Application of Enemble Streamflow Forecasts for Decisionmaking

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A 2-Year Research-to-Operations Project

A Proposal to
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Climate and Societal Interaction - Sector Application Research Program
Federal Funding Opportunity Number: NOAA-OAR-CPO-2012-2003041

Integrating Climate Forecasts and Reforecasts into Operations Management

	Investigators	Expertise
Academia		
Principal Investigator (Lead):	Dr. Austin Polebitski	Reservoir system operations and management
Investigators (Co-):	Dr. Casey Brown	Reservoir system operations and management
	Dr. Richard Palmer	Reservoir system operations and management
	University of Massachusetts	Reservoir system operations and management
Agency		
Principal Investigator (Co-):	Dr. Andrew Wood	Hydro-climate prediction
Investigator (Co-):	Kevin Werner	Decision support
	NOAA/NWS CBRFC	

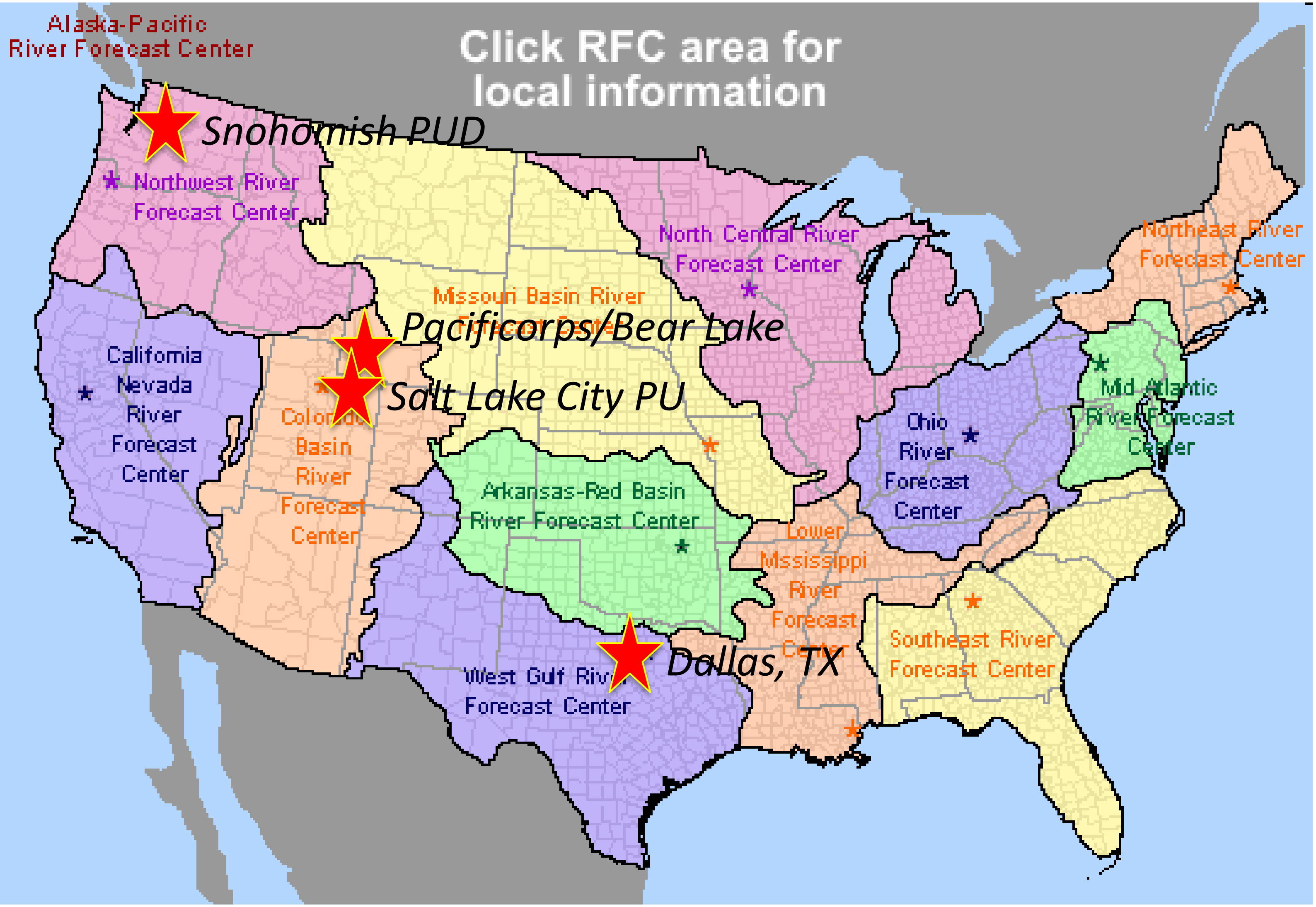
And 4 partnering water utilities: Snohomish PUD, Pacificorps/Bear Lake, Salt Lake City Public Utilities, and the Dallas TX Municipal Water Department

Project Goals

Demonstrate the potential usefulness of weather to climate forecasts and create an appropriate decision framework for their use

- Co-generate knowledge concerning system operations between researchers and water managers
- Generate ESP streamflow using reforecasts at partner locations (4 case study systems)
- Evaluate skill of GFS and CFSv2 and corresponding streamflow forecasts in the context of decision making
- !! Operational implementations of HEPS !!
- Disseminate data, case studies, and recommendations to the broader water community

Utilities / Case Studies Map



Partner	Simulation Model	Optimization Model	ESP/HEFS Streamflow	Case Study Report
Dallas	Have combined Dallas – Tarrant model, working on separating Dallas section and operation rules	Plan to complete by March or April	Summer 2013?	Fall 2013
PacifiCorp	Model Skeleton completed, working on interpreting operation rules	Plan to complete by January or February	Winter 2013?	Spring 2013
Salt Lake City	Model Skeleton completed, working on interpreting operation rules	Plan to complete by January or February	Winter 2013?	Fall 2013
SnoPUD	Model Completed	Model Completed	Generated by Fall 2012	Spring 2013

Path From Here to There

- Step 1 -- sit down and share information between all the partners

Reservoir	Reservoir Use (ie. Hydro, Water Supply, etc.)	Reservoir Capacity (acre-ft) and Active Usable Storage	Basin Area (mi^2) and Description	Major Rivers	Average Flow, Historical Lows, and Drought/Flood Years of Note

GET DETAILS ON THE SYSTEM (NEEDED FOR MODELING)

Topic	
Critical operating periods	
What dictates these critical periods?	
What factors govern decision making?	
What information is used in decision making?	
Are short-term (< 10 days) forecasts used in decision making?	
What metrics are used to evaluate short-term decisions during critical periods?	
Positive/Negative outcomes from decisions	

HOW / WHY IS THE SYSTEM RUN?

Topic	
Are long-term forecasts used (> 10 days)?	
What metrics are used to evaluate long-term decisions during critical periods?	
Positive/Negative outcomes from decisions	
What decisions are you most interested in evaluating?	
Are there existing rules that could be updated? If so, how?	

HOW DO FORECASTS AFFECT DECISIONS?

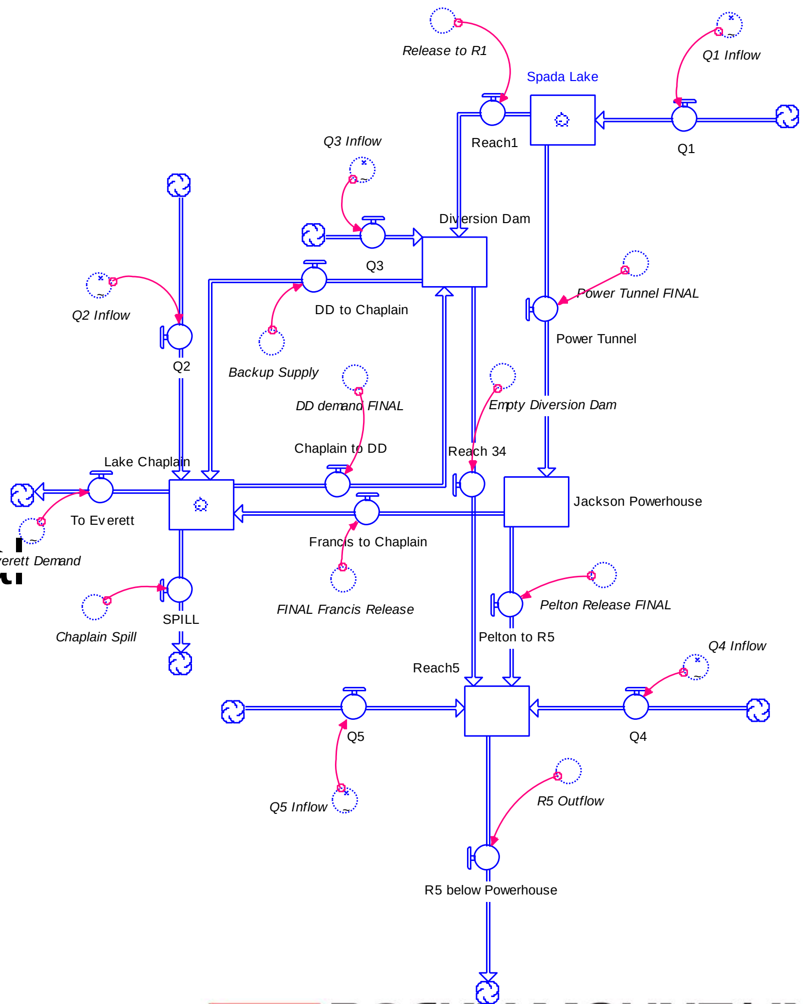
HOW DO SYSTEM OPERATORS MEASURE SUCCESS OR FAILURE?

Partner	Hydropower	Water Supply	Environmental Flows
Dallas	None	• Safe yield • Frequency of instituting voluntary of mandatory restrictions • Total revenues generated • Minimum storages in reservoirs	[illegible]
PacifiCorp Bear Lake	• Mega-watts hours produced per year • Value of total energy generat[illegible]	• Volume of w[illegible] irrigati[illegible] • A[illegible] [illegible] water	None
Salt Lake Ci[illegible]	[illegible]	• [illegible]ate storage level at [illegible]e beginning of water supply season • Balancing water sources and supplies	None
SnoPUD	• Mega-watts hours produced per year, • Total avoided costs from other purchases • Annual energy valu[illegible]	• Water provided to Everett • Need to implement curtailments	• Number of times fish flows are unmet • Minimizing peak releases that harm fish • Provide "flushing flows" to move fish

Step 2: Decision Support Tools to Capture Rules

Example: Simulation Models

- Simulates system operations at the Jackson Hydropower Plant
- Shows how water is routed through the system
- Incorporates variation in streamflow and environmental flow requirements
- Develops targets that drive/constrain Linear Program



ROCKY MOUNTAIN POWER
A DIVISION OF PACIFICORP

Decision Support Tools to Capture Rules

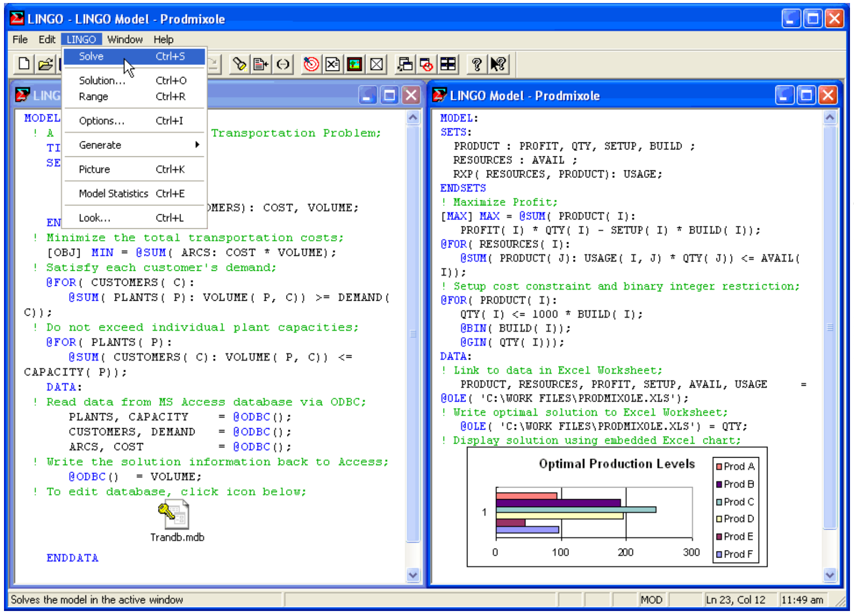
Example: Linear Optimization Model

- Represents the hydrologic and hydraulic elements of the system in a linear mathematical framework

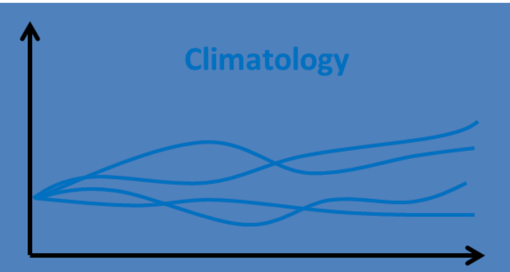
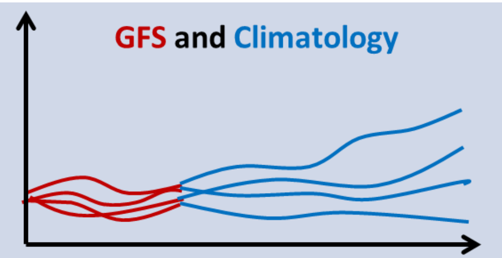
- Optimizes system operations using forecasts of streamflows and predicted energy prices

- Calculates the quantity and timing of reservoir releases that maximize energy production

- Uses environmental flows, target storages, and hydraulic capabilities as constraints

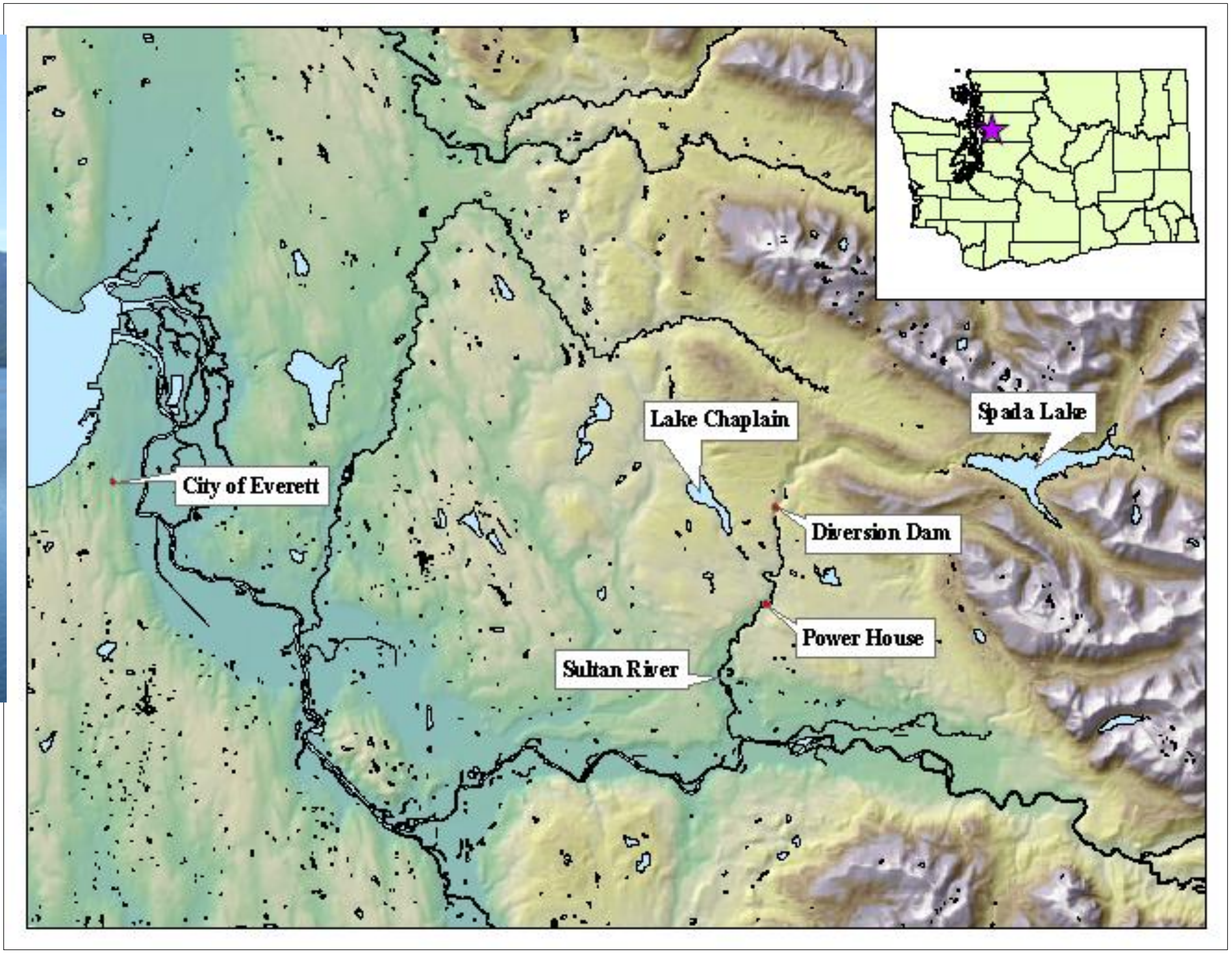


Step 3: Hindcasting / Forecasting

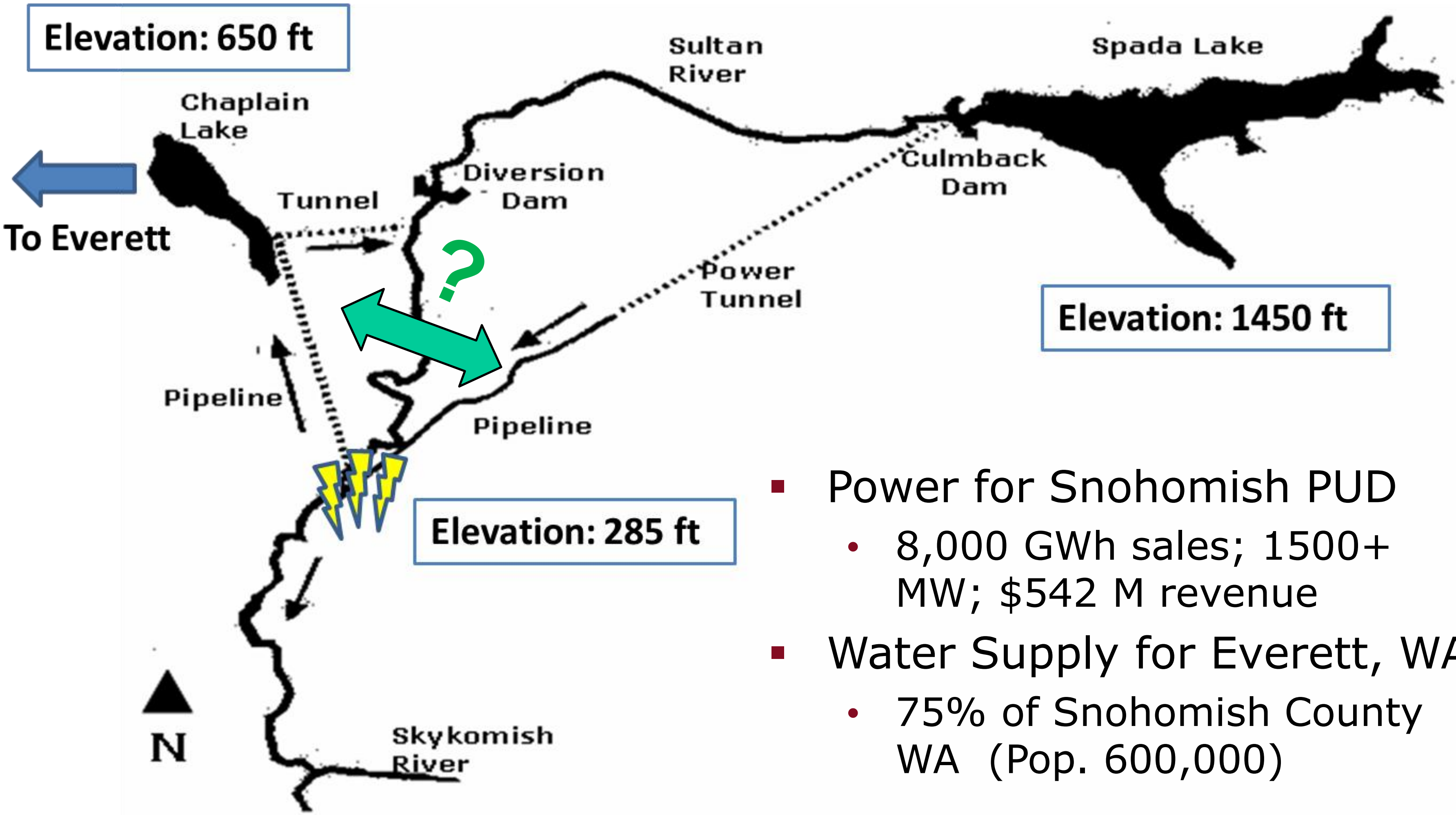
Type of Forecast	Forcings	Streamflow
ESP/Climatology	**Historic**	
HEFS short range	GFS and Climatology	
HEFS long range	GFS and CFSv2	

- ESP - Ensemble Streamflow Prediction
- HEFS – Hydrologic Ensemble Forecast System
- CFS – Climate Forecast System
- GFS – Global Forecast System

Example – Jackson Hydropower System



Overview – Jackson Hydropower System



- Power for Snohomish PUD
  - 8,000 GWh sales; 1500+ MW; $542 M revenue
- Water Supply for Everett, WA
  - 75% of Snohomish County WA (Pop. 600,000)

What benefits come from using the DSS?

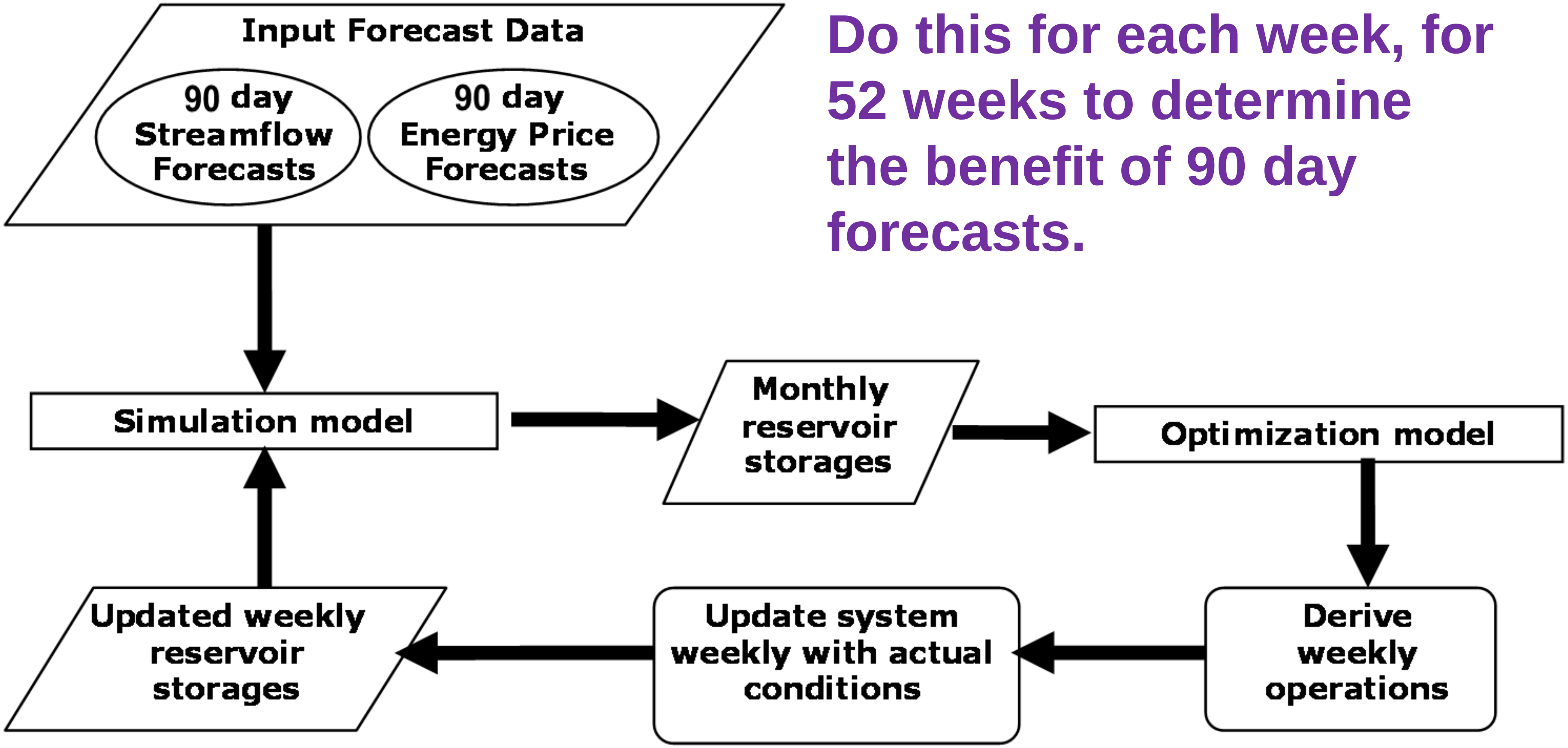
Forecasts can improve operational performance through:

- Meeting all system constraints
- Reduce Costs ($$$) for customer base
- increasing hydropower revenue

How do we do this?

- Use retrospective hydrologic and energy price forecasts to train the Decision Support System

Method



Do this for each week, for 52 weeks to determine the benefit of 90 day forecasts.

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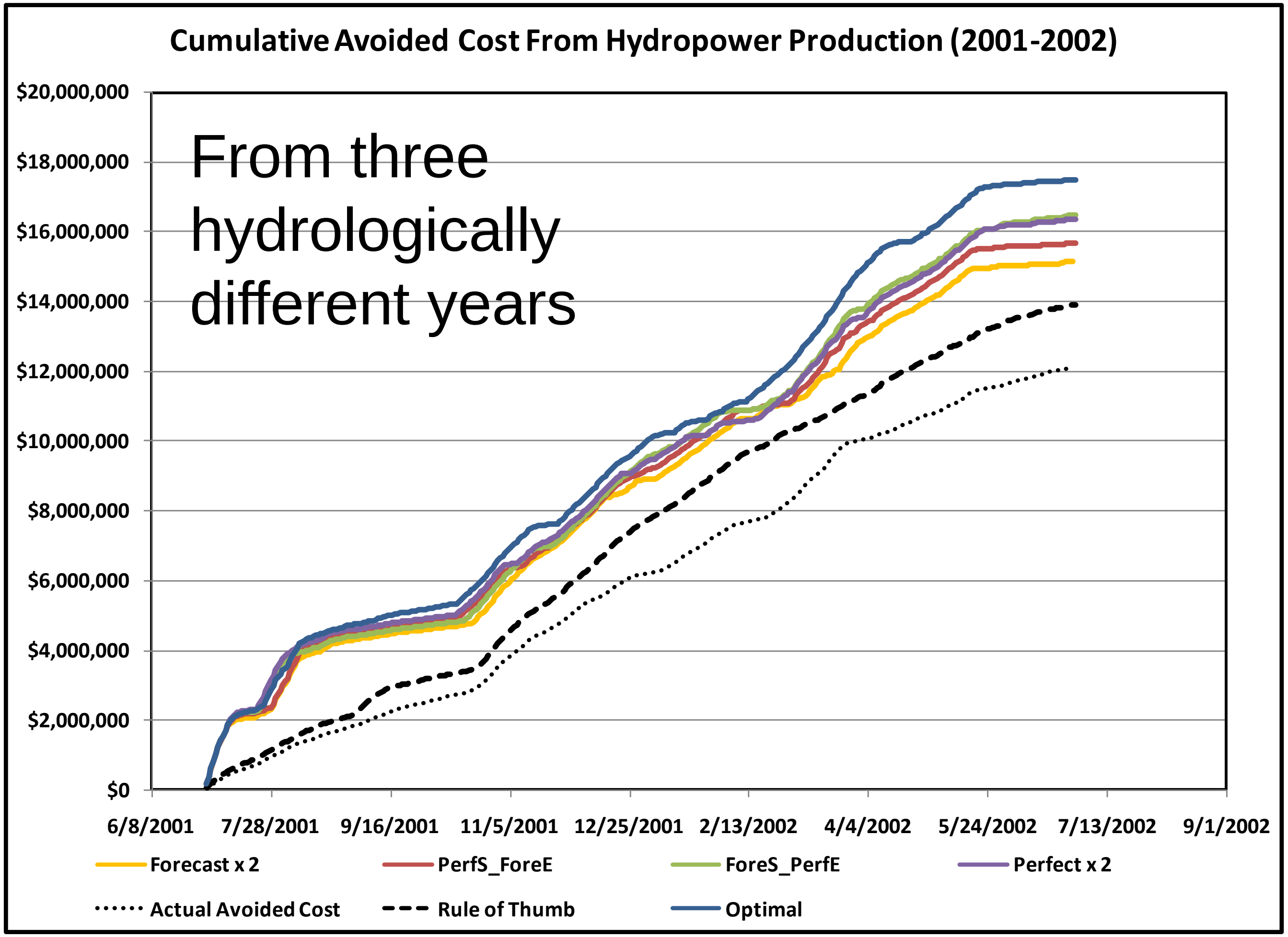
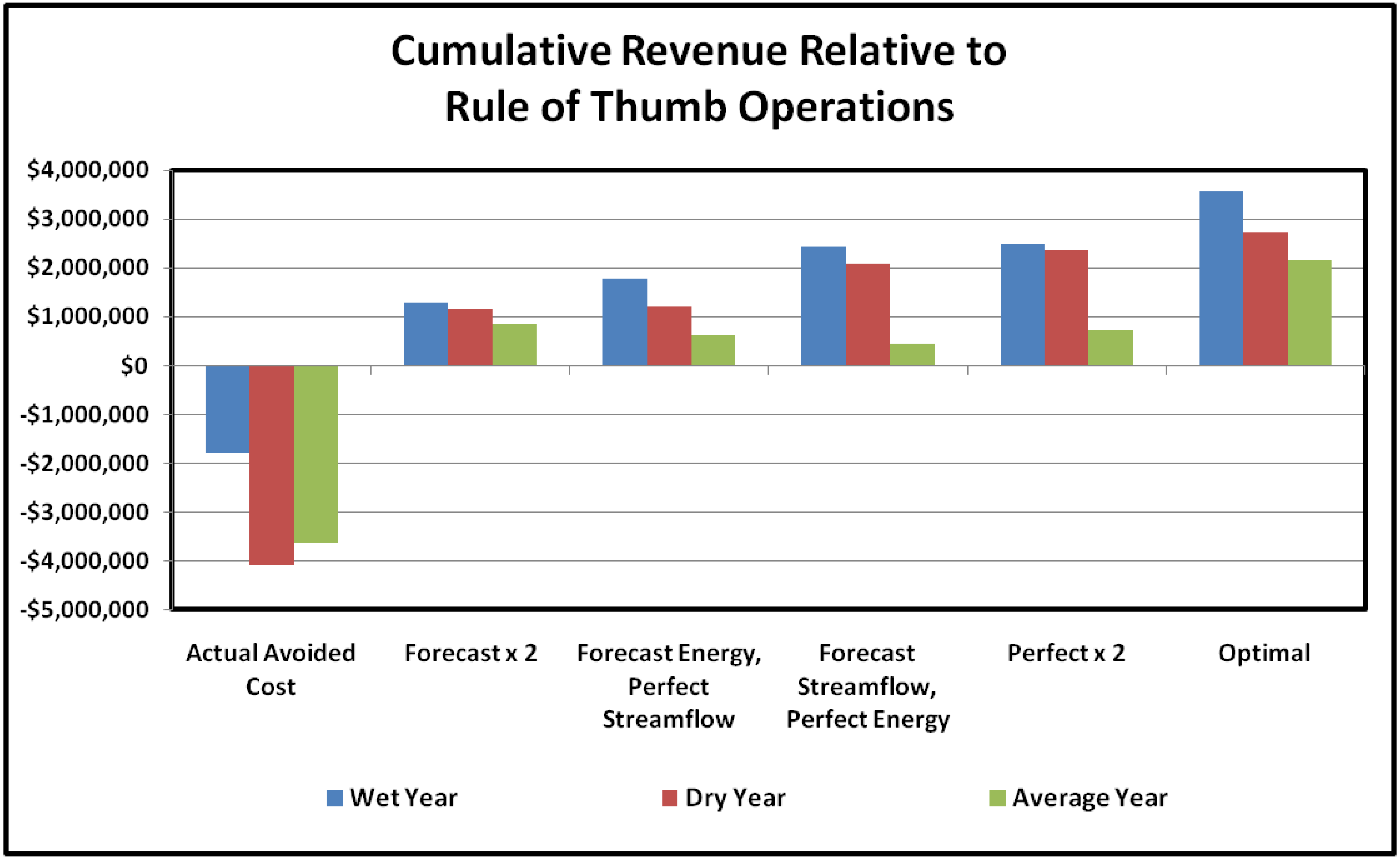
Preliminary Results



Preliminary Results



Current Operational Use

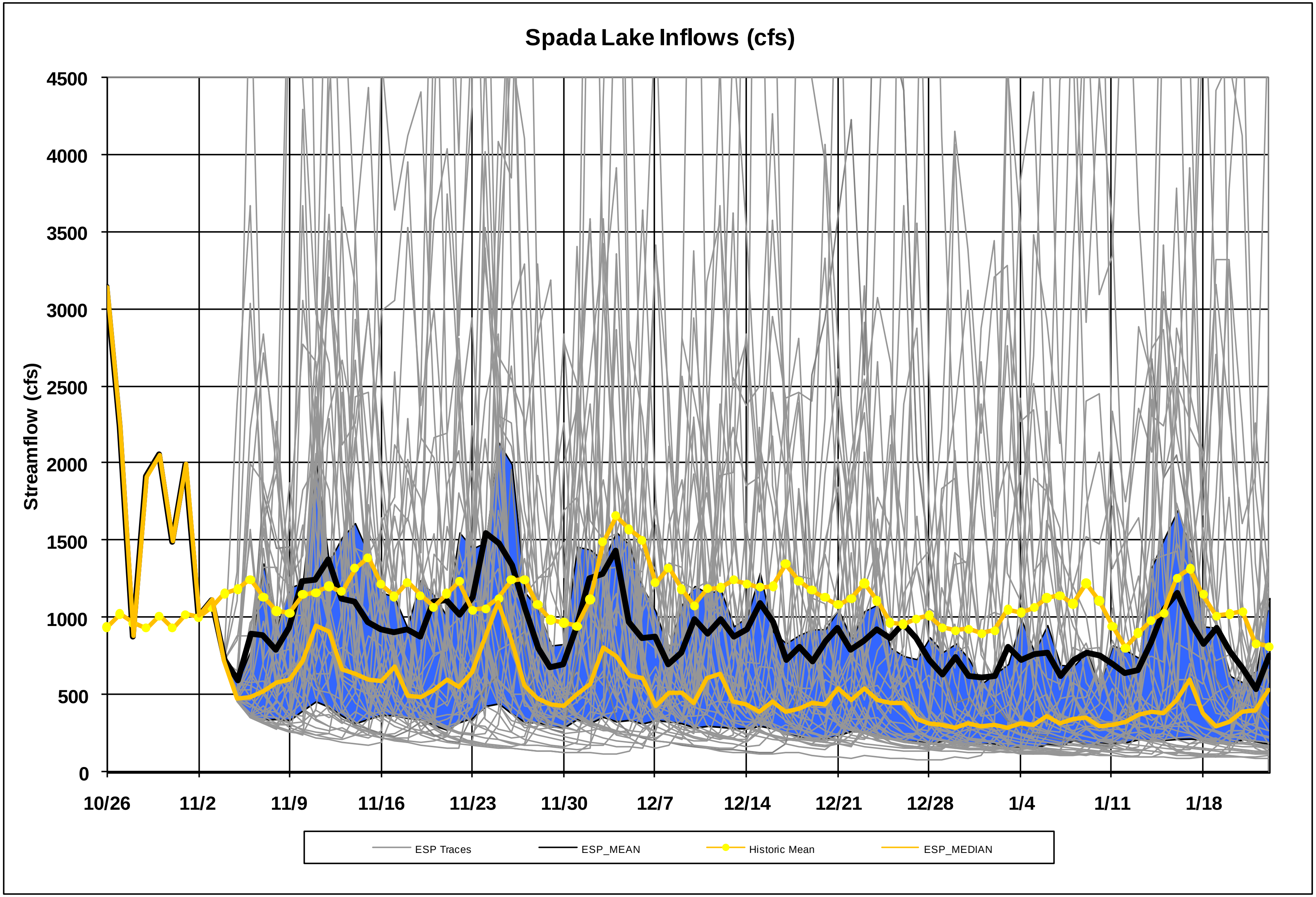
Relies on in-house energy price forecasts and NWS – NWRFC streamflow products (ESP)

Model runs are over 90 day period for 45 ensemble members

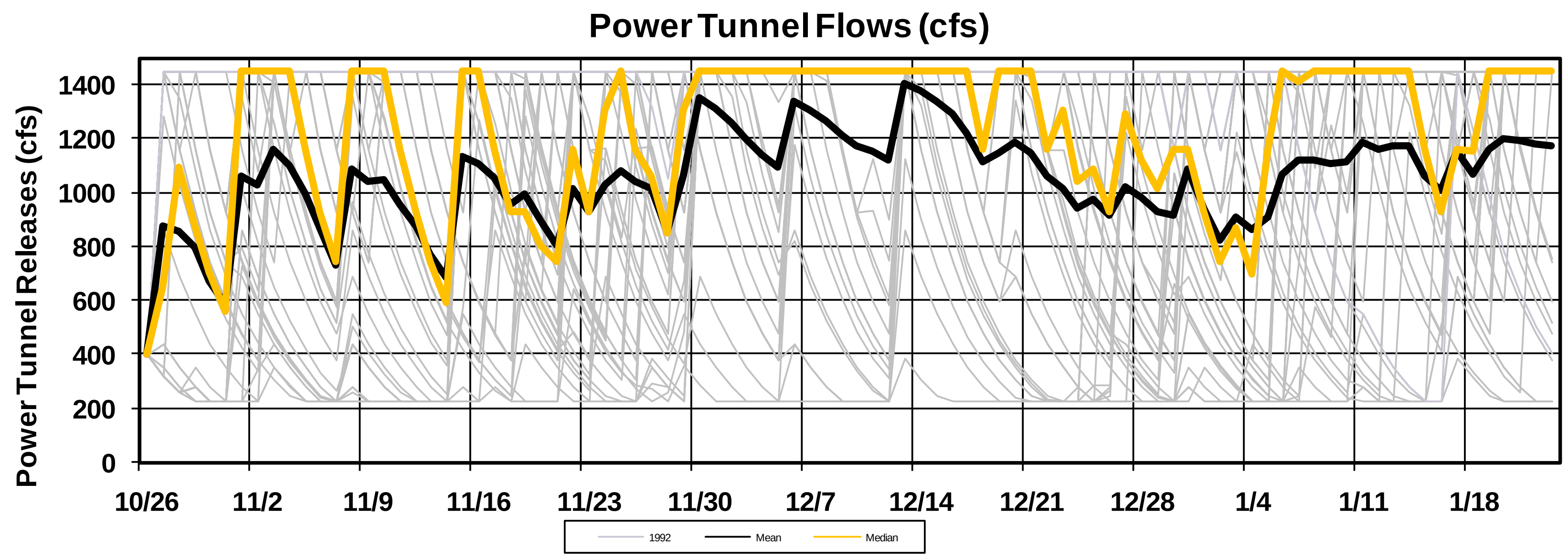
Forecast Updated weekly

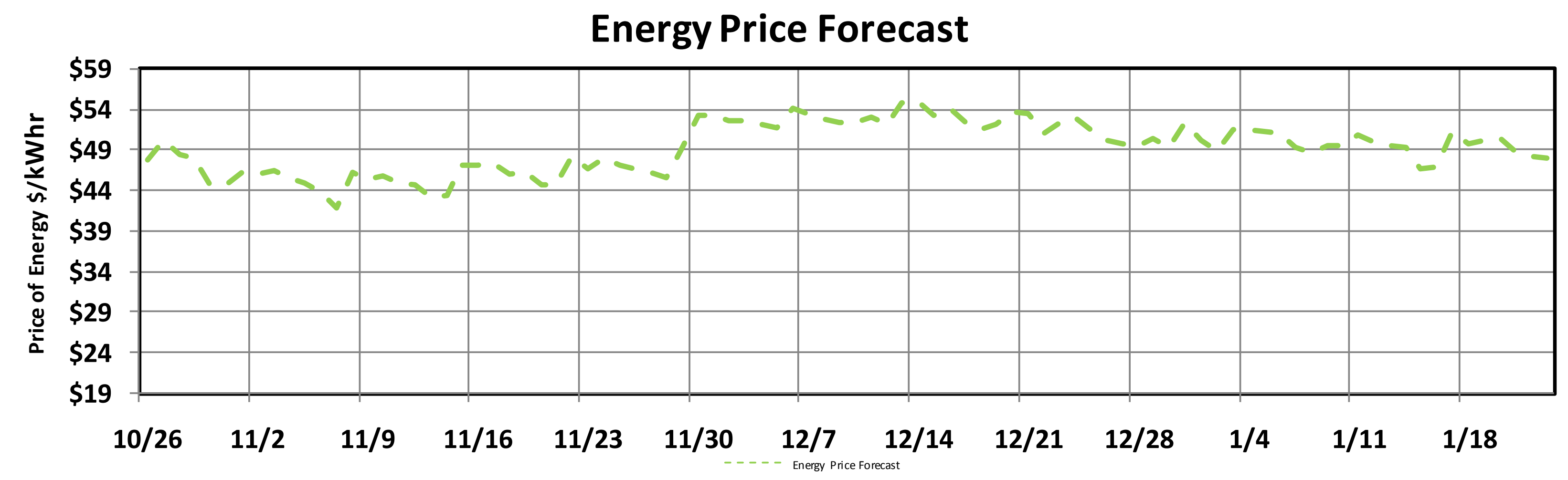
- Conference call every Tuesday to develop weekly operations plans

Current Operational Use

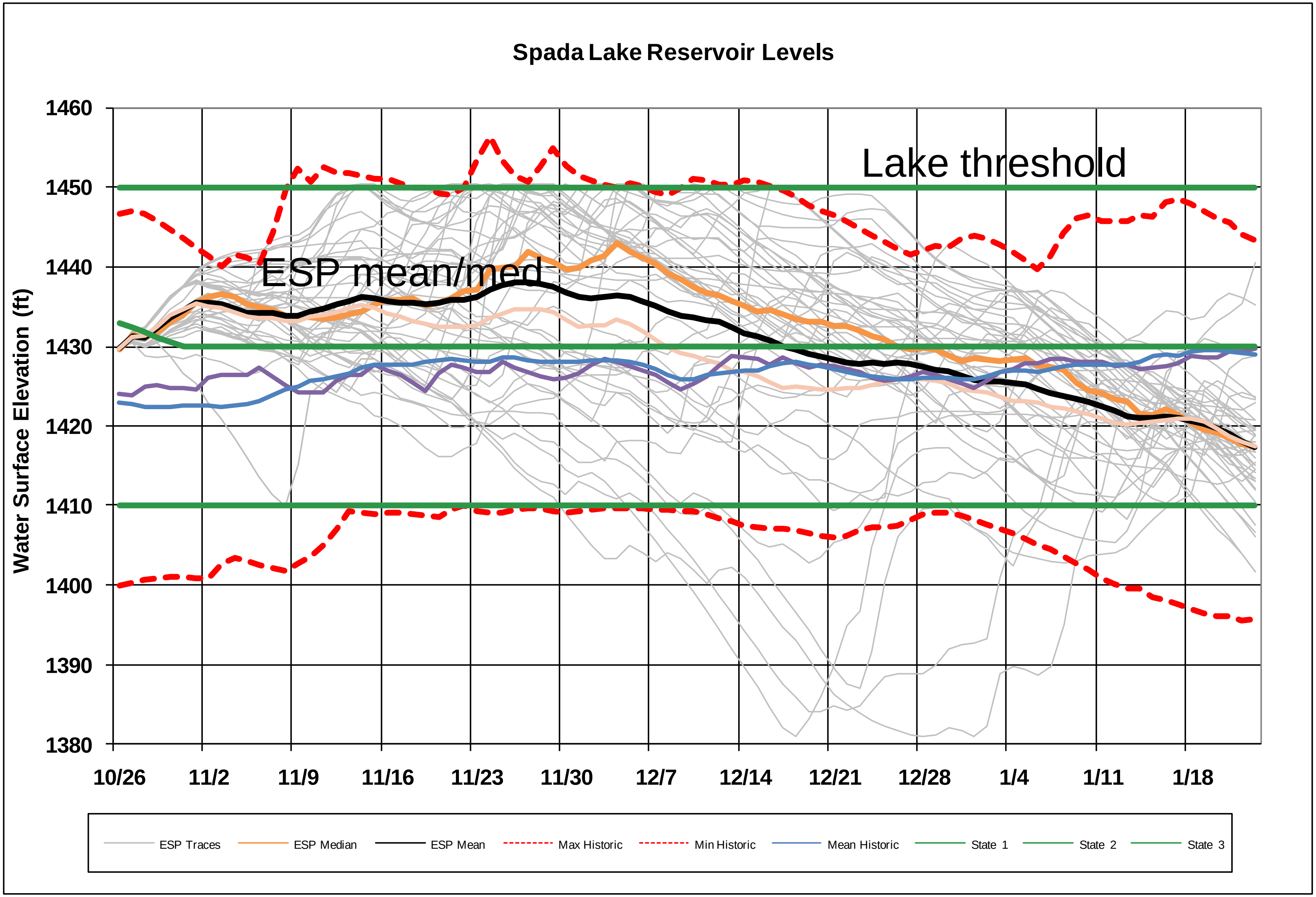


Current Operational Use





Current Operational Use



Take-away Points

- The value of ensemble prediction depends on the use
  - System operation goals, system state, system constraints, hydroclimatology, predictability
- Knowledge of HEPS will be greatly expanded through real-world case studies and operational implementation
- Collaborations need to involve: hydroclimate forecast experts, system modelers, decision theorists, and water managers / decisionmakers
- Probabilistic decisionmaking is needed to best extract value from probabilistic prediction


Questions?

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%**	
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%**	
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%**	

Seasonal Decisions

– Seasonal Irrigation (April 1st through 10th) – set irrigation allocation – forecast seasonal maximum elevation of Bear Lake before April 10th each year.

– Seasonal Flood Control (August 1 through March 1, monthly evaluations and changes) – set the flood control target elevation for the following April 1st and release water as necessary without exceeding downstream channel capacity and without causing ice-jam damage in the coldest parts of the winter season.

Short-Term Flood Control Decisions

- Bear Lake – after April 1st, determine fraction of inflow to store at Bear Lake, balancing the surcharge storage above 5922' (to allowed maximum of 5923.65') that results in nuisance calls from lakeshore homeowners with the ability to maintain downstream flows within channel capacity (considering downstream reach gains as well).

- Reservoirs downstream of Bear Lake, especially Cutler Reservoir in Cache Valley with many uncontrolled inflows. In addition to typical snowmelt runoff, February rain-on-snow floods have produced high flows in the past. Pure rainfall events have recently produced high flows.

Short-Term Irrigation Decisions

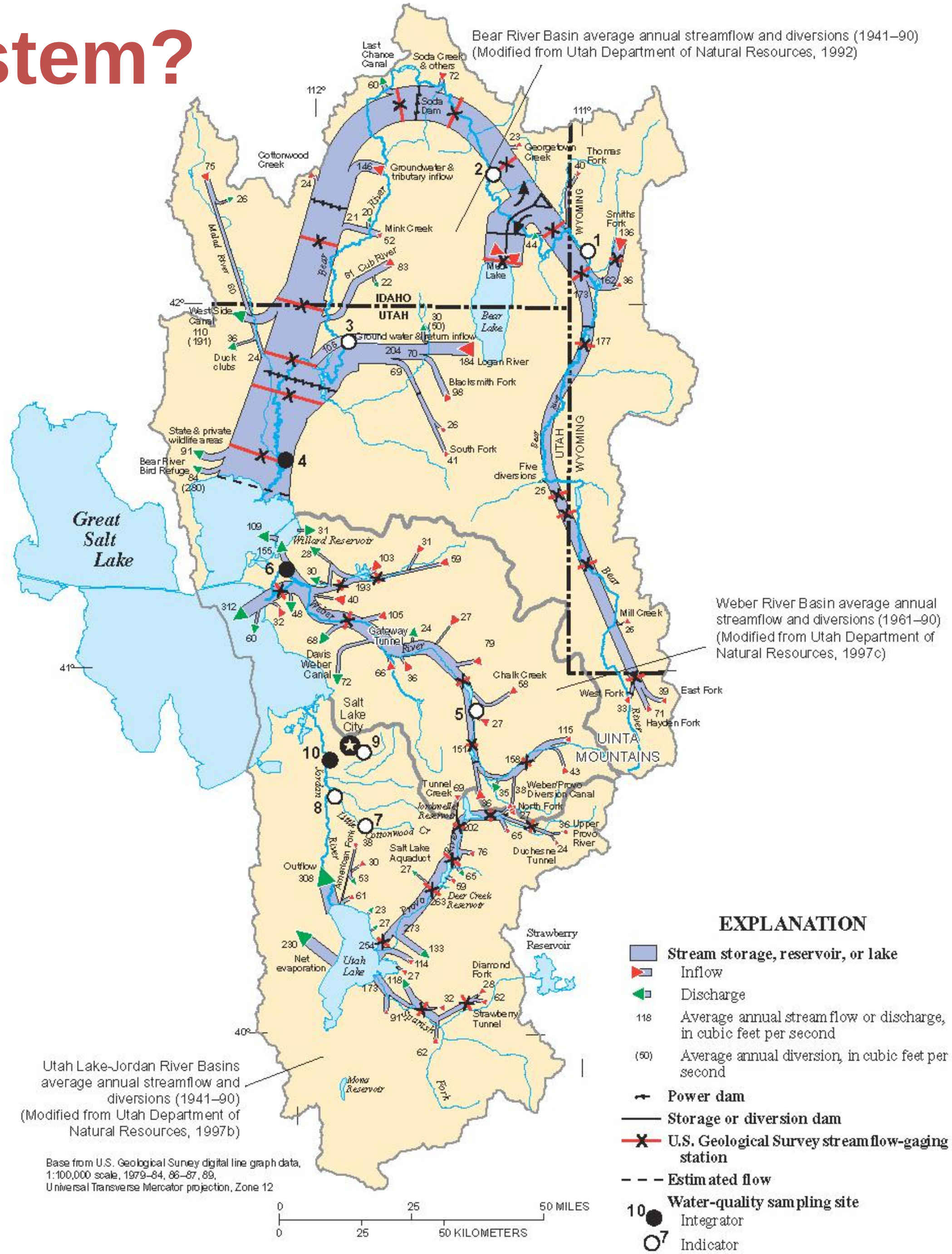
- April 15 through June 15 – transition between natural flow and storage releases to meet irrigation demand. Moving target as ungaged tributary inflow decreases and tributary irrigation use increases while trying to determine when and how much to release to meet downstream demand with a 4-day water travel time. Week-ahead forecasts, with corrections for historical irrigation use

- April 15 through October 1 – corrections for summer rainfall events to avoid passing Bear Lake storage water past the last irrigation diversion at the bottom of the system (4-day water travel time).

What drives the system?

Great Salt Lake Watershed (Non-desert portion)

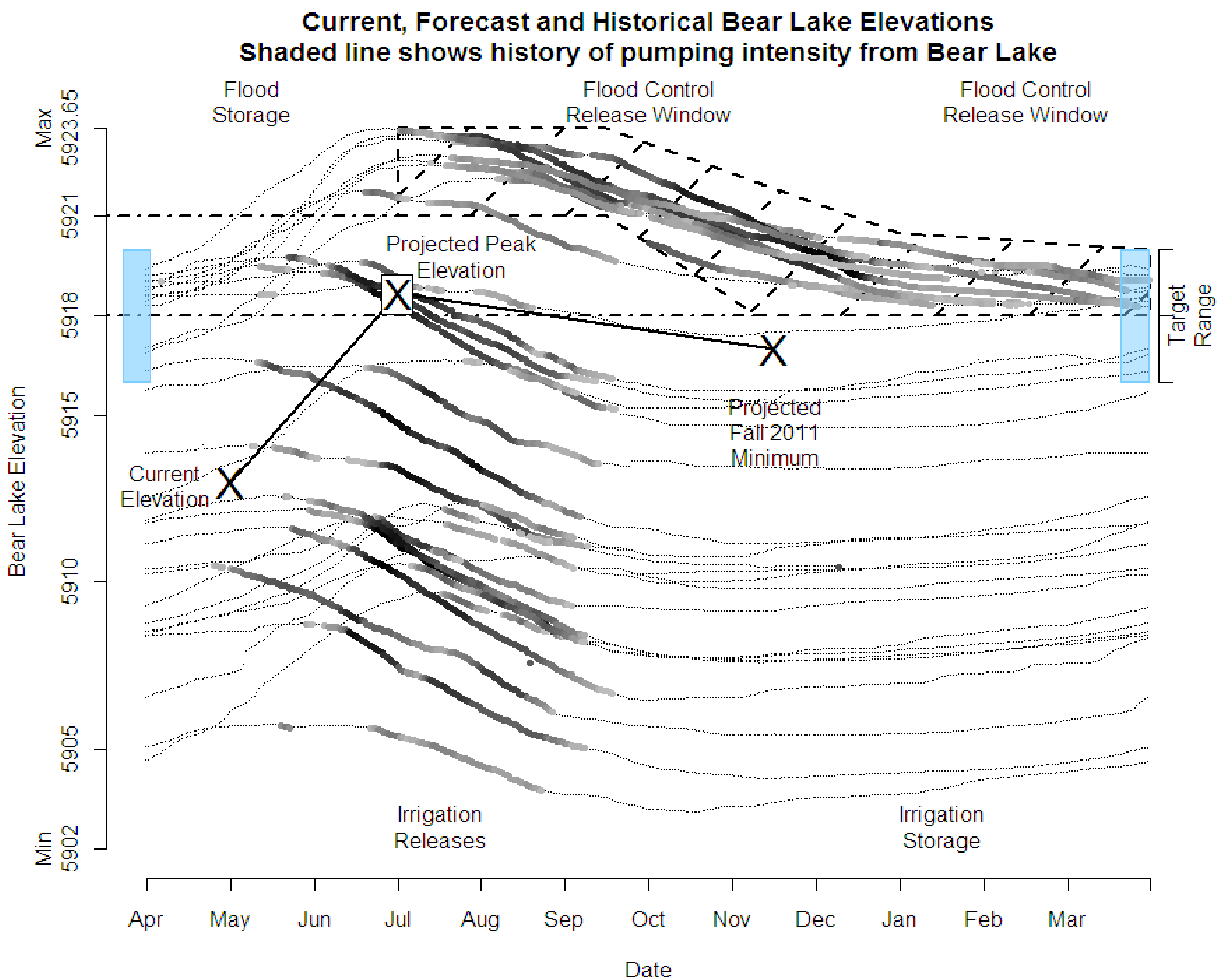
Bear Lake Outlet Canal



Typical Bear Lake Operations

- Spring Runoff – Store all water possible up to flood control target
- Late Spring – Release inflow for irrigation or flood control
- Summer – Pump Bear Lake for irrigation or flood control
- Fall – evaluate need to evacuate flood control storage
- Winter – store or release for flood control. Releases must be steady and unchanging due to downstream icing concerns.

Flood control operations summary



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Proof of Concept - Results

- Use DSS to evaluate revenue gains in three hydrologically 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