A Decision Support System for Optimizing Reservoir Operations Using Ensemble Streamflow Predictions

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Management Science Seminar Series Fall 2009

November 6, 2009, SOM 112

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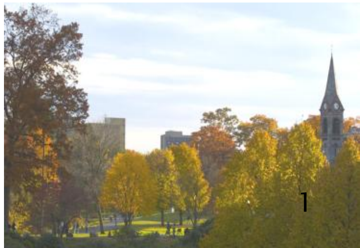
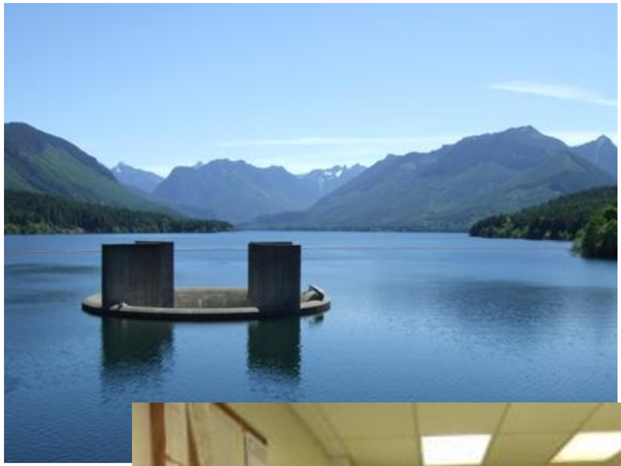
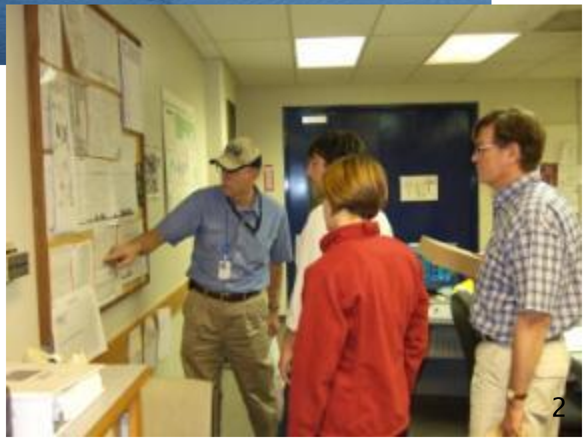


Outline

- Decision Support and Planning
- What is ESP?
- System Overview
- Proof of Concept
  - Models
  - Methods
  - Results
- Current Operational Use





Water Resources Planning

- *Collaborative planning* is a planning process in which individuals, agencies, and organizations, often with widely varied interests, work together to share knowledge and resources, and achieve mutually beneficial goals and enduring solutions through structured, civil dialogue.
  - When utilized effectively, collaboration can serve as an alternative dispute resolution process.
  - Since water resources planning is almost always contentious these techniques often offer promising approaches
  - Decision support systems can greatly add to collaborative planning

Discovering Collaborative Planning While Evaluating the Washington, D.C. Water Supply

- Ph.D. research focused on drought and water supply in Potomac
- Developed multi-objective optimization model
  (large scale linear program)
- Results indicated that the 16 reservoirs proposed by the COE were not necessary
- No stakeholder involvement

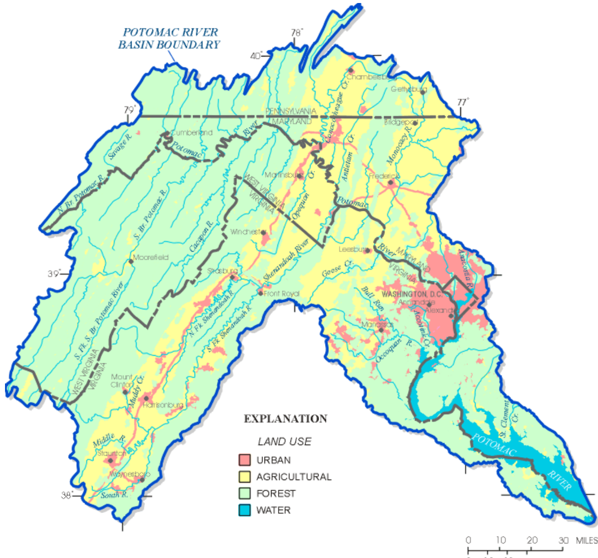


Figure 2. Major land uses in the Potomac River Basin.

Collaborative Planning

Things happening in 1979

- Margaret Thatcher elected Prime Minister
- Three Mile Island Accident
- VisiCalc becomes first spreadsheet program
- Sony Walkman introduced
- China starts 1 child program
- Little Collaborative Planning

~~Collaborative Planning~~

Discovering Collaborative Planning While Evaluating the Washington, D.C. Water Supply

- Developed an interactive simulation model to test impact of changing operations and create interest in our results
- Began to get stakeholder acceptance in the region
- Process was one of 10 Finalist in ASCE's Civil Engineering Achievement of the Year

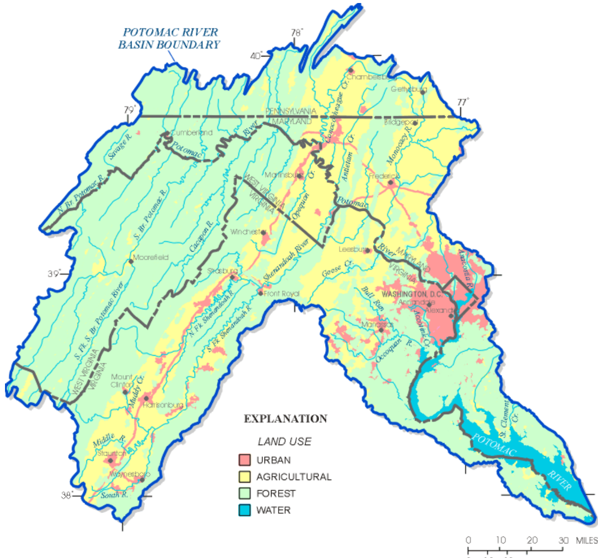
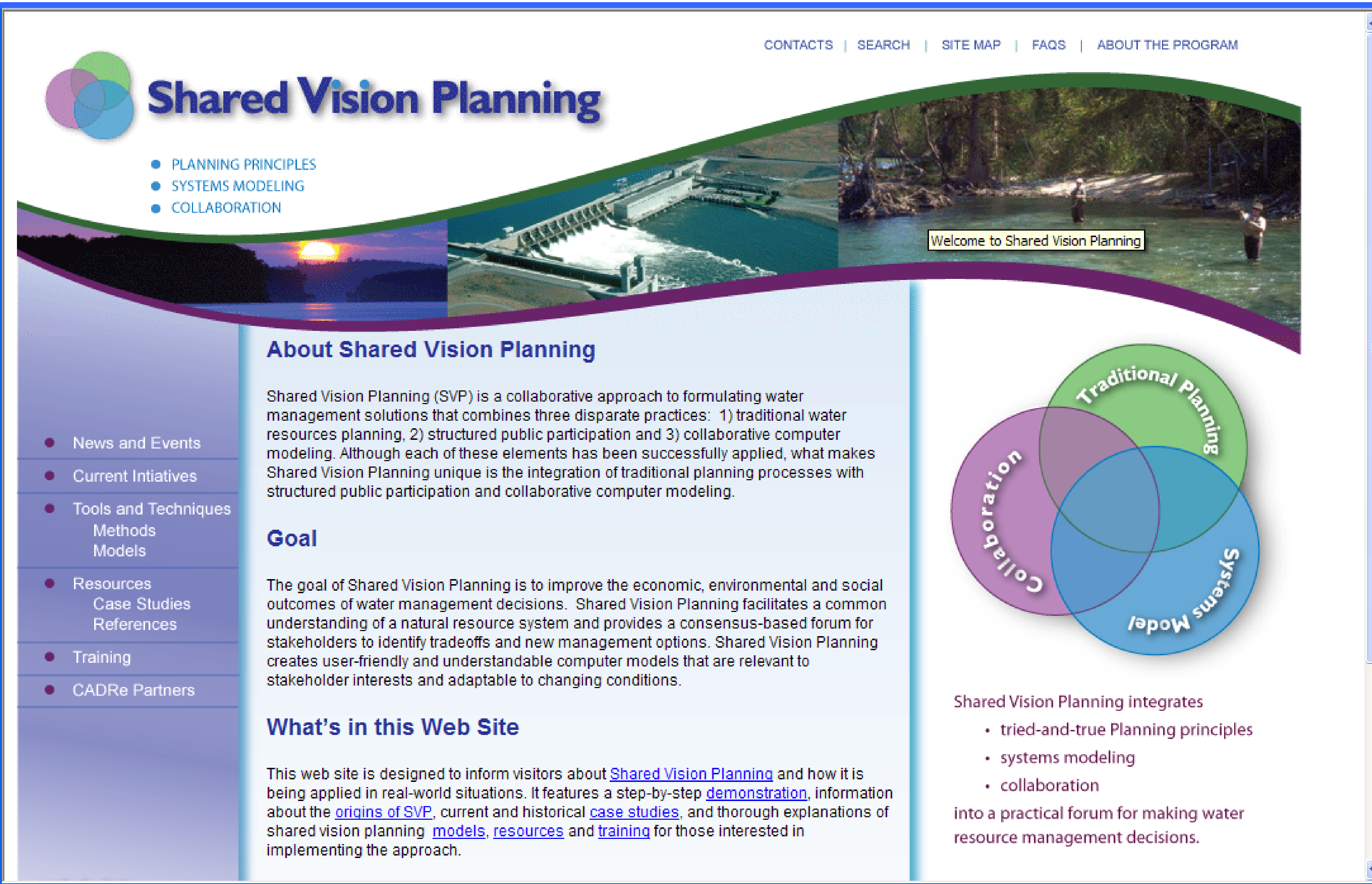


Figure 2. Major land uses in the Potomac River Basin.

A Study in Collaborative Planning – The National Drought Study

- NDS provided opportunity to test new planning approaches in case studies throughout the US and resulted in Shared Vision Planning/Modeling
- SVP is a disciplined planning approach that incorporates:
  - the best of traditional water resources planning,
  - structured public participation, and
  - the use of interactive computer modeling as an integrative tool.

US Army Corps of Engineers®
institute for water resources



CONTACTS | SEARCH | SITE MAP | FAQS | ABOUT THE PROGRAM

Shared Vision Planning

- PLANNING PRINCIPLES
- SYSTEMS MODELING
- COLLABORATION

Welcome to Shared Vision Planning

- News and Events
- Current Intiatives
- Tools and Techniques
  - Methods
  - Models
- Resources
  - Case Studies
  - References
- Training
- CADRe Partners

About Shared Vision Planning

Shared Vision Planning (SVP) is a collaborative approach to formulating water management solutions that combines three disparate practices: 1) traditional water resources planning, 2) structured public participation and 3) collaborative computer modeling. Although each of these elements has been successfully applied, what makes Shared Vision Planning unique is the integration of traditional planning processes with structured public participation and collaborative computer modeling.

Goal

The goal of Shared Vision Planning is to improve the economic, environmental and social outcomes of water management decisions. Shared Vision Planning facilitates a common understanding of a natural resource system and provides a consensus-based forum for stakeholders to identify tradeoffs and new management options. Shared Vision Planning creates user-friendly and understandable computer models that are relevant to stakeholder interests and adaptable to changing conditions.

What's in this Web Site

This web site is designed to inform visitors about Shared Vision Planning and how it is being applied in real-world situations. It features a step-by-step demonstration, information about the origins of SVP, current and historical case studies, and thorough explanations of shared vision planning models, resources and training for those interested in implementing the approach.

Traditional Planning
Collaboration
Systems Model

Shared Vision Planning integrates

- tried-and-true Planning principles
- systems modeling
- collaboration

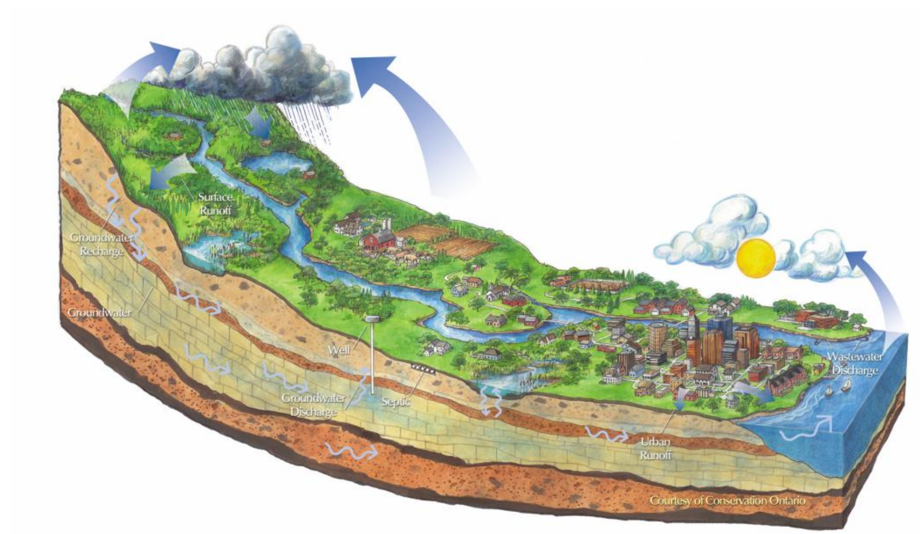
into a practical forum for making water resource management decisions.

Today's Presentation

- Use a Decision Support System to encourage communication and collaborative decision making among hydropower schedulers, biologists, energy forecasters, and other managers.
- Basic setting:
  - Each week a number of individuals arrive at a consensus of how best to operate a hydropower system for the next 7 days.

Ensemble Streamflow Predictions

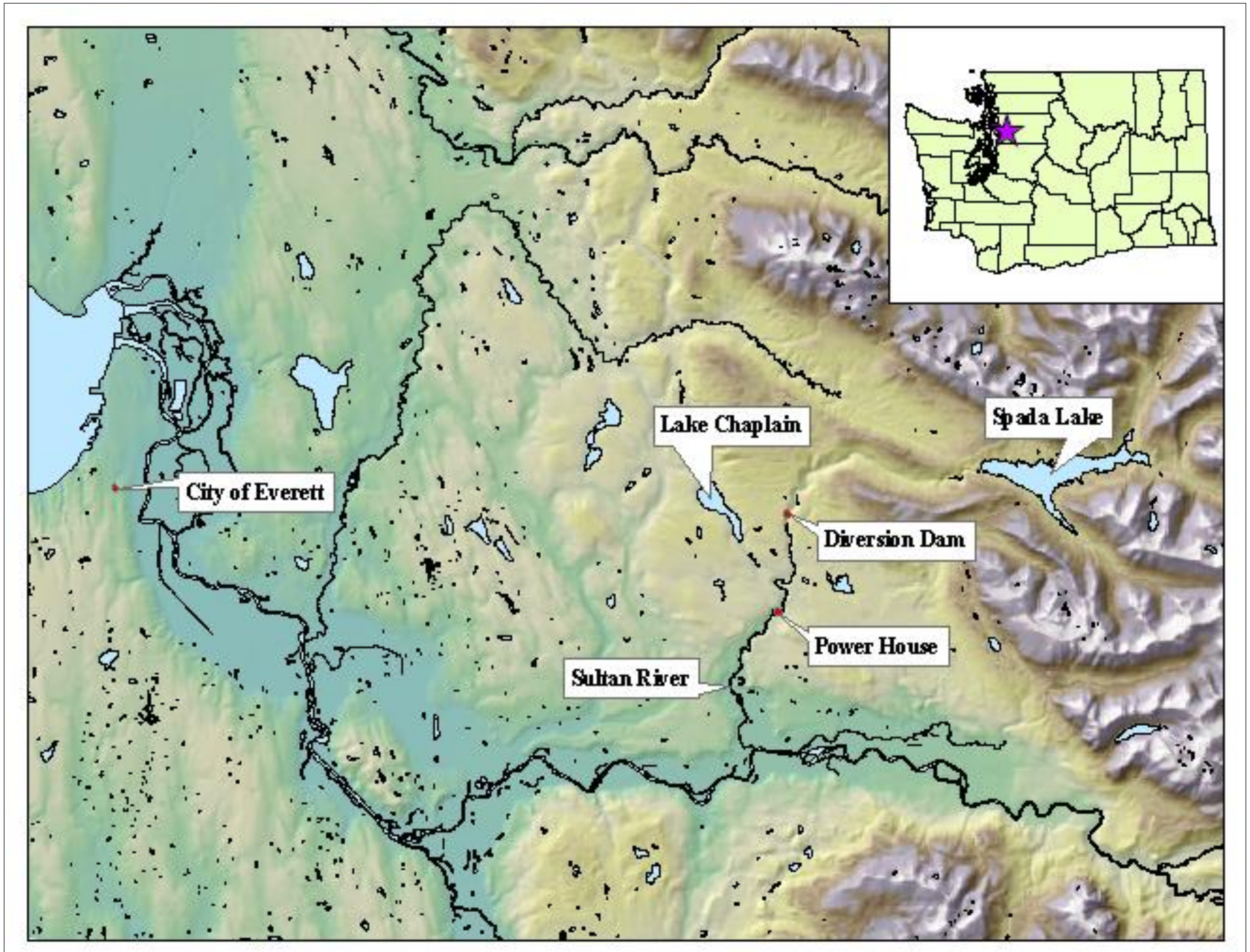
- What is ESP?
  - ESP uses the current hydrologic model states as initial conditions and drives the model using historical temperature and precipitation. ESP produces a flow trace that corresponds to a particular year of historical weather.



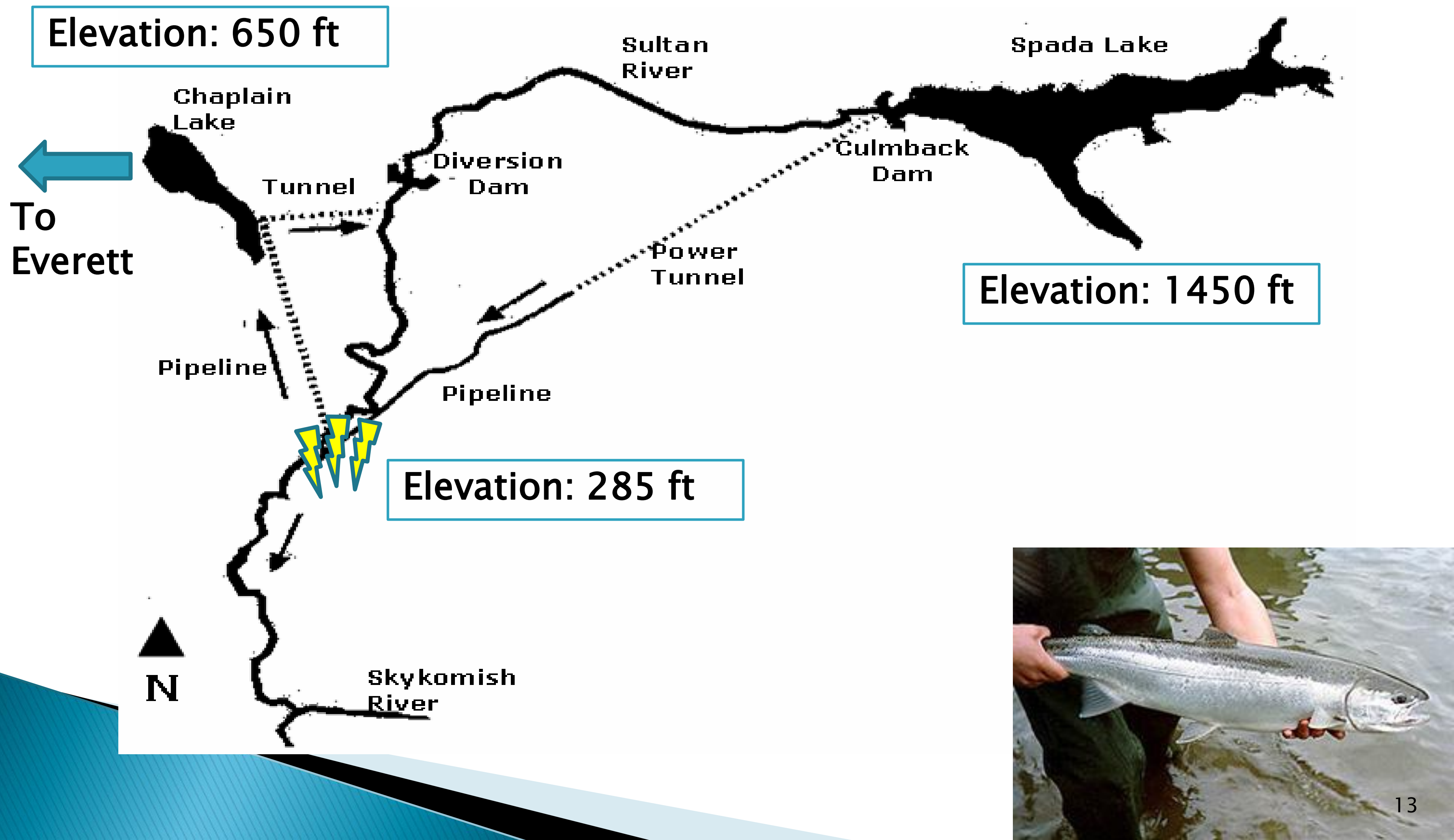
Ensemble Streamflow Predictions

- What is ESP?
  - ESP uses the current hydrologic model states as initial conditions and drives the model using historical temperature and precipitation. ESP produces a flow trace that corresponds to a particular year of historical weather.
  - We use this concept, and blend it with a deterministic forecast of rainfall and temperature for the next 7 days from NOAA, then revert to using historical data.
  - We have over 45 years of historical data.

System Overview



System Overview



What about Climate Change?

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now

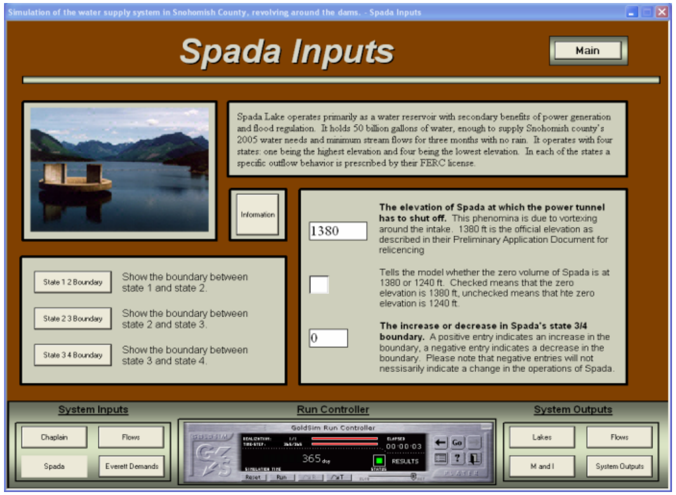
Proof of Concept

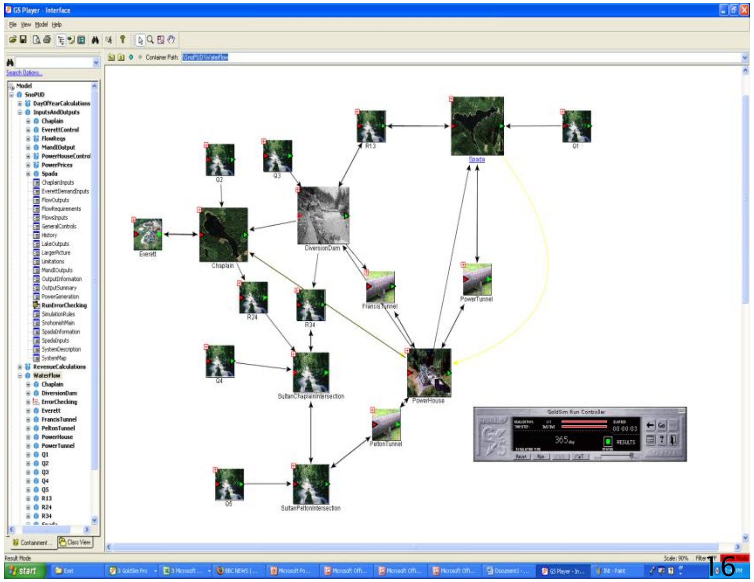
- Demonstrate use of forecasts improves operational performance through:
  - Meeting all system constraints
  - Increasing Avoided Costs ($$$) for customer base
- Use retrospective hydrologic and energy price forecasts to drive DSS
- Examine if 60 day forecasts increase hydropower revenue

Proof of Concept – Models

Simulation Model

- Built with **GoldSim** simulation software
- Simulates system operations at the Jackson Hydropower Project
- Shows how water is routed through the system
- Incorporates variation in streamflow, energy prices and environmental flow requirements
- Used to develop targets that constrain Linear Program

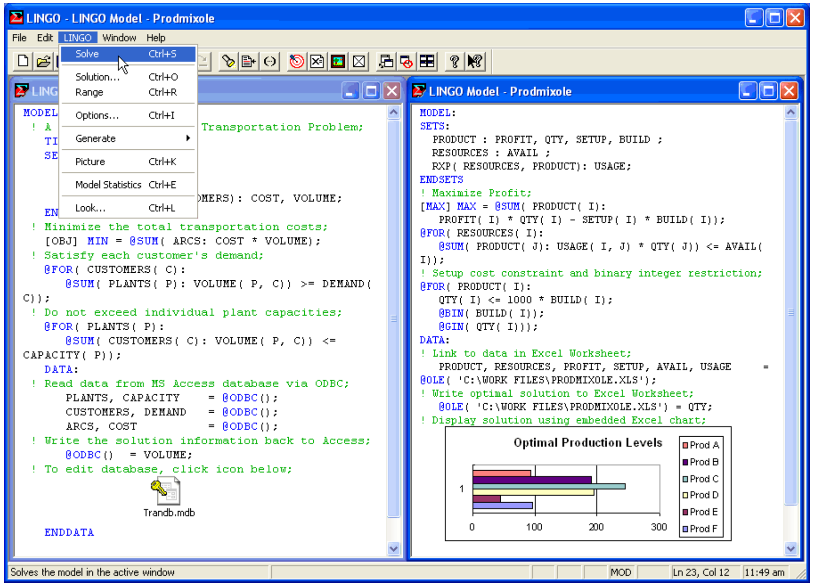




Proof of Concept – Models

Optimization Model

- Built with Lingo programming language
- Represents the hydrologic and hydraulic elements of the system in a mathematical framework
- Optimizes system operations using forecasts of streamflows and energy prices
- Calculates the quantity and timing of reservoir releases that maximizes energy production
- Uses environmental flows, target storages and hydraulic capacities as constraints



Proof of Concept – Models

Simulation Model ⟷ **Optimization Model**

- Simulation model cannot optimize
- Optimization model cannot contain all of the physics of the system
- Simulation model can put reasonable constraints on range of "acceptable" or "plausible" solutions.

Proof of Concept – The Forecasts

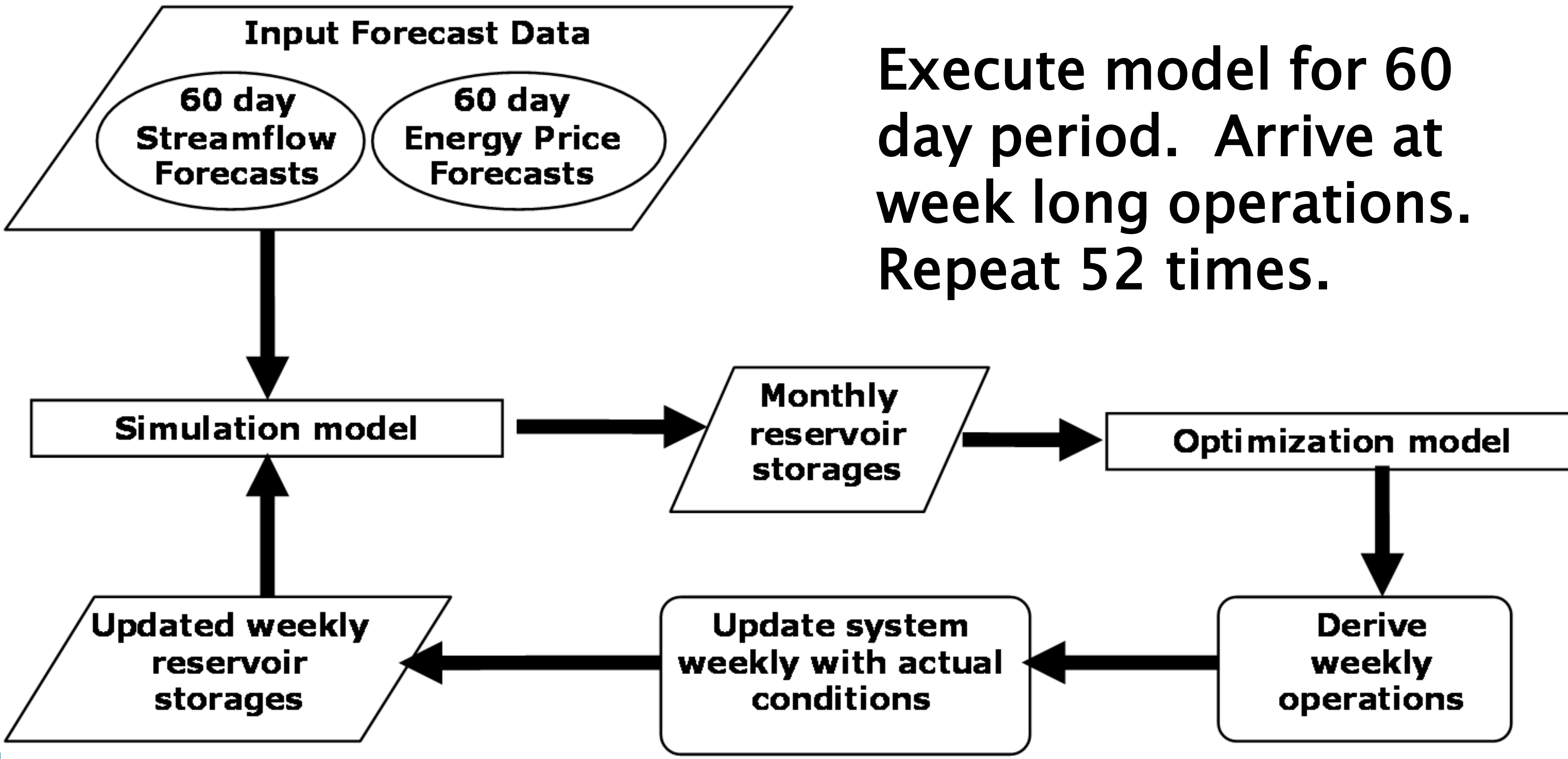
- Streamflow and Energy Price forecasts
  - Retrospective streamflow forecasts were created using a hydrology model (DHSVM) and past meteorological records. An Ensemble Streamflow Prediction (ESP) approach was used and the mean of the ensemble is used as the inflows
  - Retrospective energy price forecasts were created by using current measured forecast error applied to previous spot energy prices

Proof of Concept – The Forecasts

- In current operations, 90 day ESP streamflow forecasts come from the Northwest River Forecasting Center and energy price forecasts are created in-house at SnoPUD

Proof of Concept – Method

Execute model for 60 day period. Arrive at week long operations. Repeat 52 times.



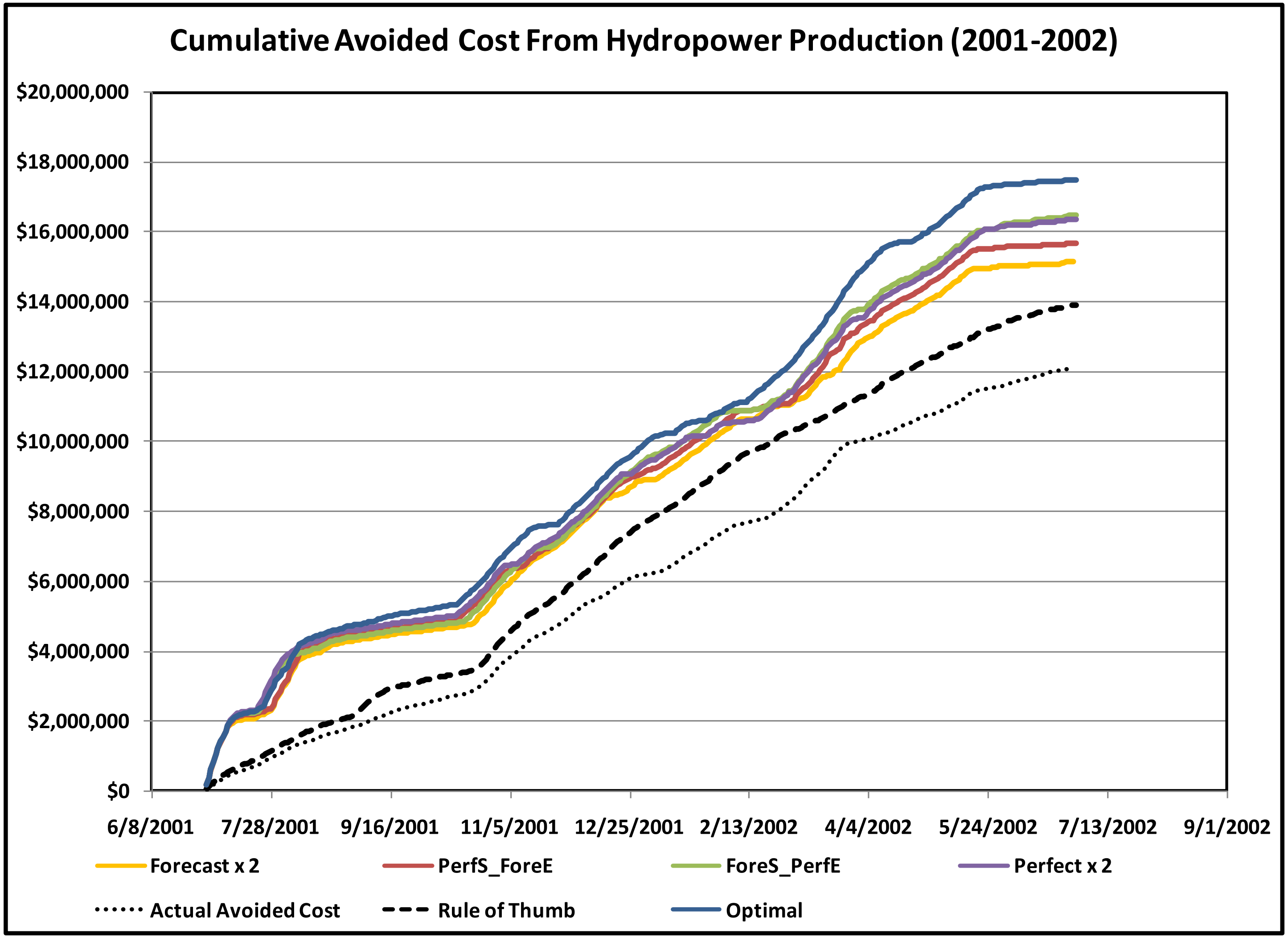
Proof of Concept – Results

- Use Decision Support System to evaluate revenue gains in three different years
- Compare the use of forecast information against 'perfect knowledge'

	Annual Inflow (AF)	Average Energy Price	Standard Deviation In Energy Prices
2001-2002	697,800	$25.93	$13.44
2002-2003	522,489	$31.07	$13.29
2003-2004	554,374	$39.49	$6.70

640 Acres in a square mile – so 640,000 acres is 1000 square miles one foot deep

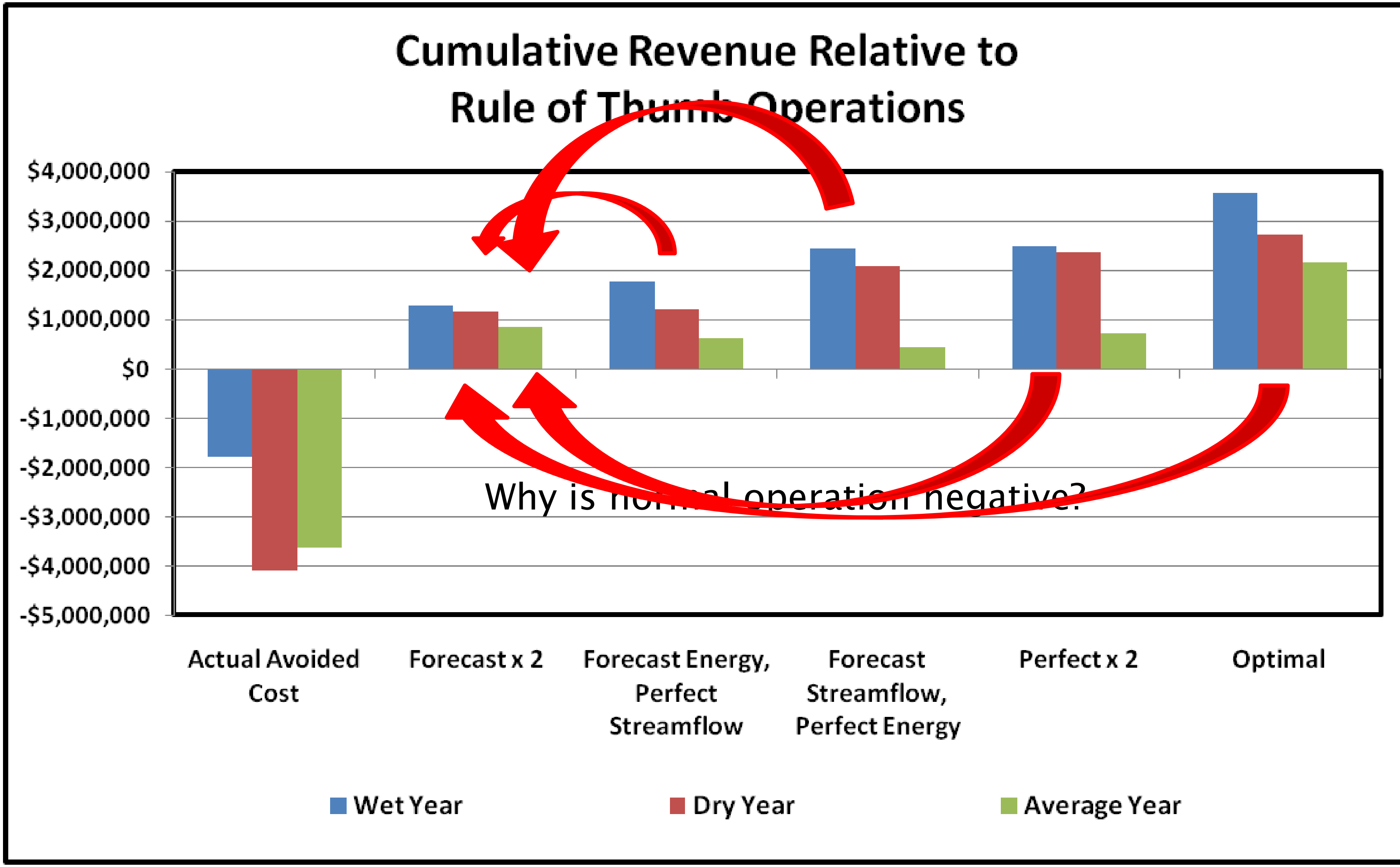
Proof of Concept – Results



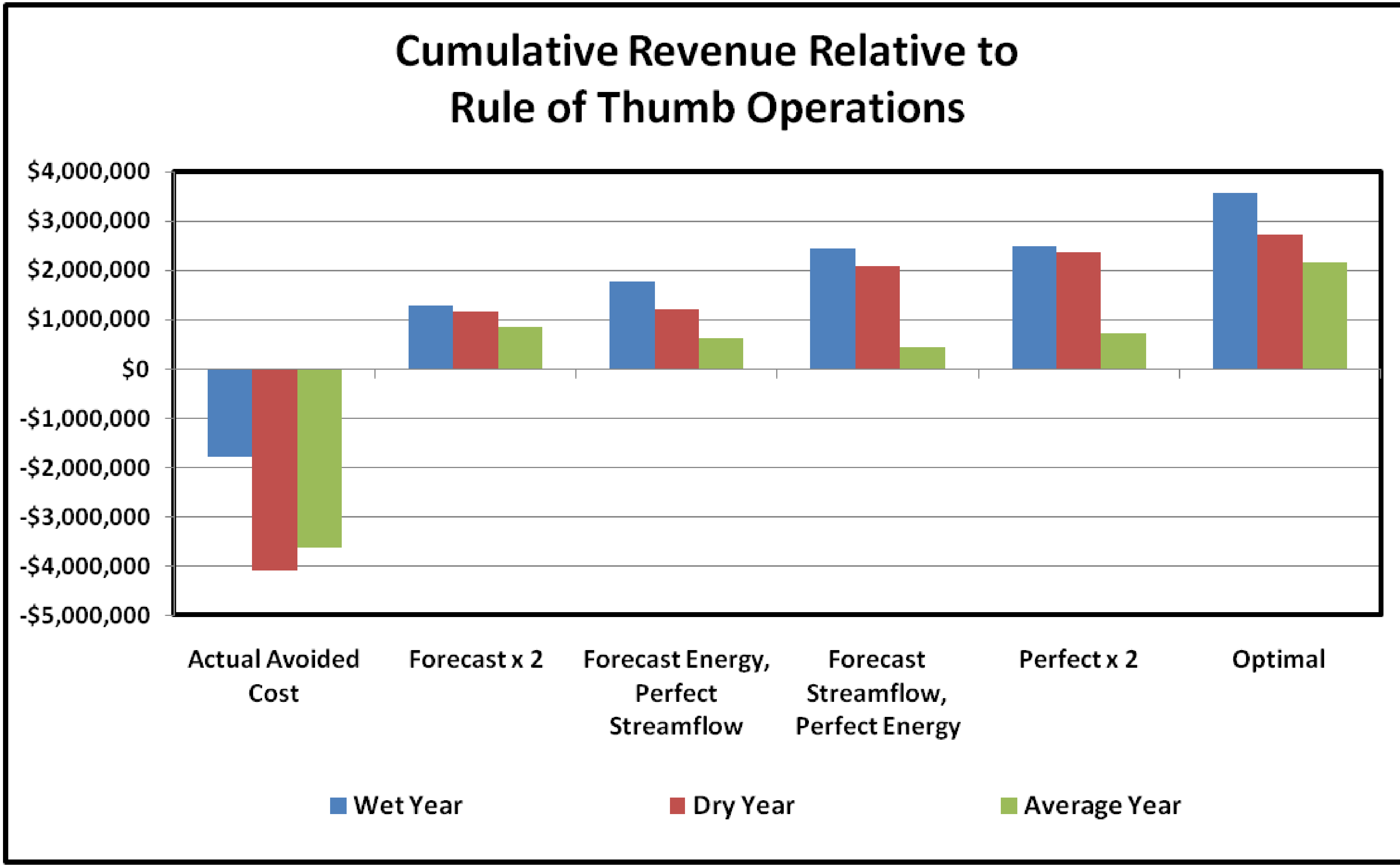
	Model Run	Income	% Change Relative to Rule of Thumb	% Change Relative to Optimal
2001 - 2002 (Hydrologically Wet Year)	Forecast x 2	$15,172,003	**9.2%**	**-13.2%**
	Forecast Energy, Perfect Streamflow	$15,680,303	**12.9%**	**-10.3%**
	Forecast Streamflow, Perfect Energy	$16,346,408	**17.7%**	**-6.5%**
	Perfect x 2	$16,378,303	**17.9%**	**-6.3%**
	Rule of Thumb	**$13,893,699**		**-20.5%**
	Actual Avoided Cost	$12,116,368	**-12.8%**	**-30.7%**
	Optimal	**$17,476,458**	**25.8%**	

	Model Run	Income	% Change Relative to Rule of Thumb	% Change Relative to Optimal
2002 - 2003 (Hydrologically Dry Year)	Forecast x 2	$16,789,950	**7.4%**	**-8.6%**
	Forecast Energy, Perfect Streamflow	$16,857,445	**7.8%**	**-8.2%**
	Forecast Streamflow, Perfect Energy	$17,723,822	**13.4%**	**-3.5%**
	Perfect x 2	$18,004,301	**15.2%**	**-2.0%**
	Rule of Thumb	**$15,634,506**		**-14.9%**
	Actual Avoided Cost	$11,552,340	**-26.1%**	**-37.1%**
	Optimal	**$18,370,633**	**17.5%**	

	Model Run	Income	% Change Relative to Rule of Thumb	% Change Relative to Optimal
2003 - 2004 (Hydrologically Average Year)	Forecast x 2	18,823,203	**4.7%**	**-6.5%**
	Forecast Energy, Perfect Streamflow	18,594,211	**3.5%**	**-7.6%**
	Forecast Streamflow, Perfect Energy	18,409,503	**2.4%**	**-8.5%**
	Perfect x 2	18,706,956	**4.1%**	**-7.1%**
	Rule of Thumb	**17,971,158**		**-10.7%**
	Actual Avoided Cost	14,348,491	**-20.2%**	**-28.7%**
	Optimal	**20,126,479**	**12.0%**	



Cumulative Revenue Relative to
Rule of Thumb Operations
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
-$1,000,000
-$2,000,000
-$3,000,000
-$4,000,000
-$5,000,000
Actual Avoided Cost
Forecast x 2
Forecast Energy, Perfect Streamflow
Forecast Streamflow, Perfect Energy
Perfect x 2
Optimal
Why is normal operation negative?
Wet Year
Dry Year
Average Year


Cumulative Revenue Relative to
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$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
-$1,000,000
-$2,000,000
-$3,000,000
-$4,000,000
-$5,000,000
Actual Avoided Cost
Forecast x 2
Forecast Energy, Perfect Streamflow
Forecast Streamflow, Perfect Energy
Perfect x 2
Optimal
Wet Year
Dry Year
Average Year

Current Operational Use

- Relies on in-house energy price forecasts and NWS – NWRFC streamflow products (ESP)
- Model runs are over 90 day period for 45 ensemble members
- Forecast Updated Weekly
  - Conference call every Tuesday to develop weekly operations plans
  - Get all parties agreeing on operational direction for week

Current Operational Use

- Weekly calls have been performed for past 18 months.
- Conversations reflect challenges that appear based on time of year
  - Flood events
  - Drought event
  - Instream fish flow
  - System Maintenance
  - Energy Forecasts
- Some weeks are simple, some not
- DSS “informs” decision making, does not dominate

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MEMORANDUM

To: Keith Binkley, Barry Chrisman, Kien Hoang, Adam Lewis, Bruce Meaker, Sam Nietfeld, and Kelley Wallace
From: Richard Palmer, Professor and Head, Dept. of Civil and Environ. Engineering
Austin Polebitski, Ph.D. Candidate
Date: November 3, 2009
Re: November 2, 2009 SnoPUD Forecast

Streamflow

During the last week (since October 27th) there were significant precipitation events and flows into Spada Reservoir has increased and decreased following the rain patterns (Figure 1). Flows began last week at 1630 cfs and are now 85 cfs on the South Fork of the Sultan River near Sultan (USGS station 12137290). (This is our reference site for inflows into Spada, actual inflows are approximately 4.5-7 times the South Fork Sultan value.) Flows increased from October 29th to October 31st, with a maximum of about 1000 cfs. The mean value and median value for this date are 152 and 96 cfs, respectively.

The 10-day forecast (on www.weather.com for Sultan) predicts significant probability of rains for the remainder of the week. Figure 2 presents the National Weather Service Forecast for a location in the Sultan basin that is 8 miles north of Index, Washington (elevation of 2549 feet, 47.94 N, 121.59W). The forecast calls for almost no rain or snow during the week, which conflicts with our other forecast (Figure 3). Streamflows continue to decline currently.

Energy Value Forecast

The "weighted forecast energy value" is very similar in shape to the forecast last week but is significantly lower, most often between $5 and $7 per mega-watt-hour less than last week's forecast. As noted previously, each month shows a discontinuous jump that is a feature of the manner in which the forecast is being made. For the current forecast, the discontinuity is especially large near December 1st but hardly noticeable in early January.

Everett Water Demands

Everett's water demands averaged 111 cfs (ranging from 107 cfs to 115 cfs). This week's average is 3 cfs less than last week's average. Unless there are large and unexpected industrial demands, this is the range that would be expected for much of the winter.

Spada Storage and Power Tunnel Releases

As of November 2nd, 8:00 am Spada Lake was 1535.46. This is up more than 9 feet from last week, and is up 18 feet from two weeks ago. Lake Chaplain elevation is approximately to be 650.27 feet, up slightly from last week. The power tunnel release on Monday morning was estimated to be 1260, up more than 800 cfs from last week.

Spada Storage and Revenue Forecast

This week we did not wait for the River Forecast Center predictions but took a very conservative view that flows would continue to decline during the week (Figure 6). The optimization model's median operating policy (the one recommended by more than half of the runs) suggests that this week releases should be decreased from their current high value to an average of 700 cfs, then the average for the next 3 weeks should be 600, 450, and 500 cfs before increasing the flows to 1100 cfs five weeks from now. The suggested releases varying during the week, attempting to release for those days for which the energy value is the greatest. The forecasted average storage (Figure 7) at first decreases, then shows a steady rise during the next four weeks. The storage is forecasted to increase to 1441 feet, before declining. This may well be too great an increase, but allows the model to capture the higher valued releases in December. The storages, in general, remain nicely between the rule curves, although there are a number of traces that reach 1450 feet.

The suggested operational pattern will result in $7.8 million of avoided energy costs over the next 90 days, on average (Figure 8). This is about $1.20 million decrease from last week's forecast due to decreasing prices in the near term. The range of energy values is a minimum of $4.6 million and a maximum of $10.5 million.

Fish Flow Forecast

For this scenario, median fish flows (Flows at Reach 5) basically reflect the operating policy of the power tunnel releases. Flows will be near the minimum releases.

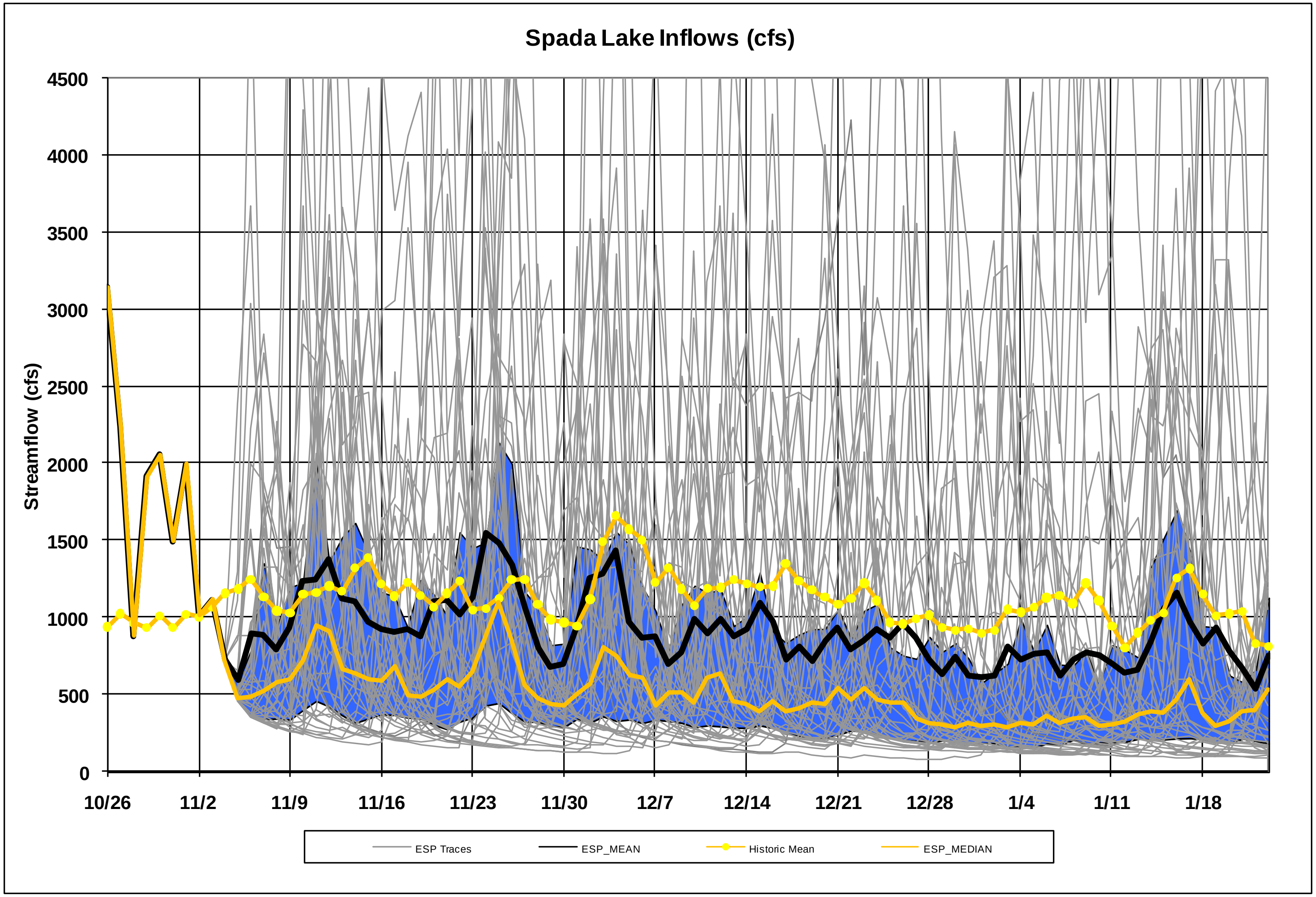
Recommendations for Operations

The model is suggesting a shift from last week's prediction. Rather than continue to release at high levels, the model's recommendation this week is to cut back releases this week and the following 3 weeks (700, 600, 450, and 500 cfs) before increasing releases in December. The model may well be "chasing prices" a little too aggressively, as if this policy is followed, storage are predicted to steadily increase during the next four week to 1441 feet. The system forecasts higher storage levels and plenty of water in the short-term. Concerns about low storage are likely over.

Power Releases

Date	Elevation, Feet	Power Tunnel Releases cfs	Pelton Releases cfs	Pelton Gen. MW	Francis Releases cfs	Francis Gen. MW	Total MW
11/2/2009	1434.60	1260	1110	85.4	150	6.3	91.9
11/3/2009	1433.83	1008	858	66.0	150	6.3	72.5
11/4/2009	1433.23	806	656	50.5	150	6.3	57.0
11/5/2009	1432.79	645	495	38.1	150	6.3	44.6
11/6/2009	1432.47	516	366	28.2	150	6.3	34.7
11/7/2009	1432.24	413	263	20.2	150	6.3	26.7
11/8/2009	1432.28	330	180	13.9	150	6.3	20.4
11/9/2009	1432.43	264	114	8.8	150	6.3	15.3
11/10/2009	1432.43	716	566	43.5	150	6.3	50.1
11/11/2009	1432.57	585	435	33.5	150	6.3	40.0

Current Operational Use



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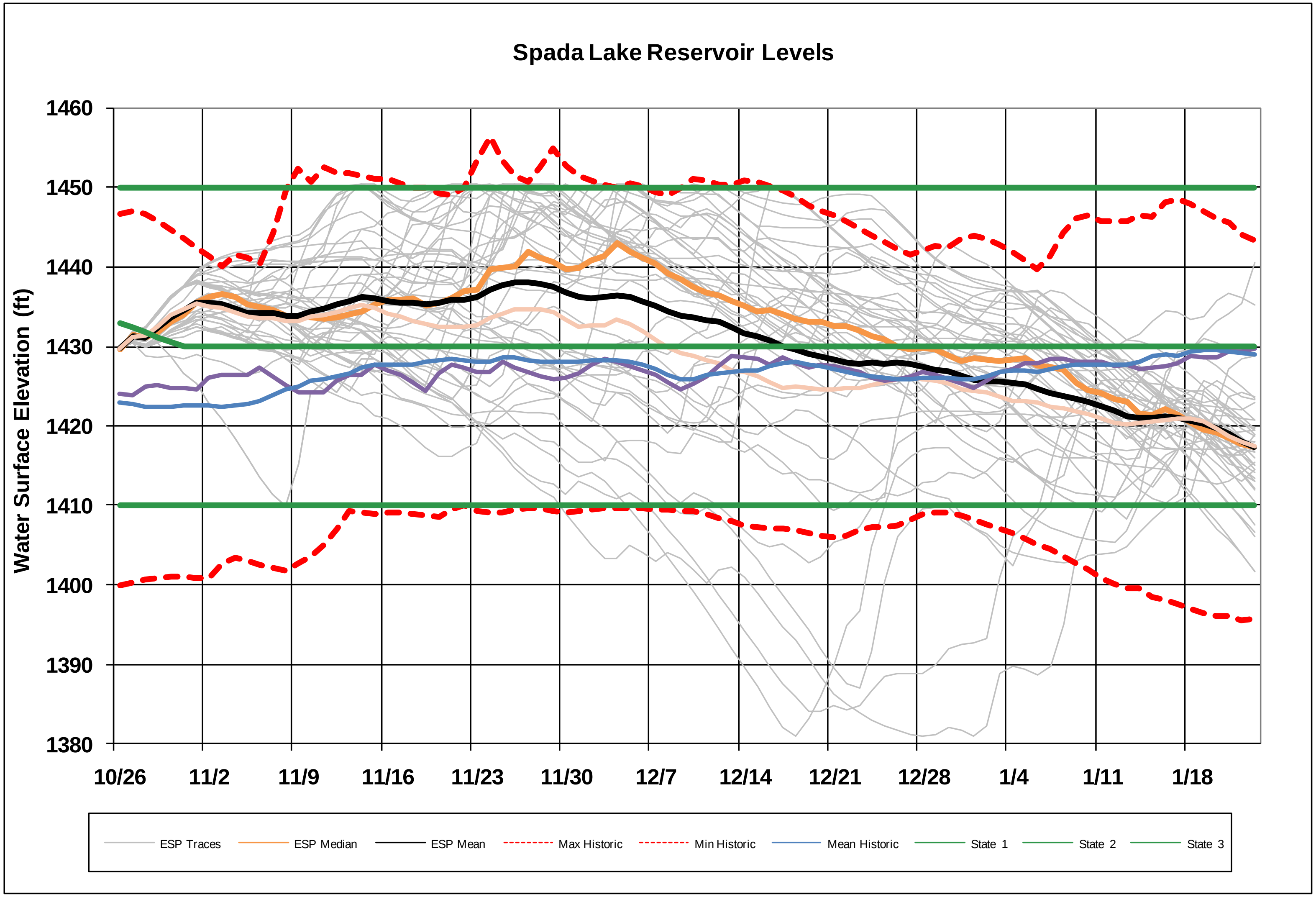

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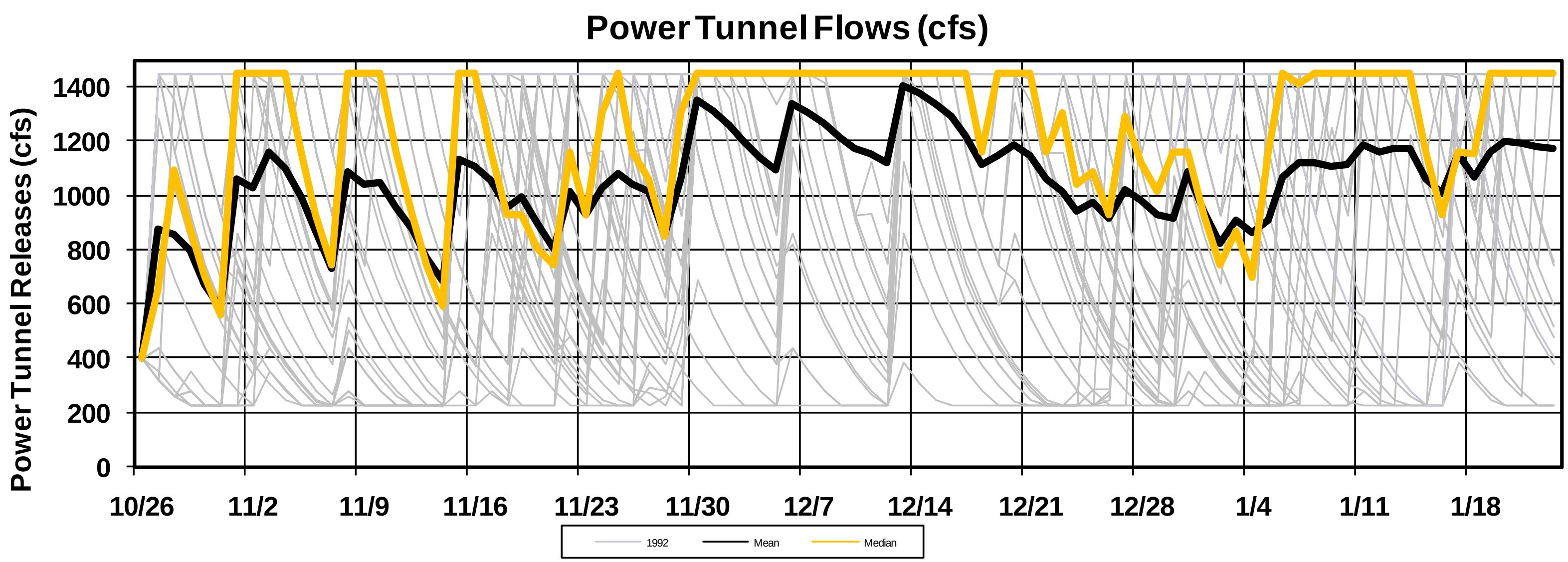

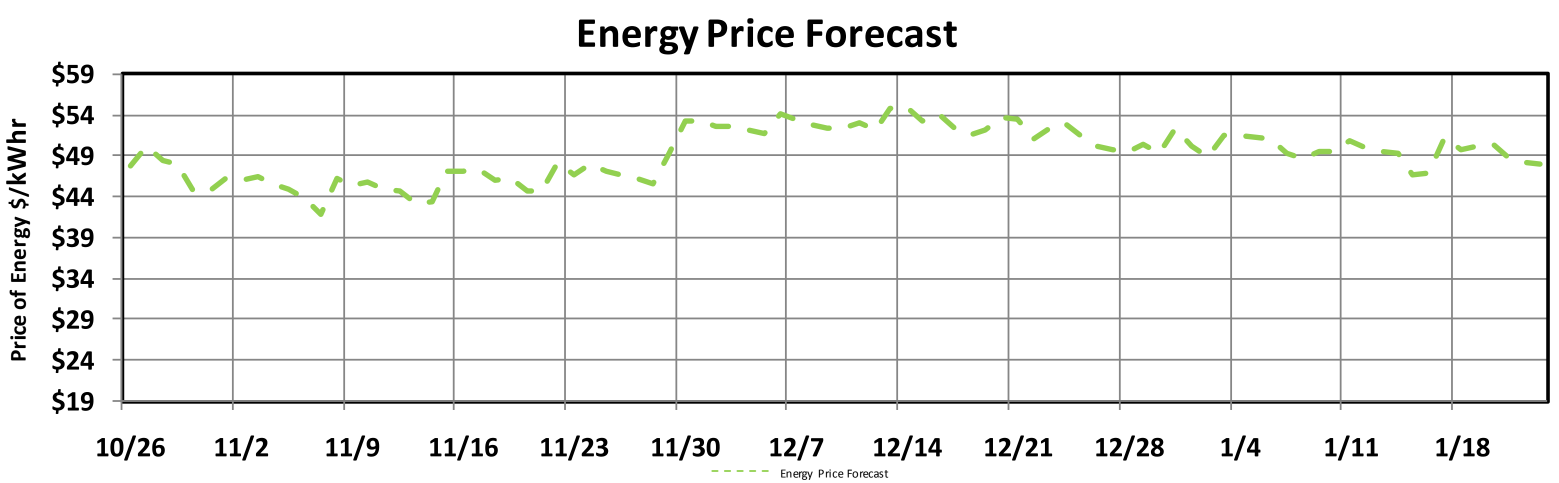

Future Model Use

- Transferring responsibility of weekly model runs (next week)
- Anticipate “challenges”
- Will continue to update model and add new functionality

Closing Comments

- Demonstrated proof of concept
- Incorporating forecasts will improve operations
- Users learning to appreciate “uncertainty”
- Energy price forecast is more valuable than streamflow forecast
- Established opportunity for expanded communication between “groups”
- Process illustrated value neutral agent

Thank You!