Climate Change and Water Resources in the South Saskatchewan River Basin

PROCEEDINGS OF THE WORKSHOP

Edited by

S. N. Kulshreshtha
R. Herrington
D. Sauchyn

DEPARTMENT OF AGRICULTURAL ECONOMICS
UNIVERSITY OF SASKATCHEWAN
SASKATOON, SASK., S7N 5A8

APRIL 2002

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Funded in part by the Government of Canada's Climate Change Action Fund

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PREFACE AND ACKNOWLEDGEMENTS

This report is based on the presentations made during the Workshop on "Climate Change and Water Resources in the South Saskatchewan River Basin", held on January 26-27, 2002, at the University of Calgary, Calgary. It was held in the Evans Room, Rozsa Center of the University of Calgary Campus. During the course of this workshop, we received help and assistance from a number of individuals.

- We like to thank the Climate Change Action Fund for providing the funding that enabled us to organize the Workshop. This assistance is gratefully acknowledged.

- We would like to express our gratitude for all the advice and guidance on the objective of the Workshop and other related matters that we received from Don Lemmen and Pam Kertland, of Natural Resources Canada.

- The report benefited from many improvements suggested by Dr. Don Lemmen, Natural Resources Canada, on an earlier draft.

- We are thankful to Professor Caterina Valeo for taking the painstaking responsibility of making local arrangements for the Workshop, and to Professor Francois Bouchart for helping the day to arrangements during the Workshop.

- Finally this Workshop would not have successful without the efforts of all the speakers and presenters at the Workshop. We are deeply indebted to all the speakers and presenters at this Workshop for their efforts.

- We are thankful to Della Nykyforak, Department of Agricultural Economics for doing a meticulous job or typing and formatting the document.

- Finally, technical assistance received from Scott Robson, Educational and Research Technology Services, is gratefully acknowledged.

Any remaining errors of commission and / or omissions are editors' responsibility.

ORGANIZING COMMITTEE

S. N. Kulshreshtha	University of Saskatchewan, Saskatoon
Ross Herrington	Environment Canada, Regina
Don Lemmen	Natural Resources Canada, Ottawa
Dave Sauchyn	Prairie Adaptation Research Collaborative, Regina
Caterina Valeo	University of Calgary

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INVITED PRESENTATIONS

Introduction and Welcome

Ross Herrington
Environment Canada
Regina

On behalf of the Workshop Organizing Committee, I would like to welcome you to Calgary and to this workshop, sponsored by the Climate Change Action Fund. I am particularly appreciative that you are here on what would normally be a 'day of rest'!

As evidenced by the strong response to CCAF's recent Letter of Intent call, we all share a common interest in the water resources of the South Saskatchewan River Basin and the present and future impacts of climate variability and change. I think we will see throughout the workshop that, while each of us has a particular research focus, there are many areas where interests converge. We need to build on these common threads and to develop the linkages that will maximize our success in enhancing our understanding of the vulnerabilities of this important Prairies drainage basin.

The workshop program will provide opportunities to better understand these basin issues. We will begin by asking our speakers and panelists to identify some of the water issues from their perspective. This will provide the backdrop for tomorrow's session where specific research issues will be identified by each CCAF proponent. Breakout groups will then focus specifically on hydrology, water management, socio-economics, and legal aspects. These groups will be charged with identifying critical issues in the basin, identifying key stakeholders, and providing guidance on the most critical limiting knowledge gaps that need to be addressed to allow effective adaptation to occur.

So, I hope that your time here will be beneficial. I encourage each of you to participate actively in the discussions over the next couple of days. Together we can strengthen existing science partnerships, initiate new ones, and move forward collaboratively.

Climate Change Impacts and Adaptation South Saskatchewan Basin Workshop

Donald S. Lemmen
Adaptation Liaison Office
Natural Resources Canada
Ottawa

Workshop Goals

1. To develop an improved understanding of <u>vulnerabilities</u> within the South Saskatchewan Basin related to climate change, based upon input from <u>stakeholders</u> and researchers.

2. To develop a prioritized list of critical knowledge gaps / research needs that need to be addressed to enable effective <u>adaptation</u> within a <u>risk management</u> context.

History

- June 2001 - CCAF Impacts and Adaptation Program issued a national call for LOI on water resources. Projects up to 36 months duration – total available funds $750k.

- Received more than 120 LOI requesting a total of more the $14M.

- Proposals ranked by SIA Technical Committee and approximately 20 proponents asked to submit full proposals. Included recommendations for merging of proposals where there was thematic / geographical overlap and opportunity for savings.

- EXCEPTION – South Saskatchewan Basin. At least 14 proposals. No single proposal seemed to fully address needs, too many to suggest merging.

Why A Workshop

- Need to address issue in a more integrative approach – biophysical, socioeconomic, regulatory / legal

- Broad expertise with limited interaction in past

- Limited resources – must utilize as efficiently as possible, maximize leverage, have priorities clearly defined

- Provide stakeholders and researchers to work together to develop directed research program

Desired Outcomes

<u>For CCAF:</u>

- A workshop report identifying what needs to be studied in order to have a comprehensive analysis of vulnerability of the SSB to climate change. This should include what has already been done, what remains to be done, and of the latter – what are the critical priorities

<u>For Stakeholders</u>

- Increased awareness of research community and capacity, input into identifying research priorities, future participation in issue through PARC

<u>For Researchers</u>

- Improved understanding of CCAF process and goals, enhanced collaboration.

Post-workshop activities

- Workshop report prepared with wide input, and submitted to CCAF.

- Based in (large?) part on the workshop report, the CCAF Impacts and Adaptation Program will issue an open Call Letter for full proposals for work in the SSB.

Proposal stage

- Will hopefully build on the recommendations and collaborations developed at the workshop.

- Beyond scientific merit, emphasis in evaluation is placed upon:

    - Gap being addressed (and rationale),
    - Stakeholder involvement (including leverage),
    - Outputs (beyond conventional publications)
    - IMPACT

How to define “Importance?

Suggestions:

- Potential magnitude of impacts (environmental, social, economic)
- Impacts that are occurring today – action is needed immediately
- Issues where decisions are being made today that have a design life extending for several decades

Adaptation

- Adjustments in practices, processes, or structures of systems to projected or actual changes of climate
- Adaptation can in response to, or in anticipation of, changes in conditions.

NECESSARY TO:

1. Minimize the negative impacts of future climate changes
2. Take advantage of new opportunities that may be presented

Adaptation Research –

- Obtaining a thorough understanding of the processes of adaptation including:
- Identification of the players in adaptation and their role
- The barriers to action by these players and what incentives exist (including those for maladaptation)
- Potential extent to which adaptation (social, technological and policy) can ameliorate the impacts of climate change.

Issue: How <u>Vulnerable is the South Saskatchewan Basin to Climate Change??</u>

Vulnerability: the change to which a system is susceptible to, or unable to cope with, adverse effects of climate, including climate variability and extremes.

It is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

IPCC WGII TAR (2001)

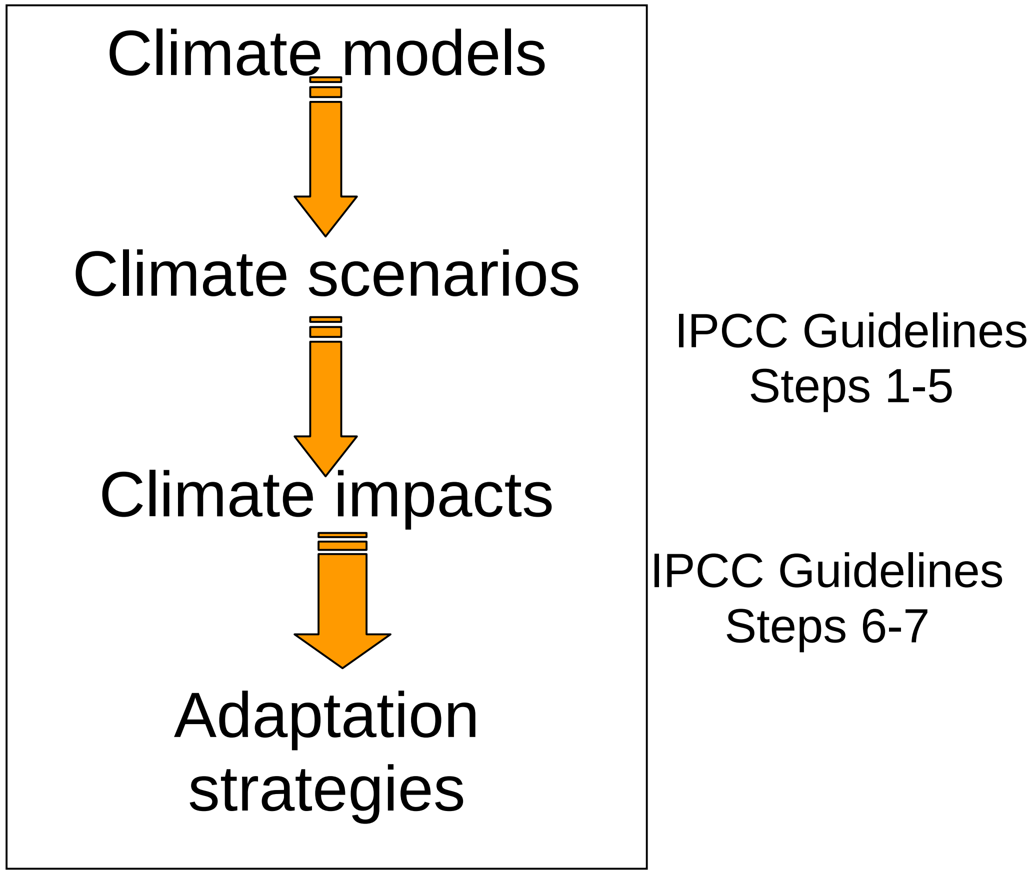
Scope of Impacts and Adaptation Issues

Biophysical | Social | Economic

Spontaneous (in response to) ↔ Planned (in anticipation of)

Need to Understand Process

Historical Approach to I&A Research

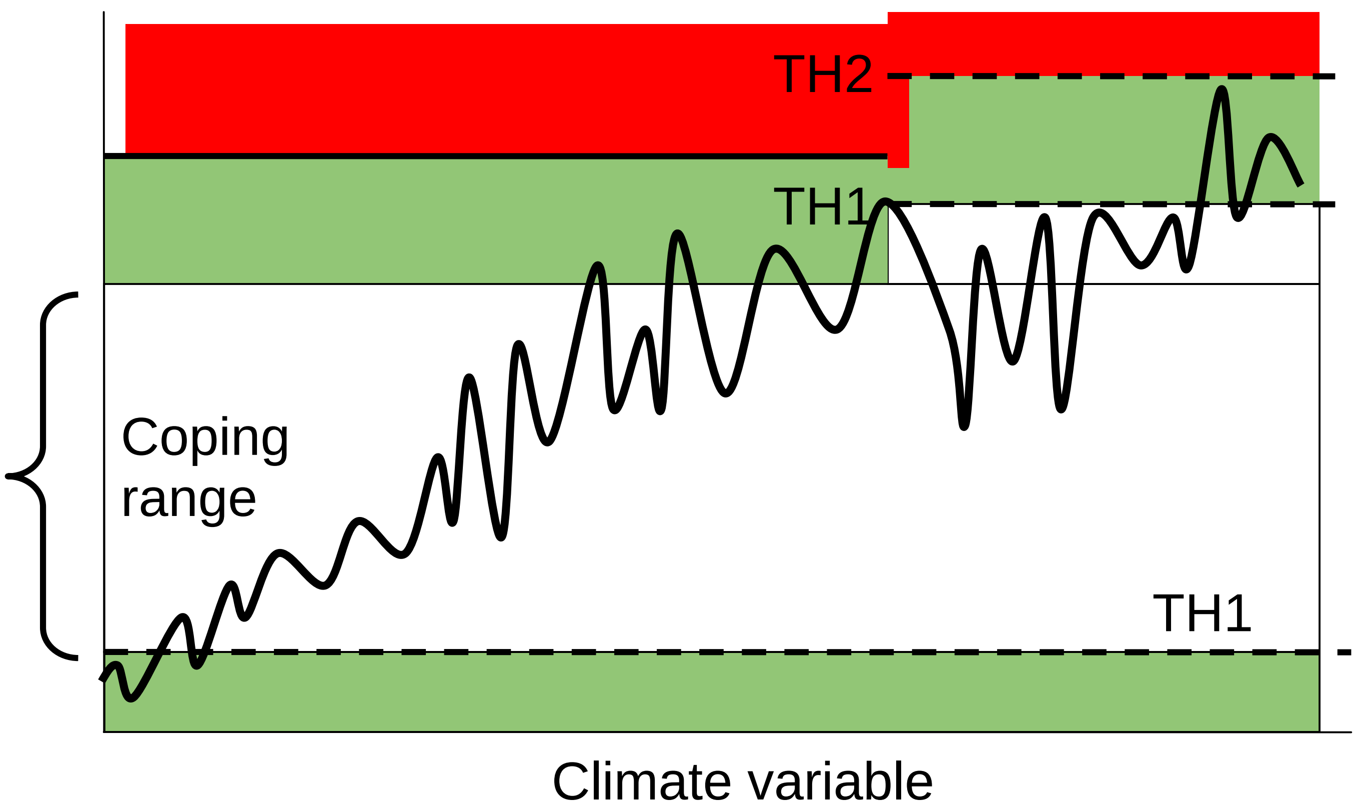


Challenges

- Adaptation becomes a hand-off (a separate issue)
- Cascading uncertainties
- Dominated by biophysical and climatic aspects, lacking in socioeconomic elements
- Lack of connection to stakeholders current concerns
- Studies not always useful for decision-making
- Adaptation research is missing –
    - The dynamics of adaptation

- The process of adaptation decision making
- Conditions that constrain or stimulate adaptation
- Role of non-climatic factors

Risk Assessment and Coping

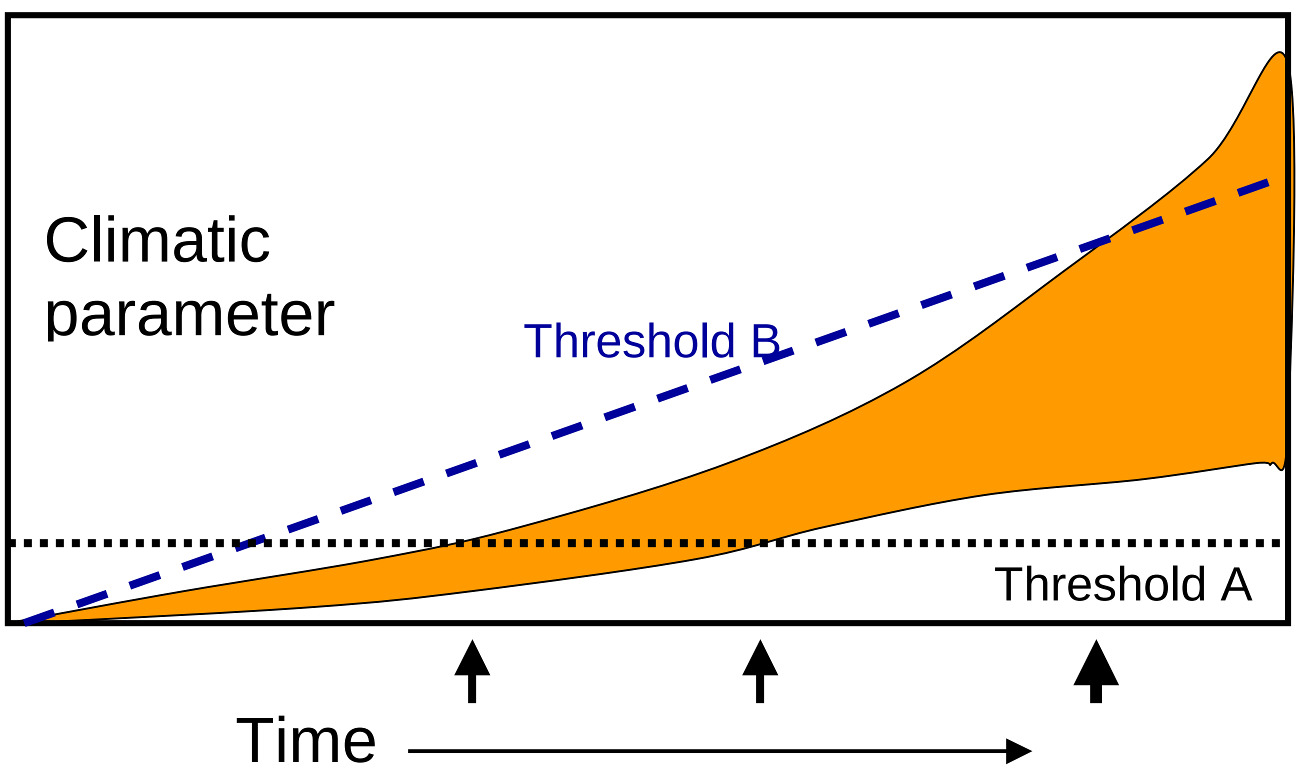


Realistic climate change impact assessments must take adaptation into account (Pittock and Jones, 2000)

Impact Threshold

- Any degree of change that can link the onset of a given critical biophysical or socioeconomic impact to a particular climate state or states

- Represent a distinct change in the conditions or level of performance of a system



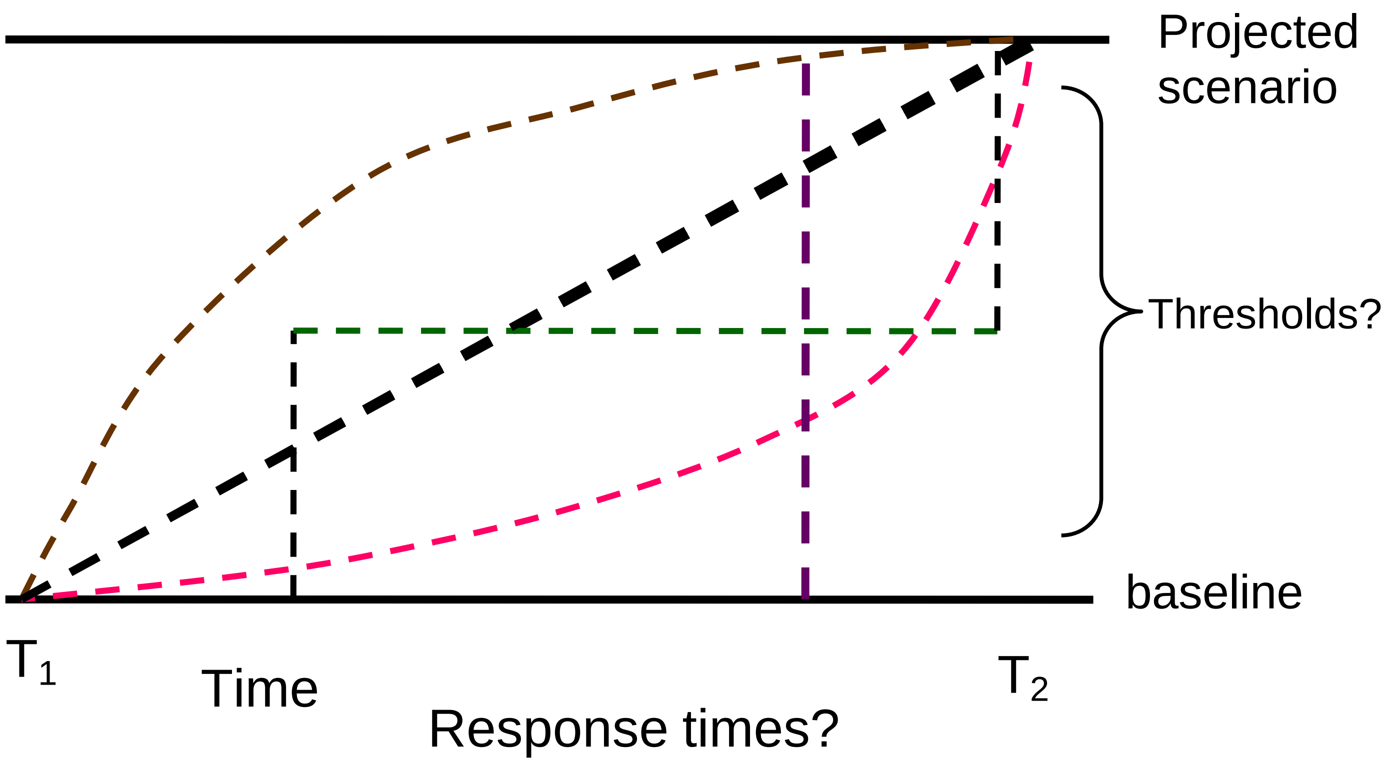
A - absolute threshold

B - rate of change threshold

Modified from
Pittock and Jones (2000)

Climate change is an ongoing process

System response is not always linear
Understanding of system dynamics critical for decision making

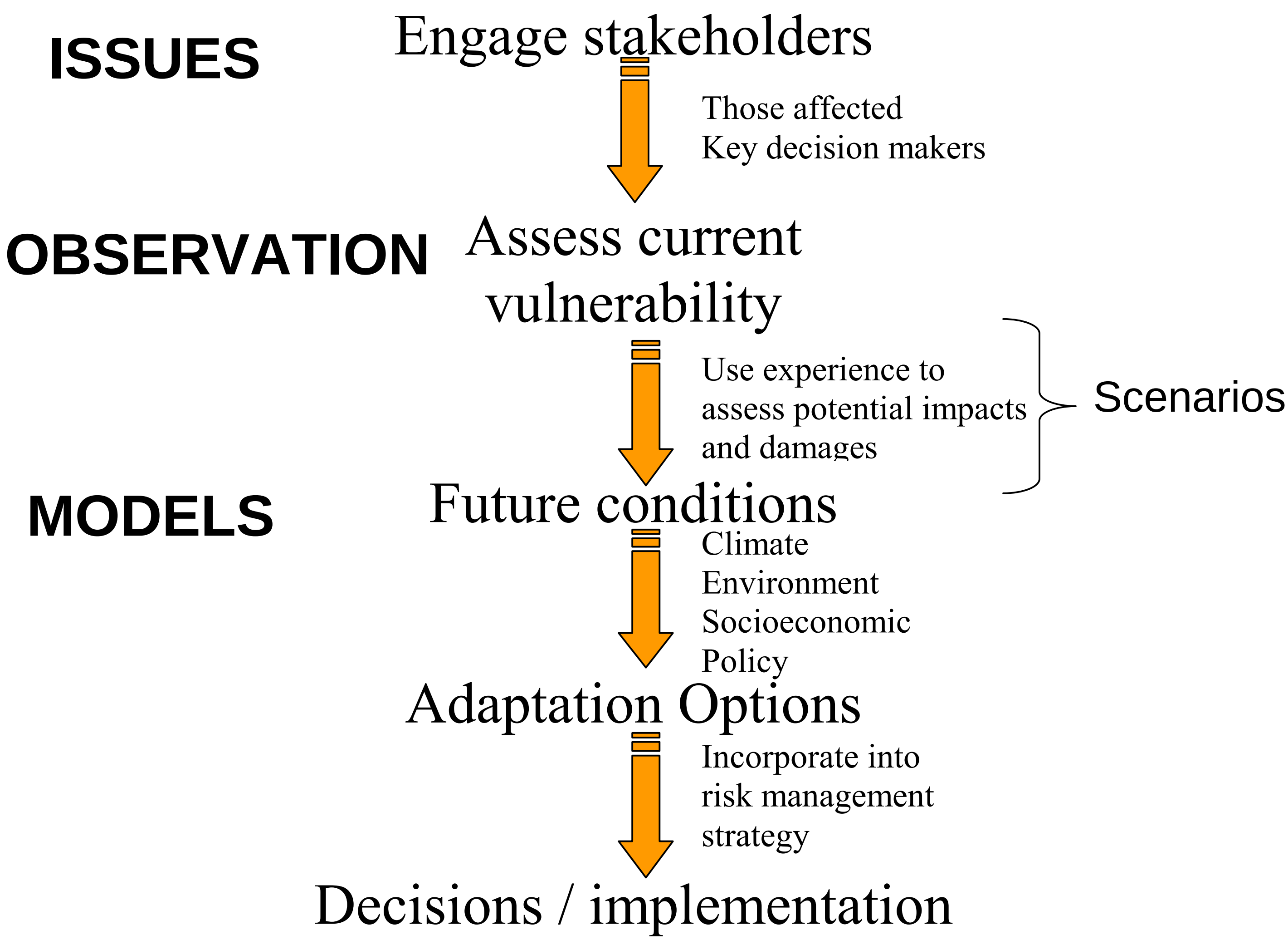


SO

Start by understanding the system of concern

- dynamics
- critical thresholds
- lag times
- multiple triggers

Adapting to Climate Change



Benefits of a Vulnerability Approach

- Does NOT require detailed prior knowledge of future climate change at initial stage of research
- Includes adaptation to climate VARIABILITY - helpful in engaging decision-makers and stakeholders
- Needs of decision makers are incorporated in the research design and includes the role of institutions in the response (adaptive capacity)
- Products are RISK-BASED, providing decision makers with a quantitative (probabilistic) basis for assessing adaptation options and defining limits to adaptation
- Incorporates expertise and tools of other disciplines early in the process
- Enables integration of information and costing

Role of Prairie Adaptation Research Collaborative in Climate Change Impacts and Adaptation Research

Dave Sauchyn
Research Coordinator
Prairie Adaptation Research Collaborative
University of Regina, Regina

PRAIRIE ADAPTATION RESEARCH COLLABORATIVE

PARC

www.parc.ca

The Prairie Adaptation Research Collaborative is a facilitative, interdisciplinary research network established to understand the potential impacts of climate change on the Canadian Prairie Provinces and conduct research necessary to develop appropriate adaptation strategies.

PRAIRIE ADAPTATION RESEARCH COLLABORATIVE

The Canadian Plains

Natural and socio-economic systems are sensitive to climatic variability, climatic change and extreme hydroclimatic events

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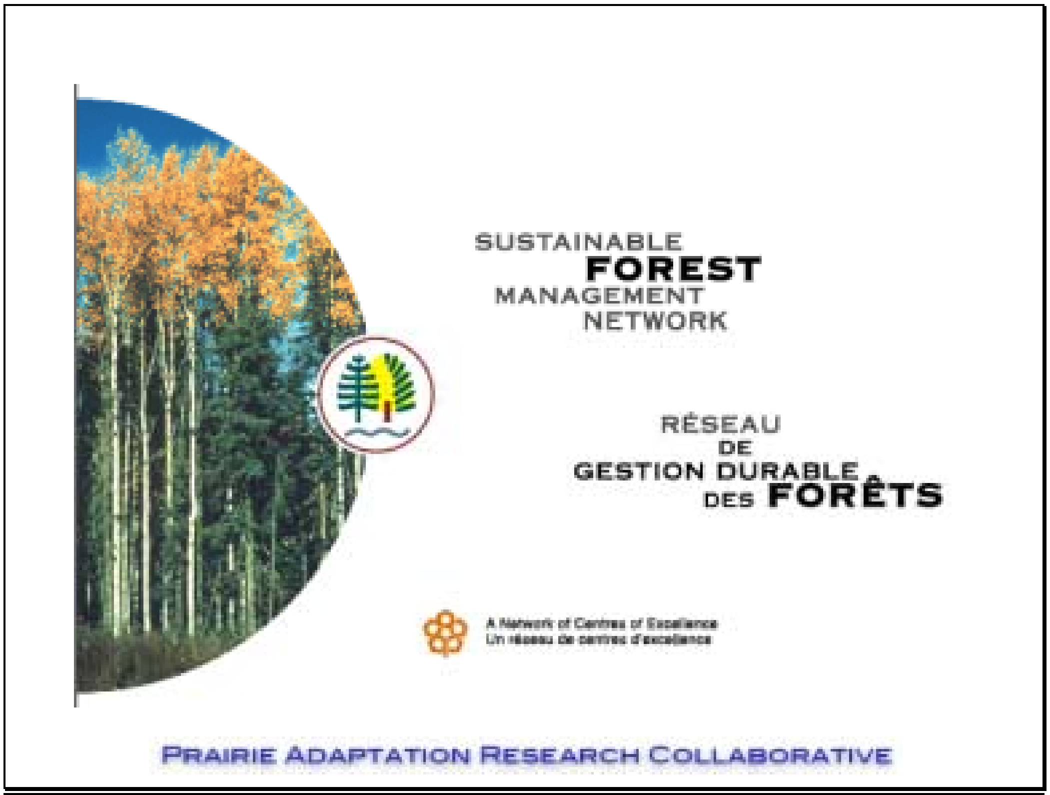
SUSTAINABLE
FOREST
MANAGEMENT
NETWORK
RÉSEAU
DE
GESTION DURABLE
DES FORÊTS
A Network of Centres of Excellence
Un réseau de centres d'excellence
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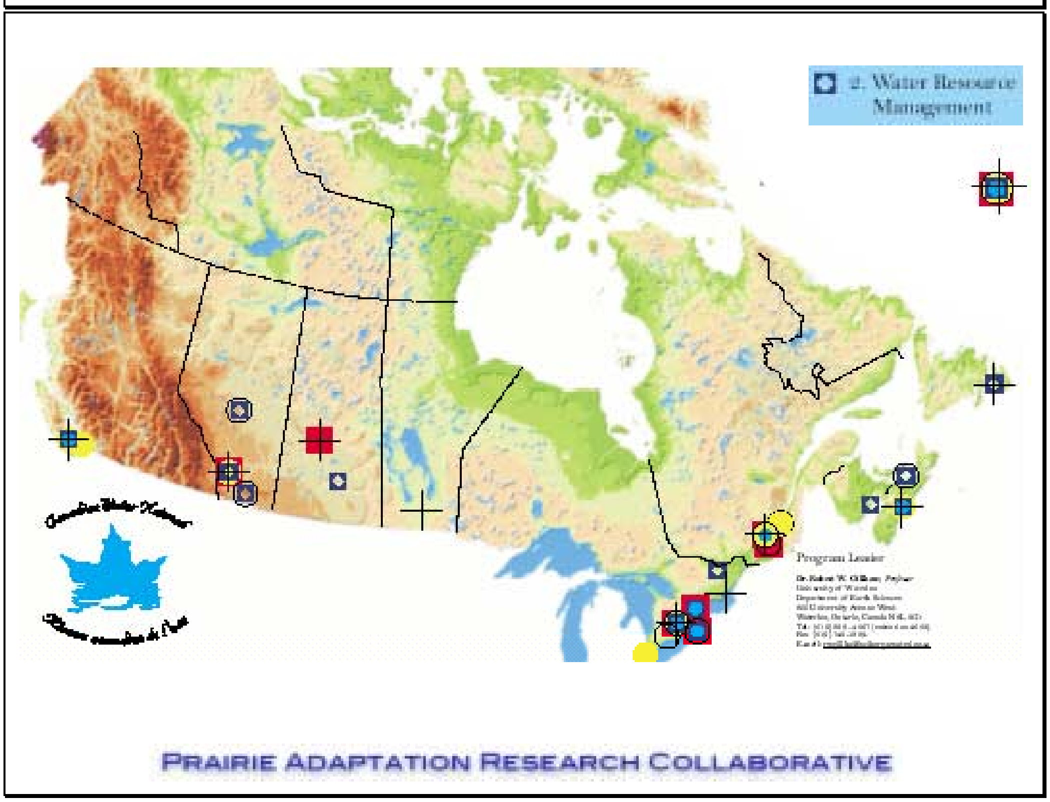
2. Water Resource Management
Program Leader
PRAIRIE ADAPTATION RESEARCH COLLABORATIVE

Historical Adaptation to Climatic Variability

… it is likely that region-specific changes in the hydrologic cycle produced the greatest societal and economic challenges. … When record keeping became routine, those cultures with some level of awareness of at least the natural variability in rainfall and perhaps even an understanding of the characteristic timescales of drought/flood cycles would be at some advantage in managing their agricultural and commercial resources. Few examples of such awareness and coping strategies exists (even for the present day)

Dunbar, 2000: 78

PRAIRIE ADAPTATION RESEARCH COLLABORATIVE

PARC's water related activities

- prairie groundwater initiative
- glaciers of the Rocky Mountain eastern slopes
- vulnerable lakes of the Boreal Plain ecoregion
- drought and water resource variability

- Special Session on climate change, CWRA annual meeting, Winnipeg, June, 2002
- PARC Conference on Climate Change Impacts and Adaptation in the Prairie Provinces, March 21-22, 2002

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PARC PROJECT FUNDING ($K)

Agriculture	10	438.8
Communities	3	163.0
Crosscutting	2	59.9
Ecosystems	4	132.0
Energy	2	64.5
Forests	5	121.0
Hazards	2	58.3
Health	1	15.8
Water	3	199.0
TOTAL	32	1 252.3

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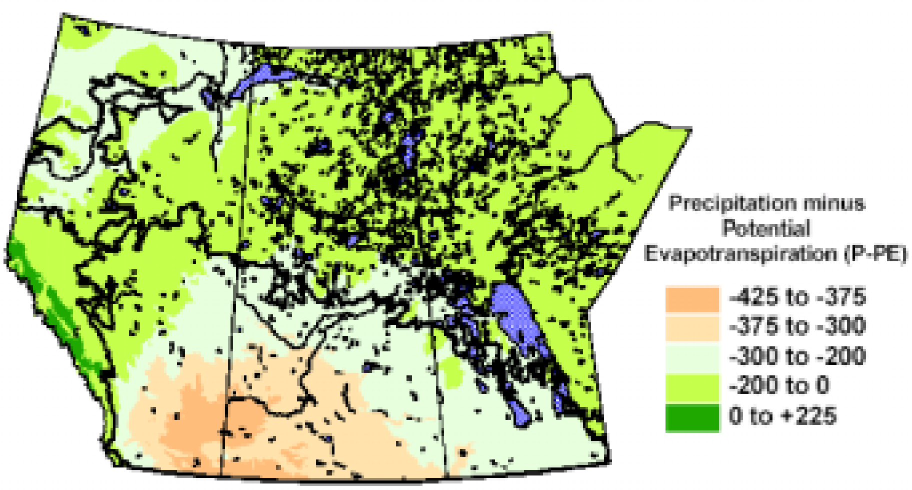
Moisture Deficit (P-PE) (1961-90)



PFRA, 2001

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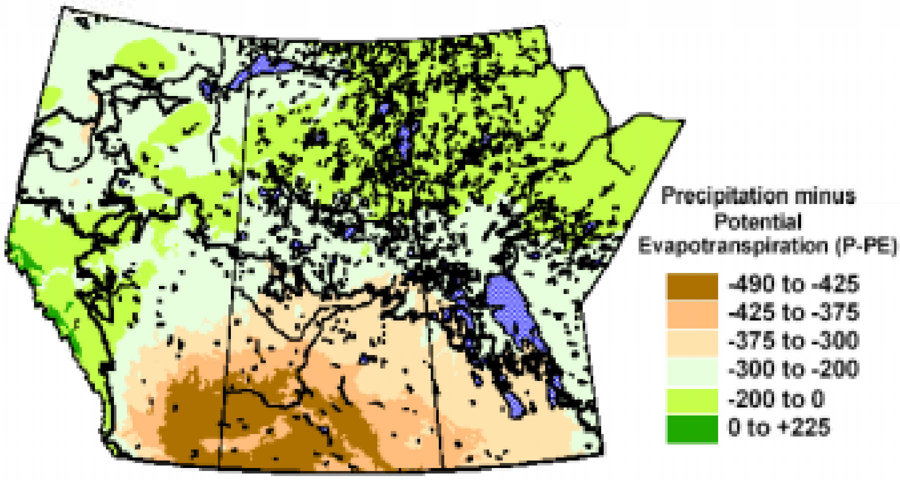
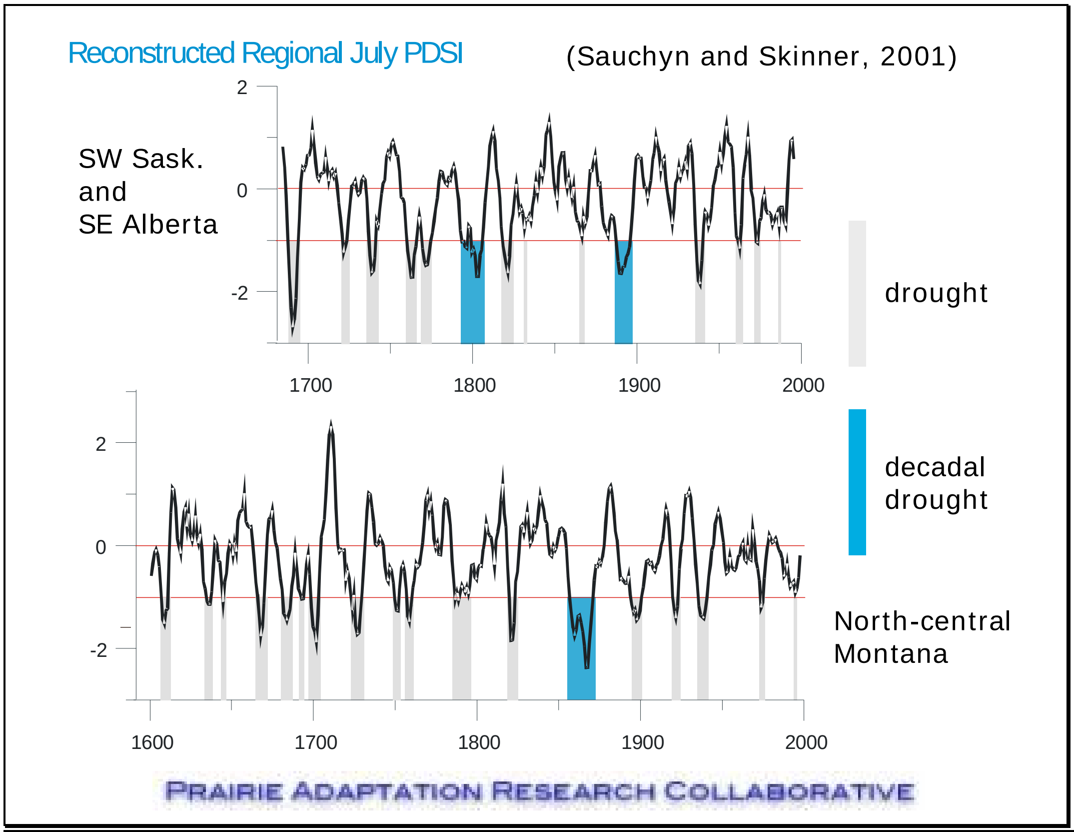
Moisture Deficit (P-PE)
(2040-69)



PFRA, 2001

Prairie Adaptation Research Collaborative

Prairie Adaptation Research Collaborative



Reconstructed Regional July PDSI
(Sauchyn and Skinner, 2001)
SW Sask. and SE Alberta
2
0
-2
1700
1800
1900
2000
drought
decadal drought
North-central Montana
2
0
-2
1600
1700
1800
1900
2000
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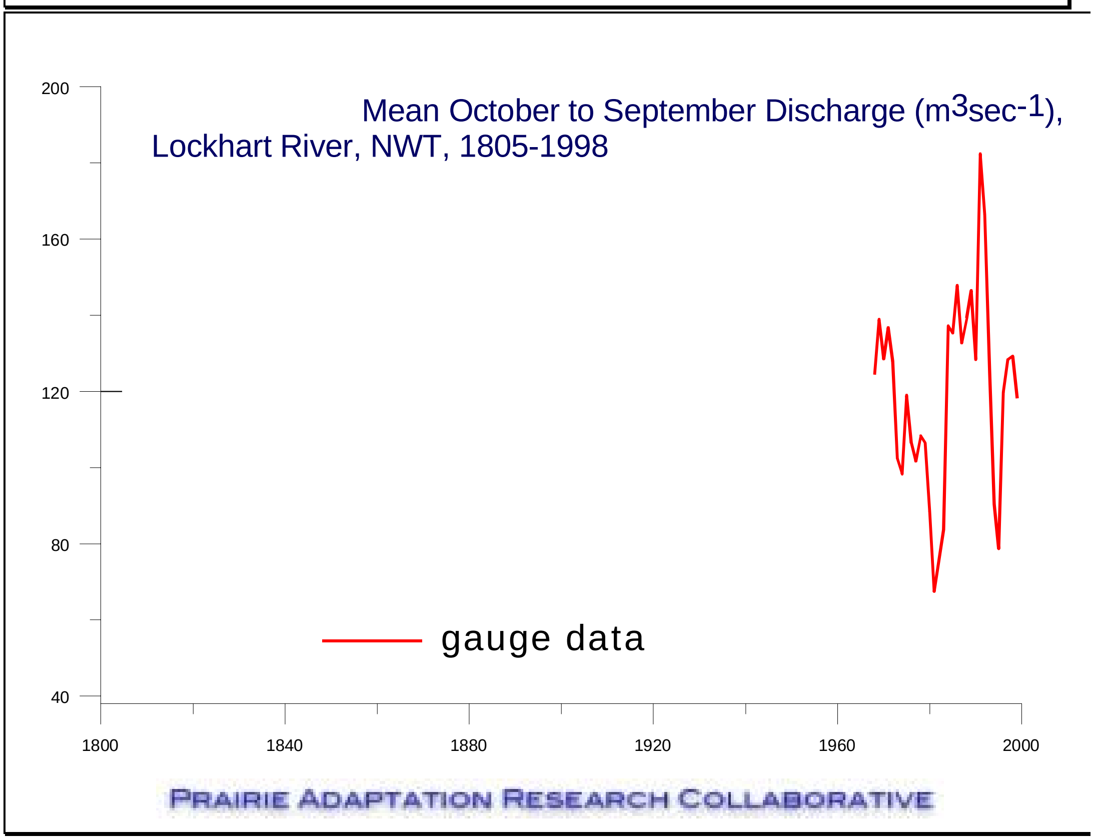

Mean October to September Discharge (m3sec-1),
Lockhart River, NWT, 1805-1998
200
160
120
80
40
gauge data
1800
1840
1880
1920
1960
2000
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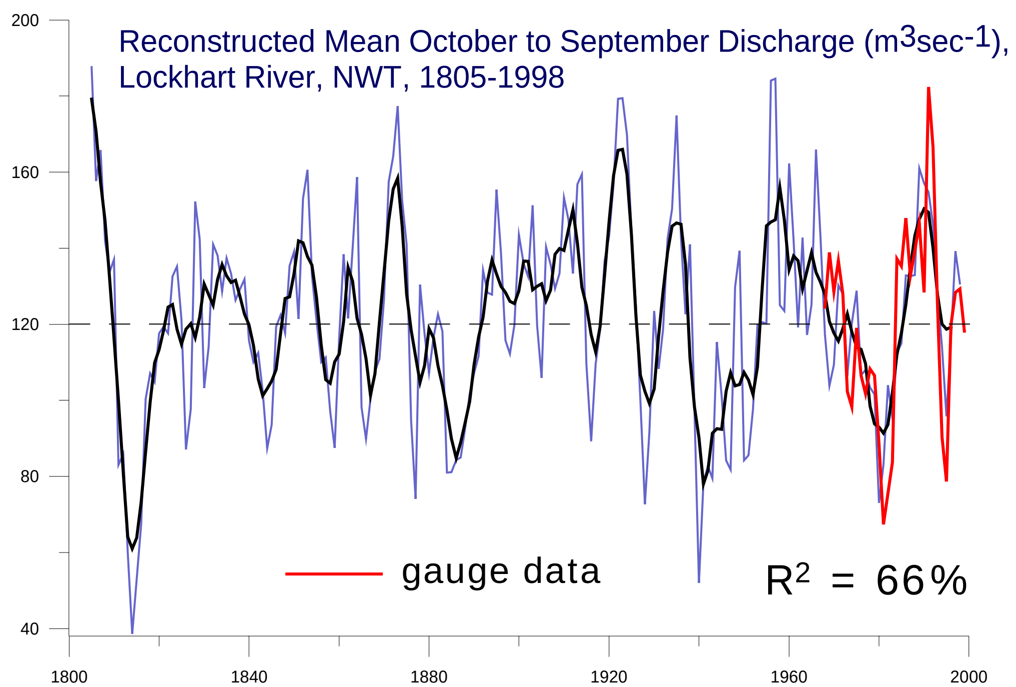

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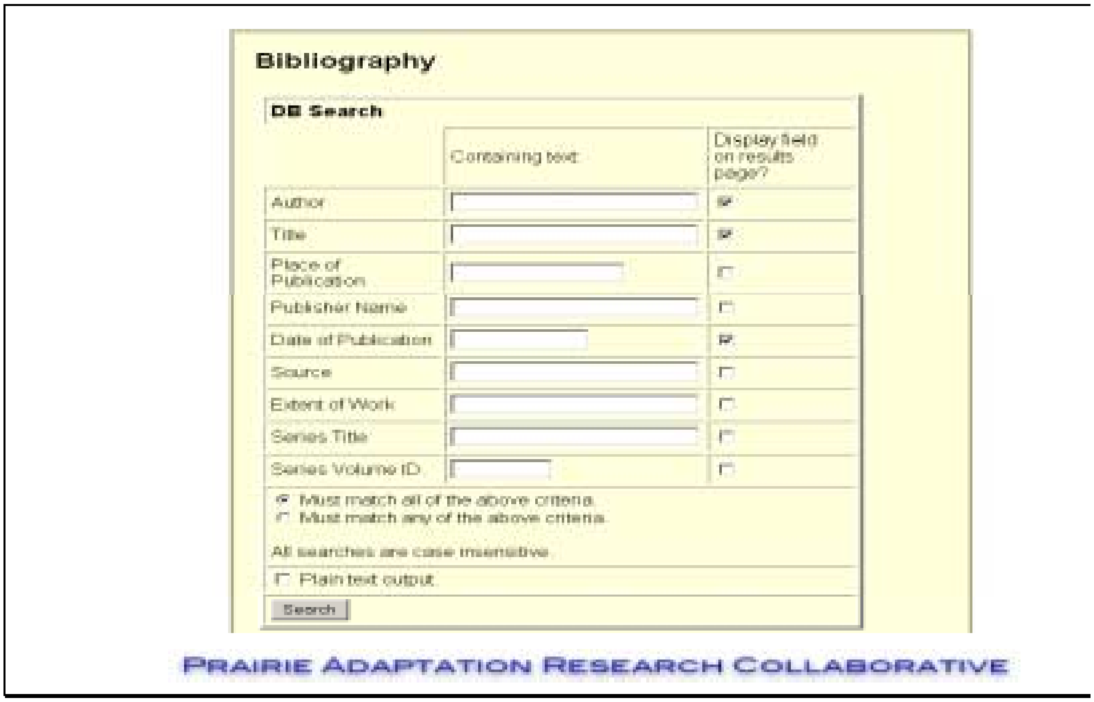

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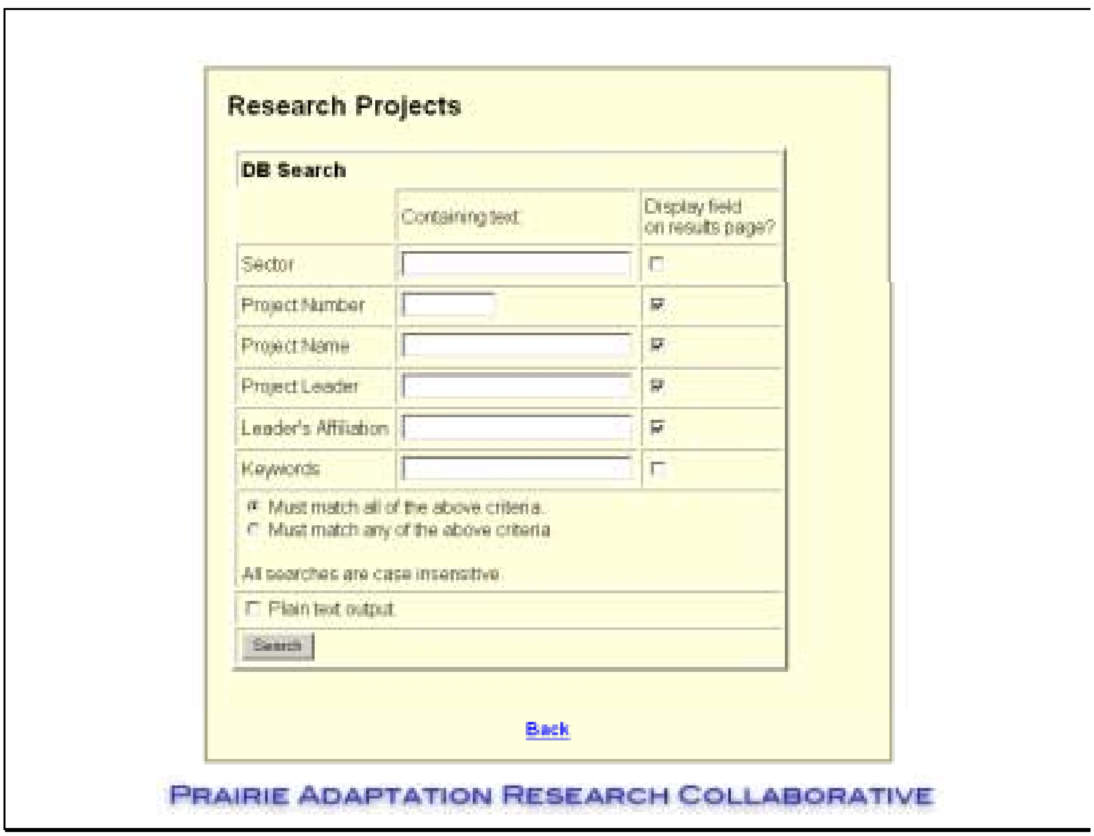

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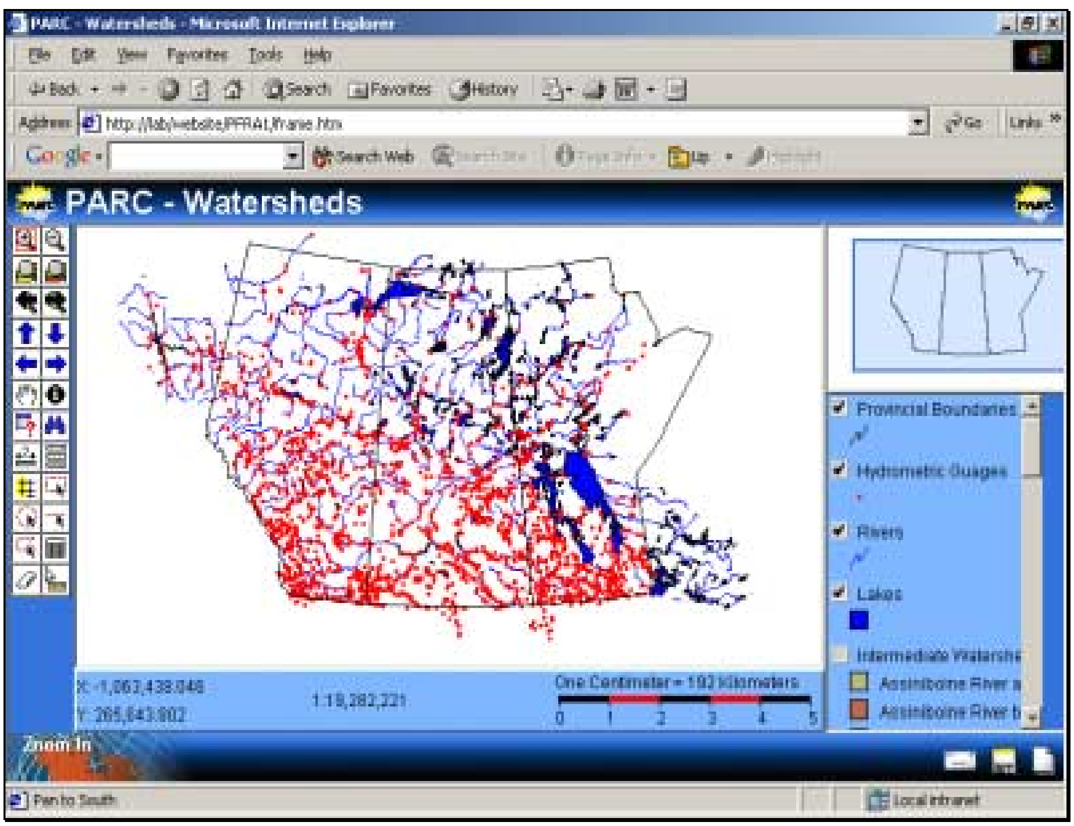
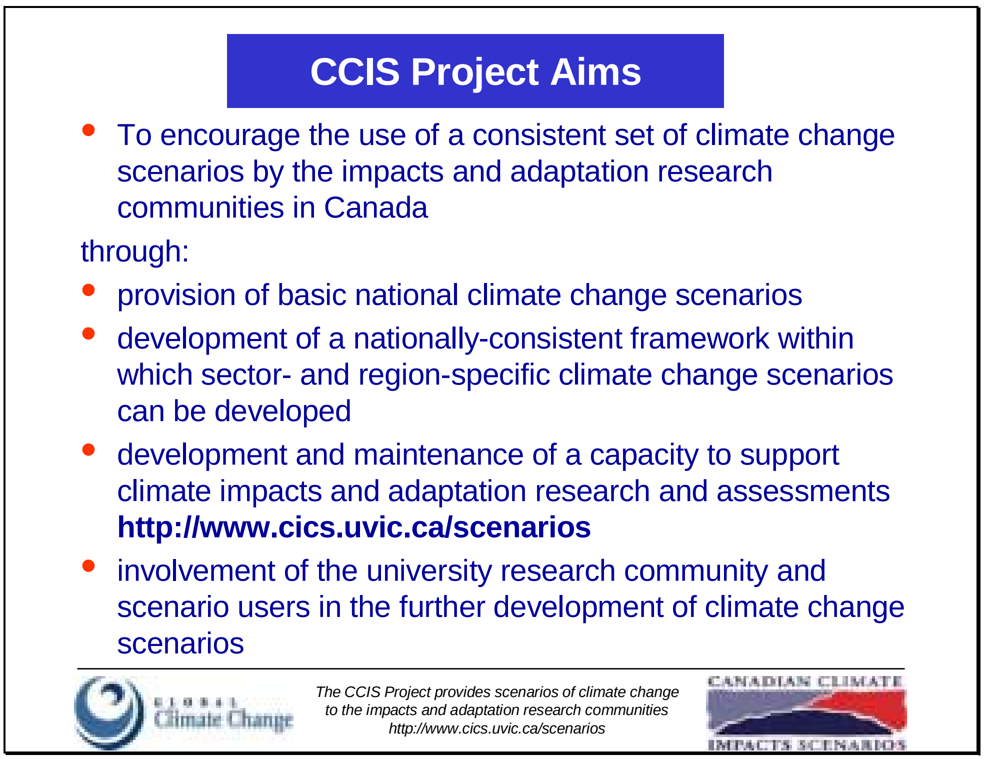
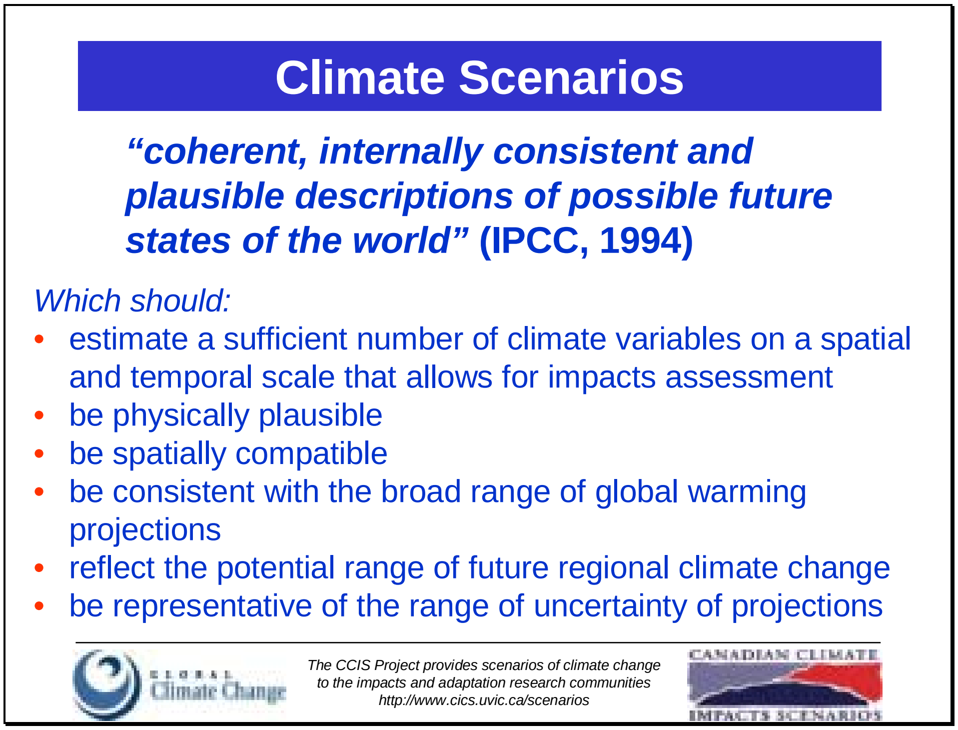

PARC - Watersheds - Microsoft Internet Explorer
PARC - Watersheds
Provincial Boundaries
Hydrometric Guages
Rivers
Lakes
One Centimeter = 192 Kilometers
0 1 2 3 4 5
Zoom In
Pan to South
Local intranet

Scenarios of Climate Change

Elaine Barrow
Canadian Climate Impacts Scenarios (CCIS)
Environment Canada, Regina

http://www.cics.uvic.ca/scenarios



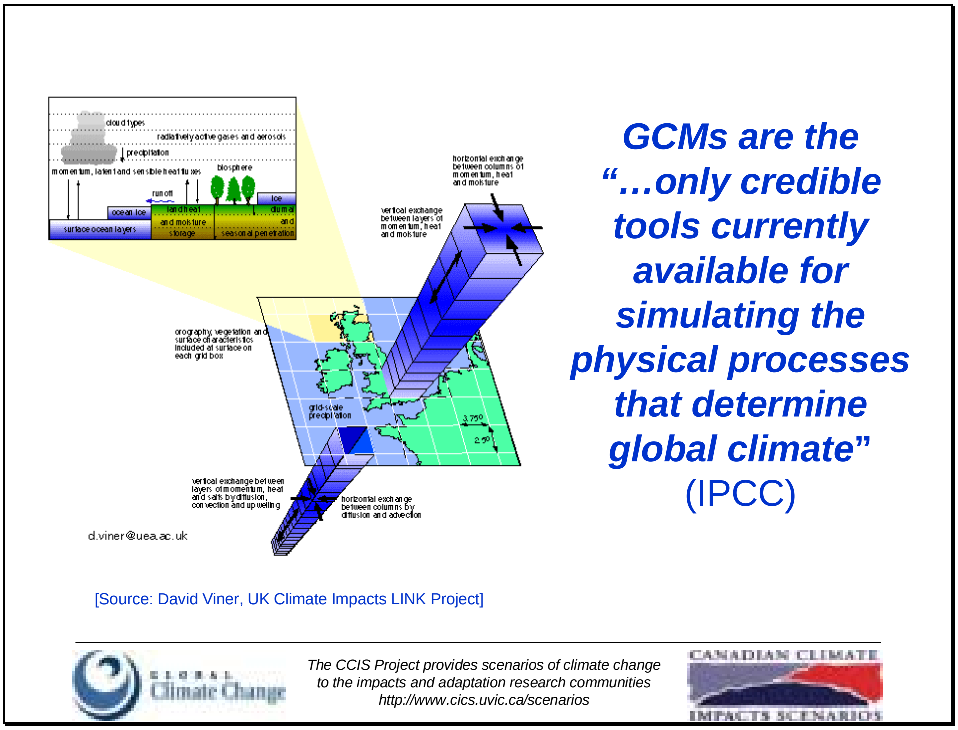


Although this scenario definition was put forward in an IPCC technical report in 1994, not all climate change impacts studies have adhered to this definition.

This was particularly apparent during the preparation of the IPCC Second Assessment Report (published in 1996) when it was realised that it is very difficult to draw any conclusions about the impacts of climate change when all manner of scenarios have been used and applied in different ways. An IPCC workshop on regional climate change projections for impacts assessment was held in 1996 and as a result of this meeting the IPCC Task Group on Scenarios for Climate Impacts Assessment (TGCIA) was formed. The main role of this group was to consider the strategy for the provision of regional climate change information with a particular focus on IPCC Third Assessment Report.

The work of this group has resulted in the establishment of the IPCC Data Distribution Centre (operational since 1998), as well as the IPCC guidelines on the use of scenario data for climate impact and adaptation assessment, available online since 1999 (http://ipcc-ddc.cru.uea.ac.uk).

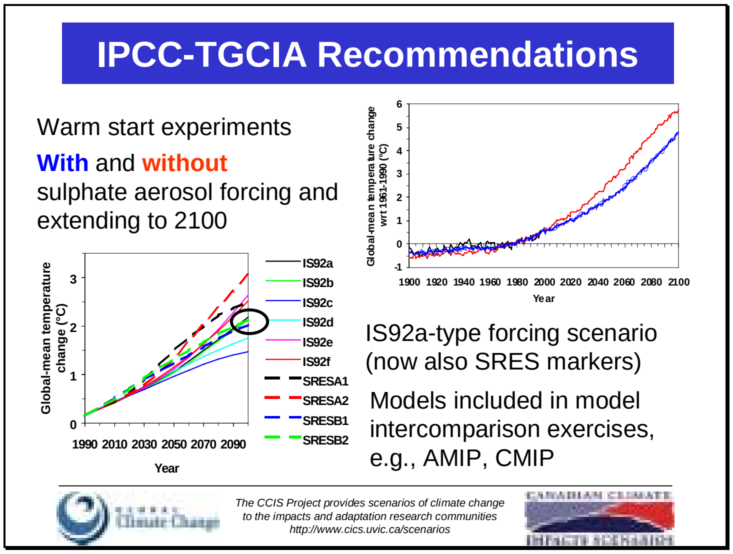
This basic scenario definition includes the main requirement - that scenarios be internally consistent, i.e., changes in the climate variables should be related in a consistent manner, e.g., changes in precipitation are reflected in the cloud/radiation values.



It has been recognised for some time that global climate models are the only credible tools currently available for simulating the physical processes that determine global climate. Experiments with these models have been ongoing since the 1970s, but it is only really in the last 10-15 years that the information from them has been used for climate change scenario construction.

These models attempt to represent the atmospheric and oceanic processes in mathematical form and so they provide internally-consistent information which is physically plausible and spatially compatible.

GCMs are able to simulate the large-scale atmospheric and oceanic features of climate reasonably well but at smaller spatial scales their performance is not as good and this has implications for the way in which scenarios are constructed from GCM data.



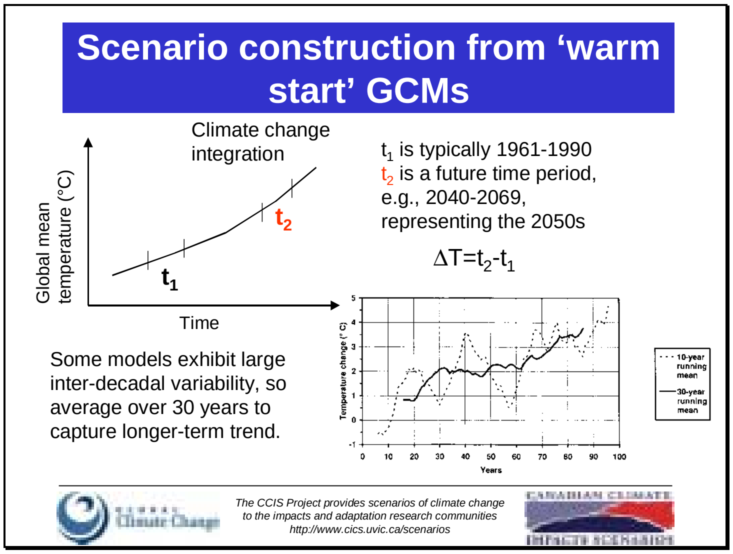
Warm start experiments include historical forcing from about 1850 to 1990, then climate change experiments are started.

Top right-hand graph shows global-mean temperature change (wrt 1961-1990) for the CCCma experiments undertaken with CGCM1. Red is GHG only, blue indicates the three GHG + sulphate aerosol experiments (darker blue line is the ensemble-mean, i.e., the average of these three experiments). Black line indicates observed global-mean temperature (from Parker and Jones). Experiments which include sulphate aerosols are much better at capturing the observed pattern of temperature change than GHG only experiments. Other GCM experiments have investigated the discrepancy apparent from the 1940s to 1960s - when the effects of volcanic eruptions and also variations in solar output during that period are included, the gap between the observed and modelled global-mean temperature just about disappears.

Most GCM experiments to date have focused on the IS92a emissions scenario - the ‘business as usual’ scenario put forward in the IPCC Supplementary Report published in 1992. Six emissions scenarios were defined, spanning a range of assumptions concerning future population growth, economic growth, energy use etc., and although all were defined as equally likely, the IS92a scenario was generally used by the climate modelling and impacts community.

For the TAR the IPCC commissioned a Special Report on Emissions Scenarios (SRES) which details 40 emissions scenarios. These scenarios can be divided into 4 families of scenarios and 4 marker scenarios have been identified - A1, A2, B1 and B2. These scenarios are currently being used by the GCM modelling community, and results of experiments using these scenarios are slowly becoming available. At the moment only scenarios from GCM experiments using IS92a forcing are available from CCIS.

AMIP - atmospheric model intercomparison project; CMIP - coupled model intercomparison project



In warm start experiments, which include a representation of the forcing which has occurred over the historical period, there is no lag in the climate response to the forcing imposed in the climate change experiment. Most warm start experiments are also flux corrected: this means that corrections have been calculated from control experiments to prevent the climate from drifting away from a realistic state. These corrections are then applied throughout the climate change experiment, with the assumption that the same correction will be required. As the modelling of the atmosphere-ocean interactions improves the need for these flux corrections is lessened.

For scenario construction from these type of experiments, 30 years of data are generally used from two time periods selected from the climate change simulation. One of these time periods represents the baseline climate (currently 1961-1990) and the other some period in the future, e.g., 2040-2069, to represent the 2050s. A 30-year mean field is calculated for each time period and the difference (or ratio) between the baseline and future time period is then calculated.

Why are 30-year periods used in scenario construction? This is a compromise between trying to capture the climate change signal without losing too much of the variability in the model results over time. Scenarios constructed from earlier transient experiments generally used only 10 years of data since this is what was available. The figure above illustrates that using such a small data set may not be advisable. In a study shown above scenarios of climate change were constructed for Finland (Carter *et al*., 1996). The figure shows a comparison of 10-year and 30-year running means of the change between the GFDL control and climate change simulations for spring temperature, averaged over 6 grid boxes for Finland. As is apparent, there is a large amount of inter-decadal variability in this time series, so much so that if decadal periods are used for developing scenarios in this instance, then the resulting change fields for a given time window may be unrepresentative of the long-term trends.

Carter, T.R., Posch, M. & Tuomenvirta, H. (1996): The SILMU scenarios: specifying Finland's future climate for use in impact assessment. *Geophysica*, 32, 235-260.

CCIS Project web site: http://www.cics.uvic.ca/scenarios
Available:

- Climate change scenarios for Canada from GCM experiments using IS92a-type forcing, warm start
  - At original GCM resolution; 0.5° latitude/longitude
  - Mean changes wrt 1961-1990 for the 2020s, 2050s and 2080s; also monthly time series, anomalies
  - Monthly, seasonal and annual values
  - Climate variables, minimum data set: mean, minimum and maximum temperature, precipitation, a radiation variable, a humidity variable, wind speed
- Advice on scenario construction, downscaling, applications, limitations and uncertainties

The CCIS Project provides scenarios of climate change to the impacts and adaptation research communities http://www.cics.uvic.ca/scenarios

All scenarios are changes with respect to the current baseline - 1961-1990. It is inconsistent to apply the scenarios to any other baseline period (e.g., 1951-1980). If an earlier baseline is being used (e.g., data coverage may be better in some areas for an earlier baseline period), then the scenarios really need to be recalculated wrt that baseline period. The CCIS Project will not do this, but there should be sufficient information on the web site to allow researchers to construct their own scenarios with different baselines if necessary. We encourage the use of the 1961-1990 period to conform to IPCC recommendations.

There is **no** observed baseline data on the CCIS Project web site - only model-simulated fields for the 1961-1990 period.

Available Scenarios

- Canadian Centre for Climate Modelling and Analysis (**CGCM1**, **CGCM2**)
- Hadley Centre for Climate Prediction and Research (**HadCM2, HadCM3**)
- Australian Commonwealth Scientific and Industrial Research Organisation (**CSIROMk2b**)
- German Climate Research Centre (**ECHAM4**)
- Geophysical Fluid Dynamics Laboratory (**GFDL-R15**)
- Japanese Centre for Climate Research Studies (**CCSR-98**)

Total number of scenarios available to date: 29

GLOBAL Climate Change

The CCIS Project provides scenarios of climate change to the impacts and adaptation research communities http://www.cics.uvic.ca/scenarios

CANADIAN CLIMATE IMPACTS SCENARIOS

At the moment, to try and encompass uncertainty range associated with the IS92a emissions scenario, all model experiments which meet the IPCC criteria to be included in the DDC have been used for scenario construction and scenarios are available from the CCIS Project web site.

Variables Available

	CGCM1	HadCM2	HadCM3	CCSR-98	CSIROMk2b	ECHAM4	GFDL-R15
Maximum temperature	•	•		•	•	•	
Minimum temperature	•	•		•	•	•	
Mean temperature	•	•	•	•	•	•	•
Precipitation	•	•	•	•	•	•	•
Radiation	total incident solar		incident solar	surface shortwave	net surface	total surface	net shortwave at ground
Mean sea level pressure	•		•	•	•	•	surface pressure
Relative humidity	⊕		•	⊕			
Specific humidity	•			•			
Vapour pressure	⊕	⊕	to be added	⊕		⊕	⊕
Diurnal temperature range	⊕	⊕		⊕	⊕	⊕	⊕
Wind speed	•	to be added	to be added	•		•	
Cloud	•	•					

• variables directly available from model
⊕ variables derived using those directly available from model

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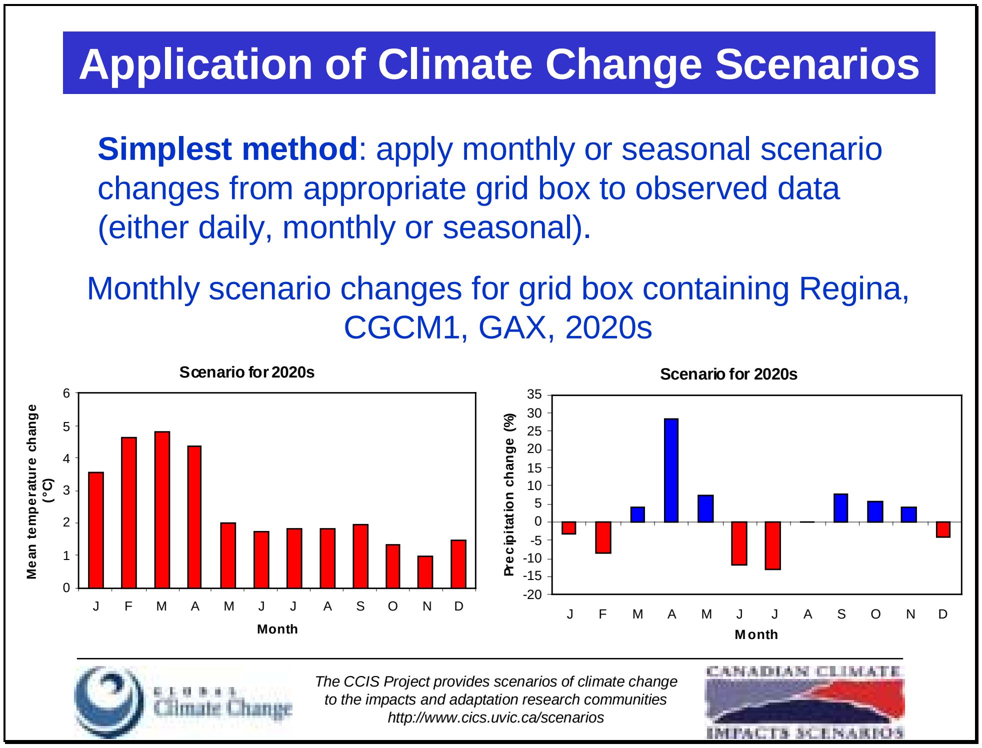
The CCIS Project provides scenarios of climate change to the impacts and adaptation research communities
http://www.cics.uvic.ca/scenarios

CANADIAN CLIMATE IMPACTS SCENARIOS



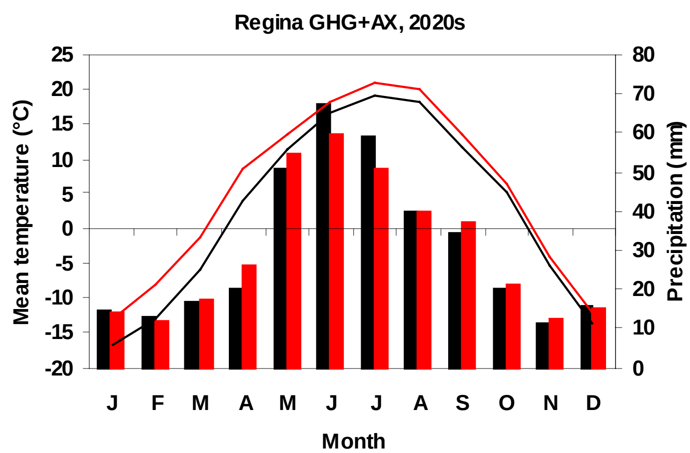
The simplest method of scenario construction is to apply the grid box changes in which the site is located to that particular site. This example is for Saskatoon for the 2020s. The graphs indicate the annual temperature and precipitation cycles. Black (line for temperature and bar chart for precip) indicate the 1961-1990 normal values. The red lines illustrate the range of future temp and precip values obtained by applying the extreme and median changes to the normal values. So, at a glance, the likely future range of temp and precip, based on this sample of experiments (all available scenarios included) can be seen for this site.

This is a 'quick and dirty' way of applying scenario information and may not be sufficient for some impacts studies. The scenario changes are generally applied to an observed data set, rather than using GCM results directly, in order to overcome model shortcomings in simulating current climate.

The advantage of this approach is that it allows a large number of scenarios to be considered relatively easily. A large number of scenarios with monthly change values is available, whereas there is a limited amount of daily model data available. Monthly change values can be applied to climate normal, monthly and daily time series data for the 1961-1990 period. The 12 monthly scenario change values would be applied to each month or day in the time series (i.e., the January scenario value would be applied to each January in the monthly time series, and to each January day in the daily time series). There are also ways of changing the variability of the time series to reflect GCM-derived variability changes.

Scenario Application

Scenario changes applied to 1961-1990 climate normal data for Regina to obtain 'actual' values for the 2020s



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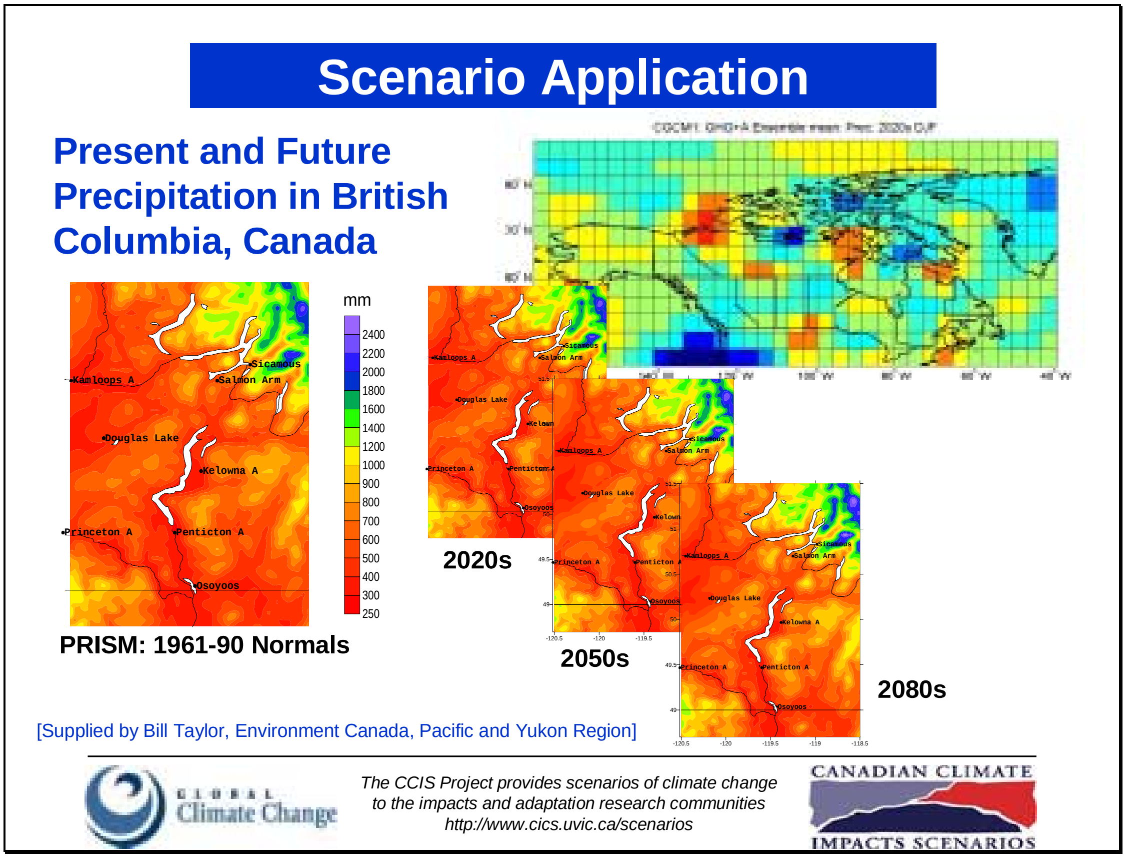
CANADIAN CLIMATE IMPACTS SCENARIOS



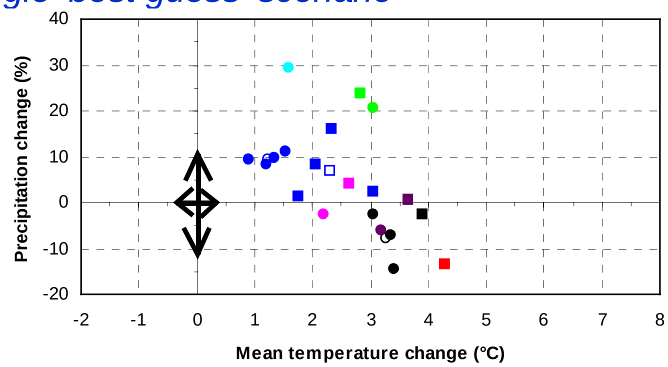
An example of scenario application supplied by Bill Taylor. Annual precip totals are shown. CCIS scenarios have been applied to a high resolution baseline (from PRISM). The CCIS plot is simply an example of the coarse-scale changes - plot is for DJF, ideally the annual plot would have been shown to correspond to the plots from Bill. A GIS was used to overlay the coarse-scale changes onto the high resolution baseline.

These scenarios have been used to look at effects on stream flow - timing of peak flow after snow melt etc. and magnitude of flow.

Scenario Uncertainty

IPCC recommendation:

users should design and apply multiple scenarios in impacts assessments, where these scenarios span a range of possible future climates, rather than designing and applying a single 'best guess' scenario

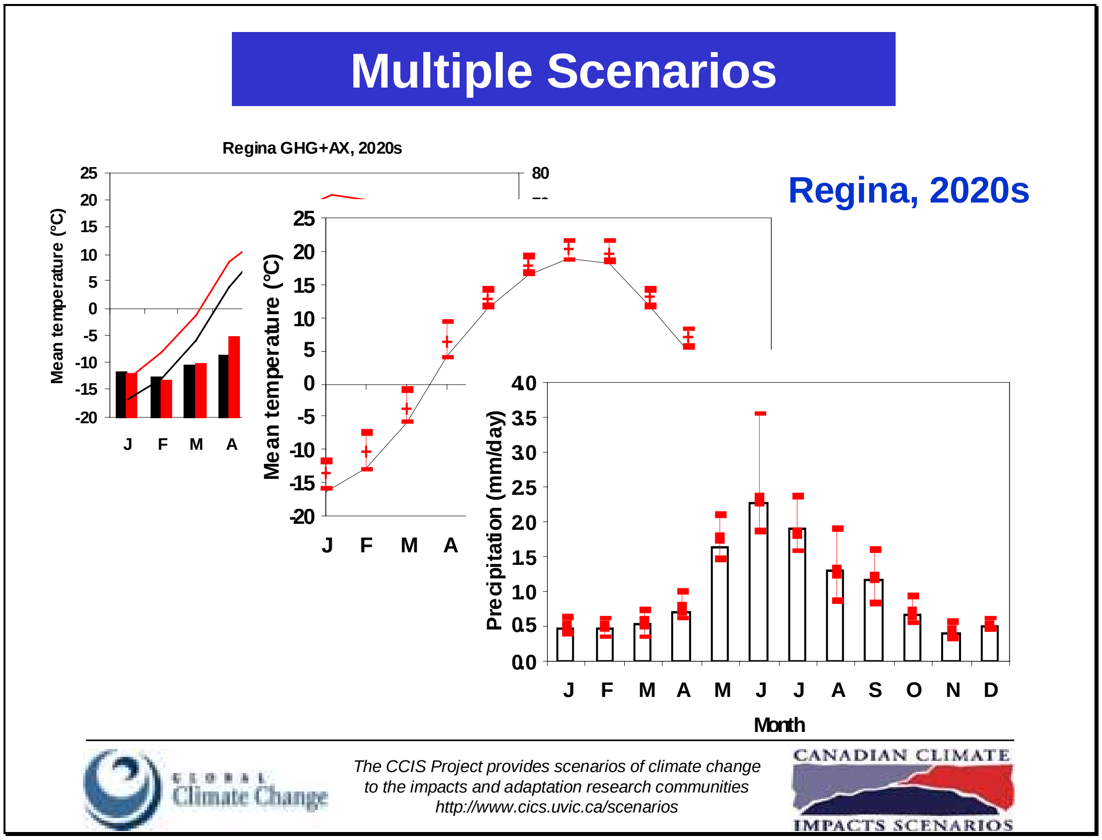


CGCM1 HadCM2 HadCM3 ECHAM4 CSIROMk2b CCSR-98 GFDL-R15

Filled symbols - individual experiments; Open symbols - ensemble means
Squares - GHG only; Circles - GHG+Aerosols

Summary of the temperature and precipitation changes associated with the GCM experiments available from the CCIS project web site, for winter and summer, 2020s. The changes are averaged over the land area within the Canadian window (plots on left hand side) used by the CCIS Project (approx. 168.75°W to 41.25°W, 87.16°N to 35.26°N). This sort of plot can be used to identify those experiments which indicate the most extreme changes, e.g., warmest and wettest, coolest and driest, in order to aid scenario selection. Ideally, researchers should be using as many scenarios as possible since although changes may be similar at the national and provincial scales, the actual patterns of change may be quite different, thus leading to different impact results. However, it is recognised that this may not always be possible. In such cases, at least three scenarios should be used, two representing the extreme changes and one a mid-range value. It may not be possible to use all available experiments, since the necessary climate variables may not be available for all expts.

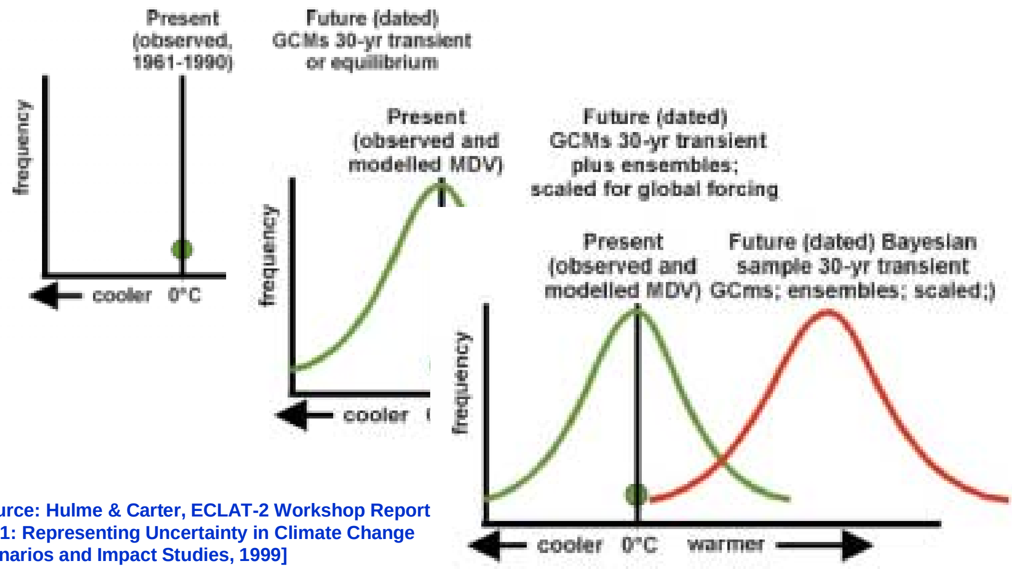
Another way of selecting which scenarios to use is to identify the climate variable to which the impacts model is most sensitive (maybe in a particular season) and then use the scenarios which represent the most extreme and mid-range values for this particular variable.



This slide indicates the simple application of the climate scenarios available from the CCIS Project web site (http://www.cics.uvic.ca/scenarios) to the 1961-1990 climate normal data for Regina.

The figure on the left-hand-side is the result of applying the ensemble-mean scenario from the CGCM1 GHG+A experiments to the observed normals of temperature (black line) and precipitation (black bars). This results in climate normal values for the 2020s (indicated in red). This illustrates the application of a single scenario. However, we know that there is a large range of scenarios which can be used, from different GCM experiments, for example, and using a single scenario gives no indication of what the possible future range of climate may be. By considering all scenarios (figures on right-hand-side) a much better indication of the likely range of future climate is given. The red lines indicate the 'extreme' range and median values (for temperature) and in the case of precipitation the red boxes indicate the interquartile range (i.e., 50% of the scenarios lie within this range). This is the sort of output which is desired, rather than that of the figure on the left-hand-side.

Uncertainty

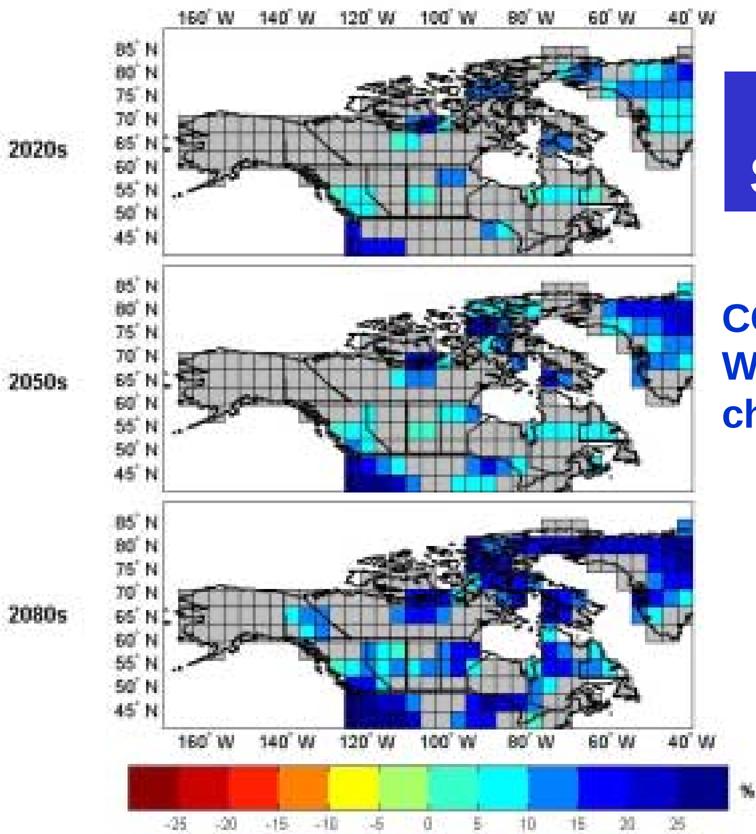


[Source: Hulme & Carter, ECLAT-2 Workshop Report No. 1: Representing Uncertainty in Climate Change Scenarios and Impact Studies, 1999]

GLOBAL Climate Change

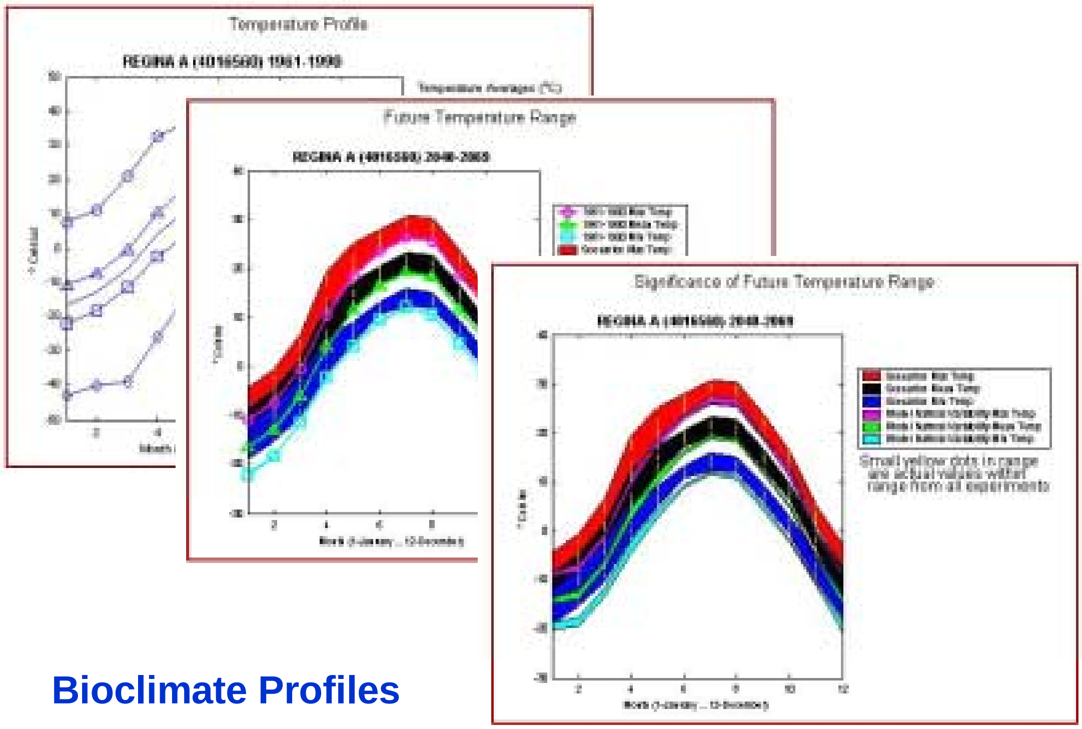
The CCIS Project provides scenarios of climate change to the impacts and adaptation research communities
http://www.cics.uvic.ca/scenarios

CANADIAN CLIMATE IMPACTS SCENARIOS



Scenario Significance

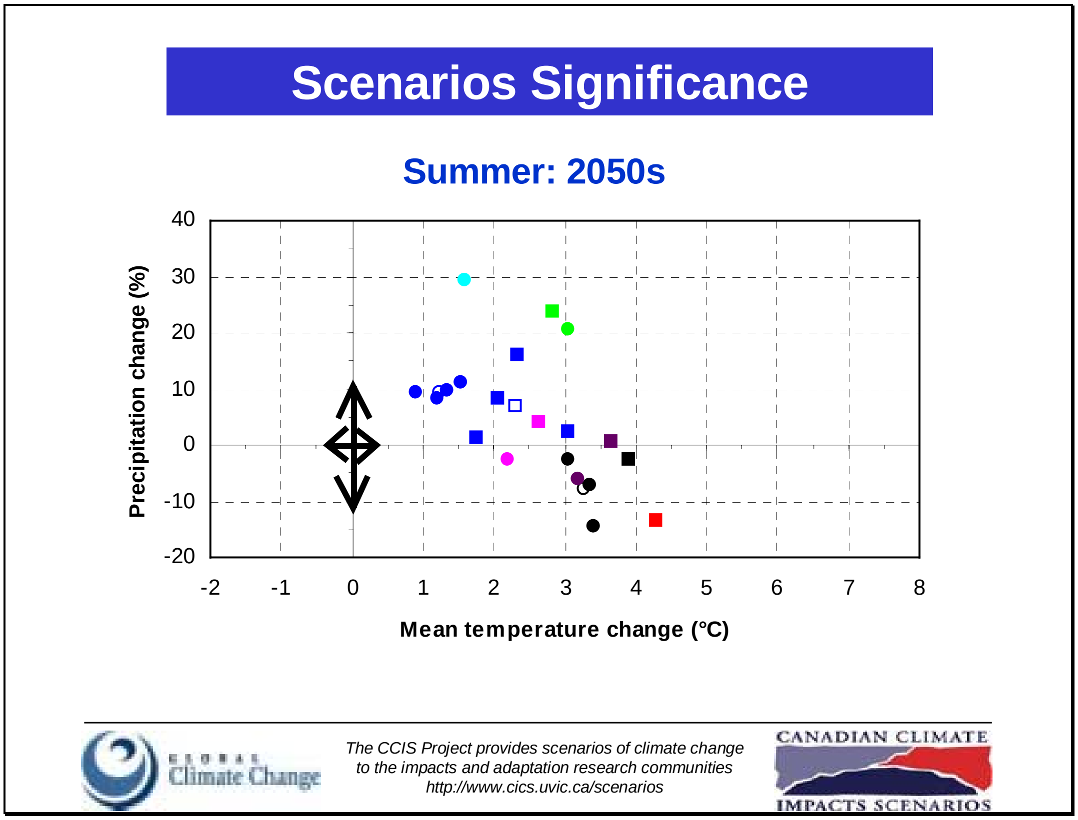
CGCM1 GAX: Winter precipitation change (%)



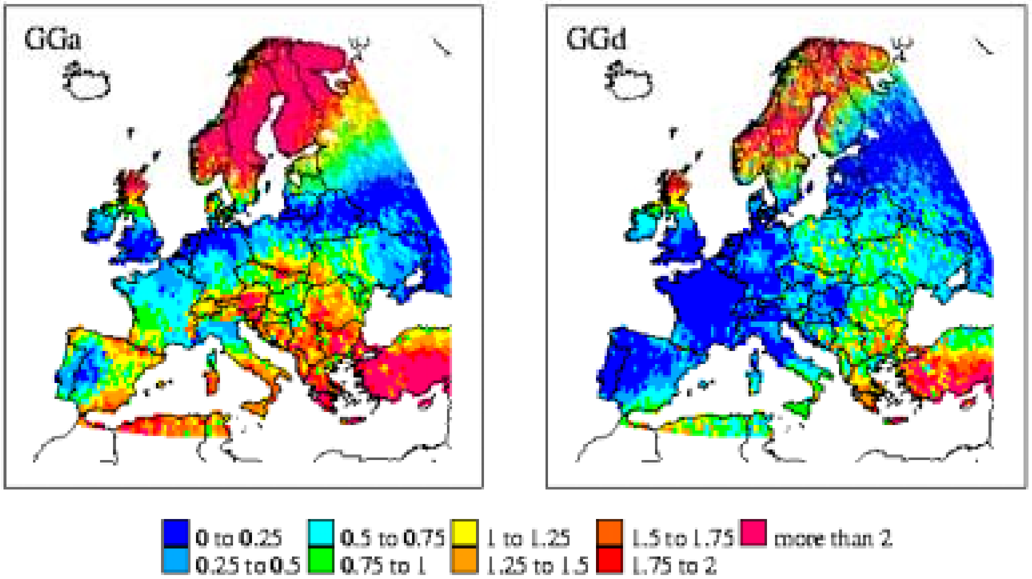
Bioclimate Profiles

The CCIS Project provides scenarios of climate change to the impacts and adaptation research communities
http://www.cics.uvic.ca/scenarios

CANADIAN CLIMATE IMPACTS SCENARIOS


Scenarios Significance
Summer: 2050s
Precipitation change (%)
40
30
20
10
0
-10
-20
-2
-1
0
1
2
3
4
5
6
7
8
Mean temperature change (°C)
Climate Change
The CCIS Project provides scenarios of climate change
to the impacts and adaptation research communities
http://www.cics.uvic.ca/scenarios
CANADIAN CLIMATE
IMPACTS SCENARIOS

Climate Change versus Climate Variability



[Source: Nigel Arnell, in Hulme *et al*. (1999), Nature 397]

Global Climate Change

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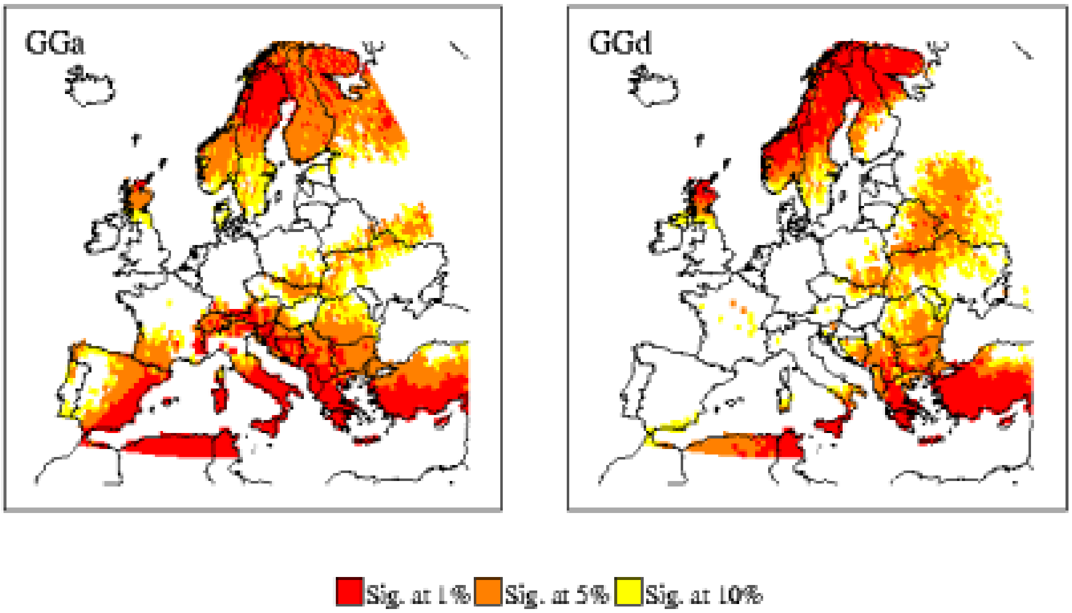
http://www.cics.uvic.ca/scenarios

Canadian Climate Impacts Scenarios

Significance of the Effect of Climate Change: Runoff



[Source: Nigel Arnell, in Hulme *et al*. (1999), Nature 397]

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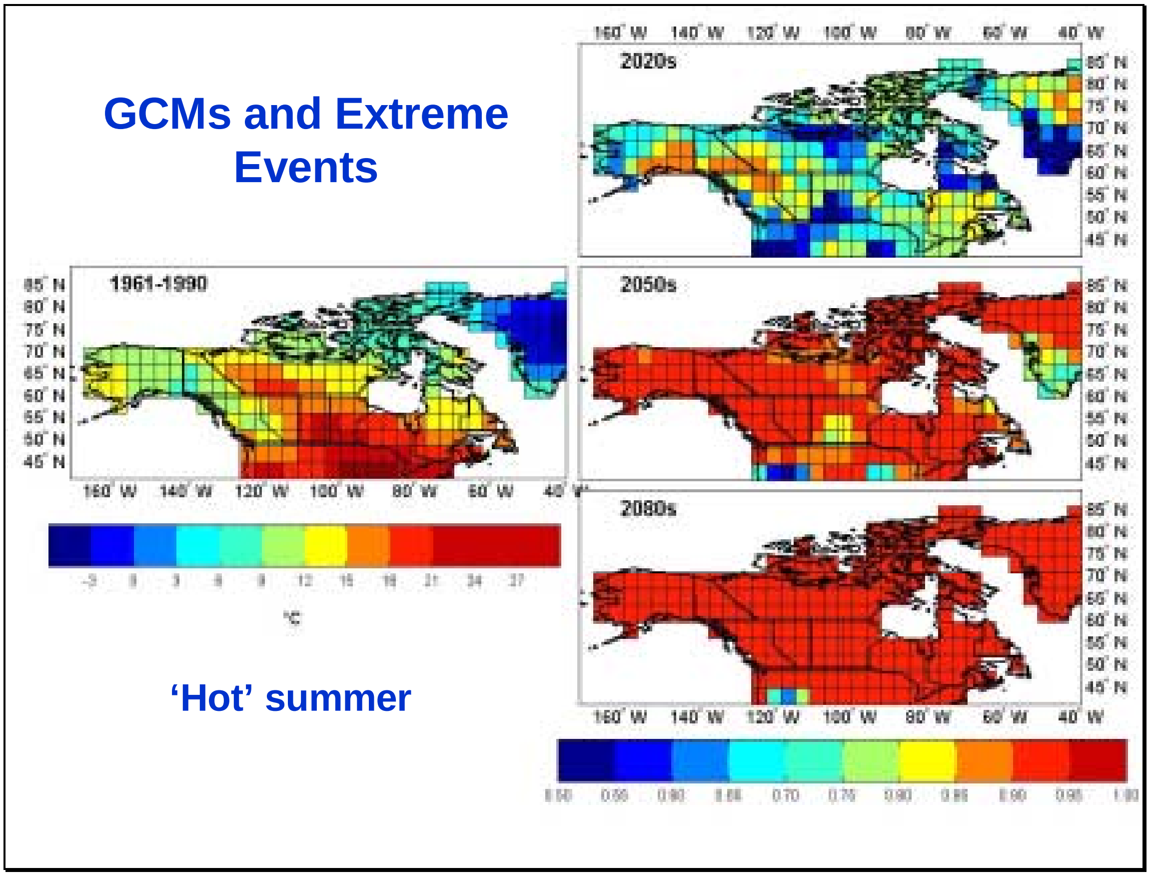
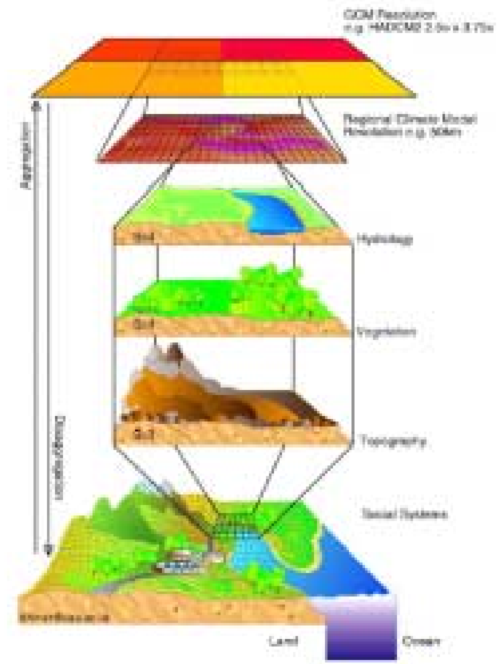
CANADIAN CLIMATE IMPACTS SCENARIOS


GCMs and Extreme Events
'Hot' summer
1961-1990
2020s
2050s
2080s
160° W 140° W 120° W 100° W 80° W 60° W 40° W
85° N 80° N 75° N 70° N 65° N 60° N 55° N 50° N 45° N
°C

Downscaling

Recognised that spatial and temporal resolution of GCMs is too coarse for some applications

Downscaling techniques may be used to 'add value' to a GCM-derived scenario of climate change



[Source: David Viner, UK Climate Impacts LINK Project]

GLOBAL Climate Change

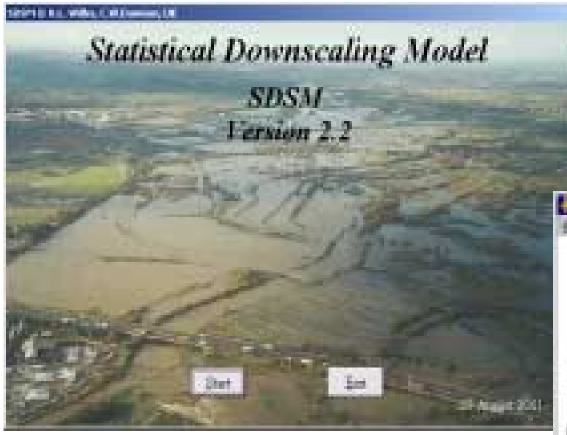
The CCIS Project provides scenarios of climate change to the impacts and adaptation research communities http://www.cics.uvic.ca/scenarios

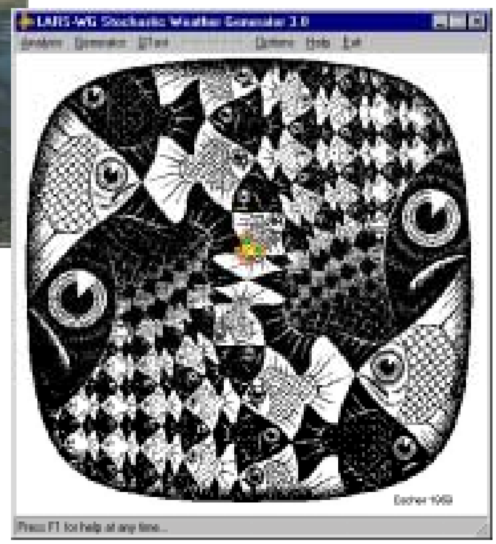
CANADIAN CLIMATE IMPACTS SCENARIOS

Figure courtesy of David Viner, of the UK Climate Impacts LINK Project.

Figure illustrates the complexity of the downscaling process.

For some studies, the simple methods of constructing finer resolution scenarios may not be sufficient and it may be better to user empirical/statistical or statistical/dynamical downscaling techniques to obtain data at the necessary resolution. An alternative is to use information from higher resolution experiments.





Downscaling Tools

The CCIS Project provides scenarios of climate change to the impacts and adaptation research communities
http://www.cics.uvic.ca/scenarios

GLOBAL Climate Change

CANADIAN CLIMATE IMPACTS SCENARIOS

Recommendations

- Use of climate change scenarios which preserve as far as is possible physical plausibility and spatial compatibility - implies use of GCM-derived scenarios
- Use of multiple scenarios in order to capture the 'state of the art' range of future climate
- If downscaling is considered to be necessary be aware of the limitations of the particular methodology - does the 'cost' of downscaling add sufficient value to the coarse-scale scenarios?

South Saskatchewan River Water management Plan

Doug Ohrn
Alberta Environment
Lethbrige

General Overview Fact Sheet

Alberta Environment is preparing the first phase of a multi-phase water management plan for the South Saskatchewan River Basin (SSRB), which includes the sub-basins of the Red Deer, Bow, and Oldman Rivers (including the South Saskatchewan). The purpose is to resolve water management issues such as the availability of water for future allocations and river flows for the aquatic environment. The water management planning process supercedes the "Year 2000 Review." All the original objectives of the Review will be accomplished.

Alberta Environment is studying the status of water availability in the SSRB. Indications are that the limit of the water resource is being approached generally across the basin. Strategies to maximize the benefits of the water in the basin are required.

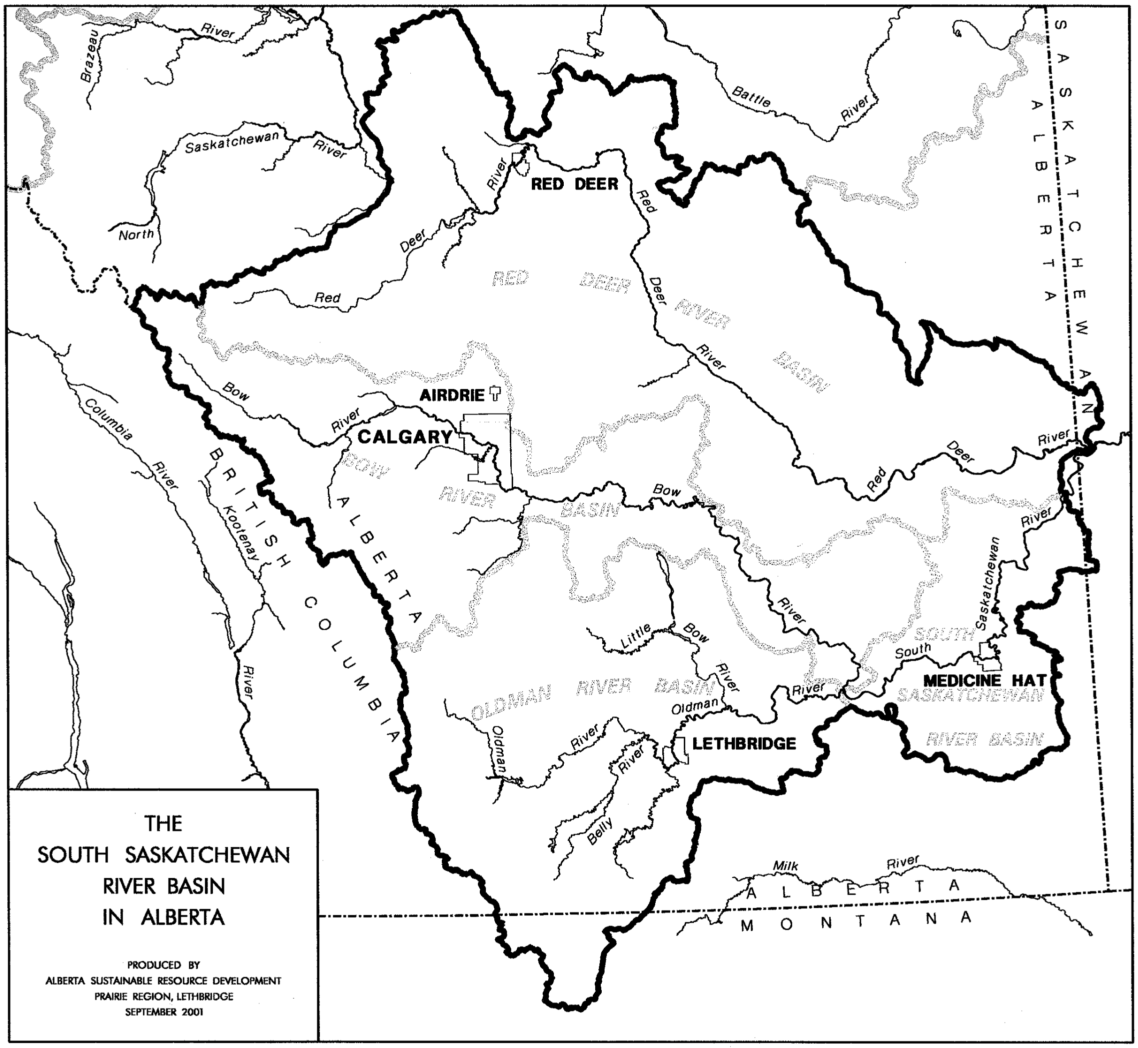
The first phase will be devoted to the development of a system for water allocation transfers. License transfers will permit water allocations to be moved (within the SSRB only) to where the water is most highly valued, subject to conditions. A key goal is to develop the conditions that will be applied. The first phase is to be ready for implementation by April 2002.

The second phase will focus on determining the flow to remain in each river. This will require an assessment of the volumes for human demands and the flows for the aquatic environment. Studies have been either completed, or are underway, to estimate future human demands for water and river flows required for the aquatic environment. The key goal of the second phase will be to reach compromises between these competing interests and make wise choices. The second phase is scheduled for completion by the end of 2002.

Additional phases of the plan are yet to be determined. Resolution of local water issues can occur in separate water management planning projects under the umbrella of the plan. Any issue that has implications for other sub-basins, must be addressed within the plan.

The planning process will involve four multi-sector stakeholder basin advisory committees and consultations with the general public at large.

The plan will respect all existing water allocation licenses that are in good standing.


THE
SOUTH SASKATCHEWAN
RIVER BASIN
IN ALBERTA
PRODUCED BY
ALBERTA SUSTAINABLE RESOURCE DEVELOPMENT
PRAIRIE REGION, LETHBRIDGE
SEPTEMBER 2001
RED DEER
AIRDRIE
CALGARY
LETHBRIDGE
MEDICINE HAT
RED DEER RIVER BASIN
BOW RIVER BASIN
OLDMAN RIVER BASIN
SOUTH SASKATCHEWAN RIVER BASIN
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MONTANA
Milk River
Battle River
North Saskatchewan River
Brazeau River
Columbia River
Kootenay River
Belly River

Climate Change and Hydrological Impacts Summary of Presentation on Hydrology and Climate Change

Alain Pietroniro
National Water Research Institute
Saskatoon

Abstract:

This talk focused on a number of issues related to climate change and its impact on hydrology of the Prairies. The main discussion focused on past trends in streamflow and changes in glacier streamflow, noting the dramatic change in mean and minimum streamflow in glaciated regions of the North Saskatchewan river basin.. This presentation also highlighted recent comparisons between Global Circulation Models (GCMs) output for simulations of current climatic conditions (1961-1990) and observed gridded climatological data. Results from this analysis show that most GCMs can capture monthly temperature reasonably well for most part of Canada, precipitation estimates from GCMs for the climate observing period was much more varied. This discussion also described the methods used in the Canadian GEWEX study to develop a hydrological modelling strategy for the Mackenzie basin. Results from this work, including preliminary results of future water resources prediction for the Athabasca River were presented. It was suggested that CCAF should take advantage of the gains made during the first phase of the Canadian GEWEX programme and perhaps look at the proposed extension of the GEWEX Mackenzie Study, for a follow on into the Saskatchewan River Basin.

Note: A slide presentation is shown on the following pages.

National Water Research Institute

Discussion Topics

- Trends
- GCM results
- Methodology for Hydrological Impacts Assessment
  - Overview of Modeling Framework
- Coupling Atmospheric-hydrological Model
  - Vertical and Lateral Water Balance
- Conclusions

National Water Research Institute

Eastern Slopes

- The impacts of short-term and historical glacier fluctuations on glacier-fed rivers of the Rocky Mountain eastern slopes has been under investigation (Demuth and Pietroniro-PARC study)

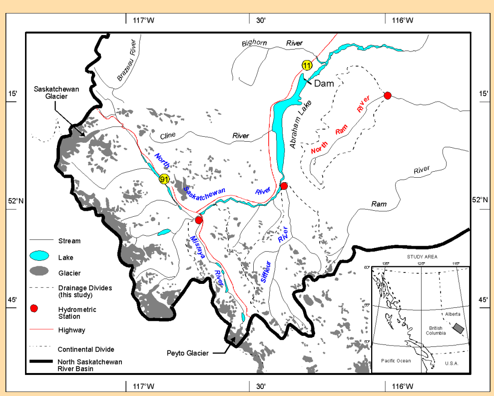


Figure 1. The headwater and eastern slope contributing basins of the North Saskatchewan River, Alberta, including the Mistaya River and Peyto Glacier. Glacier coverage is derived from the Glacier Atlas of Canada - plates 7-3,4 (Ommanney 1989).

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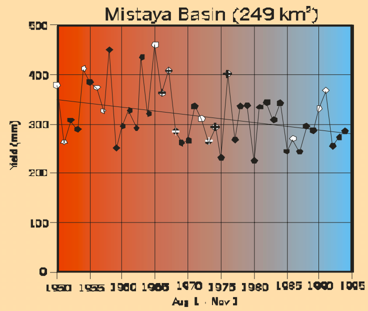
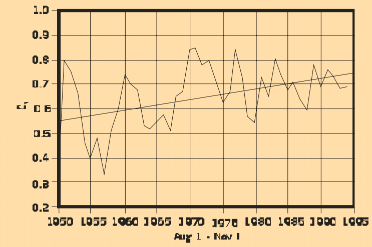
Mistaya Basin

- Aug1-Nov1
- Yield and CV for the Mistaya Basin with years of above average snow pack and positive mass balance shown
- Despite IPCC stating that contributions from glacier sources should increase in the short-medium term, and decrease in the long-term, there already evidence that, for critical periods we are already seeing a reduction in yield on account of reduced glacier area.





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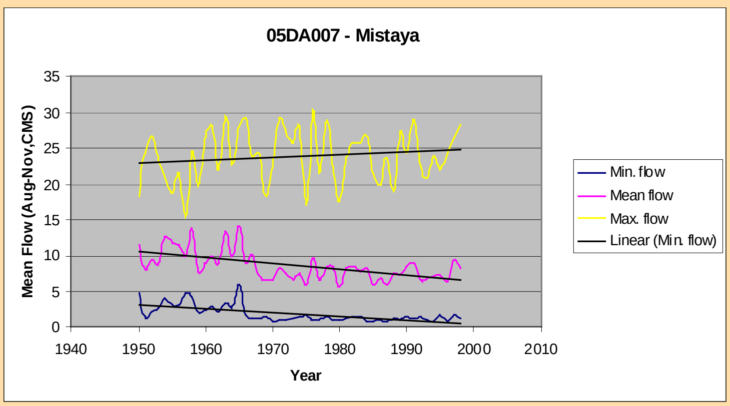

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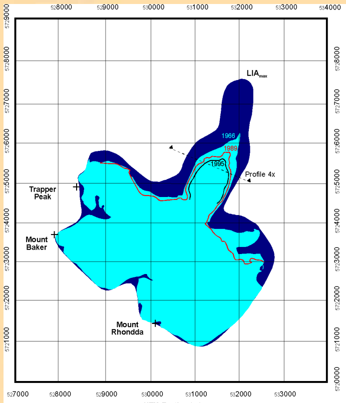
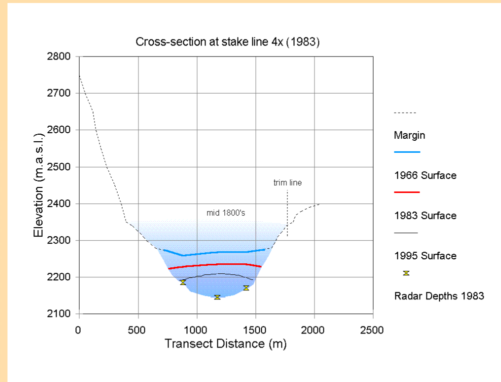
Changes in Peyto



Variation of the areal extent of Peyto Glacier: Little Ice Age maximum(ca.1850), 1966, 1989, 1995.



Cross-section Profile 4x of Peyto Glacier illustrating past-century ice thickness change.

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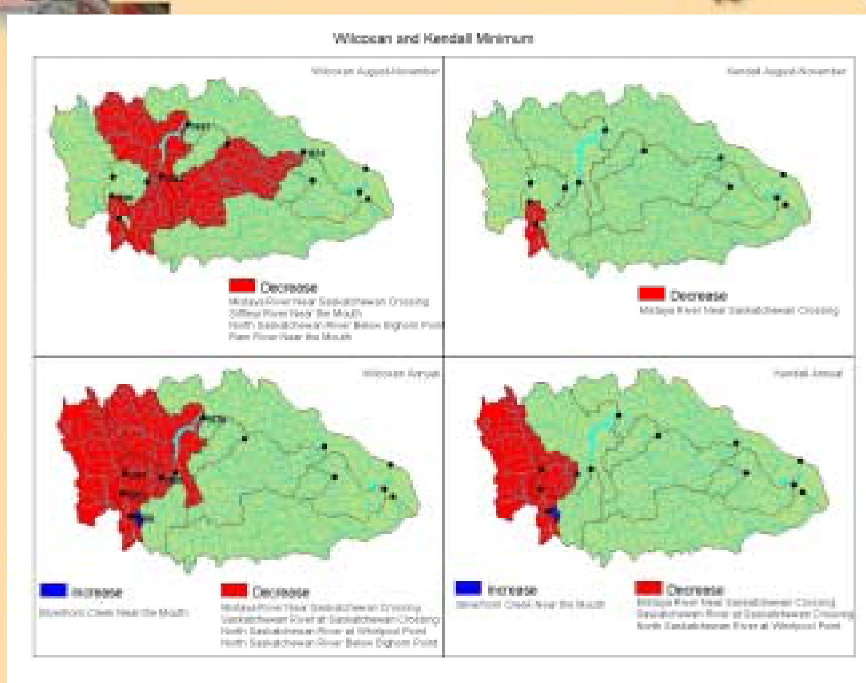
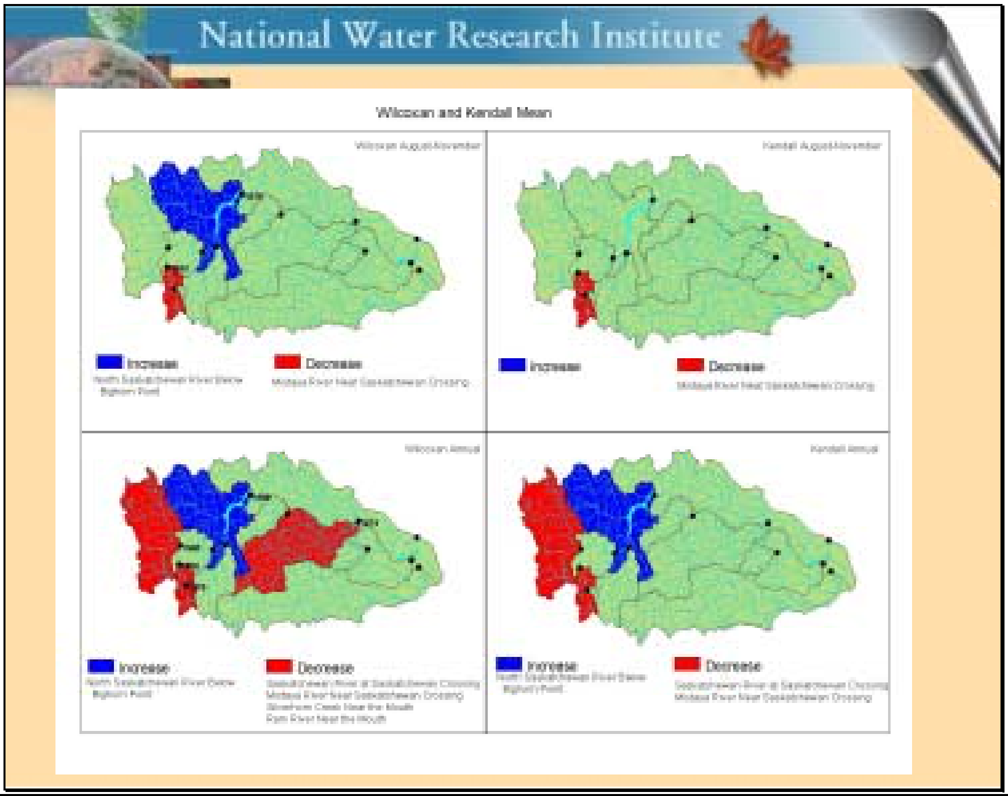
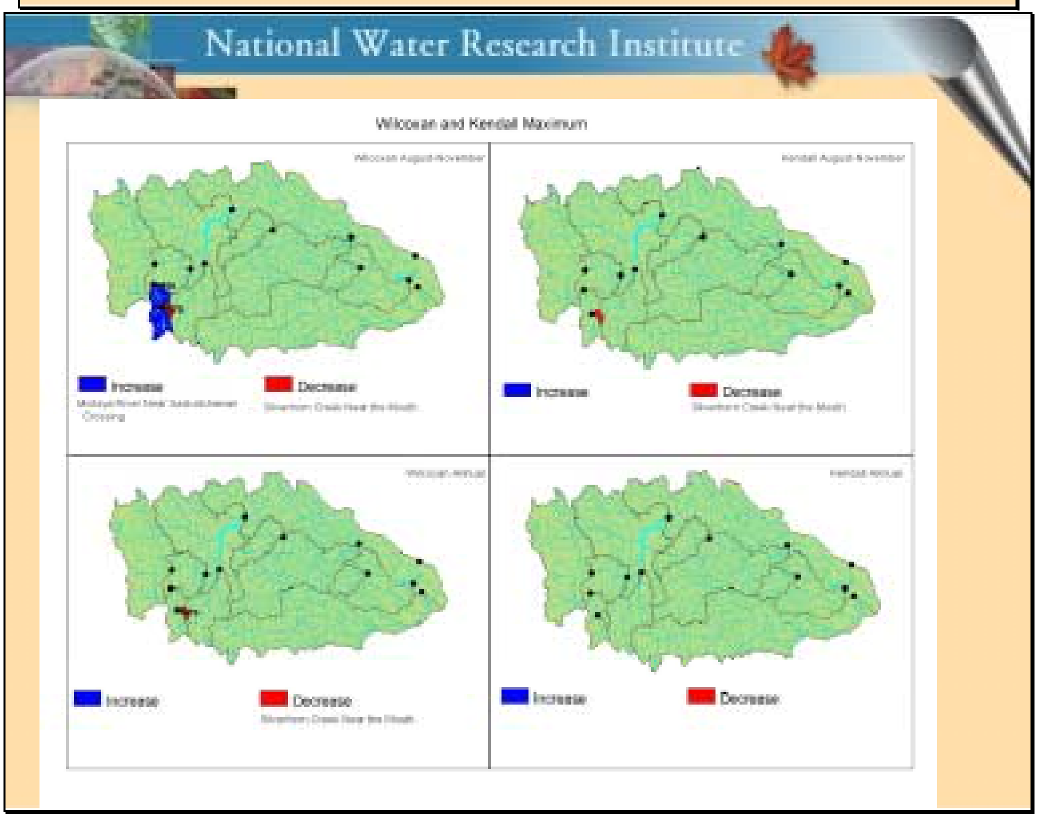



National Water Research Institute
Wilcoxan and Kendall Mean
Increase
Decrease
Increase
Decrease
Increase
Decrease
Increase
Decrease


National Water Research Institute
Wilcoxan and Kendall Maximum
Increase
Decrease
Increase
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Increase
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Increase
Decrease

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RHBN
Common Variables and Period Study

- Researchers were asked to submit station-by-station results for:
  - Trends in **annual maximum, mean** and **minimum daily flows**
  - Approximately **40 years** of record
  - Trends (positive or negative) reported at **10% significance level.**

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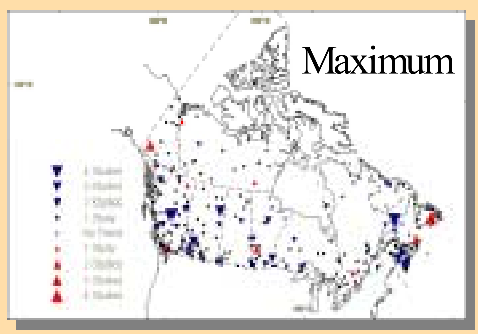
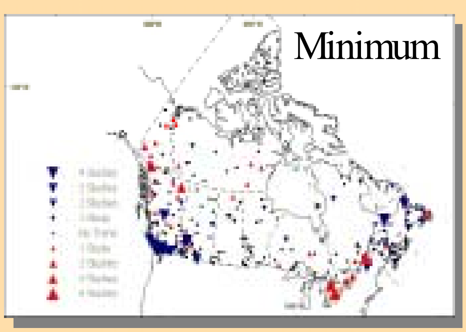
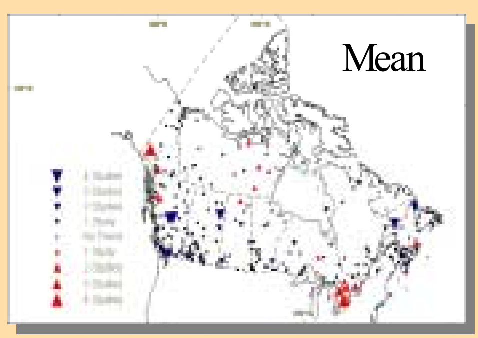
Composite of All Four Studies: Putting It All Together

	Number of Increasing Trends	Number of Decreasing Trends	Total Number of Trends
Maximum Annual Flow	12 (5%)	45 (18%)	57 (22%)
Mean Annual Flow	21 (8%)	24 (9%)	45 (18%)
Minimum Annual Flow	34 (13%)	44 (17%)	78 (31%)







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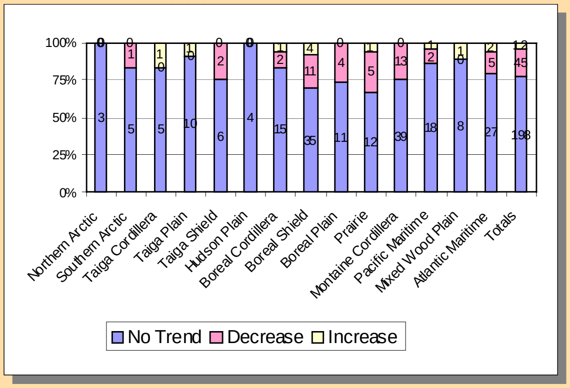
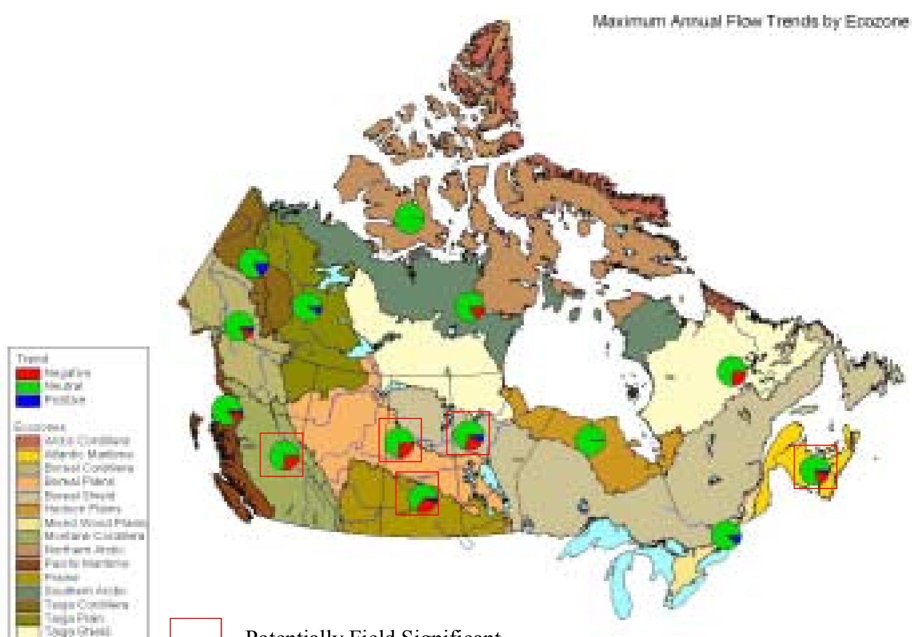
Maximum Annual Flow



Ecozones with potentially significant number of trends:

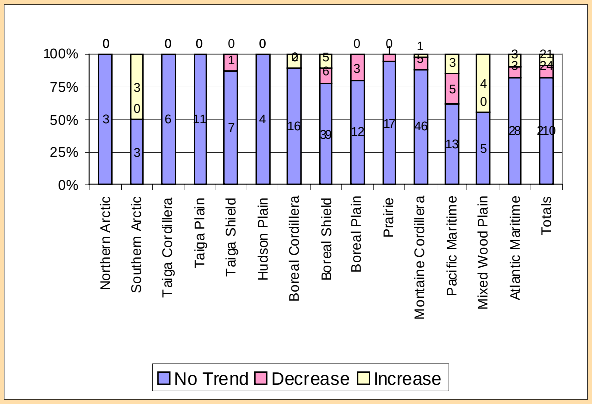
- Boreal shield(50)
- Boreal plain(15)
- Prairie(18)
- Montaine cordillera(52)
- Atlantic maritime(34)



Potentially Field Significant

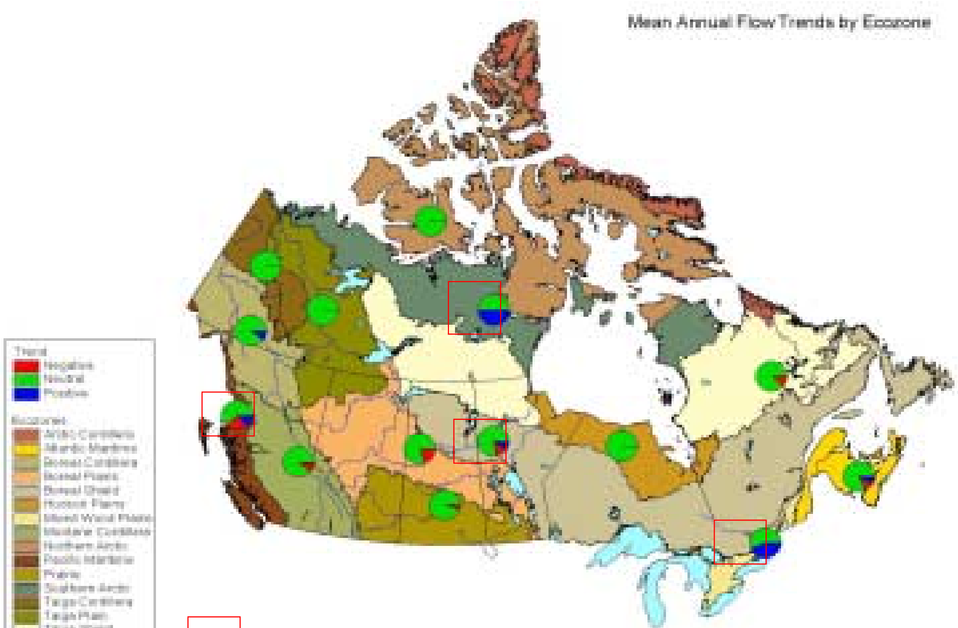
National Water Research Institute

Composite:
Mean Annual Flow



Ecozones with potentially significant number of trends:

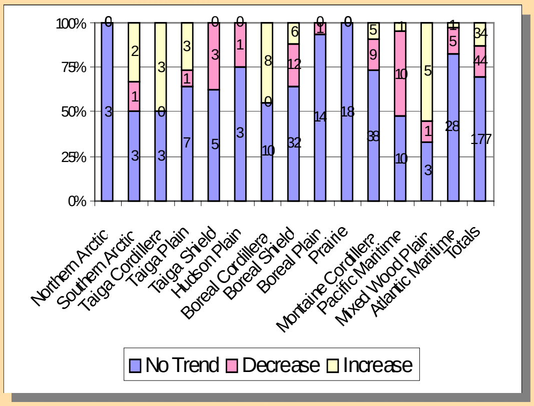
- Southern arctic (6)
- Boreal shield(50)
- Pacific maritime(21)
- Mixed wood plain (9)



Potentially Field Significant

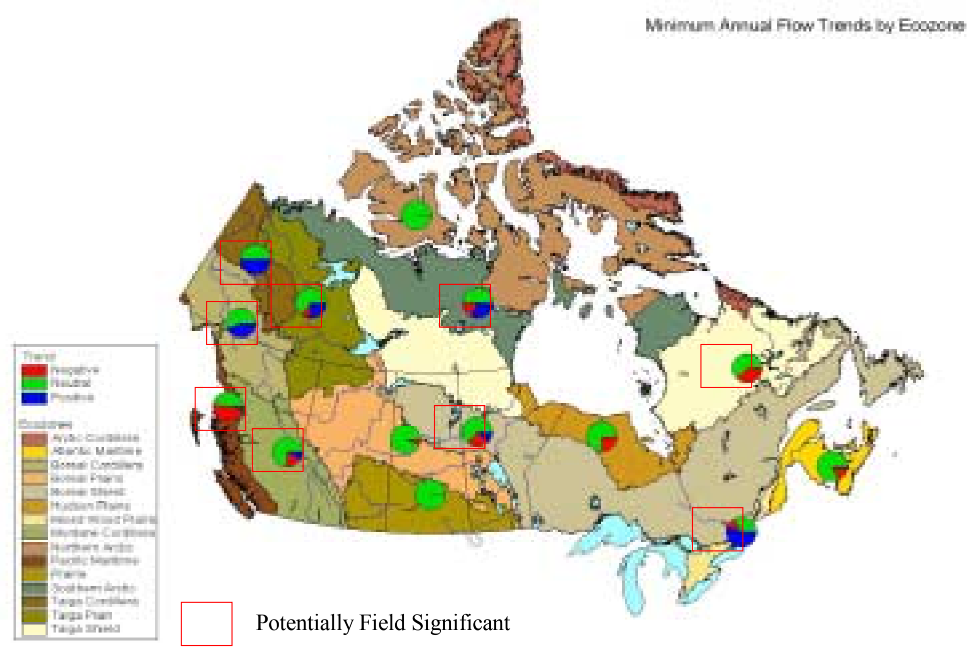
National Water Research Institute

Minimum Annual Flow



Ecozones with potentially significant number of trends:

- Southern arctic (6).
- Taiga cordillera (6), plain (11) and shield (8).
- Boreal cordillera (18), shield(50).
- Montaine Cordillera(52).
- Pacific Maritime(21).
- Mixed Wood Plain (9).



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Trend Results

- Trend analysis indicates decrease in annual flow and TBF mean and minumum flows periods for records analyzed in glaciated basins. Maximum flows show no real change.
- no apparent trend observed in headwater basins that are unglaciated(e.g. the North Ram)
- RHBN results show decreasing flows in the prairie and boreal plain for maximum annual flow.
  - Not much change in mean or minimum annual flow.

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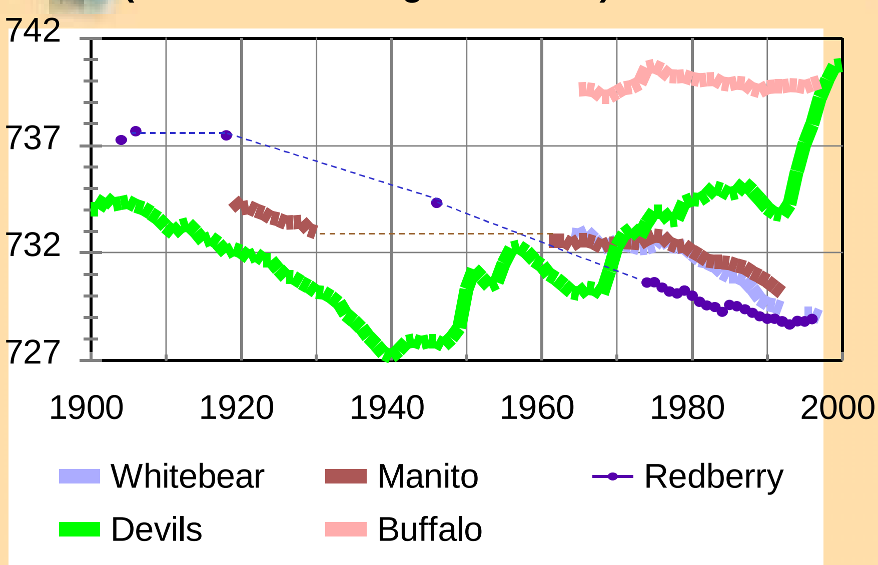
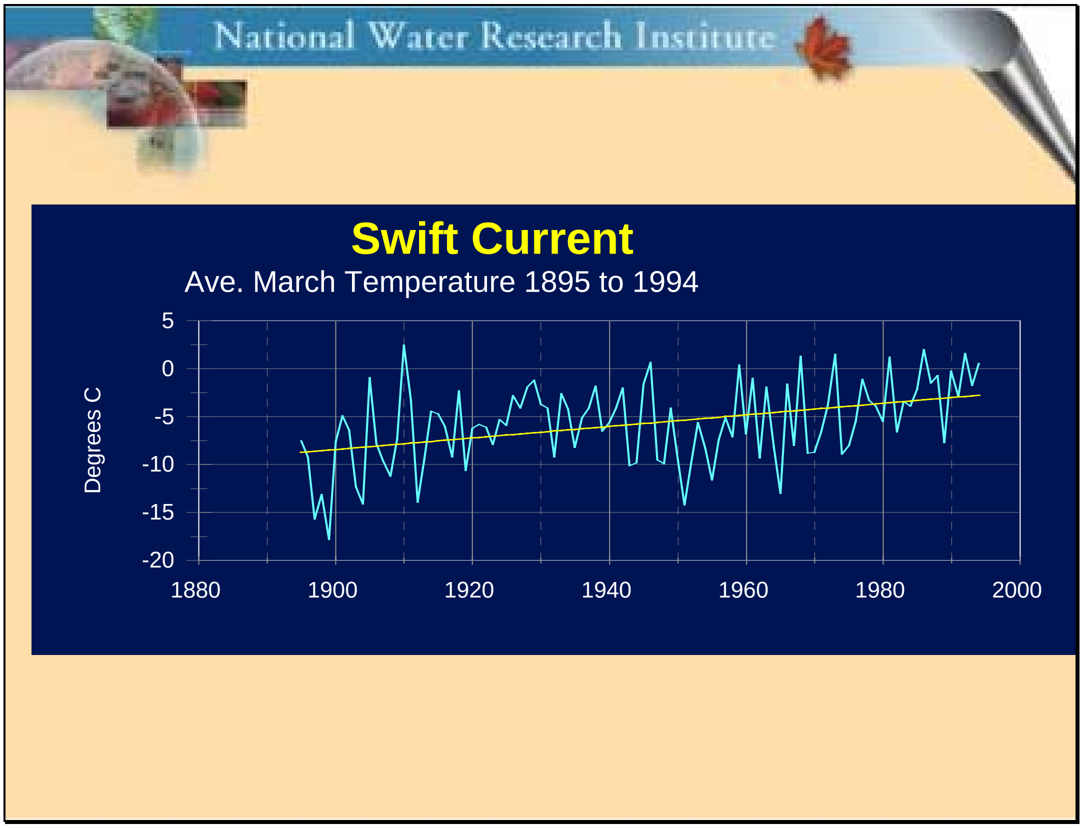
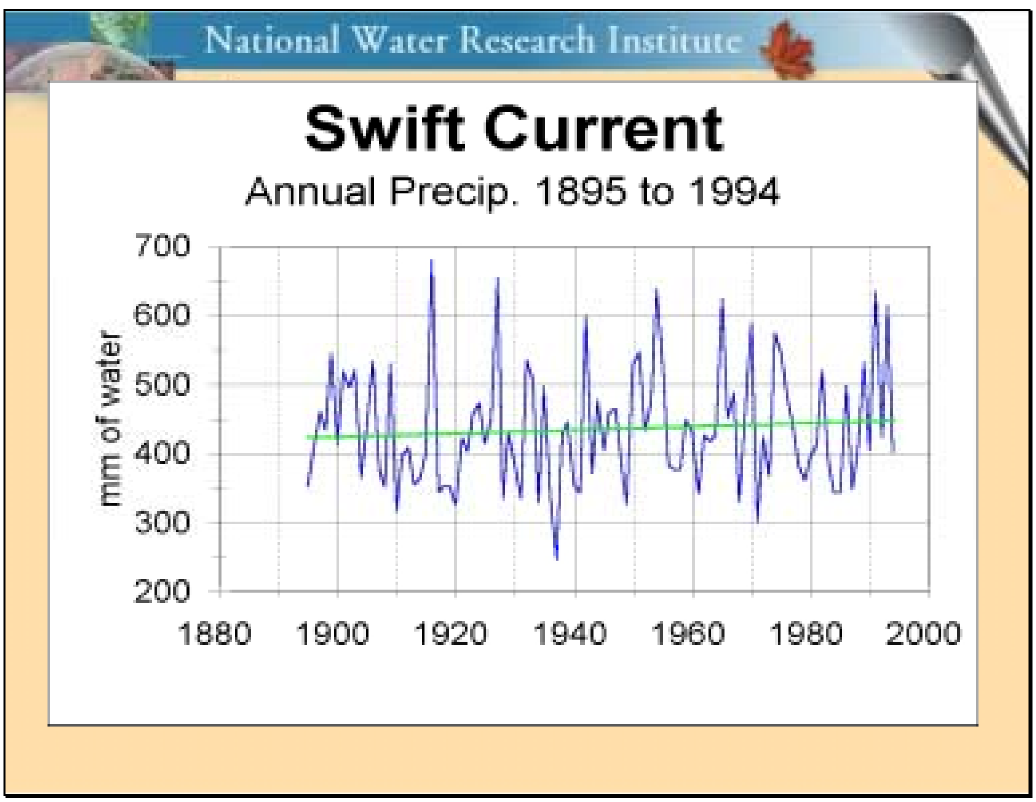
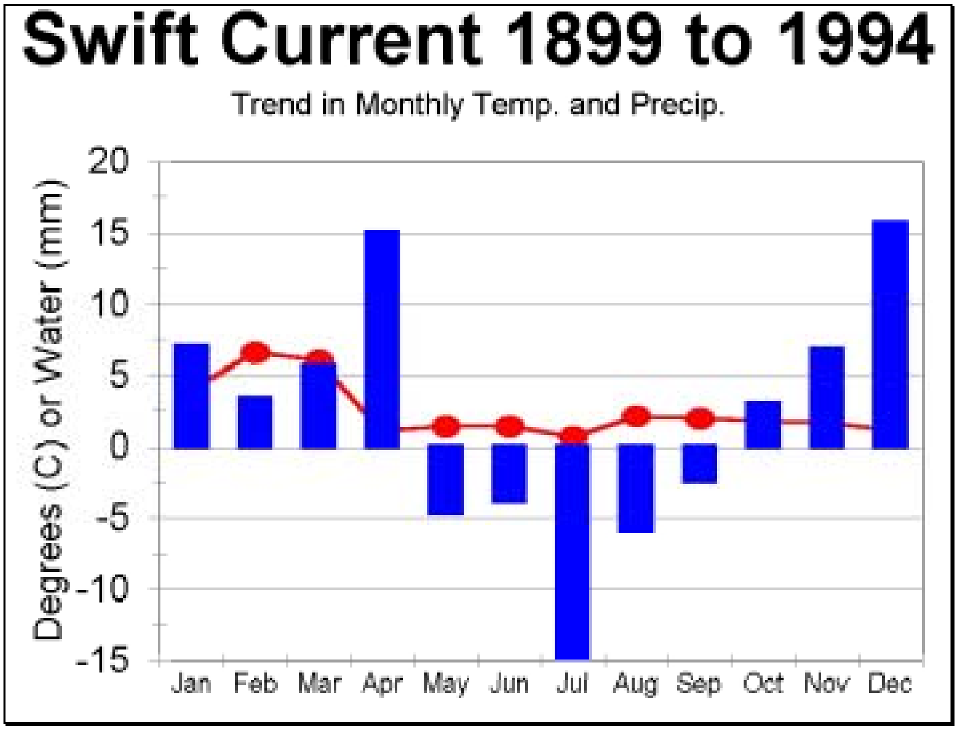
Prairie Lake Levels

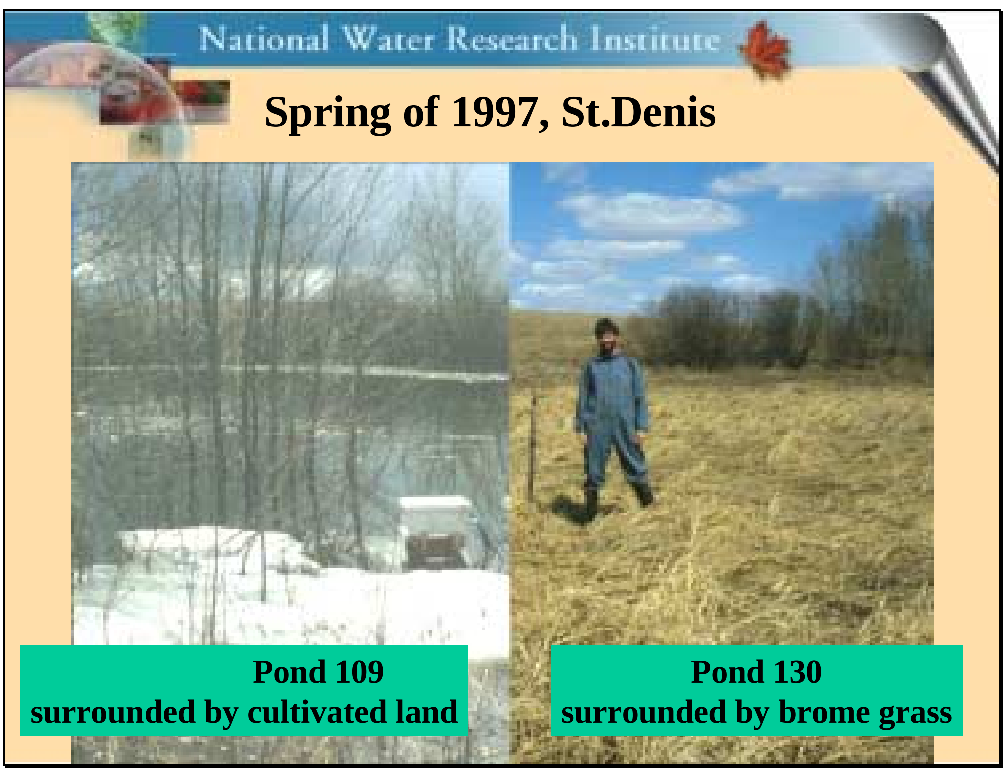
(Water level change in Metres)




National Water Research Institute
Swift Current
Ave. March Temperature 1895 to 1994
Degrees C
5
0
-5
-10
-15
-20
1880
1900
1920
1940
1960
1980
2000

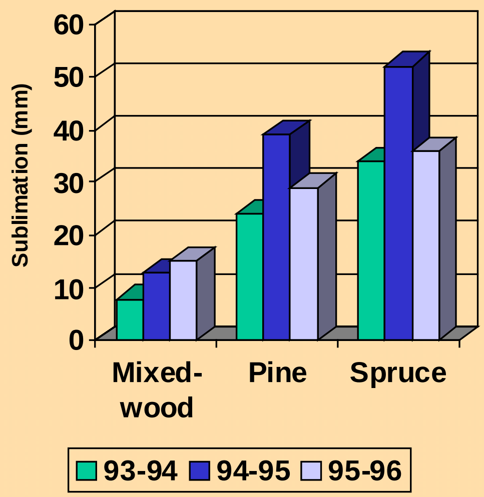

National Water Research Institute
Swift Current
Annual Precip. 1895 to 1994
mm of water
700
600
500
400
300
200
1880
1900
1920
1940
1960
1980
2000


Swift Current 1899 to 1994
Trend in Monthly Temp. and Precip.
Degrees (C) or Water (mm)
20
15
10
5
0
-5
-10
-15
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


National Water Research Institute
Spring of 1997, St.Denis
Pond 109
surrounded by cultivated land
Pond 130
surrounded by brome grass

National Water Research Institute

Annual Sublimation Losses



Sublimation loss as a percent of annual snowfall.

- Spruce 38% to 45%
- Pine 30% to 32%
- Mixed-wood 10% to 15%

Hence, reduction of winter leaf area reduces sublimation loss

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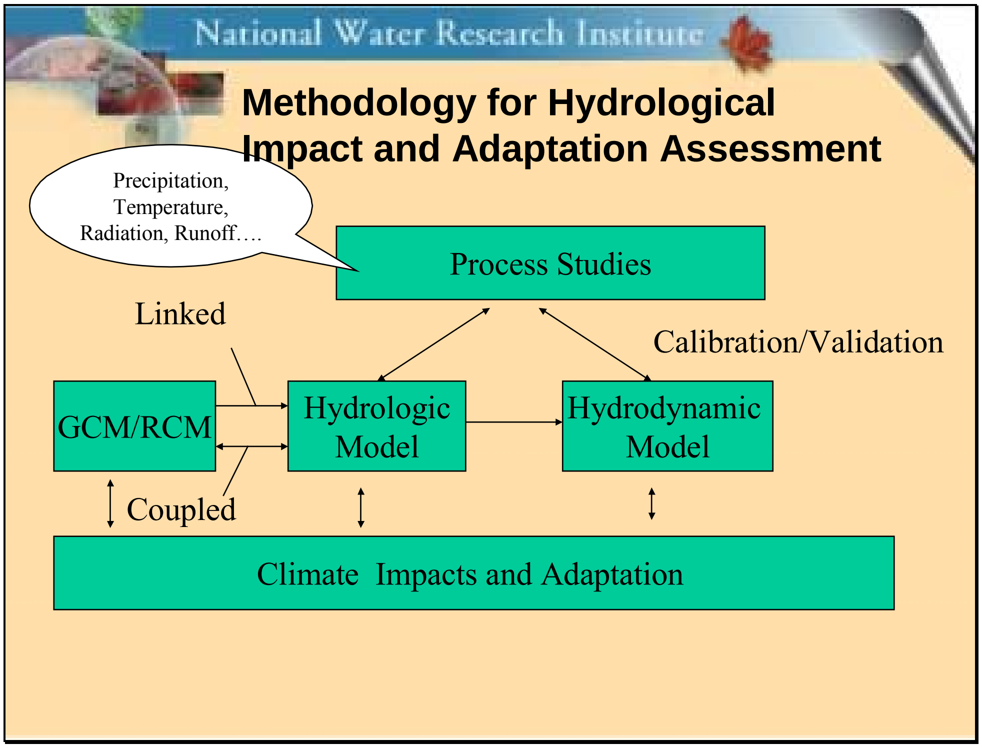
Understanding Hydrological Trends - past and future

•Requires Comprehensive understanding of hydrological regime

•Prairie hydrology - limited understanding of wetlands, frozen soil infiltration, snow sublimation, evaporation.

•Anthropgenic and climatic variability confound our understanding

•One possible methdod - hydrological models



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Meterological Forcing

- Meteorological forcing of hydrological model
  - hind-casting
    - » observations
    - » NWP analysis
    - » NWP re-analysis
  - now-casting -
    - » observation
    - » NWP analysis
    - » short term forecast
  - Climate Forecasting
    - » Global Circulation Models (RCM)
    - » Regional Climate models (RCM)

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Assessing GCM scenarios
Available Data for Canada

1961-1990

GCM Data

CGCM-1
HADCM2
CCSR/NIES
CSIRO-Mk2b
ECHAM4
GFDL-R15
NCAR-DOE

Gridded Observed Data

University of Waterloo (WAT)
Climatic Research Unit (CRU)

2040-2069

(Expressed as the change from 1961-1990)

GCM Data

CGCM-1
HADCM2
CCSR
CSIRO-Mk2b
ECHAM4
GFDL-R15
NCAR-DOE

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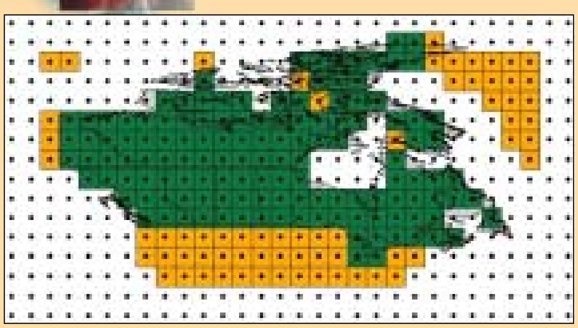
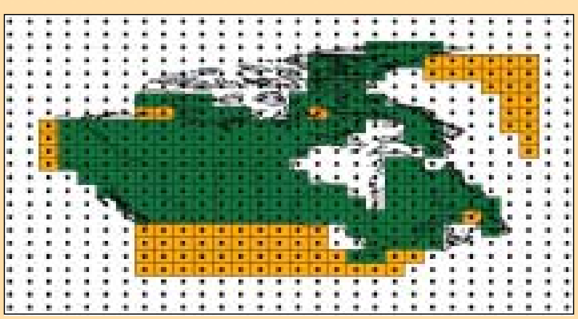


CGCM-1

- GCM Grid Centres
- Land Grid Cells (Land/Sea Mask)
- Land Grid Cells in Canada (where Waterloo > 40% land)



HADCM2

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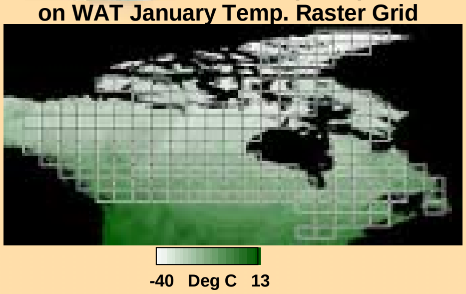
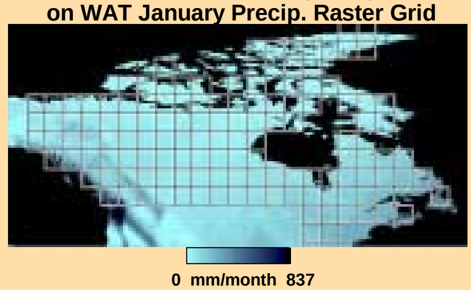
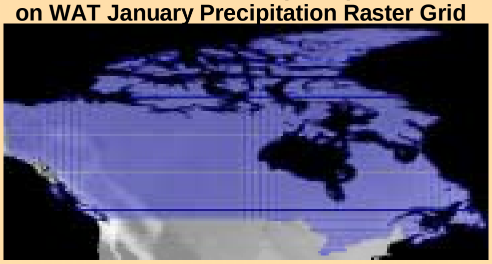
HADCM2 Vector Grid Superimposed on WAT January Temp. Raster Grid



CGCM-1 Vector Grid Superimposed on WAT January Precip. Raster Grid



CRU Vector Grid Superimposed on WAT January Precipitation Raster Grid



To compare:

Observed (WAT) vs GCM or

Observed (WAT) vs Observed (CRU)

1. Superimpose vector polygon grid (GCM or CRU) on raster grid (WAT)

2. Extract average WAT Precipitation and Temperature within each vector grid cell

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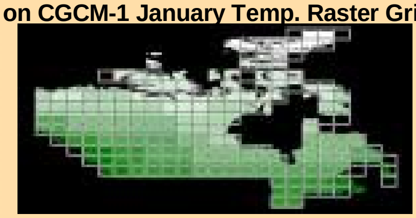
To compare: GCM vs GCM

1. Rasterize monthly precipitation and temperature for one GCM grid and overlay the other GCM vector polygon grid

2. Extract average precipitation and temperature from the raster grid within each vector grid cell

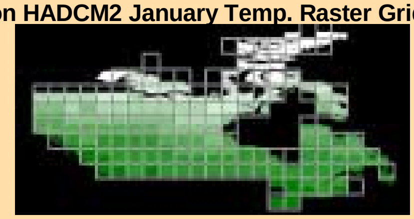
CGCM-1 Rasterized January Temp.

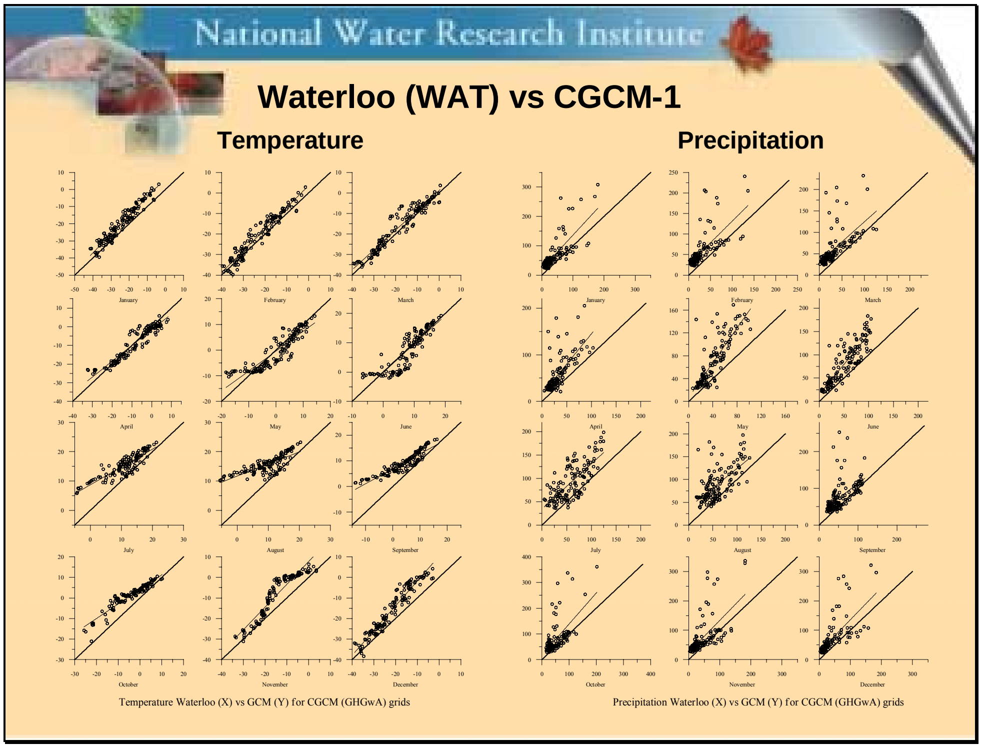
HADCM2 Vector Grid Superimposed on CGCM-1 January Temp. Raster Grid

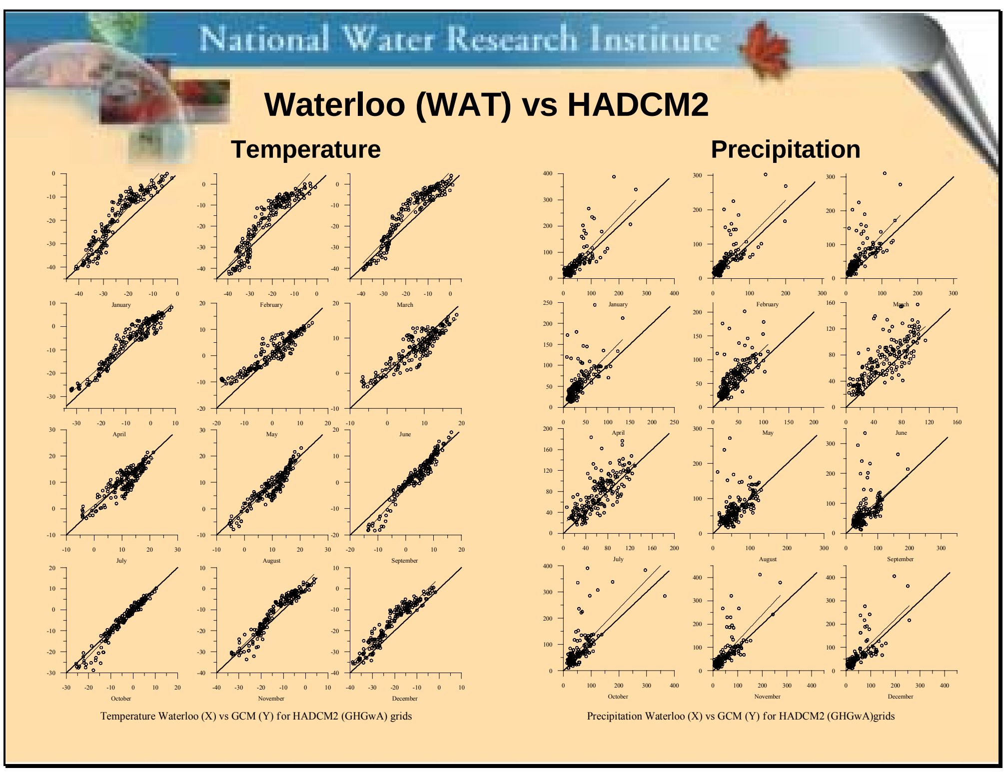


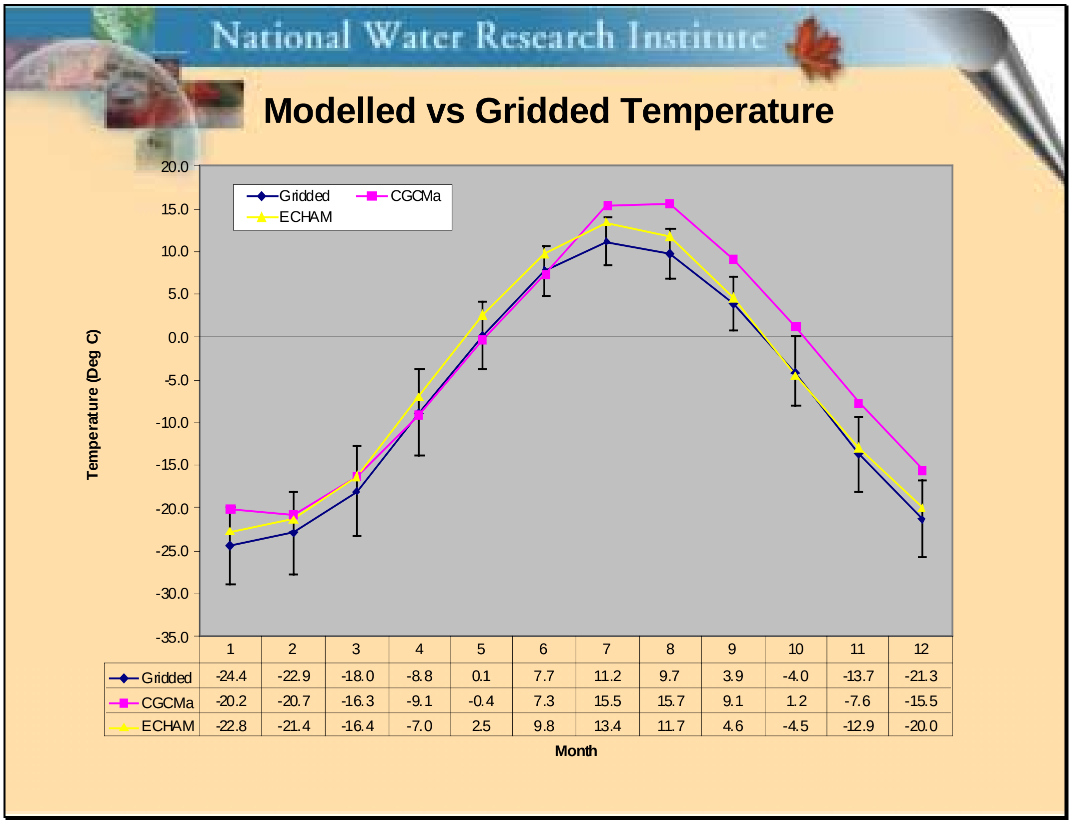
HADCM2 Rasterized January Temp.

CGCM-1 Vector Grid Superimposed on HADCM2 January Temp. Raster Grid

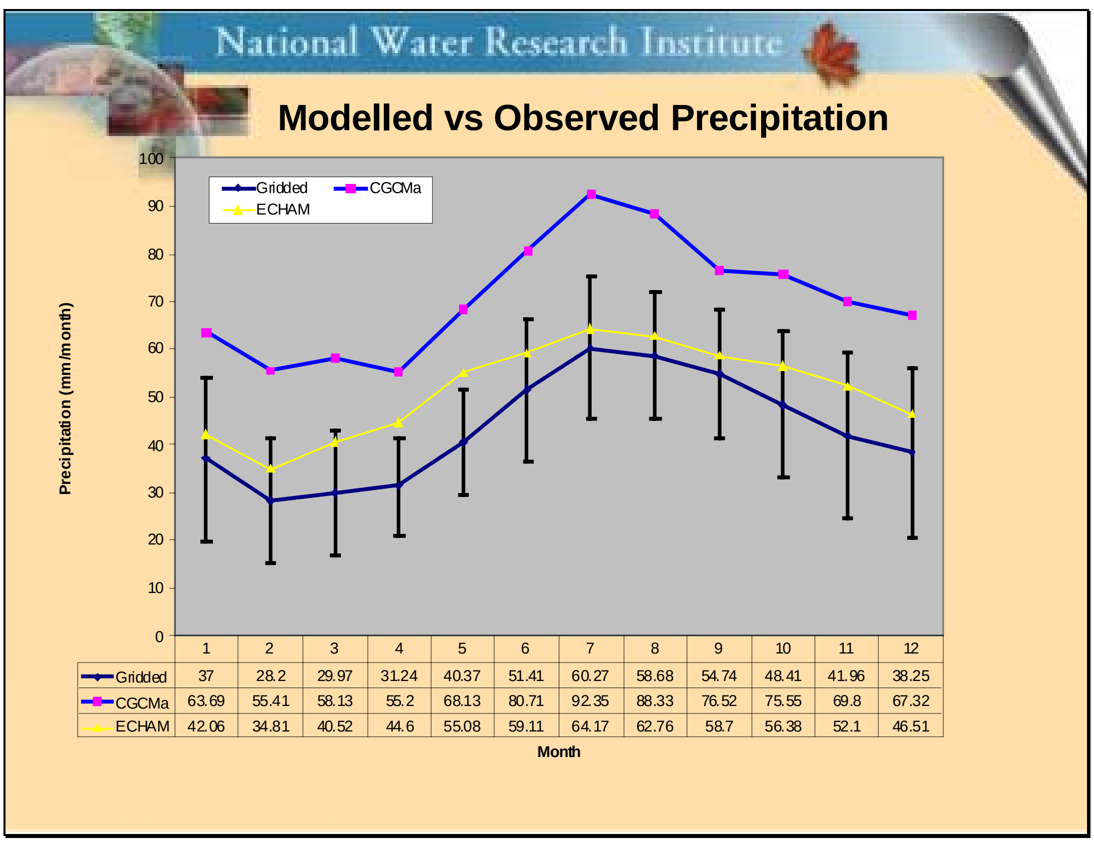



National Water Research Institute
Waterloo (WAT) vs CGCM-1
Temperature
Precipitation
Temperature Waterloo (X) vs GCM (Y) for CGCM (GHGwA) grids
Precipitation Waterloo (X) vs GCM (Y) for CGCM (GHGwA) grids


National Water Research Institute
Waterloo (WAT) vs HADCM2
Temperature
Precipitation
Temperature Waterloo (X) vs GCM (Y) for HADCM2 (GHGwA) grids
Precipitation Waterloo (X) vs GCM (Y) for HADCM2 (GHGwA)grids



	1	2	3	4	5	6	7	8	9	10	11	12
Gridded	-24.4	-22.9	-18.0	-8.8	0.1	7.7	11.2	9.7	3.9	-4.0	-13.7	-21.3
CGCMa	-20.2	-20.7	-16.3	-9.1	-0.4	7.3	15.5	15.7	9.1	1.2	-7.6	-15.5
ECHAM	-22.8	-21.4	-16.4	-7.0	2.5	9.8	13.4	11.7	4.6	-4.5	-12.9	-20.0



	1	2	3	4	5	6	7	8	9	10	11	12
Gridded	37	28.2	29.97	31.24	40.37	51.41	60.27	58.68	54.74	48.41	41.96	38.25
CGCMa	63.69	55.41	58.13	55.2	68.13	80.71	92.35	88.33	76.52	75.55	69.8	67.32
ECHAM	42.06	34.81	40.52	44.6	55.08	59.11	64.17	62.76	58.7	56.38	52.1	46.51

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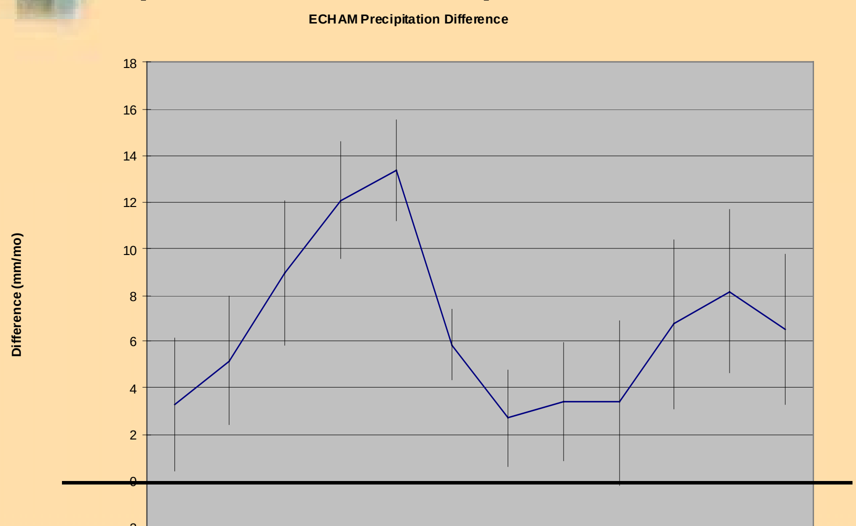
Modelled vs Observed Precipitation (Paired T-test results)



	1	2	3	4	5	6	7	8	9	10	11	12
Mean Difference	3.29	5.16	8.95	12.07	13.37	5.867	2.71	3.4	3.38	6.74	8.18	6.53
95% CI upper	6.17	7.94	12.04	14.56	15.55	7.413	4.81	5.93	6.94	10.38	11.69	9.78
95% CI lower	0.41	2.39	5.86	9.58	11.19	4.322	0.6	0.86	-0.18	3.11	4.66	3.27

Month

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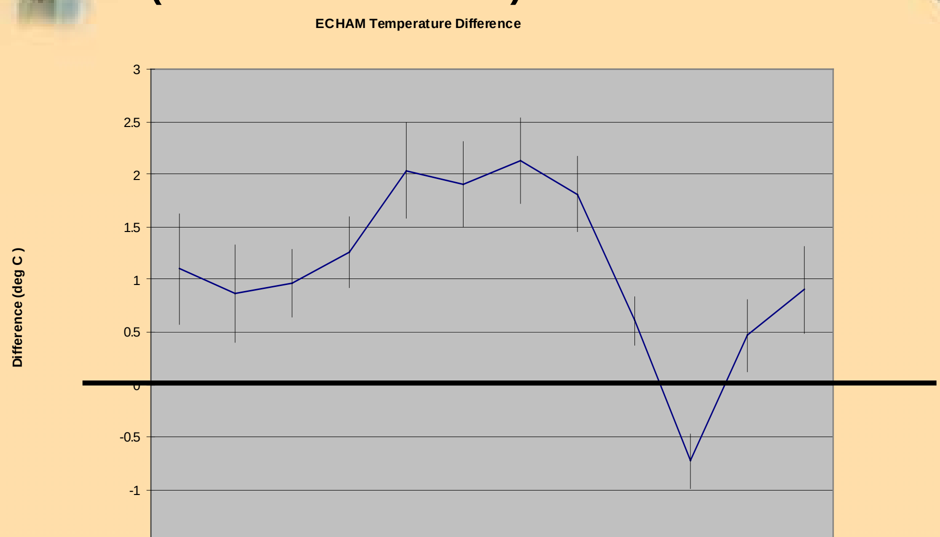
Modelled vs Observed Temperature (Paired T-test results)



	1	2	3	4	5	6	7	8	9	10	11	12
Mean Difference	1.097	0.866	0.966	1.255	2.036	1.907	2.132	1.81	0.604	-0.728	0.467	0.905
95% CI Upper	1.626	1.327	1.29	1.59	2.495	2.308	2.54	2.171	0.834	-0.463	0.81	1.321
95% CI Lower	0.568	0.406	0.641	0.919	1.577	1.506	1.723	1.45	0.373	-0.993	0.123	0.488

Month

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Level 0 modelling - The Peace and Athabasca Rivers

WATFLOOD

RCM

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WATFLOOD and WATCLASS

- Current activity in hydrologic modeling is towards more physically based models
  - Attempt to more closely represent the observed hydraulic phenomena.
  - Necessitates breaking the watershed down into smaller units.
- Two Common approaches used in hydrological modeling
  - REA (HRU)
  - GRU(ASA) - WATFLOOD and WATCLASS
    - The GRU is a grouping of all areas with a similar land cover such that a grid square will contain a number of distinct GRUs.
    - Runoff generated from the different groups of GRUs are then summed together and routed to the stream and river system.

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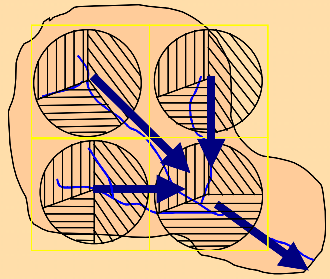
Discretization(GRU)

- The WATFLOOD model divides a watershed into a number of units known as Grouped Response Units and discritizes the basins into a series of a square grids.
- The objective in using the GRU is to model hydrologically-consistent subareas of the watershed, each with known properties.



•Two GRUs with the same percentages of land cover types, rainfall and initial conditions will produce the same amount of runoff regardless of how these land cover classes are distributed.

•The major advantage of the WATFLOOD -GRU model is that it can incorporate the necessary physics while retaining simplicity of operation.

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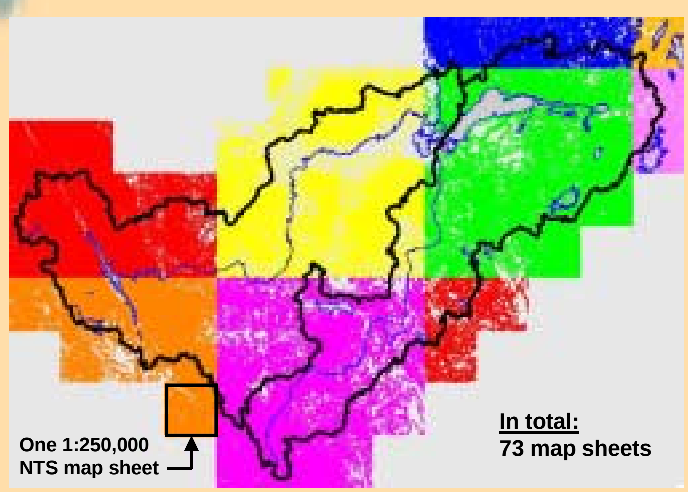
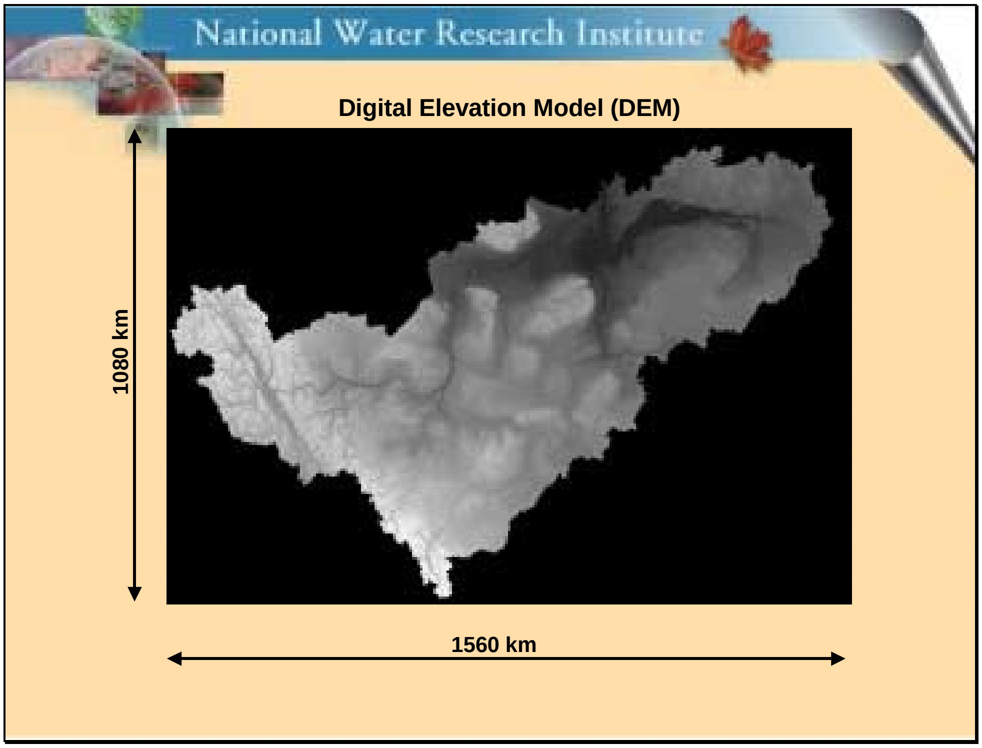
Digital contour lines used as input for the DEM



The river and lake outlines were used to correct the DEM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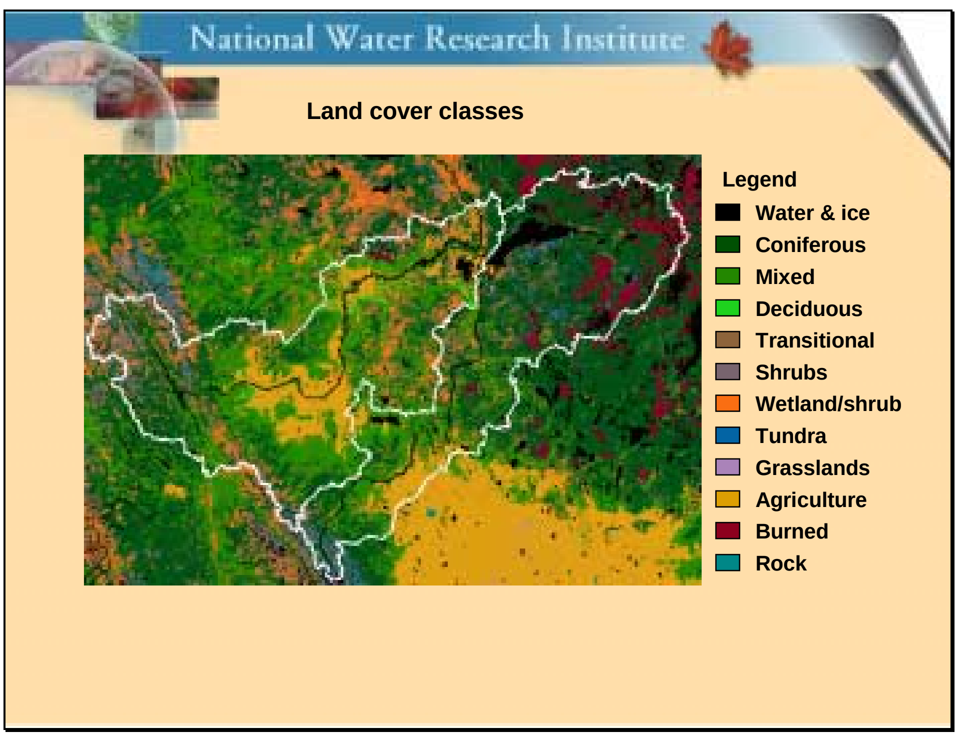
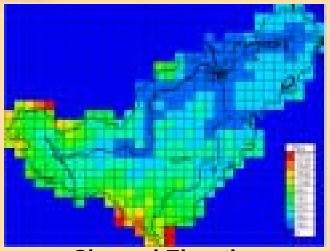
Digital Elevation Model (DEM)
1080 km
1560 km

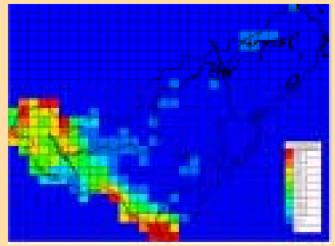

National Water Research Institute
Land cover classes
Legend
Water & ice
Coniferous
Mixed
Deciduous
Transitional
Shrubs
Wetland/shrub
Tundra
Grasslands
Agriculture
Burned
Rock

National Water Research Institute

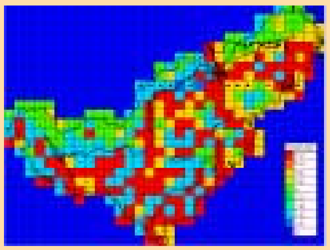
Watflood Files



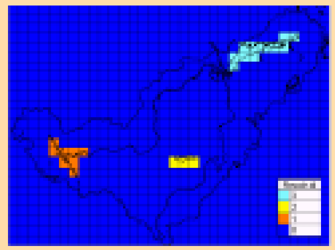
Channel Elevation



Contour Density



Drainage Direction



Reach Number

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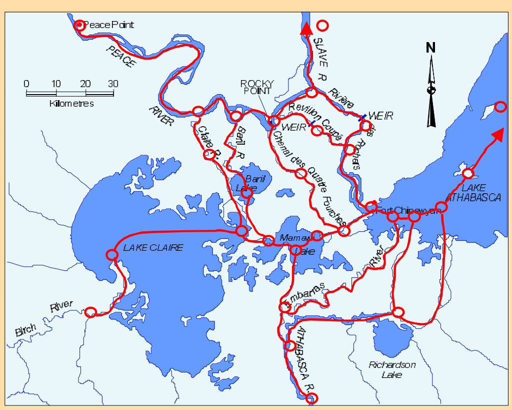
Model Analysis

Table 1 - Boundary conditions in the PAD

Node	Station	Type	Comments
1	Lake Athabasca at Crackingstone Point	Water levels	
3	Birch River	Discharges	
11	Peace River at Peace Point	Discharges	
22	Slave River at Fitzgerald	Rating curve	
29	Athabasca River	Discharges	2-day lag
	Lake Claire	Evaporation	Summer months
	Lake Mamawi	Evaporation	Summer months



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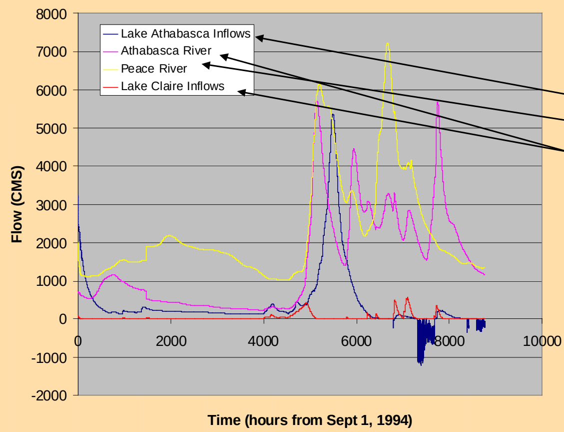
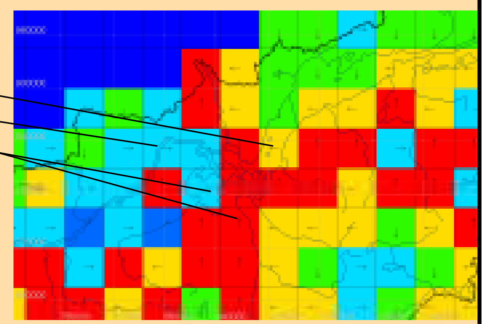
Boundary Conditions





Provides a means to estimate ungauged inflows and lake inflows

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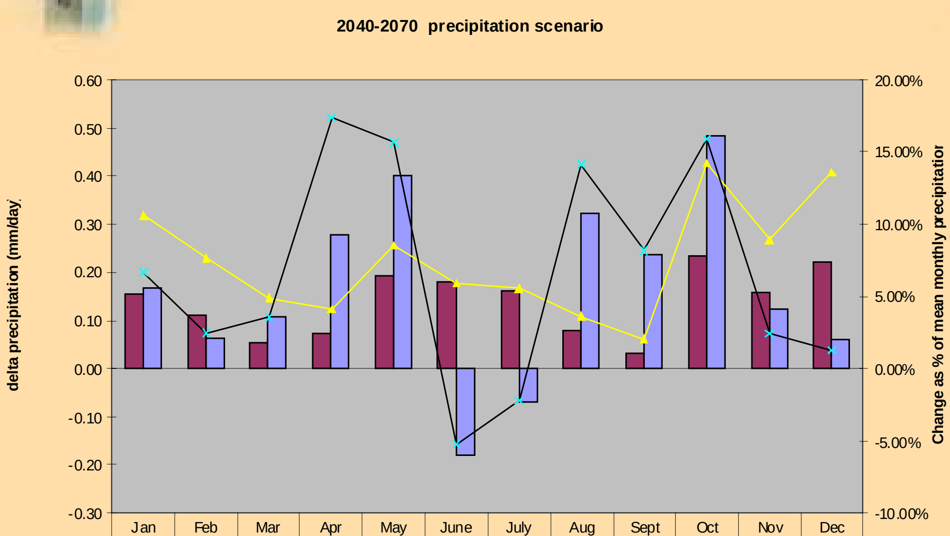
Change Scenario



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Hadley	0.15	0.11	0.05	0.07	0.19	0.18	0.16	0.08	0.03	0.23	0.16	0.22
CGCM	0.17	0.06	0.11	0.28	0.40	-0.18	-0.07	0.32	0.24	0.48	0.13	0.06
Hadley	10.61%	7.63%	4.89%	4.09%	8.51%	5.88%	5.52%	3.64%	2.06%	14.17%	8.91%	13.60%
CGCM	6.70%	2.50%	3.58%	17.37%	15.59%	-5.20%	-2.20%	14.15%	8.17%	15.84%	2.43%	1.26%

Month

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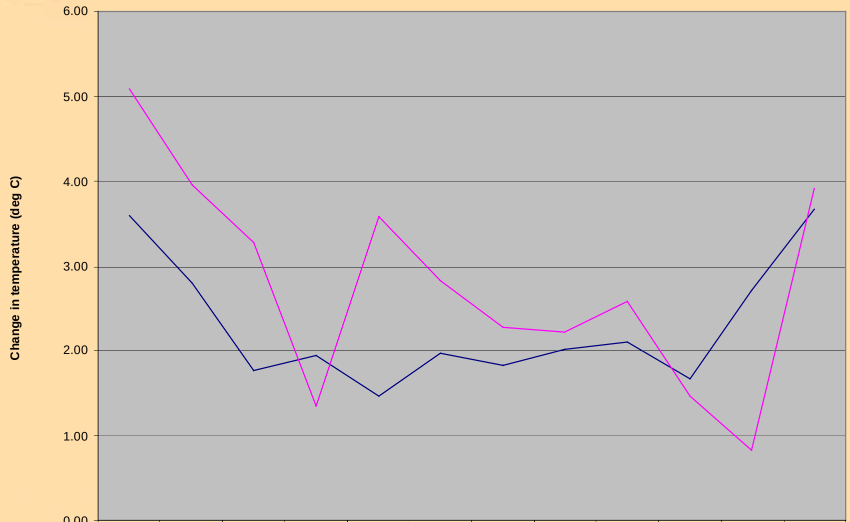
Change Scenario

Temperature Change (2040-2070 scenario)



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Hadley	3.60	2.80	1.78	1.95	1.47	1.98	1.83	2.02	2.10	1.68	2.71	3.67
CGCM	5.09	3.97	3.29	1.35	3.58	2.83	2.28	2.22	2.59	1.46	0.83	3.92

Change in temperature (deg C)

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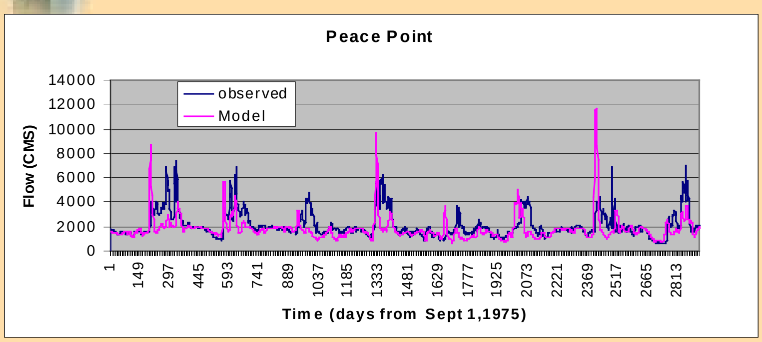
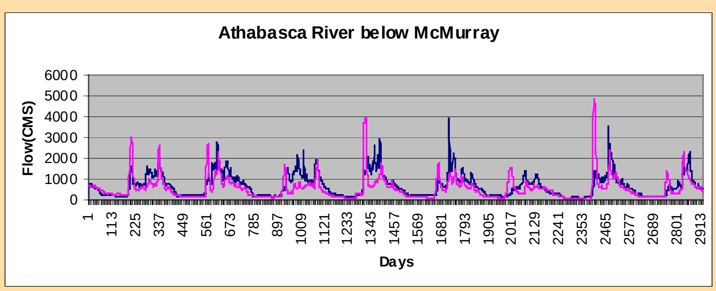
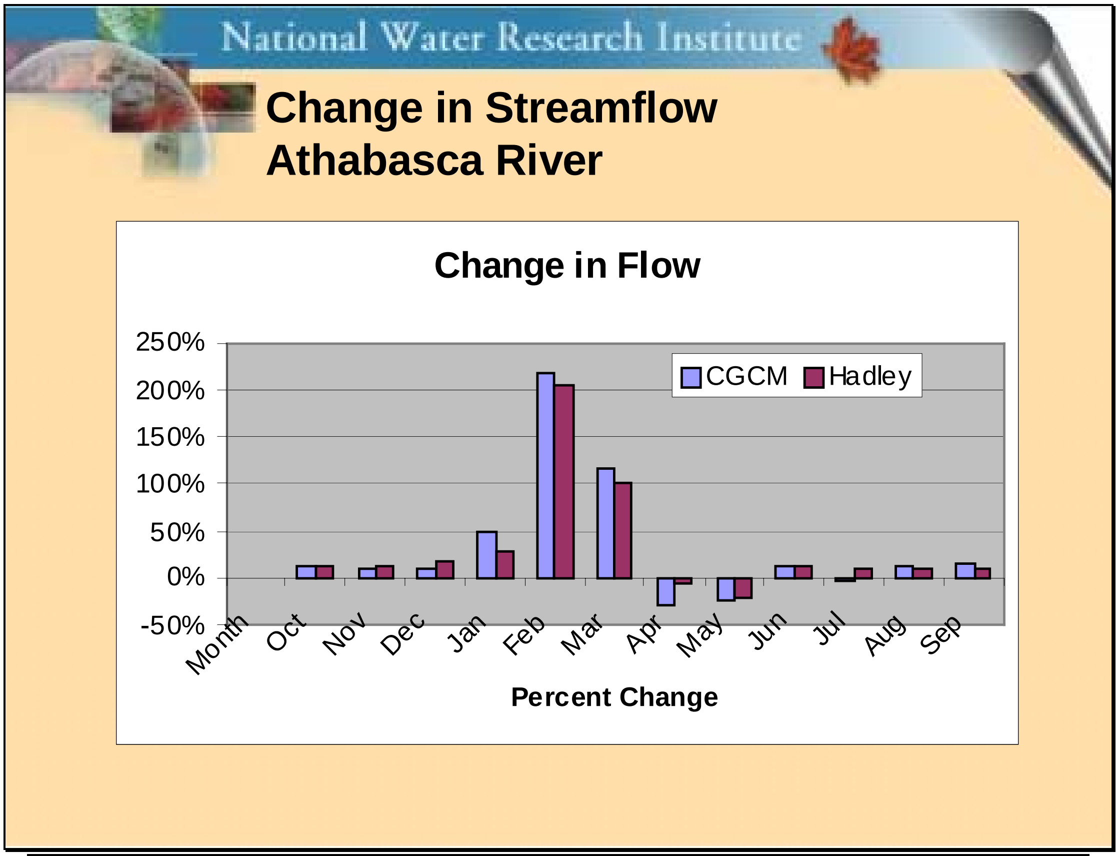
Preliminary Results



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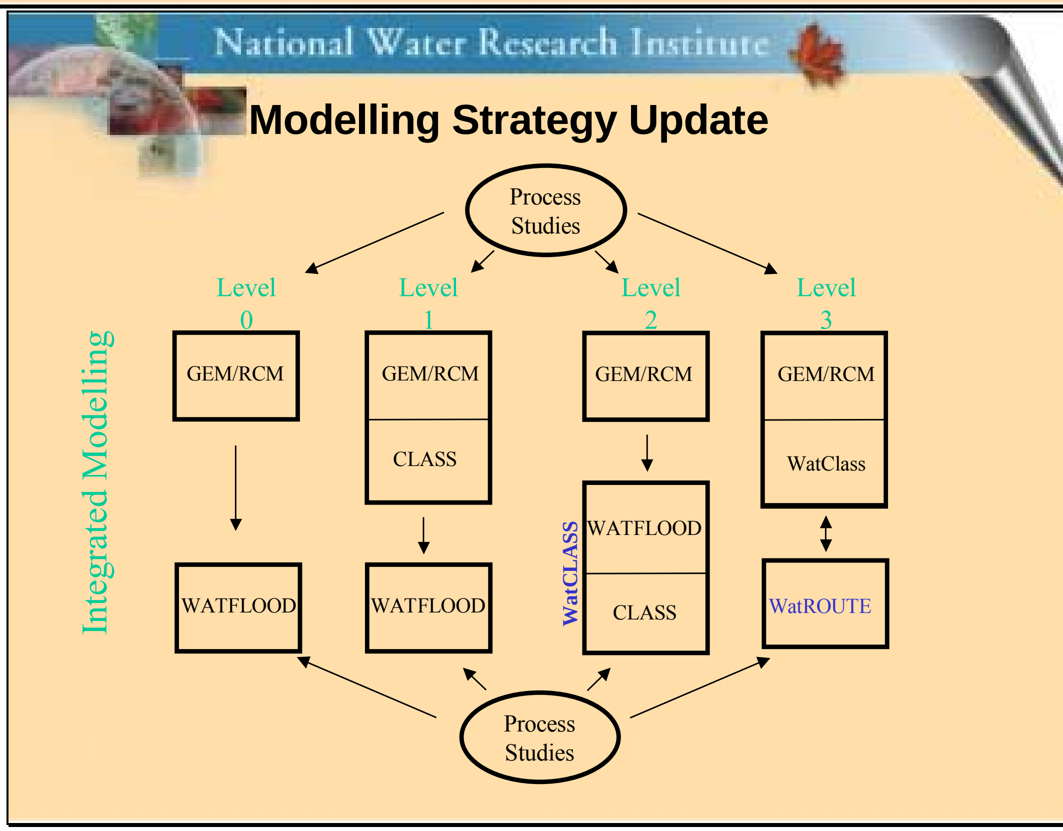
Change in Streamflow
Athabasca River
Change in Flow
250%
200%
150%
100%
50%
0%
-50%
Month
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
CGCM
Hadley
Percent Change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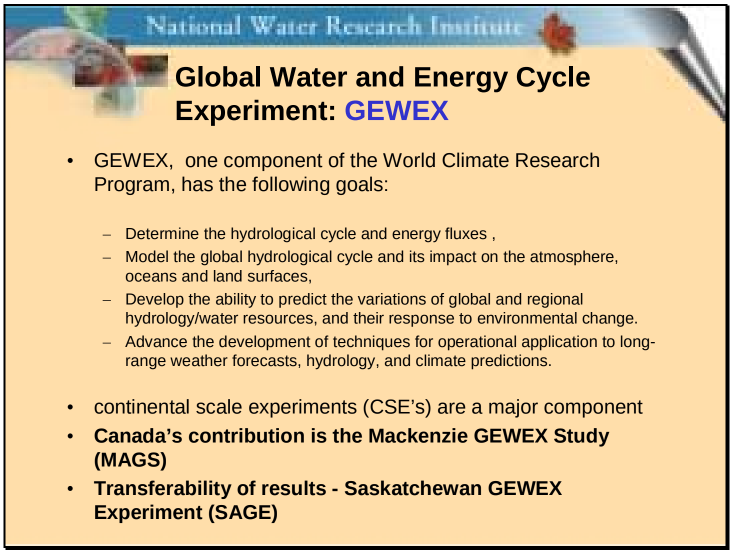
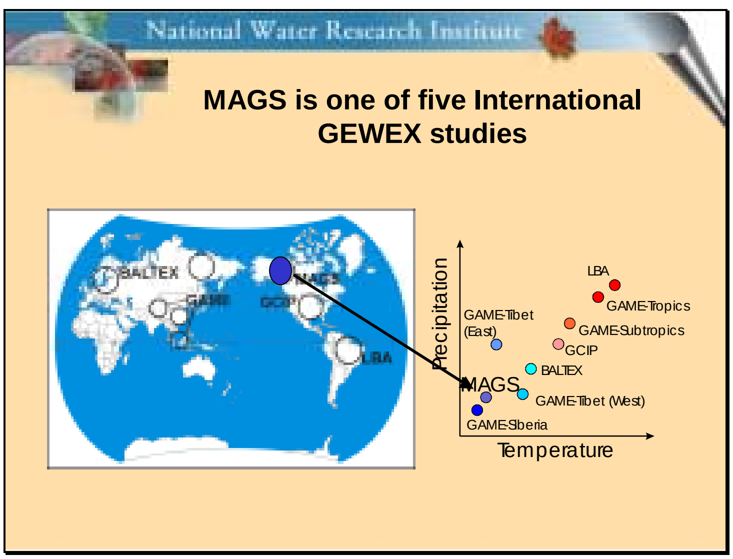
Modelling Strategy Update
Process Studies
Integrated Modelling
Level 0
Level 1
Level 2
Level 3
GEM/RCM
WATFLOOD
GEM/RCM
CLASS
WATFLOOD
GEM/RCM
WatCLASS
WATFLOOD
CLASS
GEM/RCM
WatClass
WatROUTE
Process Studies



CSEs - concerned with developing skills in predicting changes in water resources and soil moisture on time scales up to seasonal and annual



Why the Mackenzie?
one of the largest river basins in Canada
10th largest in the world
cold regions processes dominant the water cycle
is a major contributor of freshwater to the Arctic Ocean

WCRP considers this to be an important Canadian contribution to the international program as we are unique in that we are a northern Country that has the capability of carrying out such large scale study

National Water Research Institute

Strategy for South Saskatchewan (a hydrologists perspective)

- Assessing Adaptation strategies requires
  - Multi-disciplinary approach in parallel
    - Atmospheric, Hydrological,Economic and Social Scientist working in concert
- Atmospheric
    - improved precipitation in GCM/RCM
    - Downscaling from GCM
    - Adopt a coupled atmospheric/hydrological modelling strategy
- Hydrology
    - GRU modelling approach for linking and coupling with atmospheric models
    - Improved process representation, particularly wetlands
- Economics and Social Science
    - Understanding of needs, accuracy to work with the community

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Summary

- **Trend analysis indicates decrease mean and minumum flows periods for. Maximum flows show no real change.**
- **no apparent trend observed in headwater basins that are unglaciated**
- **RHBN results show decreasing flows in the prairie and boreal plain for maximum annual flow.**
  - **Not much change in mean or minimum annual flow.**
- **GCM are global models and should be treated with rigour and care**
- **Downscaling is required for regional hydrological impact assessment (especially for precipitation)**
- **The feasibility of linking atmospheric and hydrological models has been demonstrated through calibration/validation processin GEWEX and other Adaptations and Impacts work.**
  - **Some success on modelling coupling has been achieved.**
  - **WATCLASS in now ready for further evaluation**
- **SAGE will be an important next step in model verification**
  - **CCAF should take advantage of 5 years of detailed work and model development**

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Quotes on Modelling and Risk

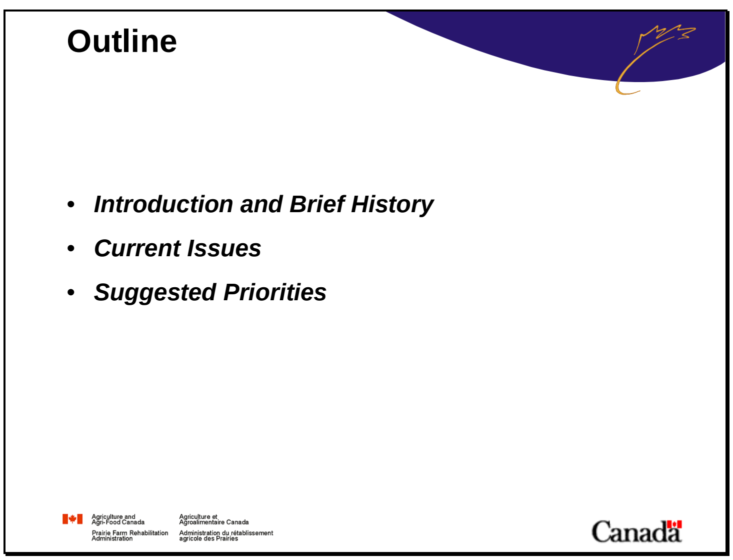
- Vit Klemeš cites a few personal experiences of the subjective nature and folly of putting too much trust in any particular risk assessment model
- **"Only kunks [known unknowns] justify analyses by rigorous mathematical methods**...," cautions Klemeš, "(being) precisely specified by known probability distributions, sampling rules, operating rules, etc."
- "Real- life uncertainties and risks clearly have the nature of **unkunks** (unknown unknowns), despite often being presented as something else."
  - And when that happens, says Klemeš, they are nothing more than **skunks**.

- **As Klemeš puts it:**
  - **Kunks** should be treated with rigour.(Hydrological and climate models)
  - **Unkunks** should be treated with care.(Climate predictions)
  - **Skunks** should be avoided.

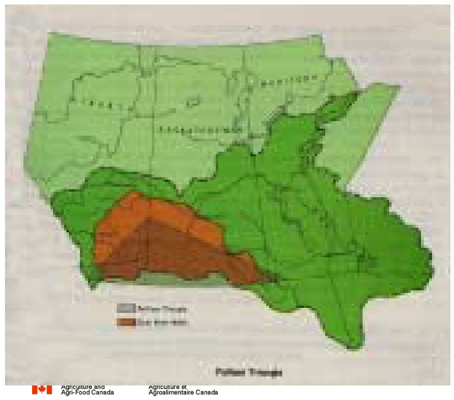
STAKEHOLDERS PANEL PRESENTATIONS

Climate Change and the South Saskatchewan River Basin
A AAFC / PFRA Perpsective

Brian Abrahamson
Agriculture and Agri-Food Canada –
Prairie Farm Rehabilitation Administration,
Regina



Area of activity focused on the Palliser Triangle in the southern Prairies.



The first office opens in Medicine Hat, Alberta, then moves to Swift Current, Saskatchewan.

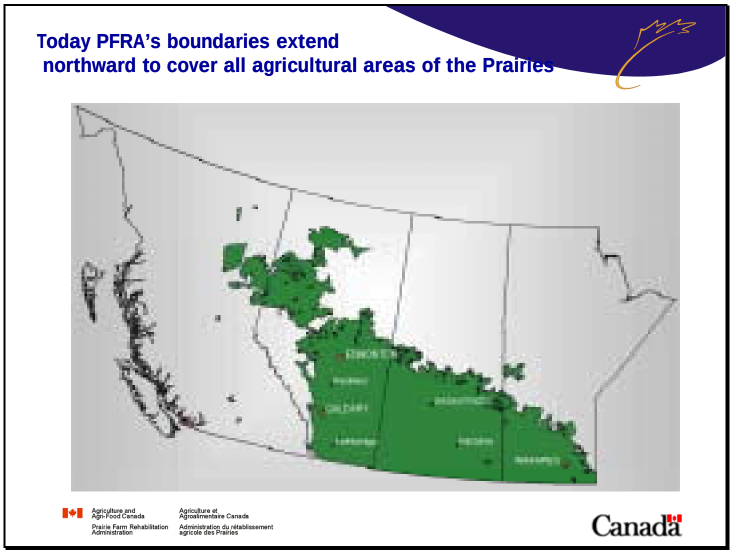
Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada
Prairie Farm Rehabilitation Administration | Administration du rétablissement agricole des Prairies

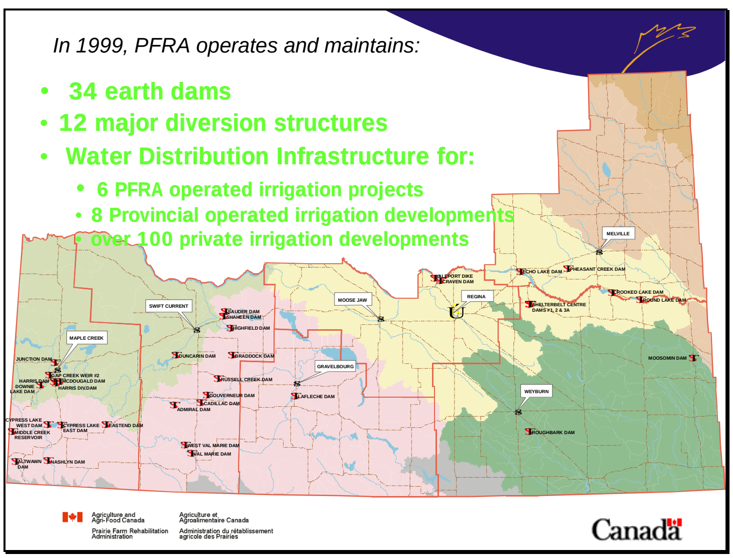
Canada

A Glimpse of the Past

Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada
Prairie Farm Rehabilitation Administration | Administration du rétablissement agricole des Prairies

Canada


Today PFRA's boundaries extend
northward to cover all agricultural areas of the Prairies
Agriculture and Agri-Food Canada
Prairie Farm Rehabilitation Administration
Agriculture et Agroalimentaire Canada
Administration du rétablissement agricole des Prairies
Canada


In 1999, PFRA operates and maintains:
• 34 earth dams
• 12 major diversion structures
• Water Distribution Infrastructure for:
• 6 PFRA operated irrigation projects
• 8 Provincial operated irrigation developments
• over 100 private irrigation developments
Agriculture and Agri-Food Canada
Prairie Farm Rehabilitation Administration
Agriculture et Agroalimentaire Canada
Administration du rétablissement agricole des Prairies
Canada

Rural Water Systems

Riparian Areas

Farm Water Quality

Agriculture and Agri-Food Canada — Agriculture et Agroalimentaire Canada
Prairie Farm Rehabilitation Administration — Administration du rétablissement agricole des Prairies

Canada

Irrigation R & D

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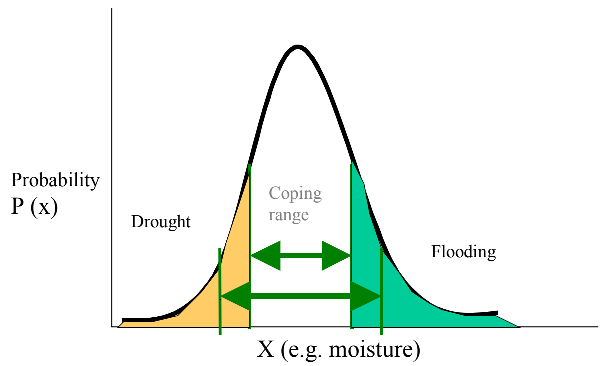
Canada

Adaptation to climate variability



Agriculture and Agri-Food Canada — Agriculture et Agroalimentaire Canada
Prairie Farm Rehabilitation Administration — Administration du rétablissement agricole des Prairies

Canada

So what do we need to consider?

- ***Start with some assumptions***
  1. **Climate Change is likely to be warmer**
  2. **Winter and Spring might be wetter**
- ***For the South Sask River Basin***
  - **Water demand will increase in proportion to supply**

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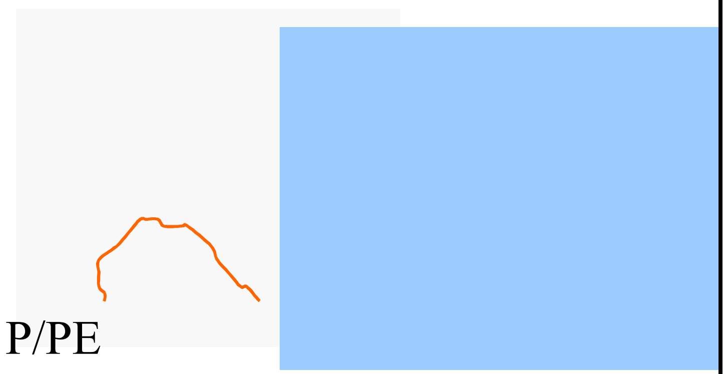
Canada

While precipitation (P) is expected to increase, the potential evapotranspiration (PE) will increase at an even faster rate. How do we manage?



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Canada

What should we be concerned about?

- *On-farm water supplies*
- *Community water supplies*
- *Major irrigation works*
- *Water Sources –Quantity and Variability*
  - Mountain/Glacier
  - Plains/aquifers
- *Floods and droughts*
- *Environment and socioeconomic linkages*

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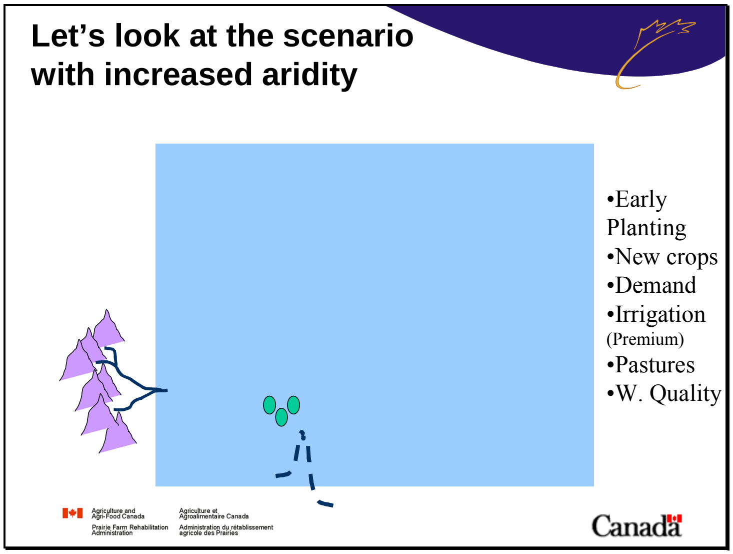
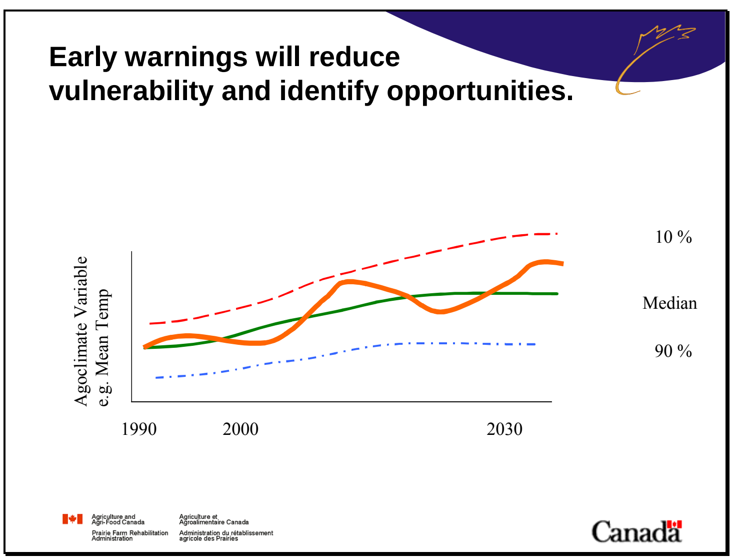
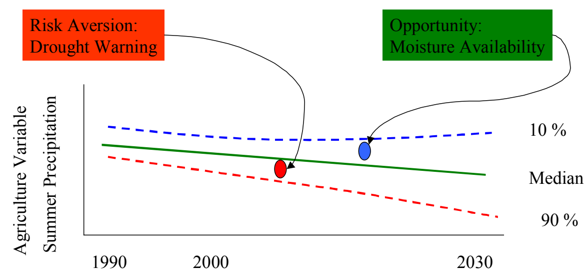

Let's look at the scenario with increased aridity
•Early Planting
•New crops
•Demand
•Irrigation
(Premium)
•Pastures
•W. Quality
Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada
Prairie Farm Rehabilitation Administration
Administration du rétablissement agricole des Prairies
Canada


Early warnings will reduce vulnerability and identify opportunities.
Agoclimate Variable
e.g. Mean Temp
1990
2000
2030
10 %
Median
90 %
Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada
Prairie Farm Rehabilitation Administration
Administration du rétablissement agricole des Prairies
Canada

What tools, policies, research, and infrastructure are needed to adapt to future climate regimes?



Get the fundamentals right and develop capacity to apply at sub-regional scale

- ***Improve estimates of P & T***
- ***Develop scenarios of annual and inter-annual variability***
- ***Develop methods for downscaling***
- ***Develop methodologies for converting precipitation into water availability***
  - **Mountain runoff scenarios**
  - **Plains runoff scenarios**

Improve our capacity to adapt to climate variability today.

- ***Adapting to today's variability is the first step in adaptation tomorrow***
  - **Stephen Wolfe et al working on sand dunes used 1988 as proxy for future state**
  - **Affordability**
- ***Water balance models***
- ***Long range forecasts***
  - **Increasingly important….global influences**
- ***Water demand***
  - **Will be opportunity driven**
  - **Demand management**
- ***Work together/communicate***

(Adapting today) **While preparing for the future!**

- ***"If you are going to give me a climate forecast for this summer tell me if it is going to be dry or wet; hot or cold, and I'll make the decision.***
- ***If you are talking about climate change I want to know that you will have the whole package ready for when the time comes: crop varieties, ……." A Saskatchewan Farmer***


Providing Knowledge to Manage Climate Risk
and Support Sustainable Practices
The End
Canada

Prairie Provinces Water Board Perspective

Jim Rogers
Secretary to the Prairie Provinces Water Board
Environment Canada
Regina

Environment Canada provides secretarial and technical support to interjurisdictional groups, such as the Prairie Provinces Water Board, the Mackenzie River Basin Board and the boards of the International Joint Commission. Climate change has the potential to change the relationships involved with these interjurisdictional groups by changing the supply and demand for water. The timing and regional patterns of precipitation will change, and more intense precipitation events are likely. As temperatures increase, potential evapotranspiration (ET), water evaporated from both the surfaces of open bodies and transpired from plants, will also increase. Consequently, even in areas with increased precipitation, higher ET rates may lead to reduced runoff, implying a possible reduction in renewable water supplies.

The Prairie Provinces Water Board (PPWB) administers the Master Agreement on Apportionment amongst Alberta, Saskatchewan, Manitoba and the federal government. The prairies are a semiarid area, which is particularly sensitive to climate variations, since relatively small changes in temperature and precipitation could result in large changes in runoff, increasing the likelihood and severity of droughts and/or floods. Seasonal problems could occur if snowmelt runoff occurs earlier, especially in the eastern slopes of the Rockies, causing lower late season and winter flows. Water quality problems may increase with lower flows to dilute contaminants. Changes in climate will also affect the demand for water as well as supply. Higher potential evapotranspiration rates will increase water use in irrigation districts and for industrial and thermo/hydro electric power uses.

The members of the PPWB will need estimates of the economic effects of climate change to plan their decisions. However, the economic effects must be based on the value given to water resources for each of the uses or demands and the costs of adaptation.

The International Joint Commission (IJC), formed by the Canada-United States Boundary Waters Treaty of 1909, is composed of equal numbers appointed by each federal government. The IJC forms committees or boards to help monitor conditions and provide technical evaluations along the boundary. The Red River Basin Board, for example, is monitoring a project proposal that would drain the saline Devils Lake into the Red River, a study to improve water supplies in the Red River, including importing water from another basin, and a proposal to apportion water in the basin. The chosen future is very important to each of these. For Devils Lake, the U.S. agency has used a “wet scenario’ under the assumption that the climate is changing and the recent wet period that has caused the lake to swell is now the norm. Whether this scenario is realistic is difficult to explain, and more information is needed on the probable and possible futures. Since each project will undergo a benefit-cost analysis, the values of the water uses today and in the future must be estimated. The question of whether the changes in climate will change the values given to water resources and the environment dependent upon the water should be answered.

Climate change will also affect the role of the IJC, since demands, supplies and quality of water will change as the climate changes.

Generally, although considerable research examines the potential impact of climate change on water resource systems, relatively little work has reviewed water planning principles as part of an adaptation program. A range of water planning issues should be examined in the context of climate change, including inter-temporal equity and discounting; incongruity between the geographic scales used by water planners and climate modelers; stochastic hydrology; ecosystem impacts; non-market valuation; adaptation; engineering design; sea level rise; reservoir storage allocation; and risk analysis.

Saskatchewan Water Corporation Perspective

Alex Banga
Saskatchewan Water Corporation
Moose Jaw

Editors' Note:

At the time of publication of this report, no written version of the presentation was provided.

Climate Change Impacts to Hydroelectric Power Generation in Saskatchewan

Mark Peters
Saskatchewan Power Corporation
Regina

For Saskatchewan Power Corporation (SaskPower) the question of climate change and what it might do to flows on the South Saskatchewan River has become just one part of a recent review of the assumptions we use when predicting the amount of electricity we produce from our hydroelectric generating plants.

This has all come about in the last little while as a result of a number of factors including such things as:

- Increased competitiveness in electricity markets;
- Record low flows on the Saskatchewan River system this past year;
- The spike in the cost of natural gas last year that lead to significant increases to our overall cost of generation for the year.

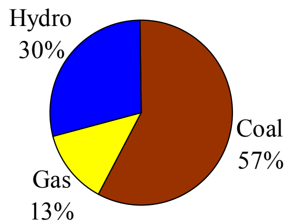
All of these things have resulted in SaskPower reassessing the value of our hydropower resources and how we predict the amount of energy that we can generate from them.

I have four slides that I want to share with you which:

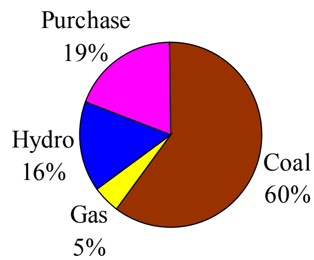
- Provide a bit of background on SaskPower's overall generating capabilities;
- Where our hydroelectric generating capabilities fit in;
- Highlight some of the questions and concerns that SaskPower has with respect to this issue of climate change and how it might affect our hydroelectric generating capabilities.

Power Generation in Saskatchewan

- SaskPower is the principal supplier of electricity in the province
- 2000 Generation Asset Base:
  - Coal 1658 MW
  - Gas 378 MW
  - Hydro 853 MW
  - TOTAL 2889 MW



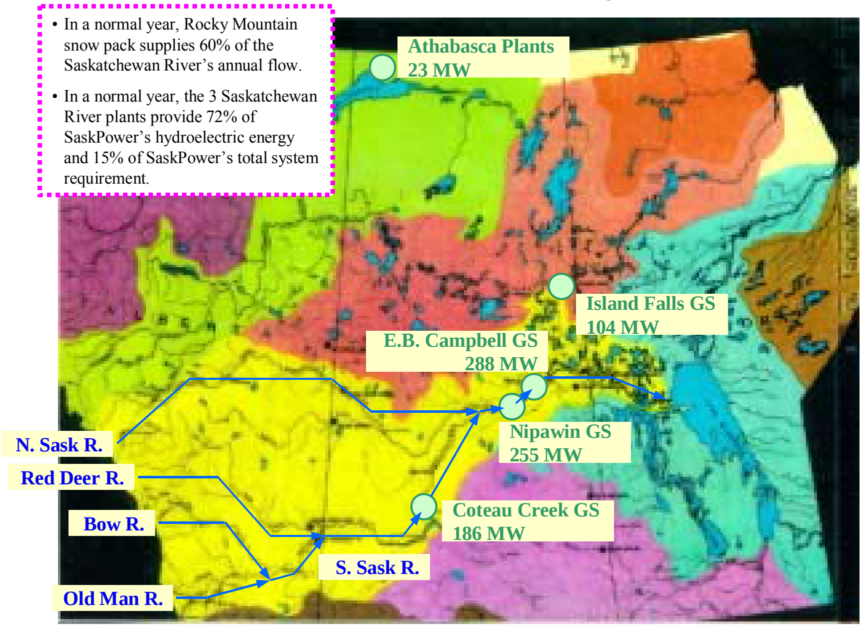
- Energy Supply in 2000:
  - Coal 11400 GWh
  - Gas 900 GWh
  - Hydro 3000 GWh
  - Purchase 3700 GWh
  - TOTAL 19000 GWh



2

Prairie Watershed and SaskPower's Hydroelectric Plants

- In a normal year, Rocky Mountain snow pack supplies 60% of the Saskatchewan River's annual flow.
- In a normal year, the 3 Saskatchewan River plants provide 72% of SaskPower's hydroelectric energy and 15% of SaskPower's total system requirement.



3

Predicting Hydroelectric Energy Production

- Traditional Approach:
  - Historical flows adjusted for upstream use
- Is this the correct approach?
  - Is the past 100 years representative of the future?
  - Will climate change result in more or less precipitation?
  - Will the range of variability of inflows increase or decrease with climate change?
  - Will there be changes to water consumption patterns causing river flow patterns to change?
  - What impact will increased use of water in Alberta have on inflows to Saskatchewan?

4

Impacts to Hydroelectric Power Generation

- Quantity of energy from our existing plants
  - Supply planning
  - Fuel and purchased power budgeting
- Future hydro projects
  - Will they be viable?

"How Will Flows on the Saskatchewan River System Change as a Result of Climate Change"

5

PRESENTATIONS BY PROJECT PROPONENTS

Groundwater Issues in the South Saskatchewan Basin

Stephen E. Grasby
Zhuoheng Chen
Geological Survey of Canada (Calgary)
3303 33rd St. NW
Calgary AB, T2L 2A7
sgrasby@nrcan.gc.ca

Agriculture is by far the largest water user in the South Saskatchewan River Basin. Taking the most heavily populated Bow River Basin as an example, municipal water use accounts for 11% of withdrawals from surface water, whereas irrigation accounts for 85.4%. In addition, municipal users return 94% of the water to the river systems, whereas irrigation users return only 19%. These statistics clearly demonstrate that water resources issues in the South Saskatchewan are largely issues of water supply for the agricultural industry. The surface water allocation in the South Saskatchewan River Basin has now reached near capacity for normal flow years. The recent drought has seen license holders withdrawing much less than typical amounts. In response to the dry conditions and lack of irrigation water the Province of Alberta declared a 'drought disaster' in the spring of 2001. As part of the mitigative measures proposed, the Province offered incentives to farmers and ranchers to drill groundwater wells to supplement surface water supplies.

It is commonly thought that groundwater forms an alternative and untapped water supply. However, in recent years there has been increased awareness of groundwater/surface water interaction. For example, work by Grasby et al. (2000) demonstrates that the Bow River is dominantly fed by groundwater. This implies that increased groundwater production in the basin may simply intercept water prior to entering the river system (i.e., it might be best to consider groundwater as part of the total surface water supply). A telling feature is the winter flow stoppages of the Upper Banff Hot Springs over the last four years, and the flow stoppage of the Kidney Hot Spring in February 2002. This indicates that the deepest groundwater flow systems show near immediate responses to drought. However at this stage little is known about how the shallow groundwater system that feeds the river is responding.

Recent modeling by Chen et al. (in prep.) suggests that groundwater levels in the Prairies are highly susceptible to changes in key climate variables. Under normal conditions precipitation is the dominant controlling factor, however after crossing a critical temperature threshold, temperature becomes the dominant factor controlling groundwater levels. This implies that with predicted global warming, higher temperatures alone will lead to declining water tables.

In summary, in order to meet the Provincial targets of developing groundwater as an alternative water supply for much of the South Saskatchewan Basin, 3 critical factors need to be addressed:

1. What is the quality, quantity, and distribution of major aquifers in the Basin?

2. How do these aquifers respond to changing climate patterns historically, and how are they likely to respond to climate change predictions?

3. What are the hydrodynamics of the aquifers and how are they related to surface water discharge?

Summary of Project Proposal Presentations

Alain Pietroniro
National Water Research Institute
11 Innovation Blvd.
Saskatoon, SK, S7N 3H5

Dr. Alain Pietroniro presented a summary of 3 related projects on prairie hydrology (Pietroniro, Granger, Elliot) and on project in which he is co-investigator with Michael Demuth examining Glaciers and their potential impacts on the water resources sector. The talked focused on the fact that some of the largest potential changes in surface water quantity under the currently predicted climate scenarios are in the Canadian prairies. It is well know that two main ecozones outline the hydrology of the prairies and in particular the South Saskatchewan River Basin. It is well understood that the main driving force for in-stream flow within the major tributaries of the South Saskatchewan river is the flow from the mountains, through both snow ablation throughout a large part of the spring and summer, as well as through glacier melt. Another important aspect of hydrology in the South Saskatchewan basin is the landscape and understanding of prairie hydrology. Given the large spatial variability of the landscape types with a large basin such as the south Saskatchewan, Dr. Pietroniro presented a impacts/adaptation modeling framework that relies on distributed hydrological modeling in order to assess, influence and understand adaptation strategies. This schematic is shown in Figure 1.

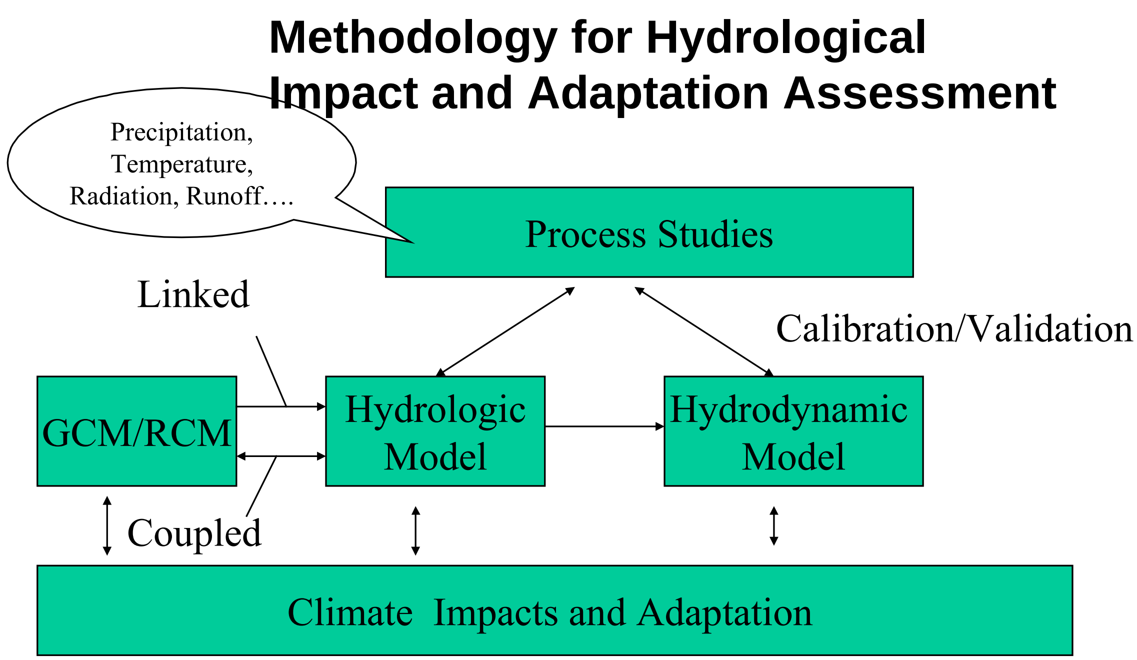


Figure 1 - Methodology for Hydrological Impact and Adaptation Assessment

It was noted that adapting to potential climate change requires sophisticated understanding of the hydrological cycle within the prairie and mountain eco-zone in tandem with understanding the influence that human intervention on the landscape has made to the hydrological regime. Hydrological modeling in the Canadian Prairie environment is notoriously difficult because of poorly-defined drainage basins, low slopes, intermittent streamflow, land use changes and often dramatic seasonal and interannual variations in precipitation and temperature. Prairie hydrology is also distinctive because of the cold and dry continental climate. Roughly one-third of annual precipitation arrives as snowfall yet roughly 80-90% of annual runoff occurs during the snowmelt season. Climate change may impact the timing and amount of precipitation on the prairies, resulting in a modified hydrological response. Vertical and lateral transfers of water that are important in the Prairie environment are not normally included in hydrological models. These include dealing with seasonally-frozen soils, Prairie potholes, wind redistribution of snowfall, river ice, snowmelt, evaporation from cold soils, and aspects of soil moisture retention in agricultural soils. Prairie streams tend to be "event-driven" hydrologic systems; although some are spring-fed or groundwater-fed, the majority of their flow results from storm runoff and/or snow melt runoff. They are therefore extremely sensitive to changes in the precipitation regime. Prairie streams and rivers, and those who depend on these for water supply (communities, agricultural operations and wildlife), will certainly be affected by any change, whether it result in an increase or a decrease in the precipitation regime. Although the climate change scenarios provided by the current generation of GCM's predict with some confidence the warming resulting from increased GHG, the effect on the precipitation regime is much less certain. Indeed, the direction of the mean change in the precipitation regime cannot yet be ascertained; what can be stated with a greater degree of certainty is that the regime will likely be a more variable one.

As well, the impacts on Prairie streams from changing precipitation regime will be very different if the major changes occur in the winter precipitation regime or in the summer rainfall. A "low-snow" year may have a greater impact on the stream flow than a "low-rain" year. A situation where variability is increased, with greater risk of extreme storm or drought events will also increase the risk associated with managing a "steady" water resource. The management challenges and opportunities will be very different depending on the nature of the precipitation regime change encountered.

The planning of adaptive measures therefore requires knowledge of the nature and timing of the impacts that would result from changes to the climate system. Prairie streams and rivers are also characterized by the fact that they have highly variable contributing areas; this, along with the redistribution of the snow cover and the presence of seasonally frozen soil, tends to complicate the prediction of stream flow in Prairie streams and rivers. Current large-scale river forecast systems do not handle these situations very well. Hence, it was noted that distributed models that complement the land-surface based work proposed by the Granger LOI is critical to an overall adaptation strategy.

It was noted through the discussion that prairie farmers would adapt to climate change as it starts to affect agricultural productivity. In the most likely scenario of drier conditions, farmers will adopt management strategies that will maximize water stored in the soil profile. Strategies that could be used include zero and conservation tillage, snow management, crop rotation and summer-fallow. It was pointed out that the Elliott LOI indicates that many of these adaptations will influence hydrology and hence surface water resources. In order to anticipate these indirect effects of climate change and avoid unpleasant surprises we must develop an understanding of the nature and magnitude of the impacts of agricultural practices on prairie hydrology. With this information water managers will be able to assess the vulnerability of water resources (wetlands, farm dugouts, reservoirs, creeks, rivers and lakes) to changes in agricultural management. Clearly a distributed hydrological modeling approach where both the mountain and prairie ecozones could be incorporated and where management and landscape understanding is incorporated is an important initiative. An example of the WATFLOOD distributed hydrological model, ant the ability to examine fundamental hydrological properties within a basin was demonstrated.

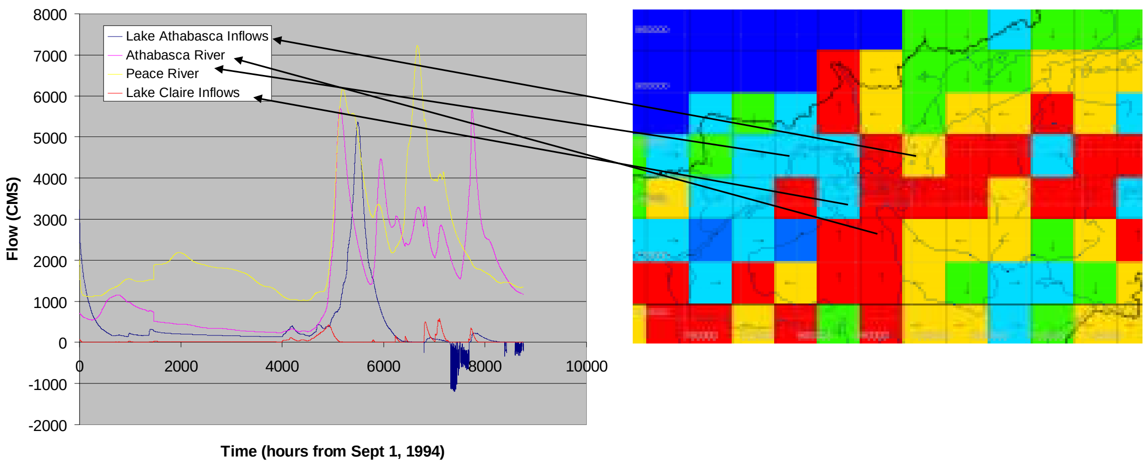


Figure 2 - Example of the WATFLOOD distributed approach. Variables such as grid runoff (shown) or soil moisture, snow-cover as examples can all be extracted for individual computational cells within the model

This presentation also included reference to the mountain ecosystem by highlighting results from a recently funded PARC initiative. The analysis for the PARC study focused on the North Saskatchewan River because of the relatively long-term database at Peyto glacier. Time series information is from the headwater streamflow gauging stations in the North Saskatchewan basin. These were derived from existing water survey of Canada records (Environment Canada, 2000). Of importance to this study were minimum flows, maximum flows and mean flows estimated on an annual and transition to base-flow period (TBF). The TBF refers to the period of maximum glacier input to streamflow and for the purposes of this study represents the average streamflow for the period August 1 to October 31 for each year. The time-series data are listed in the following table. The PARC study indicated that there was an approximate 90% decrease in minimum and 40%

decrease in mean streamflow for the transition to base-flow period (TBF-August – November) based on a 50 year trend analysis (see Figure 3). The percentage change is based on the slope of the regression line over the 50 years normalized by the 1950-50 flows. The proposed work builds upon results of Phase 1 of this project, supported in part by the Prairie Adaptation Research Collaborative (PARC), and assesses the vulnerability of prairie surface waters from both a supply and demand perspective.

.

Table 1 - Streamflow Station used in Statistical Analysis and WATFLOOD Modeling

BASIN/STATION NAME	**ID**	**AREA**	**Latitude**	**Longitude**	**Period of Record**	**% glaciated ***
North Ram River at Forestry Road	05DC011	342590529	52° 16' 55"	-115° 59' 30"	1975-1998	0.00
North Saskatchewan River at Saskatchewan Cross	05DA006	1273921710	51° 58' 00"	-116° 43' 30"	1951-1970	15.64
North Saskatchewan River at Whirlpool Point	05DA009	378760284	52° 00' 06"	-116° 28' 10"	1970-1998	2.09
Siffleur River Near the Mouth	05DA002	521076813	52° 02' 39"	-116° 23' 02"	1975-1996	2.15
Mistaya River Near Saskatchewan Crossing	05DA007	216746720	51° 53' 04"	-116° 41' 17"	1950-1998	7.21

*The % of the basin that is glaciated is based on supervised classification of 1998 Landsat TM imagery

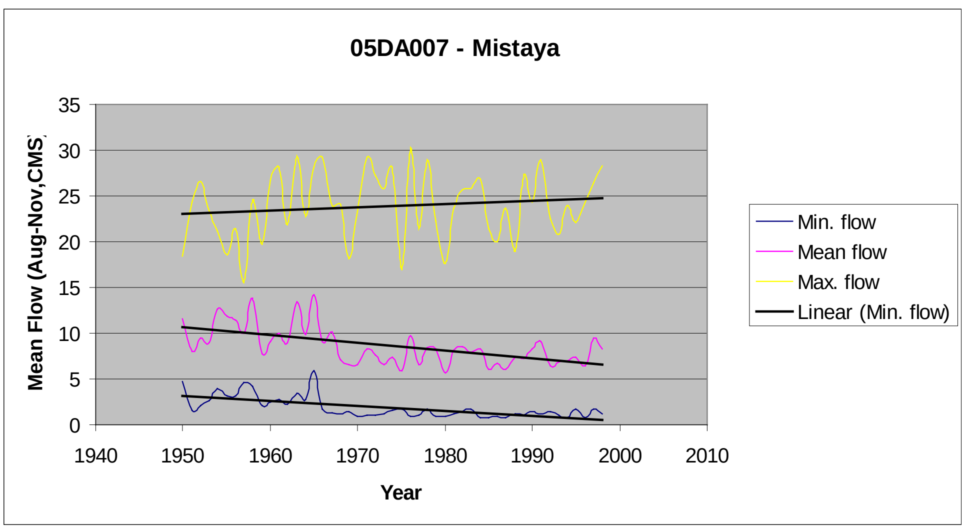


Figure 3 - Regression Analysis for TBF flow period showing trends in minimum, mean and maximum flows for Mistaya Basin

Results from the various statistical test for trend and shifts in streamflow were highlighted and are summarized in Figure 4 below for the minimum flow analysis.

As part of the PARC study, an attribution study was also proposed and initiated. Because attribution of changing streamflow is such a difficult problem, it was proposed that the WATFLOOD model be applied to the basins (see Figure 5). Preliminary results show reasonable agreement for the recession TBF hydrographs, however, there is still need for model calibration and further testing. It has been proposed that the WATFLOOD analysis be extended to include the South Saskatchewan river basin as well as the North, allowing for more calibration opportunities and a more integrated approach. It was proposed the a similar analysis that was performed for PARC be established for the South Saskatchewan basin. The objectives of such as study would be to:

1. Assess water resource and hydrologic regime shifts associated with past and projected future snow and ice regimes for a south to north transect of drainage basins along the eastern slopes of the Rocky Mountains.

2. Establish critical flow thresholds based on summary data of present and projected surface water demands for multiple sectors (energy, agriculture, communities, etc.) across the prairies in the downstream reaches of the mountain drainages.

3. Assess the present storage capacity and water management strategies to respond to seasonal and pluriannual shifts in snow/ice water resource availability and potential demand scenarios.

The same approach to hydrological modeling would be expanded and included in the proposed glacier study. This would form an integral sub-study of the entire modeling approach described earlier.

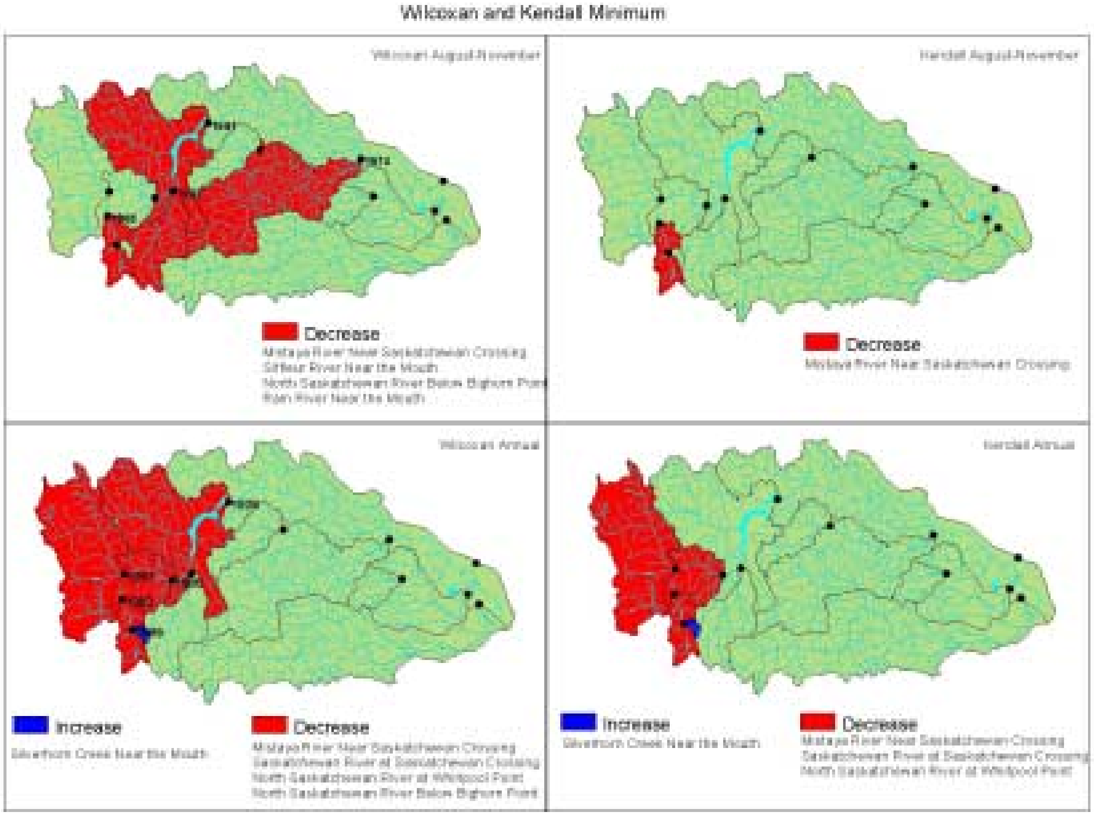


Figure 4 – Minimum Flow Results of the Wilcoxan and Kendall trend analysis. Note the dates indicated in the wilcoxen analysis are those identified by the Bayesian analysis as most probable dates for a shift in the time series

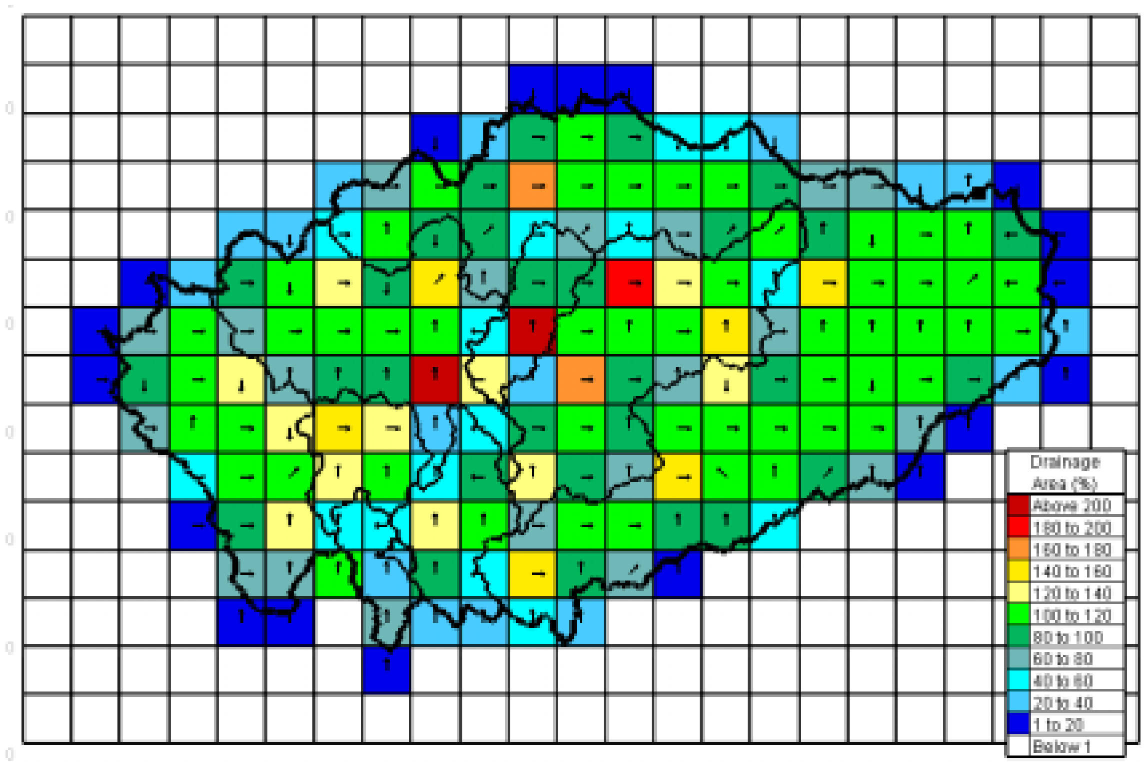


Figure 5 - The WATFLOOD modeling domain for the North Saskatchewan River Basin. Arrows indicate flow direction for each computational grid in WATFLOOD.

Climate Impacts on Water Resources of the Western Cordillera

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Introduction

Climate change is projected to have significant impacts on the future water resources of Canada. A particularly critical region involves the leeward slopes of the western cordillera where changes to the amount of snow and ice resources could have adverse effects not only for the cordillera region itself, but also for the downstream locations that rely heavily upon these resources. For example, the Peace-Athabasca Delta (PAD) relies heavily upon upstream water resources for the beneficial flooding of riparian ecosystems. In certain years, however, large snowpack conditions can result in flood hazards to several communities. In the context of this workshop, activities in the South Saskatchewan River basin including for example, irrigation, agriculture, municipal water supply and quality, and recreation also rely on the amount and timing of water supplies from headwaters of the cordillera. To determine impact and adaptation strategies for these downstream regions, reliable estimates of future changes and variability in the cordillera's water supplies are required. At this time, however, there is limited knowledge regarding the impacts of future changes to temperature and precipitation on the magnitude and timing of water resources from the leeward slope region of the western cordillera. This study addresses these knowledge gaps.

Objectives:

The main objectives of the proposed research are as follows:

1. To quantify the projected impact of climate change on the snow-water resources of, and snowmelt river runoff from, the leeward slope regions of the western cordillera.

2. To determine the potential impacts of the altered flow regimes on the hydro-

electric industry and agricultural/irrigation sector that rely on spring runoff from the leeward slopes of the western cordillera.

Within these main objectives, there are several sub-objectives including:

a) The assessment of several Global Climate Models (GCMs) in their ability to replicate current climate over the leeward slope region of the western Cordillera of Canada. From this assessment, the best GCM(s) or ensemble of GCMs will be selected and used in the next objective.

b) To incorporate daily 2x CO_2 GCM output (based on the assessment in the previous objective) to produce a suite of future snowpack scenarios using previously tested snowpack models.

c) To couple the predicted changes to snow conditions with hydrologic models to predict climate-induced changes to runoff regimes in key nodes of the leeward slopes of the western Cordillera.

d) Via interaction with various stakeholders, to determine the implications of altered spring flow regimes on activities such as hydro-electricity production, downstream water supplies, agriculture, extreme events, domestic (trans-provincial) water agreements and regulations, etc.

Methodology:

The simulated current (1961-90) monthly temperature and precipitation output from seven different GCMs (recommended by the IPCC for scenario impact studies) will be compared to various observed climate data sets (gridded data, observed station data, previously developed snow and ice data set) over the leeward slopes of the western cordillera. Based on the assessment, it will be determined which GCM or ensemble of GCMs best represents the current climate over the region. A series of predicted (e.g. 2x CO_2) changes from the selected GCM(s) will then be applied to observed climate over the study area to produce multiple scenarios of future temperature and precipitation values at the **daily** scale. Note that most previous impact scenarios have relied only on monthly data but this is not a suitable time step for assessing intra-seasonal changes in snow runoff regimes. A methodology to apply daily GCM output to observed climate has already been developed at NWRI. These future daily temperature and precipitation scenarios will subsequently be used in a snowpack model (e.g. SNOWTHERM) to determine a range of possible future snowpack conditions over the study area (i.e. amount, density structure, timing of spring melt). These factors are critical for spring runoff and thus, hydrological conditions downstream. At this point, a thorough review of usable alpine region hydrologic runoff models (that incorporate daily temperature and precipitation data) will be conducted and the best model or models chosen. Key nodes

representing different hydro-climatic regimes will then be selected (e.g.

headwaters of the Liard, Peace, and South Saskatchewan rivers) and the chosen hydrologic model(s) used to construct scenarios of future runoff regimes over the various regions. A review of climate change impact case studies over the study area, as well as, similar regions around the world will be carried out and with the results from this investigation, the most likely scenarios of future runoff characteristics (amount, timing of spring freshet) will be determined. As this work continues, the results will be discussed with various stakeholders to determine implications for future economic and environmental activities including hydro-electric power generation, agricultural demand, extreme events, and trans-boundary (provincial and international) water agreements. In addition to reports on each sub-objective, a final summary report describing all findings and recommendations will be produced.

Conclusions:

This study will directly address the vulnerability of the primary source of flow from the western cordillera to climate change. Snowmelt from this alpine area is the dominant source of water feeding the hydroelectric and agricultural systems operating in the prairie portions of Alberta and Saskatchewan. Consultations with stakeholders regarding the nature of the projected hydrologic changes assessments will also be made: a) to identify the sensitivity of the current organizational (including trans-boundary water agreements) and physical structures to such change, b) to quantify critical thresholds in seasonal availability of water, and c) to determine potential adaptation strategies or barriers in the water-use systems.

Climate Change and Water Resources in the South Saskatchewan River Basin

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PFRA Contribution

PFRA has identified stream flow and surface water supply conditions for agriculture as an issue related to water resources and climate change in the South Saskatchewan River Basin. PFRA can offer a broad range of technical and analytical expertise to this issue.

- Engineering related services: geology and hydrogeology, geotechnical engineering, design engineering and hydrology.

- Resource specialists: geographic information systems, water quality, agronomy, ecology, conservation biology, climatology, range management, agricultural economics.

PFRA is responsible for the environmental stewardship of agricultural soil and water resources:

- PFRA responds to the translation of land and water resource information into knowledge which supports decision making.

- PFRA disseminates technical knowledge, including best management practices related to land and water.

- PFRA partners with other federal departments and agencies, provincial and municipal governments, industry and organizations to maximize success.

Major activities of PFRA include:

- Water supply
- Water quality
- Land stewardship
- Resource analysis and planning
- Research and development
- Program delivery

Indications are that climate change will continue to pressure land and water resources. PFRA has conducted research on land resources and can offer a broad range of technical and analytical expertise to water resources examination.

Glacier and Snowpack Response to Climate Change in the Canadian Rockies: Impacts for Southern Alberta Water Resources

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Editors' Note:
At the time of publication of this report, no written version of the presentation made at the Workshop was provided.

Development of an Expert System for Supporting Climate-Change Impact and Adaptation Studies Within the Prairie's Water Resources System

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Abstract:

Due to the severe sensitivities to climate change, the impact analysis and adaptation planning will be crucial in the effort to improve the economic and environmental efficiencies, and the design and management of water resources system in the Prairie's provinces should consider the possible effects of climate change. An expert system is therefore developed with the state-of-the-art modeling tools, which integrates vast amounts of expertise from various stakeholders in the field of water resources management into the decision support system, for improving decision efficiencies of climate change impacts analysis and adaptation strategies within the Prairie's water resources system.

Introduction:

The water resources system is a critical component in natural ecosystems, and it is also very crucial to the societal and economic development. However, this system is very vulnerable to the changing climate, for example, many research results indicate that even small changes in temperature and precipitation patterns can result in significant changes in the amount and timing of spring runoff, the intensity of floods and droughts, and the rate of evaporation from soils and surface waters (Conway et al., 1996; Cohen, 1997; Herrington et al., 1997; Huang et al., 1998; Environment Canada, 2002). In addition, previous studies also reveals that climate change will have a major impact on regional sustainable development (Cruise et al., 1999; Mimikou et al., 2000), and it may pose serious challenges to the water resources system in the Canadian Prairie's provinces (McCarthy et al., 2001; Natural Resources Canada, 2002).

Under changing climate conditions, not only water supply and demand, but also water quality and water infrastructures can be affected. Streams that originate within the Prairies display extreme yearly variability and the majority of annual runoff may occur during a very short period. In addition, the hotter and longer summers can result in increased evaporation and therefore less surface water can be available for use, on the other hand, the mountain glaciers which are major sources of water in the Prairies, may also be melted due to increased temperature and thus result in reduced river flow, as a result, the supply of water is very sensitive to changes in climate (Herrington et al., 1997; Huang et al., 1998; Middelkoop et al., 2001). One serious threat of climate change in the Prairies may then be drought, which can result in lower surface water levels and flows and increase in the demand for groundwater, therefore more challenges will be associated with managing competing demands for a limited water resources due to the impacts of climate change (Wood et al., 1997; Natural Resources Canada, 2002). Climate changes also have the potential to affect water quality significantly by changing temperatures, flows, runoff rates and timing, and the ability of watersheds to assimilate wastes and pollutants (Cruise et al., 1999; Murdoch et al., 2000). The increases in air temperature and the associated increases in water temperature, are likely to lead to adverse changes in water quality, even in the absence of changes in precipitation, which may then increase the level of water treatment required. Changes in climate can also affect the water infrastructures, for instance, variability in climate may affect the reliability of water yields from reservoirs and also result in fluctuations in hydroelectric generation. The reduced overall water availability due to climate changes will reduce the productivity of Prairies' hydroelectric facilities, on the other hand, increases in average flows would increase hydropower production. As a result, the changes in the timing of hydroelectric generation can affect the value of the energy produced (Herrington et al., 1997; Filion, 2000).

Due to the severe sensitivities to climate change, the impact analysis and adaptation planning will be crucial in the effort to improve the economic and environmental efficiencies (Kenneth and David, 1996; Major and Frederick, 1997; Yin et al., 2000), and the design and management of water resources system in the Prairie's provinces should consider the possible effects of climate change, however, little professional guidance is available in this area so far (Hobbs et al., 1997). Few studies have been undertaken regarding how to integrate climate change into regional or local water resources planning process, how water resources system managers view climate change impacts, and how to best bring water resources planners, designers, and system managers into the discussion about future climate changes (Xu, 1999). Therefore, more researches are desired to fill this gap. In fact, adaptation to the climate-change impacts is a sensitive and complex issue since it is associated with many complicated processes and related to many different stakeholders with tremendous conflicts (Huang et al., 1998; Yin et al., 2000). For example, changes in precipitation can lead to both positive and negative impacts on water quality in the system, and the net effects on water quality for rivers, lakes, and groundwater in the future may depend not just on how climate might change but also on a wide range of other human activities. Due to these sensitivities and complexities, it is often hard to solely use quantitative mathematical models to study and plan such systems. Therefore, application of expert system (ES) technology will be more realistic for more effectively linking the quantitative components to the other qualitative, and possibly more important ones. The expert system has been successfully applied in decision-making process in many fields (Chan, 1995, 2001; Alkoc and Erbatur, 1998; Flores, 2000; Fedra and Winkelbauer, 2002), but few applications have been found in climate change impact and adaptation studies. In fact, many stakeholders related to the Prairie's water resources sector have accumulated vast amounts of knowledge on the vulnerability of different processes to climate change, the intricate relationships among the criteria for impact assessment, the various indicators of the related performances under changing climate, and the corresponding adaptation strategies. For instance, a wide range of adaptation measures have been developed and applied in the water resources sector over decades, and these may include increasing capacity (e.g., building reservoirs), changing operating rules for existing structures and systems, managing demands, and changing institutional practices (Kenneth and David, 1996; McCarthy et al., 2001). However, no efforts have been given to the integration of these vast amounts of knowledge within an integrated expert system for providing decision support. This research is proposed to fill this gap through the development of an ES with the state-of-the-art modeling tools, for improving decision efficiencies of climate change impacts analysis and adaptation strategies within the Prairie's water resources system.

Objectives:

The major objectives of this research are (1) to develop an expert system for integrated climate-change impact assessment within the prairie's water resources system, and (2) to provide decision support for improving the effectiveness in adapting water resources management system in the Prairie's provinces to climate change through application of the developed ES. Interactions among climate change, natural condition variations, human activities, water resource utilization and management, environmental concerns, and economic objectives, as well as the related policy implications will be comprehensively incorporated within the ES. The ES development will involve innovative and state-of-the-art AI techniques and will fill in the gap in the field of ES application to climate-change impact studies.

Methodology

(1) Studies on Processes and Factors Vulnerable to Climate Change

In order to make appropriate decisions about how to plan, manage, and operate the complex water resources systems in the Prairies under changing climate conditions, the reliable and efficient climate change impacts analysis and adaptation studies should be conducted (Major and Frederick, 1997). Based on the studies, decisions about future water planning and management can then be flexible, and the risks and benefits of climate change may then be incorporated into all long-term water resources system planning.

This study focuses on systematic compilation of the related information for facilitating integrated impact assessment and supporting adaptation planning. In detail, this task involves: (a) identify issues related to the socio-economic-environmental impacts of climate change on water resource system in the prairie provinces; (b) assess various methods and techniques for analyzing short and long term impacts of climate change; (c) identify possible adaptive responses to climate change; and (d) identify knowledge gaps, research needs and data requirements that will be necessary to fully evaluate adaptation options in the prairie's water resource system.

(2) Expert System Development

The expert system is an artificial intelligence system that can apply reasoning capabilities to reach a conclusion (Fayek and Sun, 2001). It has many advantages in help decision-making (Shepherd and Ortolano, 1996; Leon, 2000), including (a) handle massive amounts of information, (b) draw conclusions from complex relationships, (c) provide consistency in decision making, (d) provide new information, (e) capture expertise from scientists, engineers, planners, and stakeholders in the field of water resources utilization and management practices and apply it to problem solving, (f) realize the conceptualization and quantification of expert experience, (g) avoid subjective decision or reduce risk of decision due to absence of experts and incompleteness of individual expert experience, and (h) link the impact-assessment and adaptation-strategy-analysis results to practical decisions.

The components of the expert system is shown in Figure 1. In this system, the knowledge base stores all relevant information, data, cases, and relationships used by the expert system; the inference engine seeks information and relationships from the knowledge base and provides answers, predictions, and suggestions in the way human experts would; the knowledge acquisition facility provides a convenient and efficient means of capturing and storing all components of the knowledge base; the explanation module stores the "why?" information, and the user interface can be used to run a consultation.

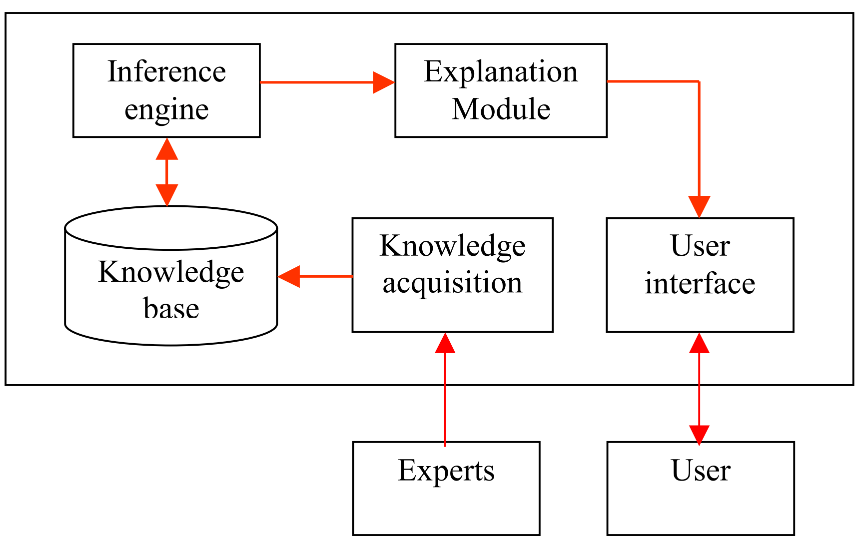

Figure 1 Components of expert system

In this research, the development of the ES will be based on extensive information survey and field investigation, and is intended for effectively linking the impact-assessment and adaptation-strategy-analysis results to practical decisions. The vast amounts of experiences from various stakeholders will be represented in the expert system, which can support assessment of the climate-change impacts and interpretation of the adaptation planning results. Specially, the expert system can investigate the key variables in a given scenario and provide more insights into the specific implications of a generalized solution. In tackling the adaptation plans, the developed expert system can complement a number of modeling programs. The results can be used for testing alternatives by simulating system responses to various input conditions and for providing inputs for further decision analyses. The expertise can be acquired using some state-of-the-art AI techniques, including Data Mining (DM), Knowledge Engineering (KM) and Object-Oriented Modeling (OOM), which will support generation of desired alternatives for adaptation actions.

(3) Field Investigation

Involvement of industrial and governmental personnel is important for not only providing necessary information for ES development through a variety of methods such as interviewing, workshop, or questionnaires but also for validating the ES inputs/outputs and generating desired decision support. Both investigation and education programs will be initiated for facilitating this involvement. Information from different industrial and governmental groups will be collected, through methods of questionnaire survey, roundtable meetings, and consultation workshops. The obtained comments will provide important sources for research inputs and facilitate related interpretations and recommendations.

(4) Application

As the ES will be developed with a user-friendly interface, results of its application will be presented graphically. This will enable decision-makers to conveniently use the developed system to examine various policies related to climate-change adaptation within the Prairie's water resources system. Through application of the developed ES, many questions, such as "how vulnerable is society to future climate-induced variations in water resources?", "what are the impacts of changing climatic condition on water resources planning and management practices in the Prairie's provinces?", "what is the potential for our water supply systems to adapt to future climate extremes?", "how will the Prairie's provinces modify their water resources management strategies to adapt to the climate change?", and "what adaptation policies should be formulated to avoid or reduce negative impacts on environmental and socio-economic subsystems?", can then be answered. In detail, effectiveness of the existing developmental plans for the Prairies will be justified or potentially modified. The potential modifications could involve not only formulation, variation, or supplementation of related policies, but also generation of more effective strategies. Where policies for significant concerns identified through this study are unavailable, establishment of them would be emphasized. For this, recommendations and technical bases could be provided based on ES application, output interpretation, decision analysis, and stakeholder involvement.

Expected results

The major expected results from this research will include (a) integrated climate change impact assessment for Prairie's water resources system; (b) investigation of stakeholders' perception on climate change impacts; (c) developed expert system software, and (d) reports for applications of the developed expert system software.

Conclusions

There are no previous efforts that have been made to integrate the vast amounts of knowledge from various stakeholders in the field of water resources management into an integrated expert system for providing efficient decision support in the context of climate change impacts and adaptation studies. This research aims to fill this gap through the development of an ES with the state-of-the-art modeling tools, for improving decision efficiencies of climate change impacts analysis and adaptation strategies within the Prairie's water resources system. The perceptions of climate-change impacts on water resources system from local stakeholders and expertises are crucial for adaptation decision support, therefore the state-of-the-art AI techniques will be employed for ES development with improved knowledge engineering efficiency, and the developed ES system can provide the vulnerability assessment of water resources and management systems to climate change in the Prairie's provinces. In addition, the case studies in the three Prairie's provinces will represent a special contribution to climate change impact and adaptation studies within a Canadian context.

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An Optimization-Simulation Approach for Assessing Vulnerabilities and Planning Adaptation Strategies of Water Resources Management System to Changing Climate in the South Saskatchewan River Basin

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Abstract

Climate change would result in a number of direct and indirect impacts on water resources system. The problems concerning vulnerability assessment and adaptation strategies for water resources planning and management are complex, and they require advanced systems analysis approaches to analyze and obtain the best or optimal solution for further decision making. In this research, a set of simulation and optimization models are developed and integrated into a general framework with the state-of-the-art modeling tools, and climate change impacts and adaptation are also incorporated within the modeling process, for improving decision efficiencies of climate change vulnerability assessment and adaptation strategies within the water resources system in the South Saskatchewan River Basin

Introduction

Climate change will lead to a number of direct and indirect impacts on water resources system, and it may pose many serious challenges to the social, environmental, and economic development. A great number of studies indicate that the water resources system is extremely vulnerable to changes in climate, for example, even small changes in temperature and precipitation patterns can result in significant changes in the amount and timing of spring runoff, the intensity of floods and droughts, and the rate of evaporation from soils and surface waters (Herrington et al., 1997; Huang et al., 1998; Environment Canada, 2002). The South Saskatchewan River Basin is a very important region for Canada's social, environmental, and economic development, and the water resources in this basin are also vulnerable to the changing climate. The climate change can affect its water resources and management system in many ways (McCarthy et al., 2001), and some possible impacts include (a) water supply and demand may be affected by changes in precipitation and increased evaporation; (b) changes in precipitation patterns may cause more flooding or more drought; (c) water quality will be influenced by changing temperatures, flows, runoff rates and timing, and the ability of watersheds to assimilate wastes and pollutants, and (d) water resources infrastructures (such as reservoir operation, hydroelectric generation) may also be affected. All of these physical and ecological impacts will show significant temporal and spatial variations that result in different social, environmental, and economic costs and benefits (Yin and Pierce, 1993; Herrington et al., 1997), therefore, assessment of vulnerability and adaptation strategies for effective and reliable planning and management of the water resources system in the basin is desired.

The problems concerning vulnerability assessment and adaptation strategies for water resources planning and management are complex, and they require advanced systems analysis approaches to analyze and obtain the best or optimal solution for further decision making (Belaineh et al., 1999; Hsu and Cheng, 2002). The system analysis is represented by a series of mathematical expressions that can well describe the complex system processes and activities, and the corresponding mathematical models are categorized into two groups, namely simulation and optimization. The simulation models are useful tools for solving water resources management problems by simulating a few plausible scenarios among an infinite number of possible options (Loucks, 1992; Xia and Huang, 2001). The consequences of the alternative management, planning, or policy-level activities, can be projected, and the simulated results of this limited set of scenarios are then compared to identify effective management schemes with the least negative impacts. Normally, it requires high cost and much time for simulation to get the "optimal" solution, and it is a better way to apply optimization approaches for obtaining “optimal” management schemes. Based on these methods, an infinite number of scenarios can be effectively evaluated rather than the few that could be assessed using simulation models. Optimization models have been widely applied to the field of water resources planning and management (Huang, 1996; Chang et al., 1997; Huang and Loucks, 2000). A water resources management system generally has multiobjective, interactive and dynamic features (Wen and Lee, 1998; Montesinos et al., 1999). For example, in a watershed system, there exists many environmental, socio-economic, and resources objectives related to a number of stakeholders. These objectives may have conflicts to each other. Therefore, the problem is how to make tradeoff or compromise between interests from different stakeholders bearing different objectives, in order to maximize the general benefits of the entire system (Yin et al., 1999). In addition, for each time period with given environmental/economic conditions, there may be interactions and conflicts between different human activities and between different objectives, the policies related to water management and planning may also be dynamic and changing. Based on these multiobjective, interactive and dynamic features, a number of optimization models have been developed and applied to this field (Chen and Chang, 1998; Guo et al., 1998; Jairaj and Vedula, 2000), but many non-linear relationships in the system are difficult to be incorporated into such optimization models. Therefore, the combination of optimization and simulation will be both more suitable and practical to water resources planning and management problems (Watkins and McKinney, 1995; Xia et al., 2001), however, few efforts have been made toward this kind of integration in the past years.

Over the past few decades, the major concerns of water resources managers and planners have been how to meet the demands of regional economic development and how to handle both floods and droughts by using simulation or optimization models (Xia and Huang, 2001), however, these concerns have been complicated by the growing understanding that climate change can pose serious challenges to the water resources system (Leavesley, 1994; Guo and Ying, 1997). The implications of climate changes for water resources system depend not only on the behavior of the climate but also on the characteristics of water utilization and the corresponding technologies, policies, and strategies. Therefore, adaptation to these changes is a complicated issue which is related to a number of social, economic, environmental, technical, political and resources factors, with multi-industry, multi-factor, multi-stage, and multi-objective characteristics (Bass et al., 1997; Chao et al., 1999). For example, the impacts on economic, resources, and environmental systems, may vary temporally with dynamic features; variations of adaptation techniques and facilities over time may also lead to changes in the effects of climate change; decisions of socio-economic and environmental objectives may affect the choice of adaptation techniques. As a result, reflection of climate change impacts and corresponding adaptation strategies as well as the system complexities would be important for effective and reliable water resources management (Huang et al., 1996; Xia et al., 1997), and the adaptation planning and management should not only consider the possible effects of climate change, but also be based on in-depth examinations of system processes. However, few previous studies have been undertaken regarding how to integrate climate change into regional water resources planning process, and how to incorporate complex processes and interactions within a general framework rather than examine them in isolation. This research is proposed to fill this gap through the development of simulation and optimization models as well as their integration with the state-of-the-art modeling tools, and the implementation of incorporation of climate change within the modeling process, for improving decision efficiencies of climate change impacts assessment and adaptation strategies within the water resources system in the South Saskatchewan River Basin.

Objectives

The major objectives of this research include two folds: (a) to develop an integrated optimization-simulation approach in which optimization models are used for planning water resources system and generating future utilization policies corresponding to different climate-change scenarios, and simulation models are employed for assessing the impacts of those policies on water resources as well as identifying the most suitable adaptation strategies; (b) to apply the developed methods to the South Saskatchewan River Basin, and the complex relationships among climate change, human activities, water resource management, water quality and quantity, other environmental concerns, and economic targets will be comprehensively considered and reflected.

Methodology

(1) System Description and Analysis

Based on the consideration of many socio-economic and environmental concerns and the requirements of system modeling, water resources system in the basin will be examined with focuses on system components, characteristics, related factors and processes vulnerable to changing climate, and direct or indirect impacts on the system's environmental and economic objectives. In planning such a system for sustainable development purposes, individual or independent consideration of one or several subsystems would not be able to account for the behavior of the entire system.

(2) Optimization and Simulation Models Development

The simulation models can provide inputs for optimization models, and they can also be used for post-optimality analysis and generation of detailed alternatives. For example, the rainfall-runoff model can provide inputs for water availability constraints, while the water quality model can provide inputs for contaminant loading constraints in the optimization models. The optimization models can be used for generating water resources management options under different climate-change scenarios, and the complexities should be incorporated within the modeling framework.

The development of simulation and optimization models includes several parts: (a) *Conceptual model formulation.* It is to identify major problems and crucial factors related to impacts of climate change on water resources system in the basin, and address conceptual formulation of model; (b) *A mathematical programming model development.* This step relates economic activities, environmental concerns, climate change impacts, water resources management, and system adaptation within the modeling framework. It will be used for generating water resources management options under different climate-change scenarios; (c) *A system-dynamics-based simulator development*, *validation and calibration.* These will be conducted based on system analysis approaches. The question such as "what's the consequence of implementing the management options?" will be answered, and (d) *Efficient algorithms development.* In this research, efforts will go to algorithm development for improving computational efficiency and accuracy.

(3) Integration of Optimization and Simulation for Decision Support (Vulnerability Assessment and Adaptation Planning)

This task focuses on integration of the developed optimization model and simulation tool for effectively assessing vulnerabilities of water resources system, planning management options under different climate change scenarios, and predicting the possible consequences. These outputs will be useful for effectively and comprehensively evaluating potential options for adapting the water resources system to changing climate. Thus, decision support regarding the most suitable adaptation strategies could be provided. In this study, several decision support tools, such as utility theory, system dynamics, regret analysis, and analytical hierarchy process, are employed for generating decision alternatives.

(4) Field Investigation and Application

Involvement of industrial and governmental personnel is important for not only providing necessary information for identifying factors related to climate change and system model development, but also for validating models' inputs/outputs and generating desired decision support. It can be carried out through a variety of methods such as questionnaire survey, roundtable meetings, and consultation workshops. Through application of the developed method, many questions, such as "how vulnerable the water resources system in the basin is to changing climatic condition?", "how will the basin modify its management practices to adapt to the climate change?" and "what adaptation policies should be formulated to avoid or reduce negative impacts on water resources system?", can then be answered.

Expected results

The major expected results from this research will include (a) integrated optimization-simulation method framework; (b) future water resources management policies and economic development patterns under different climate-change scenarios; (c) vulnerability assessment which focuses on the impacts of those policies on the South Saskatchewan River Basin; (d) adaptation strategies of water resources management system, and (e) reports for applications of the developed optimization-simulation method.

Conclusions

There are no previous efforts that have been made to incorporate climate change impacts and adaptation in the field of water resources management within an integrated framework for providing efficient and reliable decision support. This research aims to fill this gap through the development of simulation and optimization models as well as their integration with the state-of-the-art modeling tools, and the implementation of incorporation of climate change within the modeling process, for improving decision efficiencies of climate change impacts assessment and adaptation strategies within the water resources system in the South Saskatchewan River Basin. This study focuses not only on method development, but also on examining the impacts of climate change on socio-economic aspects of water resources management, and it represents an innovative method for enhancing adaptive capacity of water resources management to the impacts of climate change. In addition, this research could provide the vulnerability assessment of water resources and management systems to climate change in the South Saskatchewan River Basin, and the case study represents a special contribution to climate change impact and adaptation studies within a Canadian context.

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The Economic Impact of Different Rates of Climate Change on the Operation of the Glenmore and Glenifer Reservoirs in Alberta

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Abstract

A change in climate could seriously impact water resources in Canada. The difficulty in assessing how specific regions or watersheds may be affected in terms of altered flood and drought distributions lies in the large uncertainty imbedded in climate change scenarios scaled down from General Circulation Models (GCM) projections. It is more prudent, therefore, at present, to investigate a range of possible climate changes and their impacts on water resources, rather than singling out just one climate change scenario. The paper presents results of current research on increased flooding due to possible increase of storm severity in the Alberta foothills.

Proposed new research focuses on how the flood protection and water supply functions of two existing reservoirs on the Red Deer River and Elbow River, respectively, would be affected by climate change scenarios of various degrees of severity, and the consequential economic and social impacts.

Introduction

The two predominant functions of water storage reservoirs are to assure flood protection for downstream locations, and/or to provide adequate water supply. The design procedures for these two reservoir functions are different, but both are based on the past observations of meteorological and hydrological parameters, such as rainfall, temperature, evaporation and discharge. Based on the analysis of past records the engineering design provides the required spillway size to safely handle the design storm, and the required storage capacity to assure water supply during a drought of the design duration and severity. If the climate change is going to affect the regional meteorology and consequently the regional hydrology within the lifetime of the existing water resources structures, they may fail to operate as originally designed. In the case of reservoirs, increased storm rainfall or spring snowmelt runoff may lead to a dam failure because of inadequate spillway capacity; or a change in drought pattern may lead to water shortages because of inadequate storage capacity.

To investigate how an existing water resources structure will operate 50 to 100 years from now requires, first of all, a fairly accurate and detailed future climate scenario. This would include a 50 to 100 year long series of average monthly meteorological parameters to assess the water supply operation of the reservoir. To assess this adequacy of the emergency spillway, hourly design storm rainfall depths, characteristic of the future 50 to 100 year period, are required. Secondly, these future climate scenario driving parameters need to be converted into the reservoir inflow series, either monthly or hourly values, depending on whether the storage capacity or the spillway capacity is being investigated, by means of a watershed hydrological model.

Now the problem is that at present, there is no means of predicting such a detailed climate change scenario at a watershed scale. The present GCMs have a coarse spatial resolution of 150 to 360 km grid size (grid area of 22,500 km^2 to 129,600 km^2), which is neither adequate for distributed watershed modeling (1×1 km grid or smaller) nor for lumped modeling of small to medium large watersheds (100 km^2 to 10,000 km^2). Several downscaling techniques are being developed by the research community, however, the uncertainty of results is still large. It seems that the best approach today is to investigate the impact of an array of plausible climate change scenarios to produce a range of possible hydrological responses, which then can be used to evaluate the impact on regional water resources and the existing hydraulic structures.

Results of Current Study

Sensitivity of flood discharges in a study watershed located in the foothills of Alberta (Little Red Deer River near Water Valley) was investigated by I. Muzik (2001).

The study investigated potential changes in the frequency and magnitude of peak flood flows due to assumed increases in the mean and standard deviation of storm rainfalls of 6 to 48 hour durations deemed most critical for the size of the study watershed (449 km^2). The projected increased severity of storms was based on a literature survey indicating increased intensity and variability of storm rainfall under a $2 \times CO_2$ scenario, on the prediction by GCMs of the mid-latitude rainbelt movement northward, and on recently-observed climate variations in Canada, which indicated an increase in summer rainfall in the recent decade in the region.

Comparison of the watershed rainfall statistics with those at similar southern locations as a guide for possible future changes, led to the adoption of two climate scenarios for the study: a 25% increase in the mean and standard deviation of rainfall and a 50% increase in the standard deviation of rainfall. The first-order accuracy analysis of the study watershed sensitivity to a climate change is based on three assumptions: (1) increases in rainfall intensity and variability due to a climate change are considered to be the most significant factors affecting the flood regime; (2) changes in vegetation cover (90% evergreens) and evapotranspiration are assumed to take place initially at a slower rate than the rainfall changes, and are neglected; (3) sensitivity of the watershed can be assessed by comparing synthetic flood frequency curves of the present and the projected rainfall climates. Presently, the only practical approach to generate a synthetic flood frequency curve for a watershed is to employ a hydrologic rainfall-runoff watershed model in a Monte Carlo simulation. In this study, HEC-1 model (United States Army Corps of Engineers, 1987) in conjunction with the SCS runoff curve method (Soil Conservation Service, 1972) were used to compute flood hydrographs from randomly selected inputs of rainfall and study watershed parameters. Each simulation run represented an annual maximum discharge event. Ten thousand runs defined the synthetic flood frequency curve. The model was calibrated by comparing the synthetic flood frequency curve derived for the present climate with the existing empirical flood frequency curve of the study watershed, based on 31 years of observed flows (1964-1994).

Based on the study results the following conclusions can be made

1. Rainfall change scenario one, in which both the mean and standard deviation of storm rainfall increased, resulted in greater increases in flood flows than did scenario two, in which the means remained the same, but the extremes were increased by increasing the standard deviation.

2. Scenario one impacted very strongly on the 2-year flood flow (62.8% increase) and strongly on the 100-year flow (40.9% increase). Scenario one type of climate change may therefore be detected in a relatively short period of time (5-10 years), by observing changes in the mean annual flood flows.

3. Scenario two impacted moderately the 100-year flow (35.3% increase) and only weakly on the 2-year flow (16.9% increase). This type of climate change may be more difficult to monitor within a 10-year period.

4. A type one climate change scenario, comprising increases in both the mean and standard deviation of rainfall, may significantly increase flood flows of all return periods, and especially of the more frequently-occurring flows. Consequently, the drainage basin morphology of affected watersheds could potentially undergo significant changes. Any man-made structures would also be significantly impacted as the existing infrastructure may no longer by adequate.

5. The first-order accuracy analysis performed in this study indicates that even small-to-moderate increases in rainfall intensity may have pronounced impact on flood flows and consequently on hydrotechnical structures in the region.

6. This methodology could be applied to a more detailed climate change impact assessment flood studies, provided a number of issues can be resolved: (1) How will vegetation cover change and at what rate? (2) How will the evapotranspiration change and what impact will it have on flood flows? (3) How will the vegetation cover and evapotranspiration changes be reflected in changes of antecedent moisture conditions, initial abstractions, and eventually the basin groundwater flow?

Proposed Study

It is proposed to make detailed case studies of climate change impact and adaptation for two existing reservoirs in Alberta: the Glenmore reservoir, located in the city of Calgary on the Elbow River, and the Glenifer reservoir, located on the Red Deer River, upstream of the city of Red Deer.

Both reservoirs have an important function as water supply sources for the two cities, as well as to provide some flood protection. The objective is to determine the likelihood of failure of these reservoirs to provide the required services in the next 50 years. The validity of the research depends on two crucial components. One, the development of as realistic as possible future climate scenarios by downscaling GCMs projections for the study region. Two, the transformation of the climate scenarios into future inflow series into the studied reservoirs, by means of a hydrological model. Once the new inflow series (corresponding to a particular climate change scenario) is known, standard techniques can be applied to analyze the impact on the function of an existing reservoir, and what adaptation measures (structural, operational) if any, must be implemented to minimize or alleviate any negative social impacts.

Summary

If a climate change occurs, it could seriously impact water resources in Canada. Preliminary studies indicate that even moderate increases in storm rainfall (such as a 25% increase in the mean and standard deviation of rainfall depth for design storms) may produce flood flows in some watersheds, exceeding the existing spillway capacity. Retrofitting existing spillways to increase their capacity could prove to be a substantial economic burden as there are over 2000 small dams (8 m of height or less) in Ontario alone.

The present GCMs do not provide reliable regional or watershed scale climate change scenarios, which would allow the development of a definite hydrological scenario for the next 50 years. Instead, the climate change impact on regional water resources and structures need to be studied in a probabilistic sense at this time, by considering an array of plausible climate change scenarios.

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Water License Allocation And Reallocation: Modeling Adaptation Under Changing Water Supply And Demand Due To Climate Change

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Editors' Note:
At the time of publication of this report, no written version of the presentation made at the Workshop was provided.

Some Observations on the Nature of Adaptation Research

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Introduction

The study of climate change has emerged in recent years as a discernable area of scholarship, attracting researchers from many disciplines and supported by several high-profile, specialized journals. As the field enters its adolescence, three separate but closely related research thrusts have become obvious, *viz*. the science of atmospheric processes and change, the study of impacts, adaptations and vulnerabilities, and, thirdly, mitigation analysis. In the early period, atmospheric science dominated both scientific and public policy debates, and in the opinion of some captured a disproportionate share of research funding (Taylor and Buttel, 1992). In recent years, however, considerations relating to adaptation have become increasing prominent within the scientific literature (Smit *et al.*, 2000), and have been identified as a priority research area by the IPCC (Working Group II, 2001).

Two roles for adaptation research can be identified (Smit *et al.*, 1999). On the one hand we can conceptualize adaptation research in the context of climate change impact assessment, while on the other hand, we can conceptualize adaptation research within the domain of policy development. The purpose of this contribution is to discuss the salient features of each application.

Adaptation Research in the Context of Impact Assessment Modelling

Since the late 1970s, climate change impact assessment research has been dominated by the scenario approach (Parry, 1988). Such studies begin with the specification of several possible climatic futures, typically involving projected departures from mean conditions. General Circulation Models (GCMs) are most often used for scenario development (Gates, 1987), although some studies have employed historical or spatial analogues (Rosenberg *et al.*, 1993). The climatic scenarios are then superimposed upon a study area, and the effects projected for whatever climate-sensitive system is under investigation.

By and large, the first generation of studies were preoccupied with assessing first-order impacts only. This involved an assessment of the consequences of possible changes in climatic conditions (often with respect to average conditions) on what Carter *et al.* (1994) called an "exposure unit". This general framework was refined, and an increasing number of investigators began to consider not only first-order impacts of climate change, but higher-order ones too (Parry and Carter, 1988). Thus emerged the "cascading impact approach" (Chiotti and Johnston, 1995), as output from one modelling exercise is used as input to the next, and so on. Some investigations, such as the one by Bergthórsson *et al.* (1988) which assessed the impact of climate change first on grass yield in Iceland and then on dairy production, involved only two orders of impacts. Other studies are considerably more ambitious. For example, in a study focussing on Saskatchewan, Williams *et al.* (1988) traced the impacts of crop-yield changes through to farm-level expenditures, farm income and ultimately provincial GDP.

Further analytical sophistication was added to the assessment of cascading impacts by tracking effects within the agricultural sector to other sectors of the economy. Described by Parry and Carter (1988) as the integrated approach, input-output analysis (I-O) is sometimes used for studies of this type. This technique, which was developed by regional scientists to trace the consequences of change in one or more sectors of a regional economy, was used by Arthur and Van Kooten (1991) in their study of possible impacts of climate change in the three Canadian prairie provinces. The integrated approach has been extended in recent years with the introduction of analytical frameworks providing for the evaluation of climate change impacts in one region *vis-à-vis* climate change impacts in other regions (Rosenzweig and Parry, 1994). This development recognizes that regional economies, for example, do not operate in isolation, but are linked in various ways through a global-scale systems of production, distribution, exchange and consumption (see, for example, Bryant and Johnston, 1992). The way in which a change agent or exposure unit in one region might respond to climate change is influenced by the way in which their counterparts in other regions also respond. For example, imagine that the climate in a region shifts such that at some point in the future it is possible to grow corn, when in the past it was not possible to do so. A producer=s decision to grow corn will be influenced not only by the prevailing climatic conditions, but more importantly by whether or not corn enjoys a comparative advantage over other crops, which is governed not only by site and regionally specific production conditions but also by the supply of and demand for corn generally in the marketplace.

The "Business As Usual" Assumption

The early studies generally conceptualized climate change impact assessment in terms of a simple, one-way relationship between an exposure unit or change agent and one or more attributes of the climatic regime. Impact assessments using this simple-impact approach were grounded on the "assumption of direct cause and effect where a climatic event (e.g., a short-term variation of temperature) operating on an exposure unit (e.g., a human activity) may have an impact or effect" (Parry and Carter, 1988). Many of these studies adopted a "business as usual" position, in that it was assumed the future structure of the system under consideration would be broadly similar to the baseline year. However, in assuming the structure of any given system would remain static over time, a fundamental flaw was embedded in the conceptual frameworks employed. Simply put, the majority of these investigations failed to accommodate the possibility that systems under consideration might adapt to changing climatic conditions in order to avoid the negative consequences of climatic change or to exploit new opportunities (see, for example, Mendelsohn *et al*., 1994). The point at issue is not that researchers made wrong assumptions about decision-making behaviour, but rather that decision-making behaviour was not considered at all.

By the late 1980s this criticism had been internalized by an increasing number of impact assessment researchers (Crosson, 1993). As observed by Reilly *et al*. (1996), for example, most impact studies conducted since about 1990 have considered some technological options for adapting to climate change (see, for example, Rosenzweig and Parry, 1994). Typically such studies run two sets of analyses. First, impact evaluations are conducted for as many climate scenarios as are specified, but assuming that no adaptation will be undertaken. Then, a second set of assessments are run, this time incorporating various assumptions concerning the adaptability of the system under examination. The first step in this research design represents the control scenarios, whereas the second run can be considered transitional scenarios. In adopting this conceptual framework, researchers can theoretically identify the worst possible outcome versus the best possible outcome, as well as a range of possible adaptive strategies.

Adaptation Research in the Context of Policy Development

Used this way, adaptation research is a positive heuristic. It seeks to identify which of a range of theoretically possible adaptive options are likely to reduce the negative effects of climate change, or offer the chance of taking advantage of new opportunities. The majority of studies employing this approach omit any consideration of the likelihood that a given adaptive mechanism, or a range of mechanisms, will actually be adopted. In other words, as Smithers and Smit (1997, p. 173) observe, Athere has been relatively little attention focussed directly on the process of adaptation to environmental change@. In focussing on process as opposed to outcome, an approach which is consistent with the definition of adaptation to climate change offered by Burton (1992), researchers begin to ask about the various cultural, perceptual, institutional and other factors and circumstances, operating across a range of geographic scales, that will influence the chances that any given adaptive strategy will adopted (Johnston and Chiotti, 2000).

In order to address these concerns, an additional role for adaptation research can be defined (see, for example, Smit, 1993; Smit *et al.*, 1999; Smit *et al.*, 2000). This approach involves reference to the characteristics of systems that make them more or less vulnerable to climate change, and which in turn affect the capacity of any given system to adjust to the consequences of climate change. By focussing on the Aecological properties@ of systems (Smithers and Smit, 1997), the research question shifts from which adaptive strategies are possible to which are probable, seeking to identify those attributes of systems that constrain adaptive capacity.

Various authors have developed lists of key attributes to be used in this approach to adaptation research (e.g., Smit, 1993; Spregers *et al.*, 1994), but there would appear to be agreement on three characteristics in particular, namely sensitivity, adaptability, and vulnerability.

Briefly, sensitivity analysis is undertaken to determine which particular aspects of climate a system is especially responsive to. Some systems may be particularly sensitive to change in average conditions (e.g., average precipitation) while other systems may be particularly sensitive to an increase in the duration, frequency or magnitude of extreme events such as drought. In addressing this question, researchers are able to build knowledge about those aspects of the climatic regime to which systems will actually need to adjust.

Adaptability can be thought of in terms of the flexibility or the amount of "manoeuvrability" that exists in a system (Smit, 1993). The amount of flexibility in a socio-economic system can be constrained by exogenous variables such as the institutional arrangements that surround resource use decisions (Ivy, 2001), or by the internal structure of the system. For instance, it can be argued that systems displaying a high degree of homogeneity, such as a highly specialized farming system, may posses less flexibility and hence display less adaptability as compared with a smaller-scale, more diversified systems. Herein lies a curious conundrum, because in socio-economic systems as in ecosystems, there is a negative relationship between diversity and efficiency.

Vulnerability can be defined as the "degree to which a system, or part of a system, may react adversely to the occurrence of a hazardous event" (Timmerman, 1981) and as Smit (1993) observes is closely related to two other ecological properties of systems: stability and resilience. According to Burton (1992), stability refers to the "steadfastness" of a system, while resilience relates to the "elasticity" of a system. As Smit (1993, 24) explains: "a farming system which produces a consistent yield over time through resistance to impact or quick recuperative power is stable, while an agricultural system which can sustain itself despite large fluctuations in yields or prices etc. is resilient". To illustrate, producers who manage through substantial swings in commodity prices without any extramural support display resilience, whereas producers who remain in business on the basis of income support programmes, crop insurance, and even ad hoc disaster relief programmes can be described in terms of stability.

Finally, the concepts of sensitivity and adaptability can be combined to create a picture of a system's overall or general vulnerability to climate change. As noted by Smit *et al.* (1999), the Summary for Policy Makers developed from the Second Assessment Report of IPCC (1995) defined the most vulnerable systems as those displaying the greatest sensitivity to climatic change, combined with the least adaptability.

Conclusion

This brief submission has attempted to outline the two roles that adaptation research can play in climate change research, and to differentiate between these two roles by addressing their respective salient features. No attempt has been made to promote one approach over another. Both are important and, in fact, both have been defined by the

IPCC and others as research priorities. Having said that and acknowledging the close relationship that each approach has with the other, neither approach depends upon the other. Indeed there is considerable merit in both forms of adaptation research to be undertaken simultaneously.

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Strategies to Study Climate Change Impact and to Reduce Vulnerability for the Water Resources of South Saskatchewan River Basin

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Introduction

In both the scientific and the political worlds, climate change is a sensitive issue. The future of water resources of the Canadian Prairies (C-P) under the influence of climate change is full of uncertainties, given the complicated nature of greenhouse forcing over natural climate variability, and given that drought has already been a recurring problem in the C-P that depends heavily on spring snowmelt for water supply. Furthermore, the current water rights within the South Saskatchewan River Basin (SSRB) that comprises of Red Deer, Bow, Oldman & South Saskatchewan in Alberta and Saskatchewan are already close to fully allocated.

While the current operations of SSRB relies on a statistical understanding of past streamflows, future hydrology within this basin could be significantly different from past, which implies that past hydrological experience may not be a valid indicator for future conditions. However, before we propose a strategy to investigate if future droughts in the SSRB and surrounding areas of southern Alberta and Saskatchewan will become more severe and/or more frequent under the potential impact of climate change, let us ask ourselves a few relevant questions:

Relevant Issues

(1) *Are there clear evidence of forcing from climate change detected in the historical data?*

Gan (1998) applied Kendall's test to temperature and precipitation data from 37 weather stations, along with 50 sets of natural streamflow data, and 13 sets of evapotranspiration (ET) data. The results, together with the earlier onset of spring snowmelt runoff detected, generally show that the C-P have become warmer and somewhat drier in the last four to five decades. Warming trends are detected in more weather stations than drying trends. For example, in March and June, over 60 % of the stations tested exhibited significant warming at $\alpha = 0.05$ and 89% of the March minimum temperature shows warming trends. On the other hand, precipitation trends are scattered without any obvious pattern, and only a handful of the 50 streamflow stations show negative trends for more than 2 months. The trend homogeneity test and correlation-distances reveal that temperature data are more highly correlated across sites than precipitation. No link was found between precipitation and maximum temperature. Most temperature trend magnitudes (β) are positive, precipitation β are primarily negative, while streamflow β are generally more negative than positive, and most positive trends occur in March due to an earlier onset of spring snowmelt. ***In conclusion, it seems that the C-P have become drier, but the evidence is insufficient to conclude that warmer climate will lead to more severe droughts in the Prairies.***

(2) *Besides climate change, what are other large-scale climate factors also connected to the C-P?*

By teleconnecting with climate anomalies, Gan and Wang (2002) show that El Nino/Southern Oscillation (ENSO) affected about half the precipitation of Western Canada at its mature phase during winter. The Pacific North America (PNA) and the central North Pacific index (CNP), which are linked to ENSO, exerted significant forcing on 2/3 of the winter precipitation, while the West Pacific Pattern (WP) only affected about 1/3 of the winter precipitation. Weak CNP (PNA) leads to 11-22% (7-25%) increases in the mean precipitation while strong CNP (PNA) reduces the mean precipitation by about 10% (8%). Using wavelets, Gan and Wang detected statistically significant interannual and interdecadal oscillations that occurred haphazardly in the precipitation of western Canada. Based on the global wavelet spectrum at α=0.05, many stations show significant decadal to higher time scale oscillations, which accounts for 45 to 60% of the precipitation variability. They also detected similar low frequency oscillations in the climate anomalies. Essentially, climate anomalies linked to the precipitation of western Canada and that of C-P are such as ENSO, PNA, CNP and WP.

(3) *What are the statistical characteristics of streamflow data in the Canadian Prairies?*

From an analysis of 40 stations of unregulated, total annual streamflow, Gan (2000) found that the annual streamflow in the C-P vary from virtually zero to over 500mm in the mountains, with a mean value of 127.6 mm/year. To also check the temporal variability of annual streamflow, the ratios of 95% to 5% exceedance of total annual streamflow are computed for the same stations. Again the ratio varies widely, from a minimum ratio of 1.39 to a maximum of 123.4, with a mean value of 10.6, which is fairly high. All these results demonstrate the high variability of annual streamflow in the C-P, both temporally and geographically, which again implies the vulnerability of C-P' water resources.

(4) *What are the uncertainties involved in projecting the possible future water resources of SSRB under the potential forcing of climate change compounded by climate variability & various teleconnections?*

When subjected to the forcing of greenhouse gases, our climate system will respond with signals such as warmer temperature, earlier onset of spring snowmelt, etc. However, these signals could be complicated by the annual, interannual to inter-decadal climate variability already observed in the climate of C-P and the influence of climate anomalies. The land surface-atmosphere interactions, possible changes in biomes distribution such as forest clear-cutting or replacing forest with agriculture, climate feedback and data noise could further complicate our effort to model the possible outcome of climatic forcing and feedback on the regional climate of SSRB.

Past studies have shown that existing water supply systems in water-scarce regions and in regions with high streamflow variability, such as that of the C-P, tend to be vulnerable to droughts. Beyond that, we know that there are other factors contributing to the uncertainties of water resources in C-P, such as: (1) Changes over a lengthy horizon in social values, technological progress, resource depletion, economy, population growth, and their interactions that are too far fetched to forecast, (2) Optimal system operations derived from historical data are upset by changing hydrologic conditions, and (3) uncertainties in water demand and long term climate forecast. We have outlined some ideas to address the aforementioned issues in SSRB as below:

Strategies for Climate Change Study

Basically there are two ways to predict the possible outcome of climatic forcing and feedback on the regional climate of SSRB: (1) Statistical downscaling of general circulation model, GCM's projected climate scenarios, (2) Driving a coupled, mesoscale atmospheric model-land surface scheme (MAM-LSM) by the initial and boundary conditions of GCMs. We prefer the latter because it should be more reliable to estimate processed-based relationships between changes in basin-scale hydrologic responses to the combined and interactive effects of climate variability and climate change. Further, because of scale mismatch and uncertainties involved with GCM's projected climate at regional scale, simulating climate scenarios for SSRB and surrounding areas should be based on a downscale approach. Given our current state-of-art, this is a plausible way to bridge the gap between spatial resolution of GCM, meso-scale atmospheric model, and macro-scale hydrologic model, and to incorporate effects of local-scale heterogeneities in land-surface properties. We can force a coupled MAM-LSM that considers atmosphere and land surface feedback, such as the MM5-OSU, CRCM-CLASS, or GEM-ISBA, with boundary and initial conditions projected by GCMs (e.g., CGCM1, HadCM2, or ECHAM4) to project the climate scenarios under climate change for SSRB and surrounding areas in a multi-year framework (in the order of fifty to one hundred years).

Some of the input data for the latter approach include satellite observations to provide state of land surface and atmosphere, field measurements, re-analysis data. Given uncertainties in the forcing and variability aspects of climate, the non-linear nature of climate interactions, and climate sub-systems as high dimensional chaotic processes (Gan et al., 2002), using numerical climate models to simulate long-term climate scenarios are subjected to errors. It is estimated that ¼ of anthropogenic CO_2 release is taken up by the CO_2 sink, the terrestrial biosphere. Therefore if feasible, it would be beneficial for the coupled system to incorporate plausible biospheric responses to CO_2.

The output of the coupled system can be fed to a basin-scale hydrologic model (e.g., Biftu and Gan, 2001) operated at higher spatial resolution to estimate the time delays between precipitation events and the re-distribution of hydrologic processes at basin-scale. The hydrologic model has to be calibrated against observed land-surface water data collected at different gauging stations of SSRB. On the basis of historical data, we can map out drought zones of SSRB using the modified 6-month Standardized Precipitation Index, and the modified Palmer Drought Severity Index (Ntale and Gan, 2002). From these zones, assess the meteorological/ hydrologic drought risk for SSRB and surrounding areas where population concentrates, where there are substantial agriculture and irrigation activities. We can repeat the procedures using the projected climate and basin hydrologic scenarios mentioned above, develop summary statistics and frequency analysis from both the historical and simulated hydrologic data. By comparing both sets of information, we can assess the potential effect of climate change on the frequency and severity of droughts, the shift in the timing of spring snowmelt, changes in the ratio of snowfall/rainfall, and the overall volume of basin runoff.

Strategies to Reduce Vulnerability

Results obtained from Section 3 can form part of the basis to address issues such as our adaptation strategies to augment the adaptive capacity, to reduce vulnerability of SSRB to climate change impact on regional water supply, and the possible level of fine-tuning our water resources management. Since these projected changes obtained from model studies are subjected to ambiguities and errors, addressing these difficult issues should also involve round-table discussions with various stakeholders. The criteria to be considered are the legal, regulatory, consumptive use, in-stream water quantity and quality needs, etc. The process will also involve data collection and literature review, such as the report of Alberta Environment, "*South Saskatchewan River Basin Water Management Review*".

Given water is already a scarce resource for SSRB of semi-arid climate, it probably does not justify to use major reservoirs to provide over-year runoff storage. To increase the adaptive capacity of SSRB and surrounding areas, the strategy will likely be based upon flexibly adjusting the capacity of existing facilities, adopting short-term planning into the future and continue to upgrade relatively short-term decisions as the impact of climate change unfolds over time, e.g., a combination of small to medium scale structural and nonstructural solutions. Possible adaptation strategies are such as (a) Expanding major irrigation systems, or upgrading existing irrigation systems with more efficient irrigation technologies, or a combination of both measures; and (b) Integrate the major reservoirs of SSRB through building a fairly comprehensive network of pipelines/ water canals and computerized gate controls; (c) promote water conservation; (d) consider water right agreements between provinces and setting up a water bank to facilitate temporary water transfer between SSRB and across the Prairies during droughts, and (e) assess existing small-scale surface water and groundwater projects for SSRB, and (f) look for possible transfer of water from northern parts of C-P to SSRB if the cost involved is acceptable.

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Reconciling the Socio-Economic Drivers of Urban and Agricultural Water Sectors under a Changing Climate

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Objective

To develop a management (decision-making) framework that reconciles the socio economic drivers and consequences of agriculture and urban water use to changes in hydrologic regimes, within an appropriate legal structure.

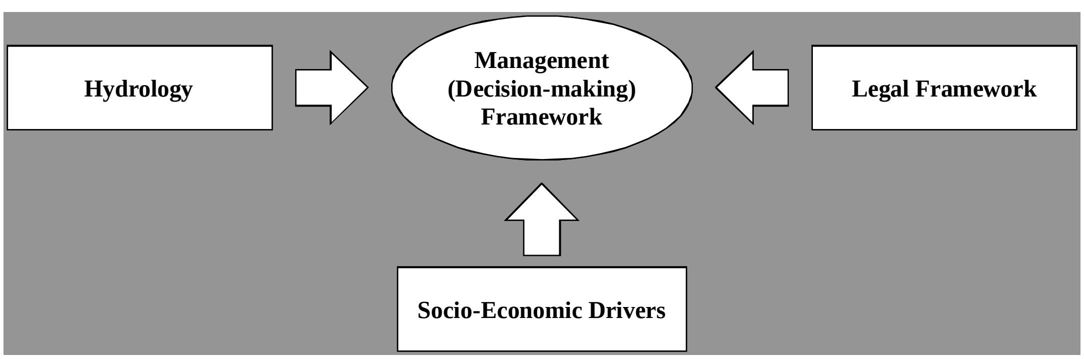

Figure 1. Components to management framework.

The focus of the project original proposed was on the question of how do you get agricultural and urban water user groups to adapt to changes in hydrologic regimes triggered by climate change. This raises the whole issue of how we interpret adaptation:

(a) Technology is not a barrier to adaptation; climate change simply changes the design parameters.

(b) There is a general feeling that society has the capacity to adapt to new climatic conditions. Therefore, climate change may be less critical, less pressing, and we will simply react to the changes as they happen. The risk of such an approach is that the costs of waiting may be more than we are willing to pay.

Proactive adaptation requires us to “control” the drawn-out (slow) transition from our present to an uncertain future. Human systems are critical to controlling and influencing (driving) the rates of desired adaptation (adaptations that minimize unwanted social changes).

Societal dimensions to adaptation include:

1. Placing value on water
2. Proactive water allocation policies
3. Social programs to influence behaviors
4. Economic incentive programs
5. Legal framework and legal mechanisms

These societal dimensions are vital to adaptation, as shown in the following examples:

1 Lack of incentives to reduce urban water consumption may lead to landscaping norms, which are unsustainable under conditions of lower water availability. The introduction of water conservation incentives and water meters can substantially modify water consumption patterns and landscaping decisions. The resulting landscaping may subsequently be less vulnerable to water shortages and restrictions.

2 Economic pressures are forcing agricultural development and the extension of irrigation systems in the face of increasingly common drought events. Reductions in water availability may subsequently prevent sufficient financial returns on investment. In effect, hydrologic risks are compounded by financial risks.

Focus of the Project:

- How conflicting water users interact and adapt to a changing environment?
- What is the legal framework that defines the rules of interaction?

[These questions are posed within the context of agricultural and urban water users.]

What are the socio-economic drivers needed to encourage appropriate (desirable) adaptations? This question implies shifts in water uses, and potential changes in water allocations. If such changes in allocations occur, then a key human system that defines the rules of water allocation transfers in the Alberta Water Act. Specifically, the following are some of the characteristics of the Albertan legal framework:

1 The Act retained historical water priority rights;

2 Water reallocations must be accomplished via water transfers;
3 Water management planning is therefore potentially very limited (due to a low volume of transfers), and may be grossly inadequate in forcing desirable adaptations. It is too simplistic to assume that the free market will facilitate adaptation;
4 Legal framework defines the parameters for any adaptation strategy;
5 Currently, the Act can adapt to climate change. Unfortunately, the Act has a clear mechanism where junior priority licenses bear the impacts of climate change. These junior licensees can purchase senior licenses (water transfer), but this might not be economically viable even if this is the correct adaptation strategy.

Voluntary mechanisms (agreements) are being put forward as a way of shifting water allocation. But can these voluntary approaches succeed under the pressures of climate change, or can the legal frameworks be modified to facilitate the necessary shift in water use. Recognizing that legal frameworks can force certain behavior patterns, the question can be extended to establish whether the legal framework can be modified to re-align socio-economic drivers, thereby guiding desirable adaptations.

Socio-Economic Issues Related to Climate Change and Water Resources in the South Saskatchewan River Basin

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The greenhouse effect (often called as global warming), being a global phenomenon, is likely to affect many aspects of the socio-economic-cultural-political aspects of our society. Although the direct effects of global warming are more physical – change in the temperature and precipitation, among others, its many indirect effects tend to touch upon ecosystems and through them various aspects of the human ecosystems.

The purpose of this paper is to illustrate the issues and implication of climate change for the society at large through changes in the water resources. The major conclusion of the study is that collaboration among physical and social scientist is warranted to develop meaningful solutions to this very complex problem.

Significance of Water for the Society

Historically, water resources and climate have played a very important role in deciding the settlement patterns world-over. According to Ayibotele and Falkenmark (1992), water plays many parallel functions both in the natural landscape and in society. It also plays pivotal role in many physical, chemical and biological processes regulating the earth system, where human activities are inseparable in its effects from the natural events.

The present day society is water dependent for many of the functions, including health, food security, energy needs, industrial activities, transportation, and recreation, among others. With all these different functions, water is closely linked to the economic development. However, according to Environment Canada (1980) the relationships between water and economic development are complex and imperfectly understood. Although water may not be a crucial factor in deciding the location of various industries (availability of cheap raw material, transportation costs, and markets appear to be more important in an overall analysis), availability, or lack of it, can influence pace of economic growth of the region. In fact, according to a survey of Saskatchewan rural and urban municipalities in 1994, 28% of municipalities indicated that lack of water is a constraint to future growth or for industrial development (Kulshreshtha, 1994).

Climate change can alter many crucial attributes of water resources in Canada, and in the South Saskatchewan River Basin (SSRB). Through these changes, which tend to be more physical in nature, society is affected in undertaking (or meeting the needs) for various functions. Waggoner (1990) has stated "Climatic variability is brought home to Americans by variable precipitation, and climate change will be brought home to Americans as changes in water resources". This statement applies in full force to the situation that may arise in the SSRB under a changing climate.

Issues for Social Studies

Climate change will affect the society both directly as well as indirectly. Direct effects of climatic variability will come though changes such as higher temperatures, variability in precipitation, and extreme events. These climatic attributes will change human behavior and thus have a direct effect on the society. One should note that society has been adjusting to many of the changes in these climate attributes over the historical past. Thus, it is known that humans are adaptable and make adjustments to a changing environment. The part that is not as well known is how is it done? How do human decide to make adjustments to changing environments? One window on this may come from a review of the past behavior under similar, or equivalent, situations. How have members of society adjusted to changing climate in other parts of the world? Such a review may provide valuable information on measures that have been successful and could be attempted in the SSRB. There is a wealth of experience in other jurisdictions that one can learn from. Such a review would be very important before embarking on the list of adaptation measures for the SSRB. Establishing transferability of these measures is essential before any recommendation regarding their adoption for the SSRB can be made.

In reviewing experience to adaptation in other jurisdictions one has to keep in mind that socio-economic changes occur not only from climate variability but also from other economic and non-economic forces. Consumer tastes and preferences for goods, and technology of production (including emergence of new products) are two major forces shaping future socio-economic systems. Every attempt needs to be made in distinguishing those from climate variability and those from socio-economic or institutional factors.

One of the possible outcomes of the review of adaptation practices in other jurisdictions is to develop a list of best management practices. Many innovative entrepreneurs in these jurisdictions may have developed measures that can reduce the impact of climate variability on the economy, and at the same time are in the economic interests of the entrepreneurs. Among these are those measures that produce not only direct mitigative effects but also associated effects, often called "co-benefits". Generation of co-benefits, for example, in terms of environmental improvement (such as air quality, water quality, reduced level of degradation of land resources, among others), can be used as additional reasons for adoption of such adaptation measures. Applying a no regret criterion, in the face of uncertainties for the climate change impacts and their timing, could be a better course of action to follow.

Implications of Climate Change for Socio-Economic Systems

In determining the socio-economic impacts from climate-induced changes in various attributes of water resources, one must make an effort to distinguish various types of impacts, so that chances of double counting are minimized. Human ecosystems may be affects in two ways: One, a direct result of the climate change on the socio-economic systems, which would affect behavior of the humans; and Two, indirect effects through water resources, where adjustments are triggered by change in the water resources. The former may include changes in production possibility curves and changes in society's preferences for various products, which may bring forth changes in the society. If there is some overlap between these two sources of socio-economic impacts, every effort should be made to avoid them.

In any assessment of the impact of climate change and water resources on the society, although avoiding double-counting is necessary, one should be cognizant of the fact that both direct and indirect effects of climate and water resource changes are relevant. Perhaps an example could clarify this distinction. Change in the water resources resulting in water scarcity could affect society's behavior in water use. People may use water more wisely through the adoption of water conservation measures. More recycling of water may also be an outcome of these types of changes. However, climate change could also affect the demand for certain products that are not required under a warmer climate. One such change may the demand for power. Under a warmers climate more power will be needed for cooling, than for heating. This will affect the water use for power generation. Thus, power generation water use may in part be affected by climate-induced change, and in part due to changes in socio-economic needs of the society.

Conceptually some of the changes in water resource attributes are well known, although their level of change in the context of the SSRB needs to be ascertained. Furthermore, more inter-year and intra-year variability in water availability would also result in higher storage requirements through construction of reservoirs. However, such projects have also been associated with environmental impacts that can have significant effects on the human ecosystems. An assessment of the climate change-induced water resources must be comprehensive in scope to include all relevant socio-economics (direct as well as indirect through ecosystem changes).

Climate change will affect both surface water and groundwater. In some parts of the SSRB, users have no choice – available sources include either surface water or groundwater only. However, in other locations people may have access to both of these water sources. Two issues can be raised in this respect: One, how would supply from these sources of water undergo change under climate change? Interactions between these two sources of water should also be taken into account. Two, how should the society develop conjoint use of these water sources?

One of the most significant changes in water resources under climate change is in terms of deterioration of water quality. If such a change were to occur, it could have both a direct impact on the society, as well as several other impacts on the human ecosystem. For example, change in water quality affects health and productivity of people, and through that competitiveness of economic systems.

Under a climate change it is predicted that primary production, such as agriculture, would move to higher latitudes. The present agricultural region may become too hot and/or too dry to sustain present day agriculture. There may be significant landscape level changes. Availability of water would essentially determine the magnitude of economic activities in this region. In the northern regions of the SSRB the major issue determining economic activities would be soil quality and availability of other factors of production.

Shift of agricultural production would generate several other social issues. For example, expansion of economic activities is heavily dependent on infrastructure availability, such as roads, and community support services. Development of appropriate infrastructure involves decisions that are highly capital intensive. Community viability of existing rural centers would be affected and, unless present infrastructure decisions are made with the impact of climate change in mind, many such decisions may become somewhat risky.

The second issue this shift may bring forth is with respect to aboriginal people, some of whom presently reside in the northern communities. As migration of non-aboriginal people commences northwards, there may be situations where some economic and cultural conflicts may arise.

In addition to the costs to the society of undertaking adaptation measures, climate change through water resources could open up new opportunities. Identification of these opportunities should also be a part of the socio-economic assessment of climate–induced changes in water resources.

Valuation of Water Resources

For many socio-economic issues, further analysis of socio-economic impacts is required. Such methods are used for ranking of alternative options. Frequently this involves a tool such as a benefit-cost analysis. Estimation of benefits or lost benefits involves valuation of water resources in alternative uses. A number of issues arise here. These may include, although not limited to:

- How should value of water be established so that it reflects future concerns that may arise due to climate change? Would an average value of water be sufficient enough to meet with various needs for the above type of project appraisals? Would it be more appropriate to estimate water values for various key locations?

- How should water be allocated among various users? In an average value of water appropriate for such decisions? Alternatively should marginal value of water in alternative uses be estimated for such allocation decisions?

- Should water be valued for efficiency improvement or for regional economic development? Depending upon which one of these frameworks is used, the value of water will be different.

- Related to valuation of water is the issue of pricing of water. At present, there is no explicit charge for water; most charges reflect cost of processing and delivery of water. Major issue related to pricing is whether pricing alone can bring forth a suitable allocation of water under a changing climate?

Other Socio-Economic Issues Related to Water Resources under Climate Change

Under a climate change scenario, many new issues related to human ecosystem and the related socio-economic systems may emerge. The following is a partial list of some of the issues:

- How should project appraisals (analysis) be conducted in the SSRB under climate change and its impact on water resources? Project appraisal needs to keep the impact of climate change in any final decisions regarding investment projects in focus

- How would these changes affect interregional and intergenerational equity? Shortage of water and increased probability of extreme events in the future would certainly affect intergenerational equity. How should society ensure that this equity is maintained?

- How should one finance adaptation cost? Private adaptation costs, by necessity, will be borne by private water users. However, actions of water users could provide significant externalities. If such externalities do exist, major issue is how should costs be shared between the public (society) and private users?

- Related to the water allocation issue is the question of property rights. Under climate change what is an appropriate mechanism to award property rights for use of water? In some jurisdictions, such rights are awarded using the principle of “first come first assigned”. Under climate change that has the potential of changing the priority for water use allocation, how should some flexibility be maintained in property rights based water allocation process?

- Related to the issue of pricing and allocation of water is the question of whether it is in the best interest of residents of the SSRB to develop water as a tradable good. In other words, should markets for water be developed as alternative institutions for water allocation?

- One of the major effects of changes in water availability triggered by future climates is going to be on the international and inter-provincial agreements. In the context of SSRB, there are no international treaties. However, since the basin crosses provincial boundaries, inter-provincial water allocation may become an issue. In what manner should these agreements be modified or maintained in order to serve the SSRB society's best interest?

Analytical Approaches to Socio-Economic Assessment

In order to assess efficacy of various adaptation measures for the SSRB, analysis needs to be conducted to assess pros and cons of adopting such measures. A number of approaches have been prescribed in the literatures. These may include, among others:

- If regional economic development impacts of alternative adaptation measures are desired, application of a regional input-output model is the best method for such assessments.

- If the objective of assessment is to measure creation of economic efficiency, application of benefit-cost analysis is preferred.

- Many of the goods and services that will be affected through climate change-induced water resource changes would be non-market in nature. Development of non-market methods for these situations will be required.

- If adaptation measures bring forth larger changes in the regional economy, there may be a need for computable general equilibrium models.

Barriers to Quality Social Science Research for Water Resources under Climate Change

Quality social science research requires financial resources and quality data. At present both of these are major constraints to undertaking socio-economic research related to water resources and climate change. Let us discuss these issues.

- Poverty of data bases in terms of suitability for such research activities is shown by the fact that no institution collects social science related data on a routine basis. Much of the data need to be collected using primary survey, which becomes an expensive proposition. Furthermore, since most surveys are done in different jurisdictions, using different concepts and measurements, comparability of such data over a period of time becomes a major issue.

- Although Census of Canada does collect information that could be used for such studies, their frequency of 5 or 10 (for some data) is not frequent enough for climate change work. Furthermore, even here the scope of data collection is now being reduced on account of financial stringency in the federal budget.

A second issue serving as a barrier to quality of social science research is related to the nature of uncertainties. In the context of water resources and climate change, there are at least three different types of uncertainties that need to be taken into account:

- Physical uncertainties related to climate variability;
- Socio-economic parameters are changing; and,
- Social variability, created by different social acceptance rates and different reactions.

Although physical uncertainties have been studies in the past, such is not the case with the other two types of uncertainties

A third barrier to quality of social science research is related to the nature of funding support available for socio-science research. Most funding agencies are of the opinion that social science research can be done cheap. Typically funding for such projects is significantly lower than that for the physical or natural sciences. Secondly, industry support for most socio-economic research is relatively poor. This limits the probability of developing a project proposal for many climate change types of research funds.

Need for Interdisciplinary Effort

Climate change and water resource interactions require an integrated approach. It needs to be interdisciplinary in nature. The social scientist need to work with hydrologists, agronomists, climate change scientists, and other natural scientists in developing meaningful interpretation to data and developing proper linkages. In my personal opinion, most socio-economic research efforts cannot be done in isolation. What is required is the socio-economic researchers being a component of the total effort, and a wholly participating members of the team. An integrated approach is a must, with socio-economic information needs are incorporated at the beginning.

Water resources would undergo significant changes under a changing climate. Capturing these changes, as Postel (1992) has put it, "Grasping the connection between our destiny and that of the water world around us is integral to the challenge of meeting human needs while protecting the ecological functions that all life depends on it'. Climate change may provide this challenge to the social sciences.

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BREAKOUT GROUP DISCUSSION

Questions For Discussion Groups: Suggested Approach For Breakout Sessions

Step 1:

What do you consider to be the most important ISSUES (3-5) with respect to your group theme as they relate to the vulnerability of the South Saskatchewan Basin to climate change ?

Step 2:

For each of these issues, rank their importance with respect to impacts in each of the following themes (1 denotes not significant, 5 denotes extremely important).

* environmental (biophysical) impacts
* economic impacts
* social impacts

Step 3:

For each of these issues, provide a list of key stakeholders who will be making adaptation decisions on the basis of available information.

Step 4:

For each of these issues, list what you feel are:

* existing barriers to adaptation
* the most critical limiting knowledge gaps that need to be addressed to allow effective adaptation to occur

Report of Group 1
Hydrology and Hydrologic Modeling

Al Pietroniro

Important Issues

- Future scenarios of all hydrometric variables
  - Precipitation, temperature (reasonable), runoff, soil moisture etc…
  - Spatial and temporal variability
  - Future land-cover/land-use changes are not incorporated in current predictions.
- How important is this?
  - Presumption in the scientific community is that current climate/hydrology scenarios are adequate for addressing some issues.
- Improved water balance/hydrology/ag and bio-meteorology modeling
  - Depression storage
  - Snowmelt runoff
  - Operational models – degree-day, should be improved on by going to energy balance approach.
  - Sublimation – unknown
  - Hydrological models are necessary for distributed water balance
  - Improvements are necessary to deal with details not considered in current approaches.
- Water Supply and demand
  - Reservoir storage capacity in headwaters
  - Climate change is just another stress – system is already over-allocated in Alberta
  - Irrigation districts are about 85 to 90% of all water.
  - Water quality concerns (bio-chemical contamination)
  - Conflicting demand ecosystem (IFN) vs. consumptive use
- Diversion and inter-basin transfer from the north to the south Saskatchewan river
  - Inter-connected –integrated allocation system
  - Adaptation may lead to re-allocation
  - Some feel economics are not there
- Regional distribution of groundwater supply
  - Surface/groundwater interactions
  - Increasing use of groundwater
  - We have no idea and no models to deal with groundwater on a regional
  - Impacts of withdrawals on streamflow

IMPACTS

Issue	Environmental	Economic	Social
Future scenarios (climate and hydrology)	*****	*****	*****
Improved hydrological models	*****	***	***
Water supply/demand	*****	*****	*****
Diversions	*****	****	****
Regional Groundwater	****	****[a]	****

a could be *****

* Least important
** Marginally important
*** Average importance
**** More important
***** Very important

STAKEHOLDERS

(1-Scenarios, 2-Improved Models, 3-Supply-Demand, 4-Diversions, 5-Regional groundwater)

Groups	Issues
Provincial Government **all issues**	1. Scenarios will play a small role but perhaps an increasing role in provincial decisions and policy 2. Provinces will not depend solely on scenarios 3. All other aspects are important to various groups and divisions within the provincial government.
Federal Government **all issues**	1. National perspective 2. Mandate for a national perspective 3. Supply and demand interested from a Department of Indian Affairs and Northern Development perspective. 4. Diversions are important from an inter-provincial and international perspective 5. Not primarily a federal interest except from a national and trans-boundary aspect.
Municipal Government 2,3,5	1. No real interest in doing the work but will be interested in results 2. Same as above 3. Same as above 4. Diversions will not be of interest 5. Depends on supply source but potentially quite interested
Irrigators and producers 1,2,3,4,5	1. Are not convinced that the scenarios are useful. As we move to more certainty in prediction there will be more interest. 2. Indirectly through the provincial or federal ag agencies. Changes in soil moisture may be of tremendous interest 3. Very interested 4. Very interested 5. Some interest – stock watering
Power Utilities 1,2,3,4	1– 5. Interest in all issues
Industry 1,3,4,5	1. Indirect use - provincial agencies 2. No 3. Yes 4. Yes 5. Not a big impact, but some isolated cases (cold lake as example)
NGO's 1,2,3,4,5	1-5.All issues
First Nations 3,5	1,2. indirect 3. some impact 5. some impact for reserves

ISSUES, BARRIERS AND GAPS

Issues	Barriers	Gaps
1) Climate scenarios	Confidence in existing scenarios (spatial and temporal)	Improved confidence Improved spatial and temporal scales (better models, downscaling)
2) Hydrological Models	Existing models are practical and reasonable for design Data is important (met, streamflow, satellite) Too expensive Little use of non-traditional data sources	Improved representation from a water balance perspective Better tools for evaluation of adaptation methods.
3) Water supply-demand	Lack of confidence in projections of water supply and demand scenarios. Time scales work against change (the problem is not now) Public attitudes are difficult to change.	Improve 1 and 2 Users do not have a good idea of risk in terms of water allocation and the future Improved communications of results Direct effects of climate change on crop-water demand (non-irrigated and irrigated areas) In-stream Flow Needs and water quality
4) Diversions	Expense Unknown ecological impacts Water rights Impacted	Unknown ecological impacts
5) Regional groundwater	Unknown extent of groundwater supply – no baseline information Cost of development and treatment Maintain present observation network	Requires a baseline Understand recharge rates and locations Understand consumptive use.

Report of Group 2
Water Management, Socio-Economics and Legal Aspects

Francoise Bouchart

1. What are the Issues to be addressed?

The participants identified the following issues:

- What are the best management practices?
    - Using the resource efficiently
    - Maximizing the benefits
- What are the "best" mechanisms to facilitate adaptation?
- Management both in the short- and long-term.
    - What are the drivers of each?
- Where / what use is water most valued? (production value, recreation value, amenity value, spiritual value, etc.)
- Current vulnerability society / hydrologic
- Will market based mechanisms provide for the achievement of socially-desirable goals
- Where is climate going?
- Do we need a high level of precision?
- What are the trade-offs resulting from conflicting demands?
    - Who are the gate-keepers?
- Policy directions within the context of uncertainties (perceptions).
- Best regional planning scheme to account for spatial / temporal variability.
- Land use changes in surface / ground water quality and quantity.
- Changes (seasonal / other) in water sources / impacts
    - Late season water supply
- Credibility gap re: climate change.
    - Communications to decision makers / public.
- Are we using science to answer their questions?
- Is information applied at the right time and the right place?
    - Knowledge transfer
- Where is water going to be and when?
    - Implications for infrastructure economics / environmental impacts

2. What are the Priority Issues?

Having brainstormed the issues, the participants condensed the above list to the most important issues to be tackled (the Priority Issues). The result is the following 4 priority issues:

1. Improved understanding of spatial and temporal distribution of water at appropriate precision.
2. Appropriate mechanisms to facilitate adaptation and enhance responsiveness.
3. Trade-offs will take place that could compromise the achievement of 1 or more values we place on water.
4. Information needs of different stakeholders are not being met.

3. What is the Overarching Goal?

The participants identified that the over-arching goal is to <u>reduce vulnerability</u>.

Goal: Reduce vulnerability

Objective: To identify mechanisms / systems to facilitate adaptation.

Strategies: (1) Spatial and temporal availability
(2) Trade-offs / drivers
(3) Information needs

4. Who are the Stakeholders?

The participants established the following preliminary list of stakeholders:

- Public
- Agriculture (AIP, Irrigation districts, agri. Organizations)
- Energy (TransAlta, Sask Power, Infrastructure)
- Umbrella groups (e.g., Bow River Basin Council, Partners for the South Sask. River)
- Provincial Government agencies (AB Env, Infrastructure, AAFRD, SRD, etc.)
- Urban and rural municipalities
- First Nations / Metis
- Environmental NGOs

5. What are the Barriers?

The participants identified the following preliminary list of barriers to meeting the over-arching goal of reducing vulnerability:

- Perceptual – need to enhance knowledge
- Limited capacity to respond

- Conflicting priorities
- Limited political will (especially in Alberta)
- Lack of integration / interaction – everyone reinventing the wheel
- Access to information / data / knowledge

SUMMARY AND SYNTHESIS

Water Resources in the South Saskatchewan River Basin: A CCAF Workshop Wrap-up Remarks

Bob Halliday
R. Halliday and Associates
Saskatoon

Introduction:

Summarizing the presentations and discussions of the last two days in a short period of time is a major challenge. What I would like to do is first discuss some of my biases and interests, then review the situation in the South Saskatchewan basin, comment on vulnerability and adaptation, and close with some suggestions on scope for future proposals.

I am an engineering hydrologist by training but have had a long experience in water data acquisition and water planning, especially interjurisdictional water management. Recently I have done some work related to flooding in Canada and elsewhere.

I see hydrology as an earth science, one with considerable empiricism. I therefore have a fondness for process science, particularly as related to land use and runoff. We need to keep in mind that runoff is a residual, albeit a well measured one. Runoff is about 50% of precipitation in the mountains and 10-15% of precipitation in the plains of the South Saskatchewan basin.

Finally, I tend to be an agnostic on climate change scenarios.

Two other scene-setting items occur to me. These relate to economics and data.

An American senator once said, "water can run uphill - towards money". (*Cadillac Desert*) My point is that economic analysis of water projects may be helpful but it is rarely the determining factor in deciding whether a "good" project will be built or a "bad" project will not. A typical benefit-cost ratio for a prairie water project is in the order of 0.4. Other factors, both political and social, tend to influence the outcome.

Adam Smith, the great Scottish economic philosopher (*The Wealth of Nations*) and guru to free-market economists, takes the view that if all the competing ideas aimed at dealing with a problem are put on the table the best idea will win. He is probably wrong, as least as it concerns water and the environment.

A few words about data.

There is a tendency now as computing power increases to consider that all data are equal. My view is that there is still a need to examine data inputs carefully to ensure we understand their provenance and uncertainties. Sensitivity analysis should be part of modeling.

Finally, there are amazing transformations taking place in the data world, from point data to spatial data and archival data to real-time data. We shouldn't underestimate the challenges those changes pose for operational hydrologists and researchers.

The South Saskatchewan Basin:

Some considerations concerning runoff, current and future water demand, and other basin issues taken from my interpretation of the workshop discussion are:

Runoff

- Eighty percent of the water that flows across the three Prairie Provinces originates in the eastern slopes of the Rockies. That is, from two grid cells in a GCM.
- Our analytical framework must therefore consider both the mountain region where the water originates and the plains region where the water is used.
- There is evidence that the 20th Century was relatively benign from a climate perspective. Ten-year droughts may be more of a consideration than we think.

Current Water Demand

- Water demands in Alberta equal the supply during drought years, taking into account the Master Agreement on Apportionment.
- Eighty percent of the Alberta allocation is to irrigated agriculture.
- There are no current allocation problems in the South Saskatchewan River in Saskatchewan although these problems exist in smaller streams in the basin.
- Water quality and environmental quality problems arise during droughts.
- There is relatively little attention paid to water conservation in the basin.

Future Water Demand

- If present trends continue, Alberta will "hit the wall" at some point, despite new technology and conservation.
- Additional heat units in Saskatchewan could lead to higher valued irrigated crops and Saskatchewan, too, might approach full utilization of its share of the River. Lake Diefenbaker and its diversion works are considered as regional resources in the province and could be used to meet water shortages outside the basin.
- Reduced flows will lead to increased water and environmental problems.
- There will be pressure to transfer irrigation water rights to higher valued (and more junior) uses. This raises rural/urban and social equity issues that will require considerable political leadership to address.

Other Issues

- Climate change effects should not be considered only in a drought context. An increase in the magnitude of low frequency (say 1:25) events has a significant impact on urban runoff, and hence storm sewer and other infrastructure design. At the same time changes in low frequency (say 1:1000) events pose challenges as well.
- Seasonal changes are as significant, if not more so, than annual changes.

In summary, the South Saskatchewan River basin is vulnerable to current climate variability and will become even more vulnerable under climate change scenarios.

Adaptation:

There are a number of factors that come into play in considering the basin's vulnerability and its ability to adapt. Some of these require new knowledge if a solution is to be found.

History

- Long history of dealing with natural variability through ad hoc measures, design improvements and financial support.
- The decade of the 80s was not unlike the decade of the 30s in Saskatchewan, yet the social and economic consequences were nowhere near as bad. In some measure this was because 60,000 farmers did things differently.
- The basin is agricultural and agriculture can adapt.

Long-term Sustainability

- Need for resilient communities that can withstand extreme natural events without devastating losses, diminished output, reduced quality of life, or significant injections of outside aid. (Mileti, 1999)
- The 2001 drought may have cost about as much as the 1997-98 ice storm. Can we withstand a 10-year drought?

Policies/politics

- Climate change is not a good news story. There are trade-offs (winners and losers) and the required timing of necessary actions is uncertain.
- Fear can be a motivator but use of leveraged worst cases destroys credibility.
- Pressure to increase supply through diversions may lead to other problems.
- Policy needed for reallocation of water rights.
- Aboriginal right to water a very specific issue needing resolution.
- Access to Canadian data still inhibits research.
- Science in support of policy is required. Policy-makers need something to work with. Can research results be described in terms of a specific policy response?

- Use umbrella groups as a means of stimulating action.

In summary, adaptation is possible but will require improved scientific understanding, policy changes and attitudinal adjustments.

Some Final Thoughts:

Al Pietroniro in his presentation, cited Klemes 1996 on "kunks" and related matters. Kunks being a **k**nown **unk**nown, and by inference unkunks being a **unk**nown **unk**nown, and skunks being a known that smells. Klemes advises:

> Kunks should be treated with rigor.
> Unkunks should be treated with care.
> Skunks should be avoided.

In the same paper Klemes cites Confucius in saying that knowing that you don't know something is the path to knowledge.

This is all worthwhile advice in designing climate change impacts and adaptation research projects and in communicating findings.

There is a tendency for scientists to gather to talk about the things they disagree on while being silent on the things in which they are in agreement. That makes for livelier meetings and advances the science. However a poorly informed viewer may well draw a conclusion that issues scientists think of as self-evident are the basis for great controversy.

Scientists also like to think that there are resolving questions to a high degree of certainty, say several standard deviations, and will plead uncertainty until that point is reached. We need to keep in mind, however, that civil law works on the basis of weight of evidence. That is 50% plus one.

A policy-maker is much more likely to be in the camp of "I don't want it perfect, I want it Friday" that looking for seven-sigma reliability. That is, unless they are looking for a reason not to do something! How we communicate with politicians and policy-makers is therefore critical to advancing science.

We also need to keep in mind that there is always far more money available to solve a problem than to avoid one. Presenting research proposals as potential solutions to problems is useful. At the same time the proposal should seek to respond to a very specific question and be focused enough to be reasonable for the resources requested.

Because of the nature of the Climate Change Action Fund, I'd speculate that a proposal having a socio-economic dimension would have a greater chance of success than one based entirely on physical science. The means by which the public or operational agencies would be involved is also important.

Thank you for your attention.

A Framework for Adaptation within the Water Resources Sector in the South Saskatchewan River Basin

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According to the IPCC Third Assessment Report, adaptation refers to the adjustments in ecological, social or economic systems in response to actual or expected climate stimuli, their effects or impacts. Adaptation can reduce the likely impact of the climate change significantly. Such a process can be planned or unplanned. In the absence of a planned process, individual and communities will adapt autonomously to the changing environment, particularly when such changes are forced upon them. Cost of such autonomous adaptations may be high. A planned adaptation course is therefore, preferable. A planned adaptation requires development of a strategy and its efficacy in the context of the climate change. In addition, water resource managers require methods of assessing the vulnerability of water resources systems to climate change to help identify when and where adaptive measures should be applied.

In developing the framework for evaluating adaptation strategies, a workshop of natural and social scientists was convened in Calgary on January 27-28, 2002. At this Workshop, various viewpoints in the climate change and water resources interactions and their impacts on the ecosystem and society at large were discussed. Based on a number of general and roundtable discussions at this Workshop, we have drawn a number of areas that need to be prioritized in the context of water resources and climate change in the SSRB.

This Chapter is divided into three parts. Part one presents an overview of the framework that is needed to study the adaptation measures in the Basin, and the modeling needs for such an undertaking. The next section addresses issues related to water supply and demand aspects, and adaptation process, with particular reference to areas that should be given a higher priority. The last section presents recommendations to the CCAF for future studies.

Analytical Framework for Adaptation to Changing Water Resources under Climate Change

An analytical framework required for climate change impact assessment needs to follow an integrated assessment modeling approach. An overview of this model is shown in Figure 1. This generic approach may not be congenial to each and every analyst, or may not apply to all the river basins, but in the context of the SSRB appears to be suitable. The suggested approach has a clear flow associated with consequences of each stage on the other. The overall purpose of the suggested approach is to display consequences of any adaptation or other measures for the ecosystem and thereby for the society as a whole. Thus, the end result of the modeling framework is to select a set of most desirable adaptation measures for the South Saskatchewan River Basin (SSRB) under climate change-induced changes in water resources. This is achieved through eight sets of activities, organized under eight components. All the components are related to the decision-making process either directly or indirectly as described below. The entire process is integrated, such that output of one component becomes input for the next. Some components may be iterative in nature, since some of the components are interdependent.

Let us start with the beginning of the model components. The first component deals with the climate change as pertinent for the SSRB region. The major purpose here is to develop a hydrological scenario for use in the study of the basin. Effects on water supply and its various characteristics would be the prime focus of this component.

The second component starts from a socio-economic perspective. Here a vision of what the region would look like in the future is provided. This would be called a "business-as-usual' scenario. Under this scenario, various socio-economic activities that would exist in the region and their respective water requirements (direct and indirect) are estimated. The output from this component feeds into Component 1, in determining the supply-demand balance. Exact nature of various attributes of water resources under this lack of balance with climate change needs to be developed in the first component as well.

The third component addresses the identification of vulnerabilities to a supply-demand imbalance of water in the SSRB and the physical quantification of the impacts. Two types of impacts are identified here: Ecosystem level and human system level. The latter impacts are dependent, at least in part, on ecosystem level changes. One of the major effects of climate change is on the vulnerability of the ecosystem and the socio-economic system. Valuation of these impacts is the focus of Component 4. Both ecological and socio-economic valuations are desired here. The socio-economic valuation would involve both market-based as well as non-market goods valuation.

Once these four components have been constructed, one can commence the process of experimenting with adaptation measures. This is the focus of the next three components. In Component 5, various adaptation strategies (measures) that could be available to the society are identified. Each of these must first go through a feasibility analysis, to show whether these can or should be pursued or not. Once a decision to proceed is made,

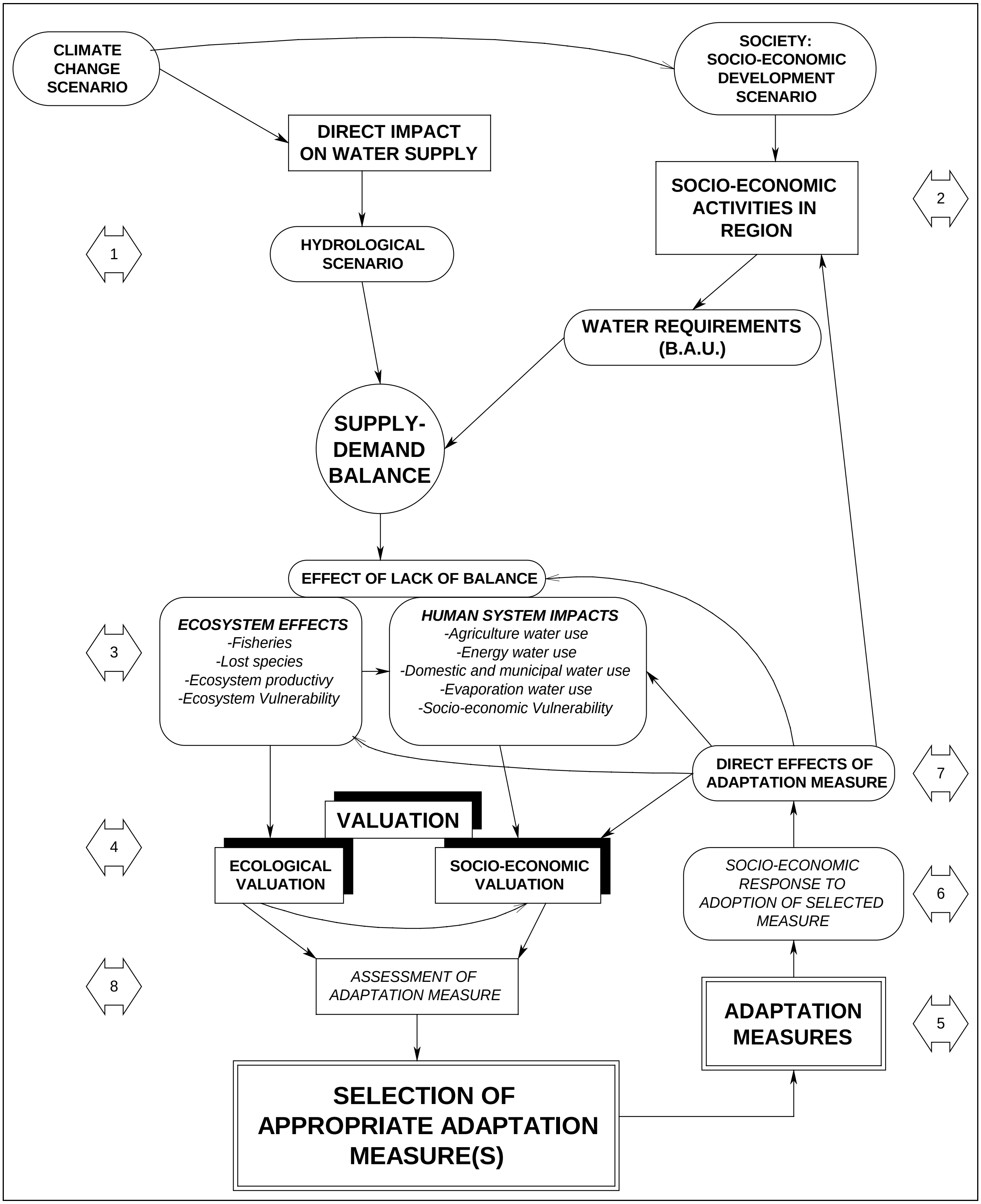

Figure 1: Schematic of Assessment of Adaptation Measures for Water Resources under Climate Change

activities in Component 6 begin by establishing the likely response of the society to undertake these adaptation strategies (measures). The response pattern would feed into the next component – Component 7, which addresses various issues related to the likely effects of the adaptation strategy (measure).

Four types of likely impacts of the adaptation measures are suggested in Figure 1. One, they will affect the water supply-demand balance, and in turn ecosystem and human systems. Two, it may alter, over a course of time, the socio-economic activities in the SSRB, which would have an effect on water use and thereby on the water supply-demand balance. Three, the nature of impact on the socio-economic system may also be affected by the possible adoption of the measure. Lastly, the adaptation could alter the valuation framework of the society for water resources and may affect the final assessment of a given adaptation strategy (measure).

The last component in the suggested integrated methodology is the assessment of adaptation strategy (measure). In this component, criteria for the selection are decided along with appropriate analysis that follows.

Although it may appear that the suggested approach is deterministic, it is far from this. The degree of uncertainties in hydrological and socio-economic scenarios, along with society's response for adoption of the selected adaptation measure, may be important in the final selection of the measures and their robustness under varying conditions.

Research Priorities in the Context of South Saskatchewan River Basin

Based on the discussions at the Workshop, we have attempted to identify major issues and priority areas for the SSRB in the context of climate change. Discussion is divided into three parts: Hydrological Studies; Socio-Economic Studies; and Assessment of adaptation measures. The first part includes Components 1, 3 (Ecosystem effects) and 4 (ecological valuation), while the second part includes Components 2, 3 (human system impacts) and 4 (Socio-economic Valuation). The last four components, as shown in Figure 1, are included under the third part. Each of these is discussed in the order shown. For each of these, priority areas for future research are indicated.

Hydrological Studies

Hydrological studies involve a set of interrelated investigations of hydrological processes in the SSRB, along with their respective ecosystem impacts. Various research activities are organized under the following four topics:

(1.1) Water Supply

Major direct impact of climate change on water resources would be felt on the supply side. Past studies have predicted several characteristics to be affected by climate change: (i) Quantity of water (affected by snowmelt and stream run-off); (ii) Seasonal pattern of water availability; (iii) Inter-year variability of stream flow; (iv) Extreme events, such as droughts and floods; and (v) Recharge of groundwater aquifers. Most likely change in the SSRB would be related to extreme events – droughts and floods. The frequency of droughts is predicted to increase under a changed climate. This will have implications for vulnerability of the region, both in terms of ecosystem and human systems.

We have selected four priority areas under the general scope of hydrological studies. These include:

Priority Area 1: There is a need for developing an operational model for the SSRB capable of predicting various characteristics of water supply using existing state-of-the-art in such models.

Priority Area 2: Modeling of snowmelt runoff in the basin is not very well understood. This area requires some special modeling effort, which could then be incorporated into the model developed under Priority area 1.

Priority Area 3: Factors that affect supply (availability) of groundwater under climate change are not very well understood, and require some special consideration. As with the priority Area 2, any modeling effort for this aspect, once completed, can be incorporated into the Operational Model under Priority Area 1.

Priority Area 4: We recommend that analysis of the SSRB should be done using a standard set of hydrological scenario(s). Generation of this scenario should also be undertaken, and made available to all project participants.

(1.2) Water Supply-Demand Balance

A methodology needs to be developed for balancing the availability of water under a given hydrologic scenario against its requirements (or demands on it). The issues facing this area would include, among others:

- What should be the scale for this balancing – Basin as a whole (too aggregate and therefore, not appropriate) or node by node (too detailed and resource intensive)?
- How should one account for evaporation losses in balancing water at the selected scale?

- What characteristics (attributes) of water resources should be included in this stage?
- How should one treat surface and groundwater in developing balancing?

Priority Area 5: Interaction between surface water and groundwater, both in supply and use, has not been studied for the basin. A study identifying and estimating these interactions within the SSRB needs to be conducted.

(1.3) Ecosystem Effects

Ecosystem level effects resulting from lack of water supply (relative to its use) would be the next logical step in studying the impact of climate change on the SSRB though water resources. Effect of increased carbon dioxide on natural ecosystems may be substantial. In addition, natural ecosystem may adjust very poorly to changing climate, leading to major disruptions (such as loss of biodiversity, population shifts). Various aspects of the ecosystem would need to be studies here. Identification of crucial ecosystem for a given part of the SSRB will need to be undertaken. One of the ecosystem effects, which has high significance for the human system effects, is change in water quality.

Priority Area 6: Impact of climate change on water quality at various locations within the SSRB is a topic worthy of a detailed and comprehensive assessment.

(1.4) Physical Vulnerability from Water Resources

The ecosystem effects, as determined above, can have a serious effect on the physical vulnerability of the SSRB. Vulnerability of the region is expected to increase under more frequent drought conditions, as well as because of higher costs of adaptation. To what extent would such be the case needs to be determined.

<u>Socio-Economic Studies</u>

The second set of studies deal with the socio-economics of climate change through water resources. These studies are grouped under the following five categories:

(2.1) Socioeconomic Baseline and Business-as-Usual Study

A good baseline study of various aspects of the region that affect water use and adaptation to climate change need to be documented. This documentation should serve as a starting point for all socio-economic and related evaluations. In addition to the current set of socio-economic data on the SSRB, there is a need for projecting the SSRB to some pre-selected future date for which climate change impacts are estimated.

A suggested list of water users in the SSRB would include four major ones: Agriculture (Irrigation and stockwatering); Power generation; Municipal and Industrial; and Other domestic water users.

Priority Area 7: A standard set of socio-economic assumptions (or scenario) should become the basis for all research activity related to water resources in the SSRB. Development of this scenario should be given a high priority.

(2.2) Water Requirements

Estimation of water requirements for various users under business-as-usual (BAU) conditions is the other side of the water balancing. Methodology needs to be developed for the impact of climate change on water use (requirements). The four user types need to be treated separately in this estimation. In addition, indirect water use should also be estimated in the SSRB though appropriate tools. The scale at which these estimates are derived should be identical to the scale of water supply estimation. Results from these studies would become input into the water supply-demand balancing.

(2.3) Human System Impacts

Human systems would be affected both directly as well as indirectly by climate change. It is recognized, at the very outset, that impacts through water resources are mostly indirect impacts on the human systems. Change in the behavior of individuals under a different climate scenario should have been already considered (accounted for) under the BAU scenario in the previous section. A number of issues can be addressed within this set of studies:

- What aspects of human society would be affected through climate-induced changes in water supply and its other attributes?
- What economic activity would find it difficult to survive under prolonged drought?
- What sectors would be particularly vulnerable under frequent droughts?
- How would climate change through changes in water resources affect human migration patterns?

Priority Area 8: Studies should be undertaken to identify the losers/gainers from climate-induced water changes are in the SSRB.

Priority Area 9: A study linking migration patterns within the SSRB (or even elsewhere in a comparable situation) needs to be undertaken.

Priority Area 10: Sectoral impact assessments are needed to determine impact of climate-induced changes in water resources in the SSRB. These should be undertaken for the four sectors listed above.

(2.4) Assessment of Socio-economic Vulnerability of the SSRB

Socio-economic vulnerability is a result of the impacts of climate-induced water resources on the human systems. Here both direct and indirect impacts need to be incorporated. The vulnerability of the SSRB society as a result of climate-induced changes in water resources needs to be addressed. Identification of changes in attributes of water resources that the society would be more sensitive to also deserves some focus.

(2.5) Valuation of Socio-Economic Impacts

Although estimation of physical effects on human systems would convey certain meaning to the society, for a comparative analysis these need to be converted into a common yardstick. In economics this yardstick is monetary value. Valuation of human impacts must include both market and non-market goods. Methodologies for non-market valuation are still in development stage, and more needs to be done in the context of water resources scarcity.

An associated issue for valuation of water is the scale at which water should be valued. For example, can an average value for the SSRB suffice for estimation of such impacts? Furthermore, there are at least two types of values that can be estimated for a given water user: Average value and Marginal value. Which one of these is more appropriate in this context?

Priority Area 11: A study on value of water for various water uses is required for a proper assessment of the damage done as well as for an assessment of adaptation measures. Focus should be placed on estimation of both average and marginal values.

Assessment of Adaptation Measures

The above two sections have laid the foundation for the analysis of adaptation measure(s) that could be selected under the climate-induced change in water resources. In this sub-section, additional steps required for reaching the final selection are described. Discussion is organized under the following four sub-sections:

(3.1) Selection of Adaptation Scenarios

The focus of studies in this set of activities is on adaptation measures that would make most sense in the wake of climate-induced changes in water resources. Since society has continually been making adjustments to changing climate (and to changing water resources), a good survey of such measures would provide the necessary background.

Priority Area 12: A survey of existing adaptation measures, related to water resources, needs to be undertaken. The scope of this investigation, by necessity, should be dryland worldwide.

(3.2) Selection of Criteria for Evaluation

Adaptation measures can be evaluated and ranked using a multitude of criteria and indicators. This research will develop a list of acceptable empirical criteria for use in the assessment of various adaptation measures. A tentative list of such indicators is shown in Table 1.

Table 1: Suggested Criteria for Evaluation of Selected Adaptation Options

Economic Criteria	Social Criteria	Ecological Criteria	Institutional Criteria
Benefit-cost Ratio	Equity and Social Justice	Risk-Benefits Ratio	Transactions Cost
Net Present Value of Benefits	Social Acceptability	Vulnerability reduction	Implementability
Cost Effectiveness	Externalities		Flexibility
Economic Viability	Local priorities		

The above list, by no means, is comprehensive, and research is needed to add relevant criteria for assessment.

Priority Area 13: A study involving various criteria that can be used for assessment of various adaptation options should be undertaken. The selected criteria should be acceptable to CCAF as well as to various stakeholders in the SSRB. Method of estimation for each of these criteria should also be a part of this study.

(3.3) Estimation of Societal Response to Adaptation

Effectiveness of an adaptation measure can only be achieved if the society adopts it. Again various adaptation options would take different time for their full (or desired) level of adoption. This adoption process may be facilitated or impeded by other factors.

Priority Area 14: A study involving adoption of selected adaptation measures and factors that act as barriers to their respective adoption should be undertaken.

(3.4) Estimation of Direct, and Second and/or Third Round Effects of Adaptation

Estimation of impacts of a selected adaptation measure would be based on the methodologies listed in the first two sub-sections, along with methodology described in this sub-section.

<u>Selection of Appropriate Adaptation Measure(s)</u>

Selection of adaptation measures will be based on the above three-part studies. These measures will be selected using criteria listed above. In some cases, a multi-criteria assessment approach may be preferred. In order to accomplish this, there exist some need for planning for such events by various water management institutions. Development of polices that would create an environment amenable to adaptation is another area that needs further investigation.

Priority Area 15: Measures need to be undertaken for improving the institutional capacity for undertaking research related to climate change-induced water resources issues.

Priority Area 16: Further examination of present policies that would be either helpful to water users under climate change or would act as barriers to adoption of innovative measures should be undertaken. This may include development of an inventory and typology of potential policy measures that may facilitate or promote adaptation to changing water resources.

Summary and Recommendations

In order to study the climate change-induced impact of water resources in the SSRB, an integrated assessment model is recommended. Scientists in different fields would provide inputs into developing and using this type of modeling framework to select best adaptation measures for the South Saskatchewan River Basin. Rather than a single major comprehensive study, we envisage a linked set of smaller projects each investigating a certain component of the integrated assessment framework recommended here. In reviewing this type of methodology, 16 areas of priority were identified.

In addition to the above priority areas, we make the following three recommendations:

One, The make-up of teams of scientists should by necessity be interdisciplinary in nature. Natural scientists, hydrologists, climate change experts, and social scientists (economists, planners, and sociologists) have to be the core of these teams. An integrated assessment requires a collaboration among physical and social scientists.

Two, To the extent possible, all teams of researchers use a common set of data for the South Saskatchewan River Basin. This could be facilitated by the Prairie Adaptation Research Collaborative, which could serve as a repository of spatial and other databases. This would make any comparison of various studies easier and would further facilitate the implementation of the selected adaptation measures.

Three, Since there are alternative approaches to modeling hydrology and social impact assessment, we recommend that teams should contain members with different modeling philosophies, working together. This would facilitate development of a "hybrid" methodology.

Appendix A

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