The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2138-07

Joint ICTP-IAEA Workshop on Vulnerability of Energy Systems to Climate Change and Extreme Events

19 - 23 April 2010

Impacts of and Adaptation Options to Extreme Weather events in the Hydropower Sector

Douglas Sparks
Hydro-Québec
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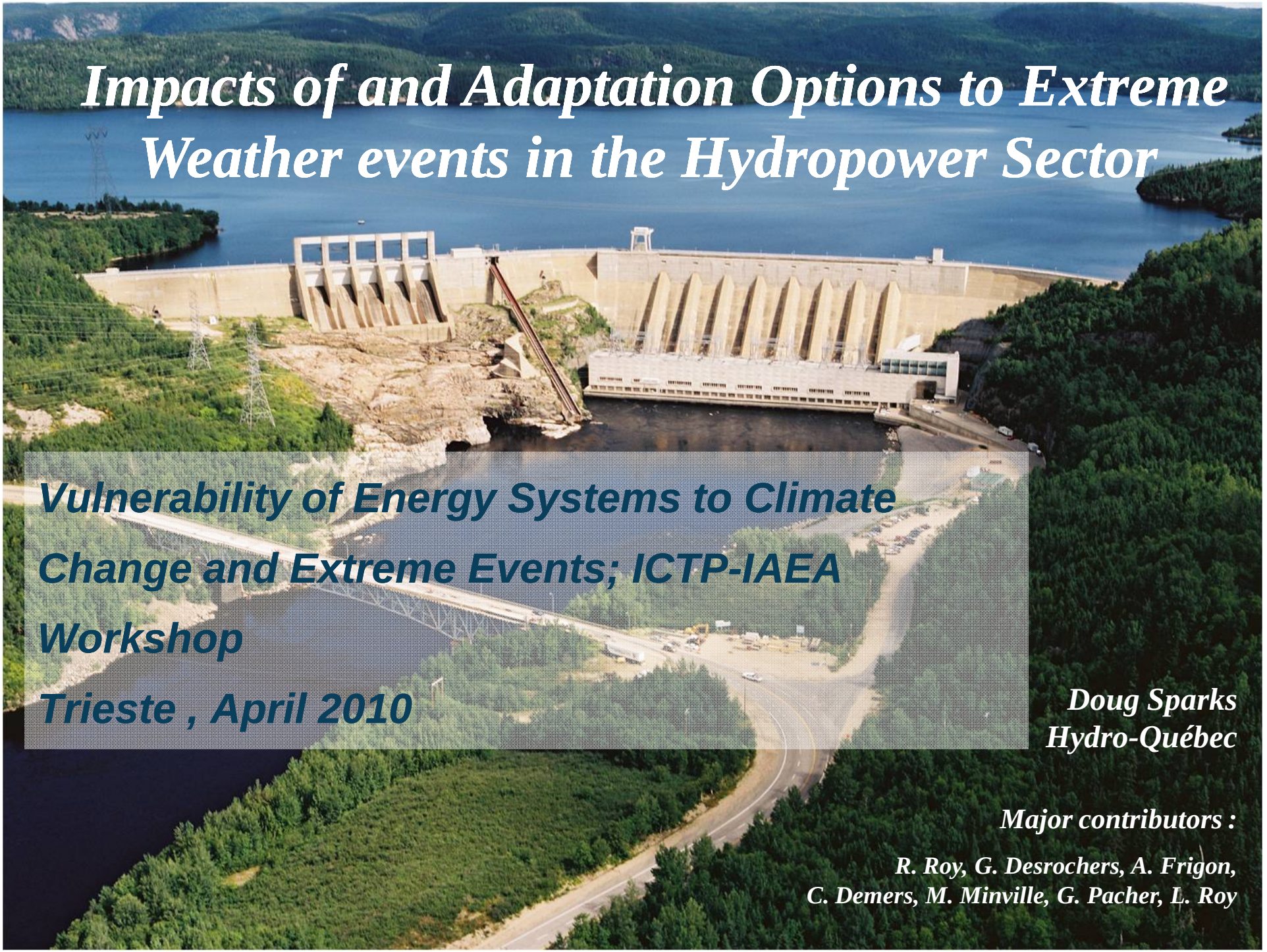
Canada



Impacts of and Adaptation Options to Extreme Weather events in the Hydropower Sector

Vulnerability of Energy Systems to Climate Change and Extreme Events; ICTP-IAEA Workshop

Trieste , April 2010

Doug Sparks
Hydro-Québec

Major contributors :

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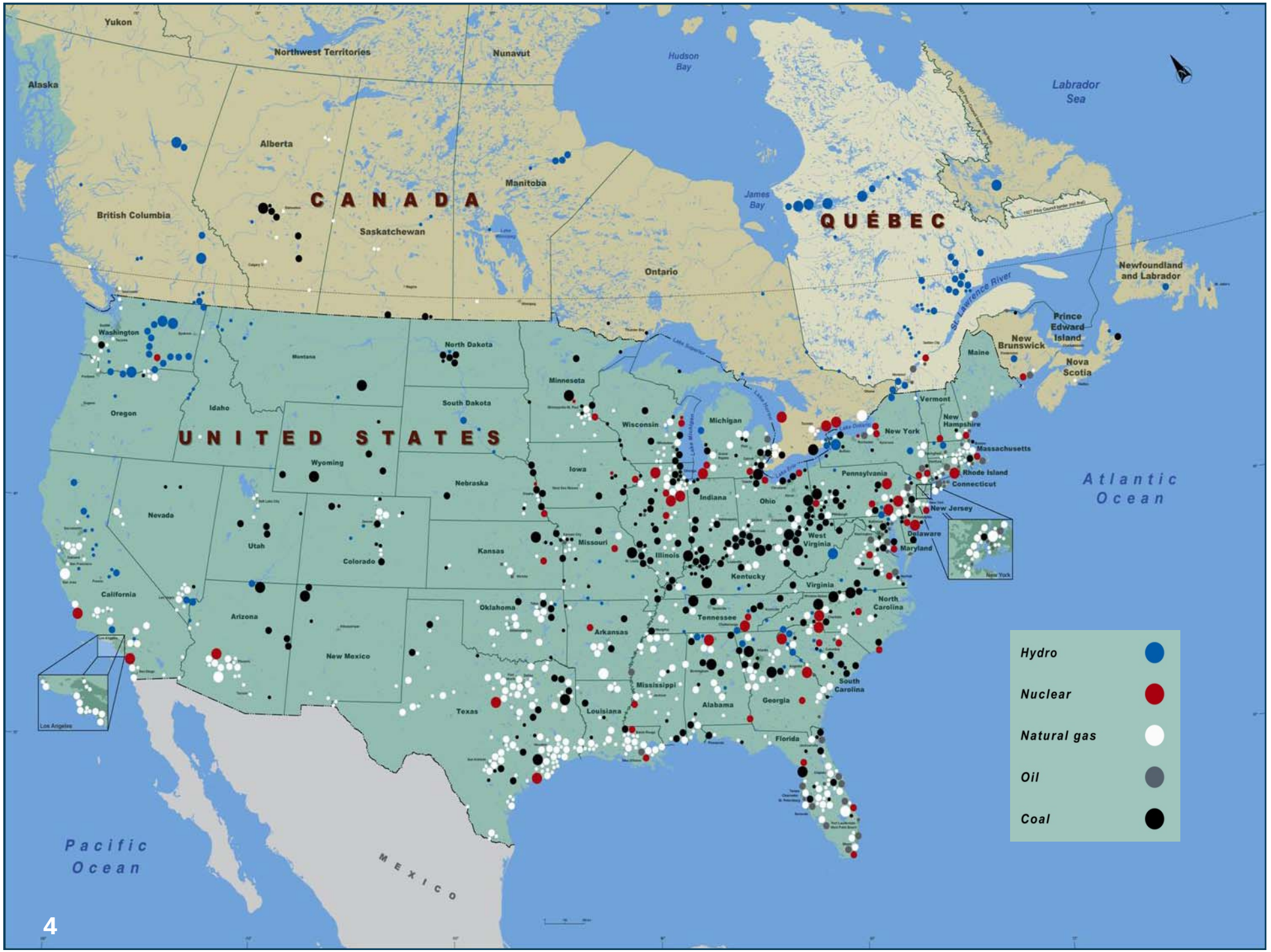
Presentation plan

1. **Hydro-Québec, Climate Change and Extreme Weather**
2. **Hydropower Vulnerabilities and Strategies**
    1. Operations
    2. Planning
3. **Current evaluations of CC on the Hydropower sector**
    1. Inflows (net gain or loss)
    2. Extremes
4. **Adaptation Options**
    1. Operations
    2. Planning


Yukon
Northwest Territories
Nunavut
Alaska
Hudson Bay
Labrador Sea
Alberta
Manitoba
CANADA
British Columbia
Saskatchewan
James Bay
QUÉBEC
Ontario
Newfoundland and Labrador
St. Lawrence River
Prince Edward Island
New Brunswick
Maine
Nova Scotia
Washington
North Dakota
Minnesota
Vermont
Oregon
Idaho
South Dakota
Wisconsin
Michigan
New Hampshire
UNITED STATES
New York
Massachusetts
Wyoming
Pennsylvania
Rhode Island
Iowa
Nebraska
Connecticut
Indiana
Ohio
New Jersey
Nevada
Utah
Colorado
Kansas
Missouri
Illinois
West Virginia
Delaware
Maryland
California
Kentucky
Virginia
Oklahoma
North Carolina
Arizona
Tennessee
Arkansas
New Mexico
Mississippi
South Carolina
Texas
Louisiana
Alabama
Georgia
Florida
Los Angeles
Hydro
Atlantic Ocean
Pacific Ocean
MEXICO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Michigan
New York
New Hampshire
UNITED STATES
Massachusetts
Wyoming
Iowa
Pennsylvania
Rhode Island
Connecticut
Nebraska
Indiana
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Atlantic Ocean
Nevada
New Jersey
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Colorado
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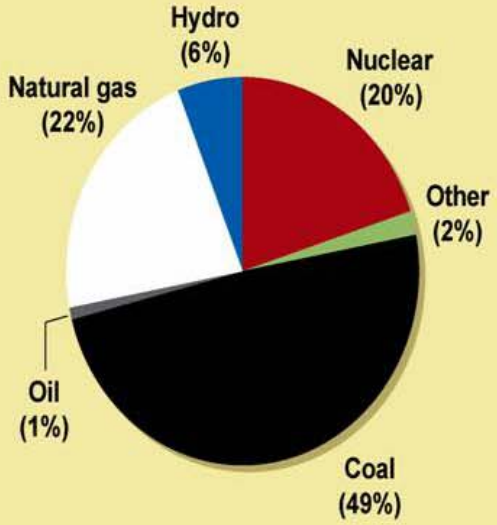
Oklahoma
North Carolina
Arizona
Tennessee
Arkansas
New Mexico
Mississippi
South Carolina
Alabama
Georgia
Texas
Louisiana
Florida
Hydro
Nuclear
Natural gas
Oil
Coal
Pacific Ocean
MEXICO
Los Angeles
New York

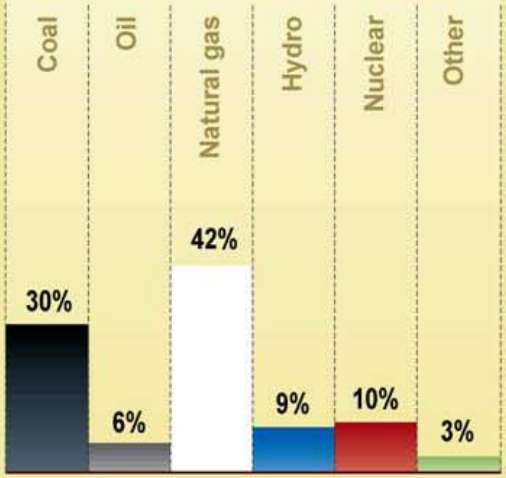
Generating Options

UNITED STATES 2008 (a)

Electricity Generation: 4,110 TWh

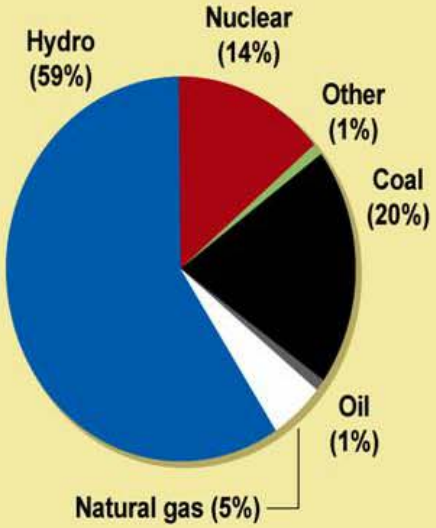


Installed Capacity: 1,088,000 MW

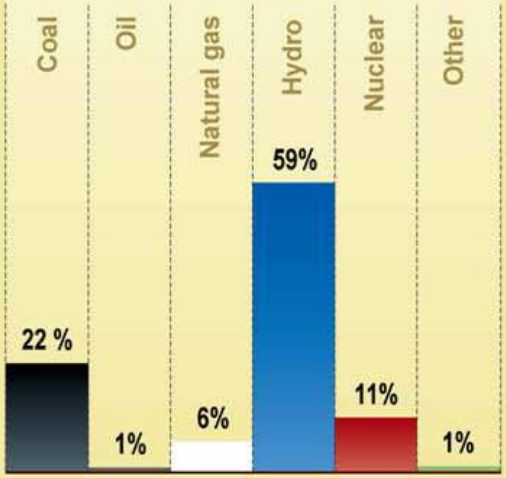


CANADA 2007 (b)

Electricity Generation: 617 TWh

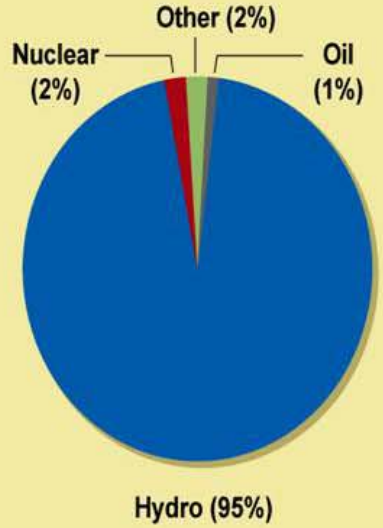


Installed Capacity: 124,000 MW

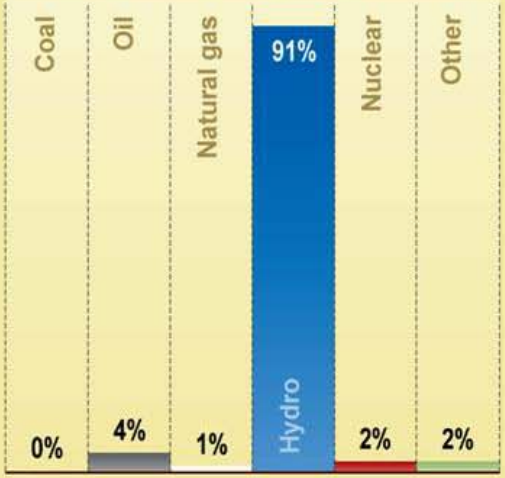


QUÉBEC 2007 (b)

Electricity Generation: 192 TWh

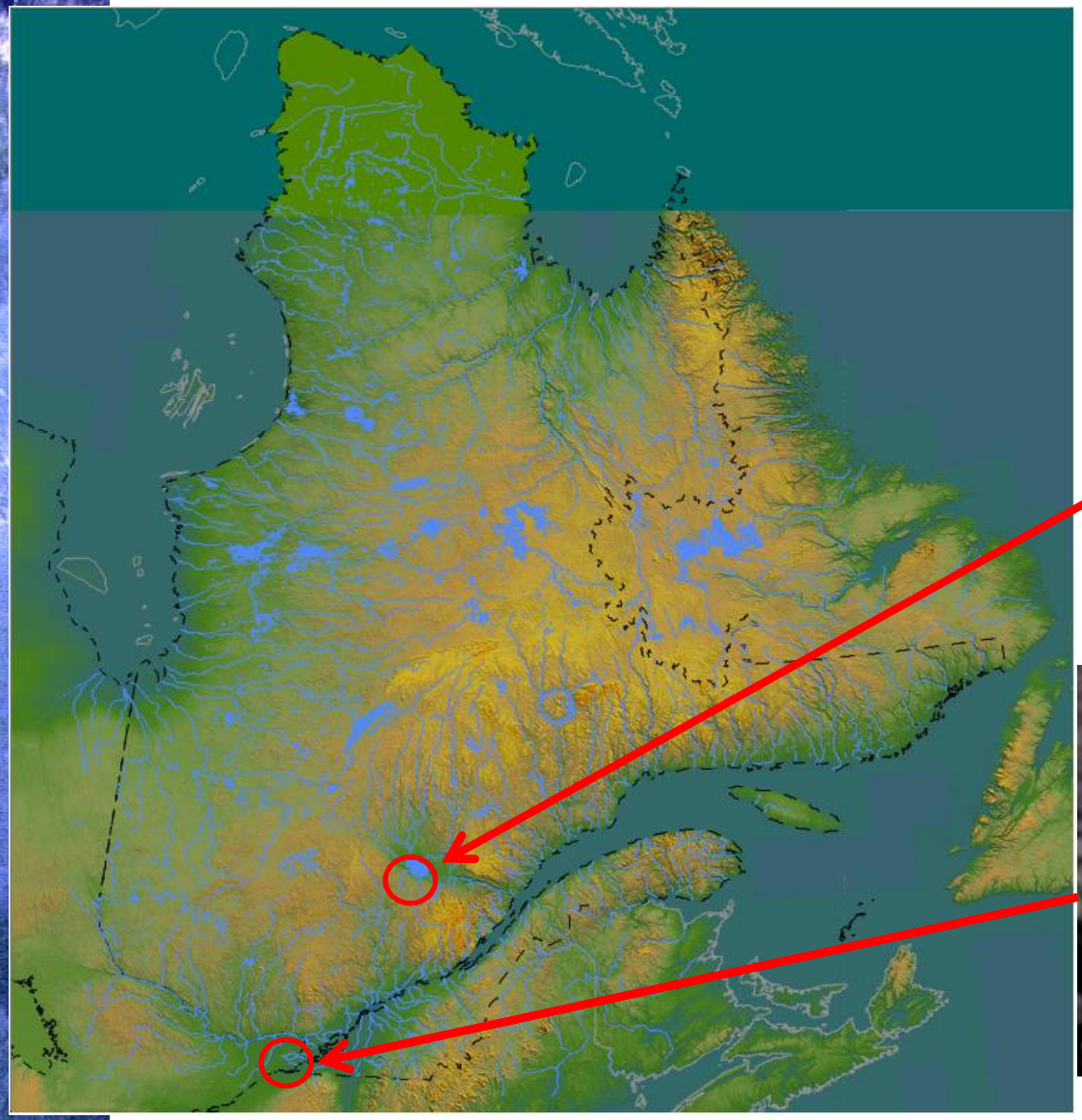


Installed Capacity: 41,000 MW



Sources: (a) U.S. Energy Information Administration, Electric Power Annual, 2009. – (b) Statistics Canada, 2007.

Extreme Climate Events

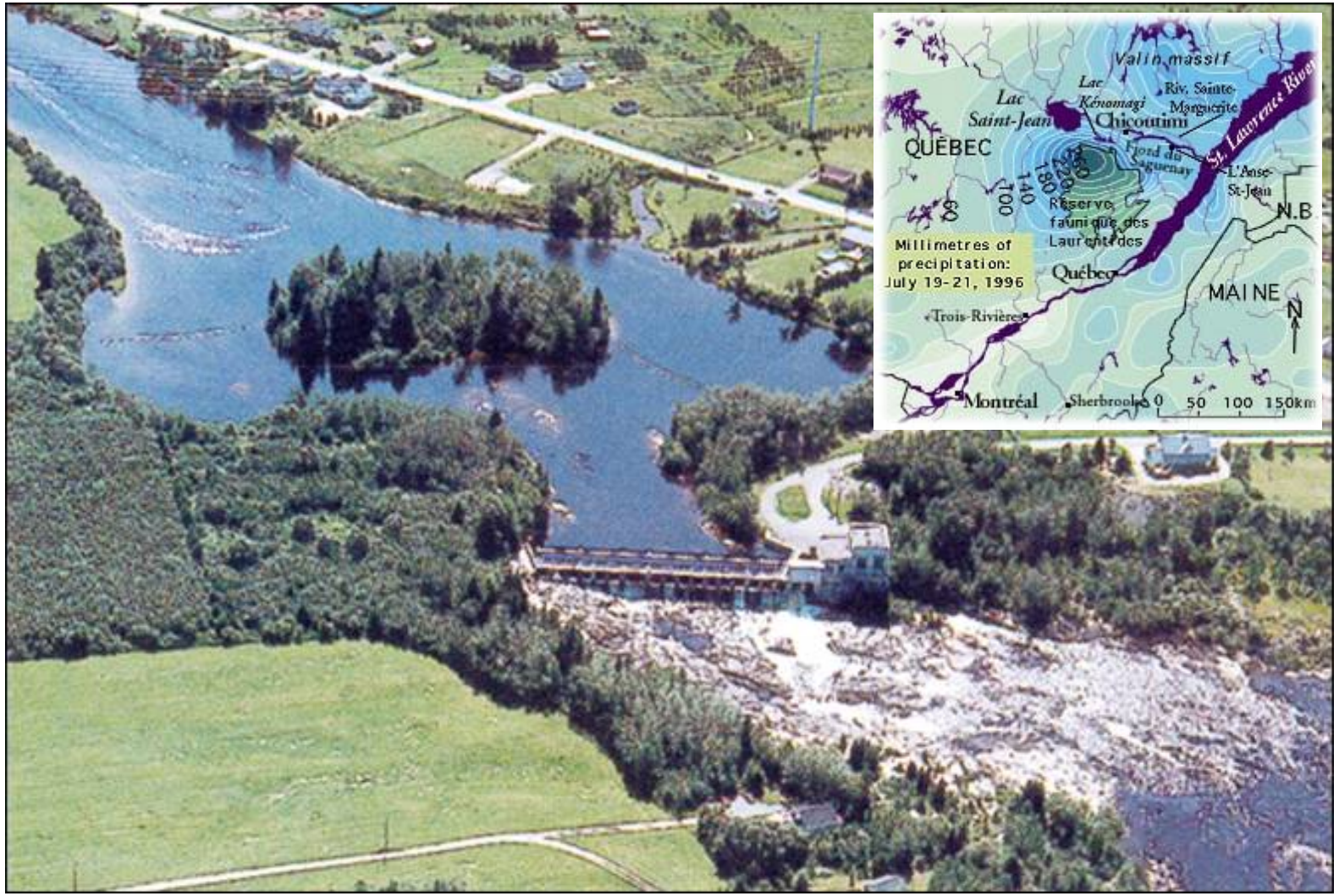


Saguenay (1996 : 800 M $)

Ice rain event (1998 : 1,6 Billions $)

Hydro Québec Production

Extreme Climate Events: Saguenay Flood July 1996

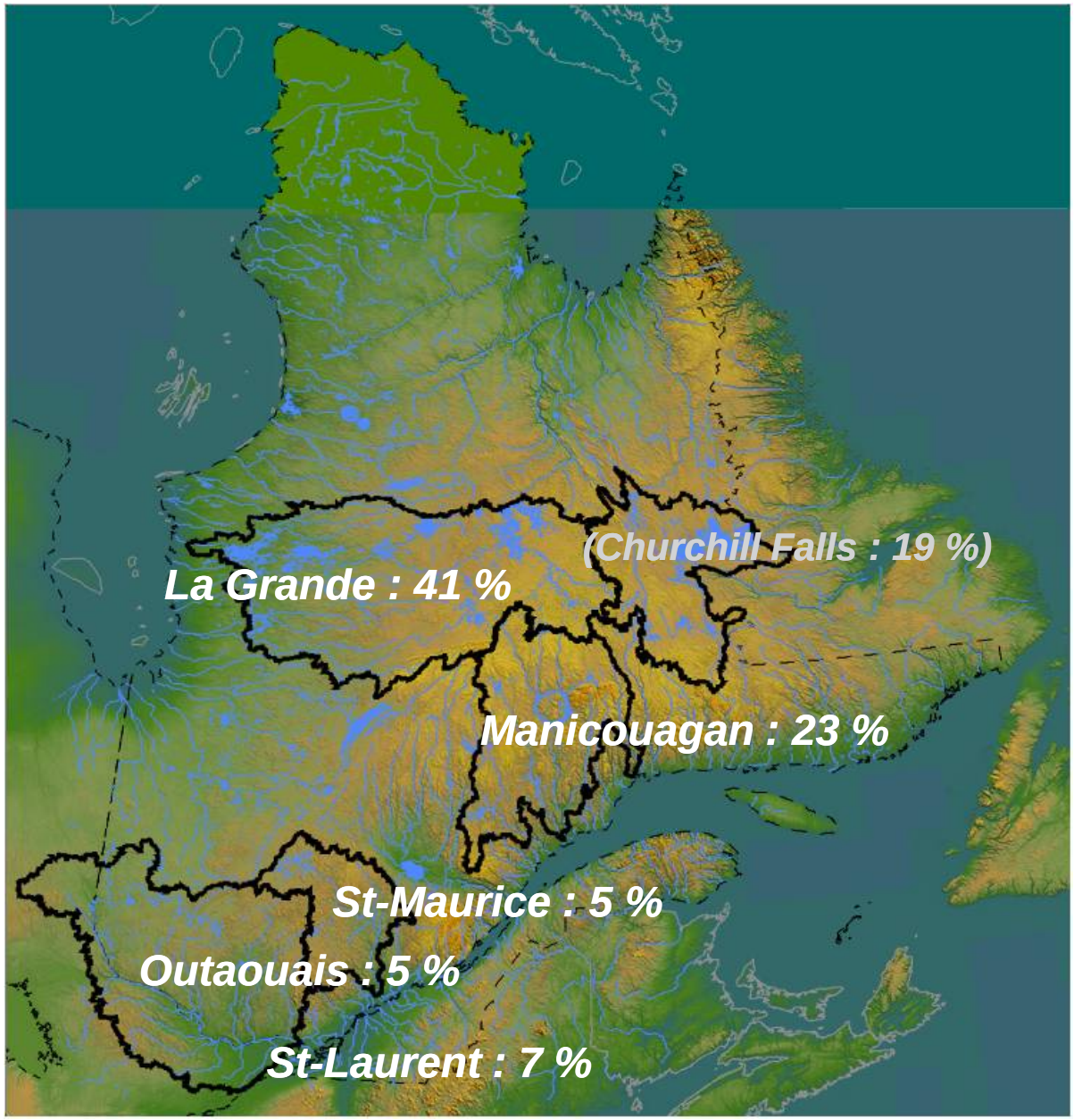


Extreme Climate Events: Saguenay Flood July 1996

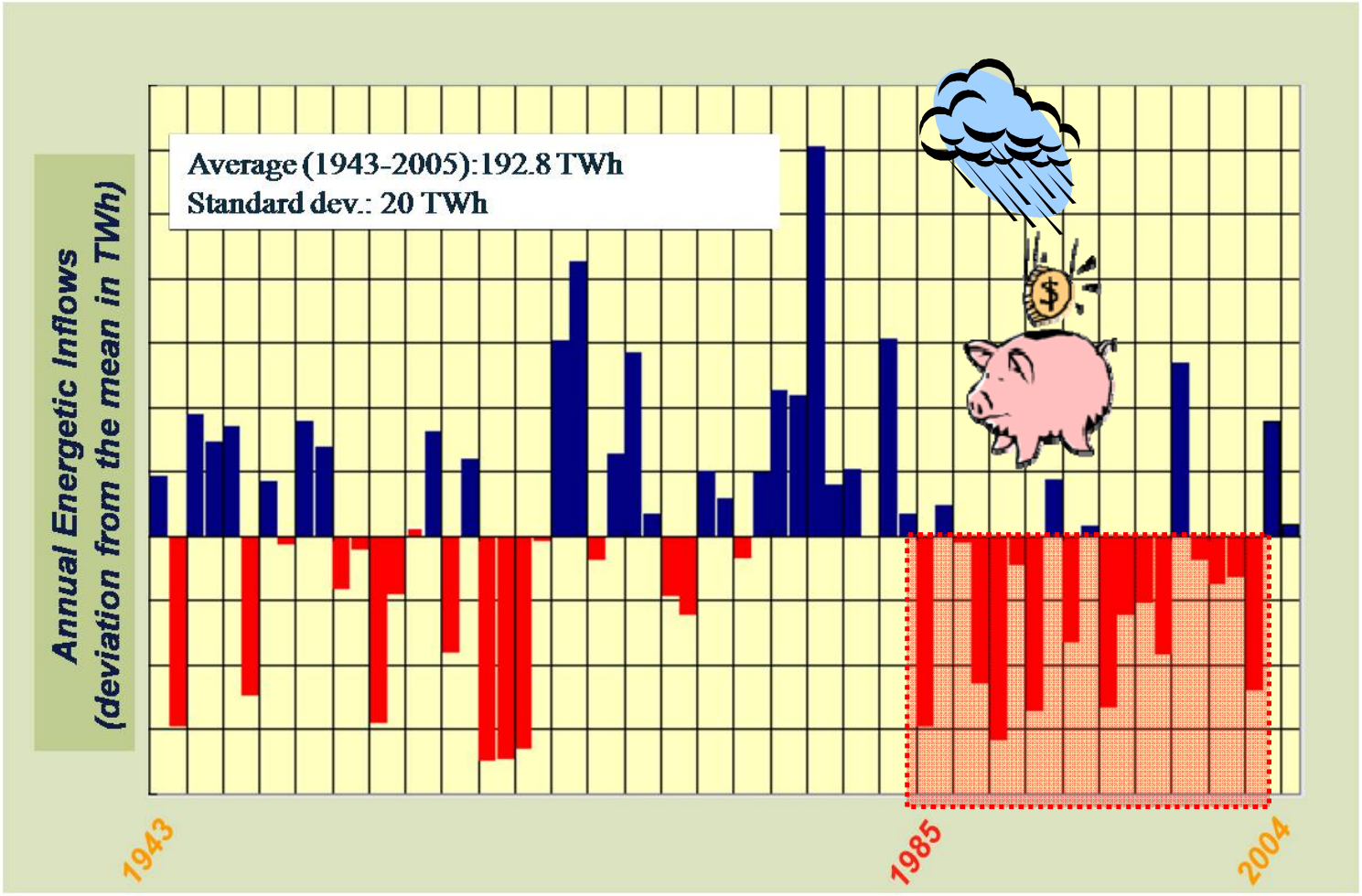
Climate variability is at the core of the Hydropower business case

- *97% of the electricity generated from hydro*
- *59 Hydropower Plants (Total Capacity : 36,805 MW)*
- *26 Reservoirs (Total capacity of 175 TWh)*

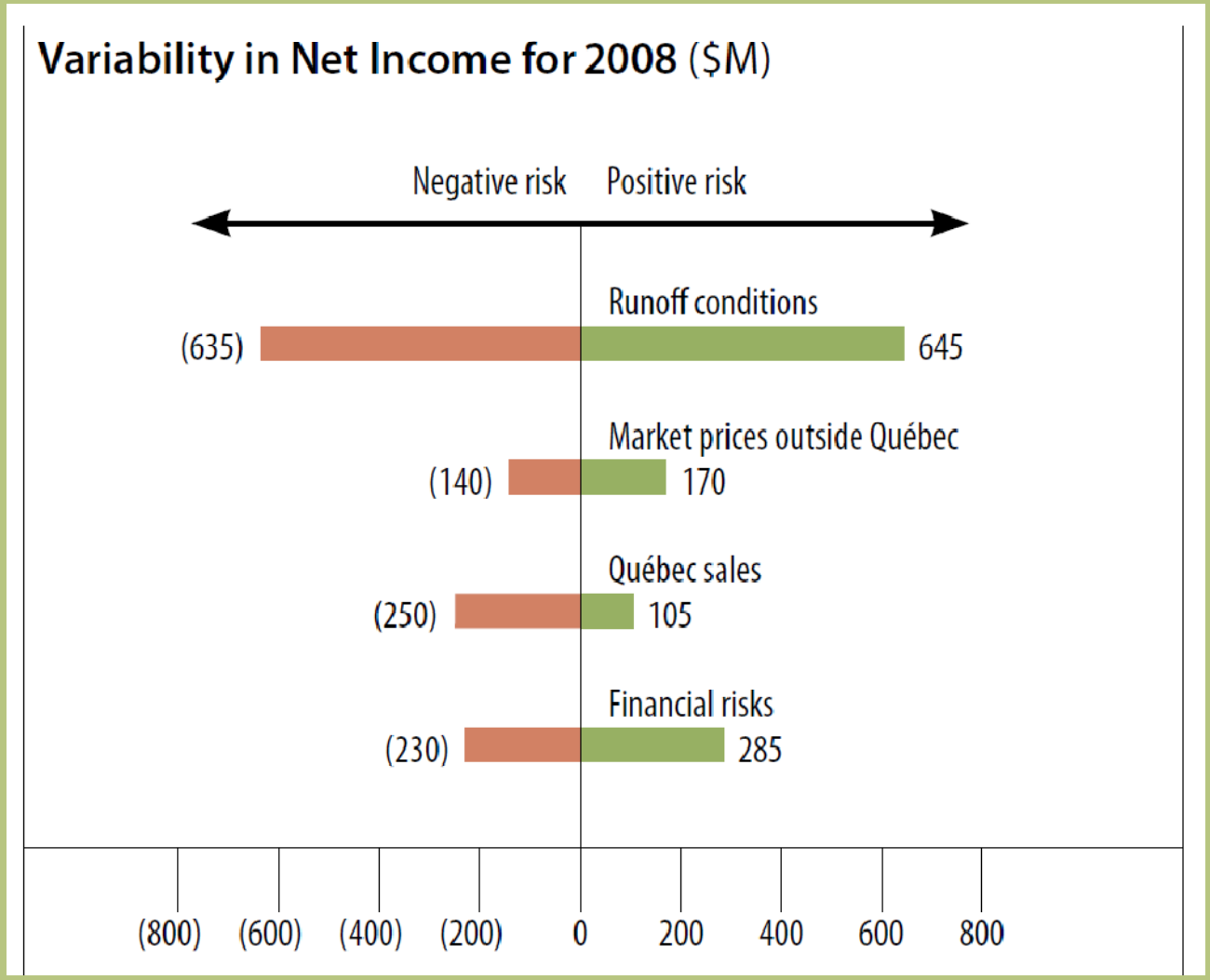
Climate variability is at the core of the Hydropower business case



Climate variability is at the core of the Hydropower business case



Major Business risks for Hydro-Québec



Source : Hydro-Québec Strategic Plan 2006-2010 (Expected Net Benefit for 2008 : 2,5 billions $)

Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

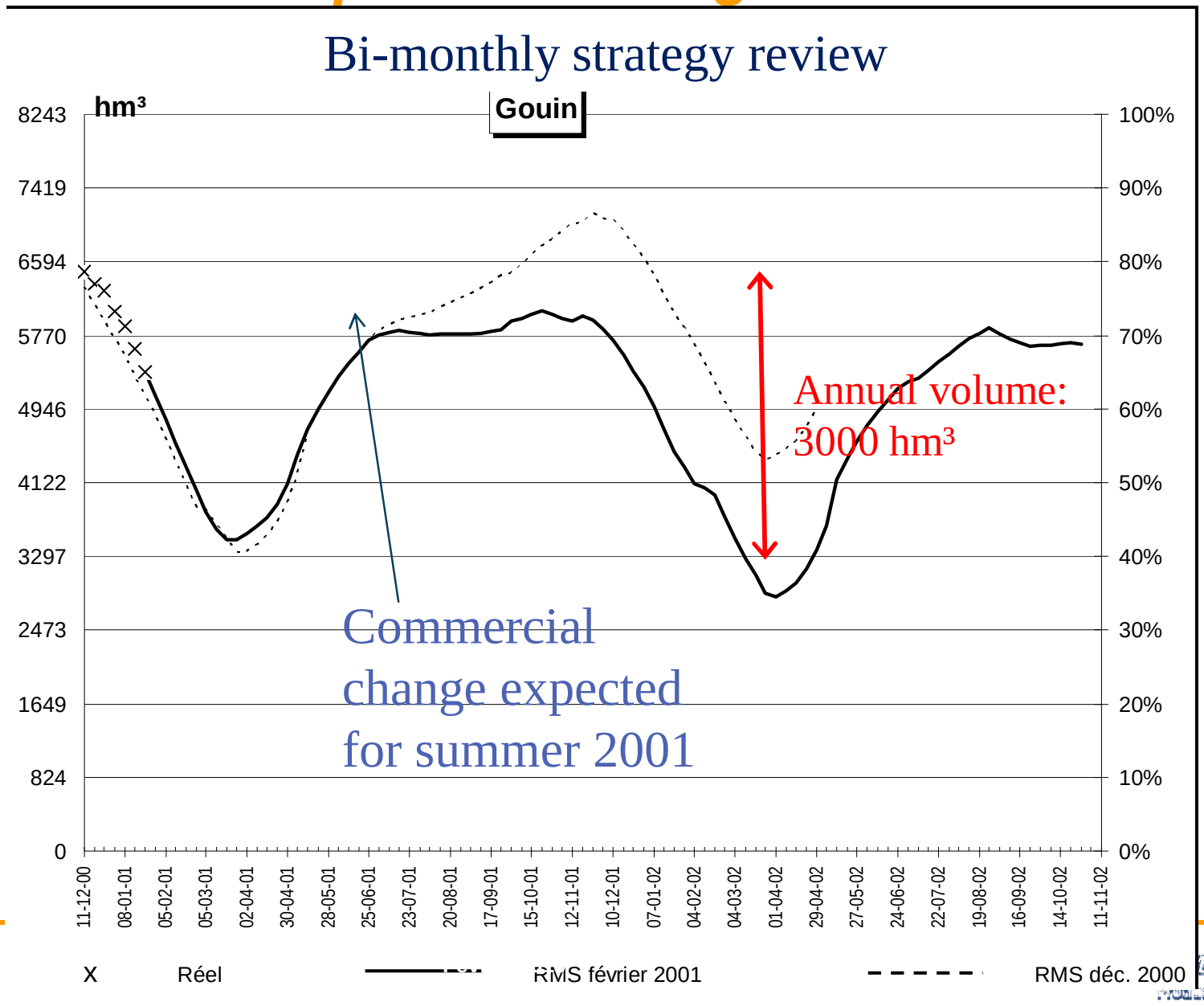
- **Operations (short term 1day – 5 years) :**
  - Annual runoff conditions (droughts)
  - Floods
  - Extreme weather (ice storm; wind storm)
  - Ice jams and debris
- **Planning (5 – 30 years…):**
  - Design uncertainty (insufficient knowledge of climatic conditions)
  - Risk associated to commissioning

Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Operations (short term 1day – 5 years) :**
  - Annual runoff conditions (droughts and floods) – 10%

- Ongoing adaptation to seasonal runoff conditions
- Long term adaptation of commercial strategy – exports and imports – can require modification or be a tool

Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

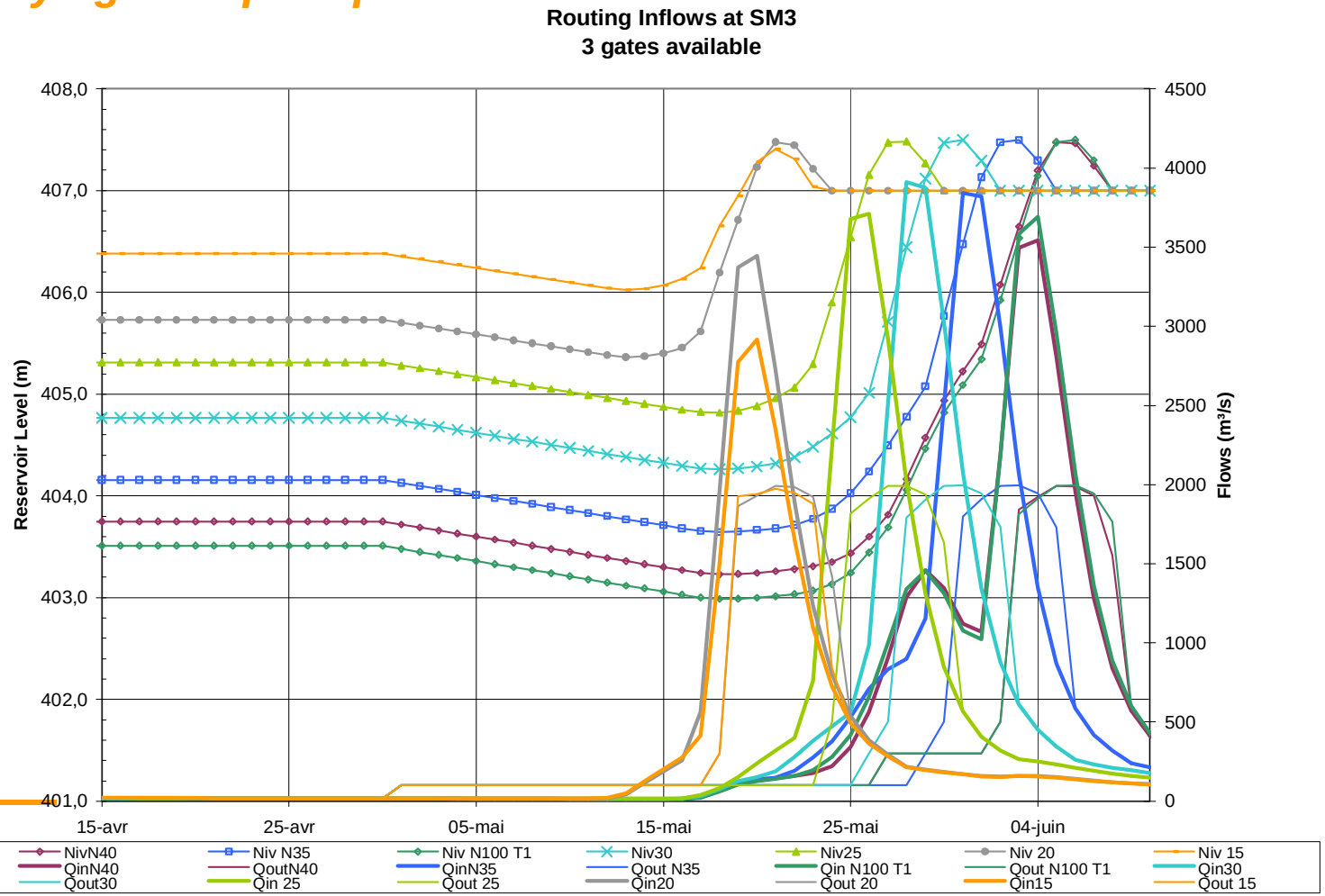


Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

Minimum Drawdown Constraints adapting for snowpack

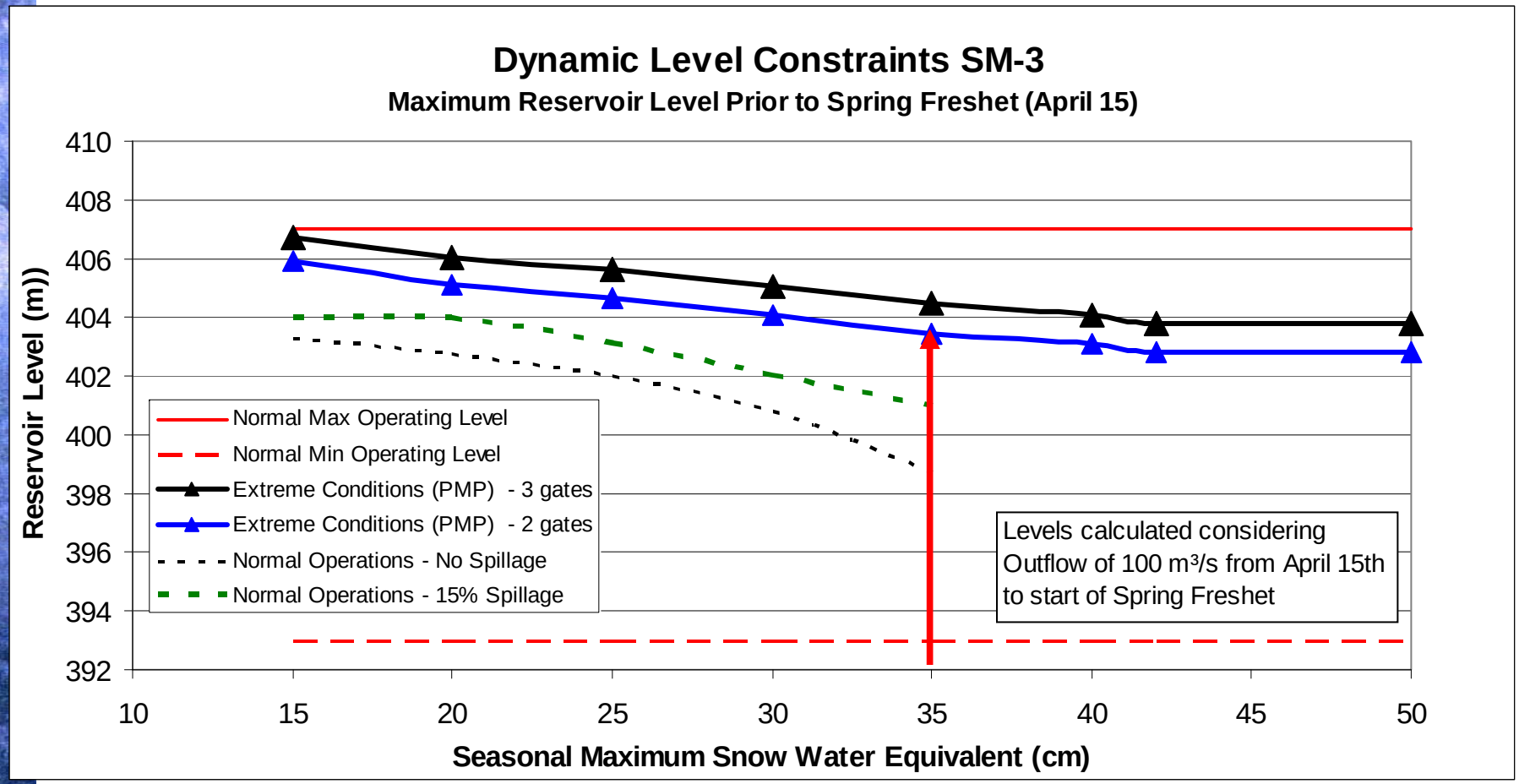
Based on fixed PMP (design flood)

with varying snowpack prior to event



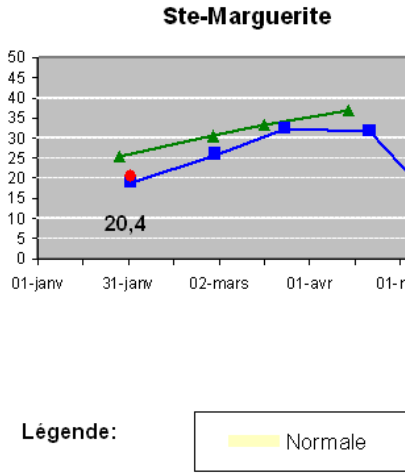
Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

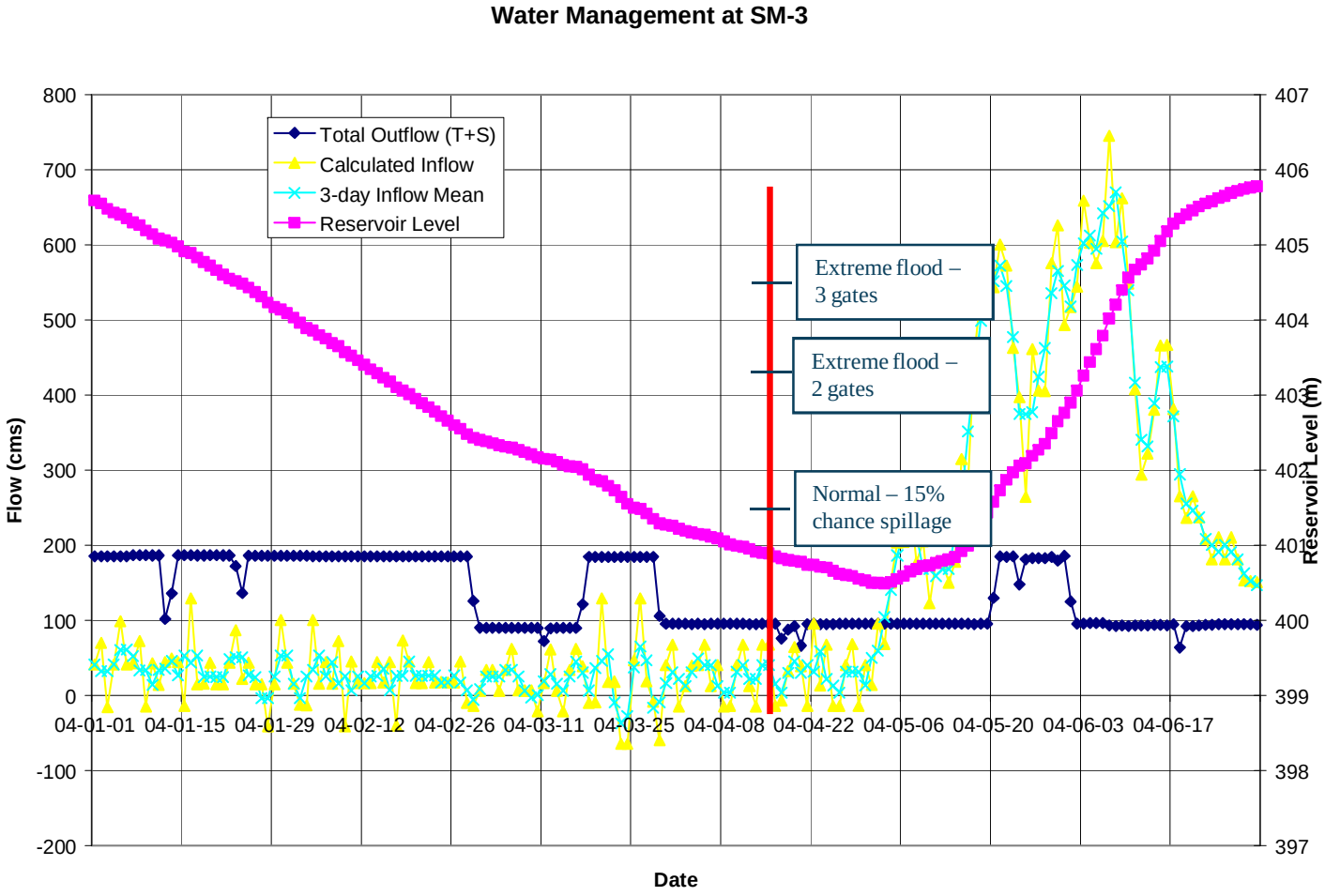
Minimum Drawdown Constraints



Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

Applying Minimum Drawdown Constraint at SM-3 in 2004



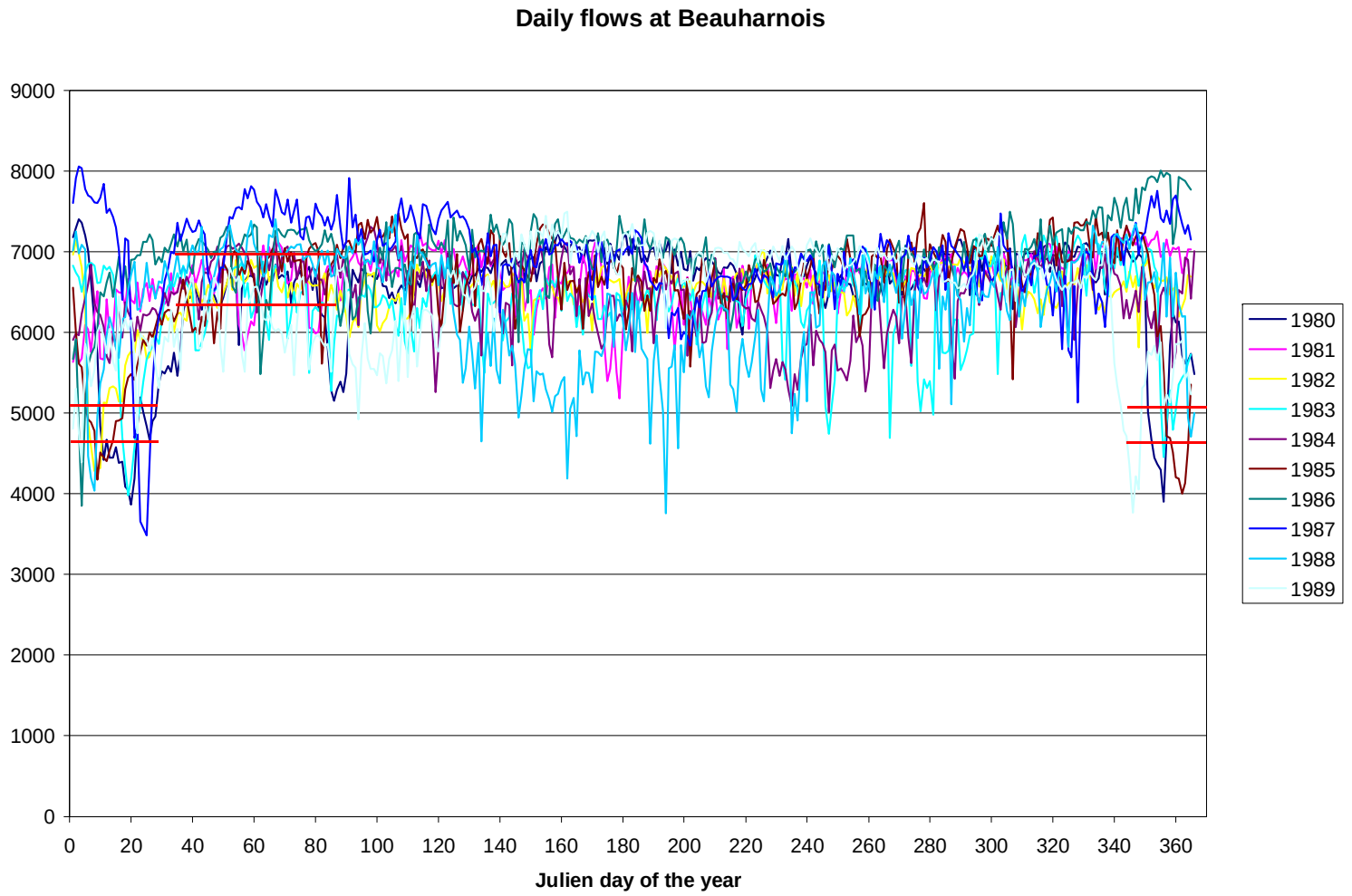


Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Operations (short term 1day – 5 years) :**
  - Ice jams - Example: Chute Hemmings 1989

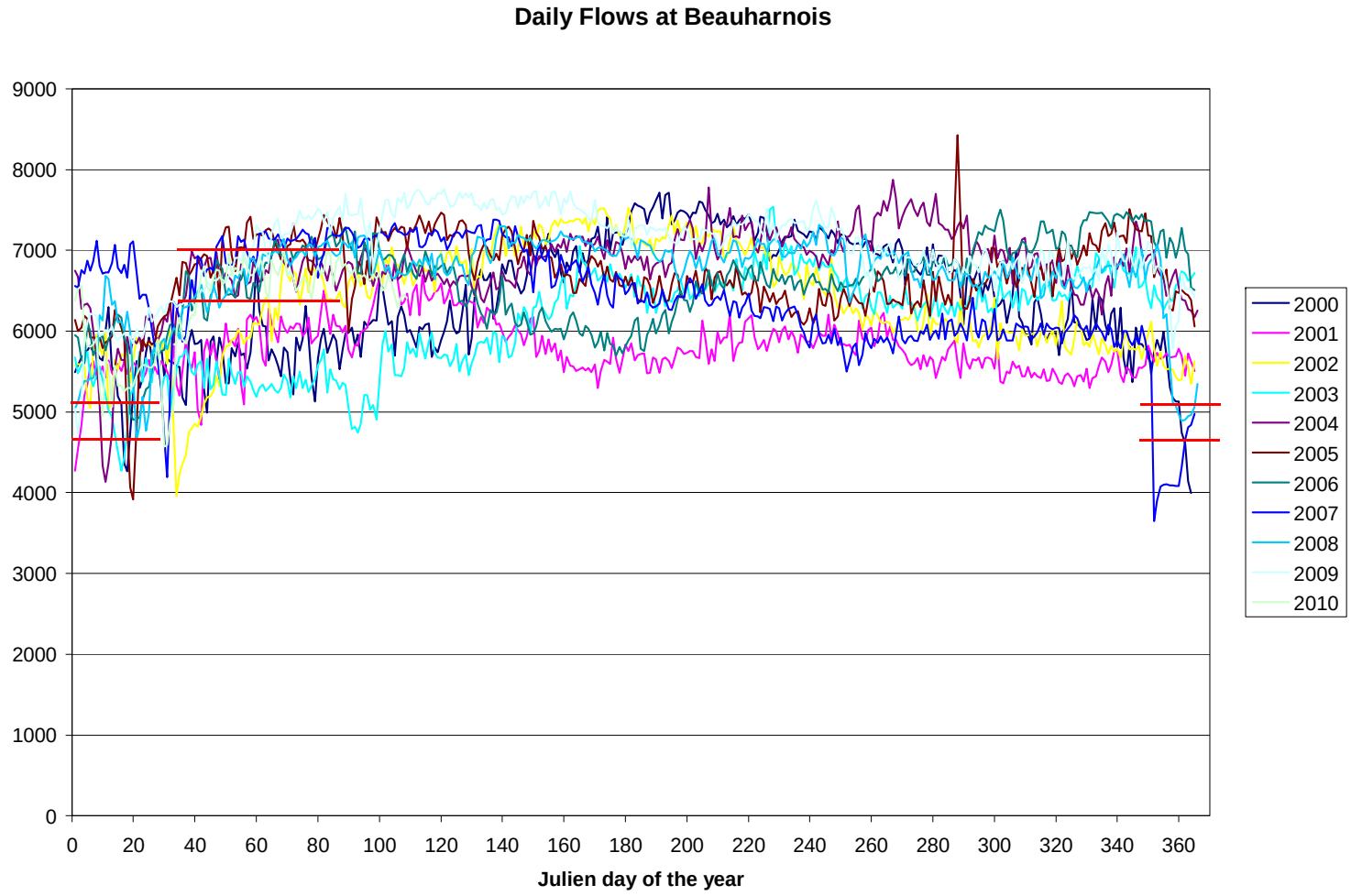
Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Operations (short term 1day – 5 years) :**
  - Ice control – forming ice-cover – what we want to do



Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Operations (short term 1day – 5 years) :**
  - Ice control – forming ice-cover – doesn't work well for recent warm winters



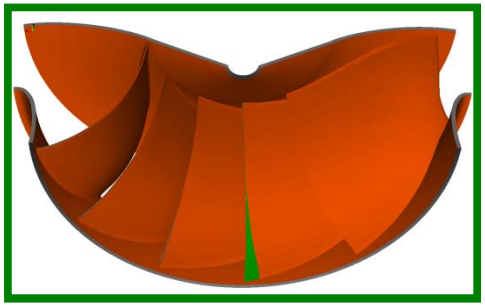
Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Planning (5 – 30 years…):**
  - **Design adjustments (insufficient knowledge of hydrologic, climatic conditions or of future role of production assets)**
  - Risk associated to commissioning

Eastmain 1A: 768 MW
Water transfer project

Improving old turbine performance

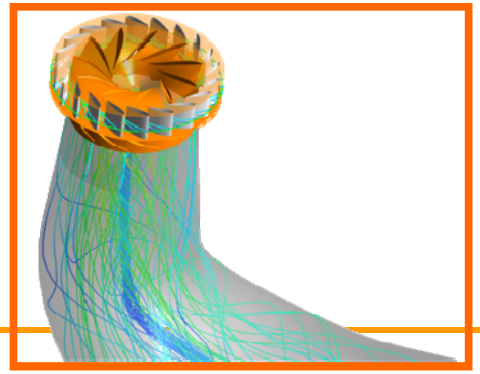
Runner geometry measurement on site



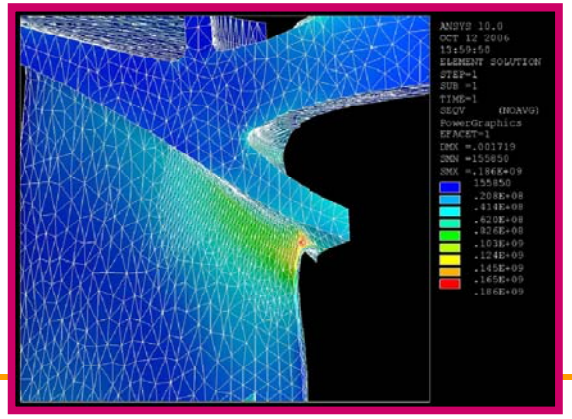
Design of a turbine modification

On-site implementation

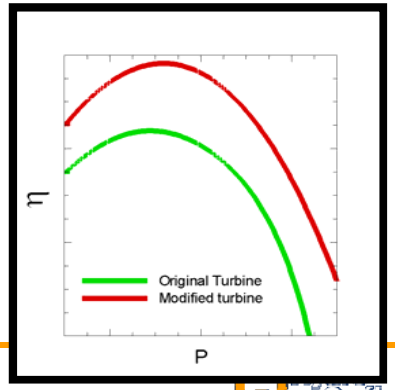
Simulation of original turbine configuration



Stress analysis



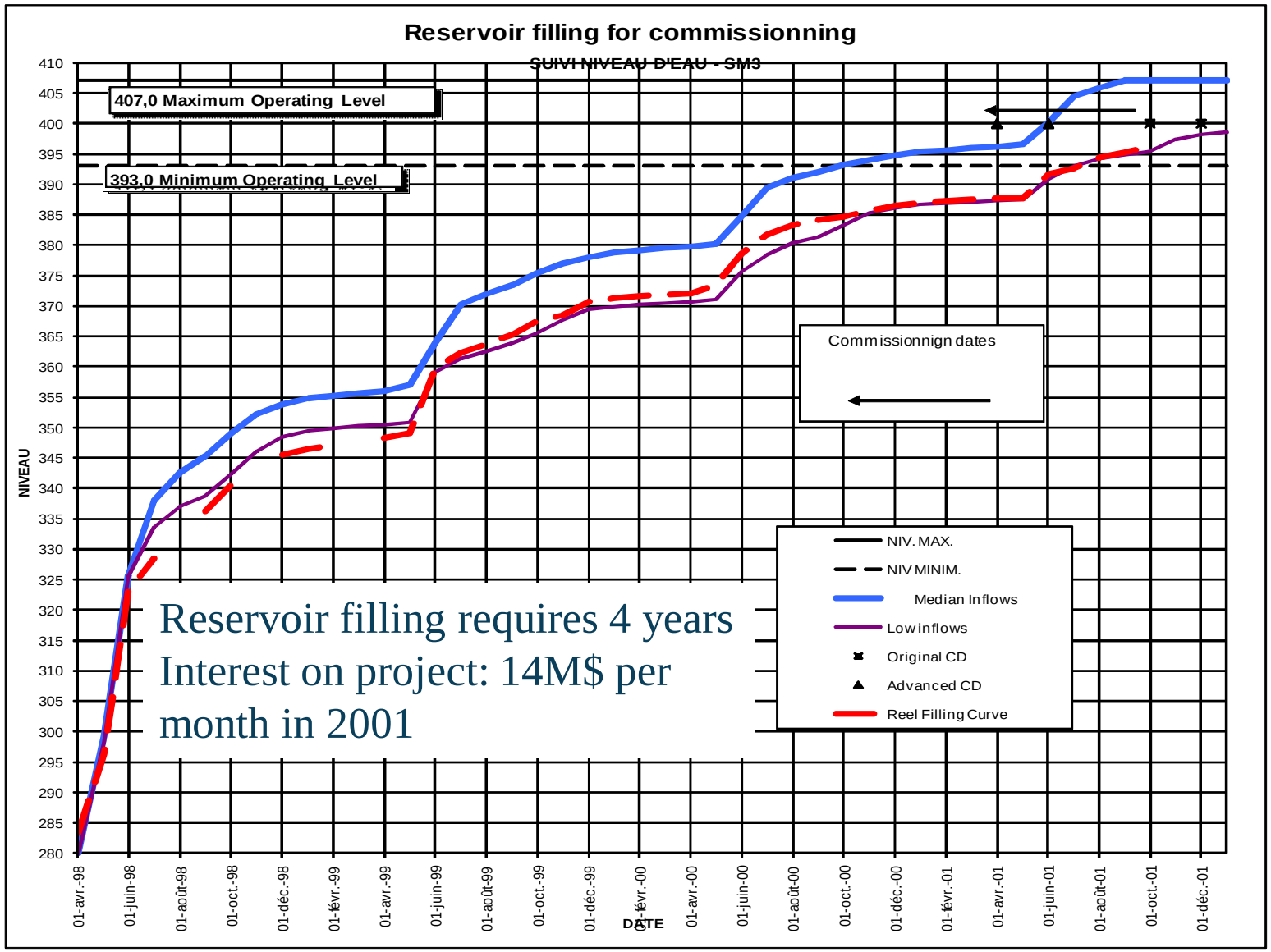
Performance gain evaluation



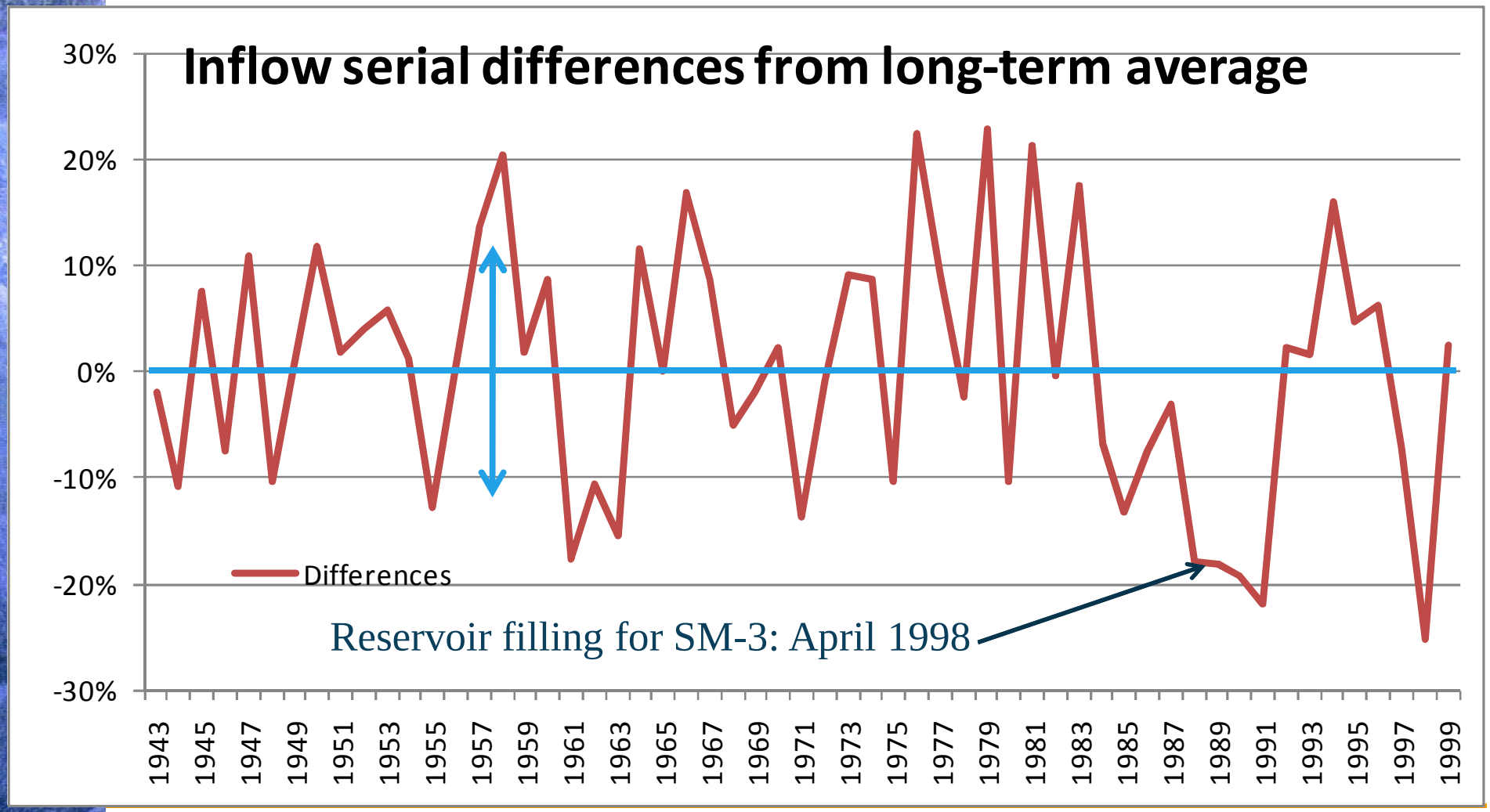
Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Planning (5 – 30 years…):**
  - Design adjustments (insufficient knowledge of hydrologic, climatic conditions or of future role of production assets)
  - **Risk associated to commissioning**

Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

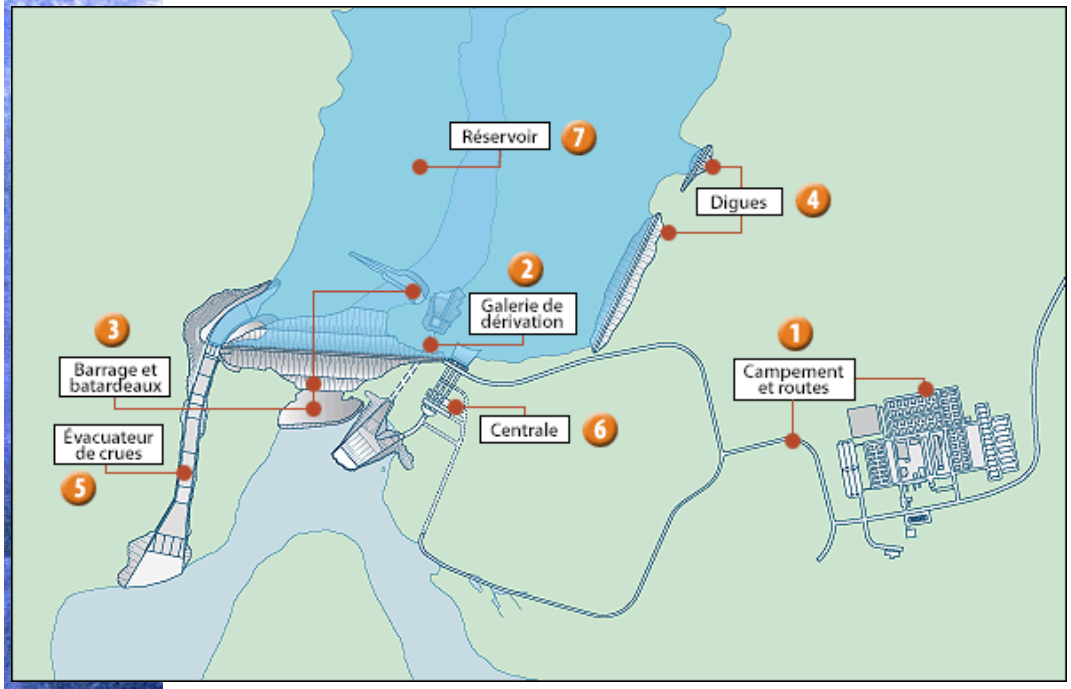


Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

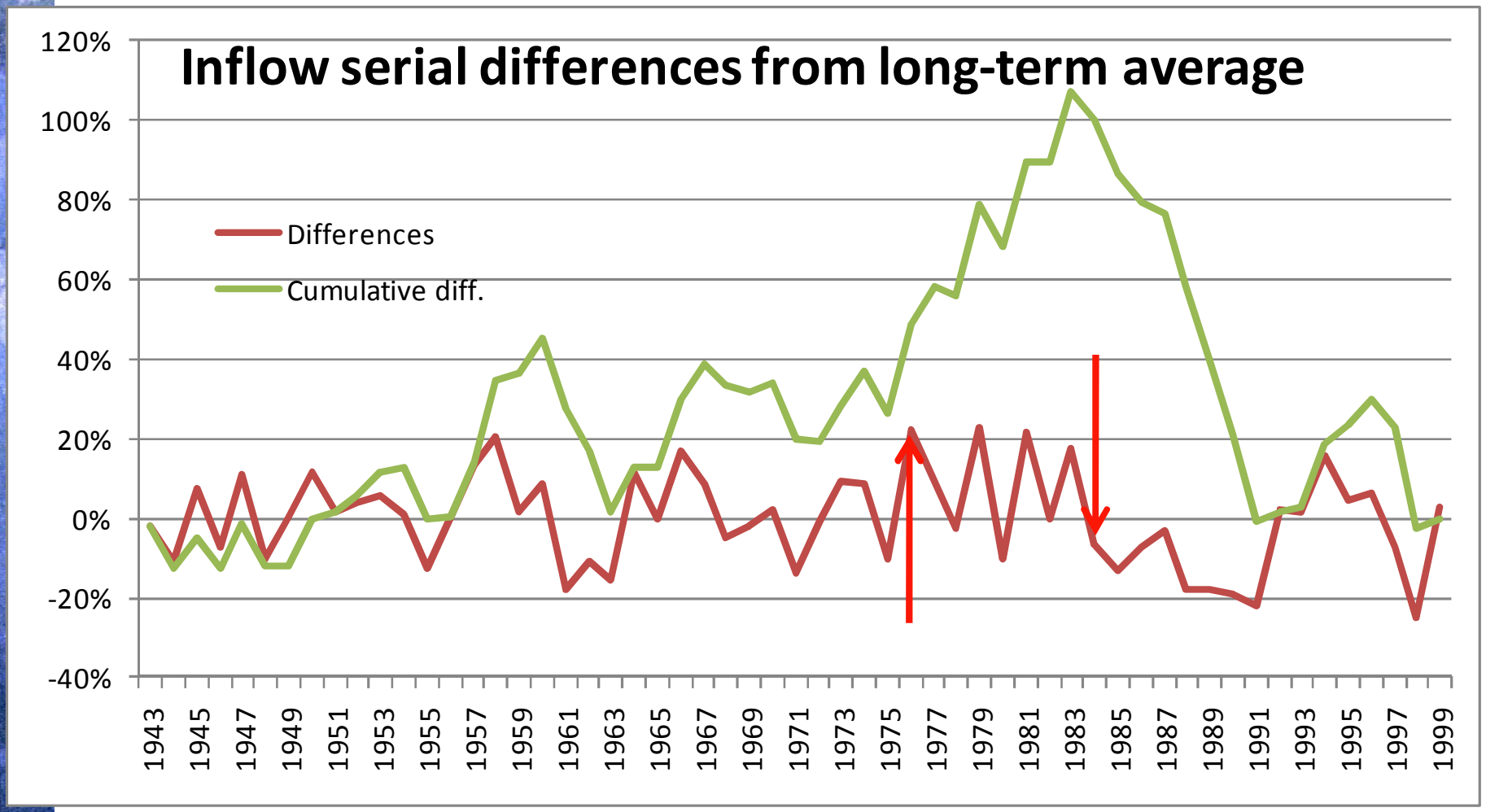


Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Planning (5 – 30 years…):**
  - Risk-based evaluation of projects that figure in climate information risk
  - Example of Peribonka – commissioned in 2008
    - 385 MW; 1.2 G$(Can)

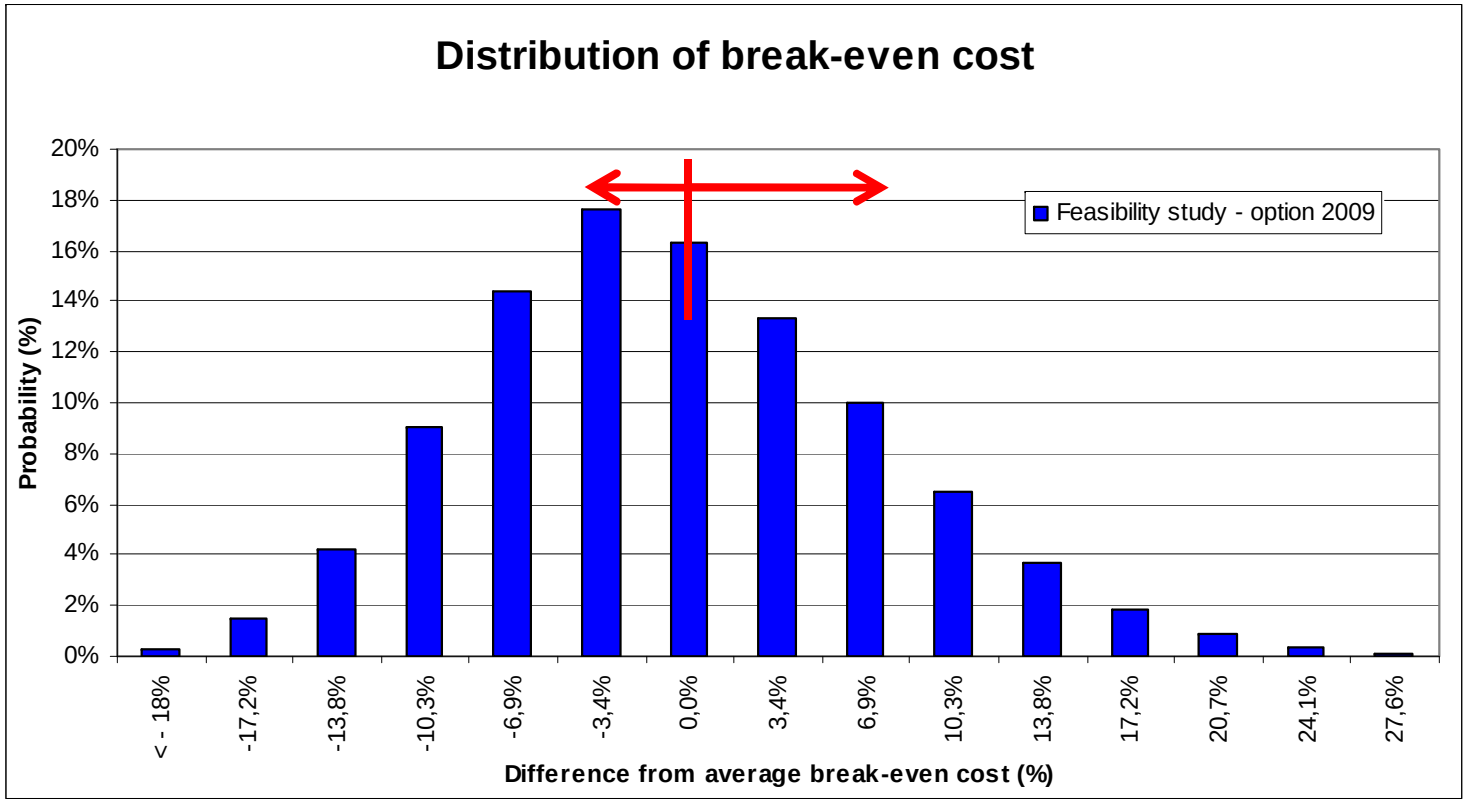


Hydropower Sector – Vulnerabilities to climate and current adaptation strategies



Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Planning (5 – 30 years…) incorporating risk:**
  - Use probabilistic inputs for project cost, financial parameters, **production (expected average; serial values)**
  - Perform Monte Carlo simulation



Hydropower Sector – Vulnerabilities to climate and current adaptation strategies

- **Adaptation strategies - Operations (short term 1day – 5 years) :**
  - Frequent revision of optimal dispatch
  - Good weather and inflow forecasting tools
  - Sufficient climate monitoring data for forecasting and studies
  - Optimization tools - nesting
  - Expert knowledge for short term adaptation strategies
- **Adaptation strategies - Planning:**
  - Annual revision of priorities
  - Develop a set of development options (turbine runner change; additional powerhouse; new site)
  - Use risk based asset planning tools integrating drought and information risk

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

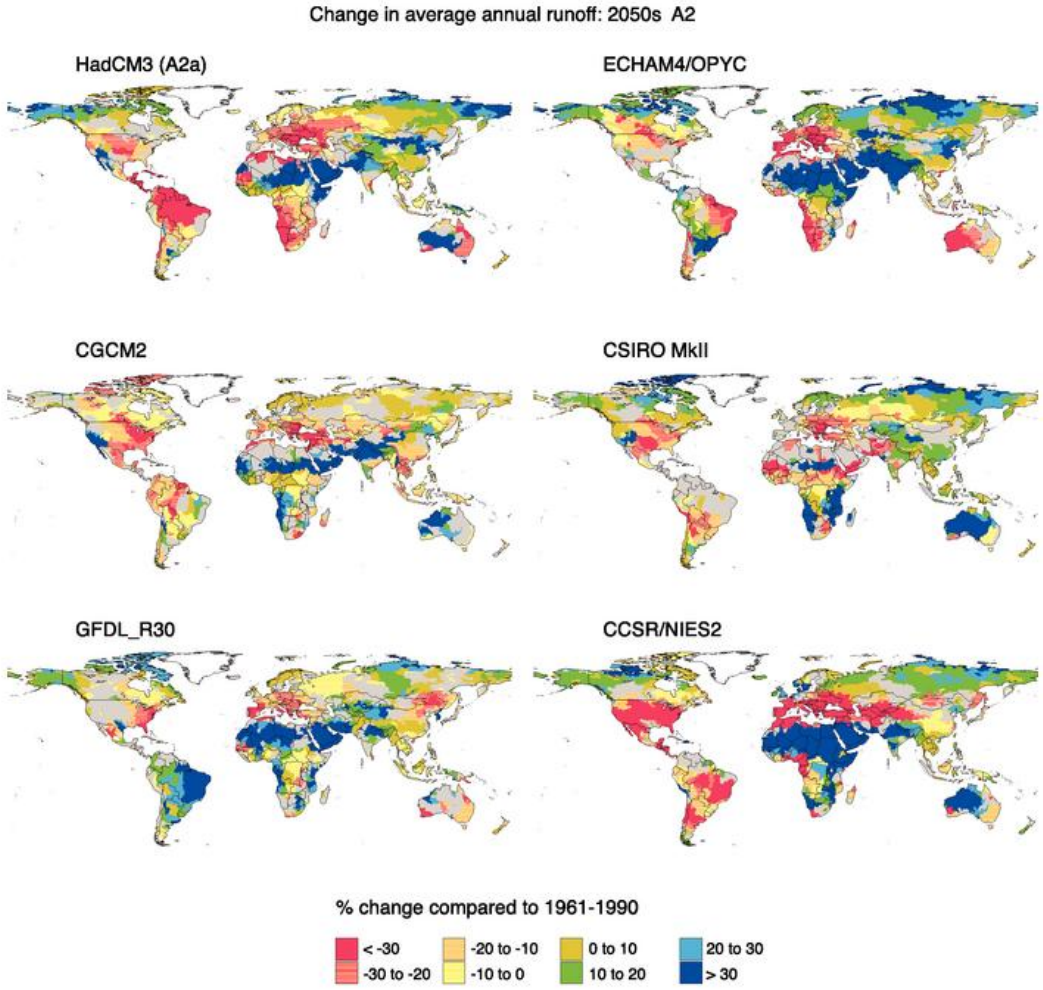
- **Inflows (net loss or gain):**

- **Extremes:**
  - Climate Factors (P and T)
  - Floods
  - Droughts

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Inflows (net loss or gain):**

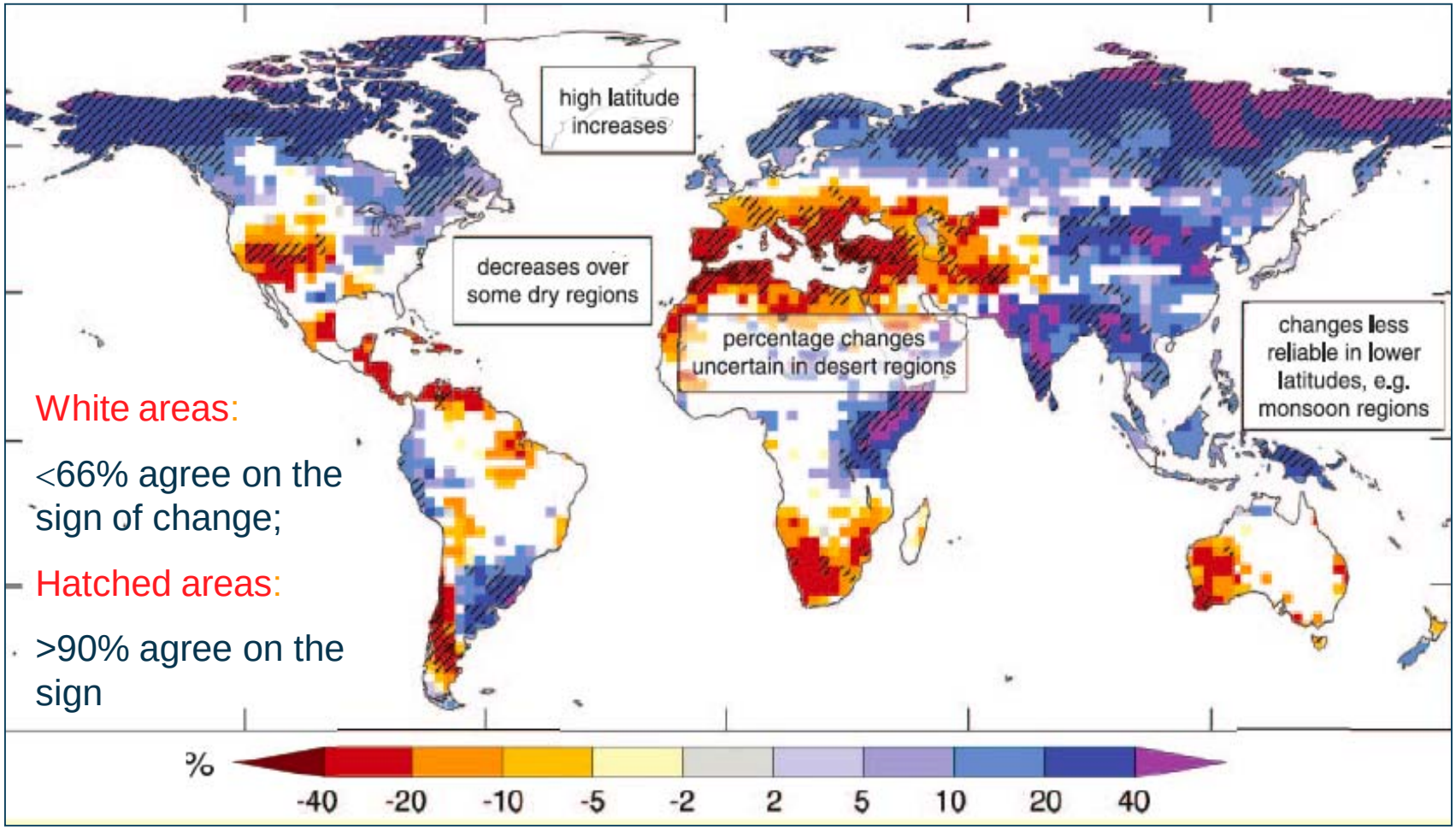
- **Very volatile**
- **All models show regions that increase and others that decrease**
- **Where do they agree?**



(source IPCC, 2007).

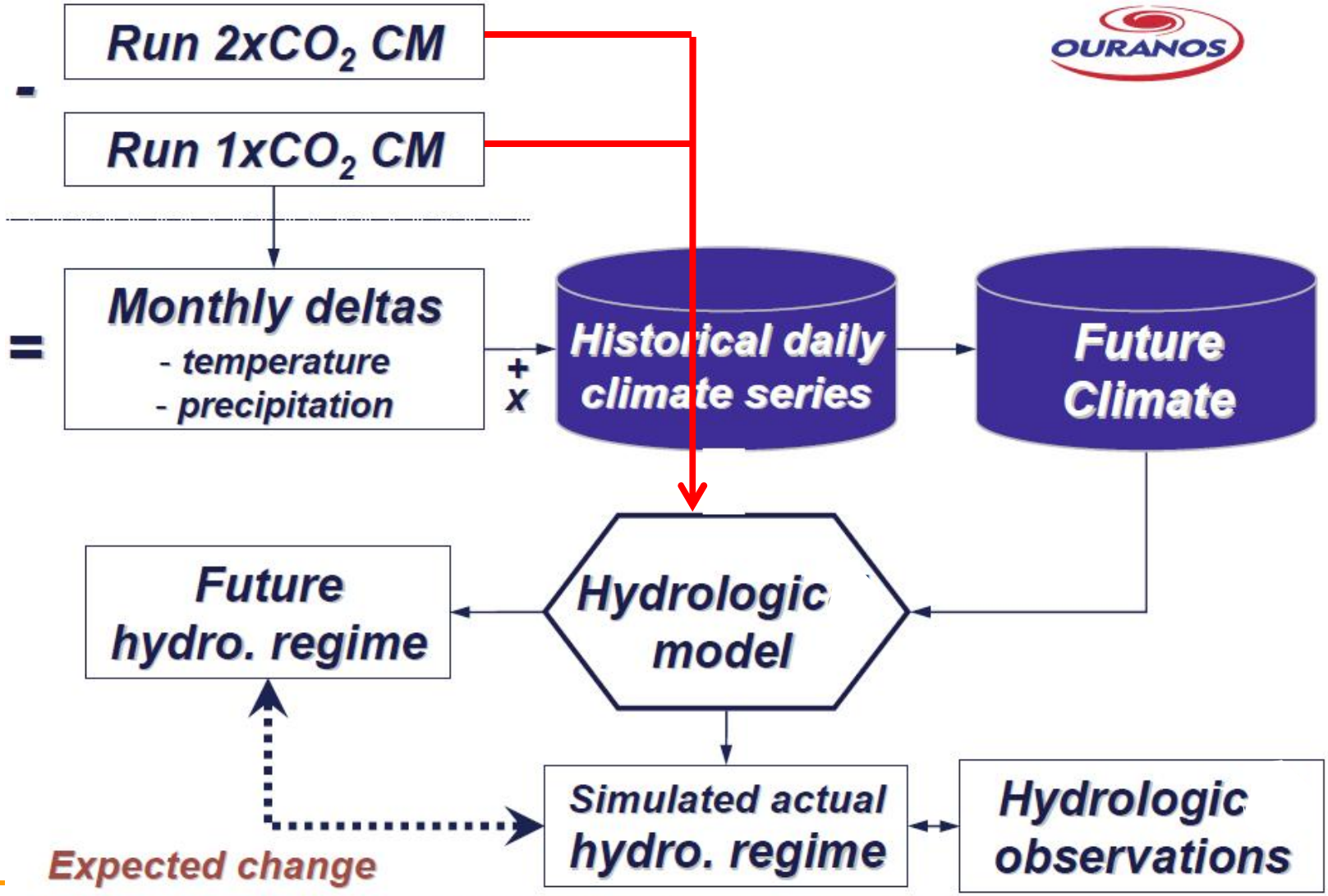
Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Inflows (net loss or gain):**



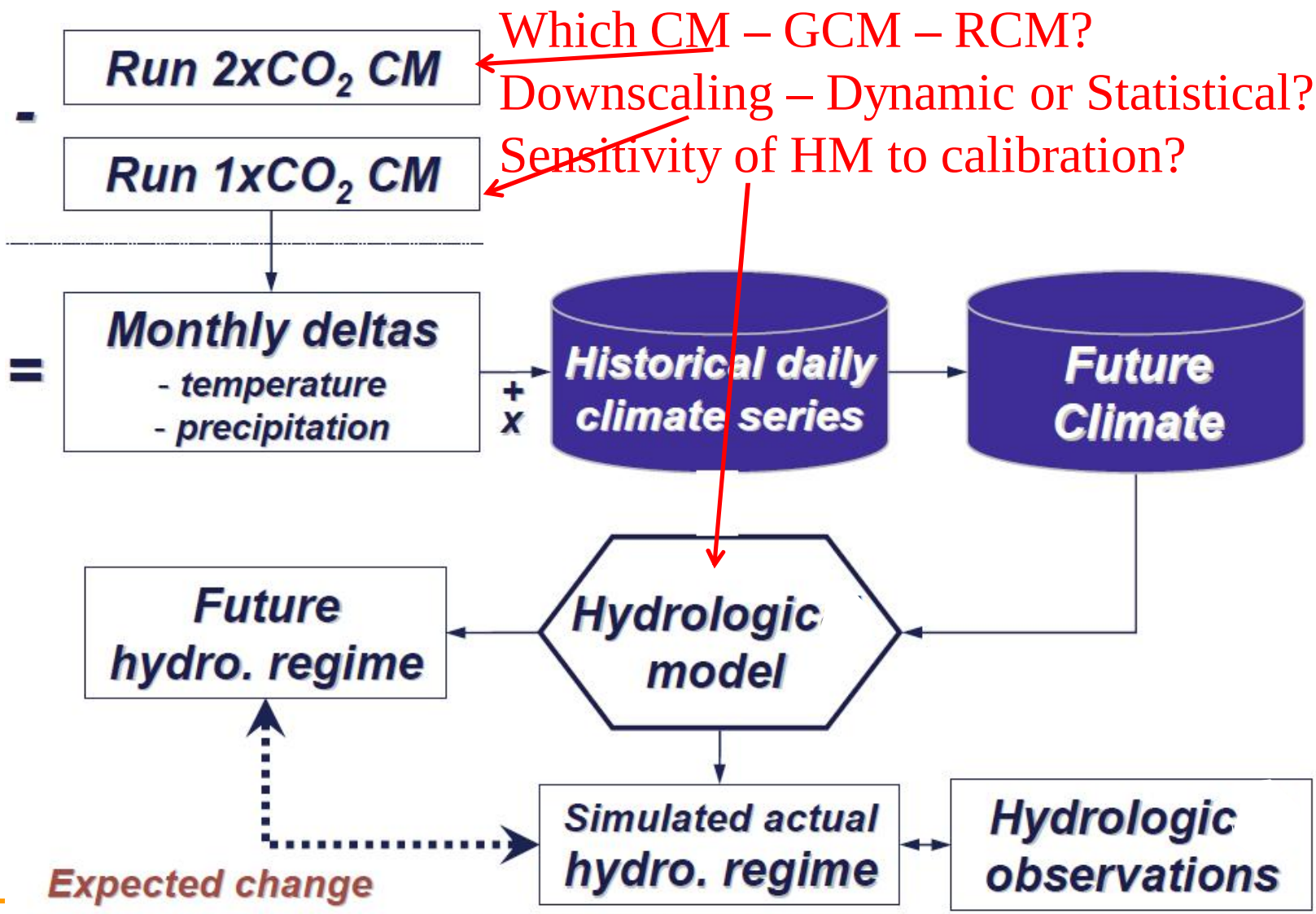
Change in runoff under the A1B scenario by the end of the 21th century, relative to 1980-1999, as projected by 12 IPCC models (source IPCC, 2007).

Current evaluations of CC impacts on the hydropower sector – methodology for basin scale



Impact of Climate Change on Operations and Planning of Hydro-Québec Generation System, WMIG 2008

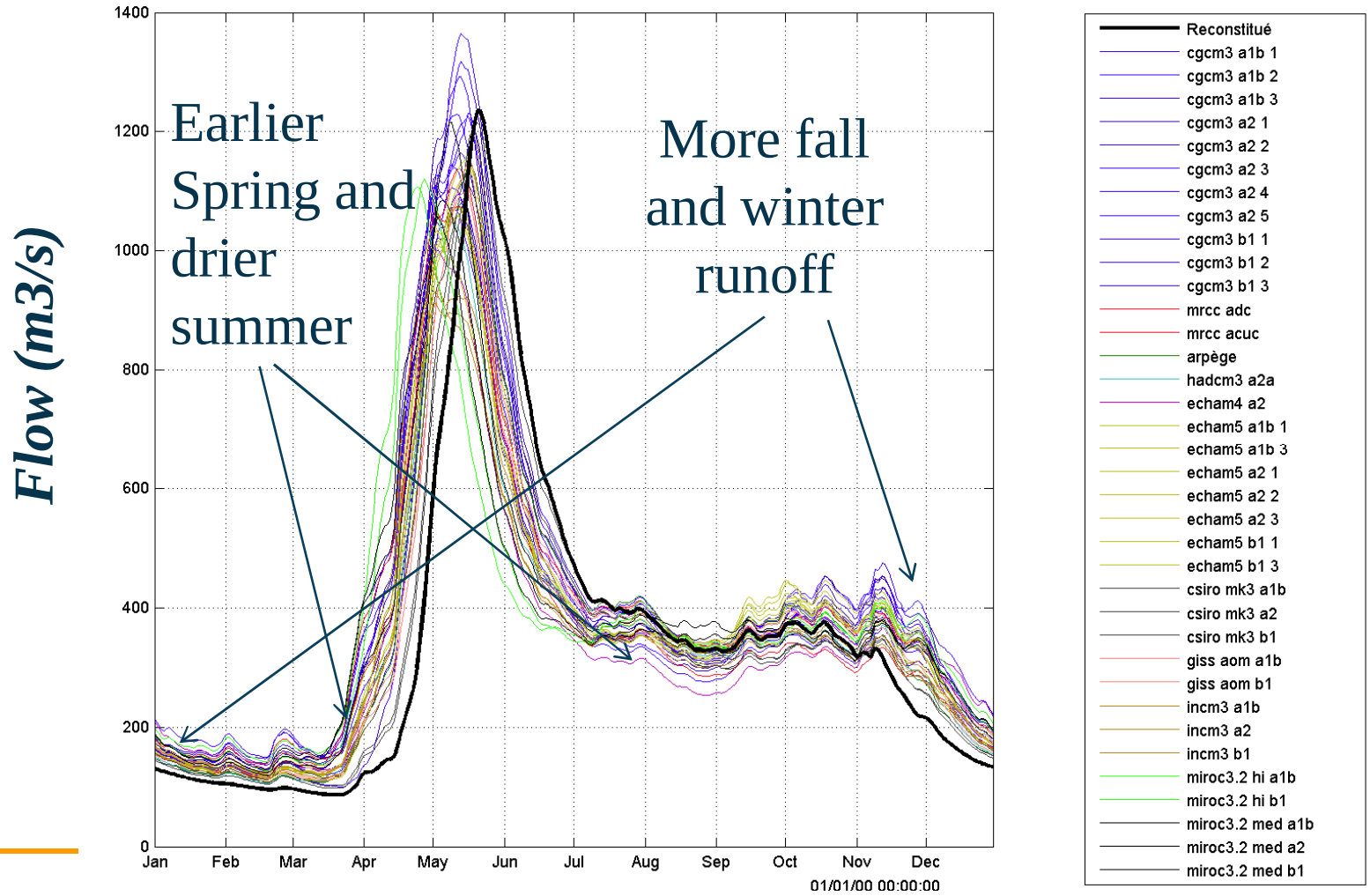
Current evaluations of CC impacts on the hydropower sector - methodology



Impact of Climate Change on Operations and Planning of Hydro-Québec Generation System, WMIG 2008

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

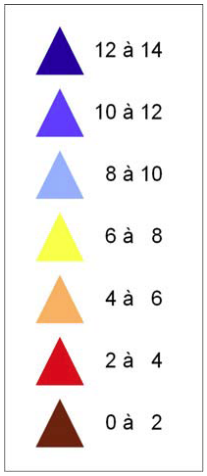
- ***Mean Hydrograph: future (2050) vs reference period (%) (average result for 30 years)*:**

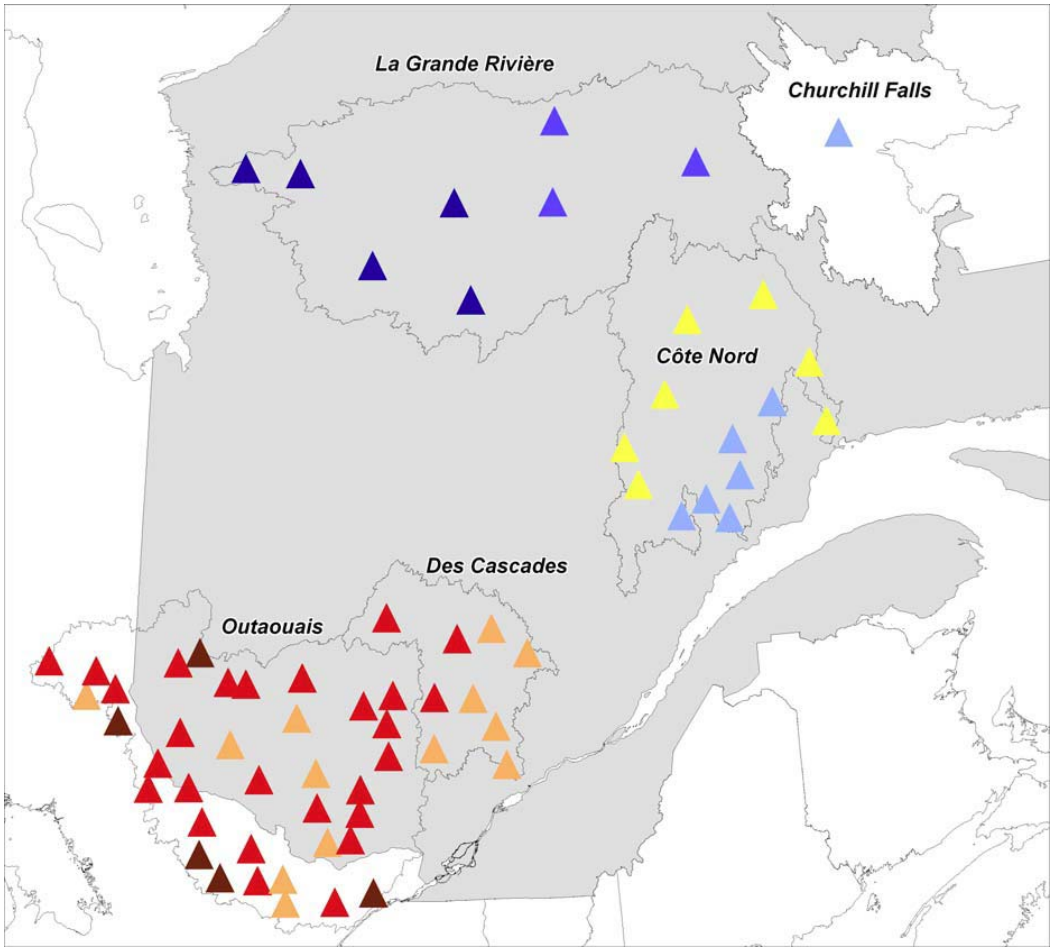


(source Ouranos, 2009).

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- ***Mean annual flow difference: future (2050) vs reference period (%) (average result for 36 scenarios)*:**





(source Ouranos, 2009).

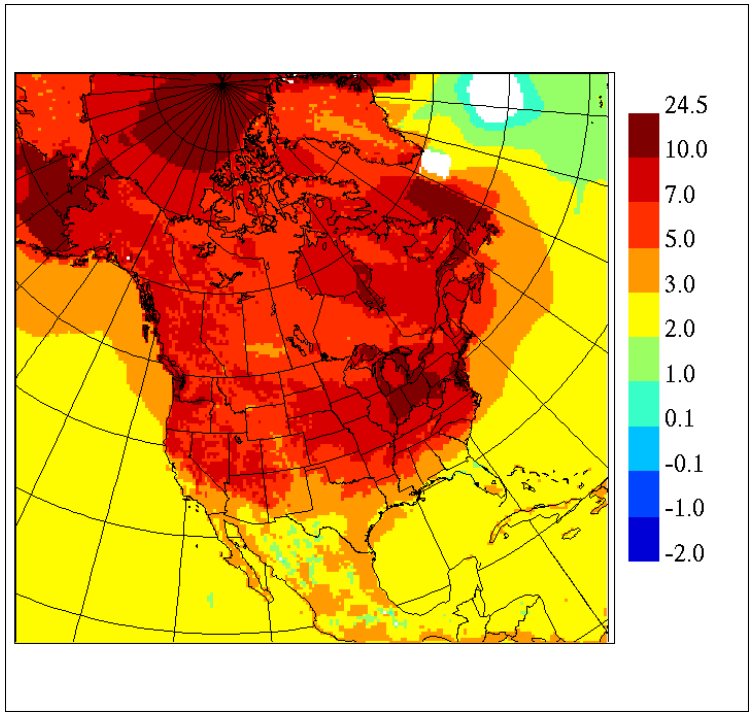
Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Extremes:**
  - Driving forces – more energy to generate extremes and more water in the atmosphere
  - Very regional – more than average values
  - Climate Factors (P and T)
  - Floods
  - Droughts

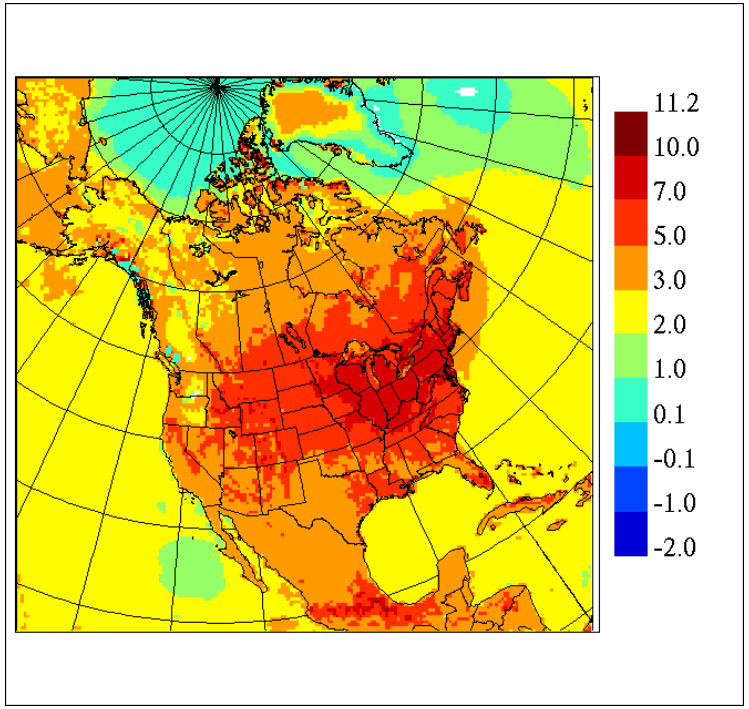
Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Extremes:**
  - Climate Factors (P and T) using RCM for NA
  - For each year (1961-2100) the annual extreme:
  - Tmin = coldest night; Tmax = warmest day

Change in Tmin



Change in Tmax

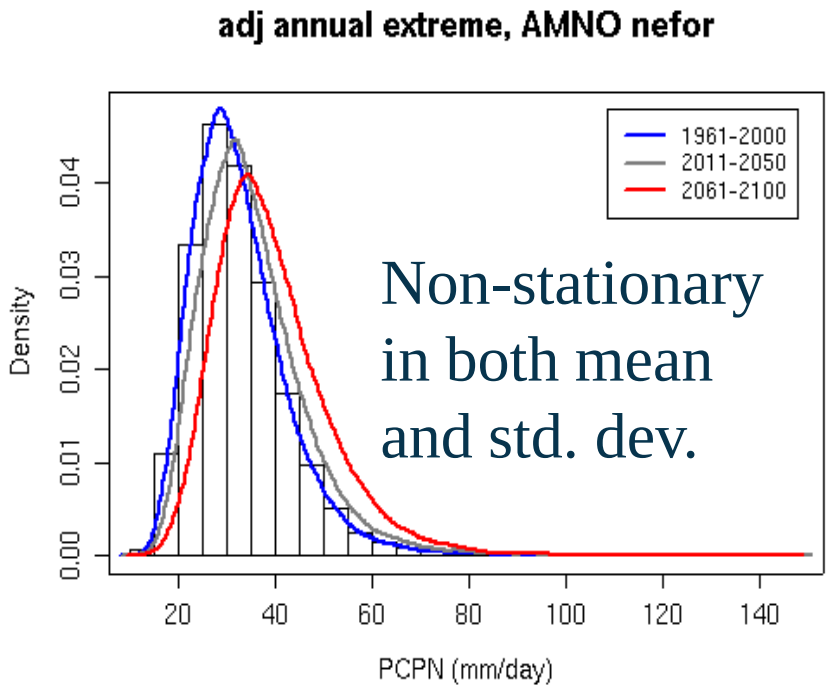


(source B. Casati Ouranos, unpublished).

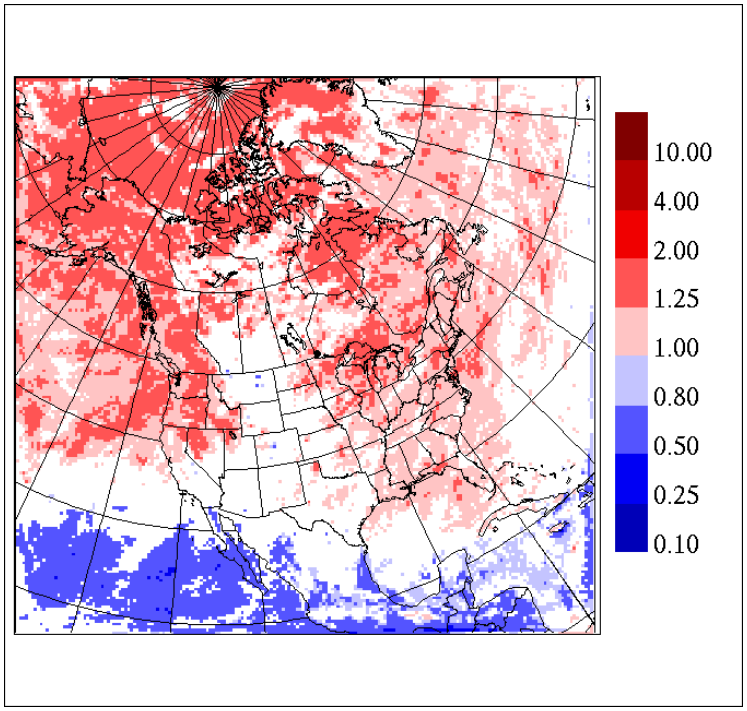
Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Extremes:**
  - Climate Factors (P and T) using RCM for NA
  - For each year (19612100) Pmax – the wettest day

PDF for Pmax in NE



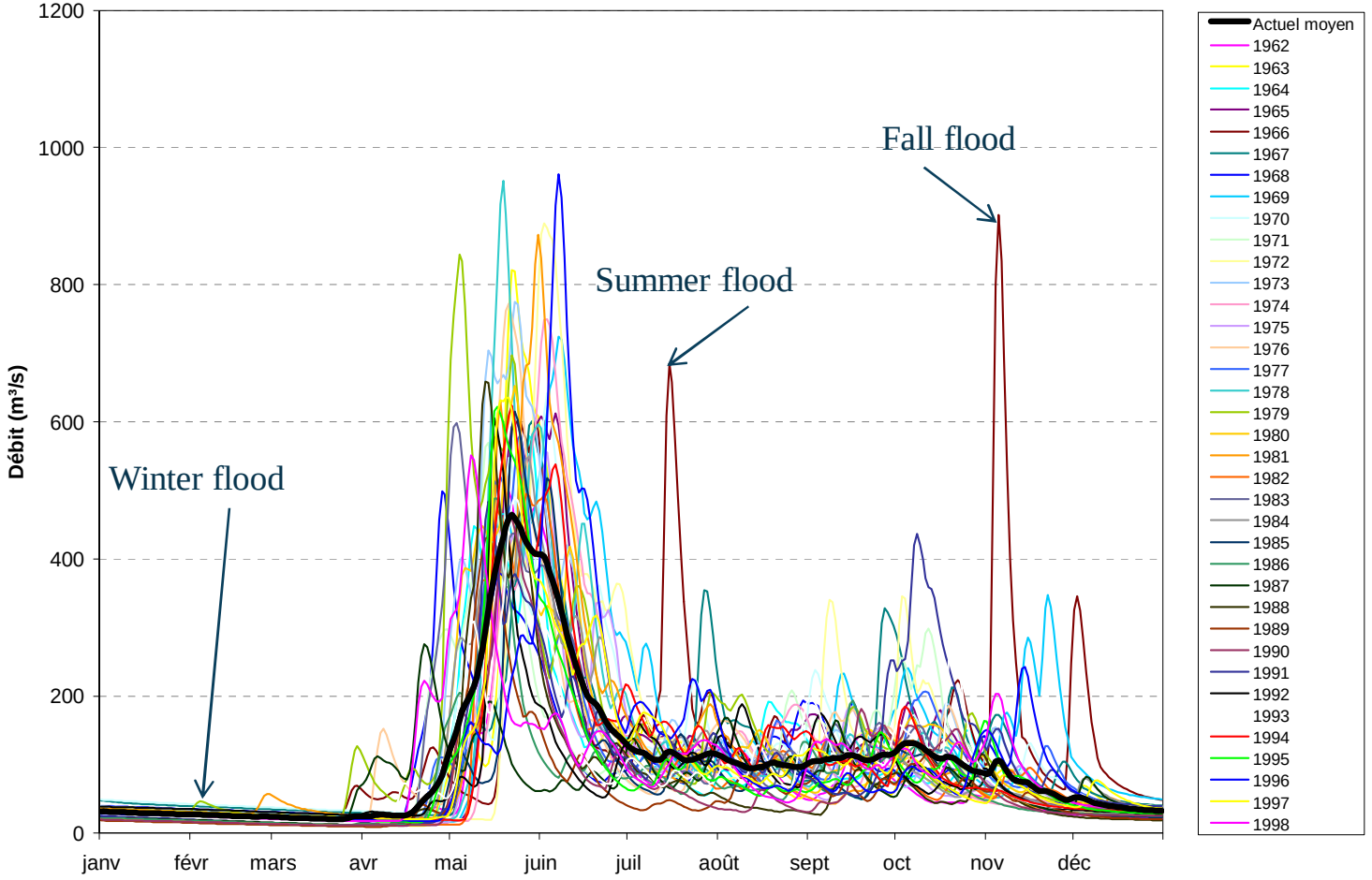
Ratio: Future hor 2080/Present 1980



(source B. Casati, Ouranos, unpublished).

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Extremes:**
  - Floods – the delta method



(Ouranos-HQ, 2009)

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Extremes:**
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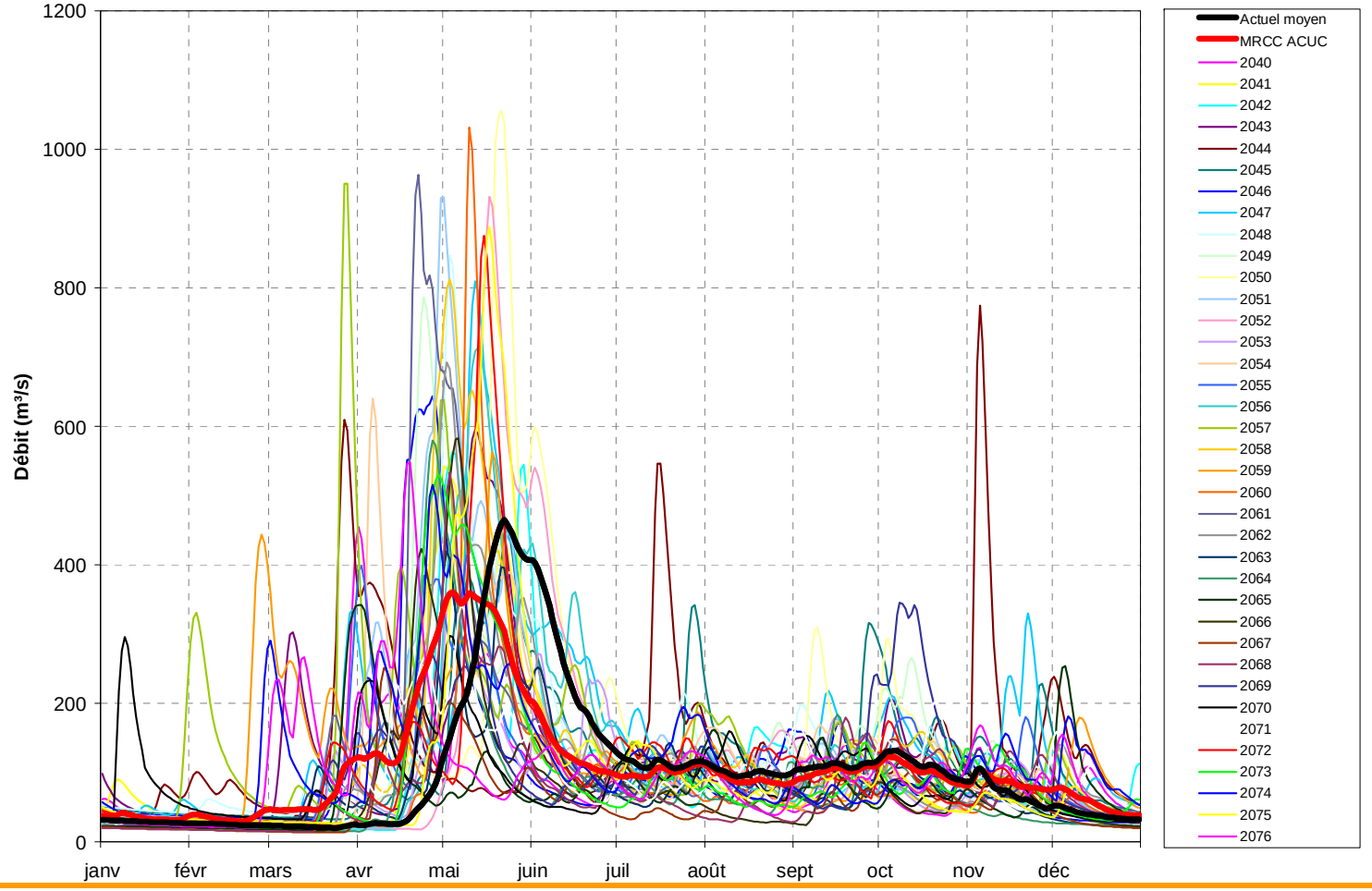
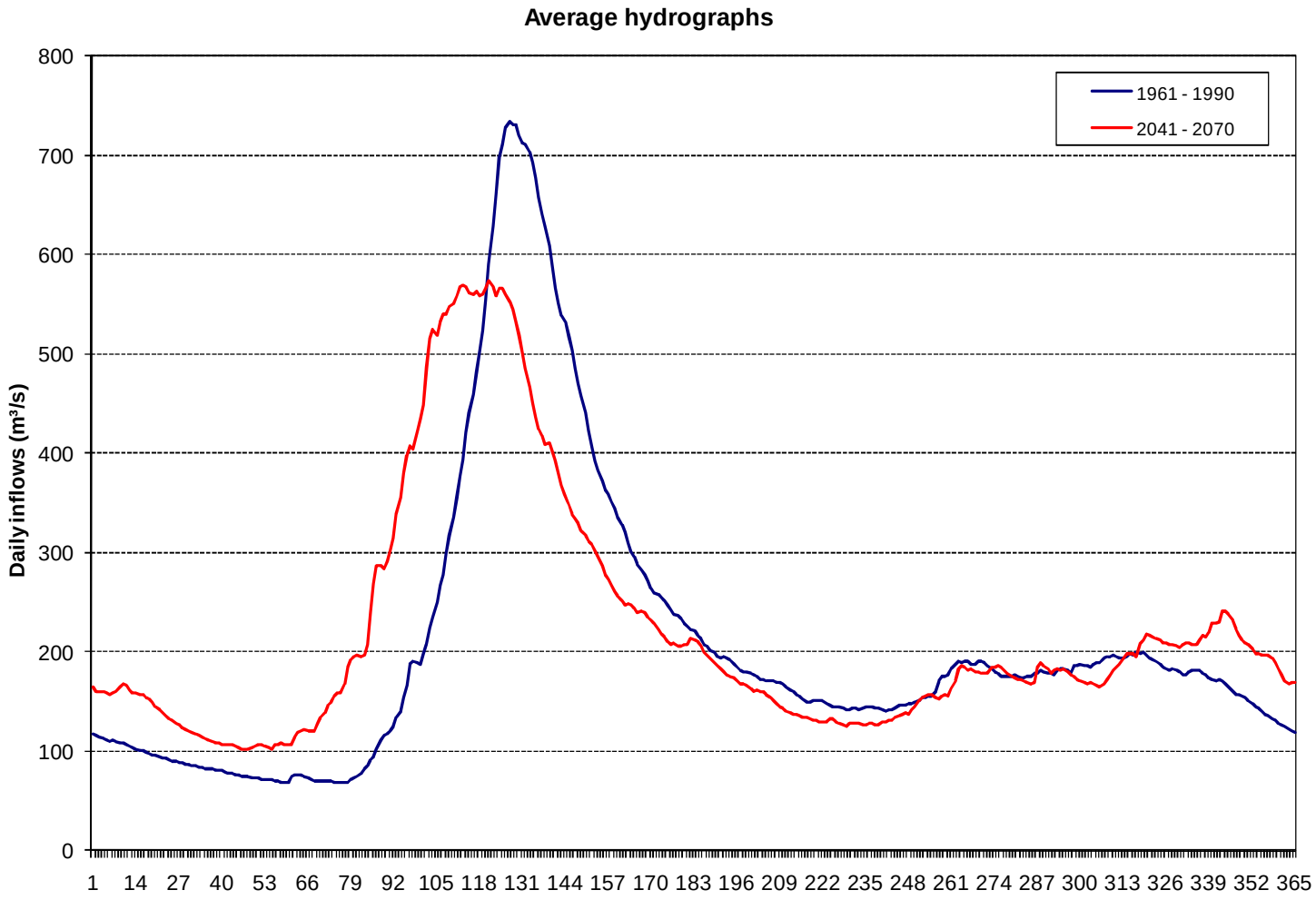


(Ouranos-HQ, 2009)

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

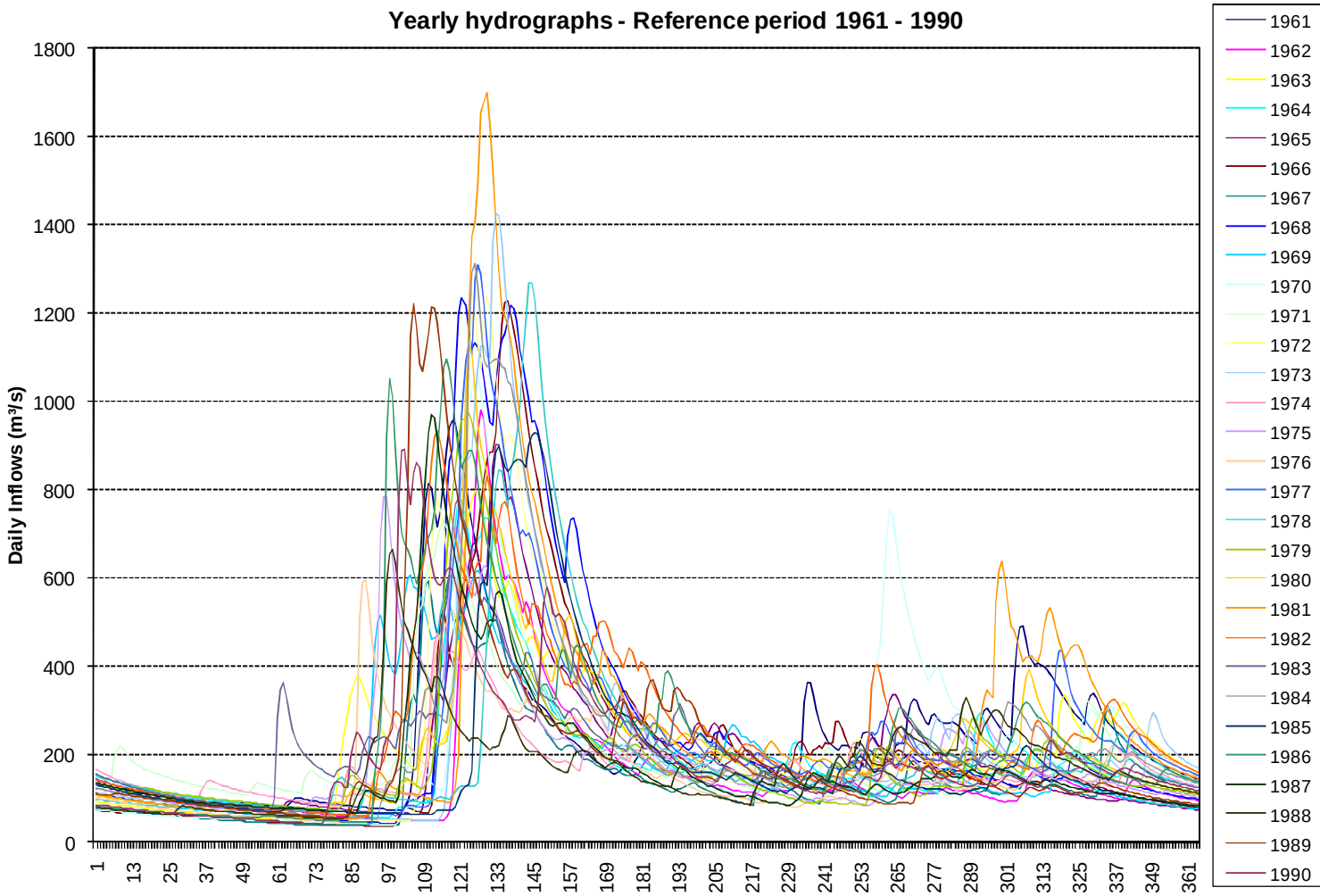
- **Extremes:Floods – direct inputs from RCM**



(Ouranos-HQ, 2009)

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

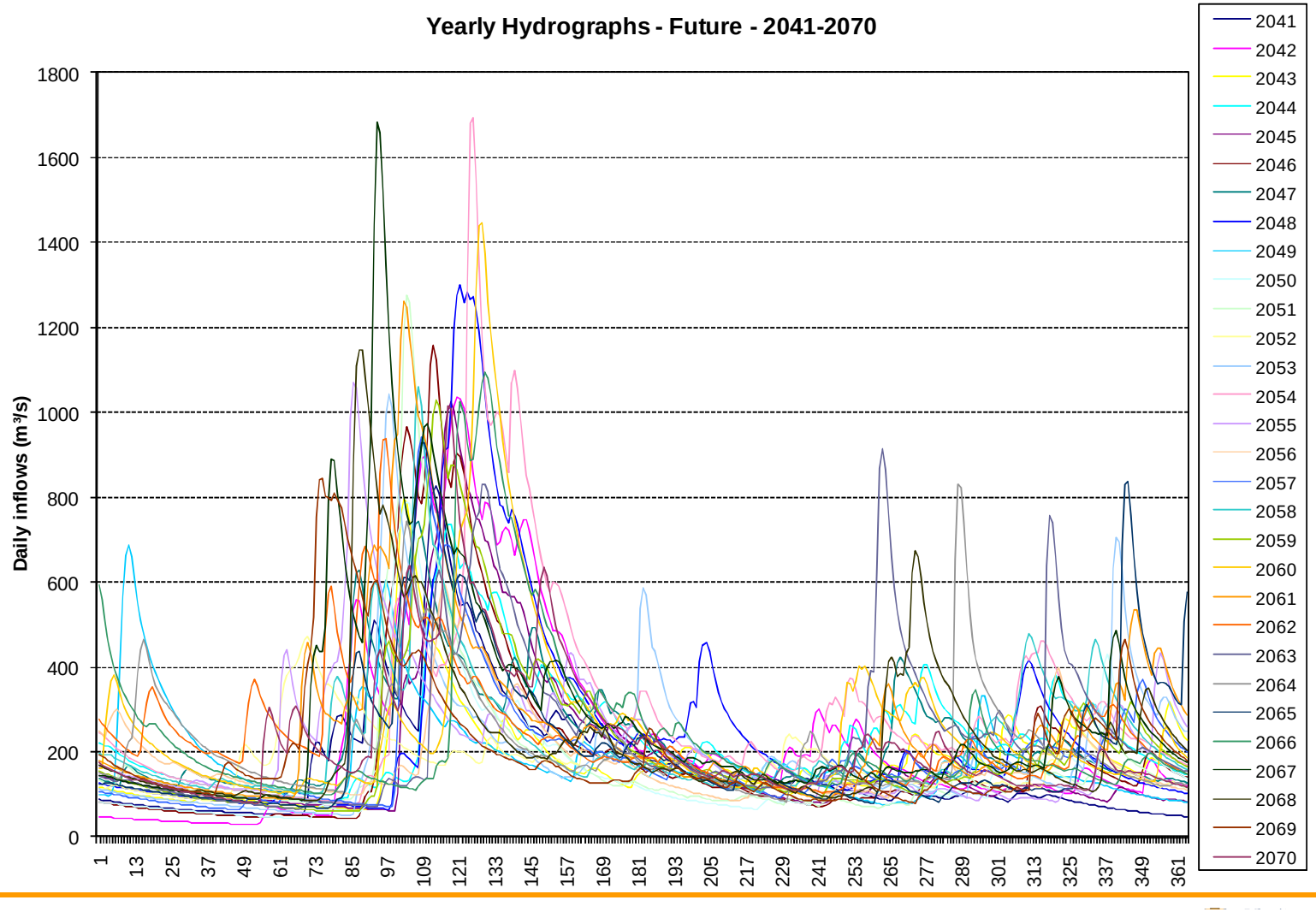
- **Extremes:Floods – direct inputs from RCM**



(Ouranos-HQ, 2009)

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

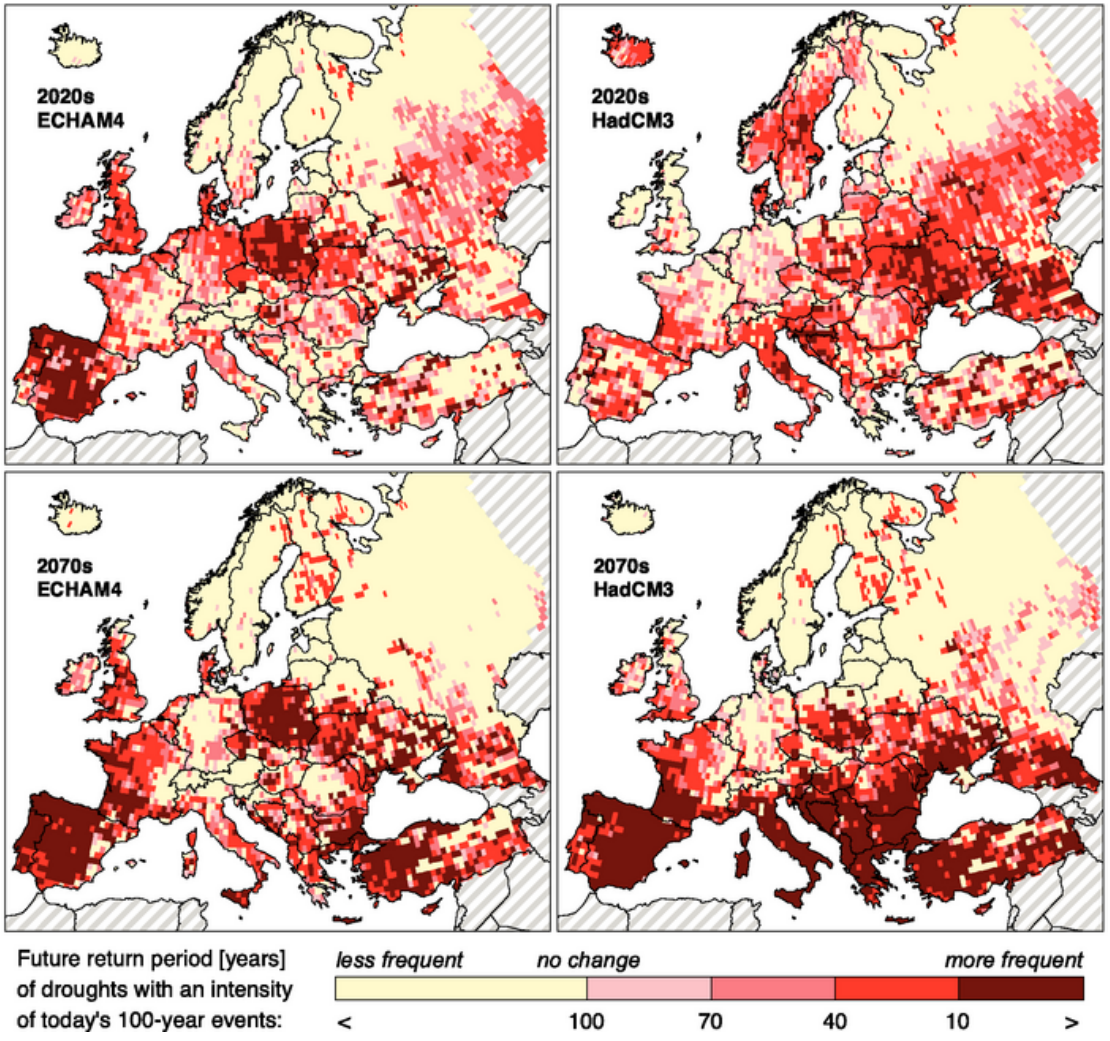
- **Extremes:Floods – direct inputs from RCM**



(Ouranos-HQ, 2009)

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Extremes: Droughts**



(source IPCC, 2007).

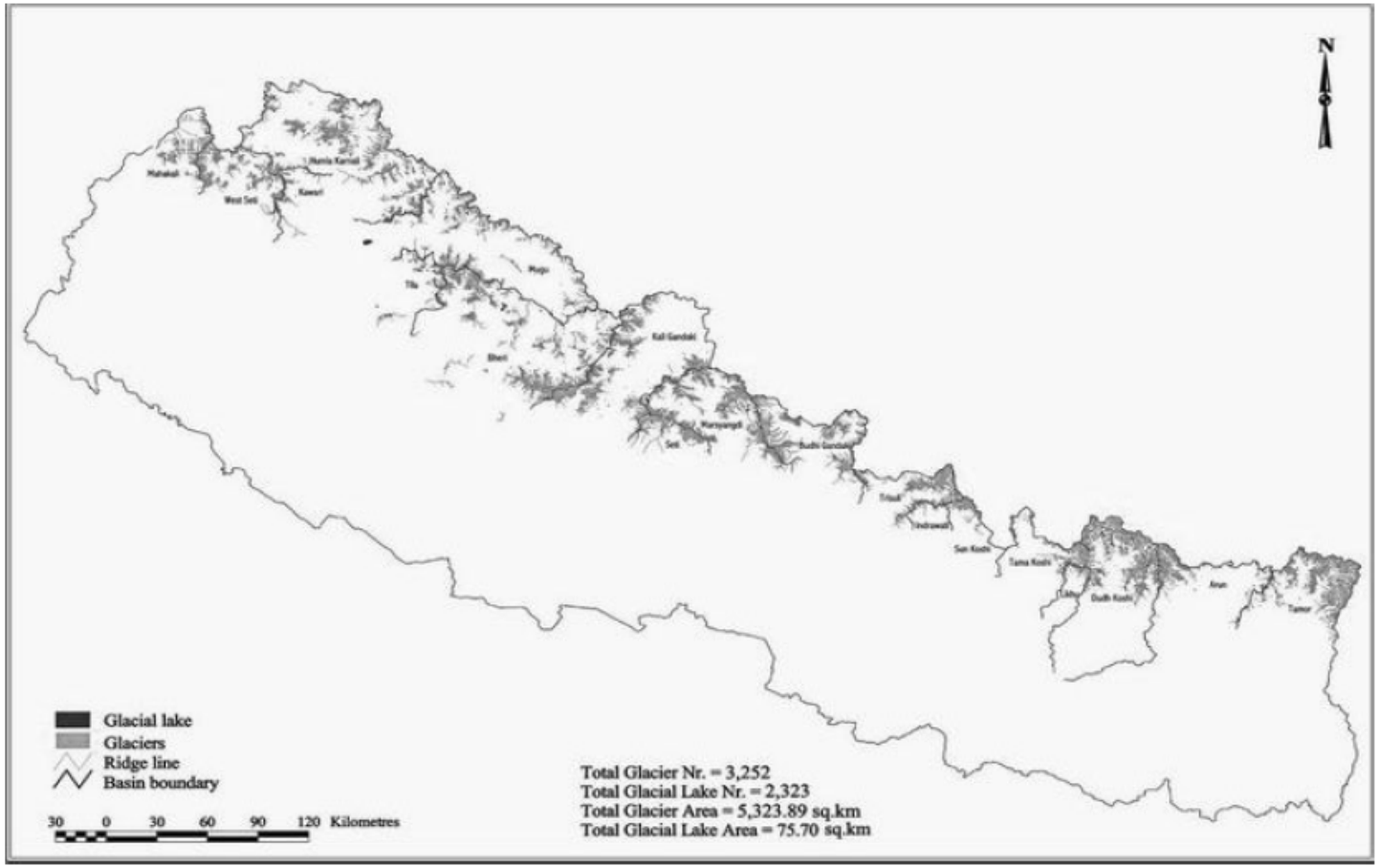
Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Extremes: Glacier Lake Outburst Floods GLOF**
  - Example of Hubbard Glacier Alaska

Hydropower Sector – Current evaluations of CC impacts on the hydropower sector

- **Extremes: Glacier Lake Outburst Floods GLOF**

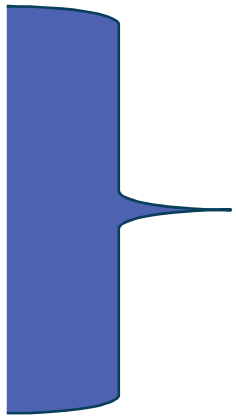
Figure 9. Glacial lakes and potential GLOF sites in Nepal



(source ICMOD and UNEP, 2002).

Hydropower Sector – Vulnerabilities to climate change – Future Adaptation options

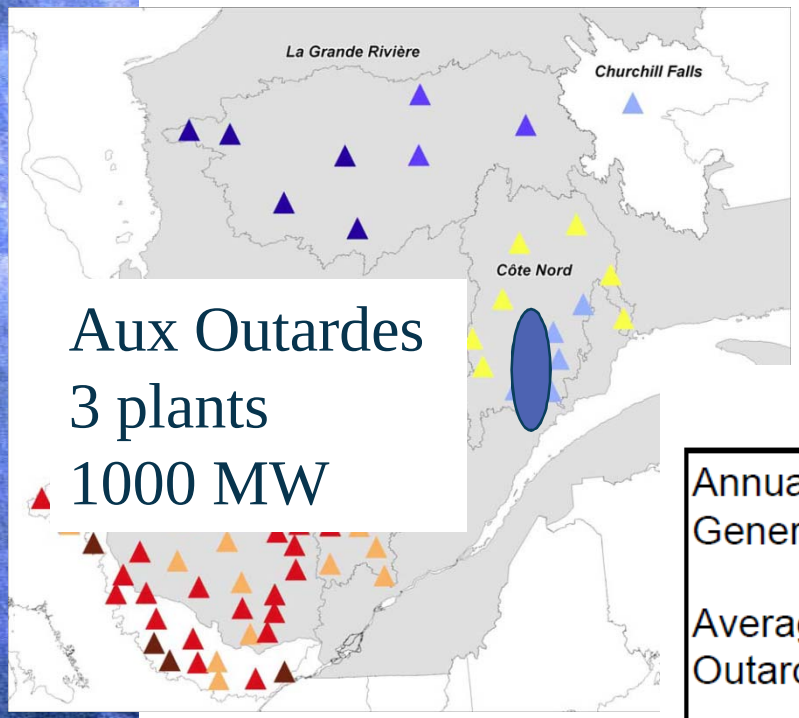
- **Operations (short term 1day – 5 years) :**
  - ***Annual runoff conditions***
  - **Are existing hydro plants able to adapt?**
- **Planning (5 – 30 years…):**
  - ***Changes in demand***
  - ***Changes in availability***
  - ***More severe extremes***



Should we design new hydro with CC data?

Hydropower Sector – Vulnerabilities to climate change – Future Adaptation options

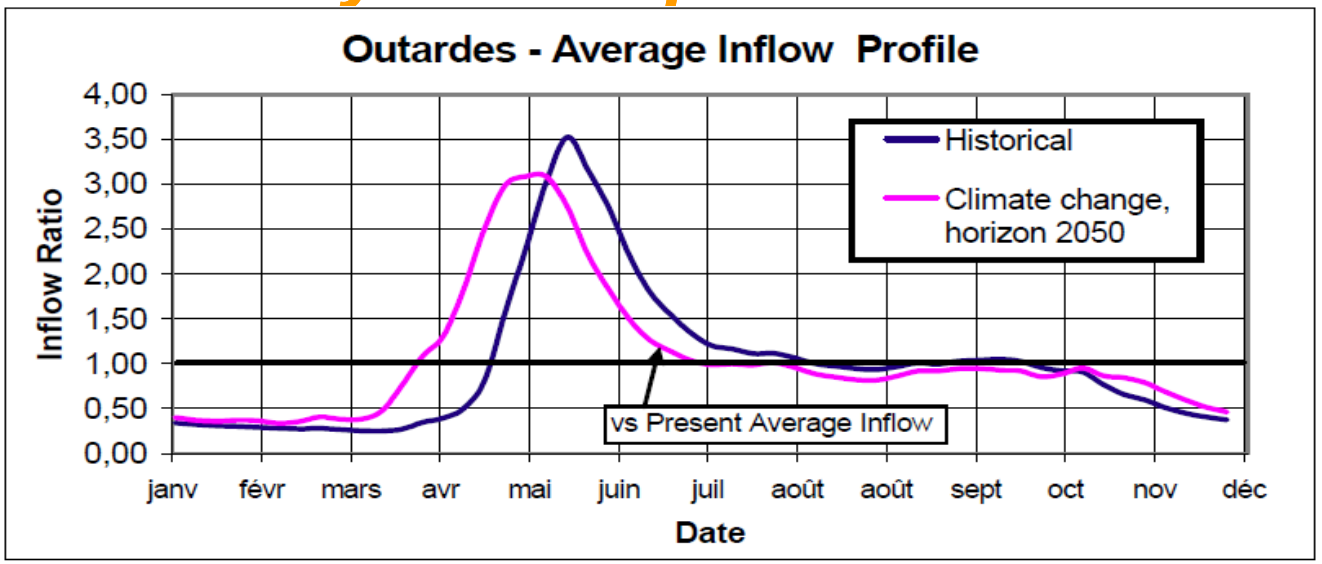
- **Operations (short term 1day – 5 years) :**
  - Evaluate using existing stochastic dynamic programming WM tool

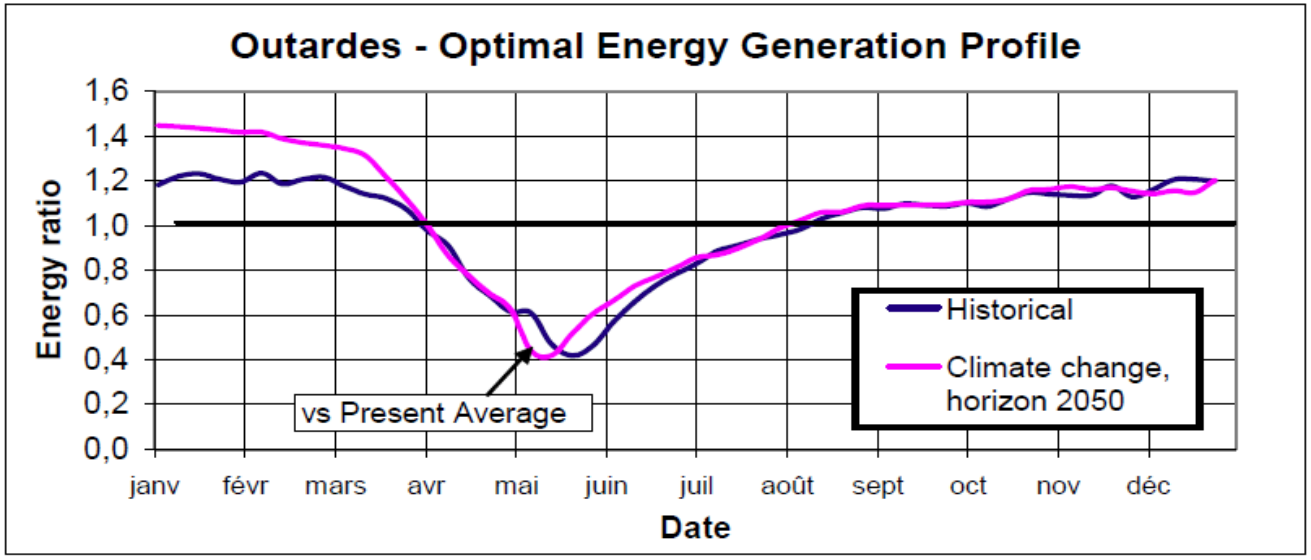


	Historical	Horizon 2050	Change
Annual Energy Generation (TWh)	9,9	10,4	5,1%
Average Inflow at Outardes 4 (m³/s)	346	365	5,4%
Outardes 4 Average reservoir Level (m)	349,55	349,67	0,12

(Raymond et al.-HQ, Ceati-WMIG 2008)

Hydropower Sector – Vulnerabilities to climate change – Can Hydro Adapt?





(Raymond et al.-HQ, Ceati-WMIG 2008)

Hydropower Sector – Vulnerabilities to climate change – Adaptation Options

- **Operations (short term 1day – 5 years) :**
  - ***Annual runoff conditions***
  - **Are existing hydro plants able to adapt?**
  - ***Where changes are limited to 10 to 20 % - yes***
  - ***Where storage is available***
  - ***Run-of –River remains vulnerable***
- **Planning (5 – 30 years…):**
  - ***Changes in demand***
  - ***Changes in availability***
  - ***More severe extremes***

Should we design new hydro with CC data?

Hydropower Sector – Vulnerabilities to climate change – Adaptation Options

- **Planning (5 – 30 years…):**
  - ***Change in climate:***
    - ***Change in demand***
      - ***Very gradual – several percent in 50 years***
    - ***Change in productivity***
      - ***Also very gradual – several percent in 50 years***
  - ***Economic and demand factors change much quicker than projected changes in climate-affected planning variables for hydropower***
  - ***Discount rates for project cost analysis make slightly uncertain or biased future less of a worry than most other planning factors***

Hydropower Sector – Vulnerabilities to climate change – Adaptation Options

- **Adapting to extremes :**
  - ***Are existing hydro plants able to adapt?***
    - ***Very early to answer this question***
    - ***Most CC studies done with delta method – doesn't capture variability***
    - ***Most tools used to manage extremes can be improved and adapted, but it is a big job – (non-stationnarity)***
    - ***Need more studies oriented to extremes***

Hydropower Sector – Vulnerabilities to climate change – Adaptation Options

Adaptation options:

- ***Non-structural:***
  - ***Improving water resource management (data, tools, communications between multiple users, etc.)***
  - ***Adapting tools for non-stationary inflows, extremes***
  - ***Work on flexibility (legal framework for water licensing; managing water for multiple basins)***
  - ***Prepare for more public discussions on water issues***

Hydropower Sector – Vulnerabilities to climate change – Adaptation Options

Adaptation options:

- ***Structural:***
  - ***When refurbishing, consider a refit that increases flexibility***
  - ***Consider pre-investment options for future needs – larger tunnels and options for additional spillway capacity***
  - ***Work on flexibility (design with non-stationarity)***

Hydropower Sector – Vulnerabilities to climate change – Looking ahead

- Activities with best return on investment:
  - Study tools – for planning and operations
  - Sharing climate change data and analysis results – building consensus
- Biggest unknowns
  - Statistical properties of future extremes
  - GCM and RCM model uncertainties

- Lots of work

Discussion