

Ensemble Optimization for Hydroelectric Operations



By Charles D. D. Howard

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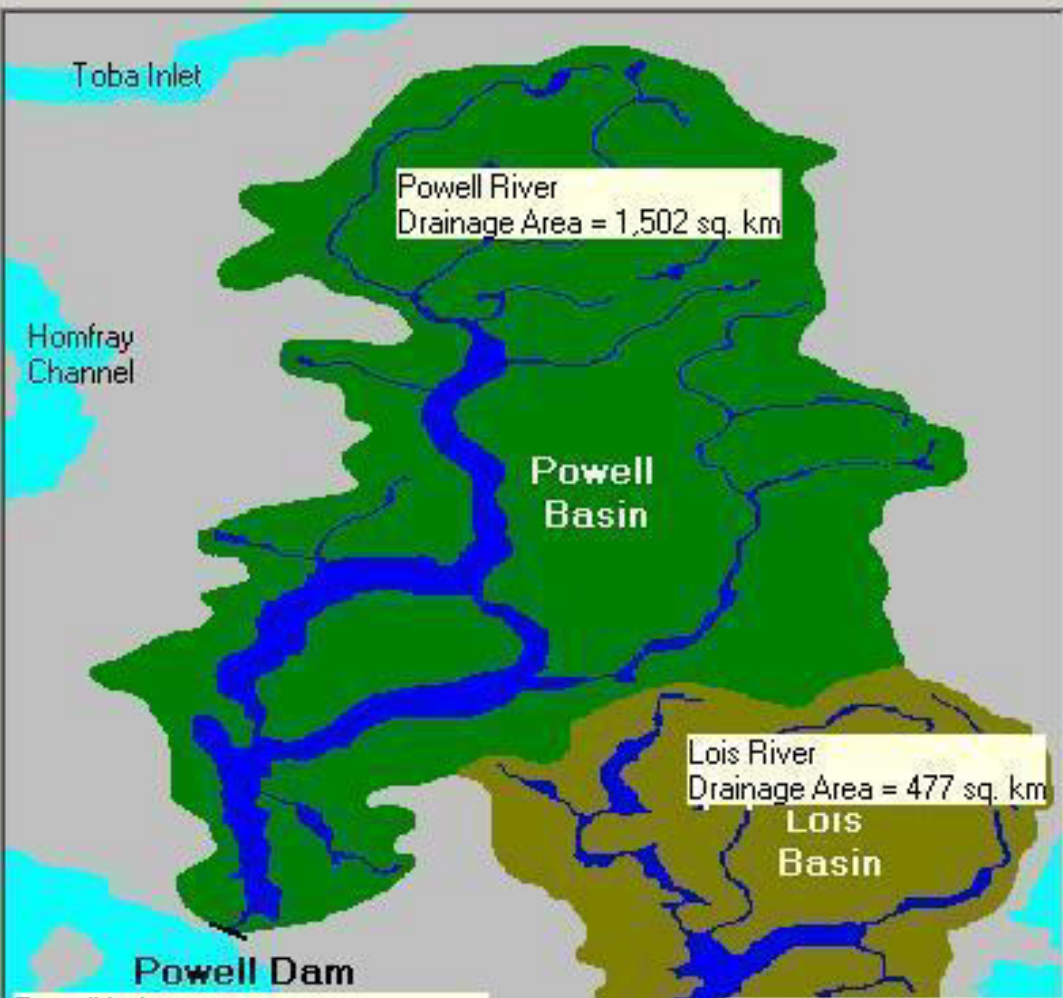
Powell & Lois Rivers

HYDROPS Annual Storage Model

Version 2.0.2

February, 2000

Charles Howard & Associates Ltd.
Professional Water Resources Engineers



Powell Dam

Capacity	= 8,295 cms-days
Physical Max Level	= 86.87 m
Physical Min Level	= 80.77 m
Normal Max Level	= 86.56 m
Normal Min Level	= 81.69 m


Lois Dam

Capacity	= 6,422 cms-days
Physical Max Level	= 158.80 m
Physical Min Level	= 140.21 m
Normal Max Level	= 158.19 m
Normal Min Level	= 147.83 m



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 

Forecast

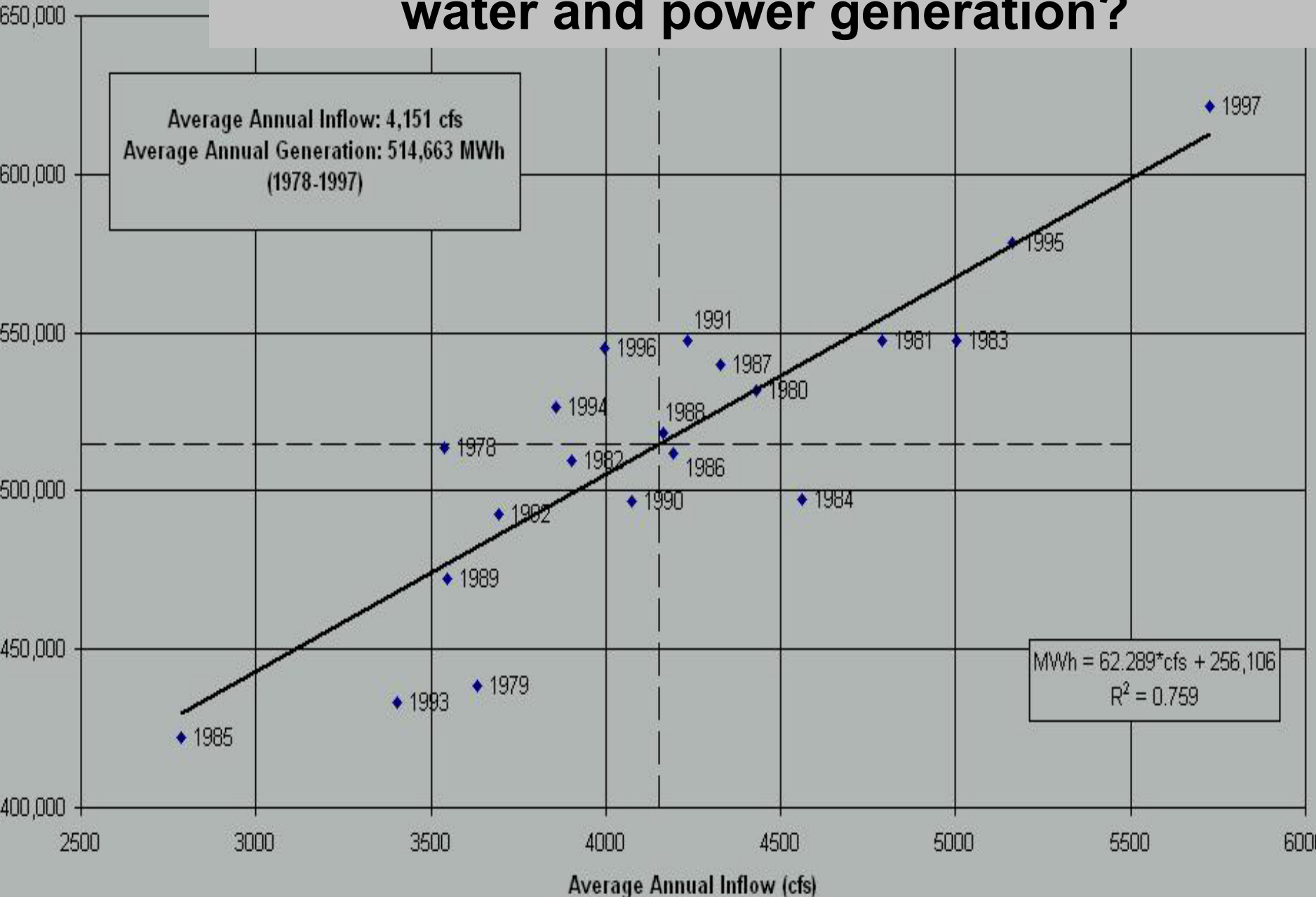
Quit

Powell River BC Basin



How to improve the relationship between water and power generation?

Generation (MWh)



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:

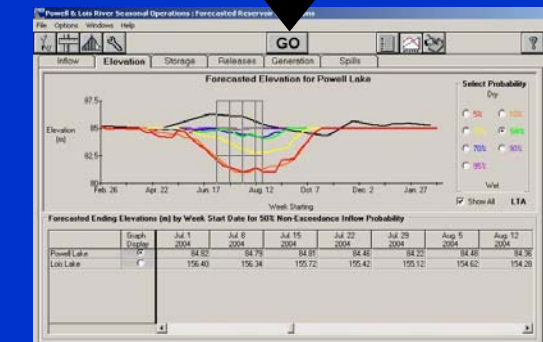
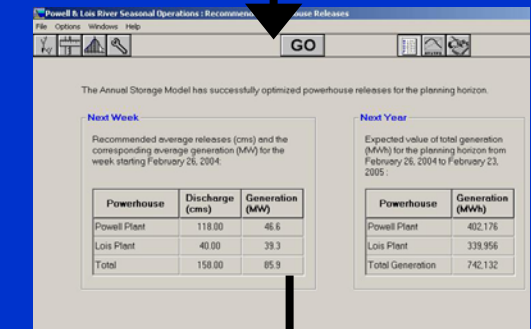
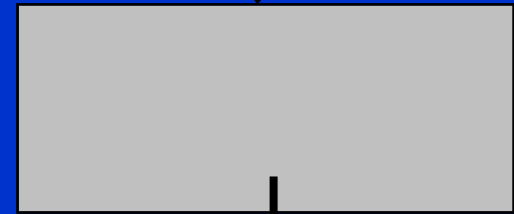
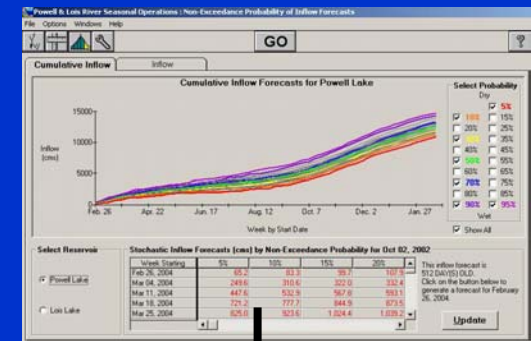
- a hydrologic ensemble forecast model,**
- an ensemble optimization reservoir model,**
- an generator optimum loading model.**

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

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

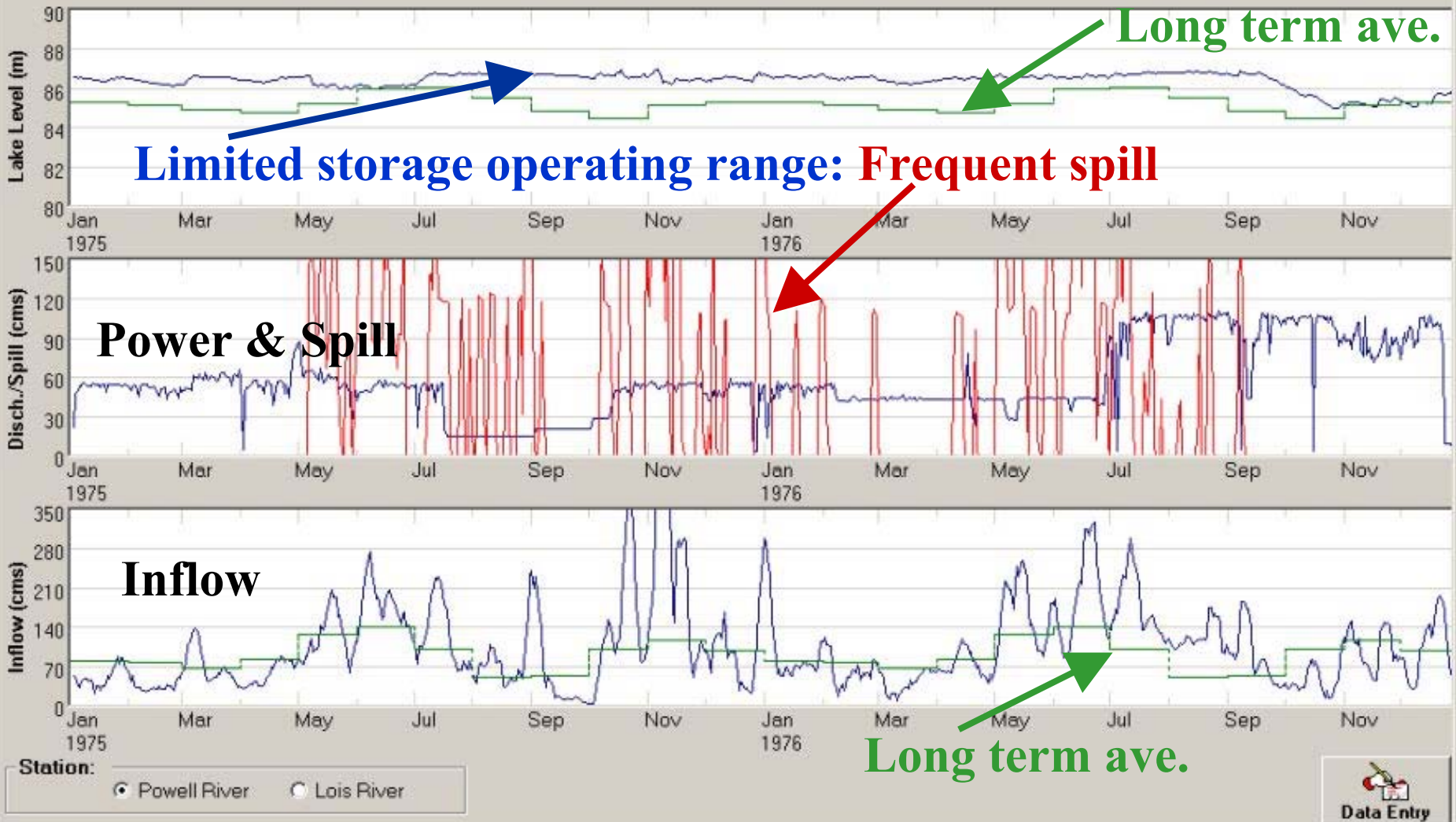
The recommendation is the **specific** optimum power generation for this week.

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



Operation Before Ensemble Optimization

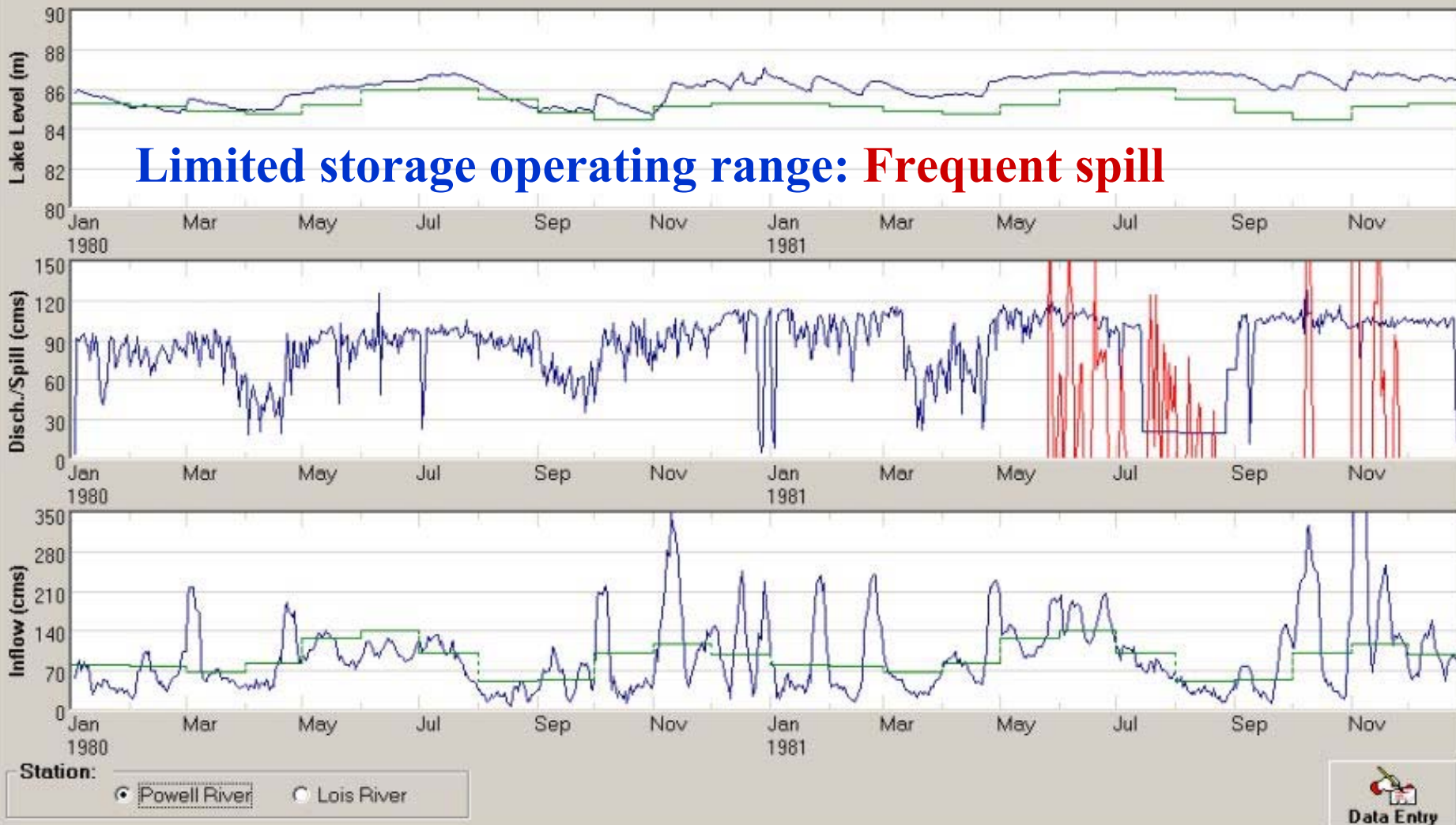
1975 and 1976 Lake Data for Powell River



Scroll to change year: ◀

Operation Before Ensemble Optimization

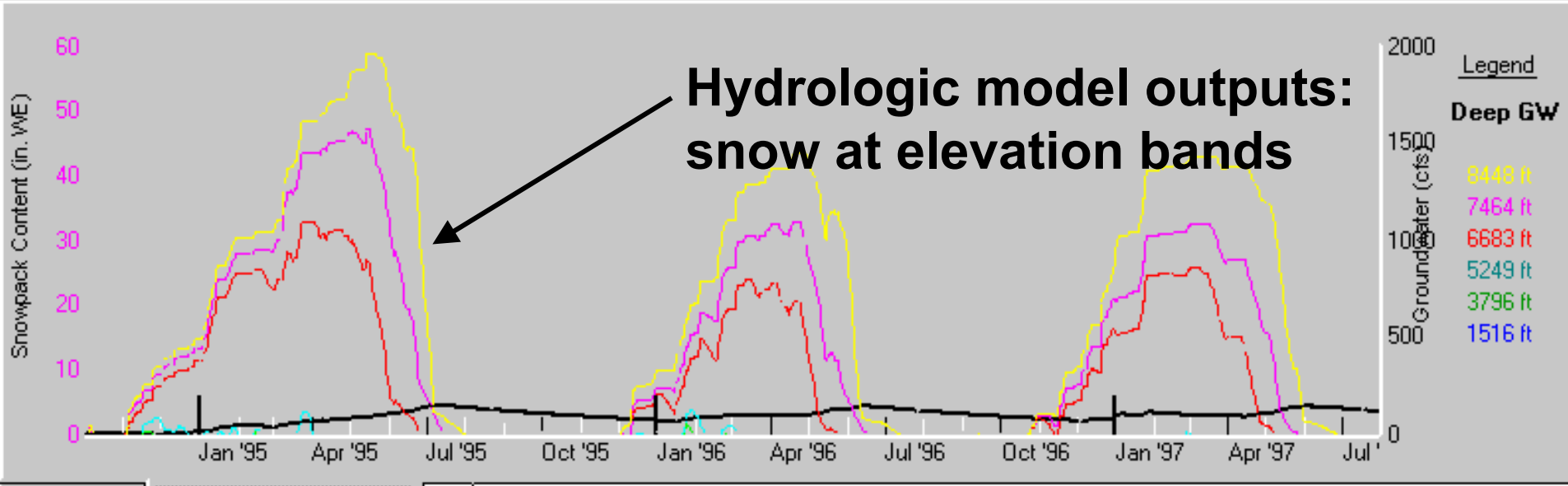
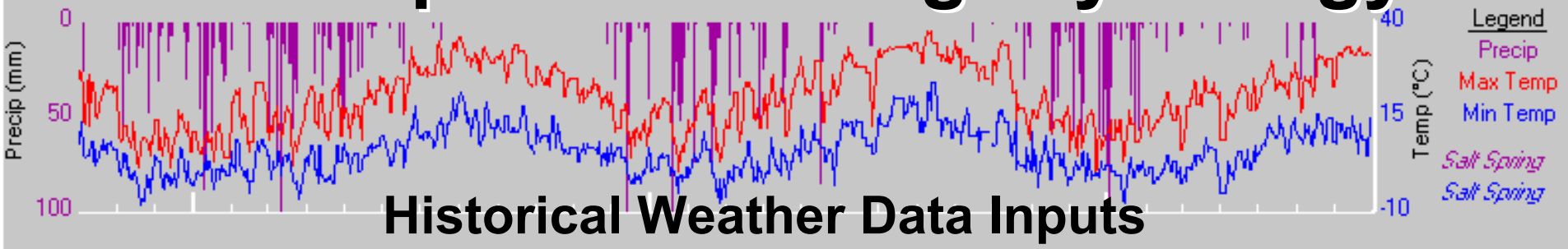
1980 and 1981 Lake Data for Powell River



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: ▼

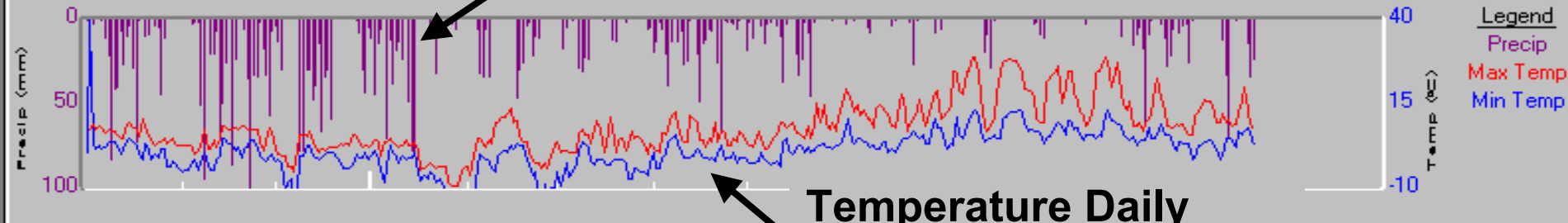
▶ || Quit

Hydrologic model outputs: daily inflow hydrographs

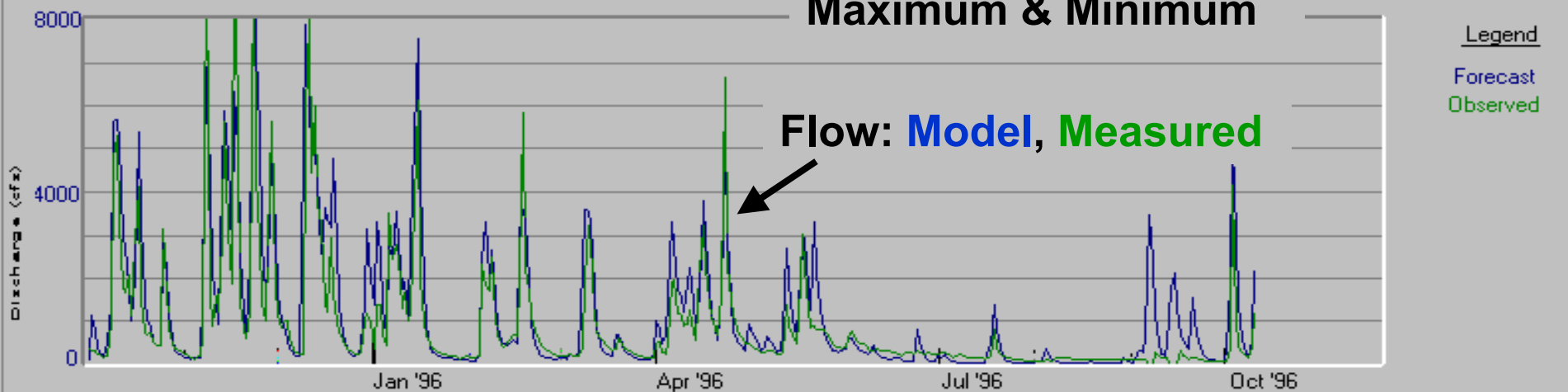
GVRD - Stochastic Runoff Forecast Model

Help

Daily Precipitation



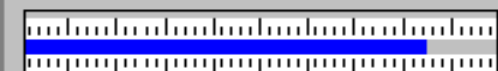
Temperature Daily Maximum & Minimum



Flow: Model, Measured

Discharge Watershed Conditions

Percent Done:



Initialization Period: Oct. 1 1995 to Nov. 22 1996

Data File Used: C:\JOBS\9703GVRD\WORKING\DATA\HOLLYCUR.AES

Now Simulating: Oct 11, 1996

Watershed: Capilano

Weather

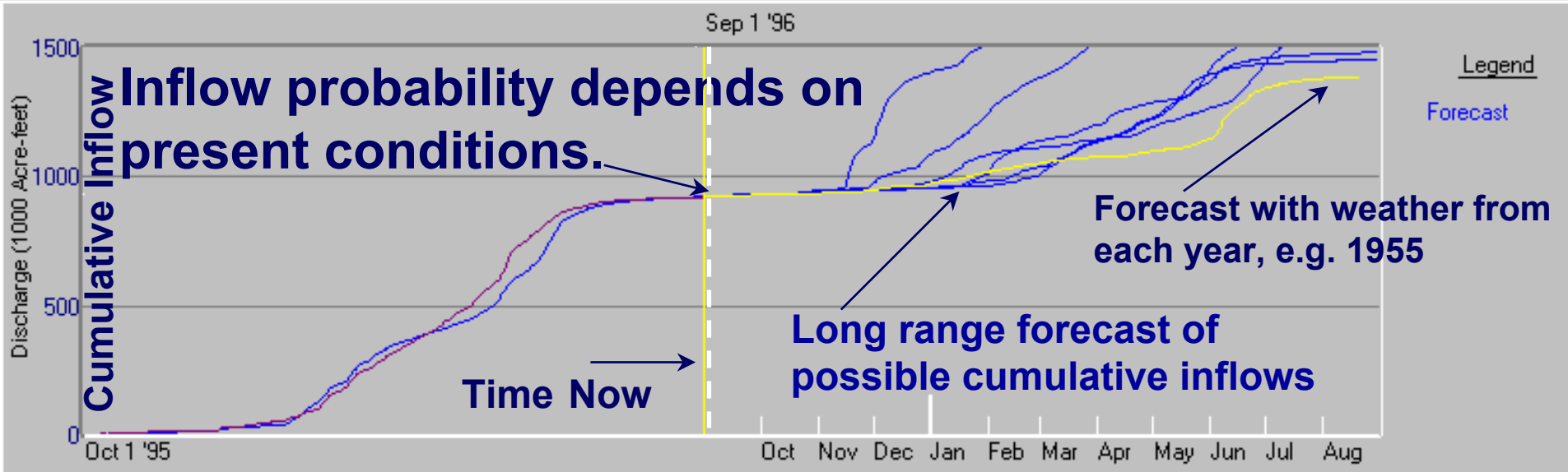
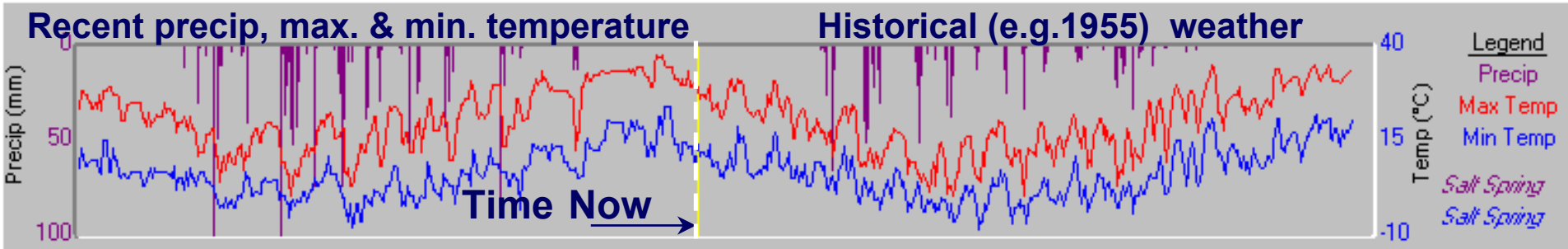
Model

Inflow Forecast

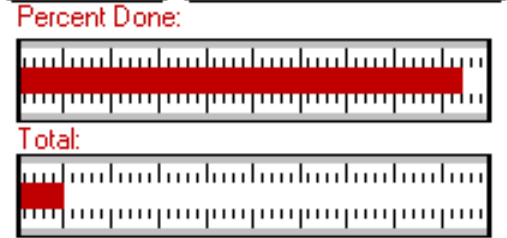


Quit

Help



Discharge | Watershed Conditions



Ensemble Forecasts

Initialization Period: Oct. 1 1993 to Sep. 1 1996 **Now Simulating:** Aug 21, 1995

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

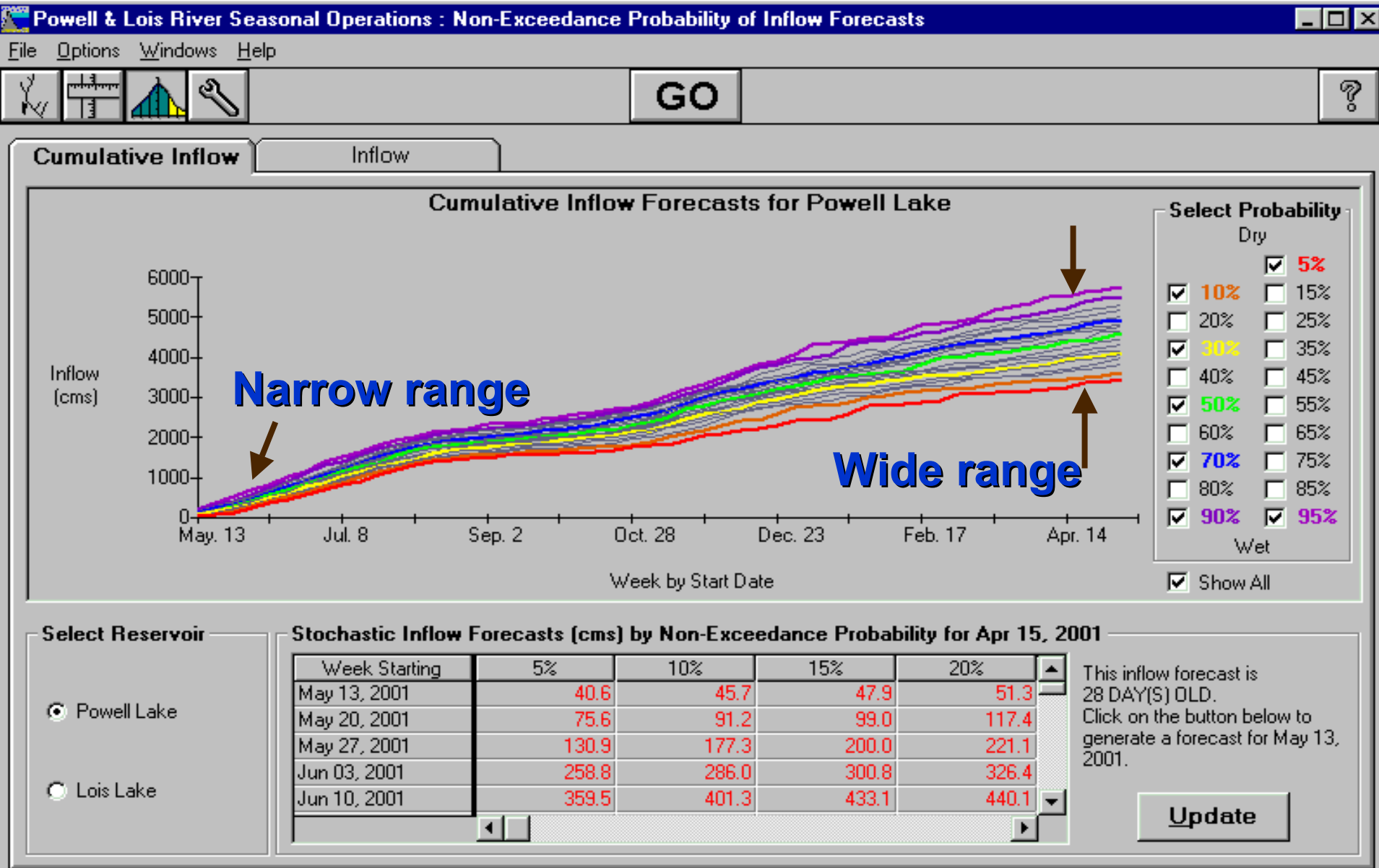
Watershed Parameter File: C:\JOBS\9218MUD\DATAMGR\DATA\MOK.PAR

Pause Options

Pause Immediately Pause At: ▼



Conditional probability of cumulative inflow



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

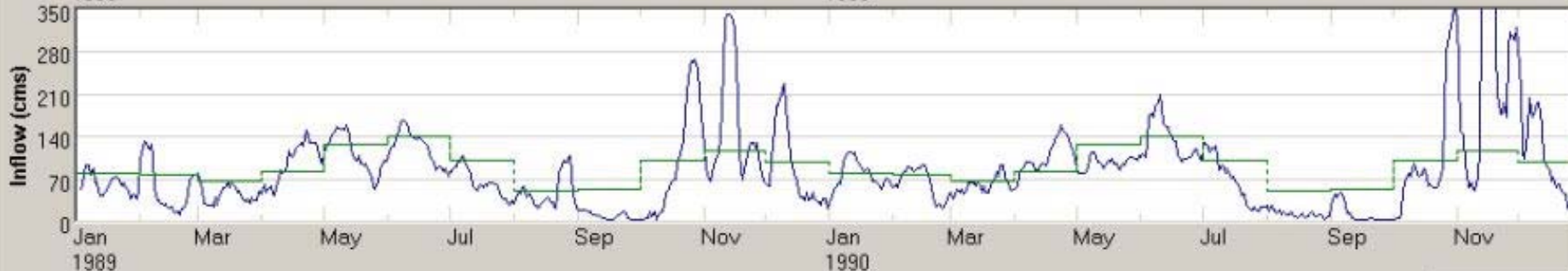
Next Year

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:

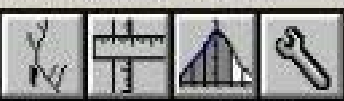
Powell River

Lois River



Data Entry

Scroll to change year: ◀

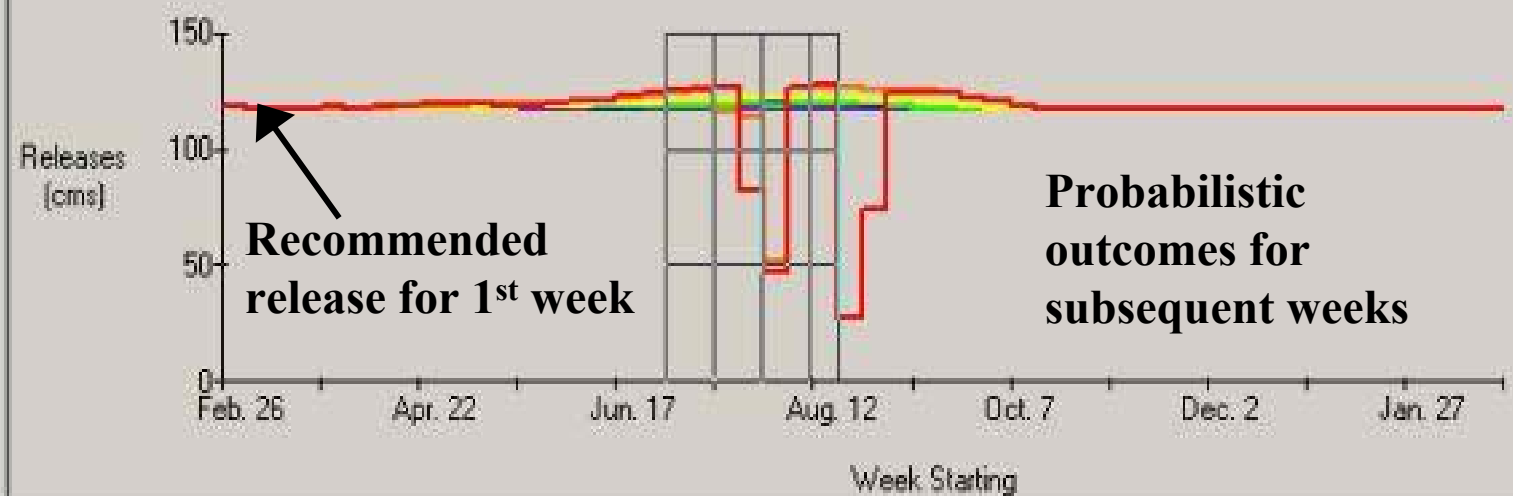


GO



Inflow Elevation Storage **Releases** Generation Spills

Forecasted Releases for Powell Plant



Select Probability

Dry

5% 10%

20% 50%

70% 90%

95%

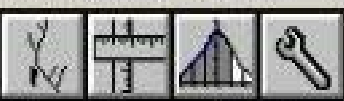
Wet

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



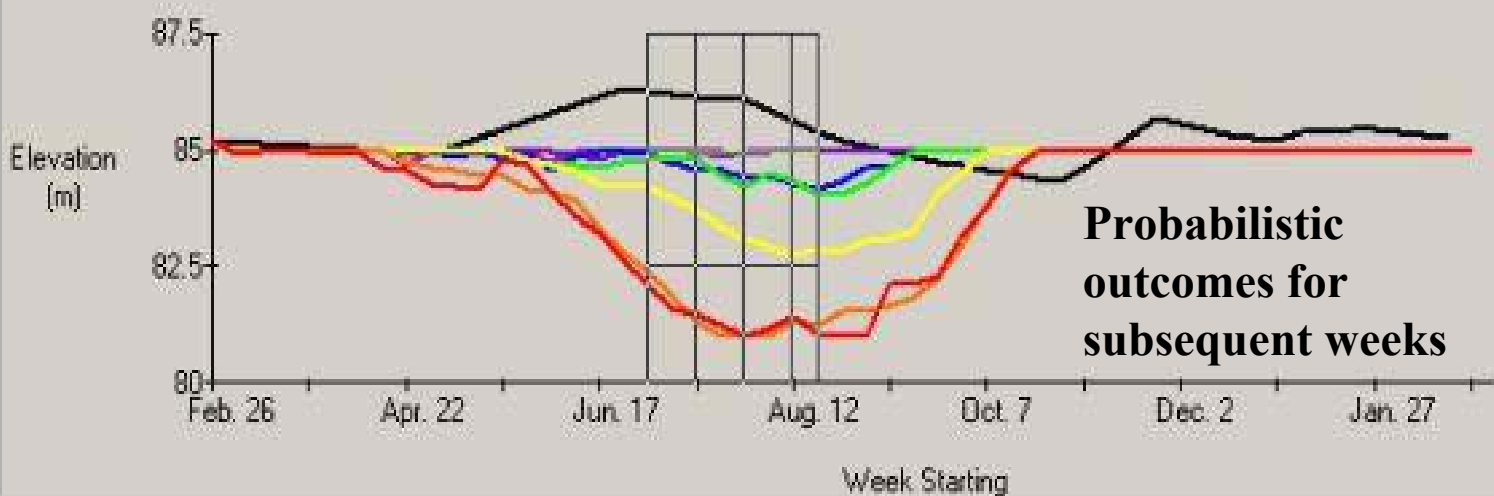


GO



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
Actual operation with software	269	292	325	302	242	307	344	330	2411
Theoretical optimum	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

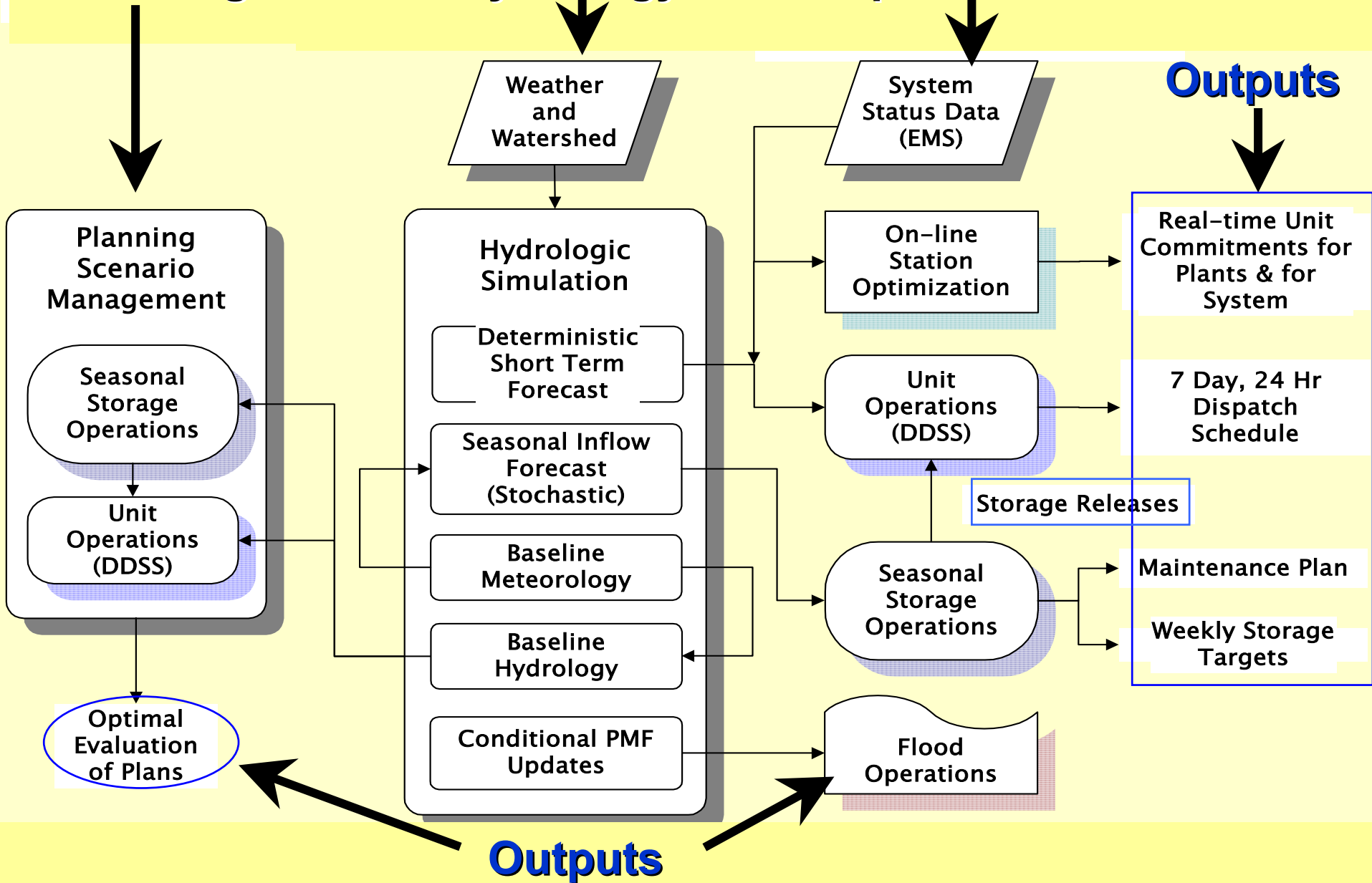
Example Decision Support System

Planning

Hydrology

Operations

Outputs



Thank you for your attention

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