-Total	11.21
Guelph ICI Intake (based on MUD '91 ratios)														
Industrial							4.96	11.0%		No reductions	0.0%			5.53
Commercial							2.07	109.0%		applied to	• •			4.33
Institutional							2.07	40.0%		ICI components	• •			2.90
Node Total							18.53							23.96
NODE 9: Grand River at Galt														
Residential Only														
Cambridge (Continuous)	93,530	265.9	(AE, 1994)	93,530	265.9	Sub-total	9.06	54.7%	144,719	-25% for new growth plus -18.75% for existing	21.0%	210.2	Sub-total	11.10
Cambridge ICI Intake (based on Associated Engineering, 1994)								ICI Growth (AE, 1994)						
Industrial							8.31	11.0%		No reductions	0.0%			9.22
Commercial							0.82	109.0%		applied to	• •			1.71
Institutional							1.15	40.0%		ICI components	• •			1.61
Node Total							19.36							23.65
NODE 10: Nith River at New Hamburg														
Milverton (Out of Basin Discharge)	1,688	215.6	(MUD '91)	1,688	215.6		0.13	47.2%	2,485	-25% for new growth	6.0%	198.3		0.18
Wellesley (Proportional to Flow)	5,986	343.7	(AE, 1994)	5,986	343.7		0.75	• •	8,813	• •	• •	316.1		1.02
Wilmot (Proportional to Flow)	1,311	120.9	(AE, 1994)	1,311	120.9		0.06	• •	1,930	• •	• •	111.2		0.06
Node Total	8,985	287.1		8,985	287.1		0.94		13,228			264.1		1.28
NODE 11 Nith River near Canning														
Plattsville (Proportional)	850	343.7	EST'D	850	343.7		0.11	45.8%	1,239	-25% for new growth	7.9%	316.7		0.14
N. Dumfries Twp (Ayr) (Continuous)	2,317	221.4	(AE, 1994)	2,317	221.4		0.19	• •	3,379	• •	• •	204.0		0.25
Node Total	3,167	254.2		3,167	254.2		0.29		4,618			234.3		0.39

Table Continued on next page

Table 2.15 (Continued) - Estimated 1991 and 2021 Urban-Municipal and ICI Water Use

Community Name (Wastewater Discharge Type)	Updated 1991 Population Served w/ water		Updated Water Intake Factor by Community & Weighted Avg (l/c/d)	Data Source	Assummed 1991 and 2021 Conditions: Total 1991 "Urban" Population	Water Intake Factor by Community & Weighted Avg (l/c/d)	1991 (Base Year) Annual Water Intake (Mm^3/yr)	1991-2021 Population or ICI Growth Rate (%)	Estimated Total 2021 "Urban" Population	Water Conservation Factors (% reduction)	Weighted Water Conservation Factor (% reduction)	2021 Water Use (l/cap/day)		2021 Annual Water Intake (Mm3/yr.)
NODE 12: Whitemans Creek near Mount Vernon					0		0.00	33.0%	0		N/A			0.00
NODE 13: Grand River at Brantford (above Brantford Water Intake)														
Paris (Continuous)	8,848		630 4	(MUD '91)	8,848	630 4	2.04	39.6%	12,354	-25% for new growth	7.1%	585.7		2.64
Node Total							2 04							
NODES 14 & 15: Grand River at Brantford (Node 14: at Brantford water intake and Node 15 below Brantford STP)														
Brantford Residential Intake only, Brantford Twp w/ ICI intake loaded on Residential														
Brantford (Continuous)	84,361	Residential	315.8	(MUD '91)	84,361	315.8	9.72	39.6%	117,785	-25% for new growth	20.5%	251.0		10.79
Brantford Twp (No STP)	104	*in node subbasin	1,627 9	(MUD '91)	104	1,627.9	0.06	" "	145	plus -18.75% for existing	" "	1,293.8		0.07
Sub-Total	84,465		317 4		84,465	317 4	9 79		117,930			252.3	Sub-Total	10.86
Brantford ICI Intake (based on MUD '91 ratios)								ICI Growth (AE, 1994)						
Industrial							4.60	11.0%		No reductions	0.0%			5.11
Commercial							0.95	109.0%		applied to	" "			1.99
Institutional							0.95	40.0%		ICI components	" "			1.33
Node Total							16.29							19.26
STUDY AREA TOTAL							**99.83**							**124.02**

Current and future water supplies for the City of Brantford were assumed to be taken from the Grand River. These supplies were modelled in WUAM by defining a zero percent groundwater supply fraction for the node containing Brantford. All other current and future urban-domestic, ICI and rural-domestic water demand within the study area were assumed to be supplied by groundwater for modelling purposes. The current and future surface water abstractions from the Grand River (Regional Municipality of Waterloo) and the Eramosa River (City of Guelph) were modelled as specified diversions from the river. This approach was necessary since, as discussed below, in both cases there are infrastructure and/or policy related limits on the abstraction volumes and neither one increases proportionally with population.

The Tri-Cities' groundwater supply is presently supplemented by a 4 Million Imperial Gallons per Day (MIGD) or 0.2 m^3/s abstraction from the Grand River at Hidden Valley in Kitchener. The maximum permissible abstraction is 54 MIGD (2.8 m^3/s). Treatment facilities above Doon have a current capacity of 16 MIGD (0.8 m^3/s), while the transmission main has a capacity of 54 MIGD (2.8 m^3/s). The Regional Municipality of Waterloo Long Term Water Strategy indicates that by the year 2001, the existing 4 MIGD Grand River withdrawal will need to be increased to meet the Tri-Cities' projected demand and will be 16 MIGD by the year 2025 (Paragon Engineering Limited, 1994). The 0.2 m^3/s and 0.8 m^3/s abstraction rates were assumed to apply for current (1991) and future (2021) conditions, respectively.

The City of Guelph recharges the Arkell spring grounds artificially with water pumped from the Eramosa River adjacent to the springs. Up to 2 MIGD (0.1 m^3/s) are pumped from the river between mid-April and mid-November to a recharge pond and open trench system located at the top of the sand and gravel bluff above the collector system. The City's water-taking permit authorizes a potential taking of 832 Million Imperial Gallons (MIG) over the period of 215 days at rates varying from 2 MIGD (0.1 m^3/s) to 7 MIGD (0.37 m^3/s). The actual water taking is dependent on water levels observed in monitoring wells in the spring grounds, the need to maintain a river flow greater than 35 ft^3/s (0.85m^3/s) past the City's STP and flow greater than 15 ft^3/s (0.43 m^3/s) at the Environment Canada streamflow gauge on the Eramosa River above Guelph, and the need to sustain dissolved oxygen levels in the Speed River at acceptable levels. In 1989, a total of 185 MIG or 841,248 m^3 was pumped over a period of 92 days. Unfortunately, WUAM cannot simulate the actual operation of this abstraction process. In lieu of this, the current maximum of 1,934,000 m^3 over the April to November period was assumed for the current conditions simulations. Similarly, the permitted maximum abstraction, representing a worst-case scenario for impacts on river flows, was assumed for future condition simulations.

All rural-domestic water demand was assumed supplied from groundwater sources for study purposes.

Return Flow

Nodal population and unit intake rates were specified to model the supply of water throughout the basin. Water consumption rates and diversion options were used to help maintain the proper return flows (wastewater) to the system.

If a subbasin contained one or more communities with a sewage treatment lagoon, the annual water intake/waste water volume estimated for each community in that subbasin (Table 2.15) was treated as an individual diversion into the river. Seasonal contribution patterns were then specified for each diversion to simulate the discharge from the related community's lagoon or continuous discharge plant. Input file data related to water consumption rates were set at 100% for these subbasins to ensure that no return water was added at the node by the water balance component of the model itself. For subbasins with continuous discharge plants only, input file consumption values of zero percent were specified and return flows calculated by the model. While this approach correctly simulated the existence of lagoons, helping to maintain proper streamflow values at each node, it invalidated many of the water demand and supply comparison tables produced by WUAM.

Unlike urban consumers, most rural residents are on private septic tank-weeping bed systems and their wastewater is not directed to the surface water system. Therefore, to ensure return water was not contributed by rural households, a theoretical consumption value of 100% was specified for both current and future conditions.

Agricultural Water Use

Water within the GRB is used for two main agricultural purposes: irrigating crops and watering livestock. Crop irrigation occurs between the months of June and August, primarily in the watersheds of Mt. Pleasant, McKenzie and Whitemans Creeks. The largest livestock water demands exist in the basins of the middle Grand and Nith Rivers.

Irrigation

Originally developed for application to the agriculture-intense Saskatchewan portion of the South Saskatchewan River Basin, WUAM contains a comprehensive irrigation water use submodel; however, this subcomponent was not used for the Grand River application. The irrigation values for the years 1978 and 2031 presented in the Grand River Implementation Committee report (GRIC, 1982) were adopted for current and future scenarios, respectively. After discussions with GRCA staff, the increase in irrigation projected in the 1982 report for the Speed River Basin was not assumed. Irrigation was treated as an abstraction using the diversion option in WUAM.

The GRIC report indicates that actual withdrawals for irrigation are generally much less that those permitted by the Province of Ontario. Intensive irrigation occurs over a relatively short period of time and the demand tends to coincide with the period of lowest water availability in streams. As a result, irrigation represents a significant potential impact on the surface water regime but one that is difficult to simulate using WUAM. Since WUAM is a monthly model and irrigation is generally an episodic application, the monthly average application rate does not have a significant impact on modelling results.

Livestock

Livestock water uses are estimated by WUAM based on animal population and water intake and consumption coefficients for each livestock type. The fraction of intake from groundwater and livestock population growth projections are also required.

Present population and water use data for livestock were obtained from Ontario Ministry of Agriculture and Food, (Ecologistics Limited, 1993). The OMAF database contains detailed population and water use statistics for 27 categories of livestock for each county and regional municipality in the GRB. Six livestock categories were defined for this study: cattle, swine, sheep, horses, poultry and "other" (which includes pelt production livestock). Subbasin livestock populations (Table 2.16) were determined based on area ratios assuming equal distribution throughout each county.

Table 2.16 - Estimated 1991 Livestock Subbasin Population (in Thousands)

Livestock Category	Subbasin										
	A	B	C	D	E	F	G	H	I	J	K
Cattle	27	22	18	52	12	15	20	32	26	15	9
Swine	43	16	29	110	18	23	38	86	58	31	16
Sheep	3	4	2	2	2	2	1	1	1	1	1
Horses	1	1	1	2	0	1	1	1	1	0	0
Poultry	549	157	262	1101	231	289	412	622	502	242	167
"Other"	20	4	13	54	8	11	18	28	21	4	5

Table 2.17 lists the livestock water use coefficients and population growth factors used. A single basin-wide water use figure for each category was determined using regional population and water use data. The GRIC (1982) report indicates that future livestock numbers will remain stable with the exception of the Nith and middle Grand River Basins where increases are anticipated. Thus, increases in livestock population were only assumed for subbasins **A, B, C, H** and **I**.

Table 2.17 - Livestock Water Use Coefficients and Growth Rates

Livestock Category	Water Intake[1.] (litres/head/day)	Consumption[2.] (%)	Growth Rate[3.] (% per annum)
Cattle	46.9	90	-0.8
Swine	10.4	70	0.1
Sheep	6.2	95	2.8
Horses	42.0	70	0.0
Poultry	0.4	95	3.5
"Other"	0.5	90	0.0

Notes.
1. A single basin-wide water use figure for each category was determined using regional data.
2. The percentage consumption figures for each livestock category were obtained from Kassem (1992). An average value of 90 percent consumption was assumed for the "other" livestock category.
3. Rates for cattle, swine and poultry: average of 1991-2001 growth figures (Agriculture Canada-Policy Branch, personal communication, 1994). Rate for sheep: average of historic population figures (1976-1993) (Statistics Canada-Agricultural Division, 1994). Rates for horses and "other": zero percent assumed due to difficulties in accurately monitoring these populations over time (Agriculture Canada-Policy Branch, personal communication, 1994).

Water supplies for feedlot or poultry farm operations are primarily obtained from wells. Pastured cattle and mixed herds on small farms are watered from a variety of sources, including streams, ponds, springs and wells (GRIC, 1982). For this study, it was assumed that 90% of the water supplies for livestock came from groundwater sources.

Non-withdrawal Water Uses

Non-withdrawal (or in-stream) water uses are a significant factor in the management of streamflows in the GRB. In WUAM applications, non-withdrawal water uses are dealt with as constraints on streamflow based on minimum flow requirements.

Water Quality

In order to satisfy water quality conditions, minimum flow target flows are specified at Hanlon, Doon and Brantford. The flows specified on a daily basis (see Table 2.3, Section 2.2.2) were assumed to apply for the monthly simulation. While it is recognized that the target flow values throughout the system may change in response to future water quality conditions or wastewater treatment capabilities (Paragon Engineering Limited, 1994) the current values were maintained for future scenario conditions to facilitate comparisons.

Recreation

Water-based recreation is an important and growing resource to local residents and tourists (O'Neill, 1990; GRCA, 1994). Some activities rely on certain flow ranges (canoeing), others on the volume of water in the reservoirs (power boating) and some on the quality and temperature of the water (swimming and fishing). Since these activities have evolved around the current flow regime, the minimum flows specified in Table 2.3 for water quality and minimum flows specified as part of the reservoir operating rules are also assumed to apply for recreational purposes.

Hydroelectric Power Generation

The Grand River Conservation Authority generates hydroelectric power at the Shand, Conestogo, and Guelph dams with maximum turbine outputs of 625 kW, 500 kW, and 80 kW, respectively. Although WUAM contains a subcomponent to estimate hydroelectric energy generation from the simulated streamflows at the nodes which contain hydropower plants, power generation is a low-priority use in the GRB and thus was not considered in this study.

2.2.4.3 Application Scenarios

In total, 24 WUAM model application scenarios were tested, 3 model-evaluation scenarios (MES) and 21 impact-assessment scenarios (IAS). Each scenario was constructed based on a combination of current or assumed future conditions for three components: (1) surface water supply; (2) system operation (reservoir configuration and operation); and, (3) water use. Table 2.18 provides a detailed summary of each scenario based on these three principal components and their attendant subcomponents.

Model-evaluation Scenarios

In order to evaluate the water balance performance of WUAM, three model-evaluation scenarios (MES1-3) were run for the 1951-88 study period using base case surface water supplies (1951-88 unregulated flows). MES1 represents current system conditions. MES1 assumed 1991 water use and the current reservoir configuration and operation. Two theoretical scenarios (MES2 and MES3), run for comparison purposes, used the same water use/wastewater conditions as the MES1; however, MES2 assumed "state-of-nature" system operation (i.e., reservoir outflows equals inflows), while the West Montrose reservoir was added to the current reservoir configuration for MES3.

Impact-assessment Scenarios

Twenty-one impact-assessment scenarios were tested. In general, scenario differences relate to the surface water supply scenario selected and the system operation assumed (Table 2.18). All 21 impact-assessment scenarios assumed estimated 2021 basin conditions with respect to withdrawal water use. Water conservation measures beyond those assumed to establish the 2021 water use rates adopted are possible but were not modelled. Since it was assumed that recreational uses have evolved based on the current flow regime and no measures which might permit lower streamflow targets for water quality purposes, such as improved wastewater treatment, were assumed, the current (1991) flow targets were used for all impact-assessment scenarios.

The 21 impact-assessment scenarios were generated in three groups based on their assumed system operation conditions:

Group 1 - Current reservoir configuration assuming current reservoir operation (IAS1-8)

As an initial step in assessing system response, each of the potential future surface water supply sequences were routed through the system assuming current reservoir configuration and operation.

Group 2 - Current reservoir configuration assuming modified reservoir operation (IAS9-13)

If surface water supplies change, it is reasonable to expect GRCA water management staff to adjust reservoir operations. As described earlier, the current operating rule curves and target outflows for each reservoir were modified to reflect the general change in the seasonal distribution of supplies suggested in Figure 2.26 for the surface water supply scenarios specified by the GLSLB Project.

Only the GLSLB Project surface water supply scenarios were routed under modified operation conditions. Modified operation scenarios were not tested for the base case nor the Arbitrary Base Case (BC)-20% and BC-50% linear change supply scenarios as they do not include shifts in seasonal distributions of supplies. Routing these linear change supply scenarios assuming the modified operating rules would not produce meaningful results.

Group 3 - Current reservoir configuration plus the West Montrose reservoir assuming current reservoir operation (IAS14, 20 and 21) or modified reservoir operation (IAS15-19) as required by the selected surface water supply scenario.

As a final step, the West Montrose reservoir was added to the current reservoir configuration. Current or modified operations were assumed at each of the four reservoirs depending on the surface water supply scenario routed. Current reservoir operation was used for the Base Case and the Arbitrary BC-20% and BC-50% linear change supply scenarios while modified reservoir operation was assumed for the five GLSLB Project specified scenarios. Additional combinations of reservoir configuration and operation, while possible, were not considered.

Table 2.18 - WUAM Application Scenarios

VARIABLES INCLUDED	WUAM APPLICATION SCENARIO RUN NUMBER																						
	MES			IAS (GROUP 1)								IAS (GROUP 2)					IAS (GROUP 3)							
	1	2	3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1) SURFACE WATER SUPPLY																								
Present-Climate Streamflows																								
Base Case (1951-88 unregulated) (0%)	•	•	•	•													•							
Changed-Climate Streamflows (GLSLB Project-specified or Arbitrary)																								
CCC GCM II (-51%)					•							•						•						
Transposition MCC1 (-2%)						•							•						•					
Transposition MCC2 (-19%)							•							•						•				
Transposition MCC3 (+13%)								•							•						•			
Transposition MCC4 (+14%)									•							•						•		
Arbitrary 20% Linear reduction of Base Case flows (-20%)										•													•	
Arbitrary 50% Linear reduction of Base Case flows (-50%)											•													•
2) SYSTEM OPERATION																								
Reservoir Configuration																								
Current (1991)	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•								
Current (1991) plus West Montrose			•														•	•	•	•	•	•	•	•
Reservoir Operation																								
Current (1991) Rule Curves	•		•	•	•	•	•	•	•	•	•						•						•	•
Modified Rule Curves												•	•	•	•	•		•	•	•	•	•		
"State-of-Nature"		•																						
3) WATER USE																								
Withdrawal Uses																								
Current (1991) Conditions	•	•	•																					
Future (Estimated 2021) Conditions				•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Non-withdrawal (In-stream) Uses																								
Current Streamflow Targets	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	MES			IAS (GROUP 1)								IAS (GROUP 2)					IAS (GROUP 3)							

MES: Model-Evaluation Scenario IAS: Impact-assessment Scenario

2.2.5 Analysis of Results

2.2.5.1 Model Evaluation

Levels and Flows

Simulated levels and outflows for the Belwood, Conestogo and Guelph reservoirs and streamflows at Brantford were extracted from the MES1 output for the period January 1984 to December 1988, the portion of the 1951-88 study period for which the GRCA has measured reservoir levels and releases. A comparison of the simulated reservoir levels and outflows with the measured values (Figures 2.28-2.30) shows a reasonable match. Generally, the model followed the rule curves more rigidly than the actual reservoir operation. In September and October 1986, for example, GRCA staff passed a large rainfall event through the system while WUAM held the water in the reservoirs, releasing it over two or more months. Simulated streamflows at Brantford (Figure 2.31) also compare well with measured values. In all cases, the annual redistribution of flow at each site suggests adequate model operation.

Target Streamflow Satisfaction

Table 2.19 presents the percentage of time during the 1951-88 study period that the specified monthly target streamflows at Doon, Hanlon and Brantford were satisfied for each of the model-evaluation scenarios. The summertime percentage satisfaction values produced using WUAM for MES1, representing current conditions, fall well below 100%, particularly at Hanlon, and are lower than results achieved by others using the GRCA Reservoir Yield Model assuming similar system operation conditions (Paragon Engineering Limited, 1994). However, the improvement due to streamflow regulation is apparent in the differences between results for MES1 and MES2 and, as expected, the addition of the West Montrose reservoir (MES3) further improves the degree of target flow satisfaction at Doon and Brantford. Therefore, it appears that WUAM adequately routes surface water supplies for comparison purposes although relative differences between scenarios should be considered--not their specific monthly values. Model limitations with respect to time step and reservoir simulation capabilities are acknowledged and should be kept in mind when drawing conclusions about climate change impacts.

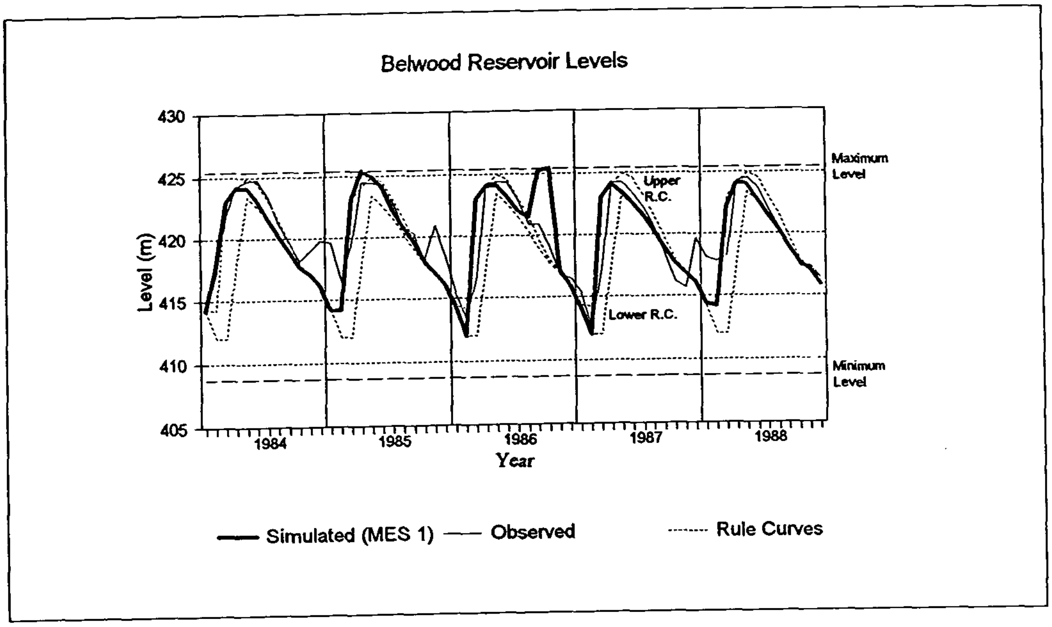
2.2.5.2 Interpretation of Scenario Impact on Streamflows

Target flow satisfaction and the distribution of streamflows about the targets were selected as the basis for interpreting scenario impacts on streamflows. This approach was possible since, as noted earlier, the current streamflow targets were selected to represent non-withdrawal water uses for all model-evaluation and impact-assessment scenarios. MES1, reflecting current basin conditions, represents the Basis-of-Comparison (BOC) scenario for evaluation purposes. Comparisons with the BOC and between impact-assessment scenarios are made. Conclusions about climate change impacts on Grand River streamflows must be made recognizing the model limitations and the uncertainties that exists in both the current and changed-climate condition surface water supply data used.

WUAM creates several output tables and plots for each scenario run. Portions of the output tables showing detailed information on target flow satisfaction and streamflow distribution at Doon, Hanlon, and Brantford have been extracted and are provided in Appendix C. Since the output tables can be difficult to interpret, summary data from the tables have been selected and are provided in graphical form for discussion purposes.

Table 2.19 - Monthly Target Streamflow Satisfaction (Percentage of Time Satisfied)

Target Streamflow Site	Month	Model-evaluation Scenario Name		
		MES1	MES2	MES3
DOON	Jan	100	100	100
	Feb	100	100	100
	Mar	100	100	100
	Apr	100	100	100
	May	100	89	97
	Jun	89	50	92
	Jul	89	26	95
	Aug	89	32	97
	Sep	84	32	97
	Oct	82	50	95
	Nov	100	87	100
	Dec	97	92	100
HANLON	May	100	100	100
	Jun	92	84	92
	Jul	87	58	87
	Aug	74	39	74
	Sep	71	50	71
	Oct	95	68	95
BRANTFORD	May	100	100	100
	Jun	100	87	100
	Jul	100	58	100
	Aug	95	61	97
	Sep	92	55	100
	Oct	95	71	100



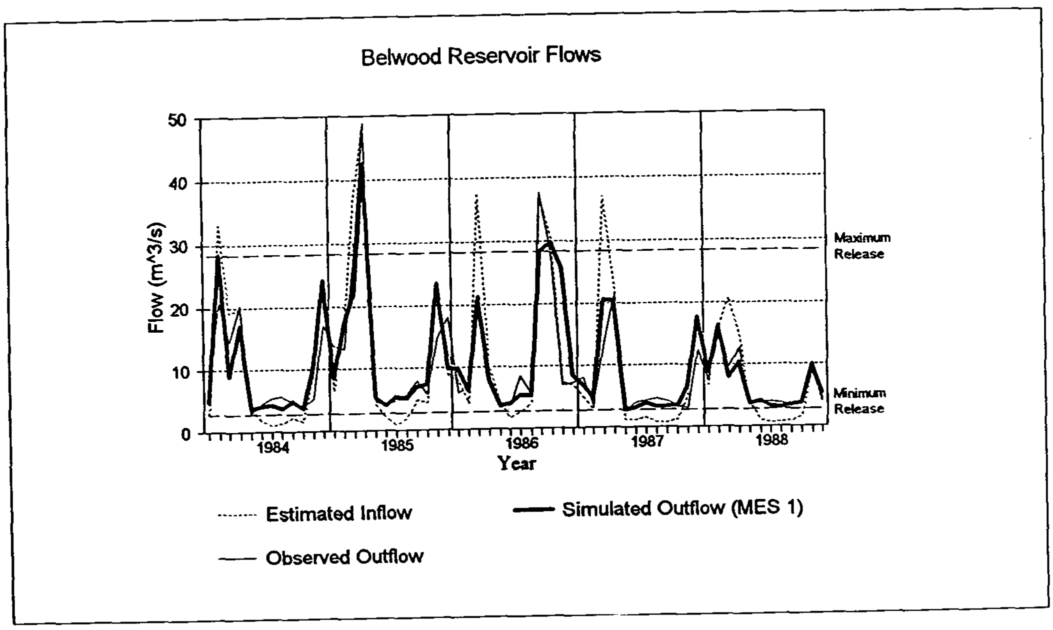
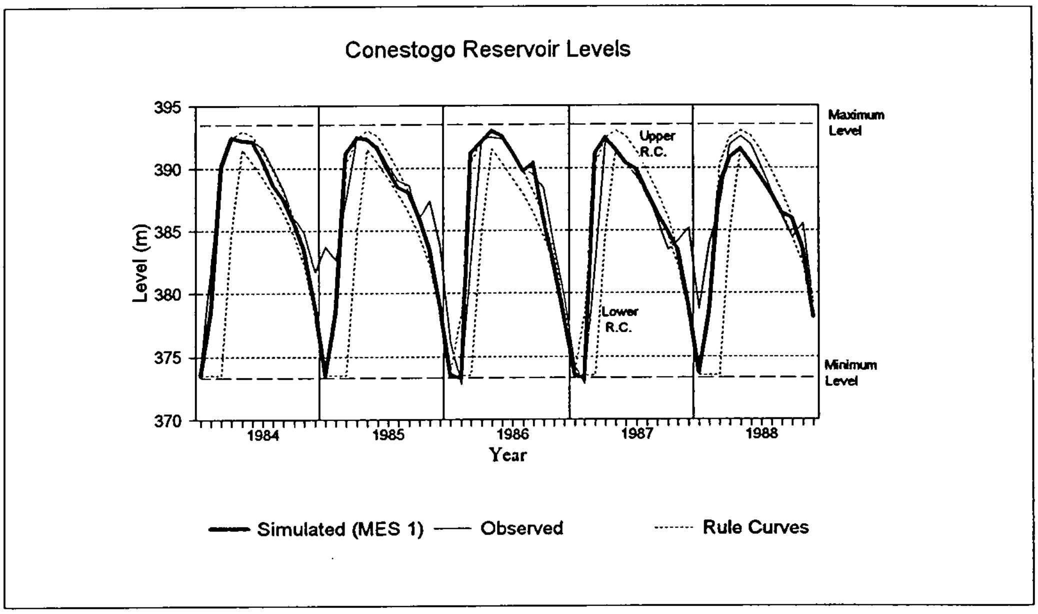


Figure 2.28 - Simulated and Observed Belwood Reservoir Operations



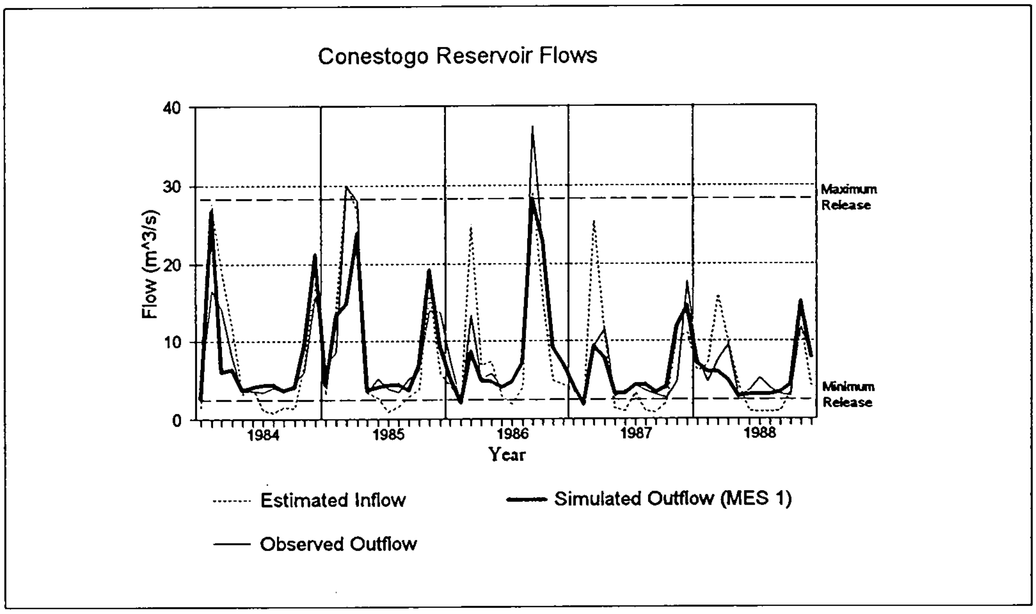
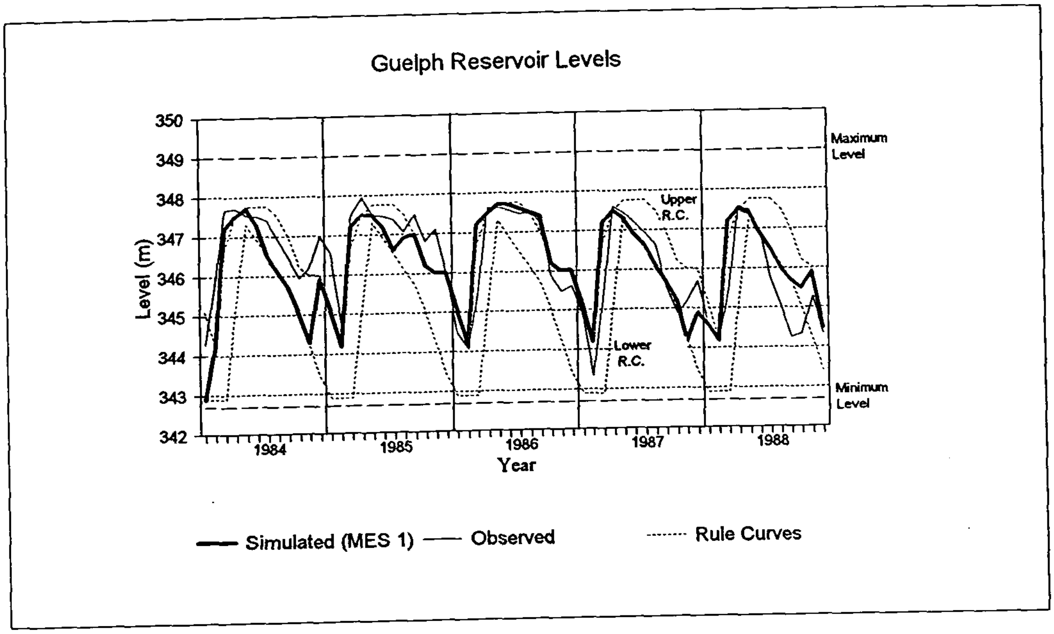


Figure 2.29 - Simulated and Observed Conestogo Reservoir Operations



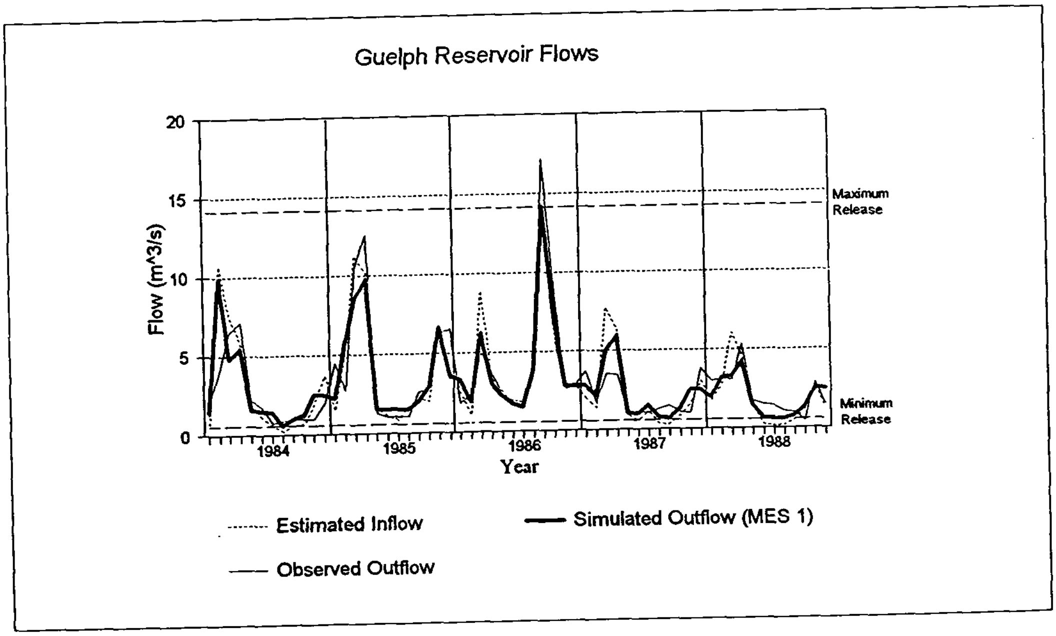


Figure 2.30 - Simulated and Observed Guelph Reservoir Operations

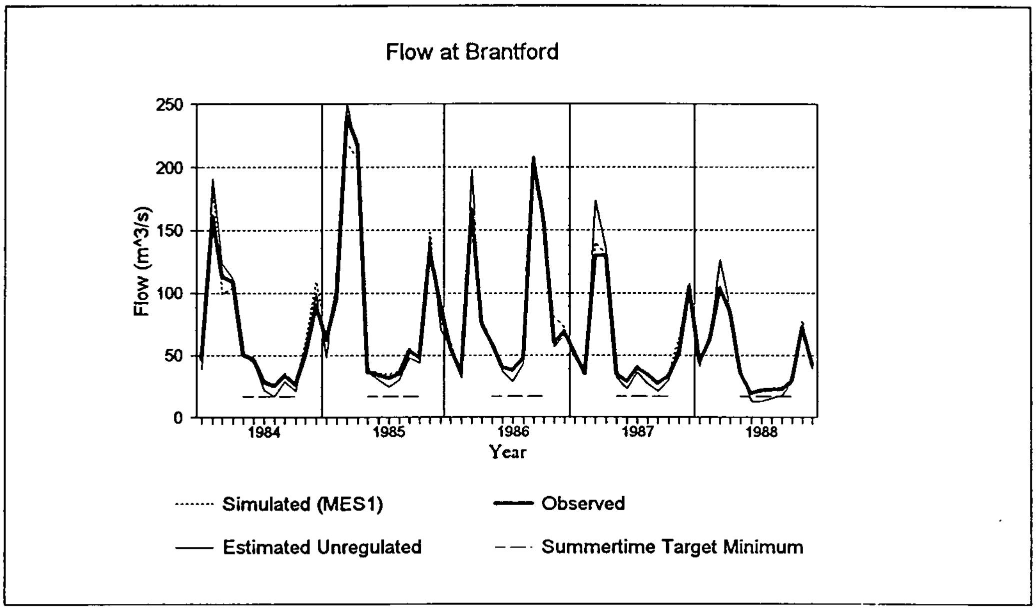


Figure 2.31 - Simulated and Observed Flows at Brantford

Model-evaluation Scenarios

Results for the three model-evaluation scenarios are presented first to help the reader interpret the graphical presentation selected. Figure 2.32 shows the overall percentage of time, by month, that the specified flow targets are satisfied for each evaluation scenario over the entire 1951-88 study period. As note, the summertime percentage satisfaction values produced using WUAM for the BOC (MES1) fall well below 100% but are considered adequate for comparison purposes. The differences between the BOC and "state-of-nature" (MES2) condition results are significant. Without regulation, July-September target flows would be satisfied less than 30%, 50% and 60% of the time at Doon, Hanlon and Brantford, respectively. The addition of a reservoir at West Montrose (MES3), improves conditions at Doon and, to a lesser extent, at Brantford. The addition of the reservoir has no effect at Hanlon which is located on the Speed River.

While, Figure 2.32 demonstrates the percentage of time minimum streamflow targets are satisfied, it does not give an indication of how flows are distributed relative to the targets. Appendix C tables provide month-by-month distributions information; however, Figure 2.33 provides a graphical representation of the summary data provided for each scenario. Typically, a stacked bar graph would be used to plot the information provided by WUAM; however, the line graph approach presented in Figure 2.33 was selected as it provided a clearer picture for discussion purposes. In Figure 2.33, the percentage of occurrence values plotted for x-axis ranges to the left of the vertical line (located on the 100-119% range line) represent a satisfied condition because the required target minimum flows are less than 100% of the available streamflow. Values to the right of the vertical line represent unsatisfied conditions, since the target flows are greater than the available streamflow. Since a value of 100% (available streamflow equals target flow) would also represent a satisfied condition, in some cases, the

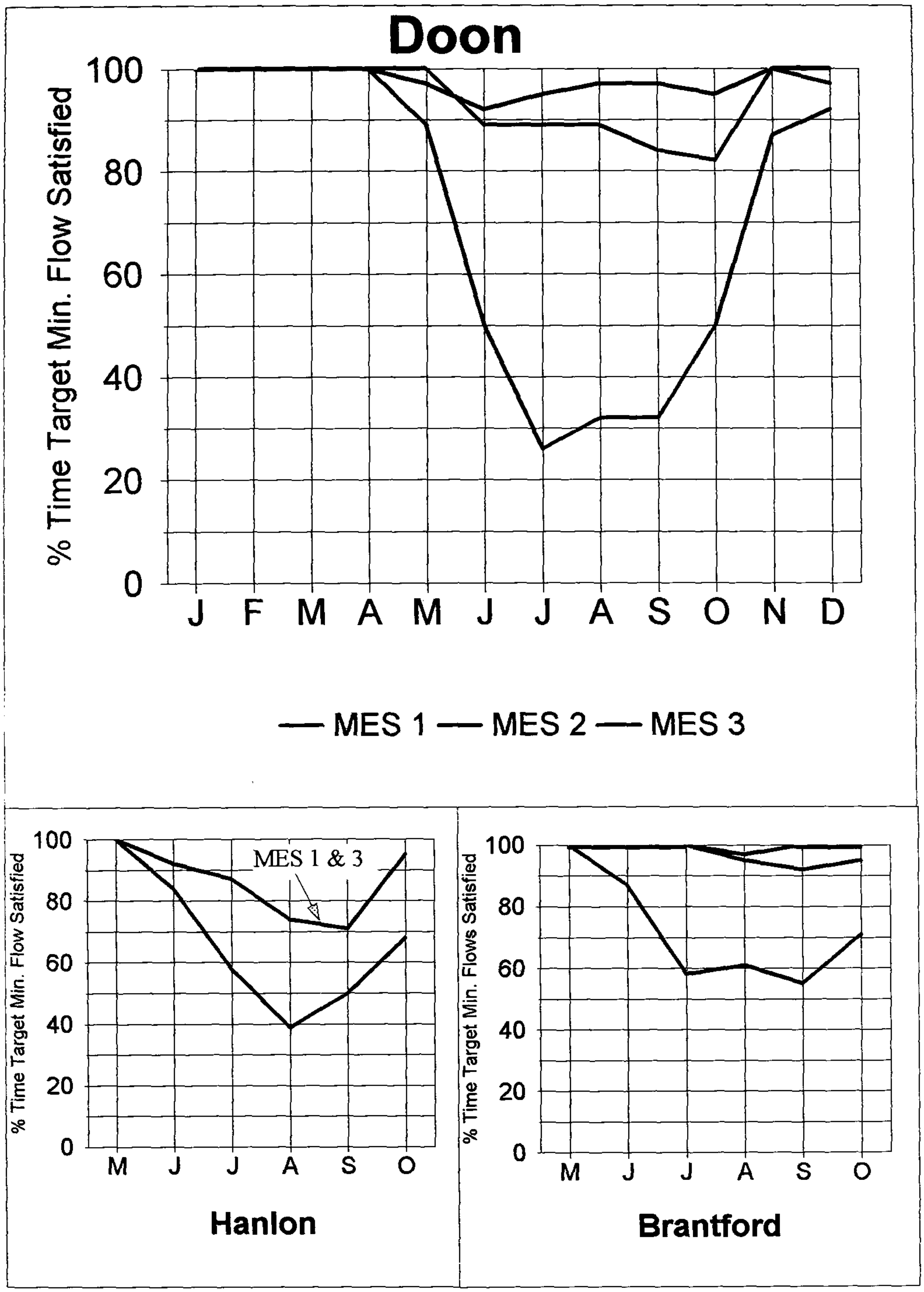


Figure 2.32 - Target Flow Satisfaction: Model-evaluation Scenarios (MES 1-3)

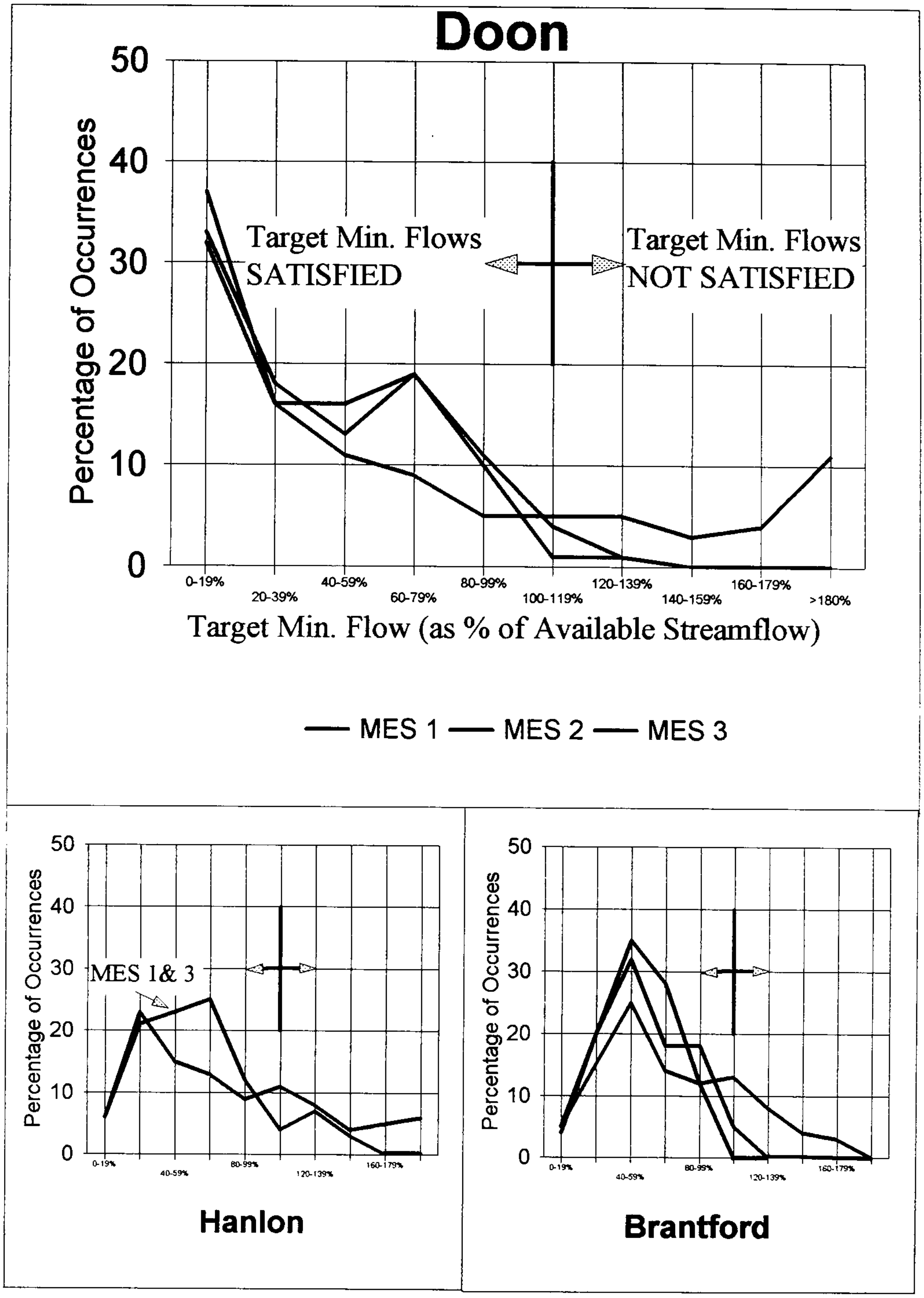


Figure 2.33 - Flow Distribution: Model-evaluation Scenarios (MES 1-3)

100-119% range may include a satisfied month or two. Generally, high values to the left of the vertical line and low (preferably zero) values to its right are desirable. Very high values for the lowest range (0-19%) may not be desirable as these may represent extreme high flow conditions. In the case of Doon, where high values do appear in this range, it must be remembered that relatively low targets are specified at this site for January through April. No targets are specified at either Hanlon or Brantford for this time period.

From Figure 2.33, it can be seen that MES2, representing unregulated flow conditions, has several occurrences of flows for all ranges in the unsatisfactory zone. For example, at Doon the demanded minimum flow (the specified target) is greater than 180% of the available streamflow more than 10% of the time. While conditions are relatively better at Hanlon and Brantford, both sites have a large number of occurrences in the unsatisfactory zone. Conditions improve significantly for the BOC (MES1) representing current regulation conditions and slightly more at Doon and Brantford with the addition of the West Montrose reservoir (MES3).

Impact-assessment Scenarios

Impact-assessment scenarios discussions are organized by the three reservoir configuration and operation groupings used in Table 2.18. The impact-assessment scenarios are described using the selected surface water supply scenario's name (e.g., CCC GCM II), the scenario's long-term percentage change in supplies relative to the base case (e.g., -51%), the IAS number (e.g., IAS2) or a combination of these items. In addition, the MES1 reference for the BOC scenario has been dropped for discussion purposes.

Group 1- Current reservoir configuration assuming current reservoir operation (IAS1-8)

The results for Group 1 scenarios are provided in Figures 2.34 and 2.35. With respect to target flow satisfaction Figure 2.34 indicates that:

- Target flows are satisfied less often under all combinations of surface water supply and 2021 water use (IAS1-8) than under the BOC. Results for the changed-climate supply scenarios (IAS2-8) are significantly worse.

- The difference between the BOC and Base Case scenario (0%, IAS1) represents the difference between current (1991) and estimated future (2021) water use and wastewater production. Impacts at each site reflect changes in water abstraction and wastewater contributions upstream.

- Differences between the BOC and IAS2-8 are a combination of the impact of the selected surface water supply scenario and the change in water use as defined by the difference between the BOC and Base Case scenario (0%, IAS1).

- Of the changed-climate scenarios (IAS2-8), the Arbitrary BC-20% linear change scenario (-20%, IAS7) has the highest percent satisfied values for all months, with the exceptions of September and December at Doon, July and September at Hanlon and July at Brantford.

- Even when changed-climate supply scenarios have similar long-term average change values, their impacts can differ significantly. Comparisons between the results for the MCC3 (+13%, IAS5) and MCC4 (+14%, IAS6) scenarios as well as between the

MCC2 (-19%, IAS4) and the Arbitrary BC-20% linear (-20%, IAS7) scenarios demonstrate this.

- A small long-term percentage change in supplies does not necessarily produce a small impact on streamflows. For example, the results for the MCC1 (-2%, IAS3) scenario fall between the MCC2 (-19%, IAS4) and the Arbitrary BC-20% linear (-20%, IAS7) scenarios.

- The streamflows for the CCC GCM II (-51%, IAS2) scenario satisfy the targets at Doon zero percent of the time in July and August. Results for this scenario approach zero during August and September at both Hanlon and Brantford. Results for the Arbitrary BC-50% linear (-50%, IAS8) scenario are consistently better than those of the CCC GCM II (-51%, IAS2) scenario.

With respect to flow distribution, Figure 2.35 indicates that:

- Under current reservoir operating conditions, all impact-assessment scenarios (IAS1-8) have flow distributions less desirable (i.e., higher Percentage of Occurrence values to the right of the plot) than the BOC. The Arbitrary BC-20% linear (-20%, IAS7) scenario is generally the least severe of the changed-climate scenarios.

Based on the results for IAS1-8, the following general points can be made:

- Without some form of remediation, all combinations of future surface water supply and water use fall below the BOC in terms of target satisfaction. Even if it is assumed that the BOC conditions were modelled better than is possible with WUAM (i.e., 100% satisfied for all months) and all the impact-assessment scenario results adjusted upward accordingly, the impacts on streamflow would still range from modest to severe.

- Although overshadowed by changes in surface water supply conditions, changes in water use add an additional negative impact on flows for all scenarios, particularly during the low-flow summer period.

- The long-term percentage change in supplies relative to Base Case conditions, often used to describe a future supply scenario, does not adequately indicate its potential impact. A long-term percentage change value does not provide information about changes in the variability or the seasonal distribution of supplies.

- Linear reduction surface water supply scenarios can be handled better by the current reservoir operation than a non-linear change scenario since the seasonal distribution of inflows to the reservoirs does not change. A changed-climate supply scenario based on linear reductions in base case streamflows may not adequately test the robustness of a river system.

- A 50% reduction in supplies, linear or non-linear, is too severe to be handled by current reservoir configuration and operation. Neither supply scenario provides adequate water for current operational purposes.

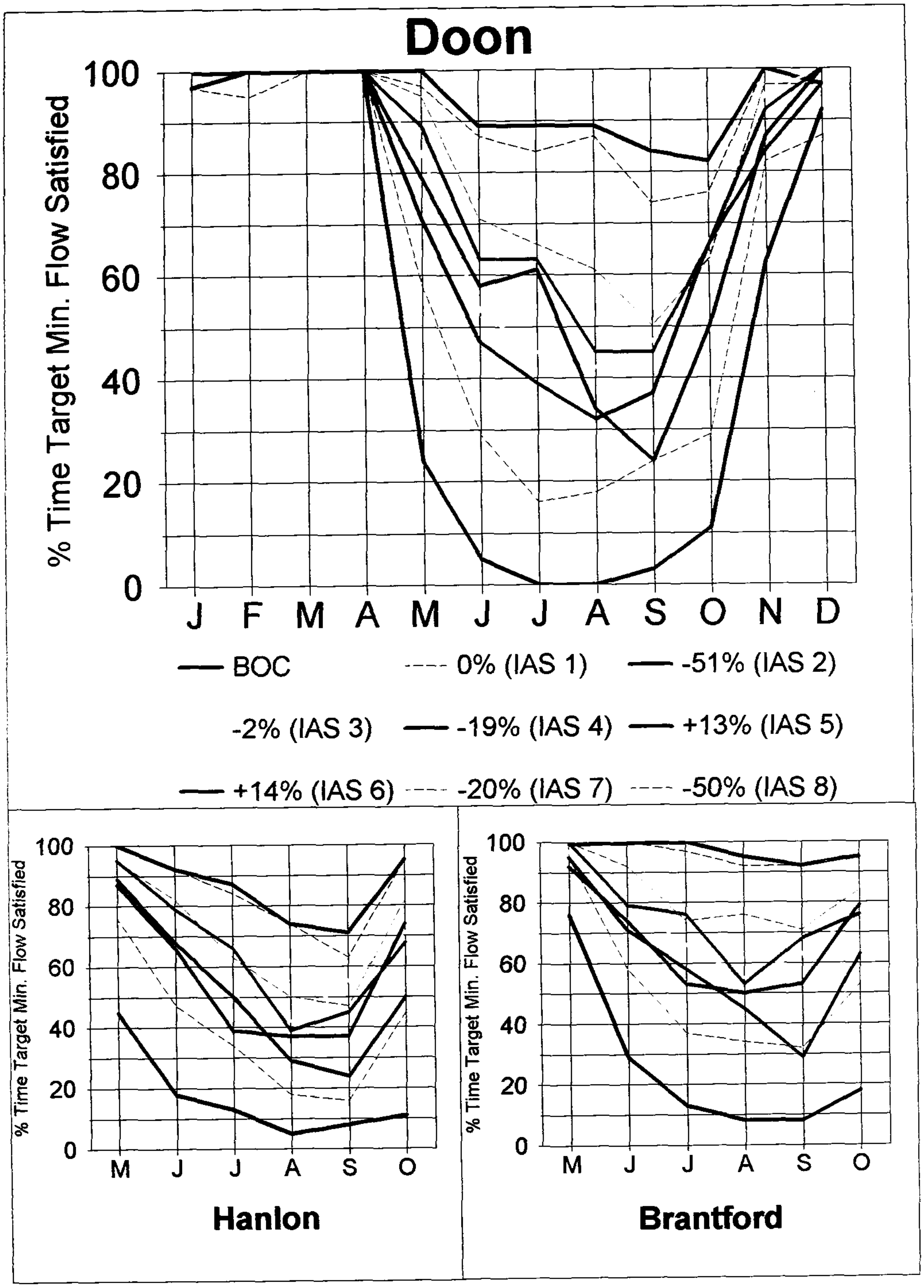


Figure 2.34 - Target Flow Satisfaction: Group 1) Impact-assessment Scenarios (IAS 1-8)

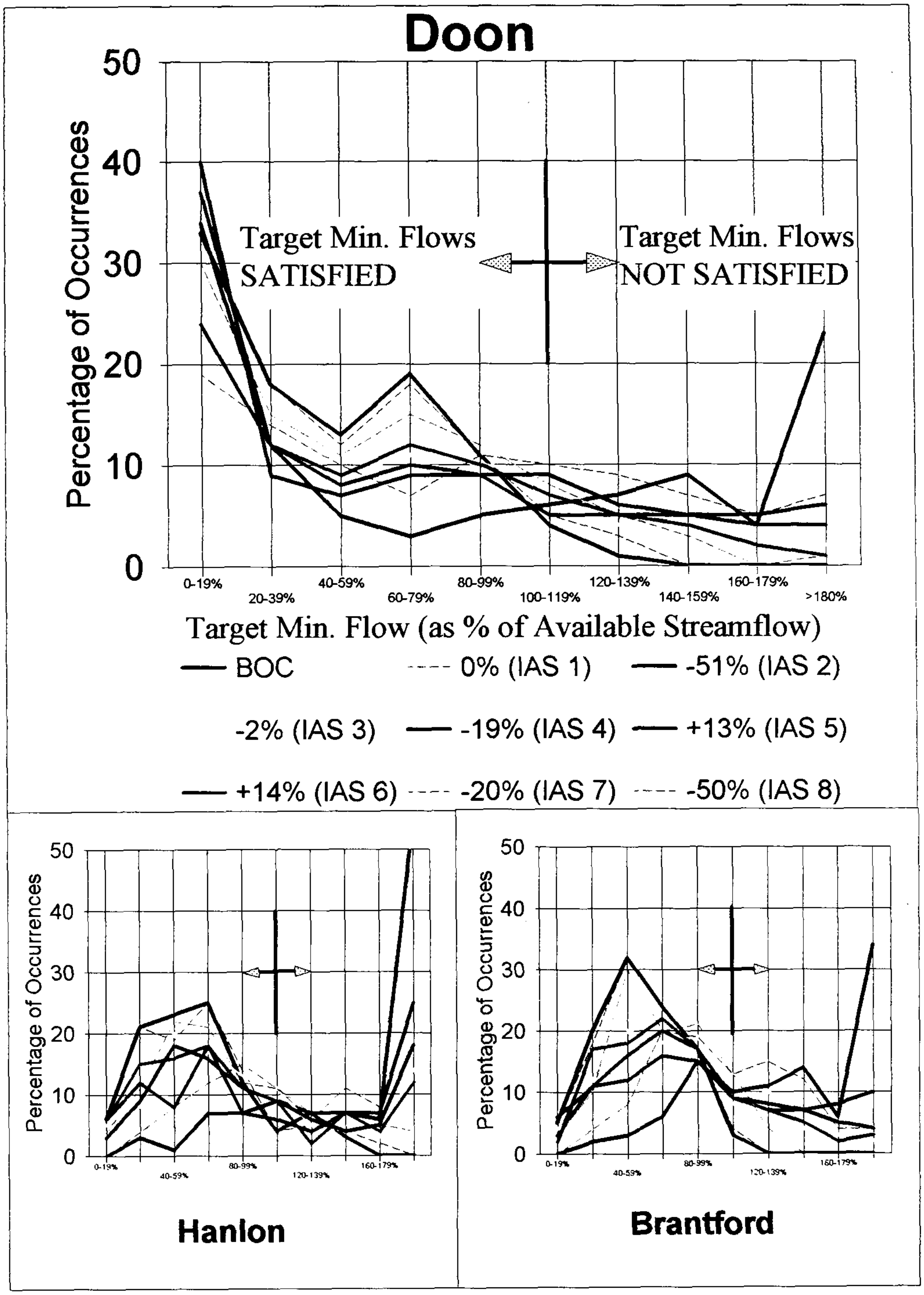


Figure 2.35 - Flow Distribution: Group 1) Impact-Assessment Scenarios (IAS 1-8)

Group 2 - Current reservoir configuration assuming modified reservoir operation (IAS9-13)

The results for Group 2 scenarios (IAS9-13) are presented in Figures 2.36 and 2.37. Simulation runs assuming modified operation were not carried out for the Base Case nor the Arbitrary BC-20% and BC-50% linear supply scenarios as they do not include a shift in the seasonal distribution of supplies. The results for IAS1, IAS7 and IAS8 are, however, included in the two figures for comparison purposes. From Figure 2.36 the following observations can be made:

- The percentage of time the minimum targets are satisfied increases for all GLSLB Project specified non-linear change supply scenarios (IAS9-13). Results improve more at Doon and Hanlon than at Brantford since reservoir releases make up a higher percentage of the summertime flows at Doon and Hanlon.

- At Doon, the MCC1 (-2%, IAS10) and the MCC4 (+14%, IAS13) scenario results approach those of the Base Case (0%, IAS1).

- The MCC2 (-19%, IAS11) and CCC GCM II (-51%, IAS9) scenario results improve and approach those of the Arbitrary BC-20% linear (-20%, IAS7) and Arbitrary BC-50% linear (-50%, IAS8) scenarios, respectively.

- Zero percent satisfaction conditions no longer occur at Doon for the CCC GCM II (-51%, IAS9) scenario; however, August and September satisfaction rates do remain near zero.

- Although results for the MCC3 (+13%, IAS12) scenario improve, the simple rule curve modifications assumed are not adequate to deal with the September low experienced with this scenario.

Figure 2.37 shows that:

- The distribution of flows about the targets improves for all non-linear streamflow scenarios (IAS9-13)

The results for this group of runs suggests:

- Rule curve modification can partially accommodate a shift in seasonal distribution of surface water supplies. A rule curve designed specifically for a supply scenario may further improve the flow conditions; however, significant modifications to rule curves may not be possible.

- Rule curve modifications are not felt equally throughout the system. In addition, the modification of a reservoir's operation cannot improve conditions at locations upstream of the reservoir or on separate tributaries.

- With rule curve modifications, the results for a non-linear change supply scenario can become similar to those of a linear change supply scenario with the same overall percentage change. This condition may help researchers relate results between studies using linear or non-linear change scenarios.

Group 3 - Current reservoir configuration plus the West Montrose reservoir assuming current reservoir operation (IAS14, 20 and 21) or modified reservoir operation (IAS15-19) as required by the selected surface water supply scenario.

The results for Group 3 scenarios (IAS14-21) are presented in Figures 2.38 and 2.39. The results presented in Figure 2.38 indicate:

- The addition of the West Montrose reservoir improves target satisfaction for all impact-assessment scenarios (IAS14-21) relative to the BOC at Doon and Brantford. Improvements are larger at Doon than Brantford. The addition of the West Montrose reservoir does not improve conditions at Hanlon which is located on the Speed River.

- The Base Case (0%, IAS14) and the MCC4 (+14%, IAS19) scenario results are approximately equal to or better than the BOC at Doon. However, results for the MCC4 (+14%, IAS19) scenario do not improve as much at Brantford.

- The MCC1 (-2%, IAS16), MCC2 (-19%, IAS17), MCC3 (+13%, IAS18) and the Arbitrary BC-20% linear (-20%, IAS20) scenario results all improve but still fall below the BOC. At Doon, the results for these scenarios, with the exception of MCC2 (-19%, IAS17), approach those of the Base Case <u>without</u> the addition of West Montrose (0%, IAS1) as shown in Figures 2.34 and 2.36.

- Results for the CCC GCM II (-51%, IAS15) and the Arbitrary BC-50% linear (-50%, IAS21) scenarios improve only slightly compared to Group 2 conditions.

- A greater portion of the differences between the BOC and each impact-assessment scenario (IAS14-19) target flow satisfaction level can now be attributed to the assumed changes in water use.

Figure 2.39 indicates that, at Doon, flow distributions for all scenarios except the MCC2 (-19%, IAS17), CCC GCM II (-51%, IAS15) and the Arbitrary BC-50% linear (-50%, IAS21) scenarios approach the distribution for the BOC. Distributions at Brantford also improve; however, to a lesser extent.

Based on the results for IAS14-21 the following points can be made:

- The addition of a reservoir, such as the West Montrose, to the modified rule curve condition increases the system's ability to deal with significantly altered streamflow volumes and distributions.

- The addition of a reservoir will not be felt equally throughout the system. For example, currently the outflows from approximately 30% of the area above Brantford and 54% of the area above Doon are controlled (i.e., lie upstream of a reservoir). With the addition of the West Montrose reservoir these controlled areas increase to 34% and 68%, respectively. Adding a reservoir at West Montrose may help maintain target flows at Doon more than at Brantford under changed-climate flow scenarios. The addition of a reservoir cannot improve conditions at locations upstream of the reservoir or on separate tributaries.

- When water is not available, additional reservoir capacity can not help improve flow target satisfaction. Even when accounting for possible improvements related to actual operating conditions, the targets would not be met more than 50% of the time throughout the summer months for conditions as severe as those experienced under the CCC GCM II (-51%) or the Arbitrary BC-50% linear (-50%) scenarios.

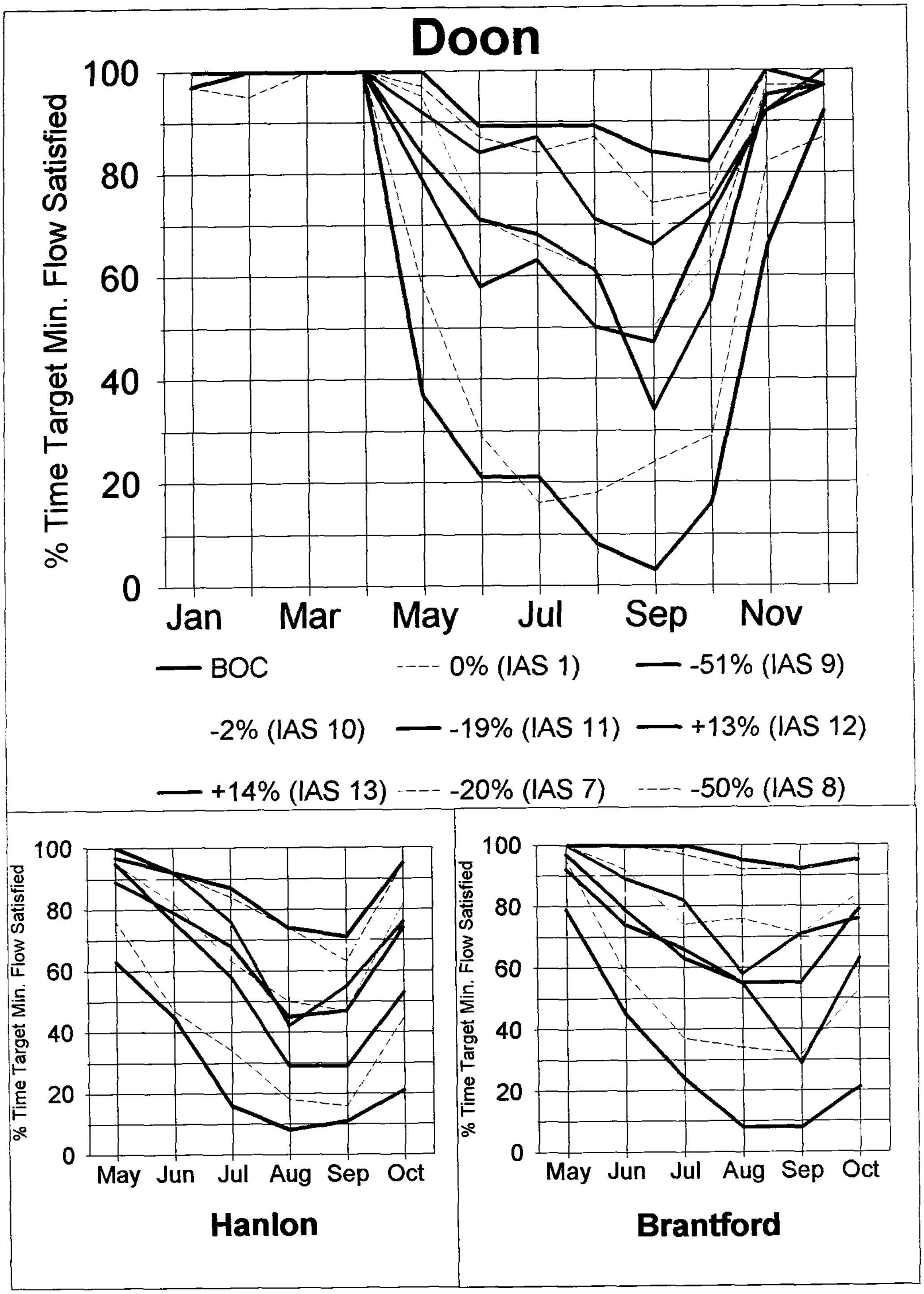


Figure 2.36 - Target Flow Satisfaction: Group 2) Impact-assessment Scenarios (IAS 9-13)

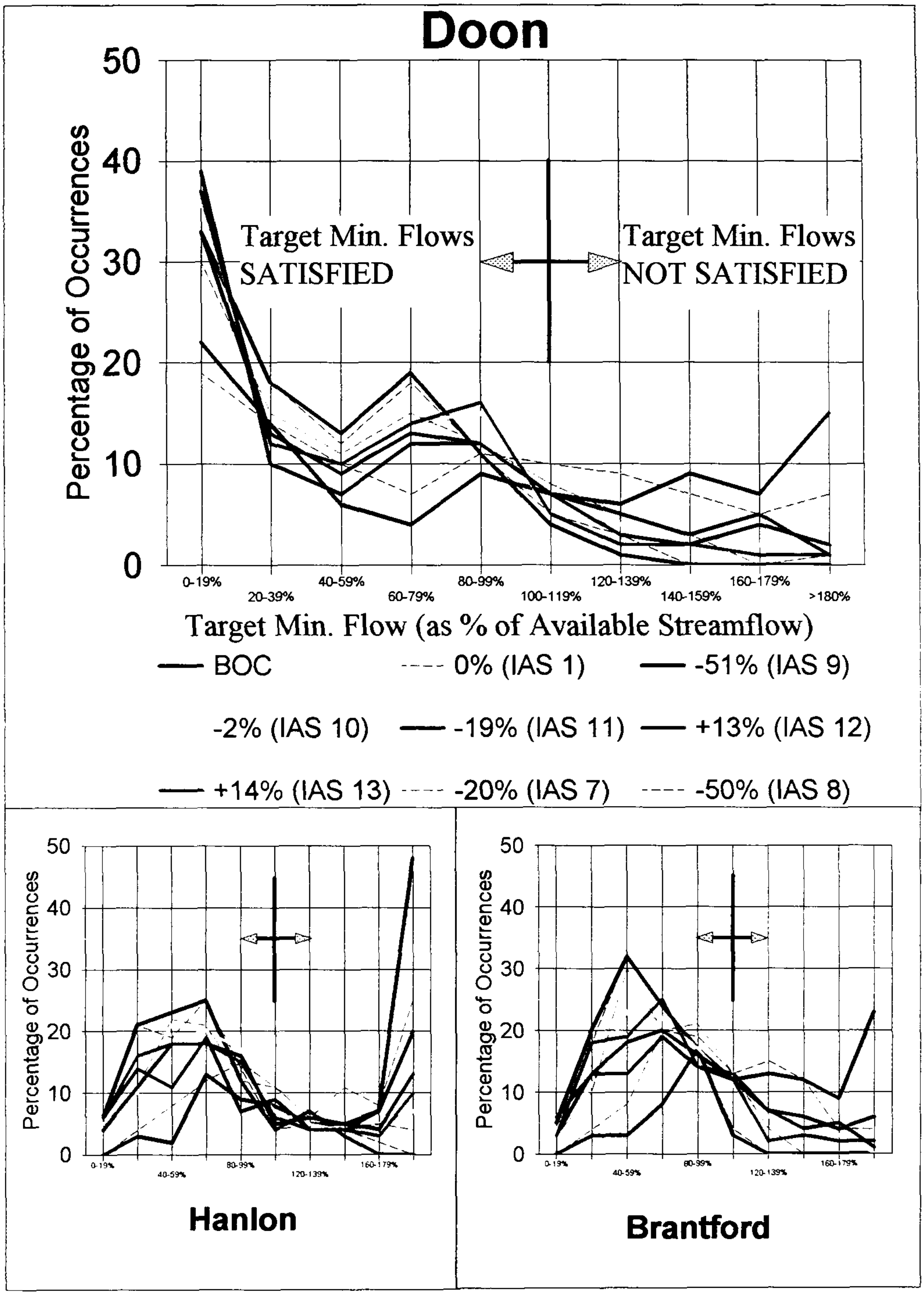


Figure 2.37 - Flow Distribution: Group 2) Impact-assessment Scenarios (IAS 9-13)

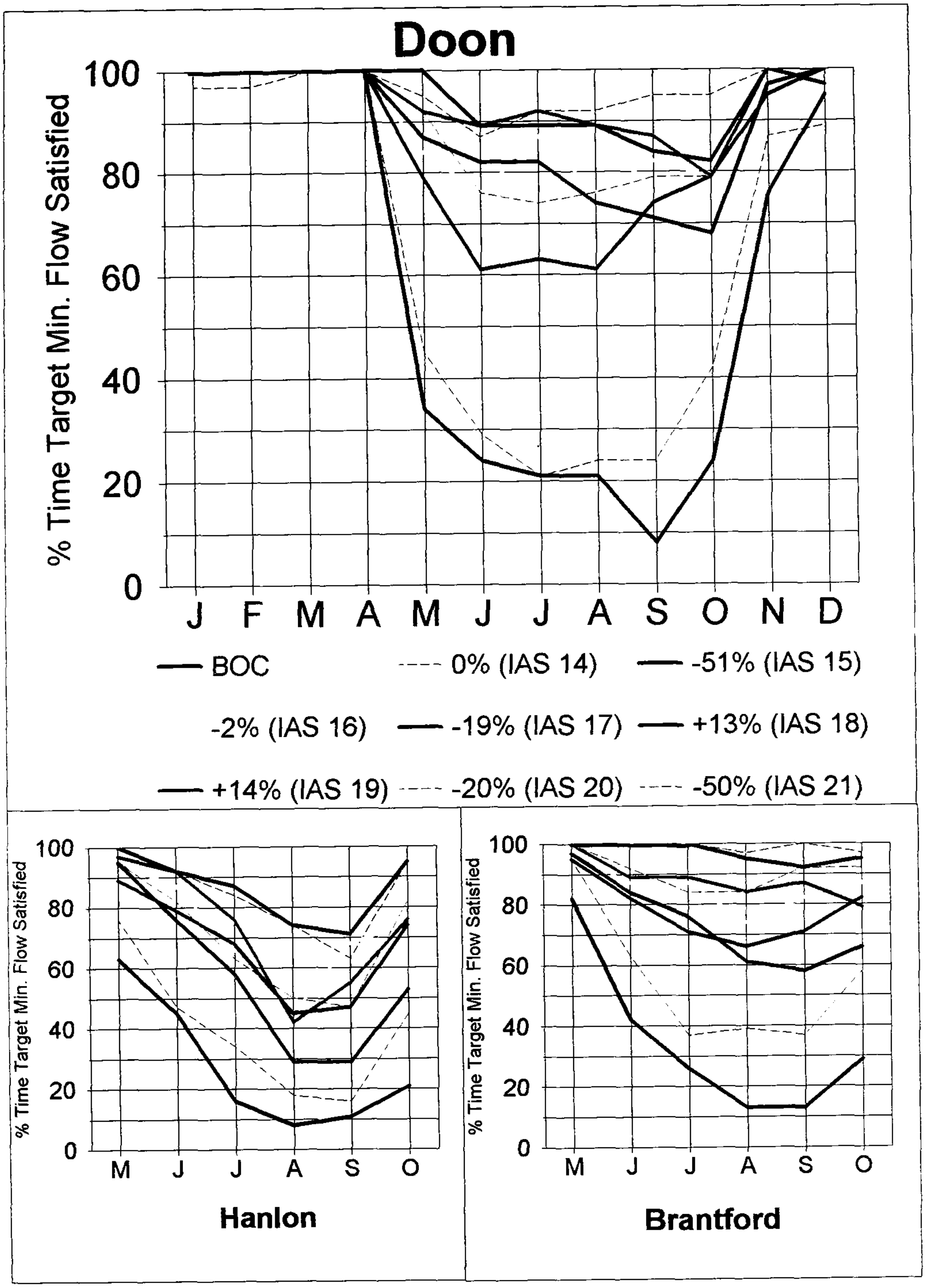


Figure 2.38 - Target Flow Satisfaction: Group 3) Impact-assessment Scenarios (IAS 14-21)

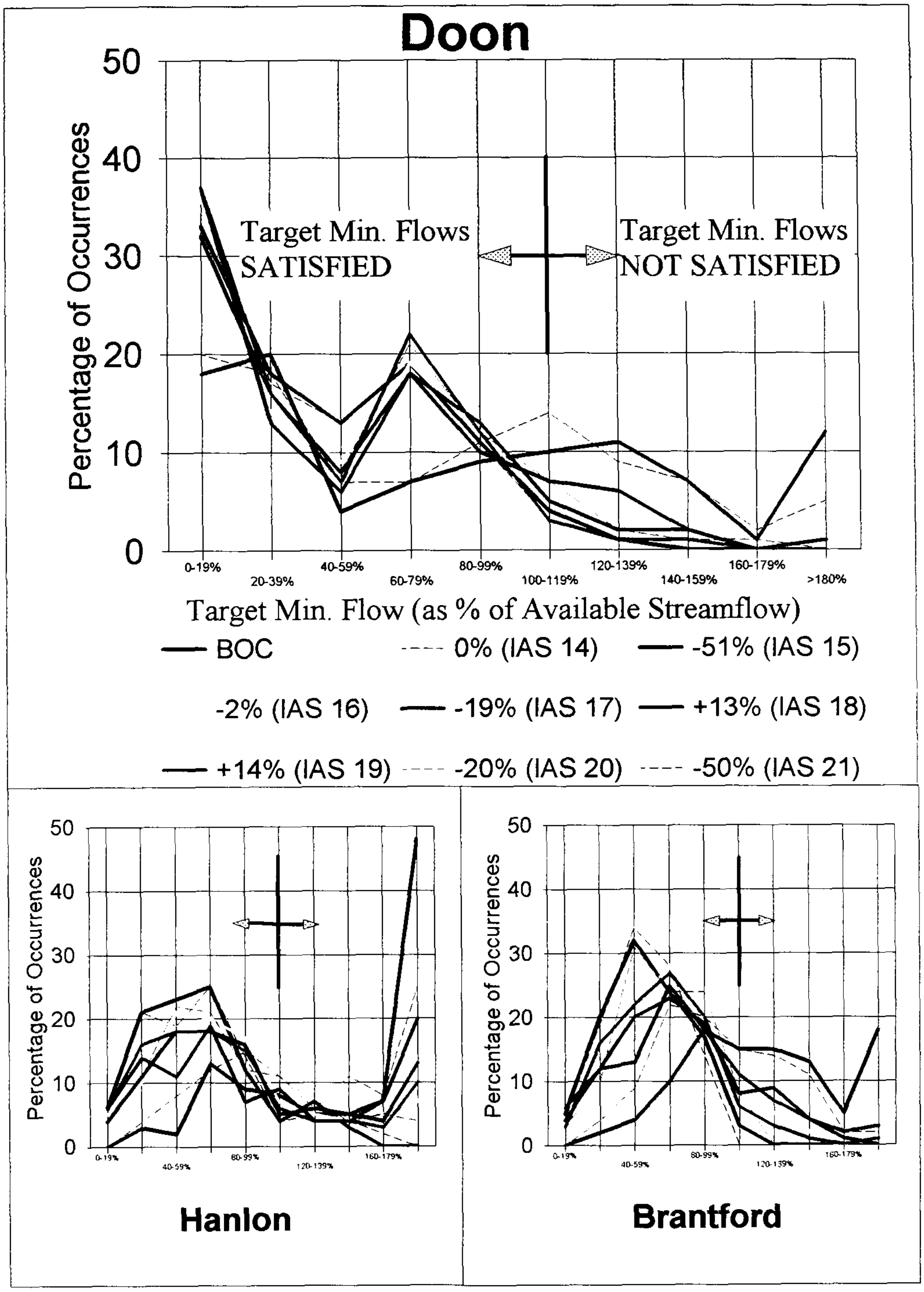


Figure 2.39 - Flow Distribution: Group 3) Impact-assessment Scenarios (IAS 14-21)

Overview

The figures and discussion presented illustrate general impacts only. While they are adequate for identifying trends, the tables in Appendix C should be consulted for further information. For example, it is possible for two scenarios to have similar summary results but significantly different flow distributions.

Scenario results are for comparison purposes only. The assumptions made in developing the changed-climate surface water scenarios and the modelling limitations must be noted. Actual operation is known to produce better reliability in meeting target flows. Nevertheless, trends between simulation run results are apparent and the modelling results provide some interesting insights into the impact of scenario selection. They also demonstrate the capabilities of the current and modified reservoir system. Results for the scenarios carried out provide adequate information to initiate discussions and develop adaptive strategies.

The following general points should be noted:

- The long-term percentage change in supplies, often used to describe a changed-climate supply scenario, does not adequately indicate its potential impact.
- Changed-climate surface water supply scenarios based on linear changes in historical supplies may not be adequate to test the system's robustness.
- By adjusting reservoir rule curves, results for non-linear surface water supply scenarios can become similar to those for a linear change scenario with the same long-term overall percentage change. This condition can facilitate comparisons between studies.
- While the impacts of the changed-climate surface water supply scenarios can overshadow those of increased water use, the latter are significant.
- Caution must be used when making conclusions based on results at only three target flow sites. The potential impact of climate change on supplies will be experienced basin-wide and the effects of adaptive measures, such as changes in reservoir configuration and operation, are not equal throughout the basin.
- Additional reservoir capacity can not improve conditions downstream if water is not available to fill the impoundment.

2.2.5.3 Attendant Impacts by Watershed Activity

The impact-assessment scenarios used in this study produce a wide range of impacts on streamflow. These changes would have an impact on water management capabilities in the Grand River system affecting watershed activities in terms of the objectives defined in the vision statement for the GRB. Presentations on preliminary study results were made to *The Grand Strategy* Coordinating Committee and three of its technical working groups. An information package and a questionnaire (see Appendix D) were sent to 108 people involved with *The Grand Strategy*. The mailing list was selected to target a group of people who manage activities dependent on or related to the river. As well as being a source of information for the study, the questionnaire mailing was seen as an opportunity to provide information about the study to *Grand Strategy* participants. Twenty-eight questionnaires were returned completed.

The following sections provide a brief discussion of potential impacts on watershed activities in terms of the objectives defined in the vision statement for the Grand River watershed as summarized in Table 2.1 (Section 2.2.1). The discussion is general in nature based on questionnaire feedback and the potential impacts on flows as suggested in the previous sections.

Water Quantity and Quality

The vision statement describes water supply and quality conditions sufficient to meet the current and future needs including domestic, commercial, industrial, recreational, agricultural and natural environmental uses. While impacts on groundwater supplies have not been investigated, the scenarios developed for this study indicate a potentially significant change in the overall volume and seasonal distribution of surface water supplies. Results for the impact-assessment scenarios suggest that meeting the minimum flow requirements at Doon, Hanlon and Brantford will become more difficult. The water supply and quality necessary to meet the vision objectives may not be available under climate change.

Significant amounts of water are abstracted from the river system to service Brantford, Six Nations, Guelph and the Regional Municipality of Waterloo. The capacity of the river system to provide a large and reliable source of clean potable water for current uses and to accommodate future growth is questionable under the climate change scenarios examined. The limited supplies would have to be allocated between human and environmental needs.

The current water supply strategy for the Tri-Cities indicates that by the year 2001, the existing Grand River withdrawal of 4 MIGD (0.2 m^3/s) will have to be increased (Paragon Engineering Limited, 1994). By the year 2025, the full permitted summer abstraction rate of 16 MIGD (0.8 m^3/s) will be required. The scenario results suggest that the abstraction of 16 MIGD from the Grand River may not be continuously possible even with the West Montrose reservoir and modified operations.

Streamflow impacts will affect the ability of the City of Guelph to abstract water for artificial recharge purposes from the Eramosa River. This result, combined with potential impacts of climate change on groundwater supplies themselves, will impact on the supply capability of the Arkell Springs well field.

Increases in wastewater discharge upstream, combined with increased difficulties meeting targets, will affect the security of the Brantford and the Six Nations water supplies. Alternate sources and/or supply strategies may be required.

Abstractions for livestock and irrigation will both affect and be affected by streamflow conditions under the changed-climate scenarios. Abstracting water under the low flow conditions during the summer months or increasing storage of the annual runoff event in ponds will impact the river system. Changes in supply conditions may affect irrigation practices and trigger water allocation disputes.

The changed-climate surface water supply scenarios specified for the GLSLB Project all produce a shift in the seasonal distribution of flows and a reduction in summer supplies. Scenario results suggest that modified operation of the existing reservoirs can help meet current streamflow targets. However, these modifications will not benefit large portions of the basin which are unaffected by reservoir operation. In addition, the reservoirs in the system are multi-purpose and other users would be impacted by changes in reservoir operation.

Throughout the GRB, the source of a community's water supply may be better known than the role the river plays in assimilating its wastewater. When the potential impacts of climate change on river flows are discussed, the focus is generally on how the impacts will affect water supplies. Currently there are discussions within the basin relating to building a pipeline from one of the Great Lakes to supply drinking water. One factor which may limit urban growth within the GRB is the ability of area streams to absorb treated wastewater. The capacity of the Grand River to receive additional treated wastewater to accommodate future growth is already questionable (GRCA, 1996a). The GRCA's streamflow targets are designed to ensure water quality by maintaining a desired ratio of treated wastewater to river water. If surface water supplies drop significantly due to climate change, water managers will have greater difficulty meeting the minimum streamflow targets. The capacity of the system to receive treated wastewater will become an even greater concern. This could trigger alternate approaches to the treatment and/or disposing of wastewater. For example, wastewater could become a resource for agricultural irrigation.

The fact that the GRCA maintains flow targets for water quality purposes is generally not well understood by the public. However, the public does benefit from the improvements in river conditions due to the low flow augmentation. Water-based activities and public expectations have evolved based on augmented flows and resulting improvements in water quality. Groups such as anglers have, and wish to continue to take advantage of the improved flow/quality conditions and further enhance fish populations. If climate change makes maintaining flows impossible and negatively affects surface water quality, the impacts on recreational uses throughout the basin will be significant. Equally, pressure from recreational interest groups may limit the ability of water managers to cope with changes in streamflow.

Flood and Erosion Potential

The impacts discussed thus far emphasize concerns about reduced streamflows in the GRB. These concerns are based on a modelling exercise which considered water balances over periods of one month and longer. Possible changes in the climatology of short-term extremes have not been addressed due to modelling constraints. There may be a tendency for both the public and professionals to equate the lower expected water yields in a greenhouse climate with a reduction or even elimination of flood risks. However, this could be an unwarranted and dangerous assumption since warmer temperatures could lead to a more vigorous hydrologic cycle (Environment Canada, 1995). Several models indicate that climate change may cause an increase in precipitation intensity, suggesting a greater occurrence of extreme rainfall events

(Environment Canada, 1995). Recorded evidence of this trend has been offered by the IPCC (1995) which reported that the proportion of rainfall attributable to extreme events for the contiguous United States has increased recently.

While a majority of historic flooding events in the Grand River basin can be attributed to high spring flows (GRIC, 1982), most often resulting from a combination of snowmelt and heavy rainfall, two of the larger floods, occurring in October 1954 and May 1974, were associated with warm season rains. Should extreme rainfall events become more common, a greater proportion of floods may occur during the warm season. Event-oriented modelling is currently used by the GRCA for flood forecasting purposes. It has also being used to estimate the damage potential if a specific event, such as the July, 1996 Saguenay, Quebec storm, hit the Grand River watershed (GRCA, 1996b). While estimates of shifts in precipitation frequency and intensity resulting from climate change are currently speculative, the risk is great enough to justify more event-oriented hydrological modelling in the GRB. This modelling effort is required to assess the watershed response and possible damages from individual storm events in a climate affected by greenhouse warming.

In the past, erosion problems have been caused by natural erosion processes and through human interference with natural channel processes; for example, straightening streams, confining flows in the channel and removing stabilizing vegetation. Rehabilitation efforts using bioengineering and natural channel design methods to improve self-maintenance and restore natural channel processes may be hampered by a change in seasonal flow distribution and chronic low flow conditions.

Growth and Business Development

The growth and development vision describes a future where growth is promoted and accommodated in such a way that resources are sustained. The pressure for continued growth is substantial. The central part of the GRB is one of the fastest growing areas in Ontario (GRCA, 1996a) and the basin's population is expected to increase by about 50% by the year 2021. Climate change may affect this vision through impacts on water supplies, a critical resource which supports population growth, business and tourism development within the basin. Specific implications resulting from modelling efforts are described in the sections on water quantity and quality and outdoor recreation.

Natural Areas and Biodiversity

The vision for natural heritage and biodiversity emphasizes the continued protection and enhancement of areas and species which are representative of the GRB's natural heritage. This vision reflects a desire to curb the mounting pressures of human settlement encroachments, arguably the most significant factor altering the landscape over the past two centuries. However, it must be recognized that environmental conditions are in constant flux, although these changes are less perceptible than those attributable to contemporary human influences. As environmental conditions change, so will terrestrial and aquatic ecosystems; certain species which are considered "natural" today will cease to exist in the future. Human-induced climate change threatens to accelerate environmental change and is a pressure which may exert significant impacts upon natural ecosystems (IPCC, 1992; Rizzo and Wiken, 1989). Therefore, human-induced climate change must be considered in the future management of ecosystems.

This study is focused on issues related to water management within the basin. The clearing of forests prior to the beginning of this century altered the hydrology of the Grand River and its tributaries. Without a significant forest cover, water drains much more rapidly into streams as it is not retained and slowly released following precipitation or snowmelt. As a result, watersheds lacking significant cover are much more responsive to precipitation. This fact has two major implications on streamflow: higher high flows during flood events and lower low flows during dry periods.

The operation of the Belwood, Conestogo and Guelph reservoirs has in part compensated for the change in runoff characteristics; however, much of the system is unaffected by reservoir operations. The GRCA has been attempting to reforest sections of the watershed to enhance its flood protection and water management efforts. The potential impact of climate change on streamflows highlights the value of continuing efforts to target reforestation and natural regeneration to areas with the greatest hydrologic benefit. Those engaged in reforestation activities should recognize the potential for shifts in temperature and moisture regimes under climate change when selecting species for regeneration purposes. The direct impact of climate change and increased concentrations of CO_2 on forests has been examined primarily in the context of large commercial forestry activities, mainly in the boreal forest. Studies have noted the potential northward displacement of many Canadian ecosystems and a shrinking of the boreal forest (CCPB, 1991; Rizzo and Wiken, 1989). In the GRB, conditions may become more favourable for the northward encroachment of the Carolinian forest.

The issues associated with climate change and natural area management go beyond the scope of this study. Interested readers are encouraged to consult Bridgewater (1991), Wyman (1991) or Warrick *et al.* (1986) for additional information. Fooks (1996) developed a list of criteria to evaluate natural area management policies under climate change in the Hamilton/Halton region of southern Ontario. Some of her findings may be relevant to the Grand River watershed.

Tourism and Recreational Uses

While not the primary focus of this study, it is recognized that in-stream water uses are a significant factor in the management of the GRB. Water-based recreation is an important and growing resource for local residents and tourists (O'Neill, 1990; GRCA, 1994).

A descriptive inventory of recreation activities in the GRB was compiled by O'Neill (1990). The information presented has been synthesized into Table 2.20 to present an account of various forms of recreation in the basin. Climate variability and change may affect each of these activities differently as some rely on certain flow ranges (canoeing), others on the volume of water in the reservoirs (power boating), some on the presence of adequate snowfall (cross-country skiing) or lack of inclement weather (festivals) and some on the quality and temperature of the water (swimming and fishing). Most activities are sensitive to multiple aspects of climate variability and change. Many of the water-based activities listed above have evolved rapidly based on streamflow and water quality characteristics of the recent past. The adjustments necessary to deal with altered flow regimes may be difficult to make.

Table 2.20 - Extent of Various Forms of Recreational Activities in the Grand River Basin

ACTIVITY	EXTENT
Canoeing	Grand River from Belwood Lake to Port Maitland on Lake Erie. Portions of Conestogo, Nith and Speed Rivers
Power boating	Belwood and Conestogo reservoirs, Grand River below Brantford
Water skiing	Belwood and Conestogo reservoirs, Grand River above Dunnville
Sailing/windsurfing	Belwood, Conestogo, Guelph and Laurel Creek reservoirs; Shade's Mills and Pinehurst Lake
Swimming	Any access point along the Grand River; 13 active Conservation Areas; municipal and commercial parks, Lake Erie shoreline near river outlet
Nature/Scenic Appreciation	Luther Marsh, Elora Gorge, Dumfries landscape complex between Cambridge and Paris (Grand River Forest), Guelph Lake, Dunnville marshes
Fishing	Throughout Grand River (more diversity in lower section); Conestogo Lake, Belwood Lake, Guelph Lake
Hunting	Luther Marsh, Conestogo Lake Conservation Area, hunting preserves managed by the Ontario Ministry of Natural Resources
Trails and Corridors	Throughout the Grand River Valley
Human Heritage Appreciation	Sites throughout Grand River Valley including Elora, Kitchener-Waterloo, Cambridge, Paris, Brantford to Dunnville
Cross-country skiing	Elora Gorge, Laurel Creek, Pinehurst Lake, Shade's Mills Conservation Area
Snowmobiling	Trails around Belwood and Conestogo Lakes, Luther Marsh
Festivals/Public events	Major Grand River festivals in Cambridge, Brantford and Dunnville

Source: O'Neill, 1990 with updates by D. Boyd and B. Veale, GRCA, personal communication, 1997

Fisheries are a key element of the Grand River's recreational and tourism resources. Approximately 80 to 100 species of fish inhabit the Grand River watershed, 20 to 25 of them are gamefish sought by anglers (W. Yerex, GRCA, personal communication, 1996). Species diversity generally increases from the headwaters to the outlet at Lake Erie (O'Neill, 1990). Recent attempts to cultivate a brown trout sports fishery in the upper stretches of the Grand have been tremendously successful, with the fishery receiving many accolades in popular magazines (Poling, *Outdoor Canada*, 1996; Kettle *et al.*, *Ontario Out of Doors*, 1995; Bastian, *Fly Fisherman Magazine*, 1995). The importance of the fishery is reflected in the shared management plan for the watershed which envisions a future world class resource generating substantial contributions to the local economy.

Based on climate impact research in other regions (Magnuson *et al.*, 1990; Regier and Meisner, 1990) and the possible effects on Grand River streamflows described previously, climate change may affect the future sustainability of the Grand River fishery, to the detriment of some species and to the advantage of others. The following aspects of the fishery appear most at risk:

- species such as the brook trout which are presently near their tolerable environmental thresholds for water temperature and other water quality factors (Meisner, 1990);
- species including the brown trout which in some locations are dependent upon human manipulation and augmentation of streamflow;
- fisheries which could be adversely affected by invasive species taking advantage of the new water habitats afforded by a changed climate (Mandrak, 1989).

As climate change alters the future fishery it will also impact on the economic activities which have evolved from the promotion and capitalization of the resource.

In responding to a particular issue, including climate variability and change, the relative value placed by various management authorities and interests on particular uses of water in the basin must be considered. Typically recreational uses are viewed as being secondary to the provision of water to municipalities or to the assimilating function the river provides sewage treatment plant effluent (GRIC, 1982). However, as efforts to capitalize on recreation resources increase, through the designation of the Grand River as a Canadian Heritage River for instance (GRCA, 1994), the value of recreational uses will undoubtedly increase in some areas to the point where conflicts with other interests could arise. The need to manage outdoor recreation on a watershed basis will be magnified under the potential impacts of climate change.

2.3 Identification of Adaptation Options

There are three general responses which can be taken in coping with or adapting to the potential impacts of climate change and variability. One could ***do nothing*** until there is a greater certainty concerning the timing, rate of change and nature of regional impacts. In light of the mounting evidence supporting global climate change, this approach seems unwarranted. At the opposite end of the response spectrum, one could ***assume a worst case scenario*** and react swiftly and aggressively regardless of cost or other implications of actions. If the certainty of regional climate change and impacts were high, or if climate were the only factor considered in decision-making, this might be a suitable approach; however, neither condition is true. A more palatable and medial position is to ***take a precautionary adaptive approach*** by identifying and implementing responses that make sense now even if the worst case scenario does not materialize. Such an approach to climate change involves being pro-active with respect to potential risks and impacts as well as opportunities that occur.

2.3.1 Adaptive Measures

There are many alternative classifications of adaptive measures. Adaptations may be categorized into "software" (programs, behavioural modification) or "hardware" (machines, structures) options (NAS, 1991). Adaptations can be grouped into legal, financial, economic, technological, public education, management, research and training measures (Carter *et al.*, 1994) or organized by social scale, economic scale, duration, timing or spatial unit (Smit, 1993). In de Loë and Mitchell (1993) a list of 72 measures was organized by measure goal and/or type (increase supply, ensure quality, administrative). Nuttle (1993) categorizes adaptive measures as either incidental or purposeful.

Incidental Adaptation

Incidental adaptation to climate change is described by Nuttle (1993) as occurring when an action motivated for another purpose has an additional effect of reducing the impact of climate change. Incidental adaptation results from good water management practices. By accounting for uncertainties in what is known about climatic and hydrologic processes, and designing a water resource system with robustness, resilience, flexibility and reliability, the capacity exists to accommodate many perturbations whether they originate from climate variability, commodity price fluctuations, economic restructuring, population growth, or other environmental, economic or social factors.

Purposeful Adaptation

Purposeful adaptation refers to measures taken primarily to reduce the impacts of climate change. The objective of a purposeful adaptive measure may be to prevent effects, share the loss, bear the loss or avoid the loss. A broader classification of purposeful adaptation is provided in Table 2.21. Numerous adaptive measures are noted in the literature. A detailed inventory of adaptation measures was compiled by Smit (1993) for a number of human activities including the water resources sector. Nuttle (1993) specifically addressed adaptation in water management to climate change. Many of the measures listed by Smit (1993) and Nuttle (1993) were noted by respondents to the survey of Grand River stakeholders by de Loë and Mitchell (1993) and to the questionnaire distributed as part of this study.

Table 2.21 - A Classification of Purposeful Adaptation Measures

Share the Loss	insurance; government support/subsidies
Bear the Loss	survival of the fittest, possible response (actually no response) if risk not considered worthy of action
Accept Loss	water rationing (for example, water available only on certain days or during certain hours of the day); changing from cold water fishery to warm-water (no-water?) fishery; more individual and community specific responsibility for handling shortages (e.g., cisterns, lagoons); accepting a certain frequency of crop failure for irrigated land
Modify the Events	global nature of problem means the GRB population cannot by itself undo the problem of climate change; can set mitigation targets as examples
Prevent the Effects	most responses fall within this category (generally either reduce reliance on river or increase reliability); varying levels of risk, some no-regrets options to lessen the effects
Education, Behavioural	minimal regrets, possible to raise awareness/appreciate the risk to support certain "prevent effects" options
Avoid the Impacts	changing use as a means to remove vulnerability is an option under severe climate change scenarios (for example, stop fishing brown trout, start fishing other species or take up another recreational pursuit more consistent with river conditions)

2.3.2 Adaptations Options

At present, research on climate change impacts and adaptation can only address possible changes using a "what if" scenario approach but risks and potential opportunities can still be identified. For example, for the impact-assessment scenarios modelled in this study, three distinct conditions (modest, moderate and severe changes in streamflow) and response strategies (eliminate, reduce or accept the impacts) seem to present themselves. The three conditions are described below and summarized in Table 2.22.

1) Modest Change in Streamflows - Eliminate Impacts

Modest changes in streamflows were found under the MCC1 (-2%) and MCC4 (+14%) scenarios. Combining some of the incidental adaptive capacity of the current system, afforded by flexibility available in reservoir operation, with minor adaptive measures would appear sufficient to deal with the changes experienced under these two scenarios.

As shown by the simulation results, reservoir rule curve modifications can partially accommodate changes in surface water supply volume, variability and seasonal distribution. Changes in reservoir operation are currently used by the GRCA to deal with short-term changes in supply and some of this operating flexibility could be use used to address climate change impacts. Purposeful adaptive measures such as the management of water abstractions and the ones provided in the two policy packages established as part of the de Loë and Mitchell (1993) study (see Table 2.2, Section 2.1.2) could also be considered to deal with the residual changes in streamflow. Many of the measures identified in the packages are already under discussion in other contexts and make good water sense regardless of whether or not streamflows decrease due to climate change.

The measures that would have to be adopted under a modest change in streamflow conditions would not be controversial; would have high levels of support; and,would be the easiest ones to implement. While still achievable, the flow conditions and the requisite adaptation measures will complicate the process of implementing the shared vision for the watershed.

2) Moderate Change in Streamflows - Reduce Impacts

If moderate streamflow changes, similar to the MCC3 (+13%), MCC2 (-19%) or the Arbitrary BC-20% linear (-20%) scenarios, occur it would take the actions described under Condition 1) plus additional major purposeful measures to reduce the impacts on streamflow and related activities.

There are numerous additional purposeful adaptation measures available to reduce the impact of climate change on streamflows or related activities. While the addition of the West Montrose reservoir was modelled in this study, another measure (or group of measures) may provide the same adaptation capacity. The 30 measures, which were "clearly supported" at the 20% flow reduction level by participants in the de Loë and Mitchell (1993) study, may be reasonable candidates. The remaining measures which were not supported until much larger flow reductions, if at all, may also need to be considered.

The additional measures necessary to respond to a moderate change in streamflow conditions may be more controversial in nature; have varying degrees of support; and, may be difficult to implement due to political, economic and environmental barriers. Even with adaptation, it will be difficult to meet the objectives of the shared watershed vision as a whole, and the adaptation decisions required may conflict with the goals of individual interests.

3) Severe Change in Streamflows - Accept Impacts

If either of the CCC GCM II (-51%) or Arbitrary BC-50% linear (-50%) scenarios occur, major impacts on streamflows and related water-based activities can be expected. Achieving the current vision objectives for the river system may not be a realistic goal. Changes in supplies as significant as these two scenarios produce will require a shift in thinking, away from trying to eliminate or reduce the impact of climate change on flows to actually accepting the conditions as the new "operating environment". Accepting these changes may be particularly difficult since water users are often buffered from the effects of short-term climate change by water management capabilities, such as augmentation of low summer flows. This problem is compounded by the widely held view that climate and hydrologic processes are random variations superimposed on a stable mean (Nuttle, 1993).

Table 2.22 - Impact/Response Strategies

Impact on Streamflows	Response Strategy	Adaptation Measures	Considerations	Implications for Watershed *Vision*
Modest	Eliminate Impacts	Modify reservoir operations plus modest purposeful measures	• Would not be controversial • Have high levels of support • Easiest ones to implement	• Still achievable • Implementation process more complicated
Moderate	Reduce Impacts	Above measures plus large (or numerous) purposeful adaptation measure(s)	• More controversial in nature • Have varying degrees of support • May be difficult to implement	• Difficult to meet as a whole • Adaptation may conflict with goals of individual interests
Severe	Accept Impacts	Shift in thinking, away from trying to eliminate or reduce the impacts to accepting conditions as the new "operating environment"	• May be difficult since water users are often buffered from the effects of short-term climate change by water management capabilities	• Achievement may not be a realistic goal

2.4 Constraints to Adaptation

If water managers knew when and by how much climate may change they could modify their actions accordingly. The unpredictability of climate change with respect to its degree of impact and timing is a barrier to the use of traditional management measures. There is no way to quantify the benefits to society of a particular project required to maintain system reliability and it is very difficult to justify changing priorities and reallocating resources to respond to specific scenarios of future climate given the uncertainty of the scenarios (Nuttle, 1993).

Water managers in the GRB have some capacity to cope with change and variability in river supplies. Nevertheless, the expected adaptive capacity of the system may not materialize under climate change conditions due to conflicting uses or new uses which develop over time. For example, public expectations for reservoir operation, such as maintaining a specific range in levels or outflows, may create conflicts. Water managers may believe they have the flexibility necessary to deal with a change in flow regime, but public or political opposition may occur when they attempt to exercise it.

The vision statement for the Grand River watershed provides a ruler against which adaptive strategies can be gauged. The goal of a single or group of adaptive measure should be consistent with the watershed objectives. However, *The Vision* can also become a constraint to adaptation. As people accept *The Vision* and invest time, effort and money into its implementation, it may become more difficult to respond to external forces. The promotion of fisheries in the Grand River, for example, requires considerable investment and its success will spawn secondary industries. Clearly, as increasing numbers of people and economic activities become dependent on the fishery, its priority relative to other water management considerations will increase. Should climate impacts occur which jeopardize the brown trout fishery, for instance, water managers may be faced with decisions lacking historical precedence in the watershed. Water managers may be faced with the question of determining what priority to place on maintaining augmentation of streamflows for the benefit of anglers and dependent economic activities versus the benefits of other uses (for example, irrigation, domestic use, other recreational uses).

Adaptation raises questions of equity, sustainable development and conflict resolution. The perceived inequity of constructing the West Montrose Reservoir in a rural area to solve urban problems of flooding and water quality has been raised in the past (GRIC, 1982). A logical adaptive strategy to one interest may appear intrusive to another. Similarly, the construction of a water supply or wastewater pipeline to one of the Great Lakes raises issues and concerns outside the GRB itself. The effects of potential GRB adaptation measures on other geographic areas and non-basin interests must also be considered.

Many adaptive measures can be adopted; however, whether they should and will is a matter of social and political preference (Mortsch and Mills, 1996). Five of the respondents to the study questionnaire indicated that they believe there is sufficient information on climate change available now to warrant action. There is support for strategies, such as water use reductions, which make sense now even if climate change were not to occur, given that water is already in short supply in the summer as indicated by the lawn watering bans instituted by several basin municipalities in the past. Other respondents indicated the need for specific factual information. One respondent noted they would need to be shown precisely how climate change will worsen conditions. Only then would this respondent support actions which would interfere with predicted growth and water use.

The work by de Loë and Mitchell (1993) suggests that the level of support for potential measures addressing reduced water supplies is often insensitive to streamflow reductions. Some measures are supported while others are not, regardless of the flow reduction scenario specified. Other potential measures are sensitive to the flow change specified but significant flow reductions may be required to increase support for these measures. Adaptation efforts may be both assisted and constrained by this phenomenon. The efforts may be assisted since some options which could address climate change will be supported even if there is little confidence in flow scenarios available. The efforts may be constrained because conclusive information on large changes in streamflow may be required to generate support for other measures. By the time conclusive information on the changes is available, it may be too late for the successful implementation of these options.

The surveyed group's reluctance to support Hard Regulatory Approaches suggests that factors other than the specified streamflow decrease may be more important to decision-makers (i.e., streamflow impact amelioration is not the highest priority). The results indicate that the significance of the flow reductions specified and/or the effectiveness of certain measures suggested are not clearly understood. Each respondent may have a different interpretation of the impact of a given flow reduction value. As shown earlier, a -20% change in annual flow has very little meaning without information on flow frequency, distribution and the occurrence of extremes.

3.0 STUDY FINDINGS AND RECOMMENDATIONS

The changed-climate scenarios used in this study produce a wide range of impacts on surface water supplies. Each of the scenarios specified for the GLSLB Project produces a shift in the seasonal distribution of supplies and a reduction in summer supplies. Such a change, while not certain, would have an impact on the ability of water managers in the GRB to meet minimum target flows throughout the system. Basin residents (water users), agencies (water managers) and other stakeholders may need to adapt to changes in streamflow regime which will affect their ability to achieve the current shared vision for the watershed.

For the scenarios modelled in this study, three distinct conditions (modest, moderate and severe changes in streamflow) and response options (eliminate, reduce or accept the impacts) present themselves. Although, the potential impacts and responses are not limited to these three situations, they do provide a way to address the issue in the absence of certainty about the degree of change and its timing. The organizational structure of *The Grand Strategy* provides an excellent opportunity for further discussion.

- **It is recommended that the investigation into the impacts and associated costs of modest, moderate and severe changes in streamflows be included as action items in the Grand River Watershed Management joint work plan.**

The Grand Strategy Coordinating Committee should consider having each Technical Working Group:

- Identify the sensitivity and vulnerability of their interests to streamflow characteristics.
- Identify what impact the three flow conditions and associated response strategies could have on the group's ability to meet its specific vision objectives.
- Assess whether activities being considered by them to fulfil the watershed vision are friendly, neutral or contrary to adapting to climate change and variability. This classification method was used by Leclair and Veale (1996) to help organize discussion about both positive and negative interactions around many resource issues in the watershed and to identify opportunities for collaboration.
- Categorize the adaptive measures listed in Smit (1993), Nuttle (1993), and de Loë and Mitchell (1993) as friendly, neutral or contrary to their interest.

By taking this approach, discussions can continue and trade-offs can be assessed if a proposed working group's activity is contrary to the adaptation process or a potential adaptive measure is contrary to one or more interest group. Additional or improved information on climate change scenarios and impacts can easily be incorporated during the process. These efforts will permit the final three steps--*Quantify measures and formulate alternative strategies, Weight objectives and evaluate trade-offs* and *Recommend adaptation measures*--of the seven step process to develop and assess adaptation defined by Carter *et al.*, (1994) to be carried out.

Actions to Facilitate Adaptation Process

Successful adjustments implemented over the past 50 years to meet streamflow targets for water quality purposes have clearly facilitated the expanded use of the river for recreational activities, the supply of water for municipal and agricultural uses and the assimilation of treated wastewater. The rate and magnitude of climate change and associated impacts may overwhelm the incidental adaptive capacity of the system. Multiple, often conflicting uses for a reservoir may limit their use to compensate for change. External forces, not recognized until the system is stressed, may also limit the adaptive capacity of the system.

The Water Managers Working Group should consider:

- Ensuring that the role of regulation on streamflows is clearly understood by all *Grand Strategy* participants. Constant, reliable river flows are not always a given; rather, the flows are regulated and the natural flow is sensitive to climate, land use and other factors. Recent or historical examples, such as late 1950s, mid-1960s or the 1914-41 period, should be used to demonstrate the capabilities and limitations of the system under previously observed conditions.
- Developing a "hydrologic tour" of the basin to help demonstrate the impact of regulation and water use on flows throughout the system.
- Revisiting the purpose and operation of the reservoirs. Operational priorities must be clearly defined to maintain flexibility and to avoid conflicts should future supplies change dramatically. The modification or re-enforcement of operational priorities may be necessary.
- Expanding the water managers network to include upstream communities. Improved communication and coordination of lagoon discharge may be required to minimize downstream impacts in the future.

Some limitations related to basic data, simulation models and alternate streamflow scenarios were identified during the study.

The Groundwater and Hydrology Working Group should consider:

- Modifying the GRCA's Reservoir Yield Model and/or the continuous simulation hydrologic model to include water intake and discharge information in the water balance. Based on experience with the WUAM model, it is suggested that water use be determined as a separate component, possibly in spreadsheet form, and input to the model as a single net water use value at each node. This approach would minimize changes necessary to the routing model algorithms while allowing the form and detail of water use input information and calculations to be tailored as required to meet the needs of the individual subbasin.

Results of this work support the continuing efforts of the Hydrology and Groundwater Working Group to:

- Develop simple communication tools by packaging the available detailed streamflow data in a form meaningful to members of other working groups.
- Better determine the relationships between climate, groundwater and base streamflow.
- Develop and maintain a detailed water use/wastewater production database for the basin and improve methods of monitoring agricultural water use.
- Establish long-term Basis-of-Comparison and alternate streamflow sequences (both historic and changed-climate) based on climate data for system testing purposes.

The current hydrologic model operated by the GRCA is capable of continuous simulation. The lack of continuous climate data sets, either reviewed or assembled by a qualified meteorologist, representing historic and climate change conditions is a barrier to completing this final task.

Throughout the course of this study, close liaison was maintained with staff at the GRCA, the organization responsible for managing flows in the river. This liaison led to direct involvement in *The Grand Strategy* which is designed to develop and implement a shared management plan for the Grand River watershed. Participation in *The Grand Strategy* at the working level facilitated the transfer of information and presented a unique opportunity to increase awareness of the potential impacts of climate change and variability.

- **It is recommended that Environment Canada continue its direct involvement in *The Grand Strategy* process.**

Environment Canada staff should:

- Assist GRCA staff in establishing the climatic databases required for long-term continuous hydrologic modelling.
- Support research efforts related to water balance modelling; specifically the further integration of the groundwater and surface components.
- Facilitate further analysis and assessment of adaptive strategies to deal with climate change and variability. More emphasis must be placed on variability. Even though variability was addressed in this study through the use of non-linear scenarios, the discussion of the results still focuses on summary data.

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APPENDIX A

The Vision

The Vision

The following description of the Grand River watershed represents the shared vision of participants in The Grand Strategy, 1996. It is written as a 'State of the Grand River Watershed' address to watershed residents in the year 2021.

"In February 1994, the Grand River was designated as a Canadian Heritage River. On reflection, this event marked the beginning of a new era in cooperative watershed management which was accelerated in the succeeding year by federal and provincial financial restraints.

Through the ongoing collaborative efforts of individuals, community groups, businesses, landowners, educational institutions, municipalities and government agencies, The Grand Strategy has changed our attitudes, the way in which we interact with each other, and how we relate to our natural and human environments. The Grand River valley is now regarded as a prized and priceless asset, world renowned for its natural beauty, cultural diversity and economic prosperity.

Today, the rivers and streams are measurably cleaner than they were twenty-five years ago. We can now eat the fish from the river and swim almost anywhere without health concerns. The Grand River provides reliable sources of clean, potable water which support urban and rural growth within the watershed.

Our communities are economically robust and aesthetically pleasing. Pedestrian and bicycle trails make use of natural areas to link residential, commercial and industrial areas to river corridors. New residential subdivisions are compact and energy efficient. Residents widely support recycling and resource conservation programs. Public transportation is heavily used as a majority of watershed residents are employed locally. Downtown urban areas are vibrant retail and commercial centres which provide a focus for community activities. New technical and service industries are attracted to the watershed as a preferred area in which to invest and entice prospective employees. Fluctuating river flows are controlled to minimize flooding and drought.

Rural areas retain a pastoral quality and way of life. The cultural landscapes shaped by early aboriginal and European settlements are still evident. Innovative farming techniques, conservation measures and technological advances have increased agricultural productivity while reducing chemical and organic runoff into local creeks and streams. Natural corridors and forests have rejuvenated and expanded. They are now connected throughout the rural countryside providing wildlife habitat, representative flora and fauna, vegetative buffers and renewable timber.

The Grand River is now considered a 'world-class' recreational fishing river. An ever growing number of visitors enjoy a diversity of water sports such as canoeing, boating and swimming in various reaches of the river system and delight in camping and picnicking in our local conservation areas and parks each year. Hiking, cycling, and horseback riding along the extensive network of interconnecting trails attract increasing numbers of vacationers to the watershed.

Seasonal cultural events attract thousands of visitors each year. The many historical sites, buildings, and museums fascinate young and old alike. Growing numbers of painters, photographers, naturalists, and others are drawn to the valley to find renewed inspiration and to enjoy the tranquillity and peace the river offers. Watershed visitors are attracted by an aggressive tourism and accommodation industry that markets quality watershed experiences.

Coordinated by the Grand River Conservation Authority, the Grand Strategy continues to evolve through the active participation of an ever growing number of stakeholders. Community-driven actions are prominent. Landowners are well informed and play a primary stewardship role in managing and conserving resources on private lands. The Grand River Forum provides opportunities for groups, individuals, landowners, and agencies to exchange information, discuss concerns and issues, evaluate actions, celebrate successes, confirm or set new watershed goals, pool limited resources, and determine priorities for individual and shared actions. An annual "State of the Watershed" report is prepared in conjunction with this event. As a report card on watershed health, the Grand River has improved its marks every year.

We are proud of our river and its tributaries. The commitments to action instilled in The Grand Strategy bestow a special legacy to present and future generations who live, work, play and invest in the Grand River valley.

APPENDIX B

Surface Water Supply Scenario Comparison at Galt

Surface Water Supply Scenario Comparison at Galt (Unregulated streamflows in m^3/s)

Percentage Change wrt Base Case: at Galt / Basin-wide

Base Case (1951-88 Estimated Unregulated Flows)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	25.0	35.4	92.0	113.8	37.3	17.7	13.4	12.7	17.4	22.9	34.0	36.5	38.2	0%	0%
MAX	69.6	126.9	213.0	243.1	111.8	62.0	47.2	45.8	158.6	131.8	88.4	111.4	56.1		
MIN	5.3	7.8	25.4	34.5	11.5	6.0	4.0	3.8	4.5	4.7	5.7	5.5	17.2		
RANGE	64.4	119.1	187.7	208.6	100.3	56.1	43.2	41.9	154.1	127.0	82.6	105.9	39.0		
STDev	16.0	29.2	46.5	61.2	25.4	11.1	8.4	8.8	25.5	26.1	20.8	24.1	9.6		

1914-41 (Natural Conditions Recorded Flows)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	26.8	26.5	88.8	100.8	30.3	14.9	10.1	7.2	8.5	10.2	23.0	25.9	31.1	-19%	N/A
MAX	120.0	102.0	182.0	205.0	79.5	58.1	70.6	38.6	49.2	35.0	110.0	86.2	46.8		
MIN	3.0	3.3	3.9	14.9	8.5	2.5	1.6	1.3	1.9	2.8	3.8	4.4	17.7		
RANGE	117.0	98.7	178.1	190.1	71.0	55.6	69.0	37.3	47.3	32.2	106.3	81.8	29.1		
STDev	29.8	28.2	46.2	50.0	19.4	12.3	13.2	7.6	10.3	8.0	24.3	22.2	7.2		

GLSLB Project Specified Scenarios

CCC GCM II

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	29.5	40.3	36.9	33.4	15.1	6.2	4.8	3.7	4.0	6.9	10.9	25.4	18.1	-53%	-51%
MAX	84.6	121.4	74.9	77.2	56.9	18.0	13.8	13.0	49.7	73.8	35.5	83.6	30.7		
MIN	4.3	6.3	13.6	9.5	2.6	1.7	1.2	0.0	0.0	0.0	2.0	2.3	7.0		
RANGE	80.3	115.0	61.3	67.7	54.3	16.3	12.6	13.0	49.7	73.8	33.5	81.3	23.7		
STDev	19.4	28.3	15.4	17.6	13.0	4.0	2.9	3.1	8.1	12.2	7.3	16.8	5.6		

MCC1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	38.5	52.6	80.1	68.2	33.7	14.1	11.7	8.0	11.1	17.2	39.1	61.0	36.3	-5%	-2%
MAX	117.3	175.2	210.4	172.1	135.3	68.8	72.3	24.2	41.7	82.0	118.4	344.3	66.7		
MIN	6.4	13.0	19.1	13.9	5.4	3.5	2.8	1.5	2.0	1.3	3.9	4.2	18.0		
RANGE	111.0	162.2	191.3	158.3	130.0	65.3	69.5	22.7	39.7	80.7	114.5	340.1	48.7		
STDev	26.4	34.8	41.7	39.7	28.0	12.5	13.7	5.2	8.9	16.6	32.5	66.3	14.0		

MCC2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	32.6	50.2	68.4	57.8	23.0	12.1	8.2	6.8	10.9	25.5	29.1	34.3	29.9	-22%	-19%
MAX	69.0	150.8	142.5	212.7	67.9	31.8	27.7	27.0	68.8	92.1	120.6	124.0	57.9		
MIN	7.3	10.0	19.0	11.1	7.6	2.5	2.3	1.5	1.7	1.2	2.5	5.6	13.6		
RANGE	61.7	140.8	123.5	201.6	60.3	29.3	25.4	25.5	67.1	90.9	118.1	118.3	44.4		
STDev	15.7	28.5	32.0	37.8	14.6	7.7	6.0	5.0	12.2	25.2	24.4	24.1	8.7		

MCC3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	58.4	76.2	82.1	73.8	34.6	13.3	9.4	5.5	9.0	20.8	39.6	63.2	41.3	+8%	+13%
MAX	151.7	150.8	244.3	189.5	168.3	48.5	29.5	12.7	73.9	134.5	145.1	343.7	69.0		
MIN	9.2	15.2	32.1	12.0	6.5	2.5	1.7	0.7	0.0	0.0	2.8	6.8	13.7		
RANGE	142.5	135.7	212.2	177.6	161.8	46.0	27.8	12.0	73.9	134.5	142.4	337.0	55.3		
STDev	36.9	33.3	49.3	42.3	31.8	10.1	7.3	3.1	15.0	29.5	37.4	65.7	15.5		

MCC4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	58.7	77.5	103.1	87.9	33.1	14.2	9.9	8.4	10.1	17.5	29.8	52.2	41.9	+10%	+14%
MAX	140.9	193.9	216.6	242.5	101.5	43.6	31.3	46.6	31.7	62.8	120.4	176.7	66.0		
MIN	10.0	9.8	35.6	10.9	8.1	3.8	1.8	1.7	0.0	0.0	3.6	10.2	16.5		
RANGE	131.0	184.2	181.0	231.6	93.4	39.8	29.4	45.0	31.7	62.8	116.8	166.5	49.5		
STDev	33.8	45.0	46.6	47.5	20.4	9.5	6.8	9.8	8.0	15.1	28.0	43.2	11.8		

Arbitrary Scenarios

20% Linear Reduction in Base Case Flows (BC-20%)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	20.0	28.3	73.6	91.1	29.9	14.2	10.7	10.2	13.9	18.3	27.2	29.2	30.5	-20%	-20%
MAX	55.7	101.5	170.4	194.5	89.5	49.6	37.8	36.6	126.9	105.4	70.7	89.1	44.9		
MIN	4.2	6.2	20.3	27.6	9.2	4.8	3.2	3.1	3.6	3.8	4.6	4.4	13.7		
RANGE	51.5	95.3	150.1	166.9	80.3	44.9	34.6	33.5	123.3	101.6	66.1	84.7	31.2		
STDev	12.8	23.4	37.2	49.0	20.3	8.8	6.7	7.1	20.4	20.9	16.7	19.3	7.7		

50% Linear Reduction in Base Case Flows (BC-50%)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	% Change at Galt	% Change Basin-wide
MEAN	12.5	17.7	46.0	56.9	18.7	8.9	6.7	6.4	8.7	11.4	17.0	18.3	19.1	-50%	-50%
MAX	34.8	63.5	106.5	121.5	55.9	31.0	23.6	22.9	79.3	65.9	44.2	55.7	28.1		
MIN	2.6	3.9	12.7	17.2	5.7	3.0	2.0	1.9	2.2	2.4	2.9	2.8	8.6		
RANGE	32.2	59.6	93.8	104.3	50.2	28.0	21.6	21.0	77.0	63.5	41.3	52.9	19.5		
STDev	8.0	14.6	23.3	30.6	12.7	5.5	4.2	4.4	12.8	13.0	10.4	12.1	4.8		

APPENDIX C

Target Flow Satisfaction Tables for MES1-3 and IAS1-21

Table Description

The following information has been extracted from the WUAM MODULE8.SUM output file for each application scenario run. Some original output lines and text have been removed, line spacing altered and information added (bold text) for presentation purposes. Since WUAM is focused on water use, the simulation results presented are expressed in terms of the Demanded Minimum Flow (in this case the monthly target minimum flows) as a percentage of available outflow.

Referring to the table for MES1 (page C-2) the percentage values appearing under the <100 (%) heading in the summary columns (to the right of the table) indicate the overall percentage of time each month's targets are satisfied at each target flow site. High percentage values (preferably 100%) are desirable here. The values in this column for each application scenario are plotted in Figures 2.32, 2.34, 2.36 and 2.38 of the report.

The tables also provide information on the distribution of streamflow with respect to the month-by-month targets. Again referring to the table for MES1, values to the left of the vertical line (added for display purposes) represent a satisfied condition since the target flows (Demanded Minimums) are <u>less</u> than the available streamflow. Values to the right of the vertical line represent unsatisfied conditions, since the target flows are <u>greater</u> than the available streamflow. Since a value of 100% would also represent a satisfied condition, in some cases, the 100-119% column may include a satisfied month or two. Generally, high values in columns to the left of the vertical line and low (preferably zero) values to its right are desirable. Very high values for the lowest range (0-19%) may not be desirable as these may represent extreme high flow conditions. In the case of Doon (Node 4), where high values do appear in this range, it must be remembered that relatively low minimum flow targets are currently specified at this site for January through April. At present, targets are not specified at either Hanlon (Node 7) or Brantford (Node 14) for this time period. The summary row (identified as Months), provides the average of the monthly occurrence values and gives a general picture of how flows are distributed about the targets. Although the table indicates the total number of months is 456 (12 months times the study period of 38 years) for all three nodes, the summary values are the average of the percentages of occurrences values shown. These values are presented in Figures 2.33, 2.35, 2.37 and 2.39 of the report.

MES 1 WATER SUPPLY: **Base Case (1951-88 Unregulated Flows, 0%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves**
WATER USE: **1991 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	66	32	3	0	0	0	0	0	0	0	0	100	0
Feb	38	58	42	0	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	100	0	0	0	0	0	0	0	0	0	0	100	0
May	38	8	21	29	34	8	0	0	0	0	0	0	100	0
Jun	38	0	5	26	34	24	8	3	0	0	0	0	89	11
Jul	38	0	3	18	42	26	11	0	0	0	0	0	89	11
Aug	38	0	3	26	37	24	5	5	0	0	0	0	89	11
Sep	38	3	11	13	26	32	13	3	0	0	0	0	84	16
Oct	38	5	13	24	21	18	11	5	3	0	0	0	82	18
Nov	38	29	39	11	21	0	0	0	0	0	0	0	100	0
Dec	38	32	47	8	8	3	3	0	0	0	0	0	97	3
Months	456	33	18	13	19	11	4	1	0	0	0	0	94	6

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	18	58	16	5	3	0	0	0	0	0	0	100	0
Jun	38	3	26	39	18	5	0	3	3	3	0	0	92	8
Jul	38	0	8	32	32	16	3	8	3	0	0	0	87	13
Aug	38	3	5	18	29	18	11	11	5	0	0	0	74	26
Sep	38	5	5	16	32	13	5	16	8	0	0	0	71	29
Oct	38	5	24	16	32	18	3	3	0	0	0	0	95	5
Months	456	6	21	23	25	12	4	7	3	0	0	0	86	14

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	16	47	32	5	0	0	0	0	0	0	0	100	0
Jun	38	0	18	45	26	11	0	0	0	0	0	0	100	0
Jul	38	0	11	34	32	24	0	0	0	0	0	0	100	0
Aug	38	0	11	26	34	24	5	0	0	0	0	0	95	5
Sep	38	3	16	21	29	24	8	0	0	0	0	0	92	8
Oct	38	11	16	32	18	18	5	0	0	0	0	0	95	5
Months	456	5	20	32	24	17	3	0	0	0	0	0	97	3

MES 2 WATER SUPPLY: **Base Case (1951-88 Unregulated Flows, 0%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration assuming State-of-Nature Operation**
WATER USE: **1991 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	55	29	13	3	0	0	0	0	0	0	0	100	0
Feb	38	58	29	13	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	100	0	0	0	0	0	0	0	0	0	0	100	0
May	38	13	24	29	24	0	5	5	0	0	0	0	89	11
Jun	38	0	5	8	24	13	8	16	8	11	8	0	50	50
Jul	38	0	3	8	11	5	11	13	18	11	21	0	26	74
Aug	38	0	3	8	11	11	0	16	8	13	32	0	32	68
Sep	38	3	5	8	8	8	13	5	5	3	42	0	32	68
Oct	38	5	8	11	18	8	11	5	0	11	24	0	50	50
Nov	38	24	37	13	8	5	5	5	0	0	3	0	87	13
Dec	38	21	45	16	5	5	3	0	0	3	3	0	92	8
Months	456	32	16	11	9	5	5	5	3	4	11	0	71	29

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	21	63	11	5	0	0	0	0	0	0	0	100	0
Jun	38	3	29	29	8	16	8	5	0	0	3	0	84	16
Jul	38	0	11	24	13	11	11	13	5	5	8	0	58	42
Aug	38	3	8	3	16	11	21	8	11	8	13	0	39	61
Sep	38	5	8	8	18	11	11	11	3	16	11	0	50	50
Oct	38	5	18	18	18	8	13	11	5	0	3	0	68	32
Months	456	6	23	15	13	9	11	8	4	5	6	0	67	33

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	16	45	32	5	3	0	0	0	0	0	0	100	0
Jun	38	3	13	34	18	18	11	3	0	0	0	0	87	13
Jul	38	0	3	24	16	16	26	8	5	3	0	0	58	42
Aug	38	0	8	18	13	21	8	18	5	8	0	0	61	39
Sep	38	3	13	11	18	11	18	16	5	5	0	0	55	45
Oct	38	8	11	34	13	5	16	5	5	3	0	0	71	29
Months	456	5	15	25	14	12	13	8	4	3	0	0	72	28

MES 3 WATER SUPPLY: **Base Case (1951-88 Unregulated Flows, 0%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Current (1991) Rule Curves**
WATER USE: **1991 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	84	16	0	0	0	0	0	0	0	0	0	100	0
Feb	38	71	29	0	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	100	0	0	0	0	0	0	0	0	0	0	100	0
May	38	11	21	32	26	8	3	0	0	0	0	0	97	3
Jun	38	0	8	26	34	24	5	3	0	0	0	0	92	8
Jul	38	0	3	24	55	13	0	5	0	0	0	0	95	5
Aug	38	0	3	29	47	18	0	3	0	0	0	0	97	3
Sep	38	3	8	24	32	32	3	0	0	0	0	0	97	3
Oct	38	11	8	29	26	21	3	3	0	0	0	0	95	5
Nov	38	34	50	16	0	0	0	0	0	0	0	0	100	0
Dec	38	32	50	11	5	3	0	0	0	0	0	0	100	0
Months	456	37	16	16	19	10	1	1	0	0	0	0	98	2

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	18	58	16	5	3	0	0	0	0	0	0	100	0
Jun	38	3	26	39	18	5	0	3	3	3	0	0	92	8
Jul	38	0	8	32	32	16	3	8	3	0	0	0	87	13
Aug	38	3	5	18	29	18	11	11	5	0	0	0	74	26
Sep	38	5	5	16	32	13	5	16	8	0	0	0	71	29
Oct	38	5	24	16	32	18	3	3	0	0	0	0	95	5
Months	456	6	21	23	25	12	4	7	3	0	0	0	86	14

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	16	45	34	5	0	0	0	0	0	0	0	100	0
Jun	38	0	21	45	26	8	0	0	0	0	0	0	100	0
Jul	38	0	11	37	37	16	0	0	0	0	0	0	100	0
Aug	38	0	11	32	39	16	3	0	0	0	0	0	97	3
Sep	38	3	16	24	37	21	0	0	0	0	0	0	100	0
Oct	38	11	16	37	24	13	0	0	0	0	0	0	100	0
Months	456	5	20	35	28	12	0	0	0	0	0	0	100	0

IAS 1 **WATER SUPPLY:** **Base Case (1951-88 Unregulated Flows, 0%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	63	34	3	0	0	0	0	0	0	0	0	100	0
Feb	38	58	39	3	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	100	0	0	0	0	0	0	0	0	0	0	100	0
May	38	8	21	26	37	5	3	0	0	0	0	0	97	3
Jun	38	0	5	21	29	32	11	3	0	0	0	0	87	13
Jul	38	0	3	18	39	24	11	5	0	0	0	0	84	16
Aug	38	0	3	21	32	32	5	5	3	0	0	0	87	13
Sep	38	3	11	8	32	21	18	8	0	0	0	0	74	26
Oct	38	5	13	24	18	16	13	8	0	3	0	0	76	24
Nov	38	29	39	11	18	3	0	0	0	0	0	0	100	0
Dec	38	32	47	8	5	5	0	3	0	0	0	0	97	3
Months	456	33	18	12	18	11	5	3	0	0	0	0	92	8

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	18	58	16	5	3	0	0	0	0	0	0	100	0
Jun	38	3	26	34	24	5	0	0	3	3	3	0	92	8
Jul	38	0	8	29	32	16	3	8	3	3	0	0	84	16
Aug	38	3	5	8	32	26	8	11	5	3	0	0	74	26
Sep	38	5	5	13	24	16	13	13	8	3	0	0	63	37
Oct	38	5	21	16	32	21	3	0	3	0	0	0	95	5
Months	456	6	21	19	25	14	4	5	4	2	0	0	85	15

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	16	45	34	5	0	0	0	0	0	0	0	100	0
Jun	38	0	16	47	24	13	0	0	0	0	0	0	100	0
Jul	38	0	11	32	32	24	3	0	0	0	0	0	97	3
Aug	38	0	8	26	37	21	5	3	0	0	0	0	92	8
Sep	38	3	16	21	26	26	8	0	0	0	0	0	92	8
Oct	38	11	16	32	18	18	5	0	0	0	0	0	95	5
Months	456	5	18	32	24	17	4	0	0	0	0	0	96	4

IAS2 **WATER SUPPLY:** **CCC GCM II (-51%)**
SYSTEM OPERATION: Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	61	34	3	0	0	3	0	0	0	0	0	97	3
Feb	38	76	18	5	0	0	0	0	0	0	0	0	100	0
Mar	38	87	13	0	0	0	0	0	0	0	0	0	100	0
Apr	38	58	42	0	0	0	0	0	0	0	0	0	100	0
May	38	0	0	8	11	5	34	26	11	0	5	0	24	76
Jun	38	0	0	0	0	5	8	29	21	11	26	0	5	95
Jul	38	0	0	0	0	0	11	11	29	13	37	0	0	100
Aug	38	0	0	0	0	0	5	8	16	13	58	8	0	100
Sep	38	0	0	3	0	0	0	5	24	5	63	18	3	97
Oct	38	0	3	0	3	5	5	5	11	5	63	13	11	89
Nov	38	0	5	11	13	34	8	3	3	3	21	0	63	37
Dec	38	11	24	34	13	11	3	0	0	3	3	0	92	8
Months	456	24	12	5	3	5	6	7	9	4	23	3	50	50

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	0	11	5	13	16	24	13	11	3	5	0	45	55
Jun	38	0	0	0	8	11	13	13	8	11	37	0	18	82
Jul	38	0	0	0	5	8	3	13	8	8	55	0	13	87
Aug	38	0	0	0	5	0	3	0	5	5	82	8	5	95
Sep	38	0	3	0	3	3	3	0	0	5	84	16	8	92
Oct	38	0	3	0	5	3	11	5	13	3	58	8	11	89
Months	456	0	3	1	7	7	9	7	7	6	54	5	17	83

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	0	8	13	16	39	13	5	0	0	5	0	76	24
Jun	38	0	0	3	5	21	21	11	8	8	24	0	29	71
Jul	38	0	0	0	0	13	13	16	18	11	29	0	13	87
Aug	38	0	0	0	3	5	3	11	29	5	45	0	8	92
Sep	38	0	3	0	0	5	5	13	13	3	58	0	8	92
Oct	38	0	3	0	11	5	3	13	16	8	42	0	18	82
Months	456	0	2	3	6	15	10	11	14	6	34	0	25	75

IAS 3 WATER SUPPLY: **Transposition MCC1 (-2%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	76	21	3	0	0	0	0	0	0	0	0	100	0
Feb	38	89	11	0	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	89	11	0	0	0	0	0	0	0	0	0	100	0
May	38	8	11	21	26	18	11	3	3	0	0	0	84	16
Jun	38	3	3	5	21	21	24	5	16	3	0	0	53	47
Jul	38	3	3	8	18	13	24	8	13	5	5	0	45	55
Aug	38	0	0	8	16	18	21	8	13	5	11	0	42	58
Sep	38	0	0	16	16	16	16	13	13	5	5	0	47	53
Oct	38	3	11	13	18	18	11	11	5	8	3	0	63	37
Nov	38	24	45	16	3	8	3	0	0	3	0	0	95	5
Dec	38	45	29	13	8	5	0	0	0	0	0	0	100	0
Months	456	37	12	9	11	10	9	4	5	2	2	0	77	23

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	13	24	42	5	5	8	0	3	0	0	0	89	11
Jun	38	5	11	16	26	11	13	5	3	3	8	0	68	32
Jul	38	3	5	16	21	5	13	13	5	8	11	0	50	50
Aug	38	0	3	8	13	18	13	5	11	0	29	0	42	58
Sep	38	3	5	13	13	21	8	5	3	3	26	0	55	45
Oct	38	5	3	26	21	16	13	3	0	3	11	0	71	29
Months	456	5	8	20	17	13	11	5	4	3	14	0	63	37

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	13	26	37	13	8	0	3	0	0	0	0	97	3
Jun	38	3	11	16	29	21	8	11	3	0	0	0	79	21
Jul	38	3	5	16	8	34	13	5	8	5	3	0	66	34
Aug	38	0	3	11	24	18	16	11	5	5	8	0	55	45
Sep	38	0	11	18	16	18	5	21	8	3	0	0	63	37
Oct	38	5	16	21	18	16	8	8	3	3	3	0	76	24
Months	456	4	12	20	18	19	8	10	4	3	2	0	73	27

IAS 4 WATER SUPPLY: **Transposition MCC2 (-19%)**
SYSTEM OPERATION: Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	79	18	3	0	0	0	0	0	0	0	0	100	0
Feb	38	95	5	0	0	0	0	0	0	0	0	0	100	0
Mar	38	97	3	0	0	0	0	0	0	0	0	0	100	0
Apr	38	82	18	0	0	0	0	0	0	0	0	0	100	0
May	38	0	8	13	29	21	18	11	0	0	0	0	71	29
Jun	38	0	0	8	29	11	16	13	11	13	0	0	47	53
Jul	38	0	0	5	13	21	16	11	16	13	5	0	39	61
Aug	38	0	0	3	11	18	16	13	16	8	16	0	32	68
Sep	38	3	0	5	13	16	21	13	11	3	16	0	37	63
Oct	38	5	16	24	13	8	11	3	5	11	5	0	66	34
Nov	38	24	32	13	8	8	8	3	0	3	3	0	84	16
Dec	38	21	39	24	8	5	0	3	0	0	0	0	97	3
Months	456	34	12	8	10	9	9	6	5	4	4	0	73	27

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	5	21	26	21	13	5	3	5	0	0	0	87	13
Jun	38	0	8	29	21	8	3	8	5	5	13	0	66	34
Jul	38	0	3	8	21	8	24	8	5	3	21	0	39	61
Aug	38	0	3	3	13	18	11	8	3	3	39	0	37	63
Sep	38	0	3	16	8	11	11	8	5	13	26	0	37	63
Oct	38	13	16	24	13	8	3	3	3	8	11	0	74	26
Months	456	3	9	18	16	11	9	6	4	5	18	0	57	43

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	3	26	24	32	8	8	0	0	0	0	0	92	8
Jun	38	0	5	29	21	18	5	13	3	5	0	0	74	26
Jul	38	0	5	3	21	24	16	8	11	8	5	0	53	47
Aug	38	0	0	8	13	29	5	11	16	11	8	0	50	50
Sep	38	3	8	11	16	16	16	16	8	3	5	0	53	47
Oct	38	13	24	21	16	5	3	0	5	5	8	0	79	21
Months	456	3	11	16	20	17	9	8	7	5	4	0	67	33

IAS 5 WATER SUPPLY: Transposition MCC3 (+13%)
SYSTEM OPERATION: Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	92	8	0	0	0	0	0	0	0	0	0	100	0
Feb	38	95	5	0	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	92	8	0	0	0	0	0	0	0	0	0	100	0
May	38	11	13	18	26	11	11	8	3	0	0	0	79	21
Jun	38	0	3	13	21	21	5	16	8	13	0	0	58	42
Jul	38	0	0	11	26	24	0	5	11	16	8	0	61	39
Aug	38	0	0	0	13	21	16	8	11	16	16	0	34	66
Sep	38	0	8	3	8	5	13	13	16	11	24	3	24	76
Oct	38	8	11	8	8	16	8	3	8	11	21	3	50	50
Nov	38	32	24	16	5	11	5	3	0	0	5	0	87	13
Dec	38	47	29	16	5	3	0	0	0	0	0	0	100	0
Months	456	40	9	7	9	9	5	5	5	5	6	0	74	26

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	21	21	26	13	8	5	3	3	0	0	0	89	11
Jun	38	0	24	8	29	8	0	5	8	8	11	0	68	32
Jul	38	0	8	5	29	8	5	3	11	18	13	0	50	50
Aug	38	0	0	0	18	11	5	5	11	11	39	0	29	71
Sep	38	3	8	5	5	3	3	3	8	0	63	0	24	76
Oct	38	13	13	5	11	8	16	5	3	3	24	3	50	50
Months	456	6	12	8	18	7	6	4	7	7	25	0	52	48

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	18	24	26	16	11	5	0	0	0	0	0	95	5
Jun	38	0	16	16	24	16	8	8	8	5	0	0	71	29
Jul	38	0	8	11	24	16	11	8	8	11	5	0	58	42
Aug	38	0	0	3	18	24	11	5	13	11	16	0	45	55
Sep	38	3	8	8	3	8	16	13	11	16	16	0	29	71
Oct	38	16	11	8	11	18	3	8	0	5	21	0	63	37
Months	456	6	11	12	16	15	9	7	7	8	10	0	60	40

IAS 6 WATER SUPPLY: **Transposition MCC4 (+14%)**
SYSTEM OPERATION: Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
Jan	38	87	13	0	0	0	0	0	0	0	0	0	100	0
Feb	38	97	3	0	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	97	3	0	0	0	0	0	0	0	0	0	100	0
May	38	3	24	24	24	16	8	3	0	0	0	0	89	11
Jun	38	0	3	11	32	18	16	11	11	0	0	0	63	37
Jul	38	0	3	8	32	21	11	8	11	5	3	0	63	37
Aug	38	0	5	3	13	24	18	13	16	3	5	0	45	55
Sep	38	0	0	16	18	11	21	18	11	3	3	0	45	55
Oct	38	0	16	16	13	21	8	11	5	8	3	3	66	34
Nov	38	24	18	29	8	13	8	0	0	0	0	0	92	8
Dec	38	32	55	8	5	0	0	0	0	0	0	0	100	0
Months	456	37	12	9	12	10	7	5	4	2	1	0	80	20

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
May	38	29	21	34	8	3	3	3	0	0	0	0	95	5
Jun	38	3	18	21	26	11	13	0	3	3	3	0	79	21
Jul	38	0	5	18	18	24	8	3	11	3	11	0	66	34
Aug	38	0	5	3	16	16	5	0	16	16	24	0	39	61
Sep	38	0	11	8	21	5	13	8	8	0	26	0	45	55
Oct	38	3	29	11	16	11	11	0	5	5	11	0	68	32
Months	456	6	15	16	18	11	9	2	7	4	12	0	65	35

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
May	38	8	42	29	16	5	0	0	0	0	0	0	100	0
Jun	38	0	11	24	34	11	18	3	0	0	0	0	79	21
Jul	38	0	3	13	39	21	3	5	13	0	3	0	76	24
Aug	38	0	5	8	16	24	16	16	5	5	5	0	53	47
Sep	38	0	8	26	8	26	13	8	5	3	3	0	68	32
Oct	38	3	32	11	18	13	3	8	5	3	5	0	76	24
Months	456	2	17	18	22	17	9	7	5	2	3	0	75	25

IAS 7 WATER SUPPLY: **Linear Reduction of Base Case by 20% (i.e., Base Case - 20%)**
SYSTEM OPERATION: Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	53	34	13	0	0	0	0	0	0	0	0	100	0
Feb	38	55	29	16	0	0	0	0	0	0	0	0	100	0
Mar	38	97	3	0	0	0	0	0	0	0	0	0	100	0
Apr	38	100	0	0	0	0	0	0	0	0	0	0	100	0
May	38	8	8	21	39	18	5	0	0	0	0	0	95	5
Jun	38	0	3	5	37	26	16	8	5	0	0	0	71	29
Jul	38	0	3	5	34	24	13	13	5	3	0	0	66	34
Aug	38	0	3	8	18	32	21	3	13	0	3	0	61	39
Sep	38	3	3	13	18	13	21	24	3	0	3	0	50	50
Oct	38	5	8	13	21	16	16	11	8	0	3	0	63	37
Nov	38	18	42	18	5	13	0	0	0	3	0	0	97	3
Dec	38	18	45	18	11	5	0	0	3	0	0	0	97	3
Months	456	30	15	11	15	12	8	5	3	0	1	0	83	17

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	13	26	45	8	3	5	0	0	0	0	0	95	5
Jun	38	0	16	34	26	5	5	3	3	3	5	0	82	18
Jul	38	0	3	21	24	16	18	5	5	3	5	0	63	37
Aug	38	0	8	5	18	18	13	13	8	11	5	0	50	50
Sep	38	3	5	11	24	5	13	13	8	11	8	0	47	53
Oct	38	5	5	18	29	24	8	5	3	3	0	0	82	18
Months	456	4	11	22	21	12	11	7	4	5	4	0	70	30

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	8	26	53	8	5	0	0	0	0	0	0	100	0
Jun	38	0	8	34	26	24	8	0	0	0	0	0	92	8
Jul	38	0	3	24	26	21	18	8	0	0	0	0	74	26
Aug	38	0	3	16	29	29	16	5	0	3	0	0	76	24
Sep	38	3	11	16	16	26	24	5	0	0	0	0	71	29
Oct	38	5	8	37	16	18	11	3	3	0	0	0	84	16
Months	456	3	10	30	20	21	13	4	0	0	0	0	83	17

IAS 8 **WATER SUPPLY:** **Linear Reduction of Base Case by 50% (i.e., Base case - 50%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration assuming Current (1991) Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	16	53	21	8	0	0	3	0	0	0	0	97	3
Feb	38	37	26	29	3	0	3	3	0	0	0	0	95	5
Mar	38	89	11	0	0	0	0	0	0	0	0	0	100	0
Apr	38	84	16	0	0	0	0	0	0	0	0	0	100	0
May	38	0	5	11	11	32	34	8	0	0	0	0	58	42
Jun	38	0	0	0	8	21	26	16	18	5	5	0	29	71
Jul	38	0	0	0	5	11	18	26	16	18	5	0	16	84
Aug	38	0	0	3	0	16	8	21	21	16	16	0	18	82
Sep	38	0	3	3	3	16	8	11	18	13	26	0	24	76
Oct	38	0	5	5	5	13	18	18	5	8	21	0	29	71
Nov	38	0	29	18	24	11	5	0	3	0	11	0	82	18
Dec	38	5	26	29	13	13	3	5	0	0	5	0	87	13
Months	456	19	14	10	7	11	10	9	7	5	7	0	61	39

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	0	16	18	11	32	16	3	5	0	0	0	76	24
Jun	38	0	0	13	16	18	13	5	11	8	16	0	47	53
Jul	38	0	0	3	16	16	3	8	13	16	26	0	34	66
Aug	38	0	0	8	3	8	8	3	13	13	45	0	18	82
Sep	38	3	3	3	5	3	13	5	16	5	45	0	16	84
Oct	38	0	5	3	24	13	11	13	11	5	16	0	45	55
Months	456	0	4	8	12	15	11	6	11	8	25	0	39	61

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	0	11	21	50	13	5	0	0	0	0	0	95	5
Jun	38	0	0	8	18	32	13	18	8	3	0	0	58	42
Jul	38	0	0	3	11	24	16	24	16	8	0	0	37	63
Aug	38	0	0	3	11	21	16	13	26	5	5	0	34	66
Sep	38	0	3	11	8	11	16	21	18	5	8	0	32	68
Oct	38	0	8	5	24	16	11	16	5	3	13	0	53	47
Months	456	0	4	8	20	19	13	15	12	4	4	0	51	49

IAS 9 WATER SUPPLY: **CCC GCM II (-51%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration assuming Modified Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	66	26	5	0	0	3	0	0	0	0	0	97	3
Feb	38	74	21	5	0	0	0	0	0	0	0	0	100	0
Mar	38	63	37	0	0	0	0	0	0	0	0	0	100	0
Apr	38	50	50	0	0	0	0	0	0	0	0	0	100	0
May	38	0	5	8	5	18	29	24	5	3	3	0	37	63
Jun	38	0	0	0	0	21	16	16	18	18	11	0	21	79
Jul	38	0	0	0	3	18	5	11	26	21	16	0	21	79
Aug	38	0	0	0	3	5	13	11	13	18	37	3	8	92
Sep	38	0	0	3	0	0	5	8	24	13	47	11	3	97
Oct	38	0	3	0	5	8	3	5	16	13	47	13	16	84
Nov	38	0	8	13	18	26	11	0	3	3	18	0	66	34
Dec	38	13	24	34	11	11	3	0	3	0	3	0	92	8
Months	456	22	14	6	4	9	7	6	9	7	15	2	55	45

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	0	13	13	24	13	11	8	11	3	5	0	63	37
Jun	38	0	0	0	24	21	11	5	0	8	32	0	45	55
Jul	38	0	0	0	11	5	16	11	0	5	53	0	16	84
Aug	38	0	0	0	8	0	0	5	0	11	76	3	8	92
Sep	38	0	3	0	3	5	0	0	3	11	76	3	11	89
Oct	38	0	3	0	8	11	13	3	16	3	45	5	21	79
Months	456	0	3	2	13	9	8	5	5	7	48	2	27	73

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	0	11	13	21	34	11	5	3	0	3	0	79	21
Jun	38	0	0	3	11	32	13	8	13	11	11	0	45	55
Jul	38	0	0	0	5	18	11	24	13	13	16	0	24	76
Aug	38	0	0	0	3	5	16	21	13	13	29	0	8	92
Sep	38	0	3	0	0	5	11	13	18	5	45	0	8	92
Oct	38	0	3	0	11	8	13	8	13	11	34	0	21	79
Months	456	0	3	3	8	17	12	13	12	9	23	0	31	69

IAS 10 WATER SUPPLY: Transposition MCC1 (-2%)
SYSTEM OPERATION: Current (1991) Reservoir Configuration assuming Modified Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	76	21	3	0	0	0	0	0	0	0	0	100	0
Feb	38	87	13	0	0	0	0	0	0	0	0	0	100	0
Mar	38	97	3	0	0	0	0	0	0	0	0	0	100	0
Apr	38	84	16	0	0	0	0	0	0	0	0	0	100	0
May	38	11	13	21	32	11	8	3	3	0	0	0	87	13
Jun	38	3	3	5	26	34	18	8	0	3	0	0	71	29
Jul	38	3	3	8	32	34	8	3	11	0	0	0	79	21
Aug	38	0	0	8	21	42	3	11	5	8	3	0	71	29
Sep	38	0	0	18	21	32	5	8	11	3	3	0	71	29
Oct	38	3	11	13	24	16	11	8	8	5	3	0	66	34
Nov	38	24	42	21	3	5	3	0	0	3	0	0	95	5
Dec	38	45	29	11	11	3	0	3	0	0	0	0	97	3
Months	456	36	13	9	14	15	5	4	3	2	1	0	86	14

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	13	34	39	8	0	3	0	3	0	0	0	95	5
Jun	38	5	11	18	37	16	3	5	0	5	0	0	87	13
Jul	38	3	5	18	18	21	11	8	5	5	5	0	66	34
Aug	38	0	3	8	16	18	13	11	5	5	21	0	45	55
Sep	38	3	5	13	24	24	3	5	3	11	11	0	68	32
Oct	38	5	3	26	16	24	13	0	8	3	3	0	74	26
Months	456	5	10	21	20	17	7	5	4	5	7	0	72	28

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

PERCENTAGE OF OCCURRENCES

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	16	24	39	13	5	0	3	0	0	0	0	97	3
Jun	38	3	11	18	34	18	11	3	3	0	0	0	84	16
Jul	38	3	5	21	13	37	11	5	3	3	0	0	79	21
Aug	38	0	3	13	32	13	18	8	5	8	0	0	61	39
Sep	38	0	11	21	21	16	16	11	3	3	0	0	68	32
Oct	38	5	16	24	18	13	11	5	3	3	3	0	76	24
Months	456	4	11	23	22	17	11	6	3	3	0	0	78	22

IAS 11 WATER SUPPLY: **Transposition MCC2 (-19%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration assuming Modified Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	79	21	0	0	0	0	0	0	0	0	0	100	0
Feb	38	95	5	0	0	0	0	0	0	0	0	0	100	0
Mar	38	95	5	0	0	0	0	0	0	0	0	0	100	0
Apr	38	74	26	0	0	0	0	0	0	0	0	0	100	0
May	38	0	11	16	34	18	11	11	0	0	0	0	79	21
Jun	38	0	0	11	29	18	13	18	3	8	0	0	58	42
Jul	38	0	0	8	26	29	3	11	13	11	0	0	63	37
Aug	38	0	0	5	13	32	18	8	8	13	3	0	50	50
Sep	38	3	0	8	18	18	24	8	11	8	3	0	47	53
Oct	38	5	16	21	21	8	8	5	0	13	3	0	71	29
Nov	38	24	32	16	11	11	3	3	0	3	0	0	92	8
Dec	38	21	39	24	8	5	3	0	0	0	0	0	97	3
Months	456	33	13	9	13	12	7	5	3	5	1	0	80	20

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	11	24	39	11	5	3	3	5	0	0	0	89	11
Jun	38	0	8	29	26	16	5	5	0	3	8	0	79	21
Jul	38	0	5	5	24	34	5	0	5	3	18	0	68	32
Aug	38	0	3	3	18	21	5	5	3	5	37	0	45	55
Sep	38	0	8	11	13	16	5	16	13	8	11	0	47	53
Oct	38	11	21	21	18	3	5	5	5	8	3	0	74	26
Months	456	4	11	18	18	16	5	6	5	4	13	0	67	33

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	3	29	29	29	3	8	0	0	0	0	0	92	8
Jun	38	0	8	29	24	13	16	3	3	5	0	0	74	26
Jul	38	0	5	3	34	24	11	11	3	11	0	0	66	34
Aug	38	0	3	11	8	34	13	11	11	8	3	0	55	45
Sep	38	3	11	13	13	16	21	16	5	0	3	0	55	45
Oct	38	13	24	26	11	5	3	5	3	8	3	0	79	21
Months	456	3	13	18	20	16	12	7	4	5	1	0	70	30

IAS 12 WATER SUPPLY: **Transposition MCC3 (+13%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration assuming Modified Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	92	8	0	0	0	0	0	0	0	0	0	100	0
Feb	38	95	5	0	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	87	13	0	0	0	0	0	0	0	0	0	100	0
May	38	11	16	16	32	11	8	8	0	0	0	0	84	16
Jun	38	0	3	13	26	29	13	5	3	8	0	0	71	29
Jul	38	0	0	11	39	18	13	0	13	5	0	0	68	32
Aug	38	0	0	0	24	37	13	5	0	16	5	0	61	39
Sep	38	0	8	3	11	13	24	16	5	11	11	3	34	66
Oct	38	8	11	13	3	21	8	5	8	13	11	0	55	45
Nov	38	29	29	13	13	11	3	0	0	0	3	0	95	5
Dec	38	47	29	18	3	0	3	0	0	0	0	0	97	3
Months	456	39	10	7	12	12	7	3	2	4	2	0	80	20

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	21	26	29	18	0	0	3	3	0	0	0	95	5
Jun	38	0	26	8	37	5	8	3	5	5	3	0	76	24
Jul	38	0	8	11	24	16	5	8	11	11	8	0	58	42
Aug	38	0	0	3	18	8	11	11	3	8	39	0	29	71
Sep	38	3	8	8	3	8	8	0	3	13	47	0	29	71
Oct	38	11	16	5	13	8	21	0	3	3	21	0	53	47
Months	456	6	14	11	19	7	9	4	4	7	20	0	57	43

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	18	29	26	13	11	3	0	0	0	0	0	97	3
Jun	38	0	16	16	29	18	11	5	0	5	0	0	79	21
Jul	38	0	8	16	26	13	18	5	8	3	3	0	63	37
Aug	38	0	0	3	32	21	11	11	11	8	5	0	55	45
Sep	38	3	11	5	3	8	34	8	13	5	11	0	29	71
Oct	38	13	13	11	11	16	3	11	3	5	16	0	63	37
Months	456	6	13	13	19	14	13	7	6	4	6	0	64	36

IAS 13 WATER SUPPLY: Transposition MCC4 (+14%)
SYSTEM OPERATION: Current (1991) Reservoir Configuration assuming Modified Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	89	11	0	0	0	0	0	0	0	0	0	100	0
Feb	38	97	0	3	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	95	5	0	0	0	0	0	0	0	0	0	100	0
May	38	3	32	18	29	11	5	3	0	0	0	0	92	8
Jun	38	0	3	11	37	34	5	8	3	0	0	0	84	16
Jul	38	0	5	5	47	29	3	3	3	5	0	0	87	13
Aug	38	0	5	3	16	47	18	0	8	0	3	0	71	29
Sep	38	0	0	16	18	32	16	11	3	3	3	0	66	34
Oct	38	3	13	21	8	29	3	5	8	8	3	0	74	26
Nov	38	24	18	32	13	5	8	0	0	0	0	0	92	8
Dec	38	29	55	11	5	0	0	0	0	0	0	0	100	0
Months	456	37	12	10	14	16	5	2	2	1	1	0	89	11

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	29	37	26	3	3	3	0	0	0	0	0	97	3
Jun	38	3	18	21	34	16	0	3	3	3	0	0	92	8
Jul	38	0	5	21	21	29	5	3	5	3	8	0	76	24
Aug	38	0	5	3	24	11	3	16	11	3	26	0	42	58
Sep	38	0	11	16	13	16	16	3	0	8	18	0	55	45
Oct	38	3	21	18	16	18	8	3	3	3	8	0	76	24
Months	456	6	16	18	18	15	6	4	4	3	10	0	73	27

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	13	39	26	16	5	0	0	0	0	0	0	100	0
Jun	38	0	11	24	45	11	8	3	0	0	0	0	89	11
Jul	38	0	5	24	34	18	11	0	5	0	3	0	82	18
Aug	38	0	5	8	21	24	32	3	0	8	0	0	58	42
Sep	38	0	11	24	13	24	16	5	3	3	3	0	71	29
Oct	38	3	34	11	24	5	5	3	8	3	5	0	76	24
Months	456	3	18	19	25	14	12	2	3	2	2	0	79	21

IAS 14 WATER SUPPLY: **Base Case (1951-88 Unregulated Flows, 0%)**
SYSTEM OPERATION: Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Currented (1991) Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	82	18	0	0	0	0	0	0	0	0	0	100	0
Feb	38	68	32	0	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	100	0	0	0	0	0	0	0	0	0	0	100	0
May	38	11	21	29	26	8	5	0	0	0	0	0	95	5
Jun	38	0	8	21	34	24	11	3	0	0	0	0	87	13
Jul	38	0	3	18	55	16	3	5	0	0	0	0	92	8
Aug	38	0	3	26	42	21	5	0	3	0	0	0	92	8
Sep	38	3	8	18	32	34	5	0	0	0	0	0	95	5
Oct	38	5	13	21	32	24	3	0	3	0	0	0	95	5
Nov	38	34	45	16	5	0	0	0	0	0	0	0	100	0
Dec	38	32	50	11	5	3	0	0	0	0	0	0	100	0
Months	456	36	17	13	19	11	3	1	0	0	0	0	96	4

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	18	58	16	5	3	0	0	0	0	0	0	100	0
Jun	38	3	26	34	24	5	0	0	3	3	3	0	92	8
Jul	38	0	8	29	32	16	3	8	3	3	0	0	84	16
Aug	38	3	5	8	32	26	8	11	5	3	0	0	74	26
Sep	38	5	5	13	24	16	13	13	8	3	0	0	63	37
Oct	38	5	21	16	32	21	3	0	3	0	0	0	95	5
Months	456	6	21	19	25	14	4	5	4	2	0	0	85	15

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	16	45	34	5	0	0	0	0	0	0	0	100	0
Jun	38	0	16	45	29	11	0	0	0	0	0	0	100	0
Jul	38	0	11	37	32	21	0	0	0	0	0	0	100	0
Aug	38	0	11	29	39	18	0	3	0	0	0	0	97	3
Sep	38	3	16	24	37	21	0	0	0	0	0	0	100	0
Oct	38	11	16	37	24	11	3	0	0	0	0	0	97	3
Months	456	5	19	34	28	14	0	0	0	0	0	0	99	1

IAS 15 WATER SUPPLY: CCC GCM II (-51%)
SYSTEM OPERATION: Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Modified Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	68	26	5	0	0	0	0	0	0	0	0	100	0
Feb	38	76	21	3	0	0	0	0	0	0	0	0	100	0
Mar	38	53	47	0	0	0	0	0	0	0	0	0	100	0
Apr	38	18	82	0	0	0	0	0	0	0	0	0	100	0
May	38	0	0	5	16	13	37	24	3	0	3	0	34	66
Jun	38	0	0	0	5	18	24	29	16	0	8	0	24	76
Jul	38	0	0	0	16	5	11	26	32	0	11	0	21	79
Aug	38	0	0	0	8	13	5	21	21	3	29	5	21	79
Sep	38	0	0	3	0	5	24	13	11	3	42	5	8	92
Oct	38	0	3	0	5	16	18	11	5	3	39	8	24	76
Nov	38	0	16	13	21	26	3	5	3	0	13	0	76	24
Dec	38	3	45	24	11	13	3	0	0	0	3	0	95	5
Months	456	18	20	4	7	9	10	11	7	1	12	2	59	41

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	0	13	13	24	13	11	8	11	3	5	0	63	37
Jun	38	0	0	0	24	21	11	5	0	8	32	0	45	55
Jul	38	0	0	0	11	5	16	11	0	5	53	0	16	84
Aug	38	0	0	0	8	0	0	5	0	11	76	3	8	92
Sep	38	0	3	0	3	5	0	0	3	11	76	3	11	89
Oct	38	0	3	0	8	11	13	3	16	3	45	5	21	79
Months	456	0	3	2	13	9	8	5	5	7	48	2	27	73

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	0	8	16	21	37	8	5	3	0	3	0	82	18
Jun	38	0	0	5	11	26	16	16	16	5	5	0	42	58
Jul	38	0	0	0	8	18	13	29	16	5	11	0	26	74
Aug	38	0	0	0	5	8	21	16	18	11	21	0	13	87
Sep	38	0	3	0	3	8	18	18	8	0	42	0	13	87
Oct	38	0	3	0	13	13	13	8	18	8	24	0	29	71
Months	456	0	2	4	10	18	15	15	13	5	18	0	34	66

IAS 16 WATER SUPPLY: **Transposition MCC1 (-2%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Modified Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	84	16	0	0	0	0	0	0	0	0	0	100	0
Feb	38	95	5	0	0	0	0	0	0	0	0	0	100	0
Mar	38	95	5	0	0	0	0	0	0	0	0	0	100	0
Apr	38	71	29	0	0	0	0	0	0	0	0	0	100	0
May	38	11	11	24	24	16	11	5	0	0	0	0	84	16
Jun	38	3	3	5	45	21	8	13	3	0	0	0	76	24
Jul	38	3	0	13	50	21	3	5	5	0	0	0	87	13
Aug	38	0	0	8	37	32	11	5	8	0	0	0	76	24
Sep	38	0	0	16	32	34	13	0	5	0	0	0	82	18
Oct	38	3	11	13	37	16	18	0	0	3	0	0	79	21
Nov	38	24	55	13	3	5	0	0	0	0	0	0	100	0
Dec	38	42	39	13	5	0	0	0	0	0	0	0	100	0
Months	456	36	14	9	19	12	5	2	2	0	0	0	90	10

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	13	34	39	8	0	3	0	3	0	0	0	95	5
Jun	38	5	11	18	37	16	3	5	0	5	0	0	87	13
Jul	38	3	5	18	18	21	11	8	5	5	5	0	66	34
Aug	38	0	3	8	16	18	13	11	5	5	21	0	45	55
Sep	38	3	5	13	24	24	3	5	3	11	11	0	68	32
Oct	38	5	3	26	16	24	13	0	8	3	3	0	74	26
Months	456	5	10	21	20	17	7	5	4	5	7	0	72	28

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	13	29	37	13	5	3	0	0	0	0	0	97	3
Jun	38	3	11	18	39	16	8	3	3	0	0	0	87	13
Jul	38	3	5	21	32	26	3	8	3	0	0	0	87	13
Aug	38	0	3	16	32	24	13	8	5	0	0	0	74	26
Sep	38	0	11	18	26	26	13	5	0	0	0	0	82	18
Oct	38	5	16	21	26	18	8	5	0	0	0	0	87	13
Months	456	4	12	22	28	19	8	5	2	0	0	0	86	14

IAS 17 WATER SUPPLY: **Transposition MCC2 (-19%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Modified Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	87	13	0	0	0	0	0	0	0	0	0	100	0
Feb	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Mar	38	84	16	0	0	0	0	0	0	0	0	0	100	0
Apr	38	58	42	0	0	0	0	0	0	0	0	0	100	0
May	38	0	13	11	24	32	13	8	0	0	0	0	79	21
Jun	38	0	0	8	42	11	21	11	8	0	0	0	61	39
Jul	38	0	0	8	50	5	8	16	13	0	0	0	63	37
Aug	38	0	0	3	32	26	13	16	5	3	3	0	61	39
Sep	38	3	0	5	29	37	11	11	0	3	3	0	74	26
Oct	38	5	16	21	26	11	11	8	3	0	0	0	79	21
Nov	38	21	45	24	5	0	5	0	0	0	0	0	95	5
Dec	38	21	47	21	8	3	0	0	0	0	0	0	100	0
Months	456	32	16	8	18	10	7	6	2	0	0	0	84	16

Node 7: **(Hanlon below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	11	24	39	11	5	3	3	5	0	0	0	89	11
Jun	38	0	8	29	26	16	5	5	0	3	8	0	79	21
Jul	38	0	5	5	24	34	5	0	5	3	18	0	68	32
Aug	38	0	3	3	18	21	5	5	3	5	37	0	45	55
Sep	38	0	8	11	13	16	5	16	13	8	11	0	47	53
Oct	38	11	21	21	18	3	5	5	5	8	3	0	74	26
Months	456	4	11	18	18	16	5	6	5	4	13	0	67	33

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	5	26	32	26	5	5	0	0	0	0	0	95	5
Jun	38	0	8	29	21	24	8	5	5	0	0	0	82	18
Jul	38	0	5	3	45	18	8	11	5	5	0	0	71	29
Aug	38	0	3	11	24	29	8	16	8	3	0	0	66	34
Sep	38	3	5	16	18	29	16	11	3	0	0	0	71	29
Oct	38	13	26	29	5	8	5	13	0	0	0	0	82	18
Months	456	4	12	20	23	19	8	9	4	1	0	0	78	22

IAS 18 WATER SUPPLY: Transposition MCC3 (-13%)
SYSTEM OPERATION: Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Modified Rule Curves
WATER USE: 2021 Withdrawal Water Use, Current (1991) Streamflow Targets

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	95	5	0	0	0	0	0	0	0	0	0	100	0
Feb	38	97	3	0	0	0	0	0	0	0	0	0	100	0
Mar	38	97	3	0	0	0	0	0	0	0	0	0	100	0
Apr	38	68	32	0	0	0	0	0	0	0	0	0	100	0
May	38	13	13	18	26	16	8	5	0	0	0	0	87	13
Jun	38	0	3	11	37	32	5	5	8	0	0	0	82	18
Jul	38	0	0	13	50	18	8	0	11	0	0	0	82	18
Aug	38	0	0	0	45	29	8	8	5	3	3	0	74	26
Sep	38	0	8	3	16	45	11	8	3	0	8	0	71	29
Oct	38	5	16	5	26	16	24	3	3	0	3	0	68	32
Nov	38	32	34	13	16	3	0	0	0	0	3	0	97	3
Dec	38	42	45	11	0	3	0	0	0	0	0	0	100	0
Months	456	37	13	6	18	13	5	2	2	0	1	0	88	12

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	21	26	29	18	0	0	3	3	0	0	0	95	5
Jun	38	0	26	8	37	5	8	3	5	5	3	0	76	24
Jul	38	0	8	11	24	16	5	8	11	11	8	0	58	42
Aug	38	0	0	3	18	8	11	11	3	8	39	0	29	71
Sep	38	3	8	8	3	8	8	0	3	13	47	0	29	71
Oct	38	11	16	5	13	8	21	0	3	3	21	0	53	47
Months	456	6	14	11	19	7	9	4	4	7	20	0	57	43

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	18	32	18	21	8	3	0	0	0	0	0	97	3
Jun	38	3	13	16	32	21	8	3	5	0	0	0	84	16
Jul	38	0	8	18	29	21	13	5	3	3	0	0	76	24
Aug	38	0	0	5	34	21	13	13	8	3	3	0	61	39
Sep	38	3	8	8	8	32	21	8	3	0	11	0	58	42
Oct	38	13	13	11	24	5	11	13	3	5	3	0	66	34
Months	456	6	12	13	25	18	11	7	4	2	3	0	74	26

IAS 19 WATER SUPPLY: **Transposition MCC4 (+14%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Modified Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
Jan	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Feb	38	97	3	0	0	0	0	0	0	0	0	0	100	0
Mar	38	100	0	0	0	0	0	0	0	0	0	0	100	0
Apr	38	84	16	0	0	0	0	0	0	0	0	0	100	0
May	38	3	37	16	26	11	5	3	0	0	0	0	92	8
Jun	38	0	3	11	53	24	3	5	3	0	0	0	89	11
Jul	38	0	5	13	61	13	0	3	5	0	0	0	92	8
Aug	38	0	5	3	45	37	3	3	5	0	0	0	89	11
Sep	38	0	0	16	32	39	11	0	0	0	3	0	87	13
Oct	38	3	16	16	34	11	18	0	0	0	3	0	79	21
Nov	38	26	50	13	5	5	0	0	0	0	0	0	100	0
Dec	38	29	63	3	5	0	0	0	0	0	0	0	100	0
Months	456	37	16	7	22	12	3	1	1	0	0	0	94	6

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	29	37	26	3	3	3	0	0	0	0	0	97	3
Jun	38	3	18	21	34	16	0	3	3	3	0	0	92	8
Jul	38	0	5	21	21	29	5	3	5	3	8	0	76	24
Aug	38	0	5	3	24	11	3	16	11	3	26	0	42	58
Sep	38	0	11	16	13	16	16	3	0	8	18	0	55	45
Oct	38	3	21	18	16	18	8	3	3	3	8	0	76	24
Months	456	6	16	18	18	15	6	4	4	3	10	0	73	27

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
May	38	16	37	29	13	5	0	0	0	0	0	0	100	0
Jun	38	0	11	24	45	11	8	3	0	0	0	0	89	11
Jul	38	0	5	26	37	21	3	3	3	3	0	0	89	11
Aug	38	0	5	13	21	45	8	3	5	0	0	0	84	16
Sep	38	0	5	29	21	32	8	3	0	0	3	0	87	13
Oct	38	3	32	13	26	5	11	8	0	0	3	0	79	21
Months	456	3	16	22	27	20	6	3	1	0	1	0	88	12

IAS 20 WATER SUPPLY: **Linear Reduction of Base Case by 20% (i.e., Base Case - 20%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Current (1991) Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
Jan	38	68	29	3	0	0	0	0	0	0	0	0	100	0
Feb	38	66	32	3	0	0	0	0	0	0	0	0	100	0
Mar	38	97	3	0	0	0	0	0	0	0	0	0	100	0
Apr	38	95	5	0	0	0	0	0	0	0	0	0	100	0
May	38	8	3	24	37	21	8	0	0	0	0	0	92	8
Jun	38	0	3	5	42	26	18	3	3	0	0	0	76	24
Jul	38	0	3	11	45	16	13	11	3	0	0	0	74	26
Aug	38	0	3	8	42	24	16	3	0	5	0	0	76	24
Sep	38	3	0	11	34	32	13	5	3	0	0	0	79	21
Oct	38	5	11	11	34	18	13	5	0	3	0	0	79	21
Nov	38	21	50	16	11	3	0	0	0	0	0	0	100	0
Dec	38	18	58	8	13	0	0	0	3	0	0	0	97	3
Months	456	32	16	8	21	12	7	2	1	1	0	0	89	11

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
May	38	13	26	45	8	3	5	0	0	0	0	0	95	5
Jun	38	0	16	34	26	5	5	3	3	3	5	0	82	18
Jul	38	0	3	21	24	16	18	5	5	3	5	0	63	37
Aug	38	0	8	5	18	18	13	13	8	11	5	0	50	50
Sep	38	3	5	11	24	5	13	13	8	11	8	0	47	53
Oct	38	5	5	18	29	24	8	5	3	3	0	0	82	18
Months	456	4	11	22	21	12	11	7	4	5	4	0	70	30

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
May	38	8	26	53	8	5	0	0	0	0	0	0	100	0
Jun	38	0	8	34	29	21	8	0	0	0	0	0	92	8
Jul	38	0	3	26	34	21	13	3	0	0	0	0	84	16
Aug	38	0	3	21	32	29	13	0	3	0	0	0	84	16
Sep	38	3	8	18	18	45	8	0	0	0	0	0	92	8
Oct	38	5	11	32	24	21	8	0	0	0	0	0	92	8
Months	456	3	10	31	24	24	8	0	0	0	0	0	91	9

IAS 21 WATER SUPPLY: **Linear Reduction of Base Case by 50% (i.e., Base case - 50%)**
SYSTEM OPERATION: **Current (1991) Reservoir Configuration plus West Montrose Reservoir assuming Current (1991) Rule Curves**
WATER USE: **2021 Withdrawal Water Use, Current (1991) Streamflow Targets**

Node 4: **Doon (in Kitchener)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
Jan	38	37	47	11	3	0	0	3	0	0	0	0	97	3
Feb	38	39	39	13	3	3	0	3	0	0	0	0	97	3
Mar	38	89	11	0	0	0	0	0	0	0	0	0	100	0
Apr	38	71	29	0	0	0	0	0	0	0	0	0	100	0
May	38	0	5	3	11	26	45	11	0	0	0	0	45	55
Jun	38	0	0	0	8	21	32	24	11	3	3	0	29	71
Jul	38	0	0	0	13	8	21	24	29	0	5	0	21	79
Aug	38	0	0	3	5	16	26	11	26	3	11	0	24	76
Sep	38	0	3	0	8	13	18	21	13	5	18	0	24	76
Oct	38	0	5	5	5	26	26	5	3	5	18	0	42	58
Nov	38	0	37	26	16	8	0	5	3	0	5	0	87	13
Dec	38	5	42	18	16	8	3	3	0	3	3	0	89	11
Months	456	20	18	7	7	11	14	9	7	2	5	0	63	37

Node 7: **Hanlon (below Guelph)**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
May	38	0	16	18	11	32	16	3	5	0	0	0	76	24
Jun	38	0	0	13	16	18	13	5	11	8	16	0	47	53
Jul	38	0	0	3	16	16	3	8	13	16	26	0	34	66
Aug	38	0	0	8	3	8	8	3	13	13	45	0	18	82
Sep	38	3	3	3	5	3	13	5	16	5	45	0	16	84
Oct	38	0	5	3	24	13	11	13	11	5	16	0	45	55
Months	456	0	4	8	12	15	11	6	11	8	25	0	39	61

Node 14: **Brantford**

Demanded Min. Flow (as a percentage of available outflow)

Month	No.	0-19 %	20-39 %	40-59 %	60-79 %	80-99 %	100-119 %	120-139 %	140-159 %	160-179 %	over 180 %	No Supply	Summary <100	Summary >100
		PERCENTAGE OF OCCURRENCES												
May	38	0	11	24	47	13	5	0	0	0	0	0	95	5
Jun	38	0	0	11	18	34	11	21	5	0	0	0	63	37
Jul	38	0	0	0	21	16	21	21	21	0	0	0	37	63
Aug	38	0	0	3	11	26	13	18	24	3	3	0	39	61
Sep	38	0	3	11	11	13	24	16	16	5	3	0	37	63
Oct	38	0	8	5	26	18	18	8	3	5	8	0	58	42
Months	456	0	4	9	22	20	15	14	11	2	2	0	55	45

APPENDIX D

Information Package and Questionnaire

Adapting to the Impacts of Climate Change and Variability in the Grand River Basin: Water Supply and Demand Issues

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THE ISSUE OF CLIMATE CHANGE: SOME CONTEXT

The Intergovernmental Panel on Climate Change (IPCC), an international body of scientists, recently stated that:

"The balance of evidence suggests that there is a discernible human influence on global climate" (IPCC, 1995).

Over the past fifteen years potential climate change has emerged as one of the most important global environmental issues. There is scientific consensus that human activities have increased the concentration of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere. Presently, there is approximately 30% more CO_2 in the atmosphere than in pre-industrial times and, if current levels of emissions are not reduced, a doubling will be realized and passed within the next century and a tripling is not impossible. There is scientific agreement that increasing concentrations of these radiatively active gases will lead to an enhanced greenhouse effect and a warmer and wetter global climate; global mean temperature is expected to rise 1.5-4.5°C by the end of the next century (IPCC, 1990) while Ontario temperatures could rise from 3-8°C (Mortsch, 1995). Global precipitation is also expected to increase, though certain mid-latitude regions may experience much drier summers, and changes in the frequency, distribution and intensity of extreme events are likely (Mortsch, 1995).

Scientific experiments using General Circulation Models (GCMs) of the climate system suggest that the atmospheric concentration of greenhouse gases has risen enough to induce a 0.4-1.3°C warming (SOER, 1995). Observed temperatures over the past century have increased globally by 0.5°C, nationally by 1.0°C and, in the Great Lakes -St. Lawrence region, by 0.6°C. This global warming *"...is unlikely to be entirely natural in origin"* (Global Environmental Change Report, 1995).

RESPONSE TO THE ISSUE

Response to the climate change issue has been slow relative to remediative actions targeting other atmospheric issues like ozone depletion and acid rain, largely due to the global nature of both the problem and potential solutions. First steps include an international recognition of the significance of climate change in the signing of the Framework Convention on Climate Change (FCCC) in 1992 and initial progress towards limiting greenhouse gas emissions. Canada's National Action Program on Climate Change (NAPCC) (Canadian Energy and Environment Ministers, 1995) is designed to meet the country's commitments under the FCCC. A set of voluntary measures have been established towards the target of stabilizing greenhouse gas emissions at 1990 levels by the year 2000. The NAPCC also strongly supports improving the science of climate change and variability, increasing knowledge of potential impacts and costs, and developing adaptation strategies to reduce society's vulnerability to climate change.

This study is one component of the Great Lakes-St. Lawrence Basin Project on adapting to the impacts of climate change and variability, an Environment Canada research initiative involving many partners from other federal, provincial and local agencies and private industry. The Grand River Basin study contributes to the overall project by:

1. identifying and assessing the impacts of climate change and variability on the supply and demand of surface water in the Grand River Basin;
2. identifying and evaluating strategies for adapting to possible impacts; and

3. involving and encouraging multiple disciplines and stakeholders to take part in the research and increase awareness about climate variability and change, impacts and possible adaptation responses.

The Great Lakes-St. Lawrence Basin Project and Grand River basin study contribute to the national plan by identifying and analyzing potential impacts of climate change and through the development and assessment of adaptation strategies.

HOW MIGHT CLIMATE CHANGE AFFECT THE GRAND RIVER BASIN?

Research into the potential impacts of climate variability and change has concentrated on climate-sensitive resource sectors like agriculture, forestry and water resources where significant regional impacts could occur (IPCC, 1990). In Canada, over 60 climate impact studies have been completed for such diverse topics as agriculture, forestry, sea-level rise, lake level fluctuations and tourism and recreation activities (CCPB, 1991; Herbert, 1993). A summary of research on the implications of climate change and variability recently completed for Ontario (Mortsch, 1995) identified impacts on the following interests and sectors:

- Air quality
- Biodiversity
- Forestry and agriculture
- Human health
- Transportation
- Tourism and recreation
- Water resources

While each of these sectors or interests may be affected in the Grand River Basin, the greatest impacts of climate change and variability are expected to be those associated with the supply, quality and demand of its water resources. The Grand River and its tributaries are extensively used as a source of drinking water, receiving stream for treated sewage and as a medium for tourism and recreation activities. Past research using climate change scenarios suggests that future annual streamflow could be severely reduced (Smith and McBean, 1993). Accordingly, the Grand River study is investigating these three issues which may become more complicated with climate change:

1. Ability to maintain target flow minimums established to assimilate treated sewage effluent;
2. Ability to augment or replace groundwater supplies for domestic, commercial, institutional, industrial and agricultural (irrigation) needs; and
3. Availability of water for in-stream recreation activities and habitat maintenance.

The first two issues have enormous implications for growth and development within the Basin. One factor which may limit urban growth within the Grand River Basin is the ability of area streams to absorb treated sewage. Assimilative capacity is closely associated with levels of streamflow through the principle of dilution; more water generally increases the ability of a watercourse to assimilate waste. Using data generated by the Canadian Climate Centre's General Circulation Model (CCC GCM), Smith and McBean (1993) demonstrated that climate change could significantly reduce average annual streamflow in the Grand River, by up to 39% at Cambridge-Galt.

The quantity and quality of drinking water supplies also constrain growth. The basin's largest regional municipality, the Region of Waterloo, has examined alternative sources of water, such as a pipeline to the Great Lakes or increased abstraction from the Grand River, to augment or buffer present groundwater supplies in support of anticipated growth or in the event of groundwater contamination. Water from the Grand River is already used to augment Region of Waterloo supplies at a rate of 4 Million Imperial Gallons per Day (MIGD) and this rate is expected to increase to the full 16 MIGD capacity by the year 2025 (Region of Waterloo and Associated Engineering, 1994). Other municipalities including Brantford and the Six Nations Reserve are concerned about water quality as their domestic supplies are drawn from the Grand downstream of the treated sewage effluent discharges of Waterloo, Kitchener, Guelph and Cambridge. Climate change scenarios threaten

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to reduce water quality further, especially during the summer's low flow periods when the demand for water is greatest. Several studies have concluded that climate change may increase the demand for water, especially for irrigating agricultural land. It is possible that the Grand River and its tributaries may not be able to support the increased demand for water in the future as both the quantity and quality of Grand River surface water may deteriorate.

The Grand River, its tributaries and reservoirs are used extensively for recreation and they support a wide variety of natural habitat. The Grand was recently designated a national heritage river (GRCA, 1994) and is growing as a focus for cultural and recreational events. Participation in recreational activities is partially dependent on desirable conditions and will drop when minimum acceptable streamflow and water quality are not met. Natural habitat along the Grand and its tributaries also requires minimum flows and the existence of certain flow sequences (fluctuations) in order to thrive and regenerate. Climate change may produce stream conditions which could significantly alter the river ecosystem, including its valued fisheries.

WHAT CAN PEOPLE IN THE GRAND RIVER BASIN DO?

There are three general responses which basin residents, agencies and other stakeholders can take in coping with or adapting to the potential impacts of climate change and variability. They could ***do nothing*** until there is a greater certainty concerning the timing, rate of change and nature of regional impacts. In light of the mounting evidence supporting global climate change, this approach seems unwarranted. At the opposite of the response spectrum, one could ***assume a worst case scenario*** and react swiftly and aggressively regardless of cost or other implications of actions. If the certainty of regional climate change and impacts were high, or if climate was the only factor in decision-making, this would be a suitable approach, however neither condition is true. A more palatable and medial position is to ***take a precautionary adaptive approach*** by identifying and implementing responses that make sense now even if the worst case scenario does not materialize. Such an approach to climate change involves taking a pro-active position against potential risks and impacts. It aims to consider multiple forces of change acting upon any given interest or issue and assess the role of climate relative to such factors. While this last approach is most consistent with the methodology used in the Grand River study, it is recognized that stakeholders will not always share the same opinions regarding the potential risk of climate change or its significance to their area of interest.

After reviewing the following preliminary findings, please complete the attached survey. It is designed to solicit stakeholder comments and opinions which will assist in interpreting the climate change study's final results.

THE GRAND RIVER BASIN STUDY: SOME PRELIMINARY FINDINGS

- Grand River Basin population expected to increase 50% by the year 2021; water use will only rise by 25% under this scenario if the assumed reductions in per capita water demand are realized.
- Waste water volume will also increase by 25%.
- Five climate change scenarios have been developed for testing; their impacts on long-term average streamflow range from a 51% drop to a 14% gain.
- The long-term average change is not necessarily the best index as seasonal distributions and extreme flows can change significantly; all five scenarios have reduced summer supplies.
- Initial results suggest that it will become difficult to meet minimum flow targets in the summer under both current (4 MIGD) and proposed (16 MIGD) Region of Waterloo abstractions from the Grand River.
- Scenario flows will have a direct effect on communities abstracting water to meet part or all of their demands.
- Reservoir rule curve modifications and the potential addition of a new reservoir at West Montrose will ameliorate some of the negative

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effects; however, each scenario contains years in which extreme low supplies remain problematic and may necessitate the undertaking of additional actions.

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QUESTIONNAIRE ON CLIMATE CHANGE

This questionnaire is designed to solicit information from stakeholders on adapting to the impacts of climate change and variability in the Grand River Basin. Please complete the survey by providing your personal or professional response to each of the questions. Use the back of each page if you require additional space to answer any question. Please return completed surveys to the study organizers by Wednesday, March 6, 1996 in the stamped, self-addressed envelope provided. Individual responses will be kept confidential. Questions concerning the survey can be directed to Chuck Southam, *Environment Canada* at (905) 336-4955. Your cooperation is greatly appreciated.

1. a) Please indicate below which *Grand Strategy* committee or working group you currently participate in.

____

b) Please identify the type of organization which you represent.

- ☐ private industry
- ☐ non-governmental interest group
- ☐ municipal government
- ☐ provincial government
- ☐ federal government
- ☐ private citizen (no specific organization)

2. Are the potential impacts of climate change and variability on surface water supplies in the Grand River Basin being considered by your working group in developing its component of *The Grand Strategy*?

☐ Yes ☐ No ☐ Don't know

3. What measures have your organization initiated to deal with low water supplies?

____

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4. What potential adaptation strategies would you consider appropriate for coping with ***chronic low summer flows***, as discussed in the background document? (Please identify as many as you consider appropriate with a check mark, and add any others not listed.)

- [ ] construction of additional reservoir(s)
- [ ] modification of reservoir operation to adapt to changing climate
- [ ] pipeline to import water
- [ ] improved sewage treatment
- [ ] restrictions on existing water use
- [ ] restrictions on new water uses
- [ ] pricing water to reduce demand
- [ ] other (please specify below)

5. What information about climate change and variability would you need prior to taking actions such as those which you listed in response to question 4?

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6. How could information on climate change and variability be made more meaningful or useful to you?

7. What are the most important factors that affect the vulnerability of your sector/interest to climate change and variability?

8. Please provide any other comments concerning the issue of climate change and variability or the content of the background discussion paper that you have.

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