BC Hydro
ESP forecasting

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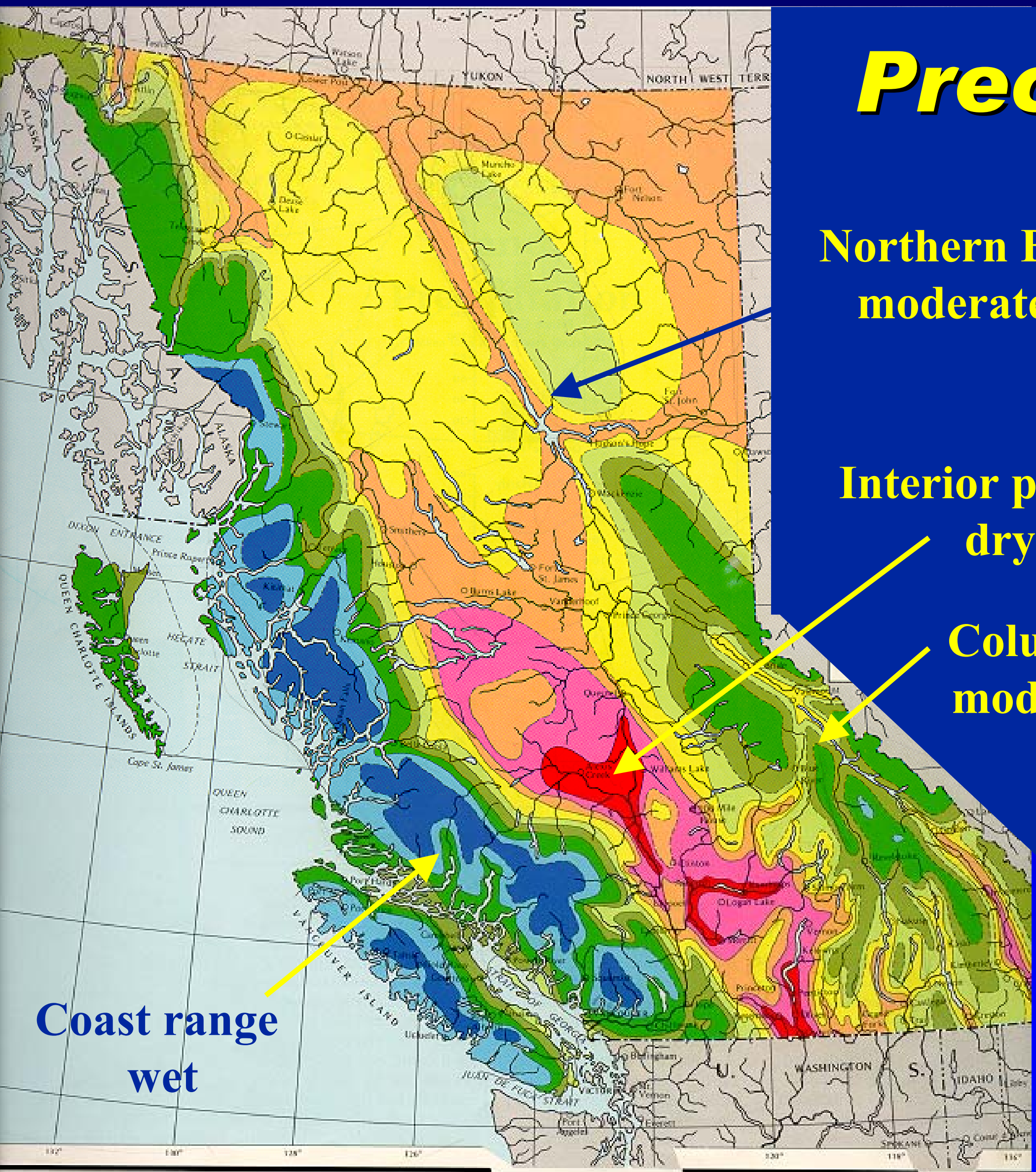
Detailed version

Seasonal forecasting

- Required for reservoir management decisions
- Seasonal forecasts encompass snowmelt freshet periods
- Winter conditions
  - different for coastal versus interior basins

Precipitation

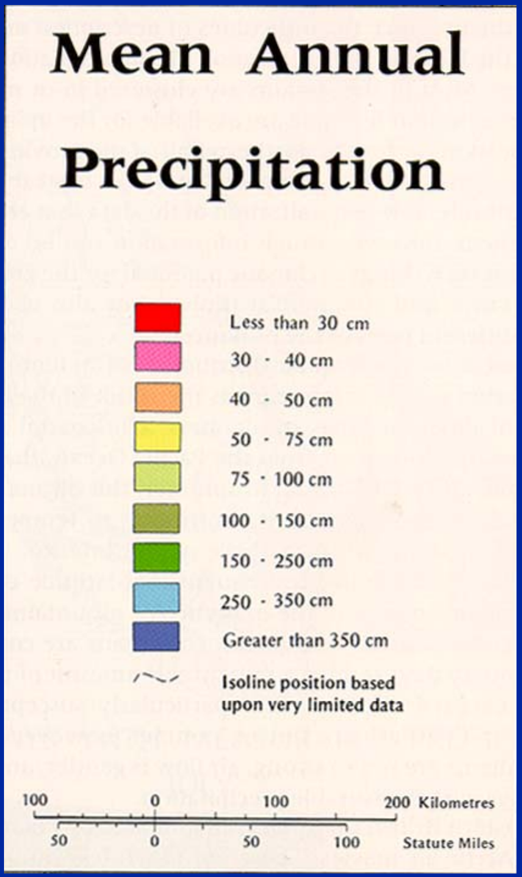


Northern BC
moderate

Interior plateau
dry

Columbia
moderate

Coast range
wet

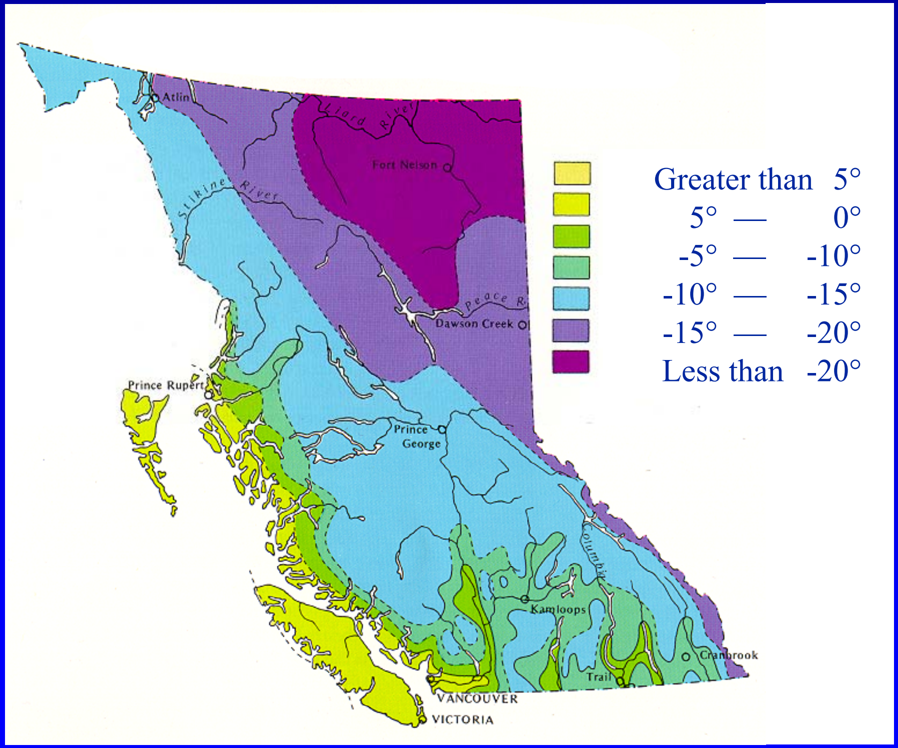


Temperature

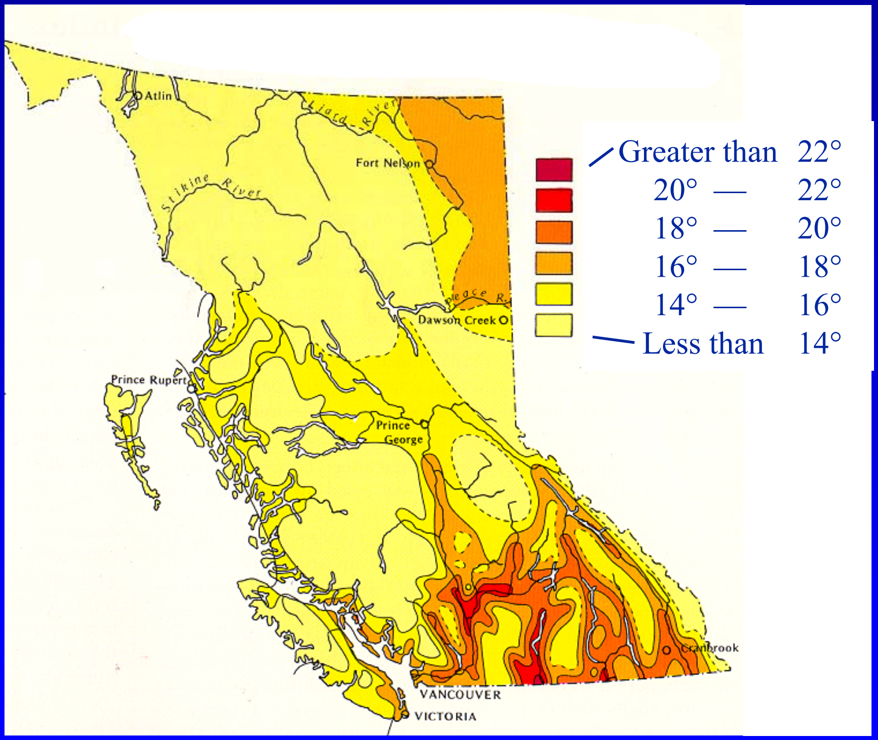
Mild winters on the coast
Cold winters in the interior and north

Moderate summers on the coast
Hot summers in the interior

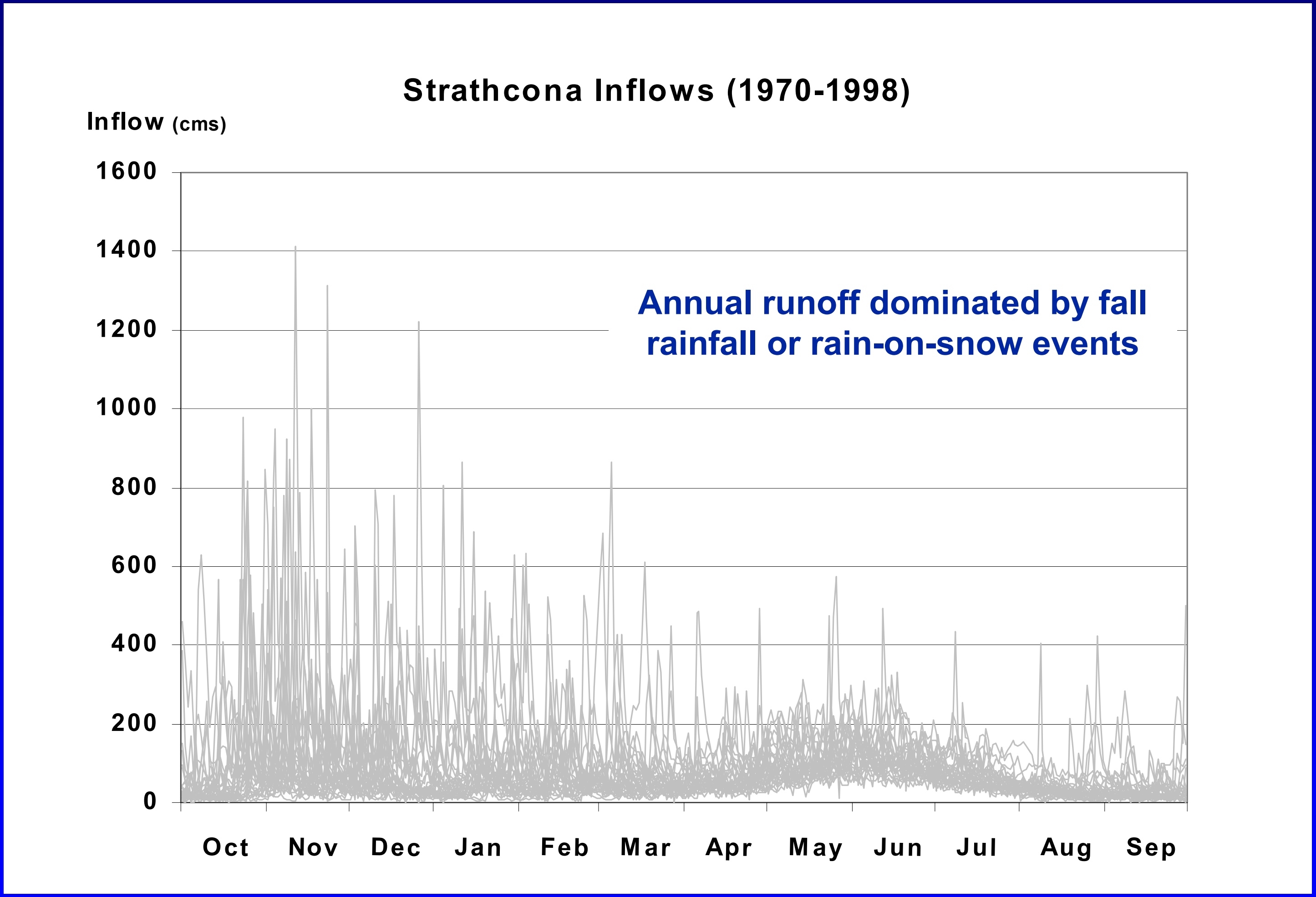
January
Mean Daily Temperatures (C)



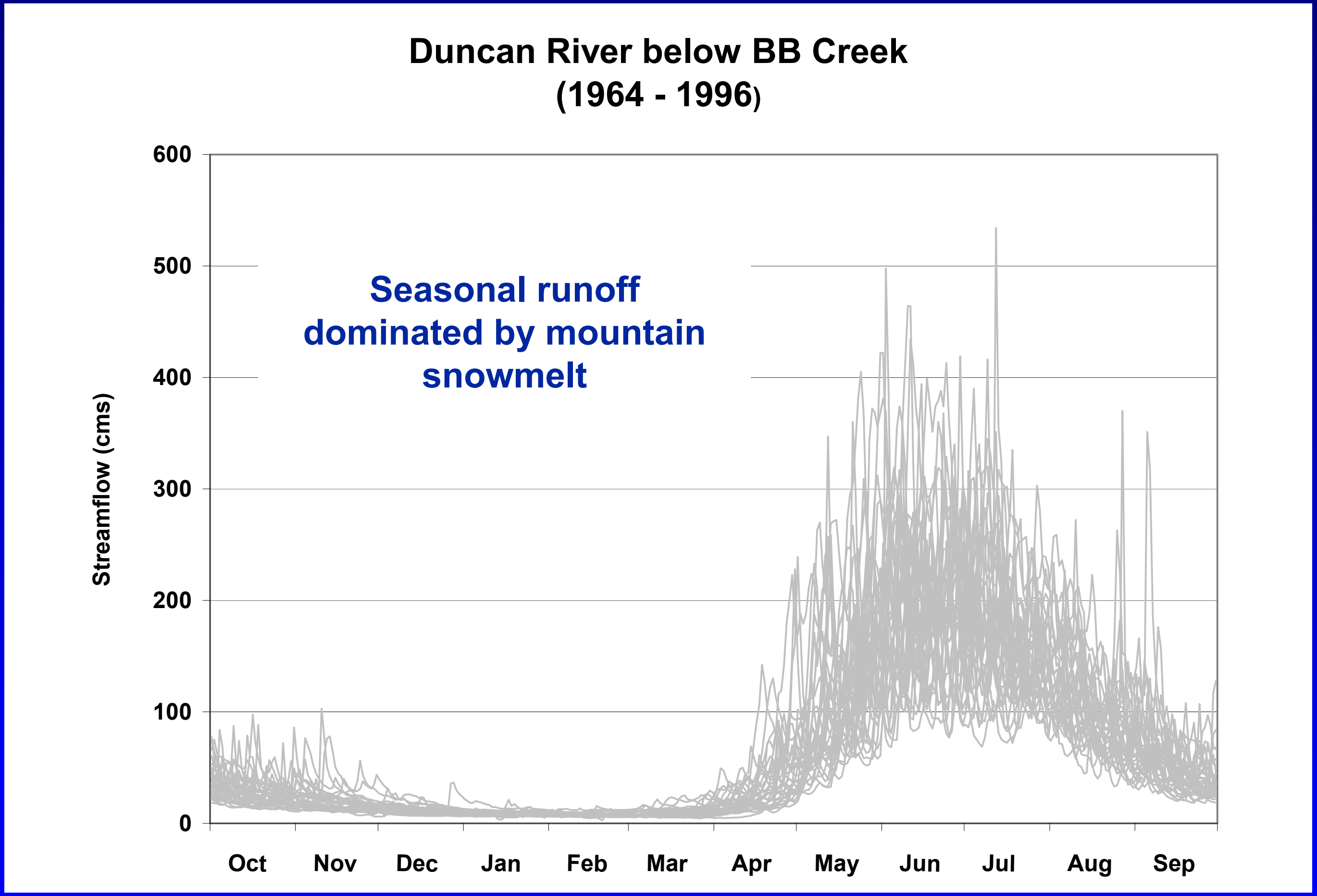
July
Mean Daily Temperatures (C)



Typical runoff distribution Coastal basin



Typical runoff distribution Interior basin



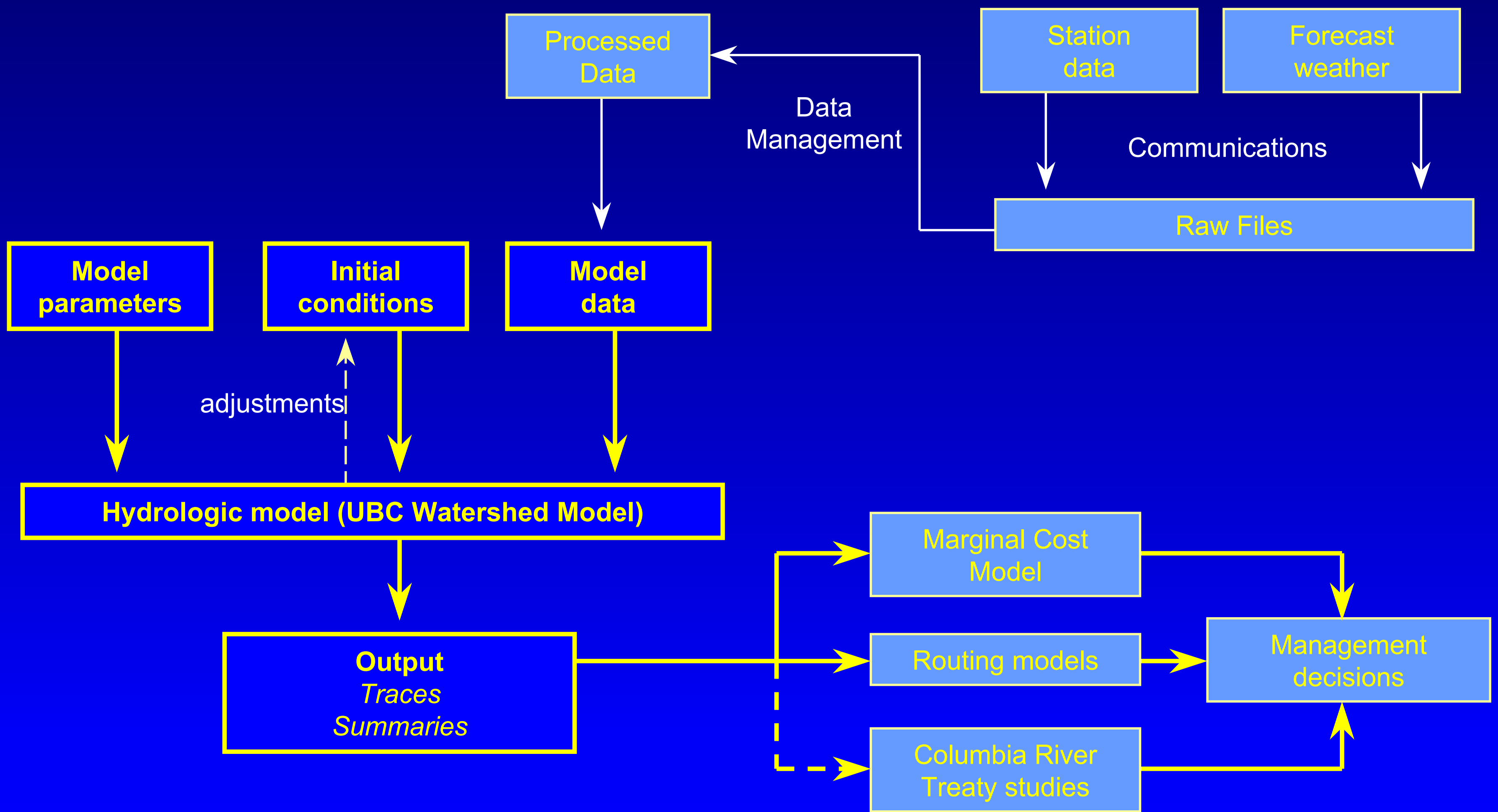
Reservoir operations

Input
- market prices
- load forecasts
- current reservoir levels
- **inflow forecasts**

Constraints
- plant operating capacity
- safety
- security / reliability
- compliance
- environmental objectives
- **Columbia River Treaty**

Objectives
- balance power and non-power benefits
- serve domestic load
- maximize profit
- minimize risk and liability
- comply with laws, licenses, etc.
- determine marginal cost of energy

BC Hydro ESP forecasting process



Seasonal forecasting
ESP reliability and credibility issues

Note: "Downstream" models referred to below include
any model that uses the ESP traces directly or indirectly as input

- **"Downstream" model or decision making requirements**
  - **Planning engineers responsible for reservoir operations are investigating new tools and models for planning purposes. Models include;**
    - **reservoir routing optimization models**
    - **marginal cost models for determining the cost of energy production**

  "Downstream" models require different types of forecast inflow input
    - **Volume inflow forecasts over a season, say Feb to Sep, inclusive**
    - **Monthly forecasts with error distributions and monthly correlation matrices**
    - **Individual ESP traces**

Seasonal forecasting
ESP reliability and credibility issues

"Downstream" model or decision making requirements (continued)

Seasonal forecasts provided by statistical methods have typically been disaggragated into weekly or monthly time steps and input to "downstream" models.

Planners are considering a Monte Carlo modeling approach that requires expected monthly inflows, standard errors, and a monthly correlation matrix as input. These inputs can be provided by ESP or statistical forecast procedures.

Direct use of ESP traces would be an alternative to the Monte Carlo approach.

Issues of model bias and the assumption of equal likelihood for ESP traces raises the question as to whether it is appropriate to input ESP traces directly to downstream models without some form of pre- or post-processing. *(See discussion on correcting ESP traces for modeling error, modeling bias, and long-term climate signals)*

Seasonal forecasting
ESP reliability and credibility issues

“Downstream” model or decision making requirements (continued)

- One advantage of ESP forecasts over statistically-based water supply forecasts is that they can be updated at any time. BC Hydro uses statistical methods to forecast water supply beginning January 1 each year, updating the forecasts at the first of each month through the spring snowmelt freshet.

  Weather is fickle. Which begs the question, “Should ESP forecasts be updated more often than monthly?” With reservoir operations accounting for many environmental and other non-power requirements, frequent changes in planned operations is not necessarily a good thing. Therefore, BC Hydro tends to prepare ESP forecasts also only once a month. A greater frequency than this could lead to a more volatile operation, which in turn, may lead to forecaster-to-management credibility issues.

Seasonal forecasting
ESP reliability and credibility issues

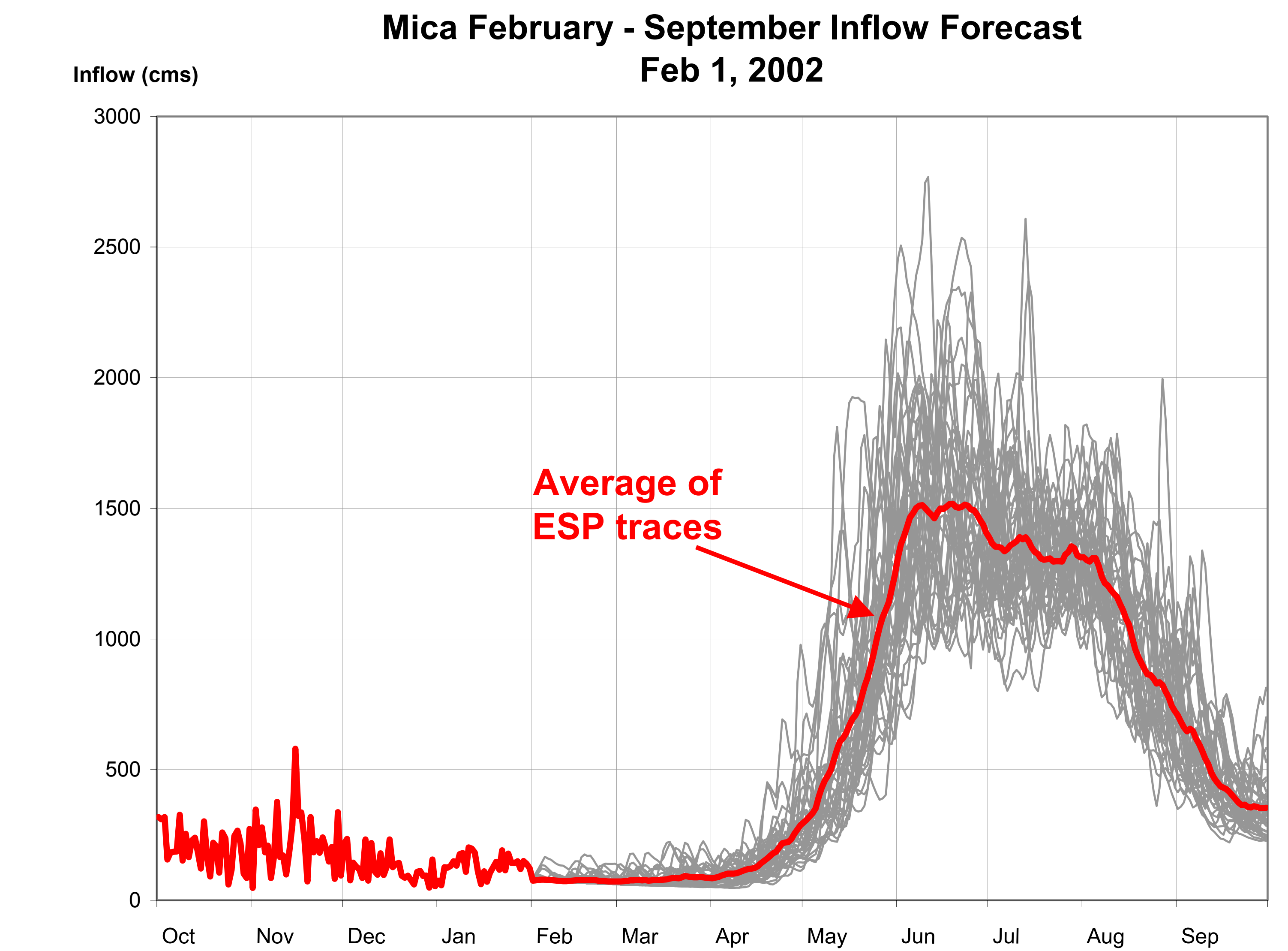
- Accuracy of ESP versus statistically-based forecasts
  - **Do ESP ensembles produce better seasonal forecasts than statistical methods? What are the implications for users of risk-based "downstream" models?**
  - **HEPEX should compare the accuracy of real-time ESP forecasts against a standard of real-time statistically-based forecasts to corroborate the notion that ESP forecasts provide at least as good a forecast of water supply volume over a season. Some work has been done on this already at BC Hydro** *(Druce, 2001. "Insights from a history of seasonal inflow forecasting with a conceptual hydrologic model", J. of Hydrology, 249 (2001), pp. 102-112)*

Seasonal forecasting
ESP reliability and credibility issues

- **Reflecting total error**
  - **ESP forecasting accounts for uncertainty in future weather. Modeling error, however, is unaccounted for in ESP traces. Given perfect foreknowledge of future weather during the forecast period, our watershed model does not produce a perfect simulation of the water supply in the coming year.**
    - *See the following 4 slides demonstrating the potential for modeling error to overwhelm uncertainty in future weather (Modeling error typically is a smaller component of total error, but can be significant in any given year)*
  - **How should individual ESP traces or probability forecasts based on ESP forecasts account for modeling error?**
    - **One thought is to use modeling error statistics from the calibration phase and somehow (?) apply them to individual ESP traces, assuming "downstream" users input individual ESP traces into their planning models. However, our calibrations are run in continuous mode, whereas real-time operation allows forecasters to stop a simulation on the forecast date and make adjustments to basin state conditions. Therefore, applying error corrections based on the calibration period would be inappropriate because of the differences in running the model. It is expected that estimating modeling error based on continuous simulations over the calibration period will over-state modeling error in real-time.**

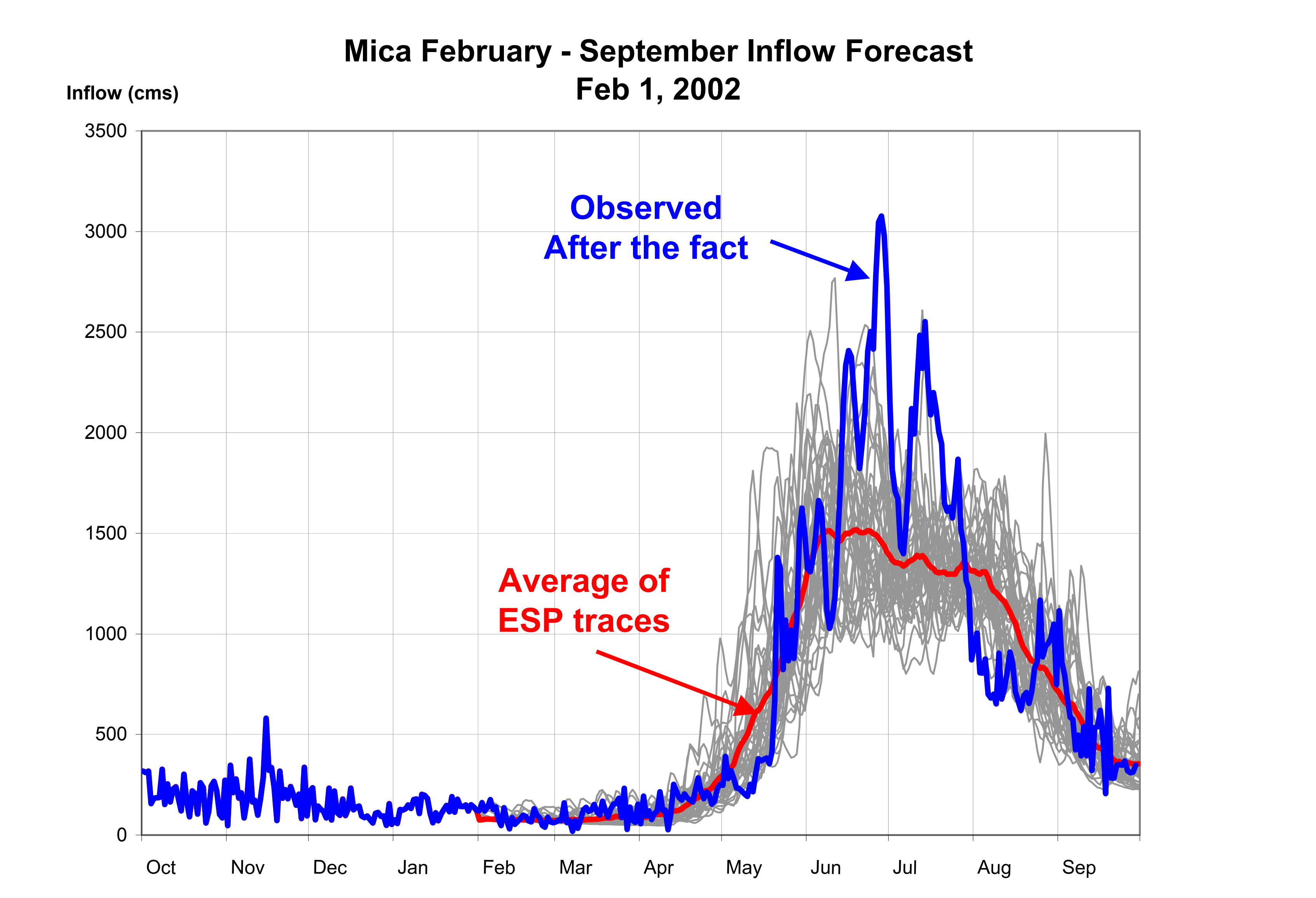
Example of modeling error (1 of 4)

Note: No corrections made to simulated snowpack



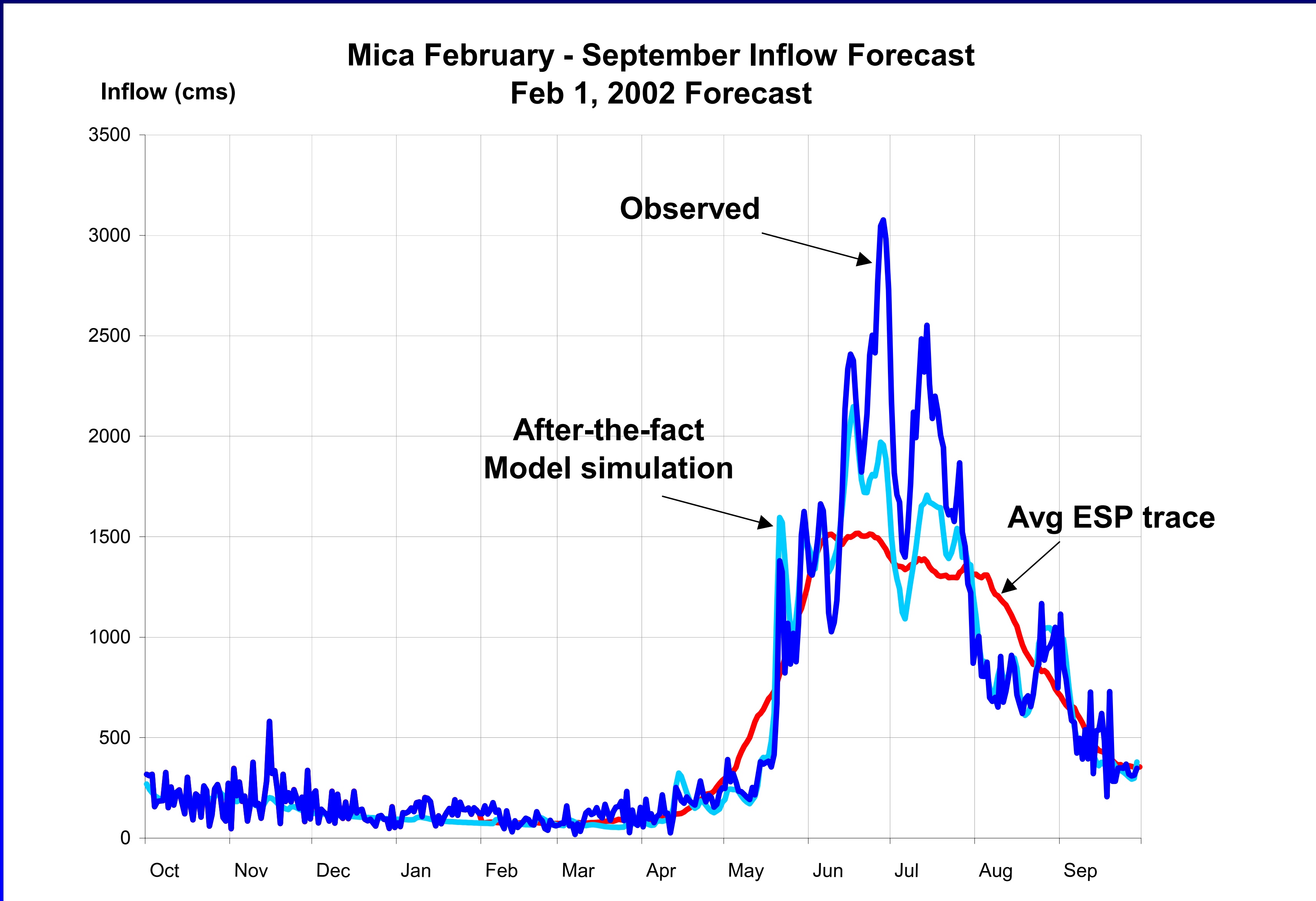
Example of modeling error (2 of 4)

Note: No corrections made to simulated snowpack



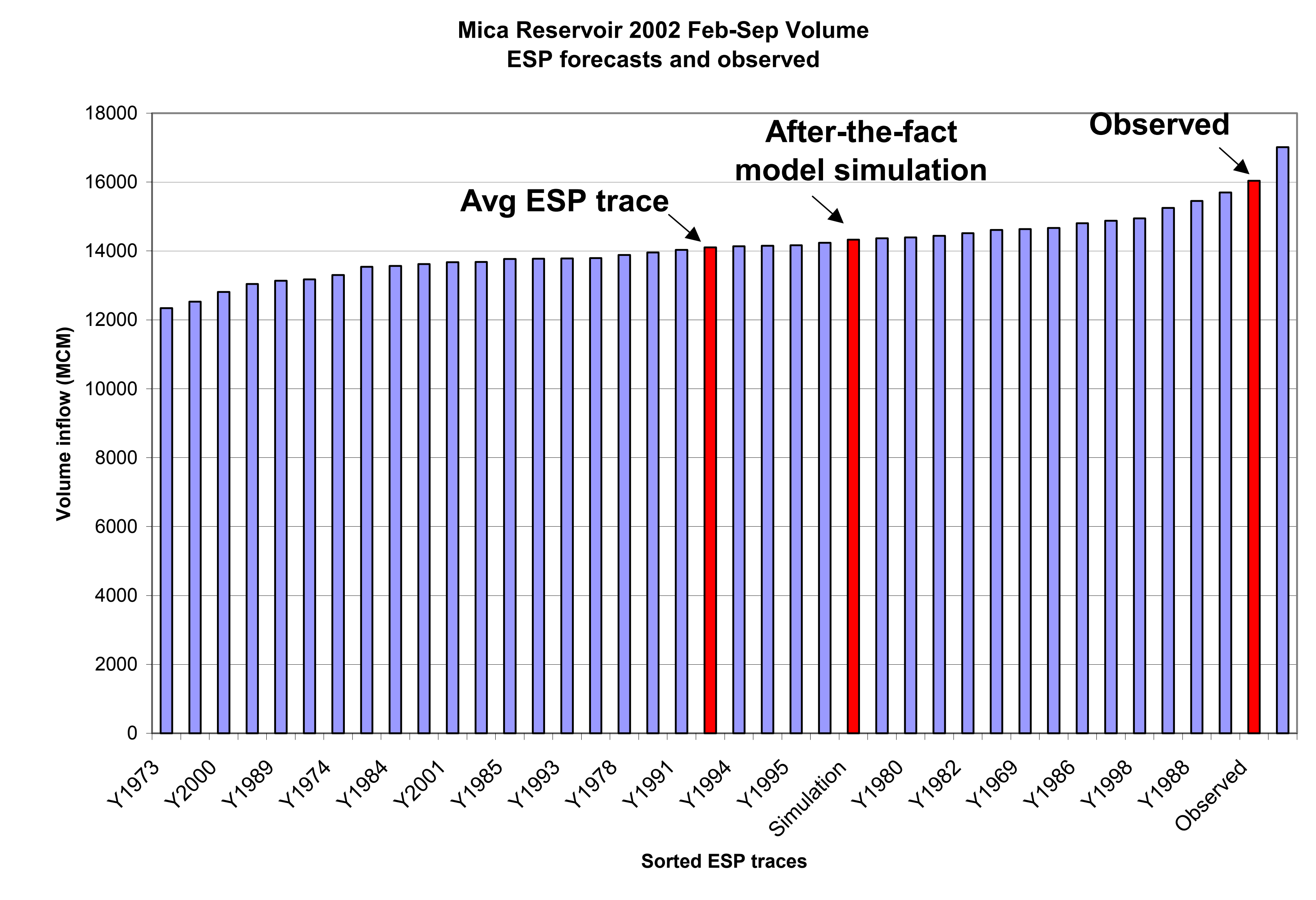
Example of modeling error (3 of 4)

Note: No corrections made to simulated snowpack



Example of modeling error (4 of 4)

Note: No corrections made to simulated snowpack



Seasonal forecasting
ESP reliability and credibility issues

- Reflecting total error (continued)

  - **Feb - Sep water supply forecast** *(average of ESP traces)* **14 100 MCM**
    Feb - Sep water supply simulation *(given precipitation and temperature data perfectly known in advance)* **<u>14 300 MCM</u>**
    Difference (Forecast - Simulated) -200 MCM or -1.4 %

  - **The related RMSE for the water supply forecast** *(based solely on uncertain future weather)* **6.2 %**
    The 1.4% computed error is within the expected error range quoted

  - **BUT, ACTUAL Feb - Sep water supply <u>16 000 MCM</u>**
  - **Difference (Forecast - Observed) -1 900 MCM or -13.5%**

Seasonal forecasting
ESP reliability and credibility issues

- *At the time that the Feb 2002 forecast was made, no snowpack adjustment routines were available. Later that season, forecasts were re-done in hindsight, adjusting snowpack using snowpack adjustment routines. The resulting forecasting error was reduced from -13.5 % to less than -4 %.*

- **Without snowpack adjustment routines in place, significant modeling errors resulted. The major contribution to the error for the Feb 2002 forecast was not the unknown future weather during the forecast period. Rather, it was modeling error. However, modeling error is not being accounted for in the RMSE.**

- **Modeling errors exist in all models, to greater or lesser extents.**

Seasonal forecasting
ESP reliability and credibility issues

- Reflecting total error (continued)
  - How do you account for modeling error in a summarized seasonal forecast (February to September Average $\pm$ Standard Error)?
    - How do you compute modeling error? One solution may be to make “real-time” forecasts (including adjustments to basin state conditions) for all available historical data in “hindcast”mode. It is important that any adjustment methods used to forecast in hind sight are the same as those used in real time. Otherwise, estimates of the modeling error may be biased. The modeling error derived above could be combined with the ESP RMSE to derive a more accurate estimate total error for a forecast. The independence of modeling and ESP errors should be confirmed.

Seasonal forecasting
ESP reliability and credibility issues

- Applying adjustments to initial model state conditions

  - The Columbia River Treaty Hydromet Committee is investigating ESP forecasting as a means to replace current statistical water supply forecasting procedures. There is the notion that results from a conceptual watershed models are more intuitive than from statistical models, particularly when observations of independent variables fall outside the range of those experienced during calibration.

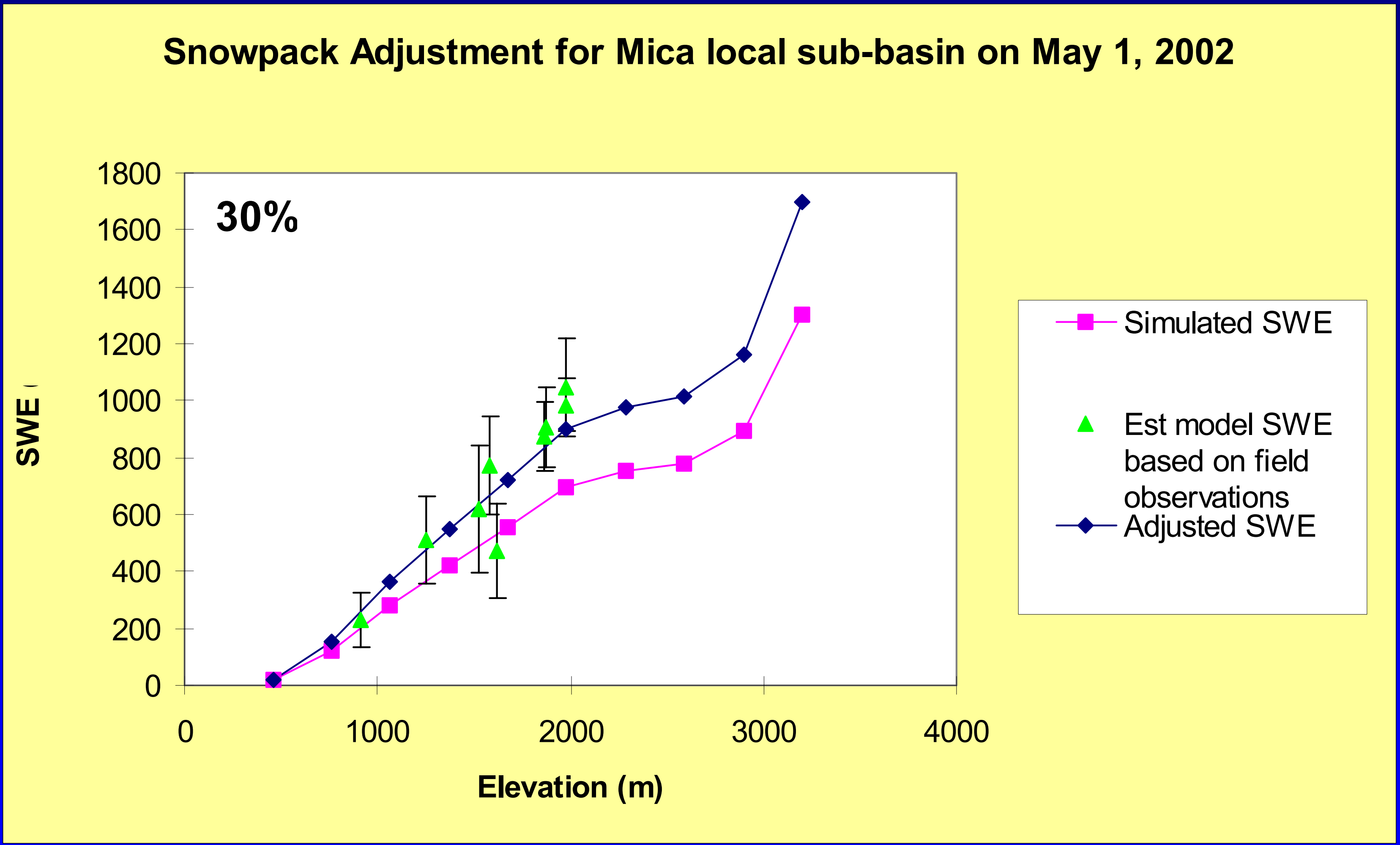
  - However, statistical methods are objective, whereas, ESP forecasts can be subjective. For example, all forecasters will arrive at the same water supply forecast using a given statistical procedure. However, for ESP forecasting, BC Hydro makes subjective adjustments to simulated snowpack and groundwater conditions at the start of a forecast and, occasionally, to input driving variable data so that simulations to the forecast date fall more in line with field observations. One forecaster may choose to adjust things one way, another forecaster another. The resulting forecasts may differ.

Seasonal forecasting
ESP reliability and credibility issues

- **Applying adjustments to initial model state conditions (continued)**
  - **At BC Hydro, the most important modelled initial basin state condition is the simulated mountain snowpack** *(as noted earlier in the discussion on modeling error).* **BC Hydro has instituted "objective" procedures for adjusting modelled snowpack based on real-time snow survey results.**
    - *See next slide for a diagram of a typical comparison between modeled and observed snowpack*
  - **However, forecasters argue amongst themselves as to whether to fully correct for snowpack simulation "errors" to date, based on these procedures, or to only use these procedures for guidance.**

Snowpack adjustment Mica local

Applying adjustments to initial model state conditions (continued)



Seasonal forecasting
ESP reliability and credibility issues

- Applying adjustments to initial model state conditions (continued)

  - **The Columbia River Treaty Hydromet Committee is concerned that ESP forecasting procedures provide an opportunity for "gaming"; that is, preparing a forecast that leads to a favorable operation of Treaty storage facilities to either Canada or the United States.**

  - **The Hydromet Committee would like to see HEPEX develop objective methods for adjusting basin state conditions, model parameters, or driving variable data that beneficially account for differences between simulations and observations of streamflow and snowpack up to a given forecast date.**

  - **Or, is there an opportunity to correct for mis-simulations using Artificial Neural Network or Kalman Filter techniques? This may not be a practical approach, particularly for reservoir inflow forecasts –inflow data tend to be noisy and pre-processing of the data would be necessary before an ANN or Kalman Filter could be effectively applied.**

Seasonal forecasting
ESP reliability and credibility issues

- Assumption of equal likelihood of traces

  - There is a great deal of interest in modifying the ESP ensembles in some way to account for long-term climate signals (for example, ENSO signals).
  - Our current assumption is that each year of historical weather sequences has an equal likelihood of occurring in the future.
  - We have reviewed the various approaches to date, including
    - restricting traces where the ENSO signal is in the same tercile (that is, El Nino, Neutral, of La Nina) as the current year
    - various weighting schemes (Werner, Brandon, Clark, and Gangopadhyay, submitted to J. of Hydrometeorology).

Seasonal forecasting
ESP reliability and credibility issues

- Assumption of equal likelihood of traces (continued)

  - Another approach may be to apply a Baysean approach to the problem.
    - No historical year is discounted outright.
    - Rather, produce a joint probability distribution of inflows by applying a likelihood function for dry, normal, and wet years to the probability distribution of the individual ESP traces.

  - The previous bullet relates to applying a Baysean approach to the streamflow traces. A (better?) alternative may be to apply this Baysean approach, not to the input data (that is, inflows traces), but to the output from "downstream" models used to assess risk in planning operations.

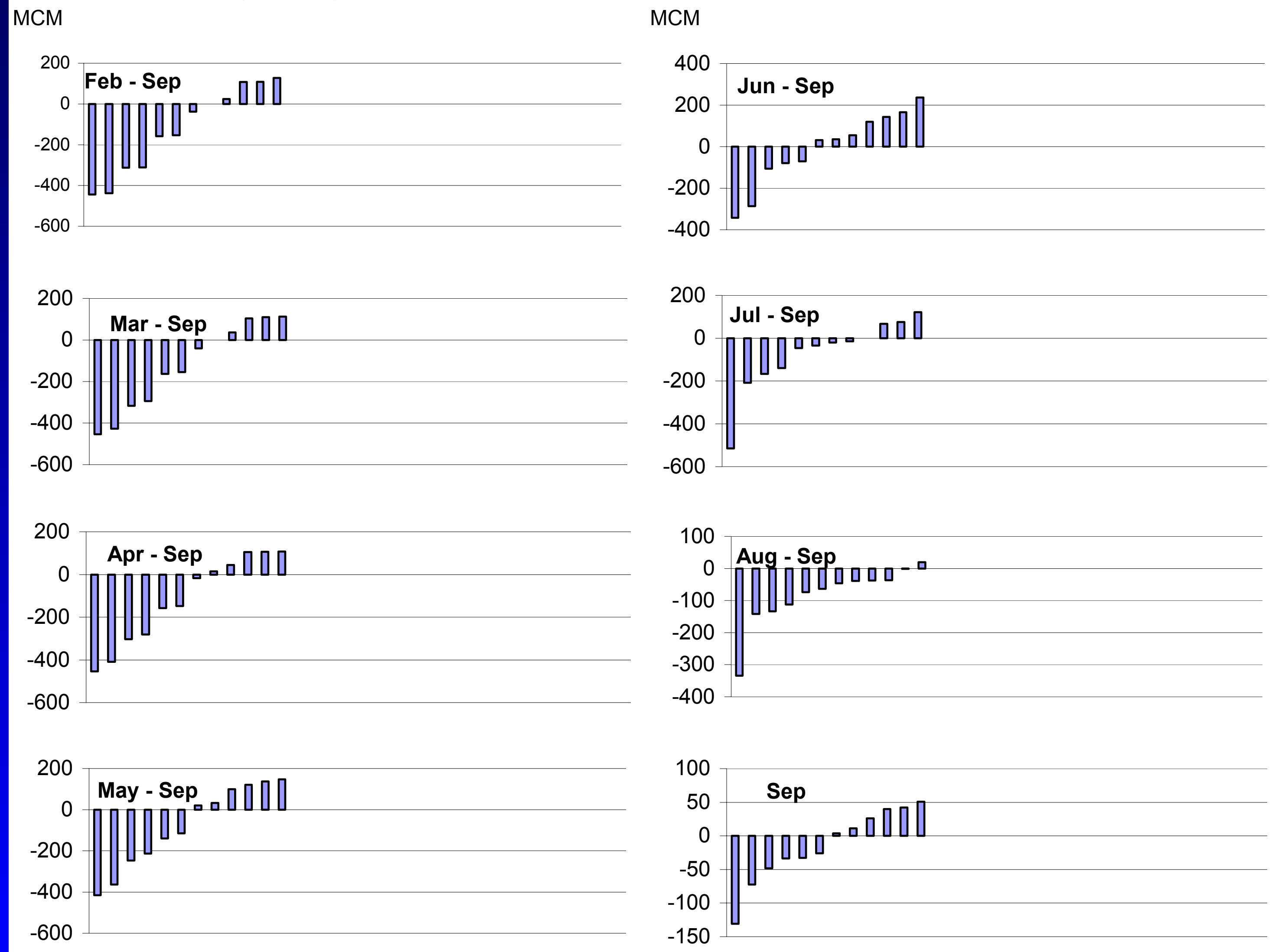
Seasonal forecasting
ESP reliability and credibility issues

- Acknowledging model bias
  - BC Hydro currently uses the same calibration results for both seasonal ESP and daily inflow forecasting
  - What should the optimization criteria during calibration be?
    - Optimizing the model for annual runoff volumes may lead to a calibration bias within the year. For example, a calibration may be unbiased on an annual basis, but tend to over-simulate May and under-simulate June.
      - *See next two slides for an example.*
  - How should ESP forecast traces be adjusted for calibration bias within the forecast period?
  - Should calibrations be optimized for individual years to determine the sensitivity of critical calibration parameters?
    - Could a likelihood distribution for these critical modelling parameters be incorporated into an ESP process to try to circumvent bias issues?

Example of bias (1 of 2)

DUNCAN

Errors in monthly UBCWM calibrations during calibration / verification
Sorted Qcal - Qobs for 1987 - 1999

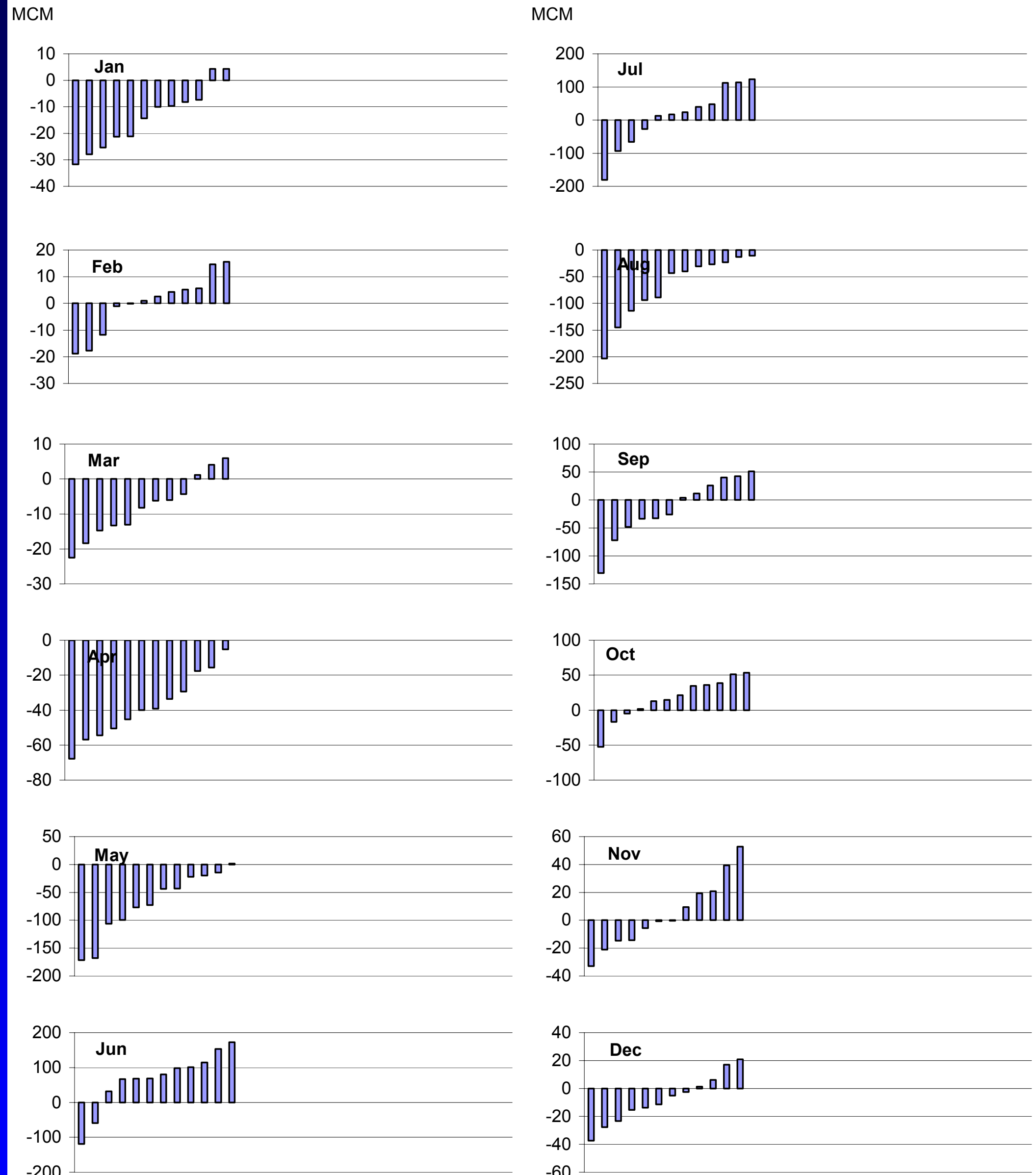


	Feb - Sep	Mar - Sep	Apr - Sep	May - Sep	Jun - Sep	Jul - Sep	Aug - Sep	Sep
Average inflow (MCM)	2884	2840	2782	2620	2098	1362	677	217
Average Error (MCM)	-124	-124	-116	-78	-8	-73	-83	-14
Average Error (% average)	-4.3%	-4.4%	-4.2%	-3.0%	-0.4%	-5.4%	-12.3%	-6.5%

Example of bias (2 of 2)

DUNCAN

Errors in monthly UBCWM calibrations during calibration / verification
Sorted Qcal - Qobs for 1987 - 1999



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average inflow (MCM)	68	44	58	161	523	735	685	460	217	135	97	76
Average Error (MCM)	-14	-0	-8	-38	-70	+65	+10	-69	-14	+16	+4	-8
Average Error (% average)	-20.7%	-0.1%	-13.7%	-23.6%	-13.4%	+8.8%	+1.5%	-15.1%	-6.5%	+11.7%	+4.5%	-10.0%

Seasonal forecasting
ESP reliability and credibility issues

- Use of short-term QPF forecasts in ESP forecasts

  - BC Hydro does not incorporate daily inflow forecasts based on short-term QPF forecasts into ESP traces.

  - We do not have probabilistic QPFs available, so by including a deterministic short-term forecast, we would be treating the short-term forecast the same as observed data.

  - Could HEPEX examine incorporating short-term inflow forecasts (2 - 5 days, or longer, into the future) based on QPFs, or probable QPFs, into the seasonal ESP forecasting procedure?
    - How should the total error (error due to modeling and error due to uncertain weather during the forecast period) be computed for the resulting ESP seasonal volume forecast?

Seasonal forecasting
ESP reliability and credibility issues

- Reliability of ESP forecasts with few traces
  - If there are many historical years of meteorological data available to drive the watershed model, the average of the ESP traces should be a good indication for expected water supply in the coming season, and the variation in the traces will provide a good estimate of the uncertainty in the forecast due to uncertain weather during the forecast period. However, some of the calibrations for BC Hydro project watersheds use relatively new stations, generally located at Data Collection Platform (DCP) sites in remote areas. Most DCPs have a minimal number of historical years to use in the ESP process, in some instances, less than 10 years.
  - How useful are ESP forecasts with relatively short historical records?
  - Should one attempt to extend historical records to bring more years into the ESP process?