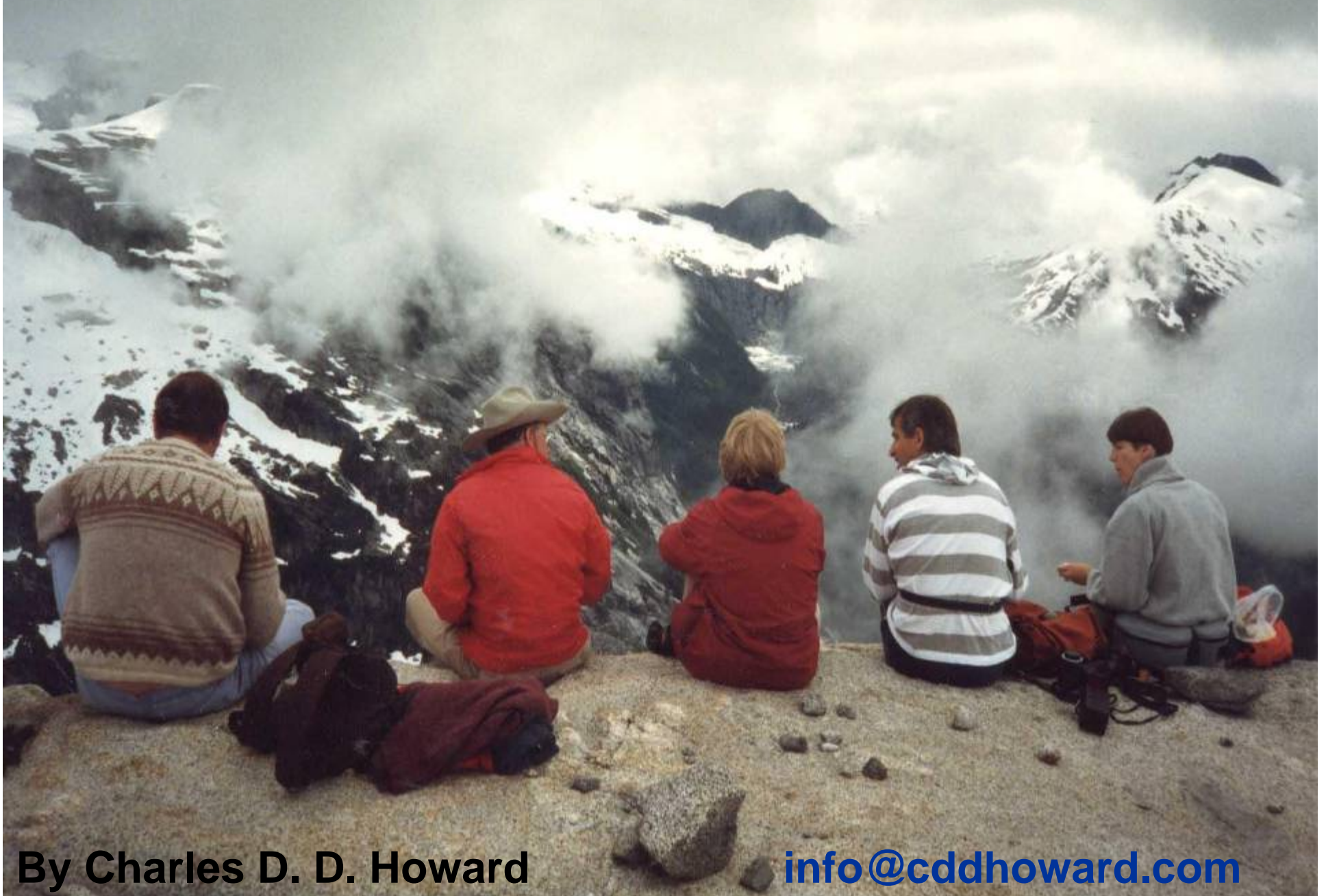
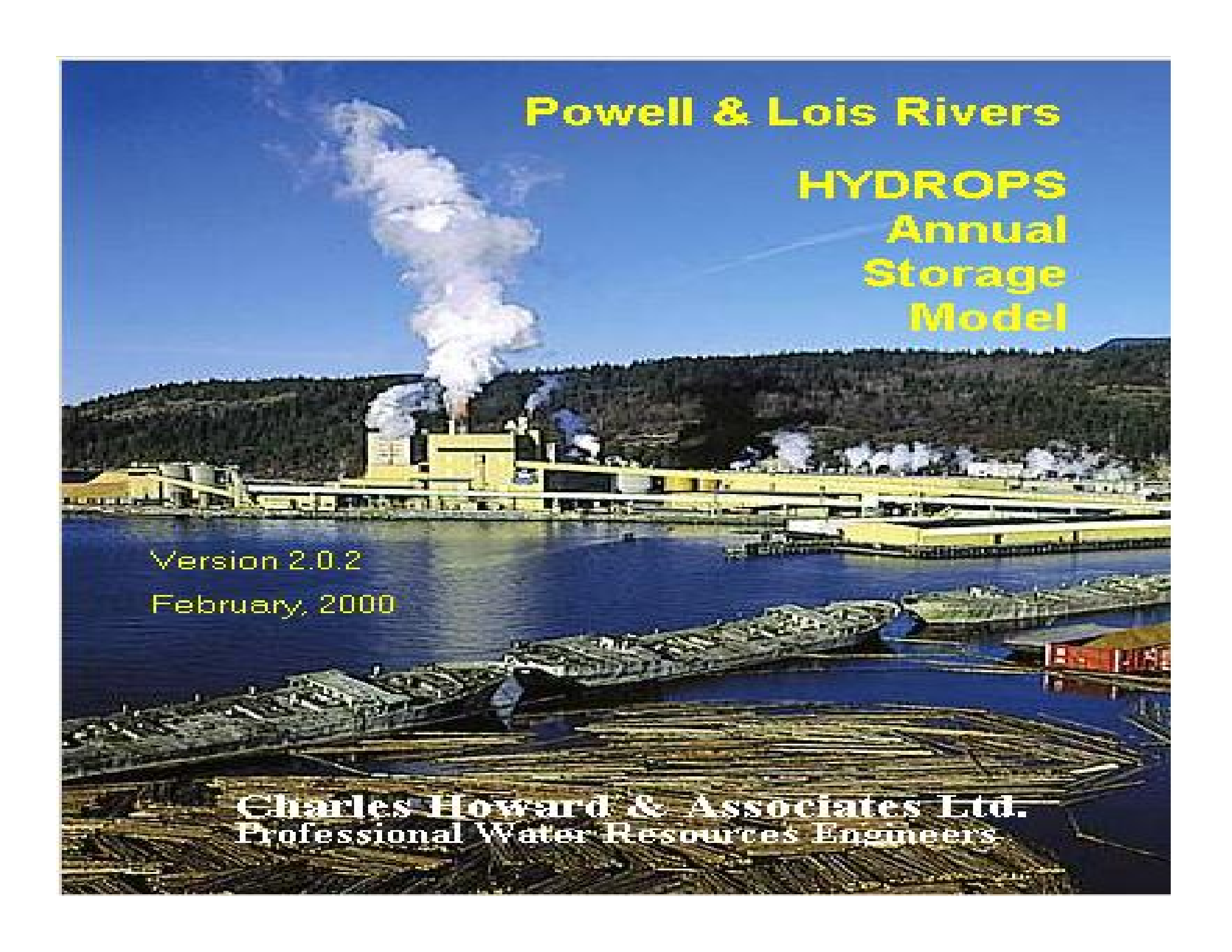


# Ensemble Optimization for Hydroelectric Operations



By Charles D. D. Howard

[info@cddhoward.com](mailto:info@cddhoward.com)



# Powell & Lois Rivers

## HYDROPS Annual Storage Model

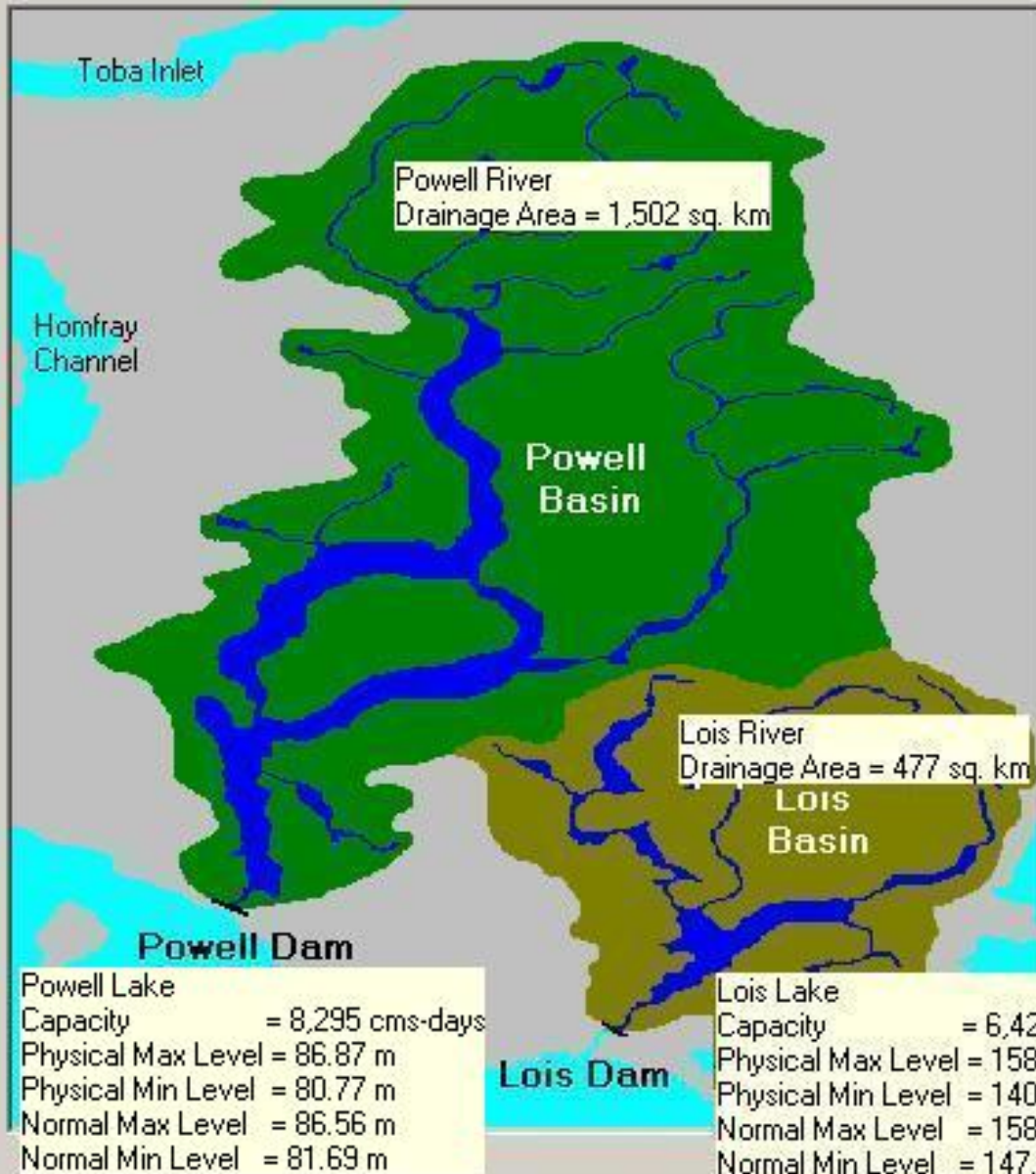
Version 2.0.2

February, 2000

**Charles Howard & Associates Ltd.**  
Professional Water Resources Engineers

# Forecast Model

File Options Help



## Forecast Initial Conditions

Basin: Powell River & Lois River

Forecast Date: February 26, 2004



Initial Inflow (cms) Powell: 122.4  
Lois: 56

## Select Forecast Model

- Using Historical Flow Data
- Using Historical Weather Data
- Display Snow Profile

## Theodosia Diversion

percentage of Powell River 5

Forecast

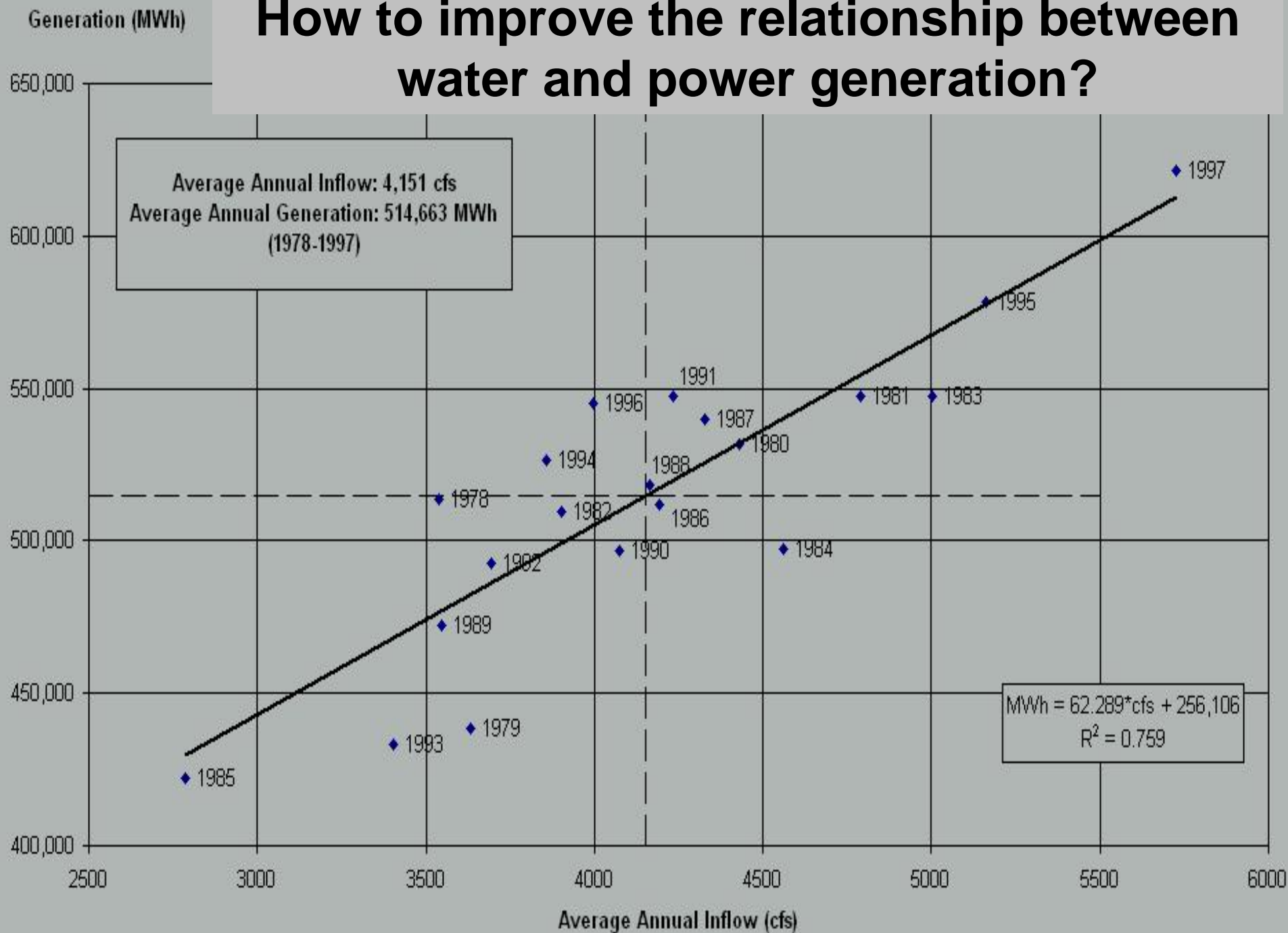
Quit

**Charles Howard & Associates Ltd.**  
Professional Water Resources Engineers

# Powell River BC Basin



# How to improve the relationship between water and power generation?



## **The Application**

**The paper mill's electricity requirements normally exceed the capability of the two hydroelectric plants.**

**The objective is to  
minimize the cost of electricity purchases.**

**A key constraint in operating the dams is to  
guarantee minimum generation of 20 Mw at all times.**

**Since 1989 a decision support system  
has been used for  
optimizing electricity purchase decisions.**

**The decision support system consists of:**

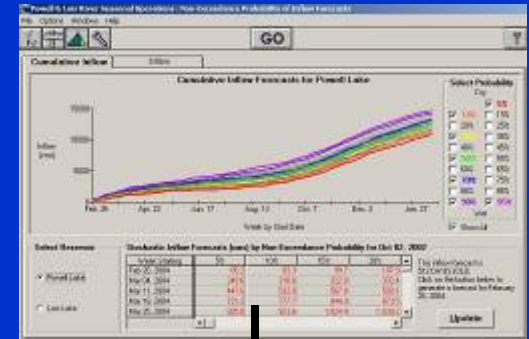
- a hydrologic ensemble forecast model,**
- an ensemble optimization reservoir model,**
- an generator optimum loading model.**

The inputs are weekly hydrologic ensemble forecasts and seasonal energy prices.

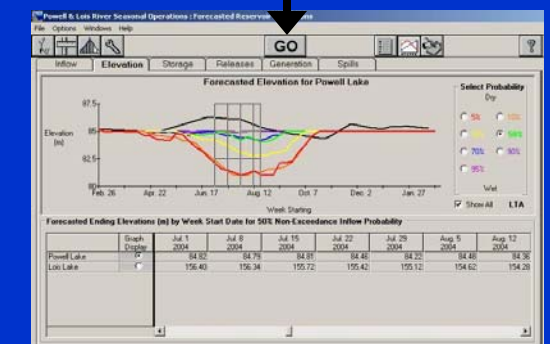
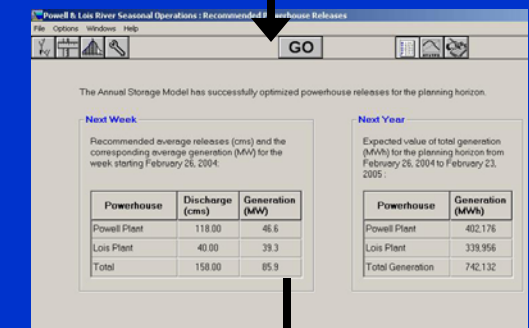
The one year time horizon reservoir operations model is a non-linear optimization.

The recommendation is the **specific** optimum power generation for this week.

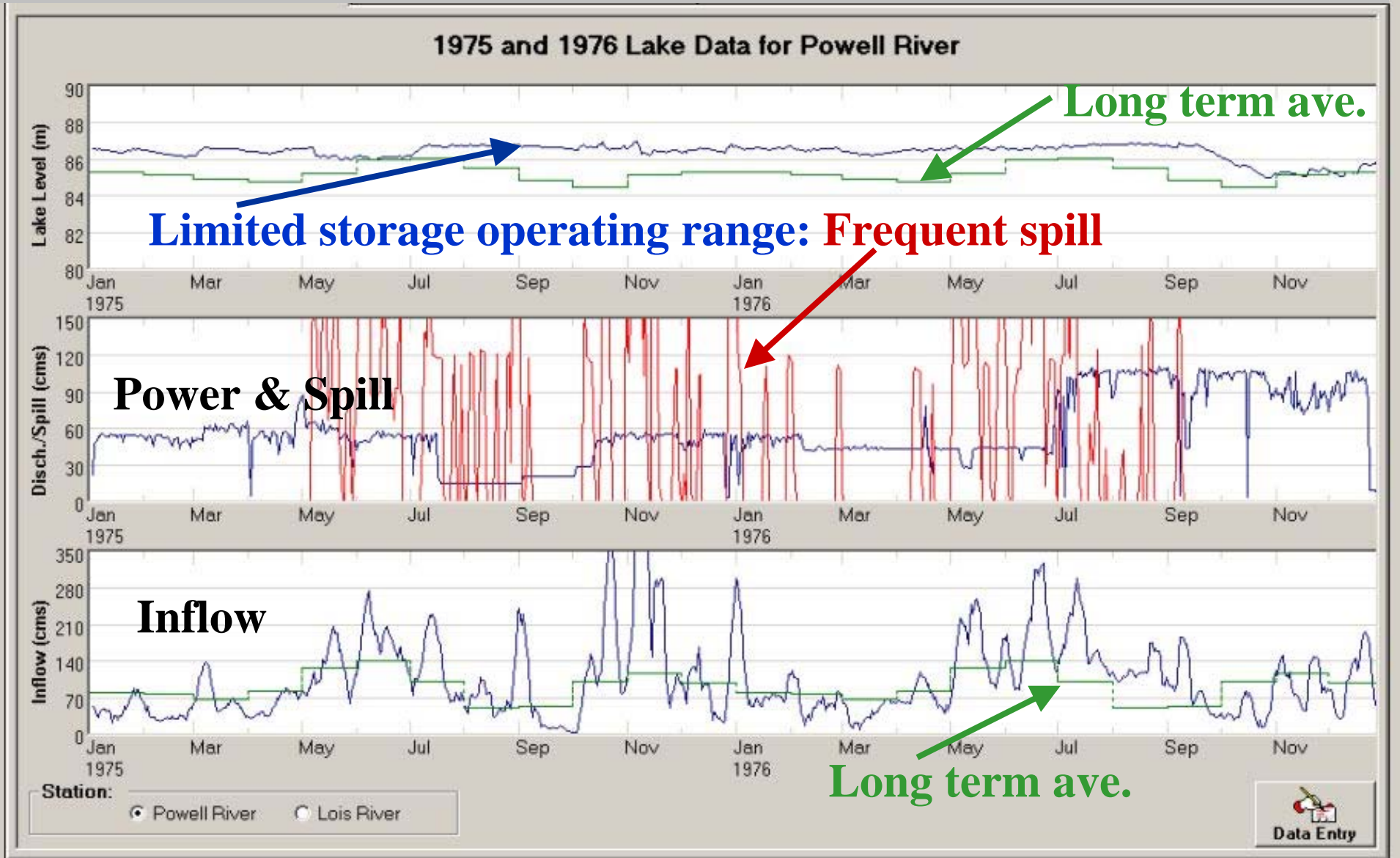
The result is the week by week probability distributions for future power and reservoir states.



Objectives and constraints



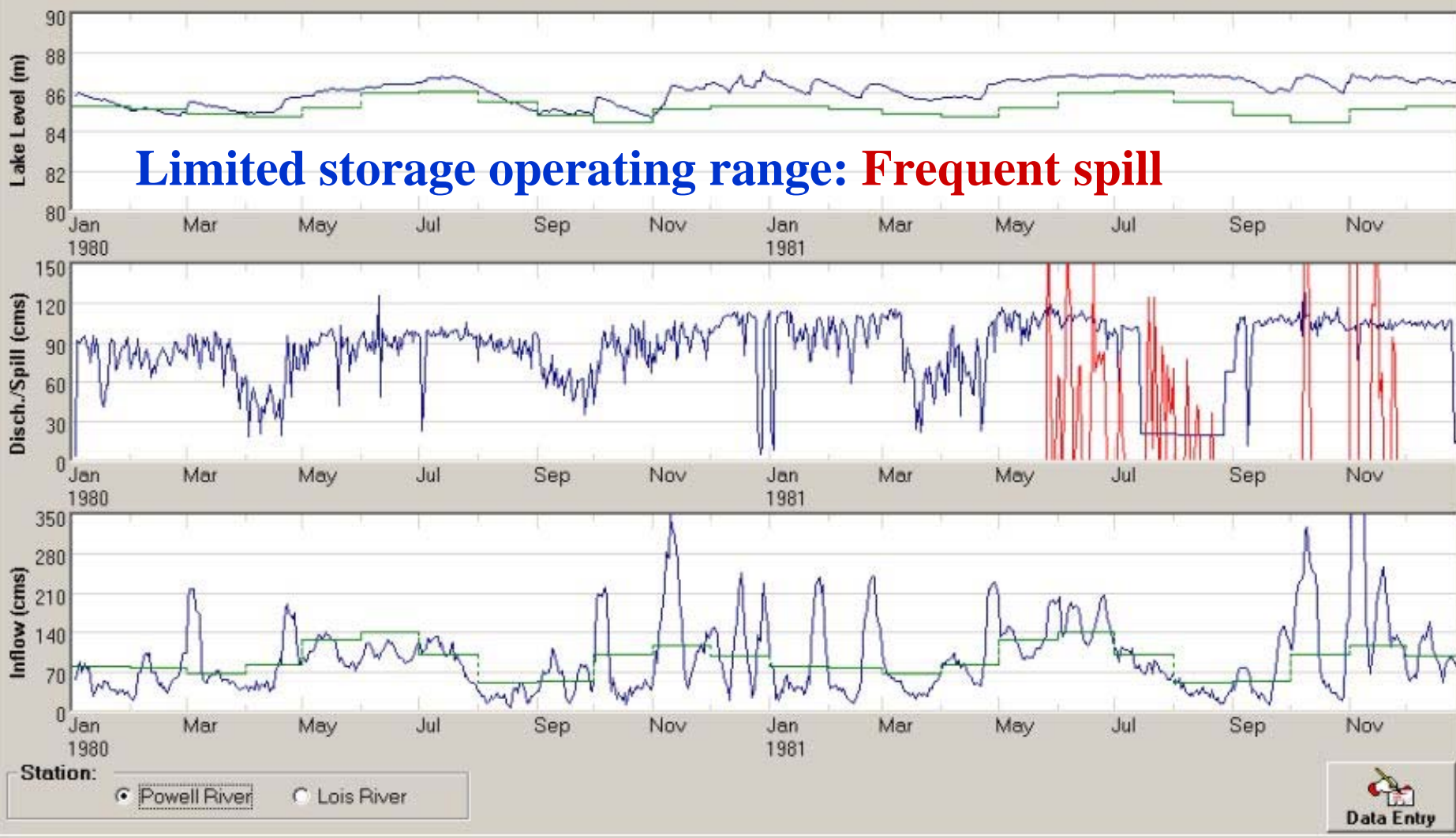
# Operation Before Ensemble Optimization



Scroll to change year:

# Operation Before Ensemble Optimization

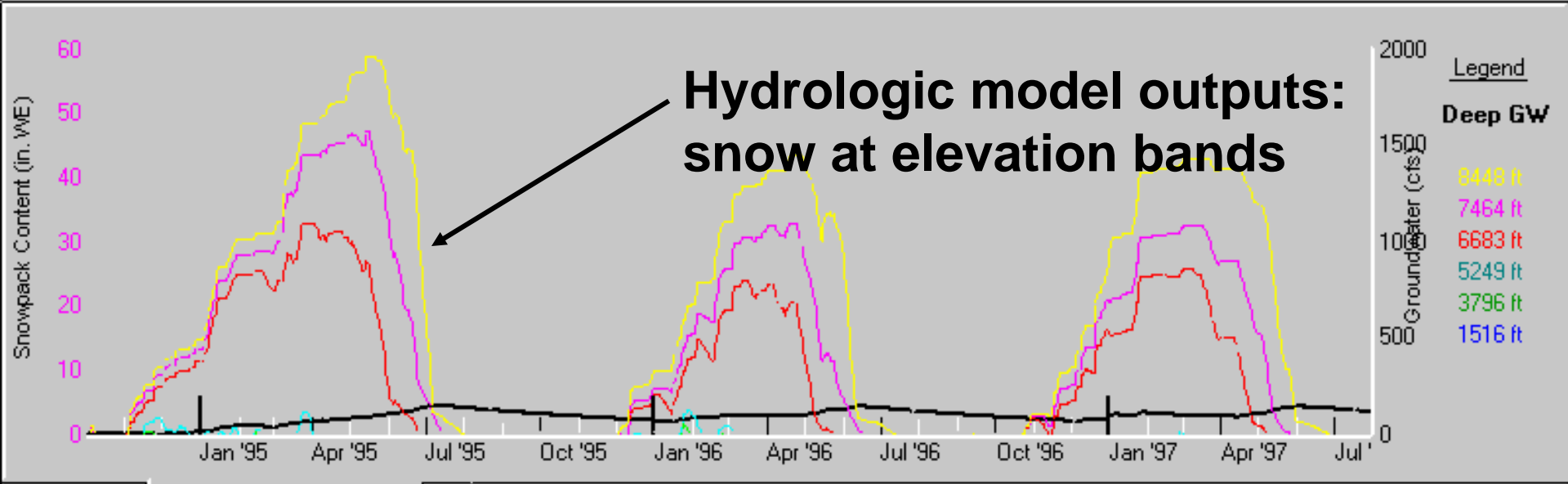
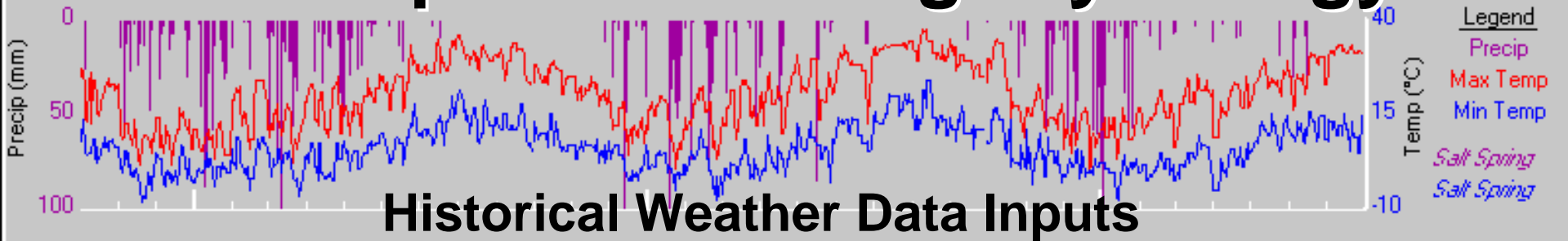
1980 and 1981 Lake Data for Powell River



Scroll to change year: [ ]

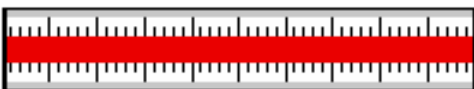
Help

# Conceptual Modeling: Hydrology



Discharge **Watershed Conditions**

Percent Done:



Initialization Period: Oct. 1 1994 to Jul. 31 1997 **Now Simulating:** Jul 31, 1997

Meteorological Data File: C:\JOBS\9218MUD\DATAMGR\DATA\HDMKPP.DBF

Watershed Parameter File: C:\JOBS\9218MUD\DATAMGR\DATA\MOK.PAR



Pause Options

Pause Immediately

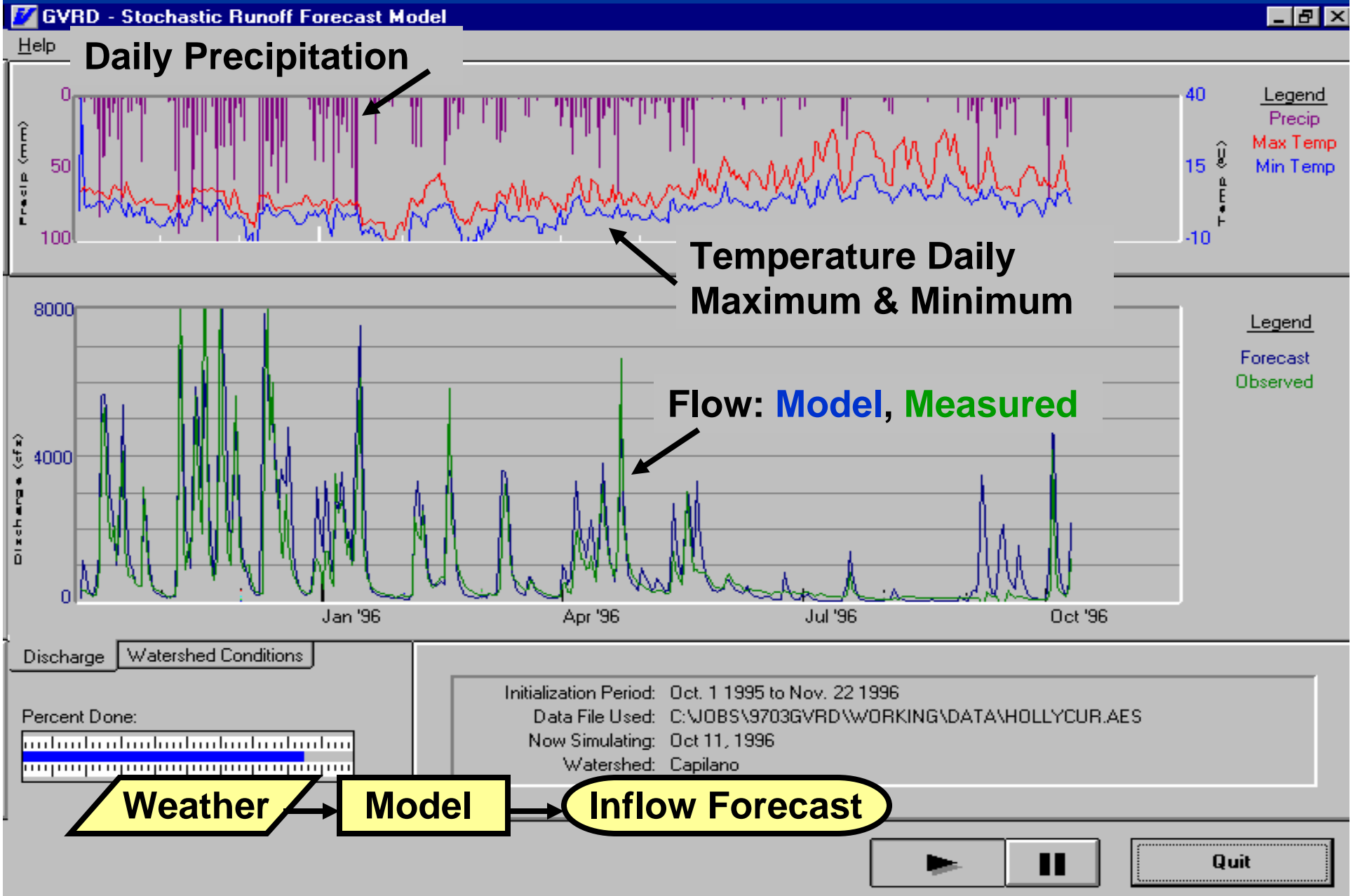
Pause At:

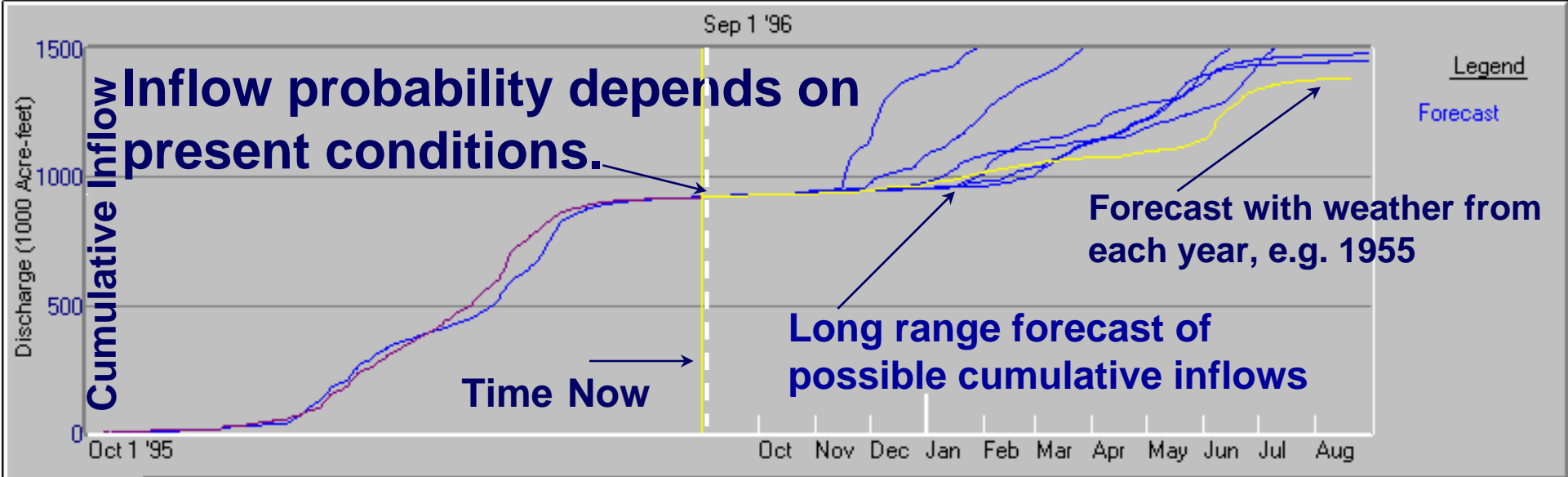
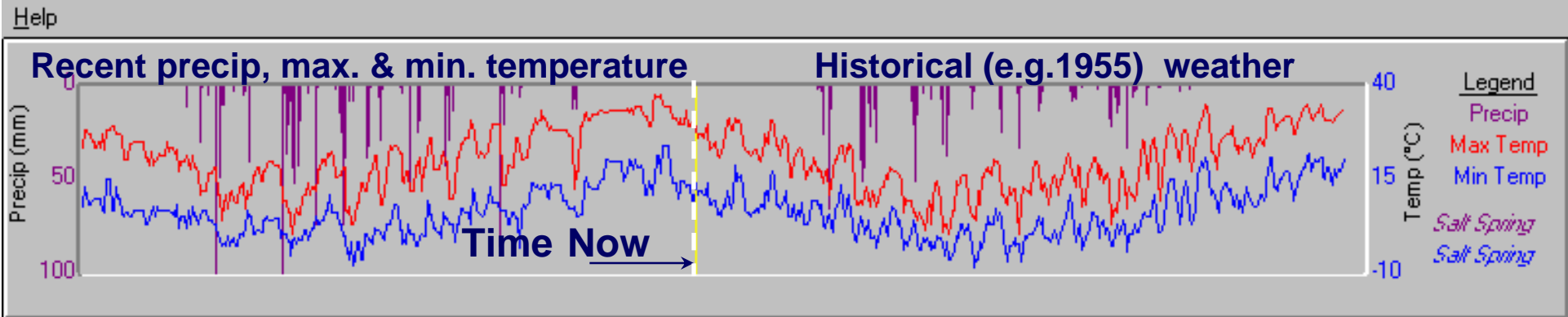
July 31, 1997



Quit

# Hydrologic model outputs: daily inflow hydrographs





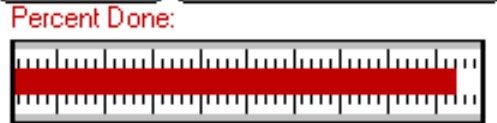
# Ensemble Forecasts

Initialization Period: Oct. 1 1993 to Sep. 1 1996      Now Simulating: Aug 21, 1955

Meteorological Data File: C:\JOBS\9218MUD\DATAMGR\DATA\HDMKPP.DBF

Watershed Parameter File: C:\JOBS\9218MUD\DATAMGR\DATA\MOK.PAR

Discharge      Watershed Conditions



Pause Options

Pause Immediately       Pause At:  ▼

▶    ⏸    Quit

# Conditional probability of cumulative inflow

Powell & Lois River Seasonal Operations : Non-Exceedance Probability of Inflow Forecasts

File Options Windows Help



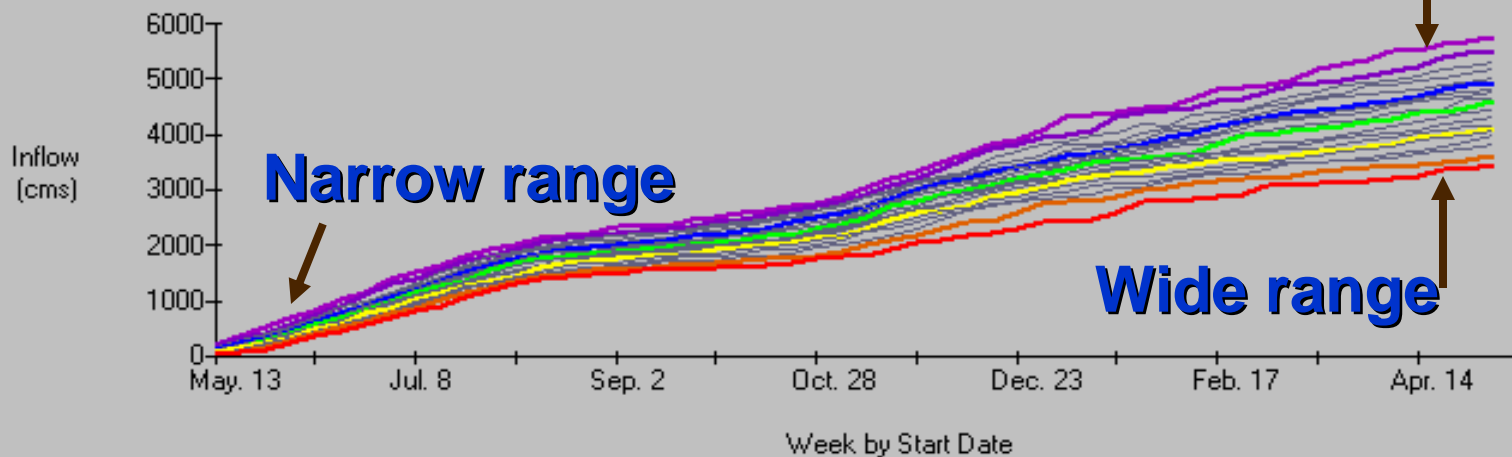
GO



Cumulative Inflow

Inflow

Cumulative Inflow Forecasts for Powell Lake



Select Probability

Dry

- 5%
- 10%
- 30%
- 50%
- 70%
- 90%
- 15%
- 25%
- 35%
- 45%
- 55%
- 65%
- 75%
- 85%
- 95%

Wet

Show All

Select Reservoir

- Powell Lake
- Lois Lake

Stochastic Inflow Forecasts (cms) by Non-Exceedance Probability for Apr 15, 2001

Week Starting	5%	10%	15%	20%
May 13, 2001	40.6	45.7	47.9	51.3
May 20, 2001	75.6	91.2	99.0	117.4
May 27, 2001	130.9	177.3	200.0	221.1
Jun 03, 2001	258.8	286.0	300.8	326.4
Jun 10, 2001	359.5	401.3	433.1	440.1

This inflow forecast is 28 DAY(S) OLD. Click on the button below to generate a forecast for May 13, 2001.

Update

Charles Howard & Associates Ltd

Starting Date: May 13, 2001

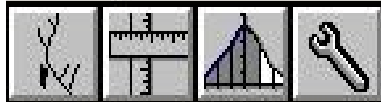
Ending Date: May 11, 2002

# Reliability of minimum generation

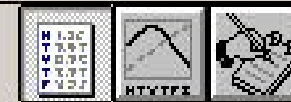
**Truncate the hydrologic ensemble forecast at an appropriate probability level.**

**For example, the recommended generation may go to the lower bound (20 Mw minimum generation) in at least one of the hydrologic sequences provided in the input.**

**The driest sequence controls the reliability.**



GO



The Annual Storage Model has successfully optimized powerhouse releases for the planning horizon.

**Next Week**

Recommended average releases (cms) and the corresponding average generation (MW) for the week starting February 26, 2004:

Powerhouse	Discharge (cms)	Generation (MW)
Powell Plant	118.00	46.6
Lois Plant	40.00	39.3
Total	158.00	85.9

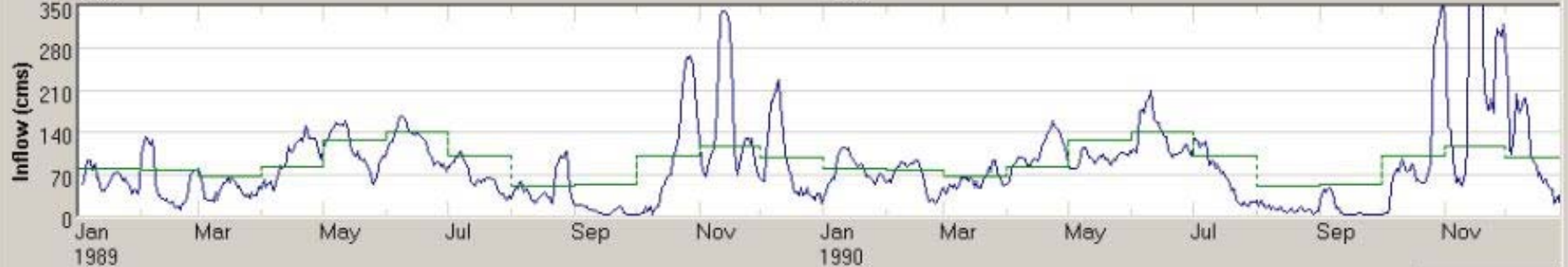
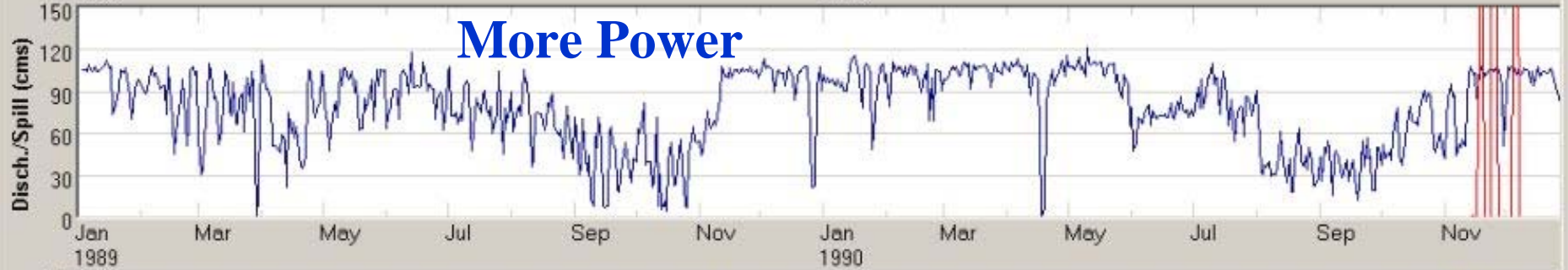
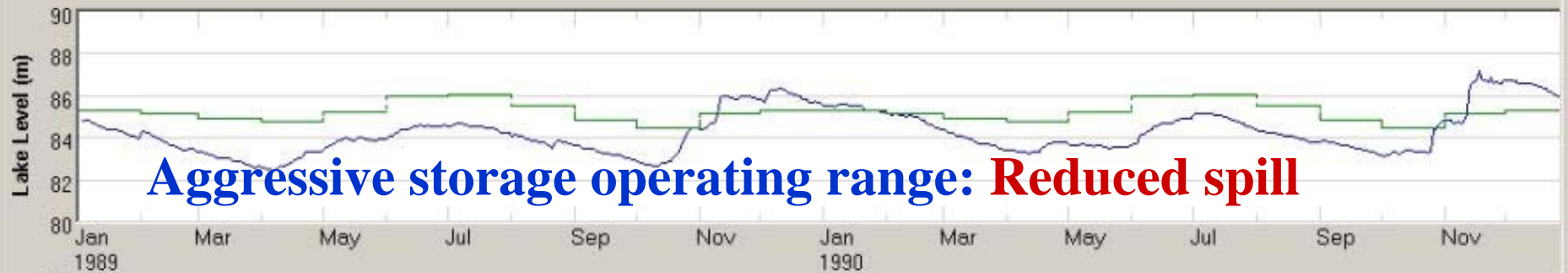
**Next Year**

Expected value of total generation (MWh) for the planning horizon from February 26, 2004 to February 23, 2005 :

Powerhouse	Generation (MWh)
Powell Plant	402,176
Lois Plant	339,956
Total Generation	742,132

# Operation After Ensemble Optimization

1989 and 1990 Lake Data for Powell River



Station:  Powell River  Lois River

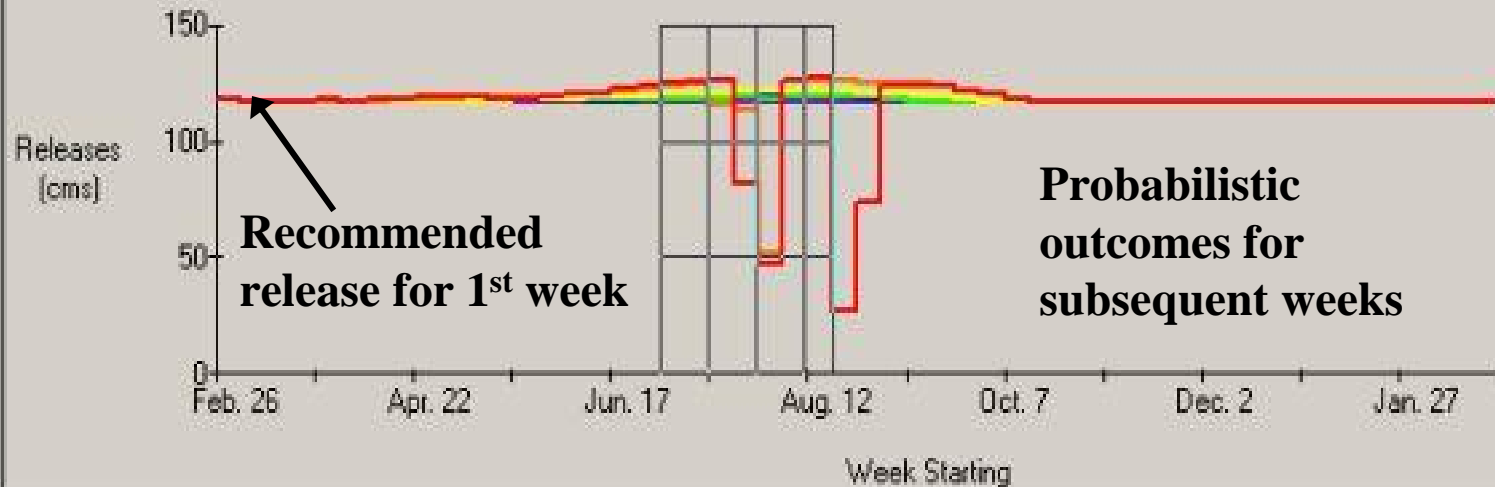
Data Entry

Scroll to change year: [ ]



Inflow | Elevation | Storage | **Releases** | Generation | Spills

**Forecasted Releases for Powell Plant**



Select Probability

Dry

5%     10%

20%     50%

70%     90%

95%

Wet

Show All

**Forecasted Powerhouse Release (cms) by Week Start Date for 50% Non-Exceedance Inflow Probability**

	Graph Display	Jul 1 2004	Jul 8 2004	Jul 15 2004	Jul 22 2004	Jul 29 2004	Aug 5 2004	Aug 12 2004
Powell Plant	<input checked="" type="radio"/>	118.00	118.00	118.00	119.00	118.00	119.00	119.00
Lois Plant	<input type="radio"/>	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Total Releases	<input type="radio"/>	158.00	158.00	158.00	159.00	158.00	159.00	159.00

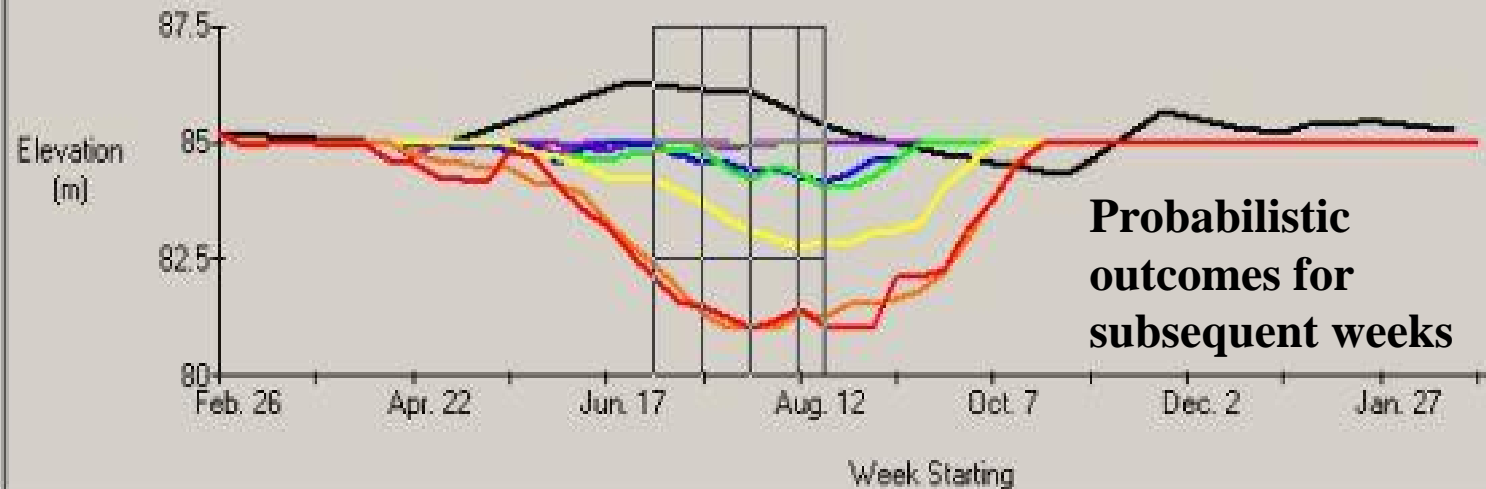
**Powell & Lois River Seasonal Operations : Forecasted Reservoir Operations**

File Options Windows Help

**GO**

Inflow **Elevation** Storage Releases Generation Spills

**Forecasted Elevation for Powell Lake**



Select Probability

Dry

5%     10%  
 20%     50%  
 70%     90%  
 95%

Wet

Show All    LTA

**Forecasted Ending Elevations (m) by Week Start Date for 50% Non-Exceedance Inflow Probability**

	Graph Display	Jul 1 2004	Jul 8 2004	Jul 15 2004	Jul 22 2004	Jul 29 2004	Aug 5 2004	Aug 12 2004
Powell Lake	<input checked="" type="radio"/>	84.82	84.79	84.81	84.46	84.22	84.48	84.36
Lois Lake	<input type="radio"/>	156.40	156.34	155.72	155.42	155.12	154.62	154.28

# Hydrologic Ensemble Optimization

## Actual Hydroelectric Benefits.

	1989	1990	1991	GwH/Year
Actual operation with software	269	392	265	295
Theoretical optimum	268	309	334	304
Rule Curve Operation	263	289	313	288

**2-percent improvement over Rule Curve was experienced.**

**Payback was less than one year**

**Up to 5-percent improvement over Rule Curve is possible if future operations follow recommendations more closely.**

# Hydrologic Ensemble Optimization

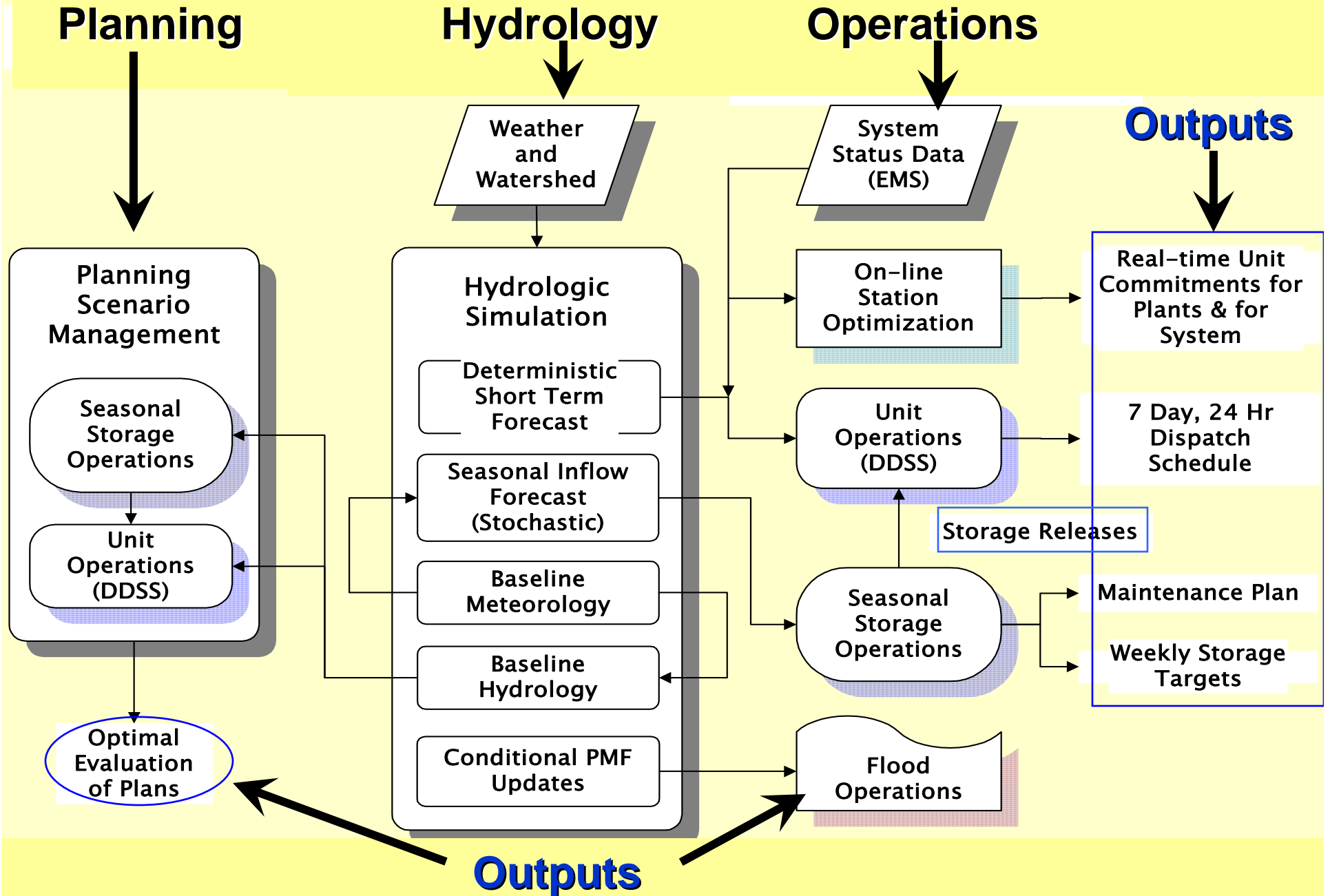
## Remaining Potential Hydroelectric Benefits.

	1989	1990	1991	1992	1993	1994	1995	1996	Totals
<b>Actual operation with software</b>	269	292	325	302	242	307	344	330	2411
<b>Theoretical optimum</b>	268	309	334	317	253	303	363	334	2481

**Overall possible improvement of 3-percent remains if the optimal recommendations can be followed more closely in practice.**

**This comparison provides a performance measure for ongoing operations**

# Example Decision Support System



**Thank you for your attention**

**[info@cddhoward.com](mailto:info@cddhoward.com)**

