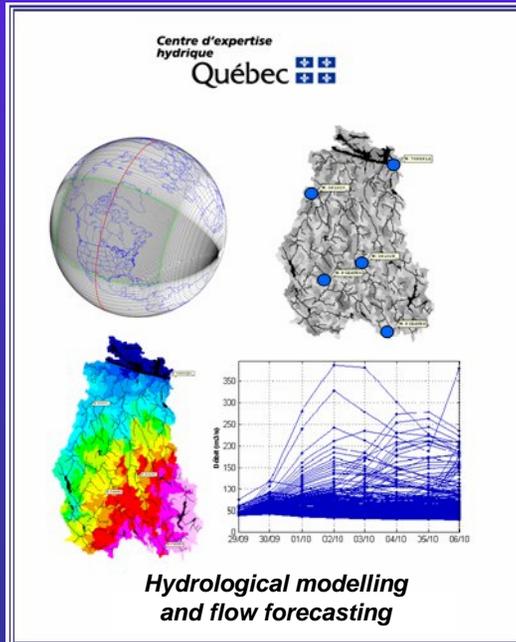




Flow forecasting scenarios to support multiple-objective management of publicly-owned dams in Quebec



Richard Turcotte

Chef de la division prévision hydrologique
Direction de l'expertise hydrique et de la gestion
des barrages publics

Centre d'expertise hydrique du Québec

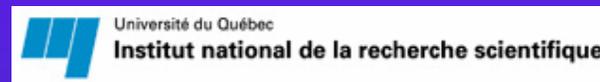


Partners

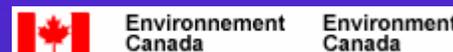
Hydro-Québec



INRS- Eau, Terre et
Environnement



Environnement Canada



Collaborators

Pierre Lacombe, Charles Poirier, Julie Lafleur, François Picard, Marco Latraverse, Douglas Sparks, Denis Tremblay, Vincent Fortin, Pierre Pellerin, Jean-Pierre Fortin, Jean-Pierre Villeneuve, ...



Scope of the presentation

1. Introduction
2. Flow forecasting at CEHQ
3. Applications
4. Conclusion and future challenges



Part 1

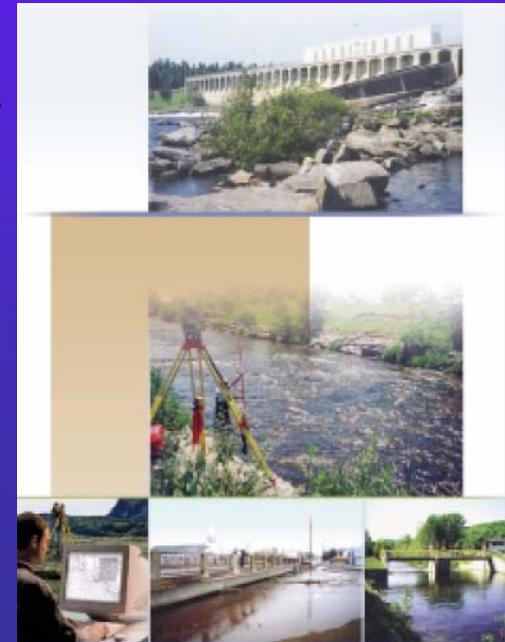
Introduction



Introduction

Centre d'expertise hydrique du Québec, CEHQ

- An agency of the Québec ministry of the Environment
- Some duties :
 - Provide expertise in hydrology and hydraulics
 - Ensure land management of the public water
 - Enforce the *Dam Safety Act*
 - Provide support to municipalities in defining flood-risk areas and effective control of floods
 - Operate hydrometric stations
 - Operate public dams





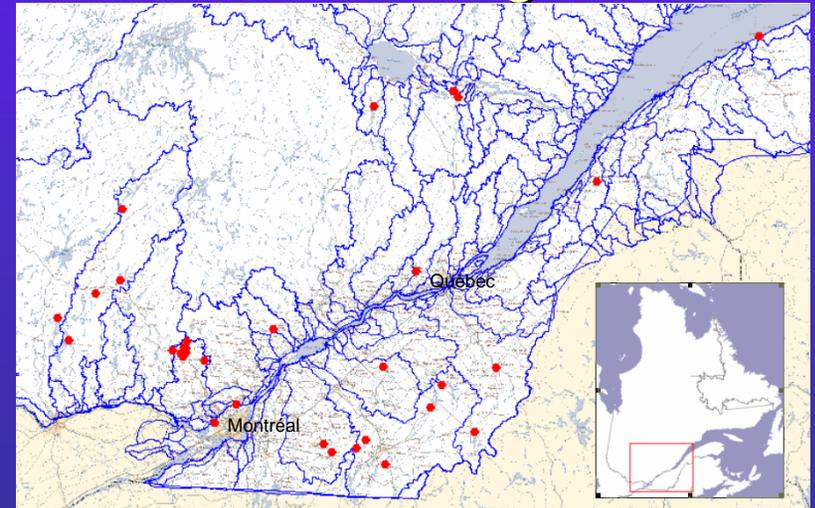
Introduction

Dam management at CEHQ

Dams used for multiple management objectives:

- Flood control;
- Water supply;
- Tourist and recreational activities;
- Hydroelectricity;
- Environmental protection;

36 publicly-owned dams which needs operational monitoring

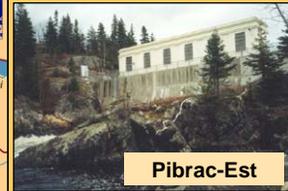
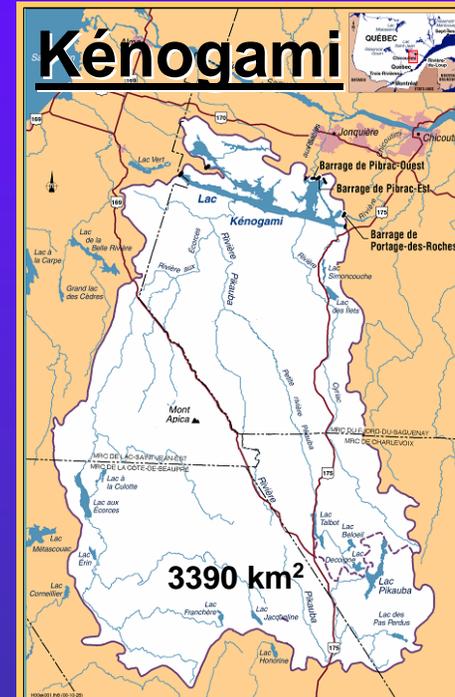


Introduction

Multiple objectives and stakeholders

Example of stakeholders

- **Hydro producers :**
 - optimal regulation to meet power needs
- **Lakeside residents :**
 - high and stable level for recreational activities
 - minimal level for water supply
- **Riverside residents :**
 - reduction of flood impacts and of outflow variations
 - minimal streamflow for water supply
- **Kayakers :**
 - targeted streamflows at given dates



Pibrac-Est



Portage-des-Roches



Pibrac-Ouest



Introduction

Opposite objectives and decision criteria

- Impact of dam operations are linked with :
 - quantitative criteria for some objectives
 - more qualitative criteria for the others
- In critical situations :
 - decisions cannot be made only using quantitative decision criteria
 - decisions must include discussions with stakeholders
- Basis for fruitful discussion :
 - a scientifically sounded information
 - a good frame-work to communicate it

t3 (and a negotiation where the government is the ultimate decision maker)
turri02, 10/4/2004

Introduction

Aim of this presentation

- To present the role of flow forecasting within communication and decision making processes
- To use operational examples to illustrate the possibilities of flow forecast scenarios



Part 2

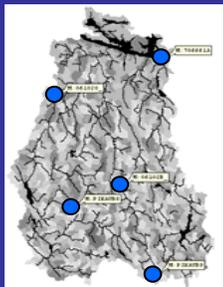
Flow forecasting at CEHQ

Flow forecasting at CEHQ

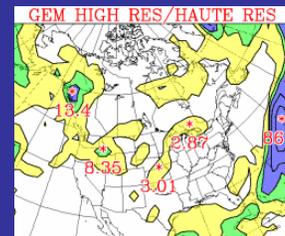
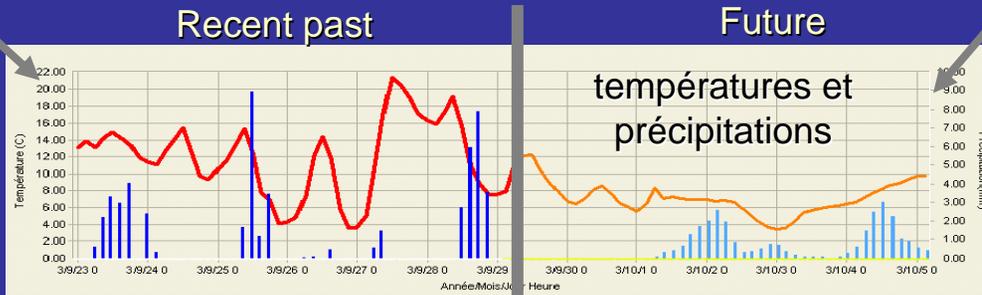
- **Flow forecasting** : a recommendation of the 1996 technical and scientific commission on dam management
 - A temporary program set in 1998
 - A permanent program set in 2000
- **Forecasted flow scenarios** : a part of the governmental project of flood regulation at Kénogami lake
 - CEHQ has participated with Hydro-Québec since 2001 for Kénogami lake
 - CEHQ started its own program for other reservoirs since march 2004

Flow forecasting

Meteorological forcing



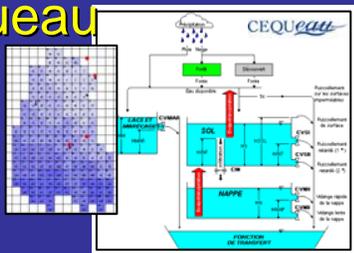
Meteorological network



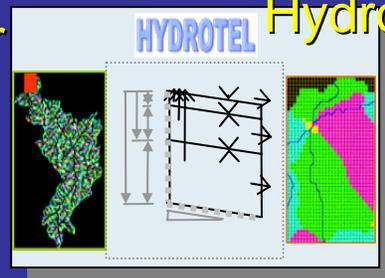
Weather forecast

Hydrological models

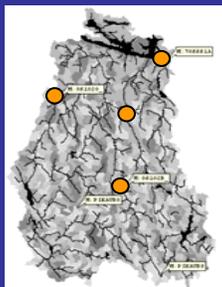
Cequeau



and/or

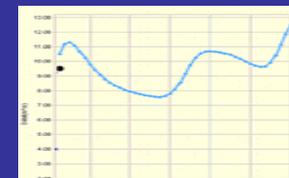
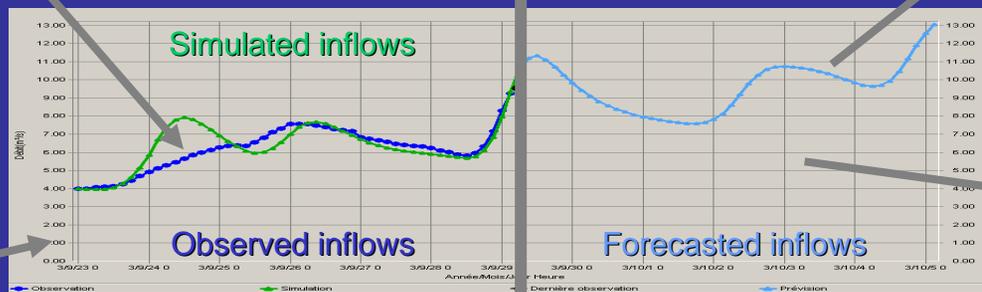


Hydrotel



Hydrometric network

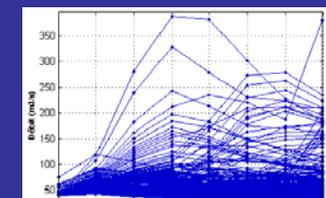
Updating of state variables



Main flow forecast



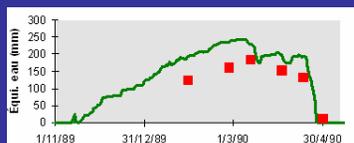
No new precipitation flow forecast



Flow forecast scenarios

Recent past Future

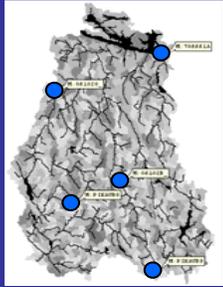
Simulated and forecasted inflows



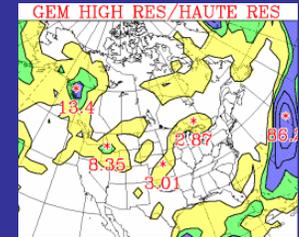
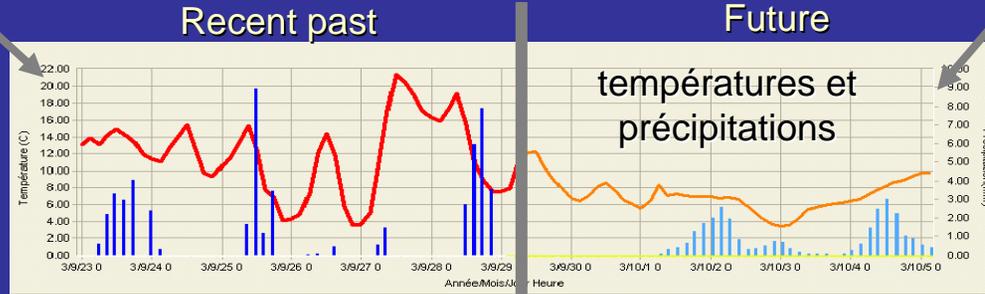
Snow surveys

Flow forecasting

Meteorological forcing



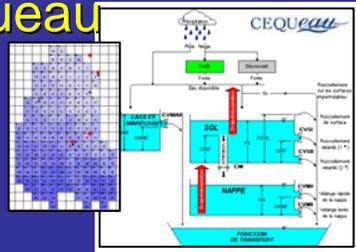
Meteorological network



Weather forecast

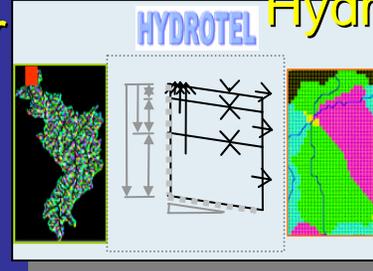
Hydrological models

Cequeau

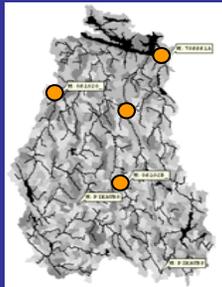


and/or

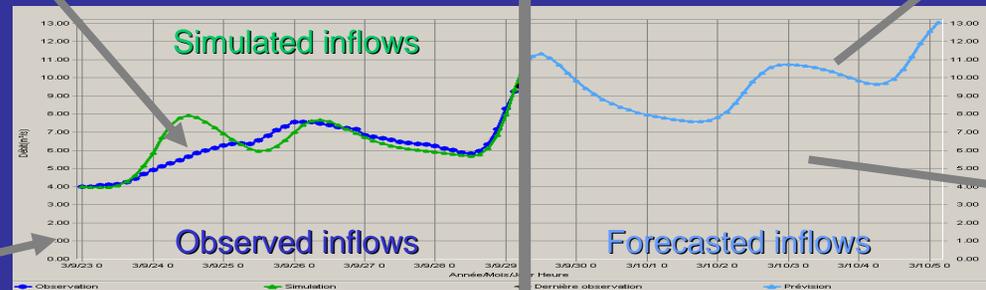
Hydrotel



Updating of state variables



Hydrometric network



Recent past

Future

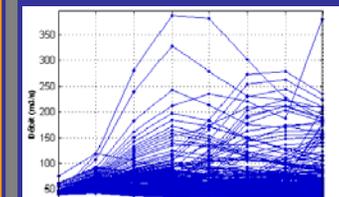
Simulated and forecasted inflows



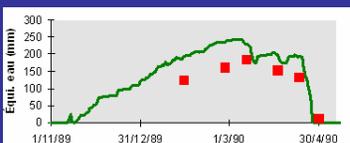
Main flow forecast



No new precipitation flow forecast



Flow forecast scenarios



Snow surveys

Outputs

- Main flow forecast :
 - using the “most probable” weather scenario
- *Ad hoc* forecast scenarios :
 - using user-defined weather scenarios
- Ensemble forecast scenarios :
 - using an empirical distribution function for QPF short-term scenarios (horizon: 4 days)

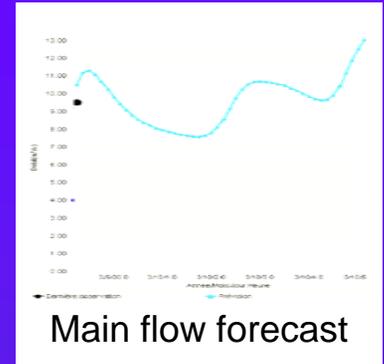
corresponding probabilities of the observation (in mm) are :

For a forecasted amount of precipitation between 5-15 mm :

0-5	5-15	15-25	25-50	50 et +
34%	40%	20%	5%	2%

Based on historical errors

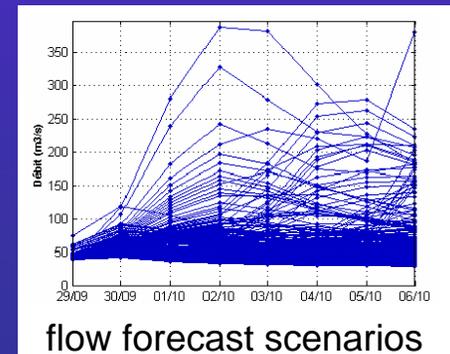
- using climatology for QPF mid-term scenarios (horizon : 6 months)



Main flow forecast



No new precipitation

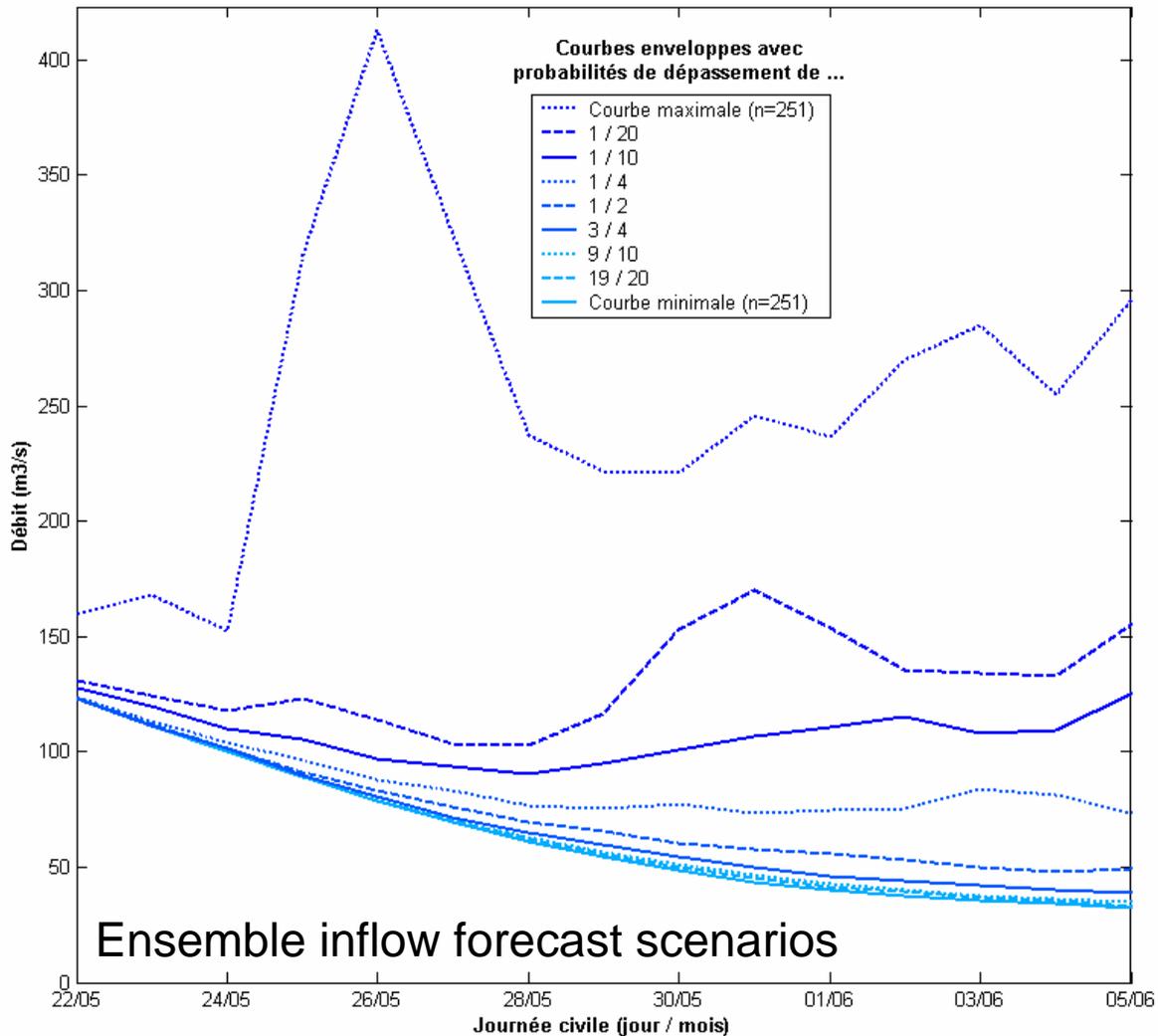


flow forecast scenarios



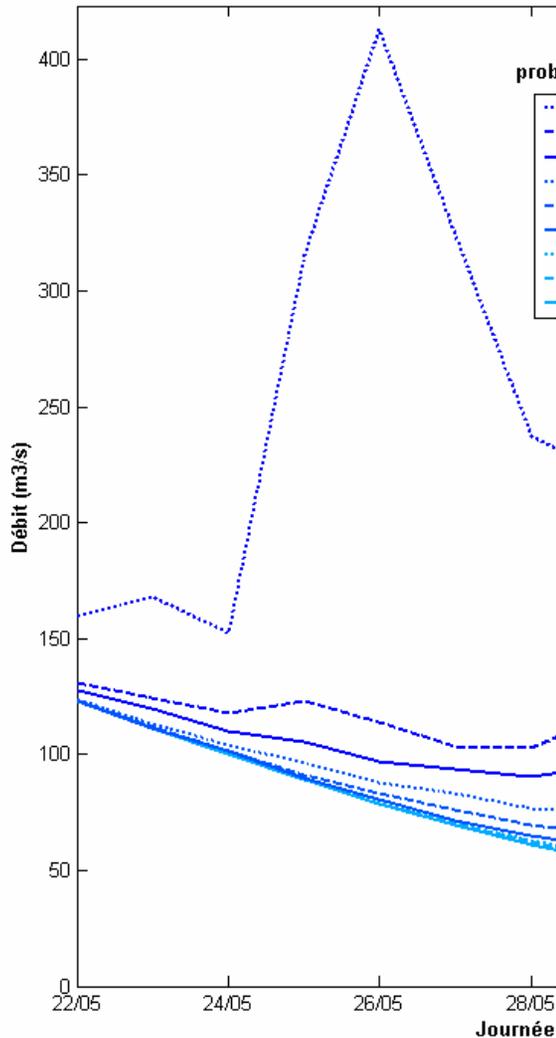
Outcome : Decision support system for dam management

Séries prévisionnelles (apports)

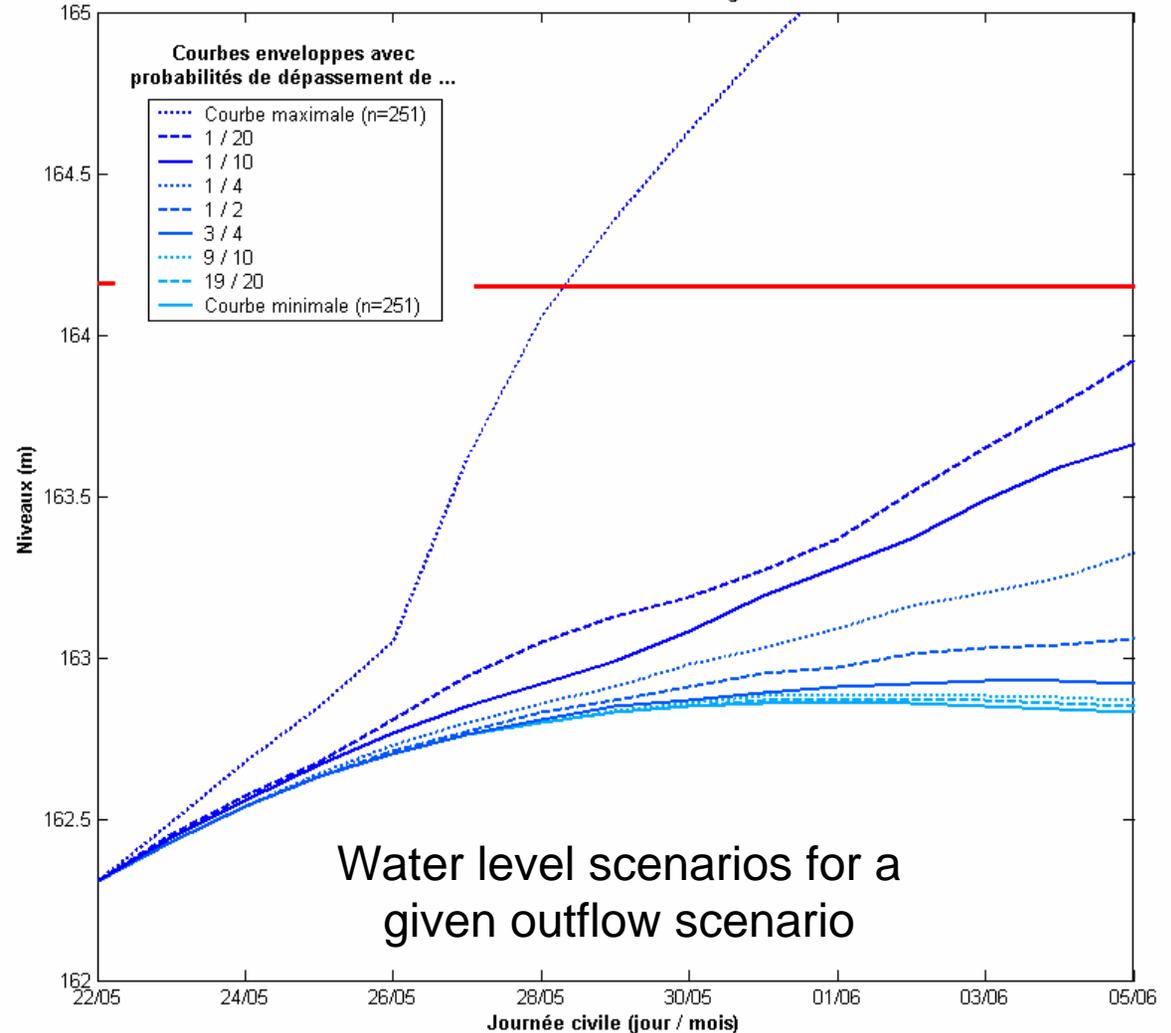


Outcome : Decision support system for dam management

Séries prévisionnelles (apports)



Niveaux simulés du lac Kénogami

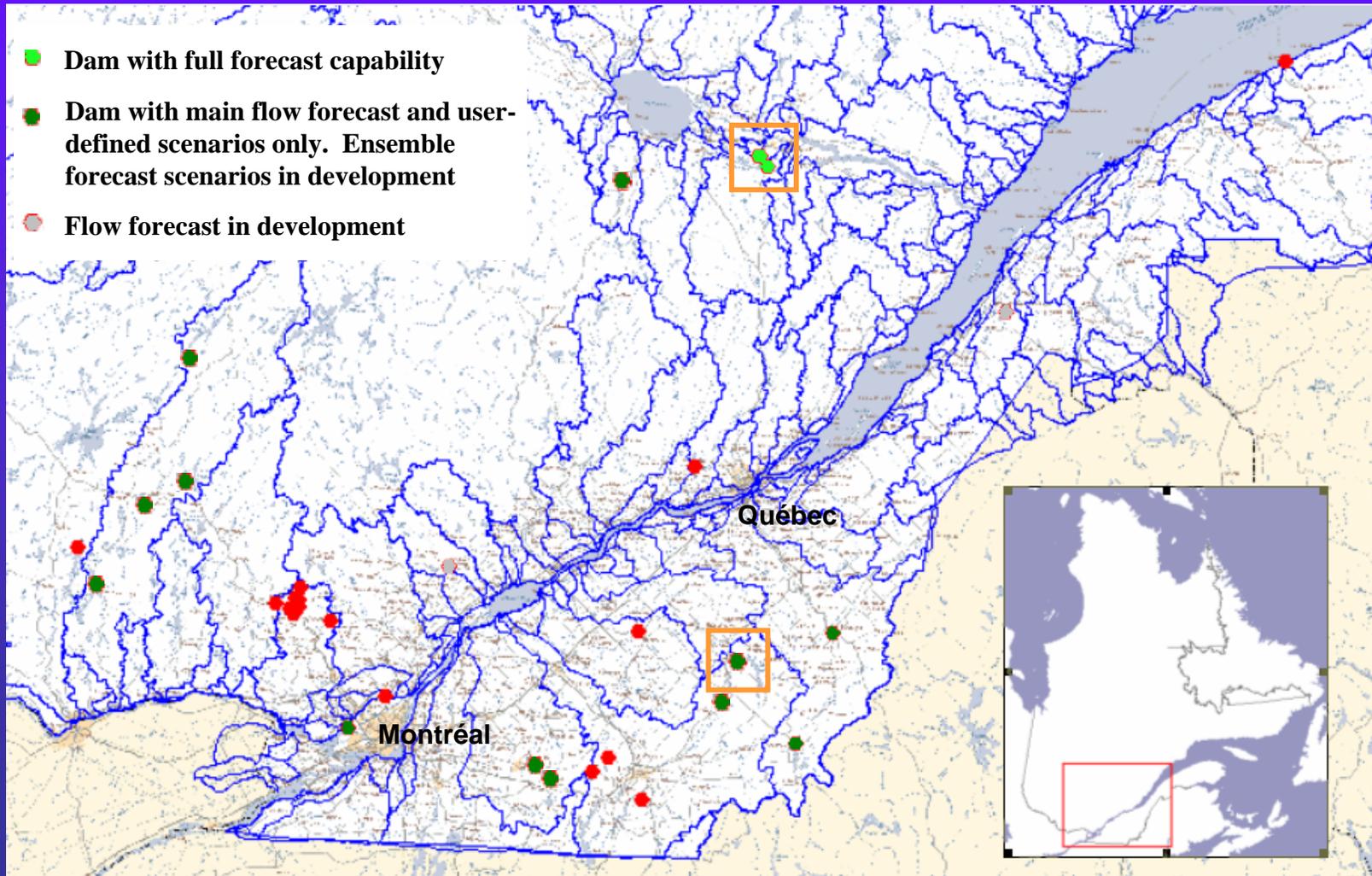




Part 3

Applications

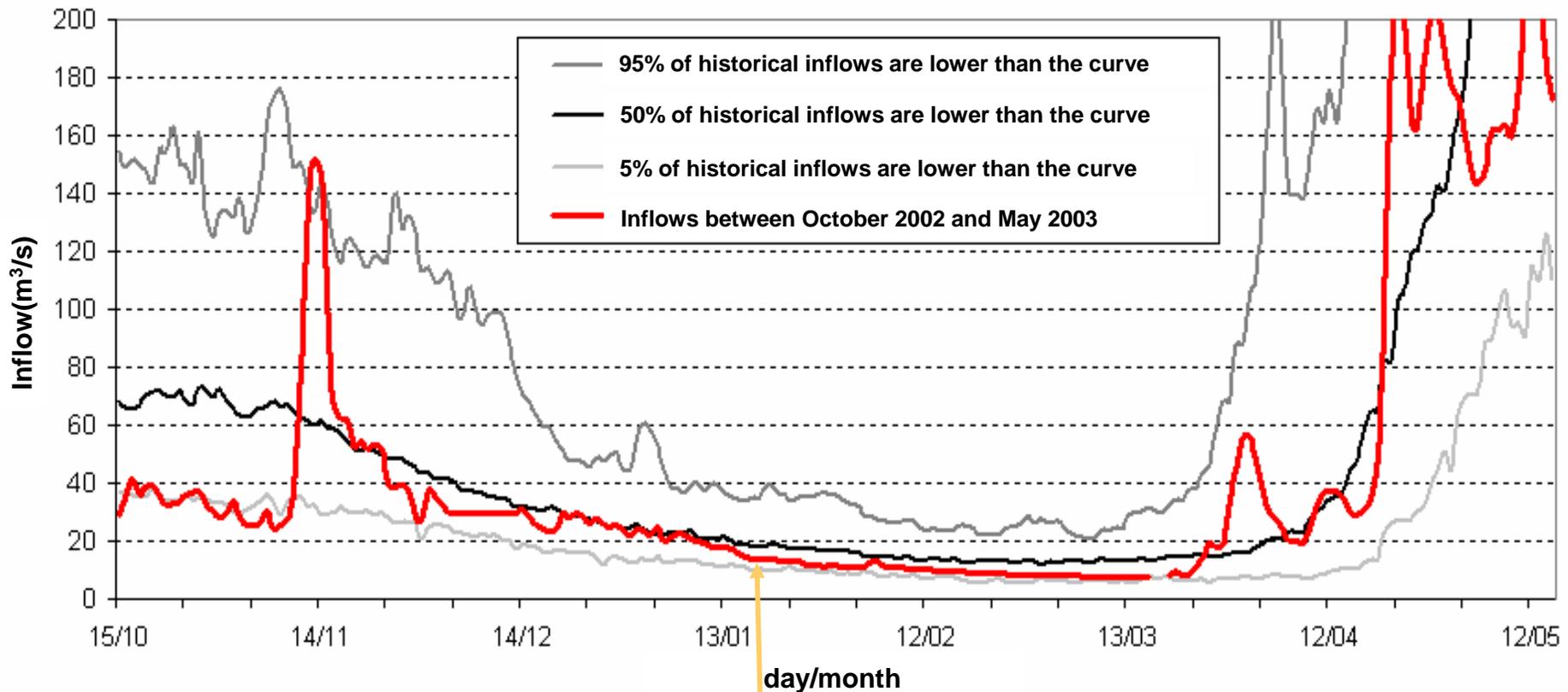
Development of the flow forecasting capability





Application #1 : Kénogami lake

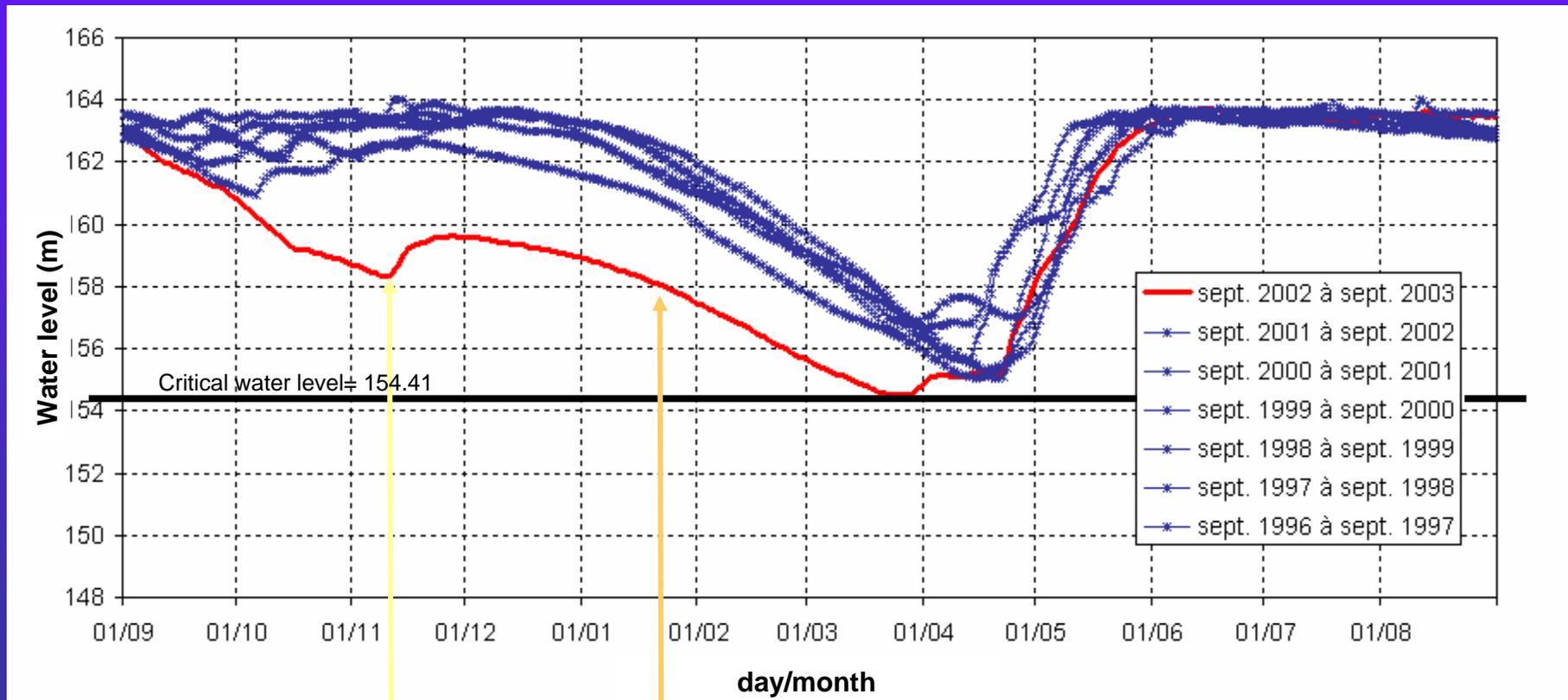
Historical inflows, October to May (1913-2003),
calculated using observed levels and outflows



Analysis of the January 21th, 2003

Application #1 : 2003 winter low flows at Kénogami lake

Observed lake level; September 1996 to September 2003



Exceptional reduction of
the outflow to $30 \text{ m}^3/\text{s}$
made November 8th, 2002

Analysis of the January 21th, 2003

Application #1 : Kénogami lake

Analysis of the January 21th, 2003

Decision to be argue with stakeholders

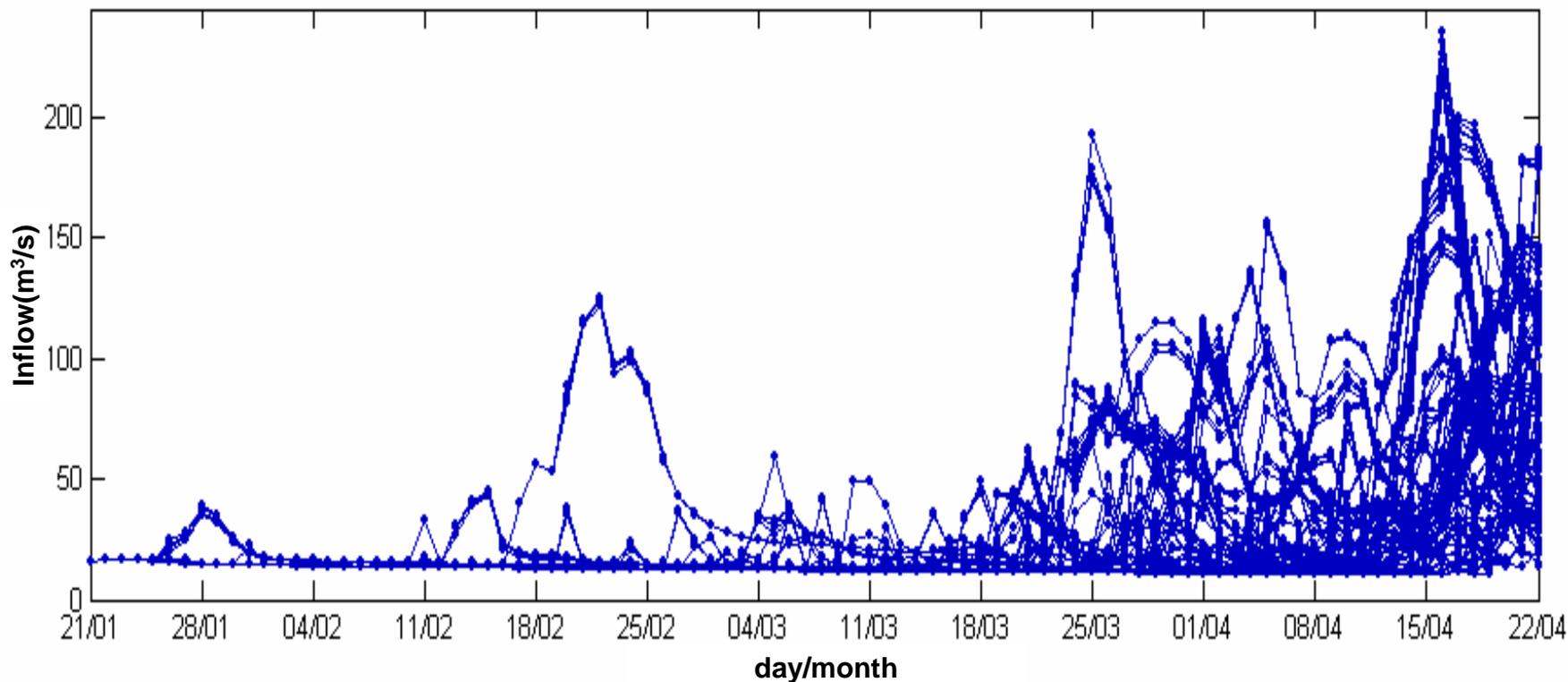
- Lakeside and riverside residents
 - Possibility to even more severe reduction of the outflow (under 30 m³/s) to avoid critical lake level

t5

Water intake
turri02, 11/1/2004

Application #1 : Kénogami lake

Analysis of the January 21th, 2003 Ensemble forecasted inflows



t4

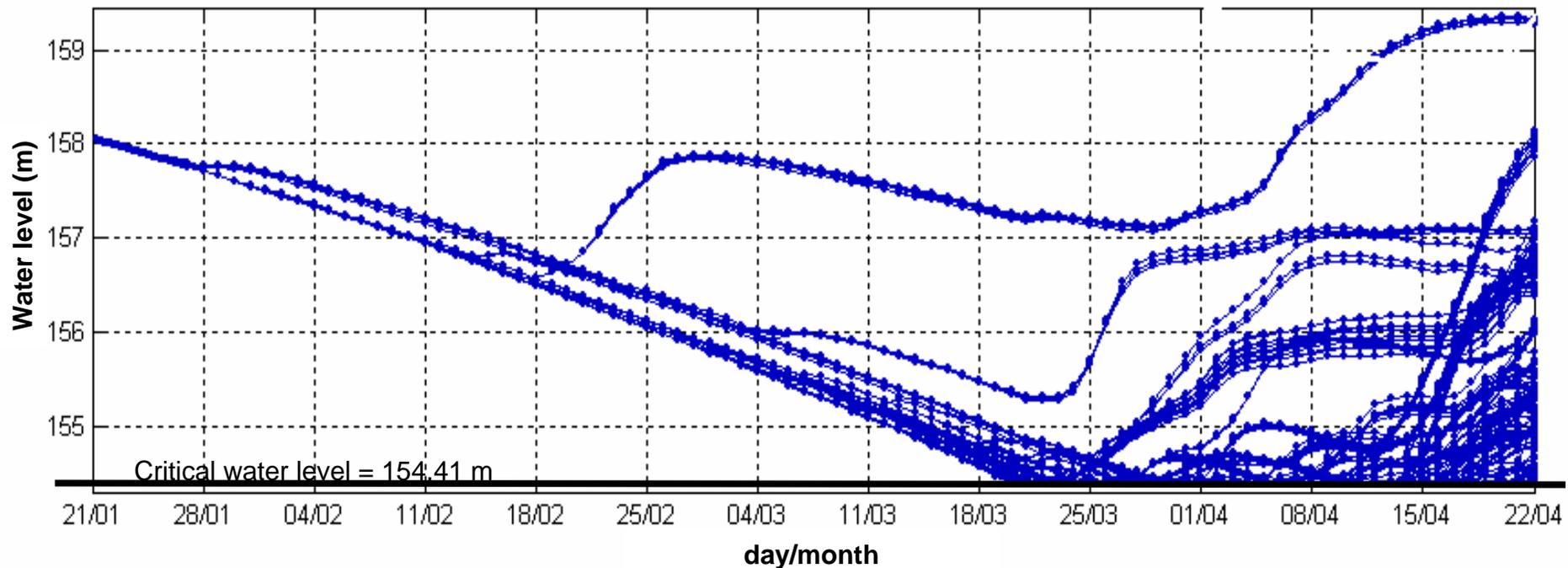
Rise in temperature

turri02, 11/1/2004



Application #1 : Kénogami lake

Analysis of the January 21th, 2003
Potential evolution of the water level using inflow scenarios
if a 30 m³/s outflow is applied for the whole period

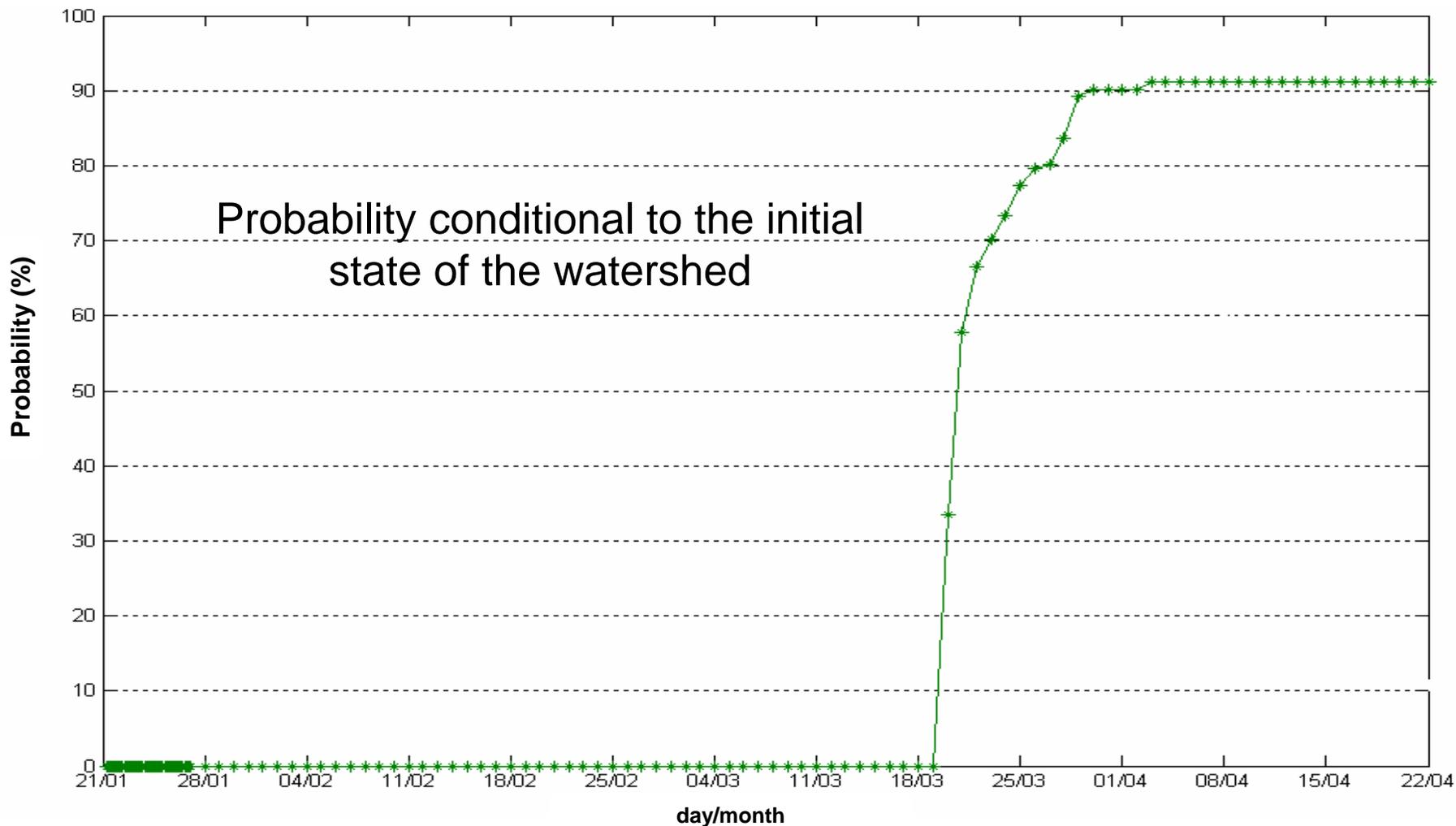




Application #1 : Kénogami lake

Analysis of the January 21th, 2003

Probability to have a water level under 154,41 m (for a given date)
if a 30 m³/s outflow is applied for the whole period

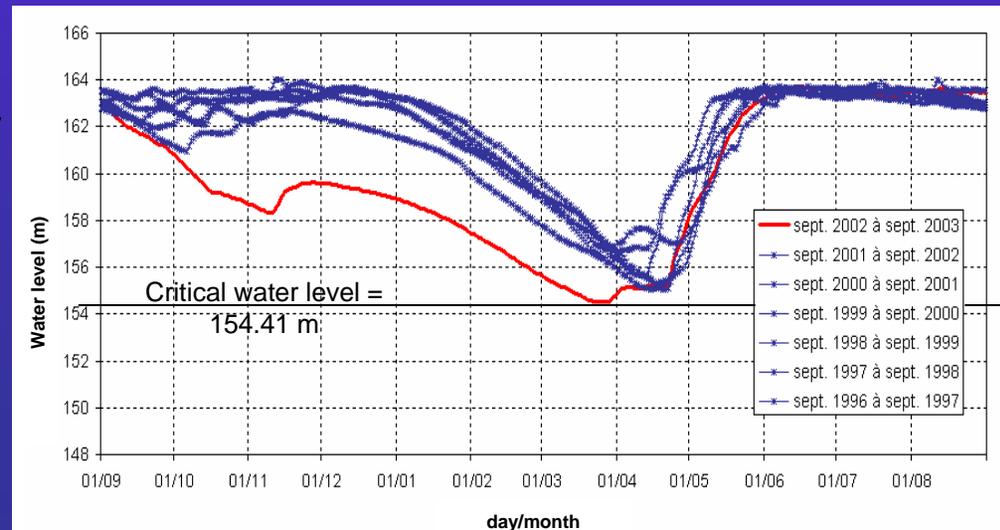




Application #1 : Kénogami lake

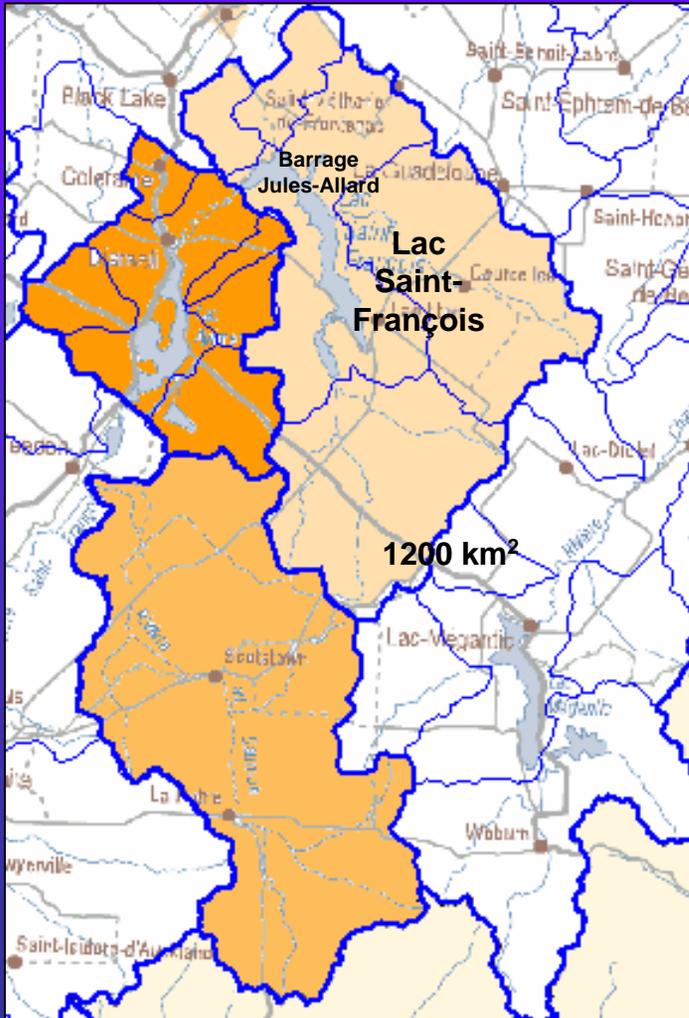
January 21th analysis served to :

- define March 18th as the date where the risk of lacking water is considerably increasing
- inform stakeholders that probability to reduce outflows under $30 \text{ m}^3/\text{s}$ is high (9 chances out of ten)
- make a decision of reducing outflows to $21 \text{ m}^3/\text{s}$ on march 6th, 2003.
- Avoid major problem for water supply





Application #2 : 2003 winter low flows at St.François lake



Winter management objectives

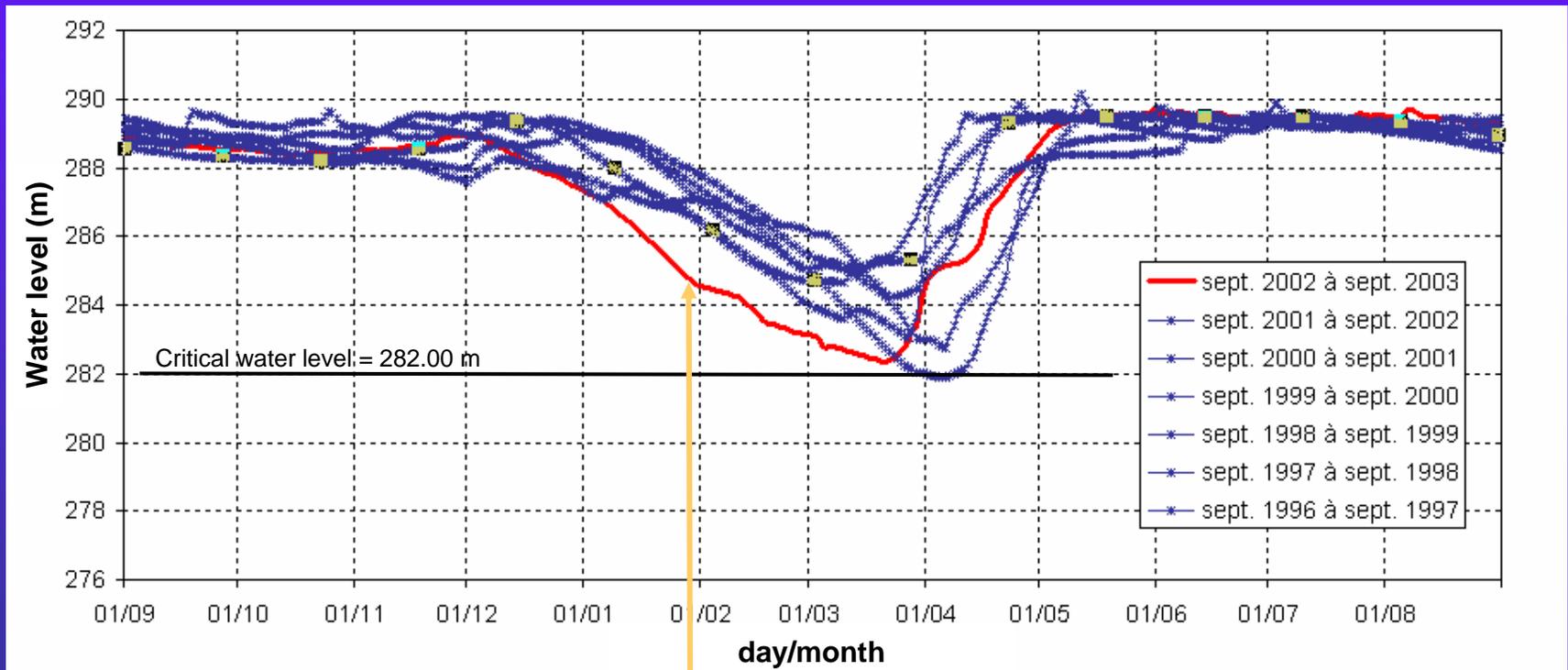
- Draining of the lake: increase the volume available for the storage of the spring runoff
- Allows the best possible hydroelectric energy production:
 - “best” discharge $\approx 45 \text{ m}^3/\text{s}$

Main constraints

- keep enough water in the reservoir for water supply demand:
 - level $> 282.00\text{m}$
- Enough water at mid-April for yellow walleye spawning
 - level $> 286.20 \text{ m}$

Application #2 : St.François lake

Observed lake level; September 1996 to September 2003



Analysis of the January 27th, 2003

Application #2 : St.François lake

Decision to be argue with stakeholders

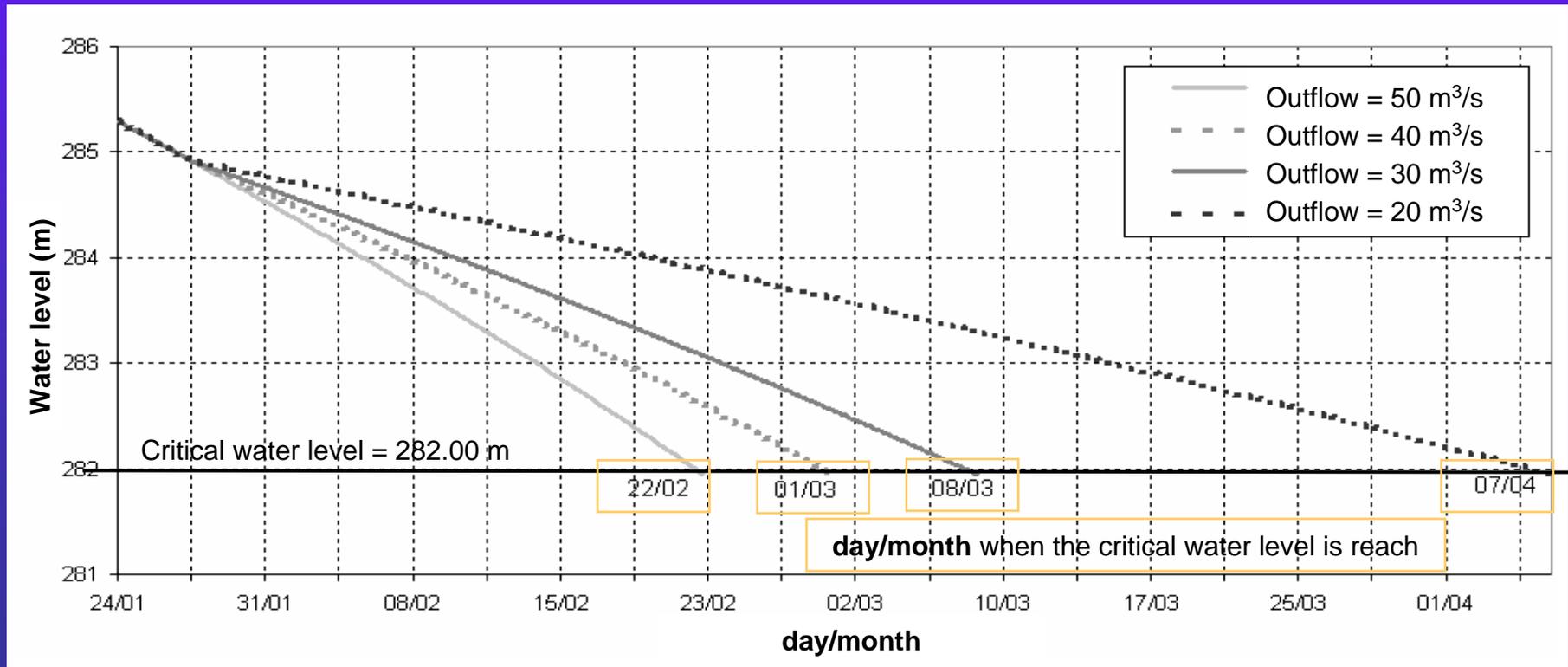
- Hydroelectric producers : reduction of the outflow at 15 m³/s (under the “best” outflow 45 m³/s) until spring freshet except for cold days
- Lakeside residents : the proposed reduction is enough to fill water supply needs until spring melt



Application #2 : St.François lake

Analysis of the January 27th, 2003

Potential evolution of the water level using a “no snow melt” inflow scenario for 4 given outflows applied for the whole period

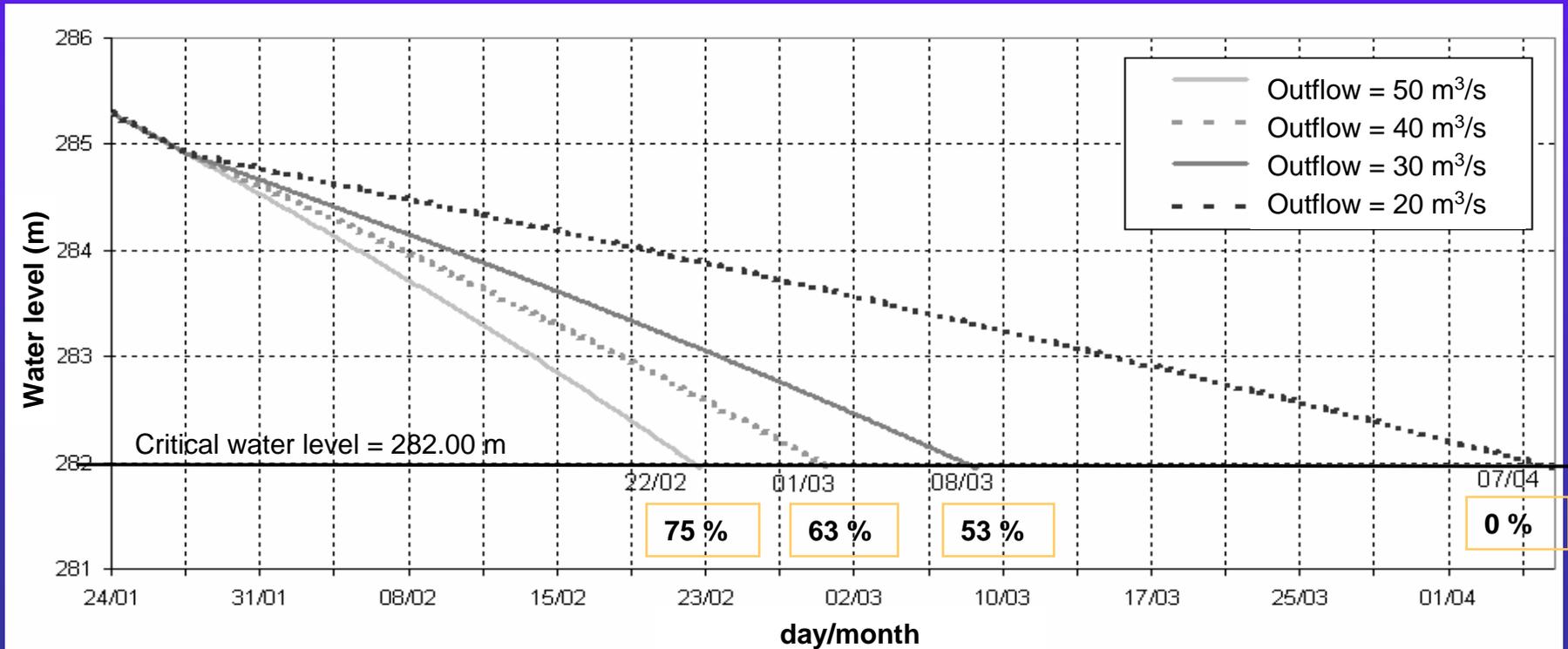




Application #2 : St.François lake

Analysis of the January 27th, 2003

Potential evolution of the water level using a “no snow melt” inflow scenario for 4 given outflows applied for the whole period

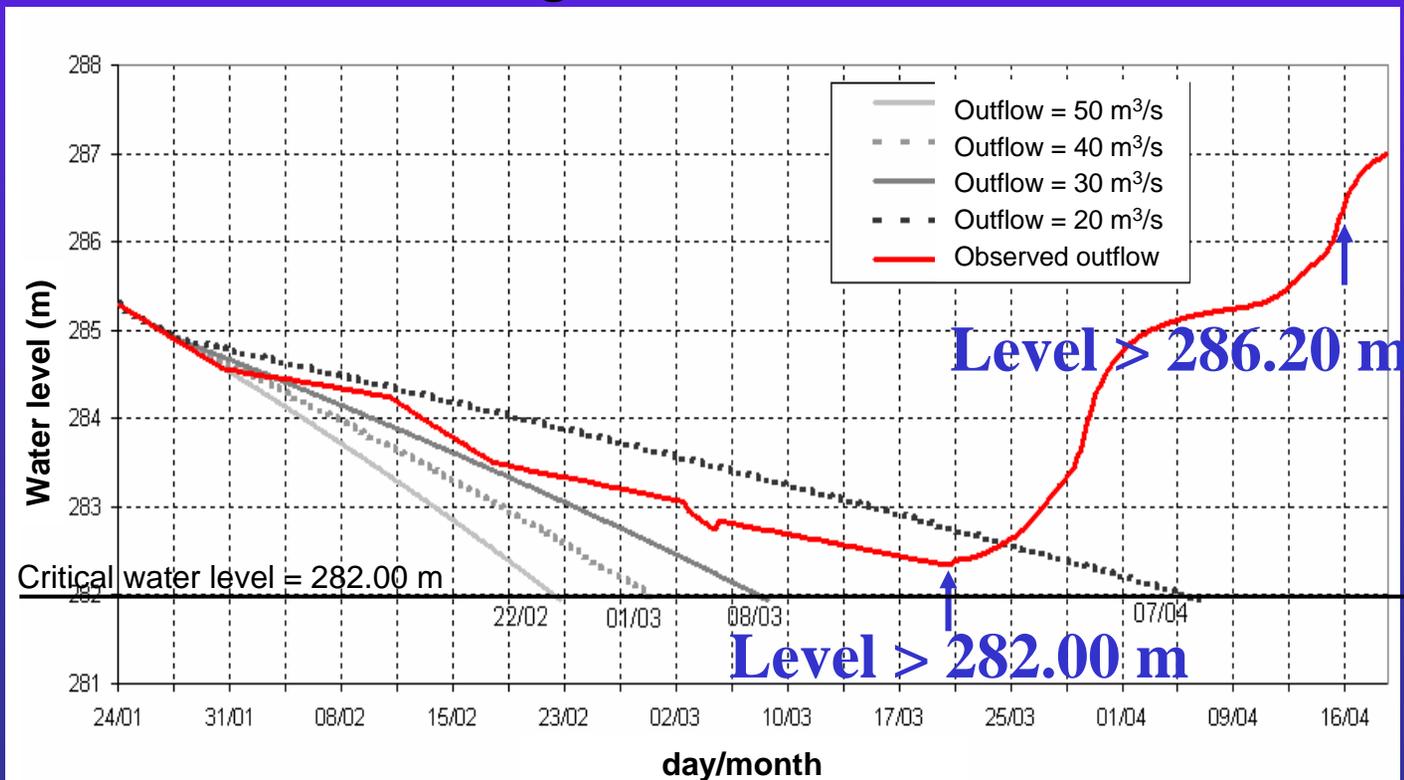




Application #2 : St.François lake

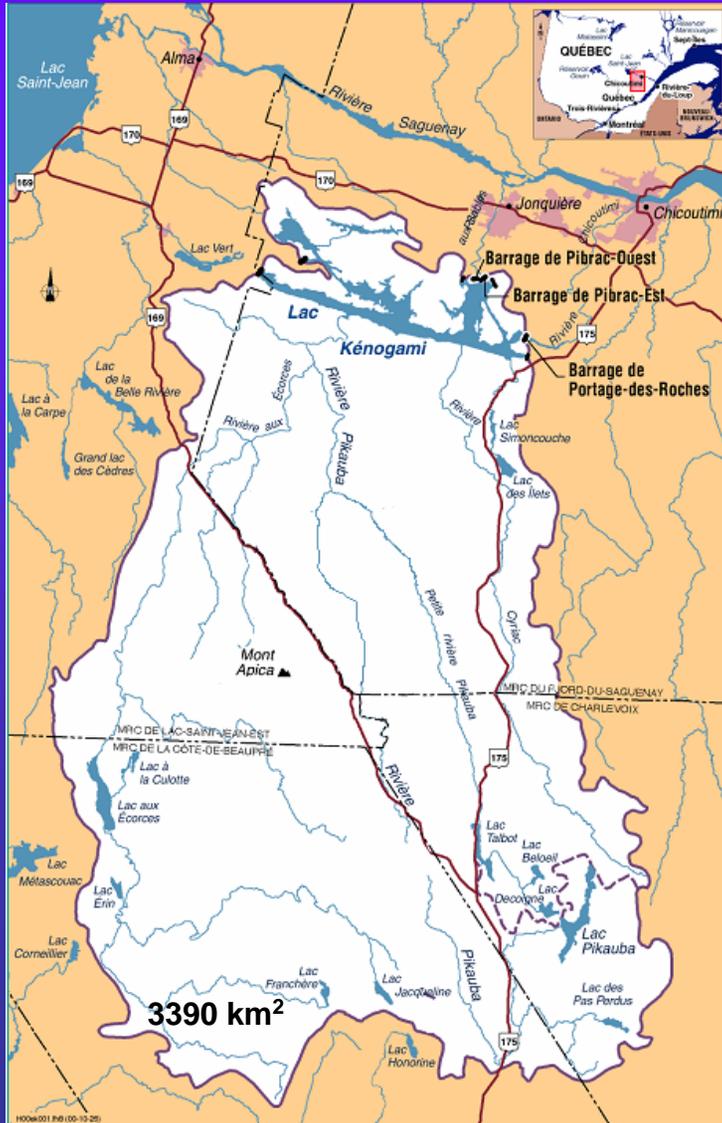
January 27th analysis served to :

- Assess the probability to reach critical lake level
- Choose outflows that reduce this probability
- Manage without violating constraints





Application #3 : FRANCES on Kénogami lake



Fall management objectives

- Allows the best possible hydroelectric energy production without spilling:
 - outflows = $81 \text{ m}^3/\text{s}$

Main constraints

- Thresholds for flooding minor impacts :
 - outflows $\leq 405 \text{ m}^3/\text{s}$
 - lake level $\leq 164.16 \text{ m}$
- major impacts :
 - outflows $\leq 480 \text{ m}^3/\text{s}$
 - lake level $\leq 164.46 \text{ m}$

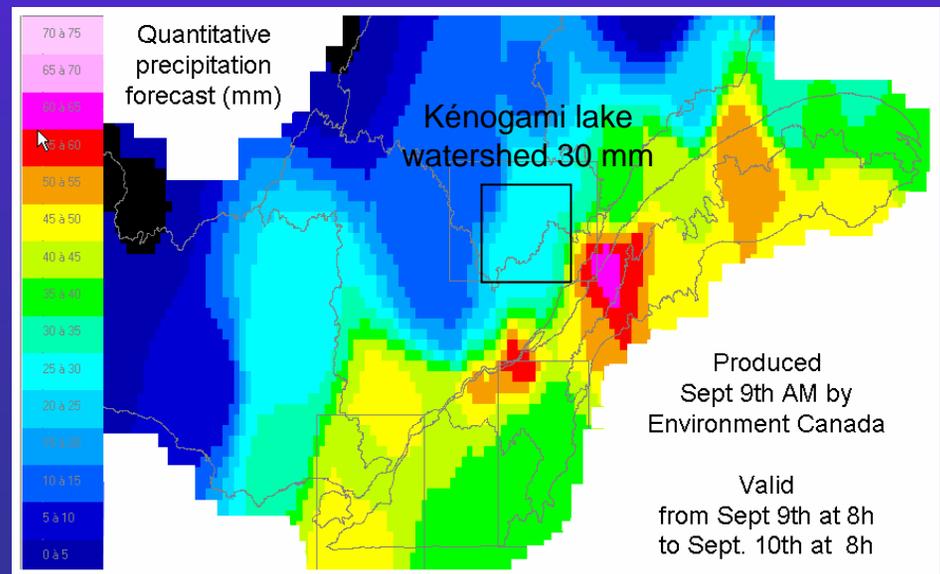


Application #3 : FRANCES on Kénogami lake

Precipitation of 62 mm between Sept 9th 3PM to Sept 10th 6AM
(remains of the hurricane FRANCES)

Context

- Media coverage of the hurricane : lakeside and riverside residents wish early dam operations based on forecast
- Quantitative precipitation forecast indicated small precipitations amounts
- Direct discussions with meteorologists, outputs from USA models and weather warnings indicated larger amounts



Application #3 : FRANCES on Kénogami lake

Decision to be argue with stakeholders

- Hydroelectric producers : need for spilling before large inflows were observed
- Lakeside and riverside residents : timing of the operations

Application #3 : FRANCES on Kénogami lake

Analysis of the September 9th at 16h

- Rainfall of 100 mm already measured in the Ottawa region
- A new “weather alert” available at 15h30 indicates 60 to 70 mm for the coming hours on the Kenogami lake watershed

2004/09/09 15h30

- **LA TUQUE.**
- AVERTISSEMENT DE PLUIE ABONDANTE EN VIGUEUR.
- CE SOIR ET CETTE NUIT..PLUIE PARFOIS FORTE.
- QUANTITE PREVUE DE **45 A**
- **55 MM.** VENTS DU NORD DE 20 KM/H DEVENANT LEGRS VERS MINUIT.
- TEMPERATURES STABLES PRES DE 11.
- VENDREDI..PLUIE CESSANT LE MATIN. DEGAGEMENT PAR LA SUITE.
- MAXIMUM 17. INDICE UV DE 3 OU MODERE.

- **RESERVE FAUNIQUE DES LAURENTIDES.**
- AVERTISSEMENT DE PLUIE ABONDANTE EN VIGUEUR.
- CE SOIR ET CETTE NUIT..PLUIE PARFOIS FORTE.
- QUANTITE PREVUE DE **60 A**
- **70 MM.** VENTS DU NORD-EST DE 30 KM/H. MINIMUM 8.
- VENDREDI..PLUIE PASSAGERE CESSANT EN APRES-MIDI. NUAGEUX PAR LA
- SUITE. QUANTITE PREVUE DE 5 MM. VENTS DU NORD DE 20 KM/H.
- MAXIMUM 12. INDICE UV DE 3 OU MODERE.

- **LAC-SAINT-JEAN.**
- AVERTISSEMENT DE PLUIE ABONDANTE EN VIGUEUR.
- CE SOIR ET CETTE NUIT..PLUIE PARFOIS FORTE.
- QUANTITE PREVUE DE **45 MM.**
- VENTS DU NORD-EST DE 20 KM/H DEVENANT LEGRS VERS MINUIT.
- MINIMUM 10.
- VENDREDI..PLUIE CESSANT LE MATIN. DEGAGEMENT PAR LA SUITE. QUANTITE
- PREVUE DE 5 MM. VENTS DU NORD DE 20 KM/H.
- MAXIMUM 16. INDICE UV DE 3
- OU MODERE.

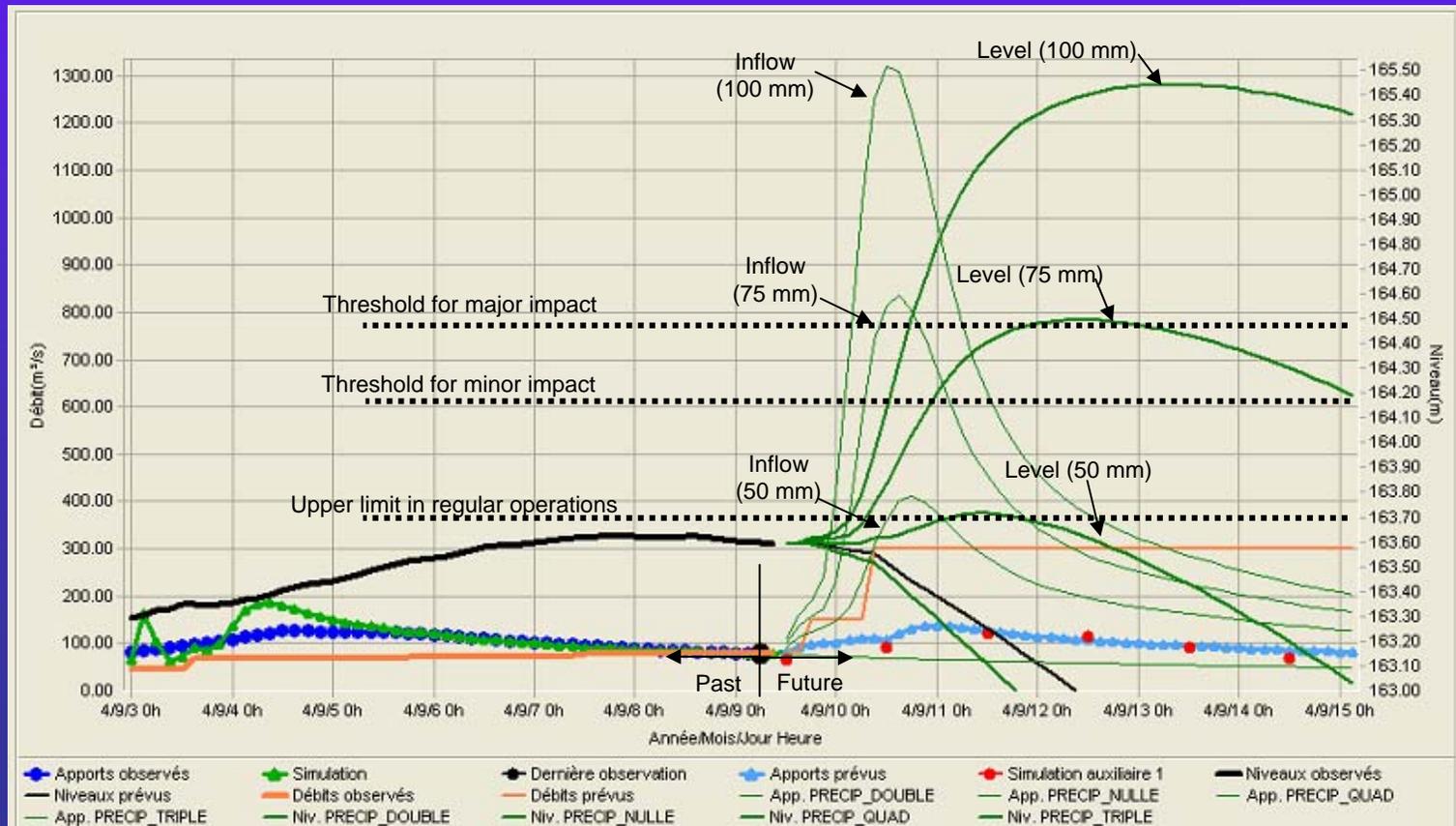
Application #3 : FRANCES on Kénogami lake

Analysis of the September 9th at 16h

Outflow scenario:

150 m³/s at 18 h (Sept 9th)

300 m³/s at 9h (Sept 10th)



Application #3 : FRANCES on Kénogami lake

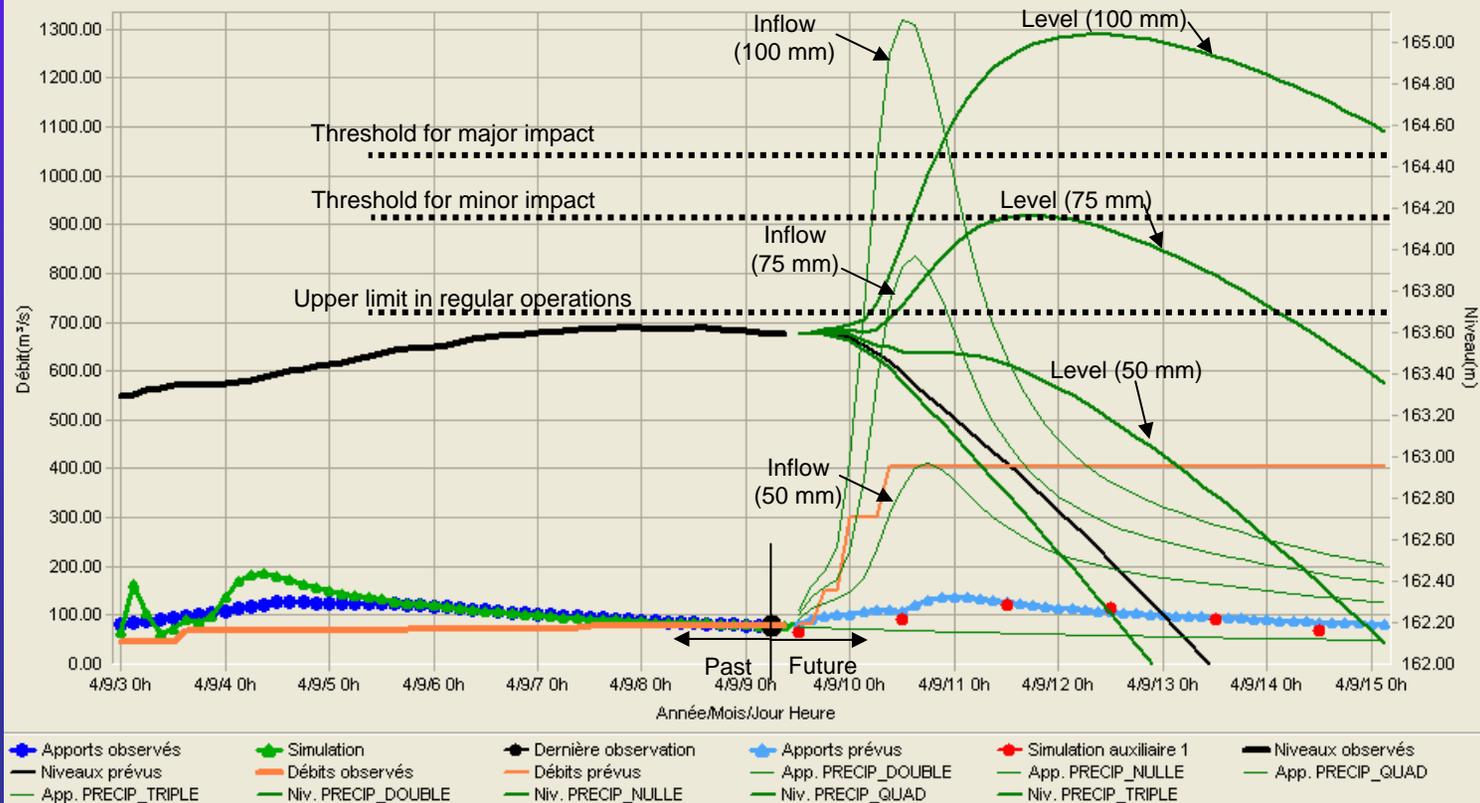
Analysis of the September 9th at 16h

Outflow scenario:

150 m³/s at 18h (Sept 9th)

300 m³/s at 24h (Sept 10th)

405 m³/s at 9h (Sept 10th) (outflow threshold for minor impacts)



Application #3 : FRANCES on Kénogami lake

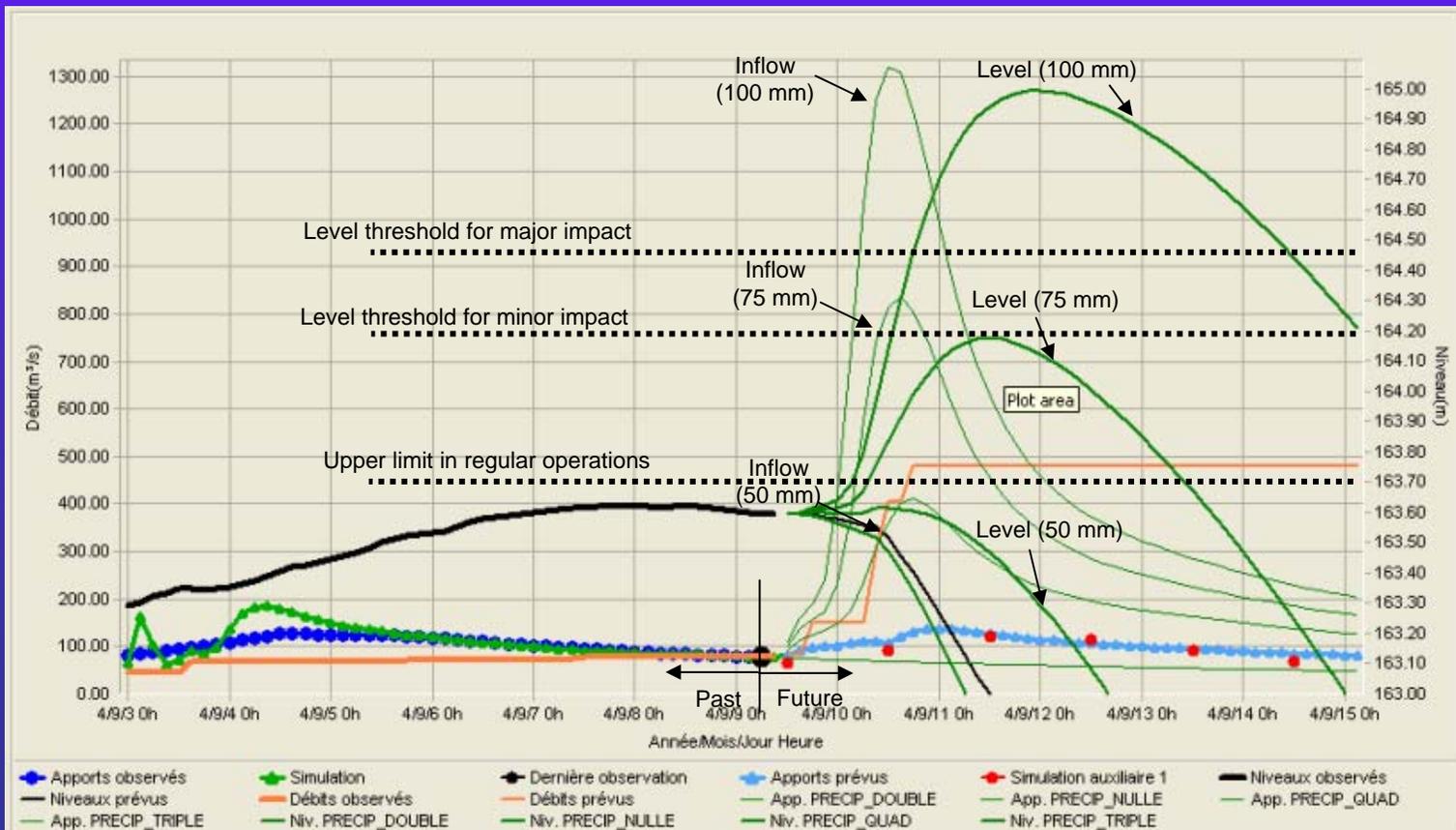
Analysis of the September 9th at 16h

Outflow scenario:

150 m³/s at 18h (Sept 9th)

405 m³/s at 9h (Sept 10th) (outflow threshold for minor impacts)

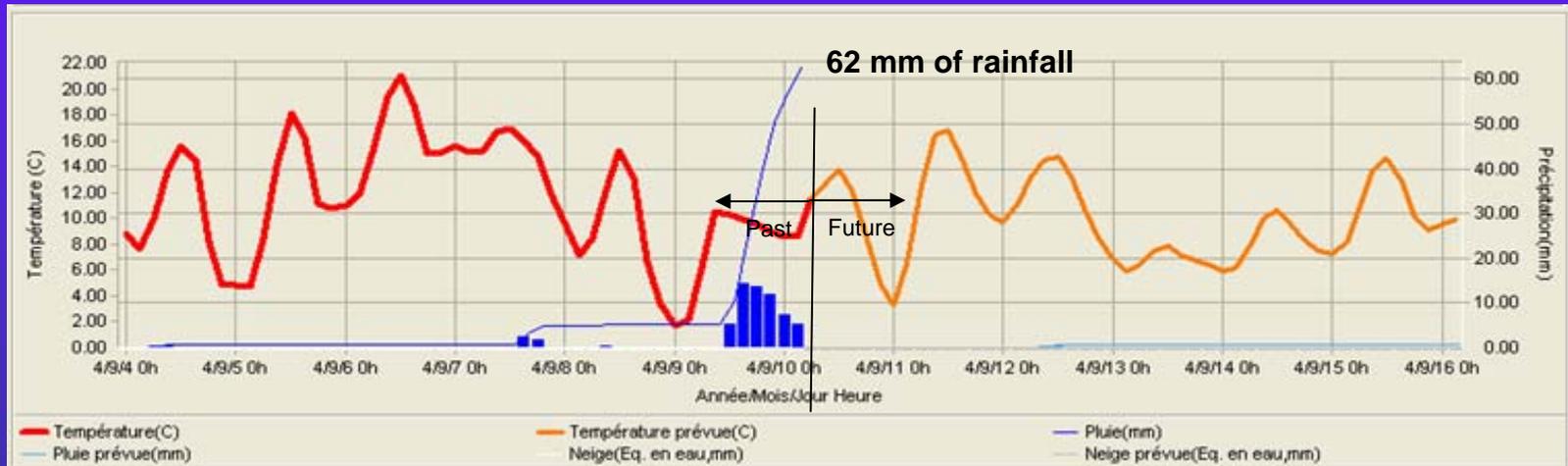
480 m³/s at 18h (Sept 10th) (outflow threshold for major impacts)





Application #3 : FRANCES on Kénogami lake

Analysis of the September 10th at 8h



Application #3 :

FRANCES on Kénogami lake

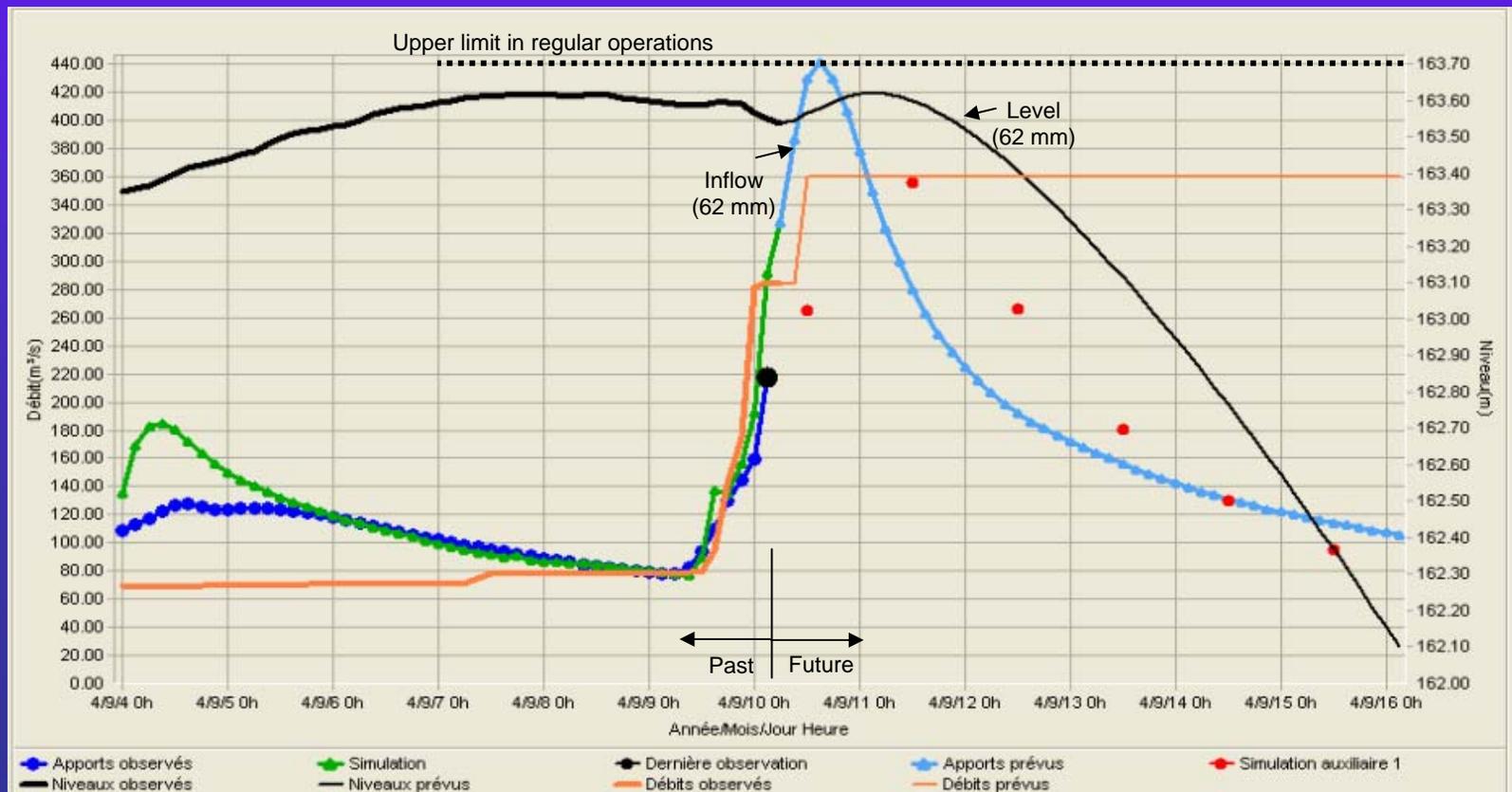
Analysis of the September 10th at 8h

Outflow :

150 m³/s at 18h (Sept 9th) -done
 300 m³/s at 24h (Sept 9th) -done
 360 m³/s at 9h (Sept 10th)

The state variables of the model were updated to correct differences between recent observed flows and simulated ones

-> reduction of 90% of the flood volume



Application #3 : FRANCES on Kénogami lake

September 9th 16h analysis served to :

- link three precipitation scenarios to corresponding outflow scenarios and their impacts
- demonstrate the need for early increase of outflows

September 10th 8h analysis served to :

- demonstrate that there is no reason remaining for an outflow equal to the threshold for minor impact



Part 4

Conclusion and future challenges

Conclusion

Flow forecasting : a powerful tool in the decision making and communication processes

- Forecasted inflow scenarios are useful for the P. Engineering team that manage dams
- They also help to explain our decisions to senior managers
- Acceptability of operations that have some negative impacts are increased by demonstrating they help to avoid even more negative impacts
- Future works:
 - Amelioration of the way information is communicated (synthesis of complex data into key statements)
 - Evaluation of the probability of occurrence associated with short-term precipitation scenarios conditionally to the current weather conditions