



# THE USE OF REAL-TIME GFS AND CFS DATA TO IMPROVE OPERATIONAL WATER RESOURCES MANAGEMENT IN NORTHERN CALIFORNIA

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# The Means

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## The INFORM Demonstration Project Integrated Forecast and Reservoir Management

### Phase I (2003 – 2009)

Development and Implementation  
Demonstration

### Phase II (2009 – 2012)

Enhancements  
Transition to Operations

# INFORM Vision Statement

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- Increase efficiency of water use in Northern California using climate, hydrologic and decision science

# Goal and Objectives

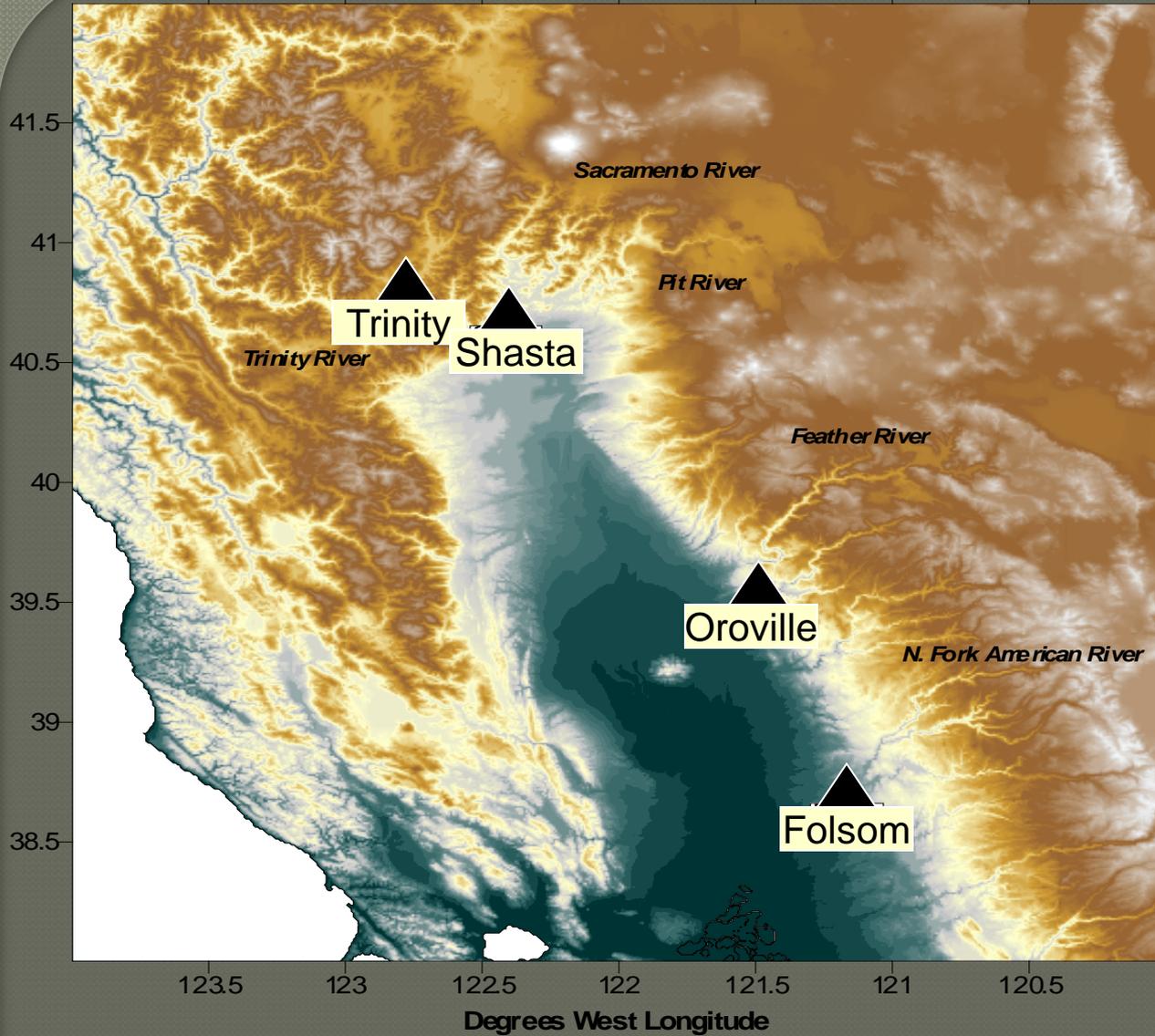
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- Implement an integrated forecast-management system for the Northern California reservoirs using real-time data and operational forecast models
- Perform tests with actual data and with management input
- Demonstrate the utility of climate and hydrologic forecasts for water resources management in Northern California
- Transition to Operations

# Major Reservoirs in Northern California

Application  
Area

Degrees North Latitude



Elevation (meters)

HRC-GWRINCEP

02/25/2010

# SPONSORS-COLLABORATORS

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## Sponsors:

CALFED Bay Delta Authority  
California Energy Commission  
National Oceanic and Atmospheric Administration

## Collaborators:

California Department of Water Resources  
California-Nevada River Forecast Center  
Sacramento Area Flood Control Agency  
U.S. Army Corps of Engineers  
U.S. Bureau of Reclamation  
National Centers of Environmental Prediction

# INFORM Detailed Publications

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- HRC-GWRI, 2006. *Integrated Forecast and Reservoir Management (INFORM) for Northern California: System Development and Initial Demonstration*. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2006-109, 244pp. and 9 Appendices

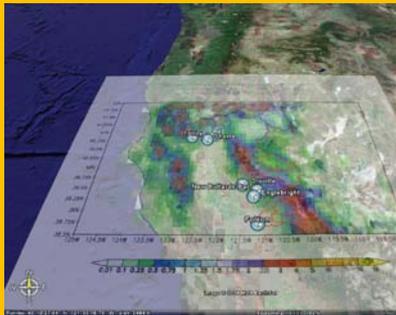
[http://www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2006-109.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2006-109.html)

[http://www.hrc-lab.org/projects/dsp\\_projectSubPage.php?subpage=inform](http://www.hrc-lab.org/projects/dsp_projectSubPage.php?subpage=inform)

# INFORM Modeling Framework

GFS & CFS INPUT  
Downscaling

Generate consistent real-time forcing sequences of rainfall and temperature.



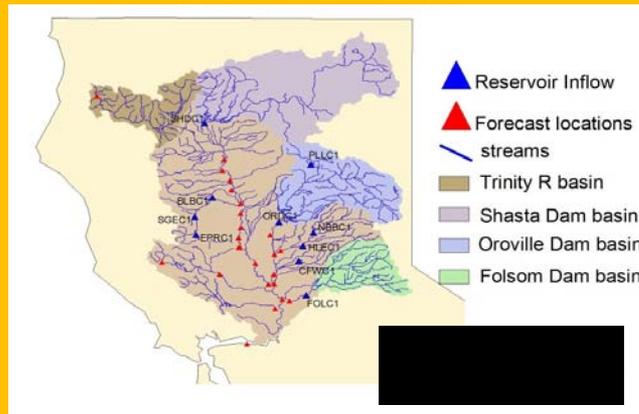
Watershed Hydrology

Simulate soil moisture, evapotranspiration, runoff, and streamflow.

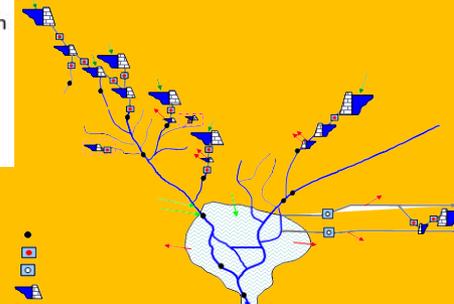


River/Reservoir  
Planning & Management

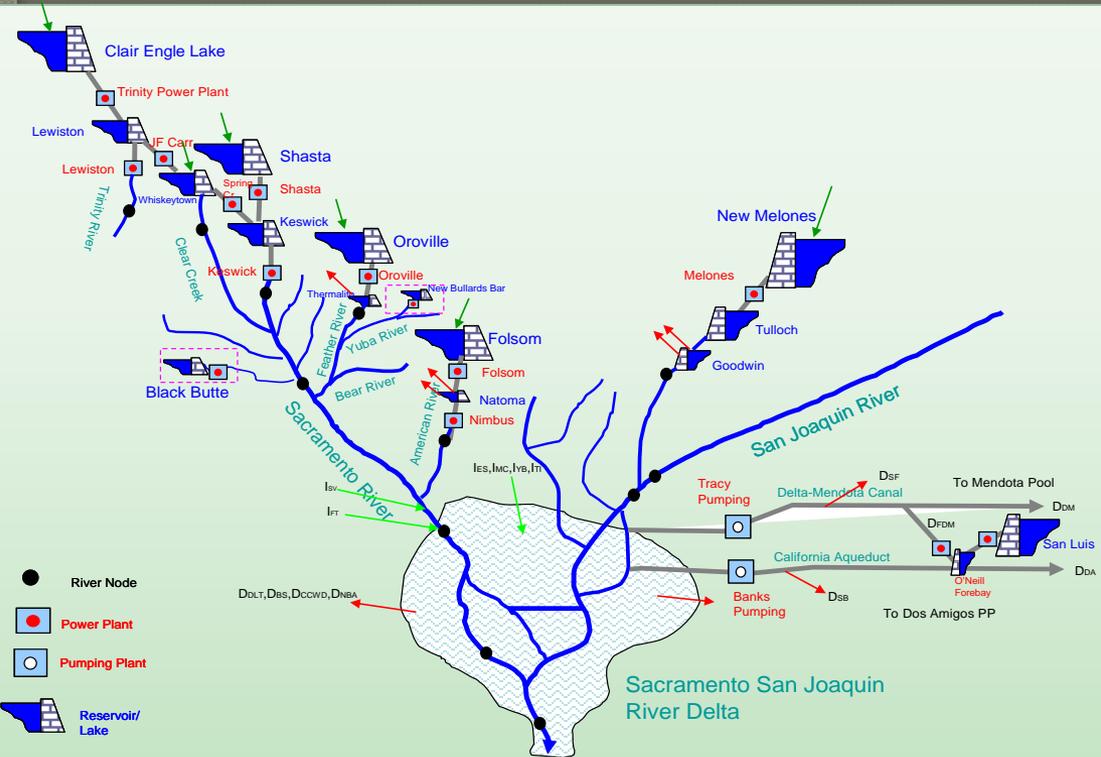
Simulate current and adaptive mgt. policies and assess impacts on water uses.



Economic and other benefits



# Reservoir Modeling System



**Trinity River System** (Clair Engle Lake, Trinity Power Plant, Lewiston Lake, Lewiston Plant, JF Carr Plant, Whiskeytown, Clear Creek, and Spring Creek Plant);

**Shasta Lake System** (Shasta Lake, Shasta Power Plant, Keswick Lake, Keswick Plant, and the river reach from Keswick to Wilkins);

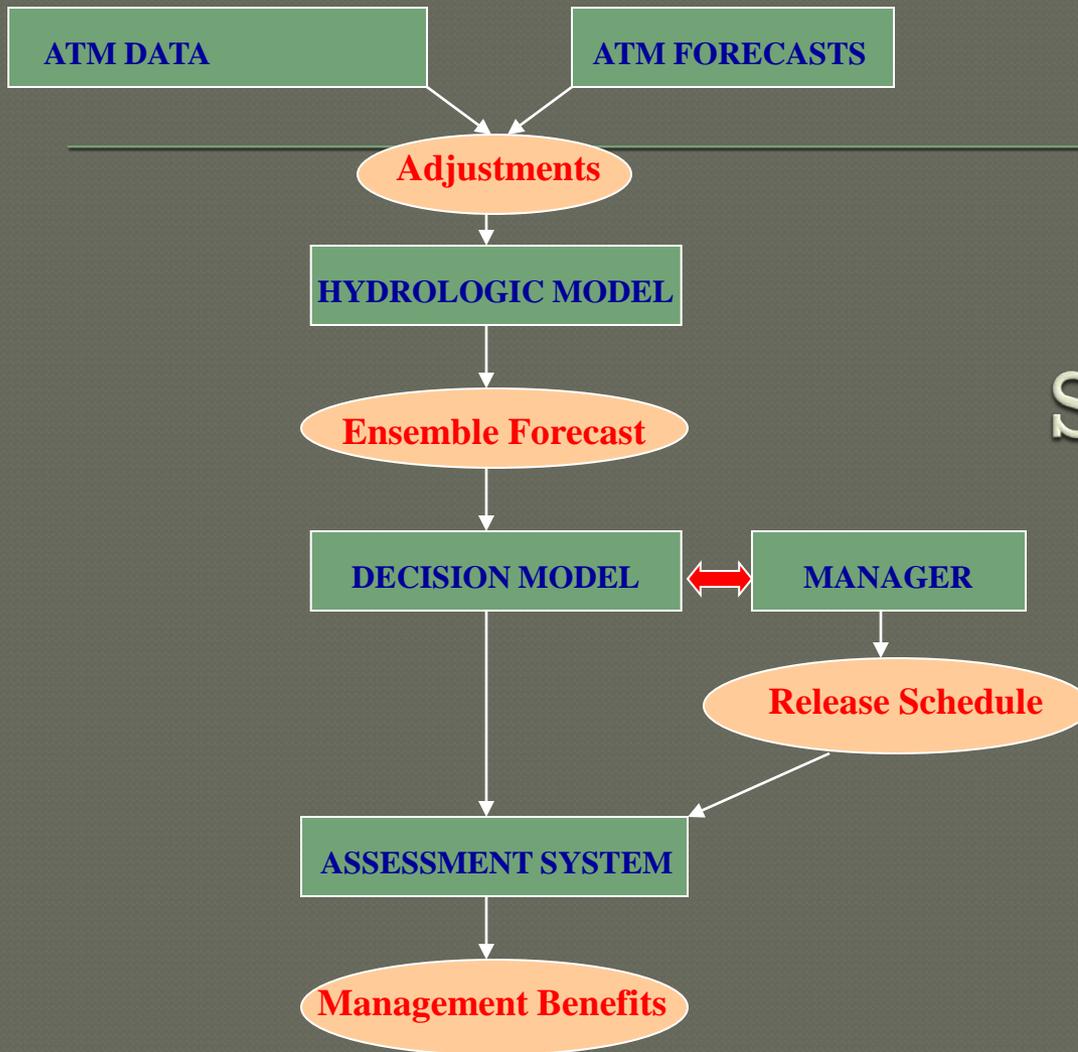
**Feather River System** (Oroville Lake, Oroville Power Plants, Thermalito Diversion Pond, Yuba River, and Bear River);

**American River System** (Folsom Lake, Folsom Plant, Natoma Lake, Nimbus Plant, Natoma Plant, and Natoma Diversions);

**San Joaquin River System** (New Melones Lake, New Melones Power Plant, Tulloch Lake, Demands from Goodwin, and Inflows from the main San Joaquin River); and

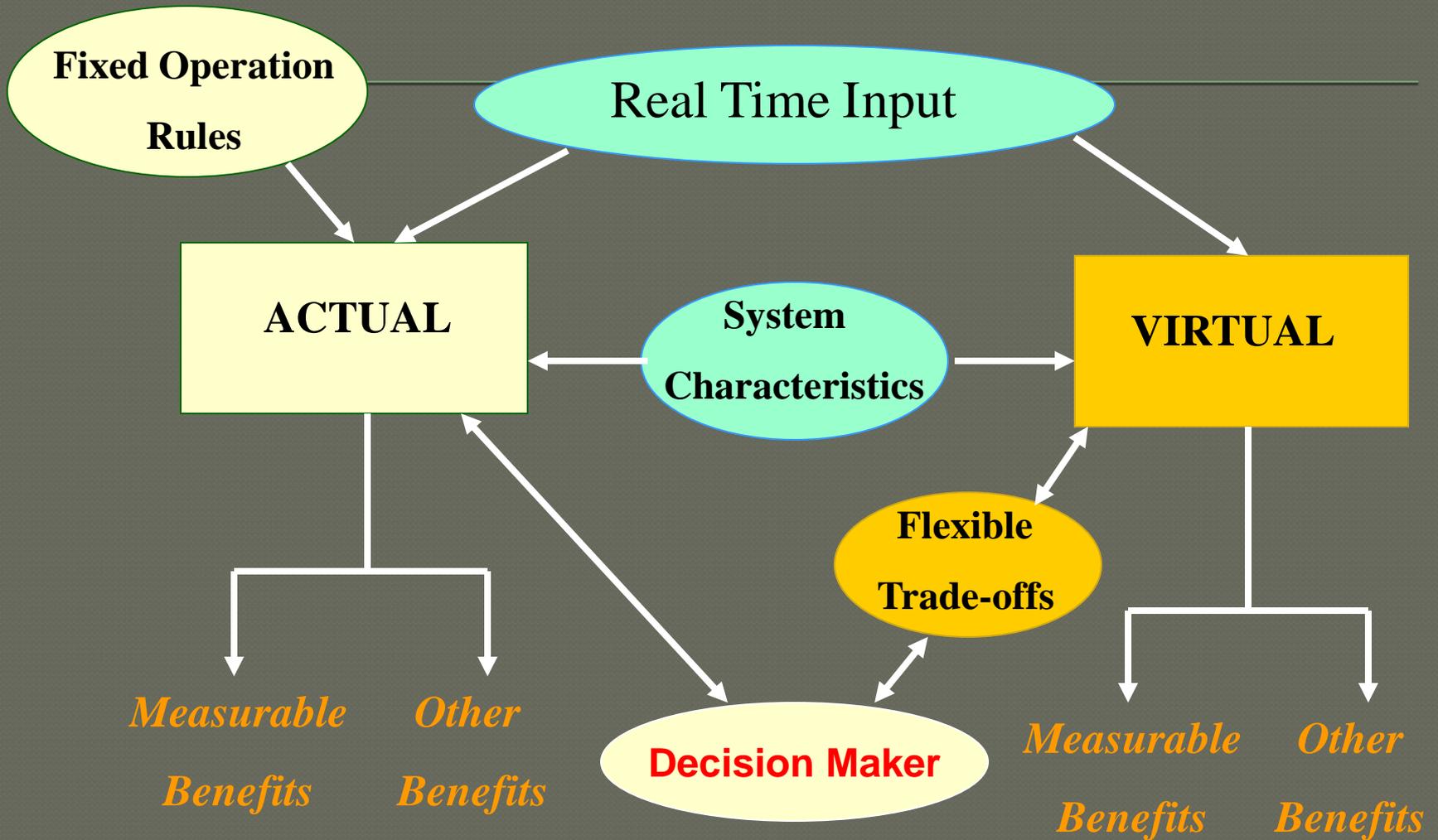
**Bay Delta** (Delta Inflows, Delta Exports, Coordinated Operation Agreement--COA, and Delta Environmental Requirements).

**Objectives:**  
 Water Supply  
 Energy Generation  
 Environment  
 Ecology  
 Recreation

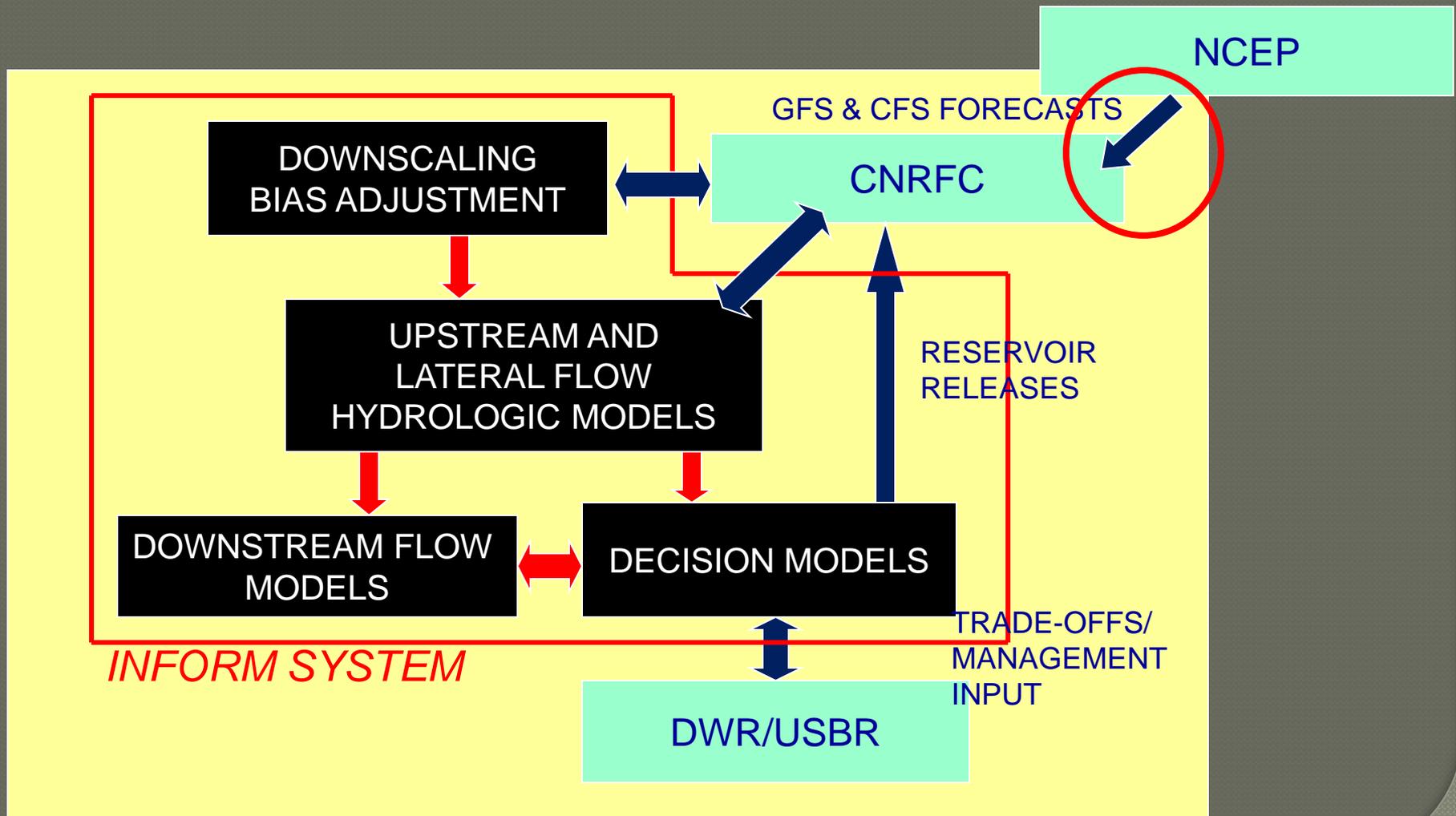


# Integrated System Diagram

# Demonstration Concept

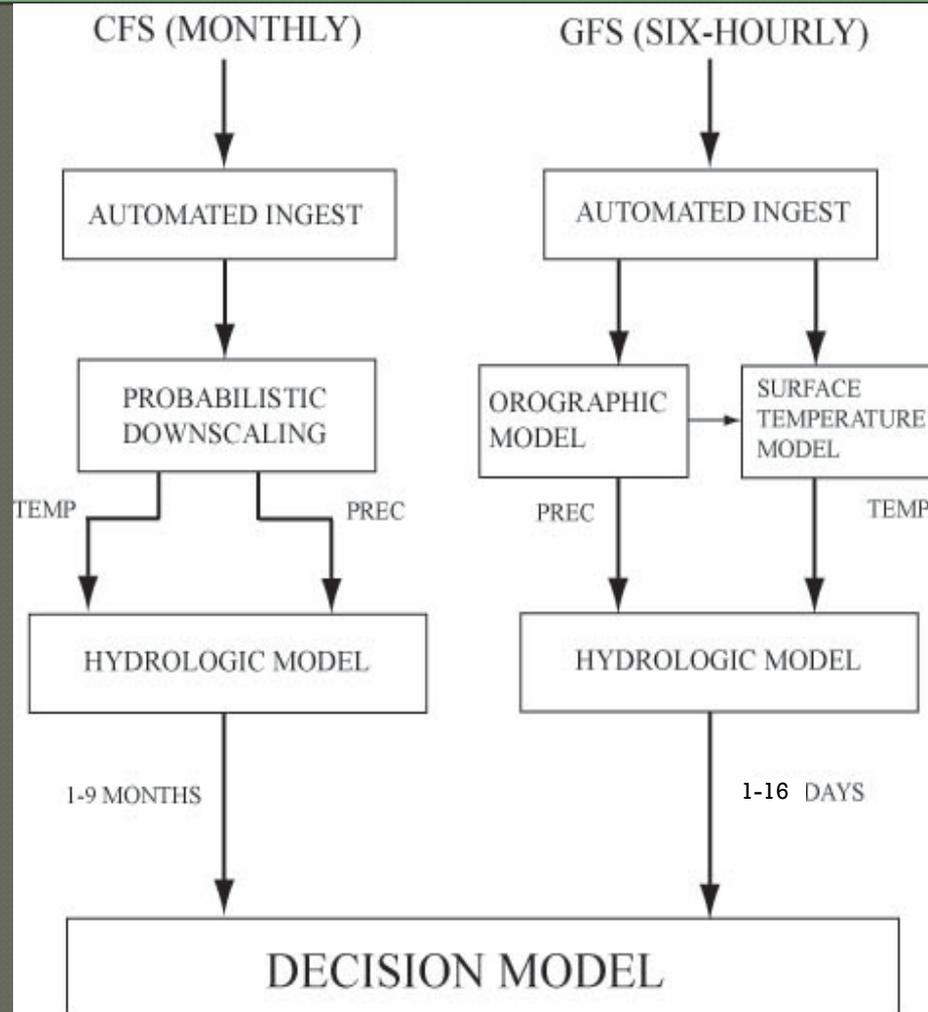


# Operational Processing and Data Links



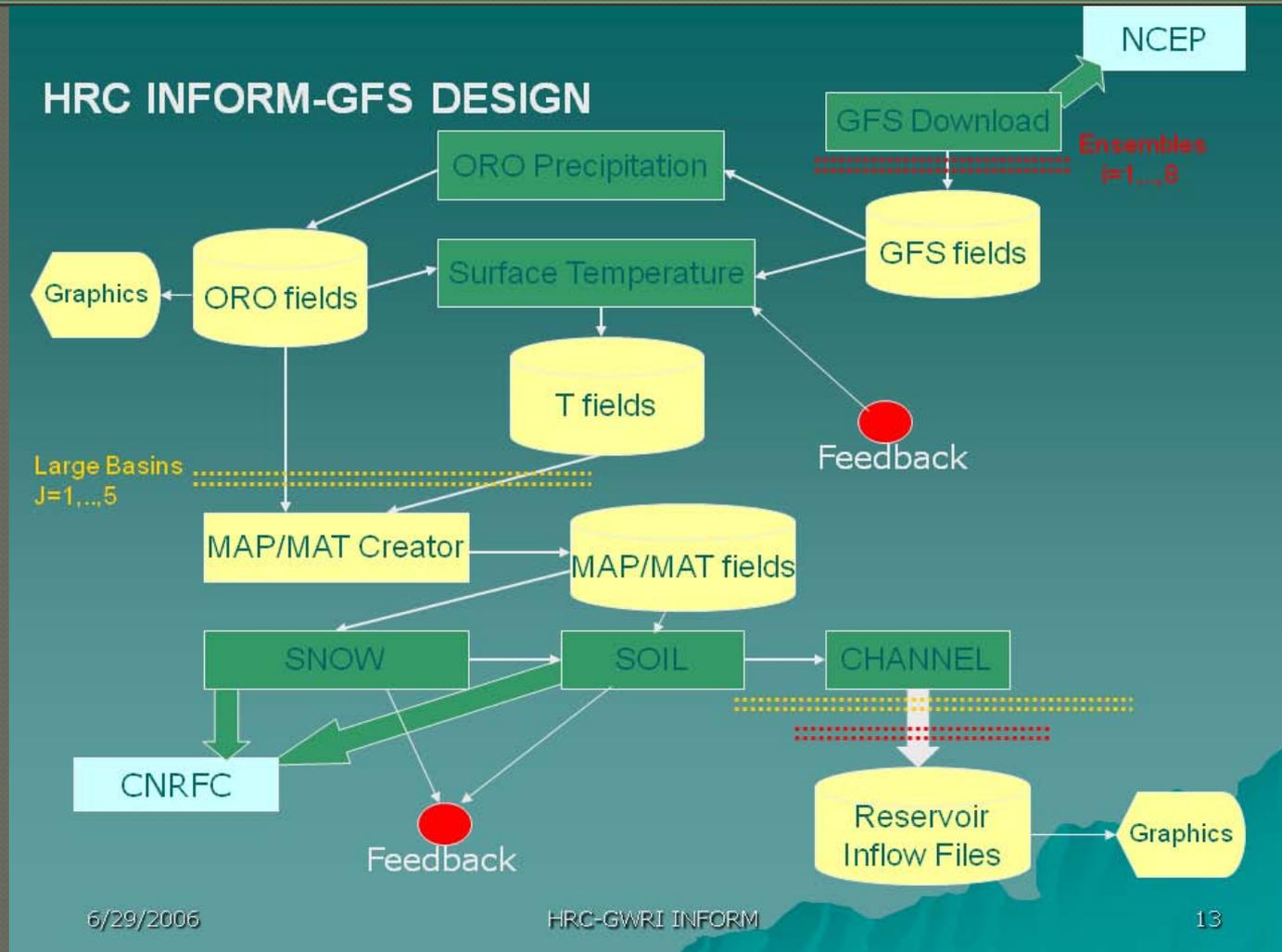
# Results and Assessments

## Forecasts



# Results and Assessments

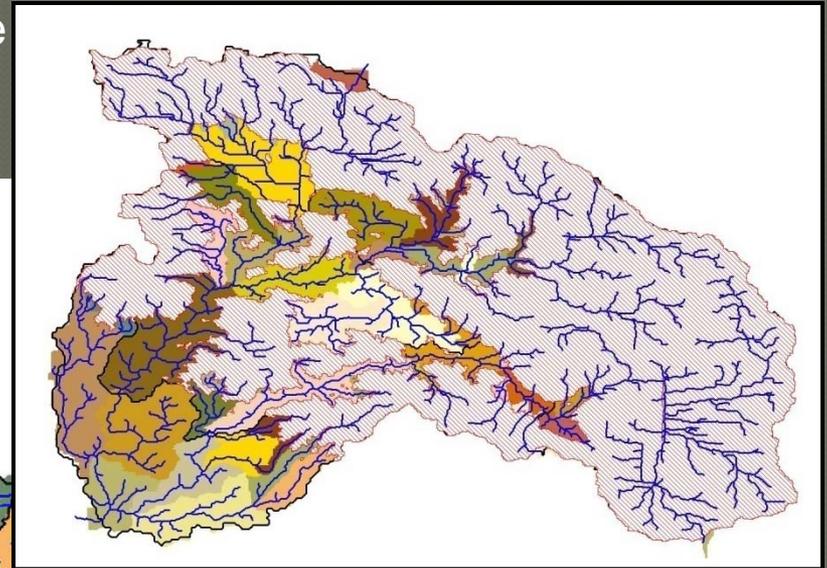
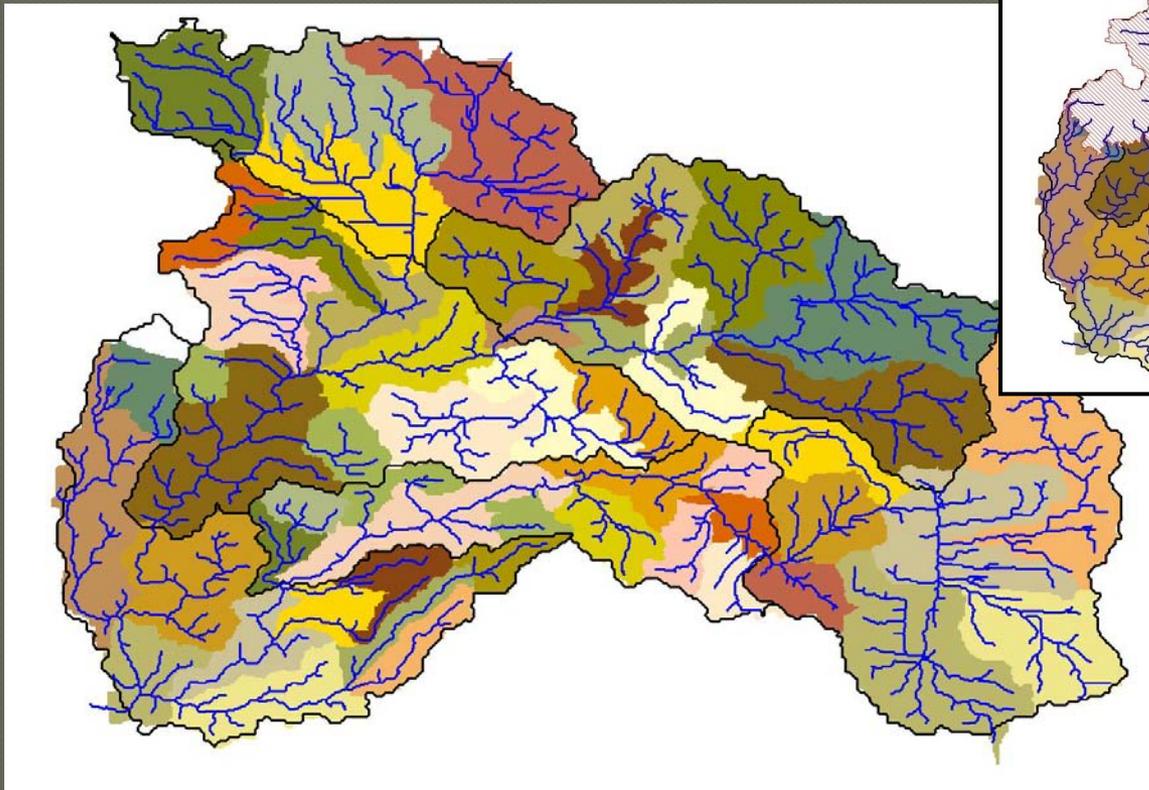
## Forecasts



# Results and Assessments

## Forecasts

Distributed Tributary Basin System for Oroville  
Example of INFORM Hydrology Modeling



# Results and Assessments

## Forecasts

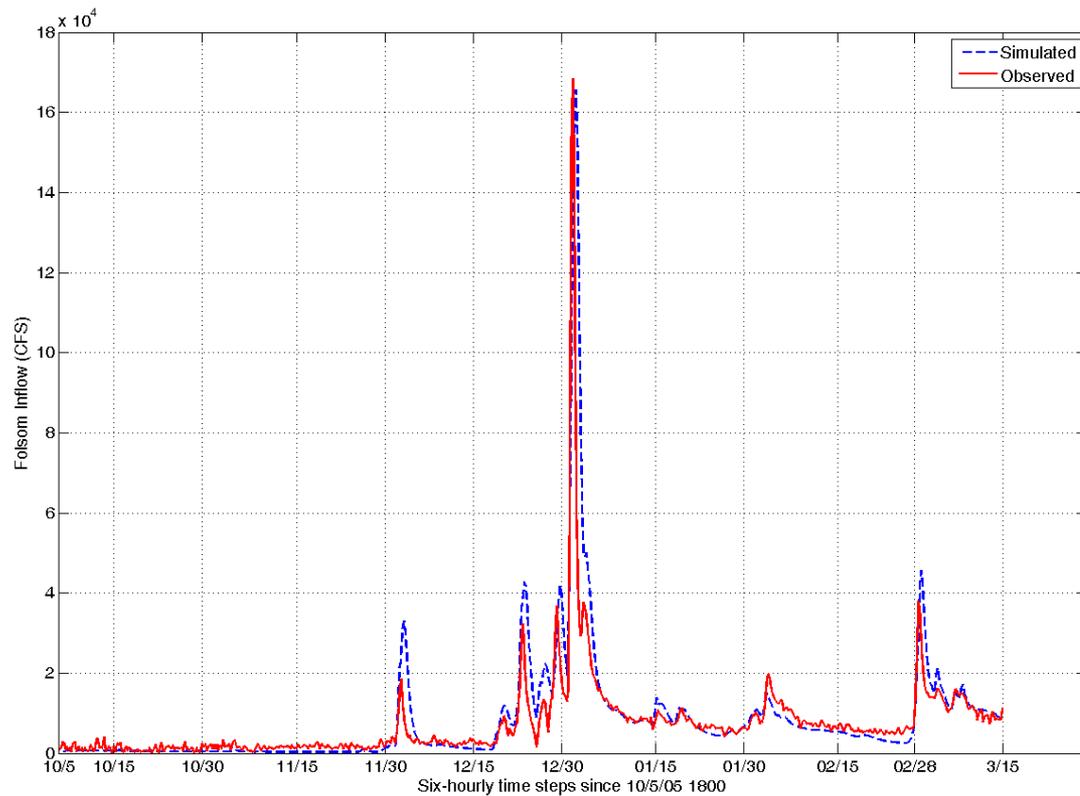
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### *Phase I - Assessment Summary:*

1. Orographic model downscaling without bias adjustment tends to overestimate (underestimate) precipitation in high (low) elevations (for areas of order 500 km). Temporal variability is reasonably well represented.
2. Temperature downscaling exhibits generally small bias with good diurnal variation.
3. Simulation with adaptations of the operational snow-soil models exhibits generally good performance with some late lags for high events of FNF.
4. Forecasts of 2-day inflow volume appear reasonable but require adjustment for bias for the range of GFS-driven ensembles to include the observed FNFs.

# Results and Assessments

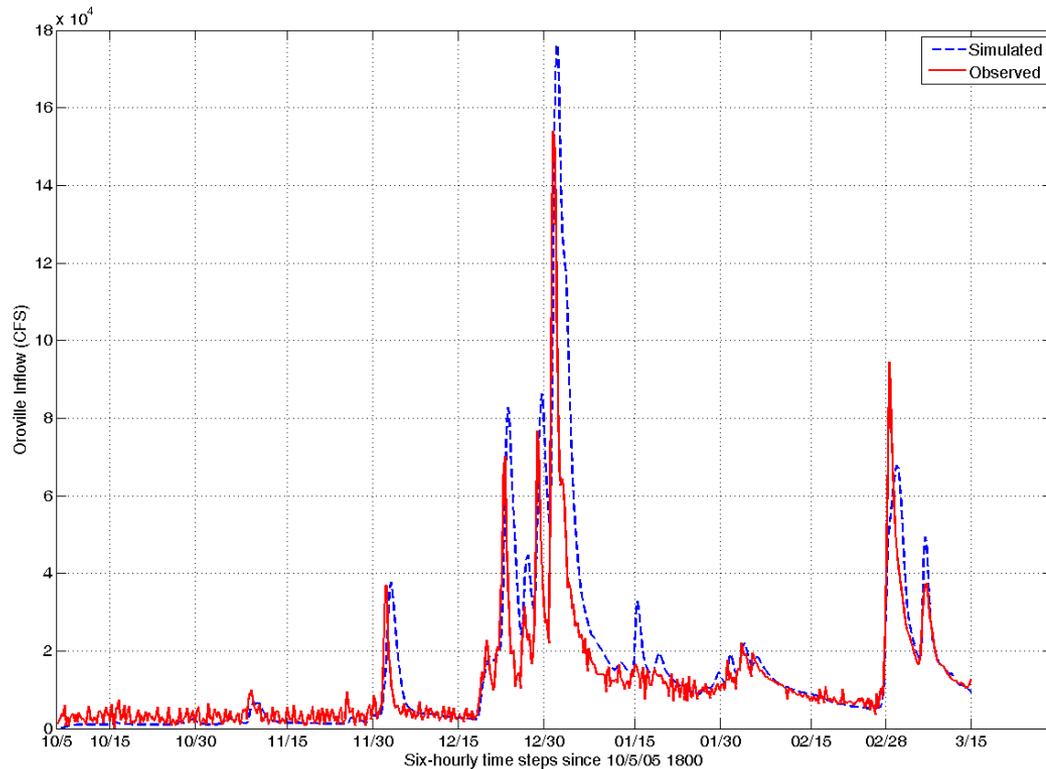
## Forecasts



Folsom  
Simulation

# Results and Assessments

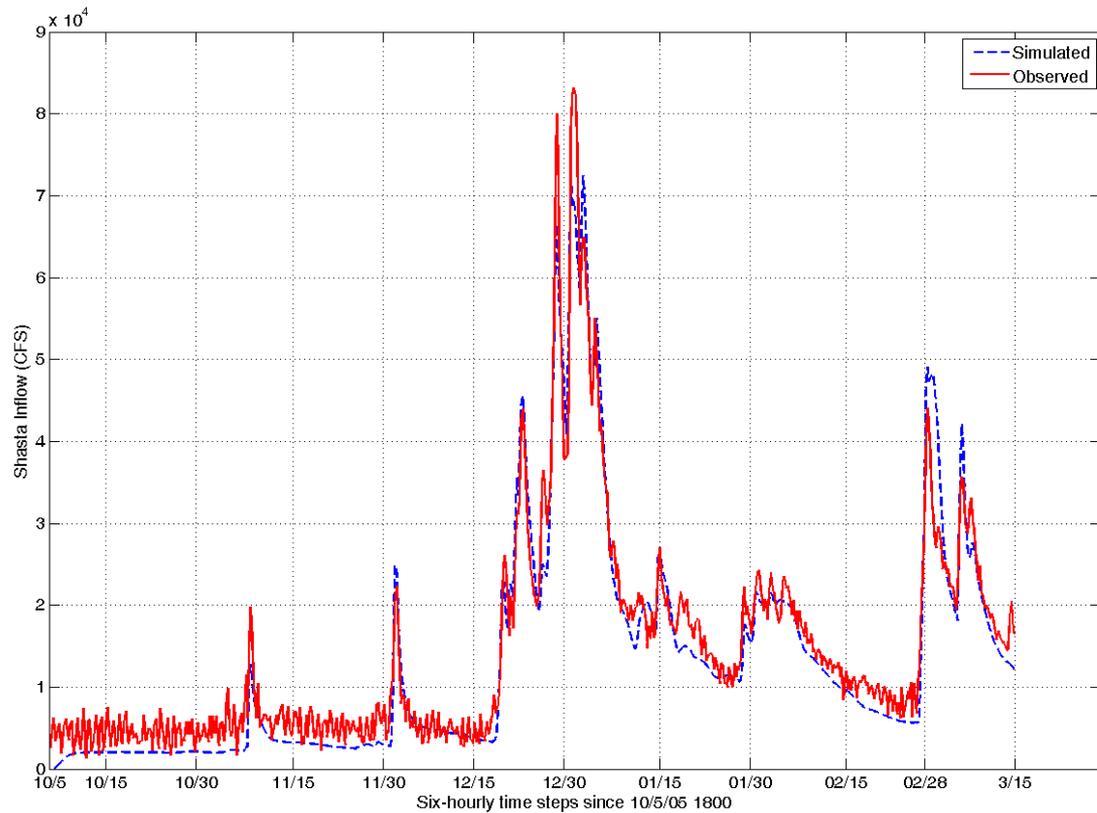
## Forecasts



Oroville  
Simulation

# Results and Assessments

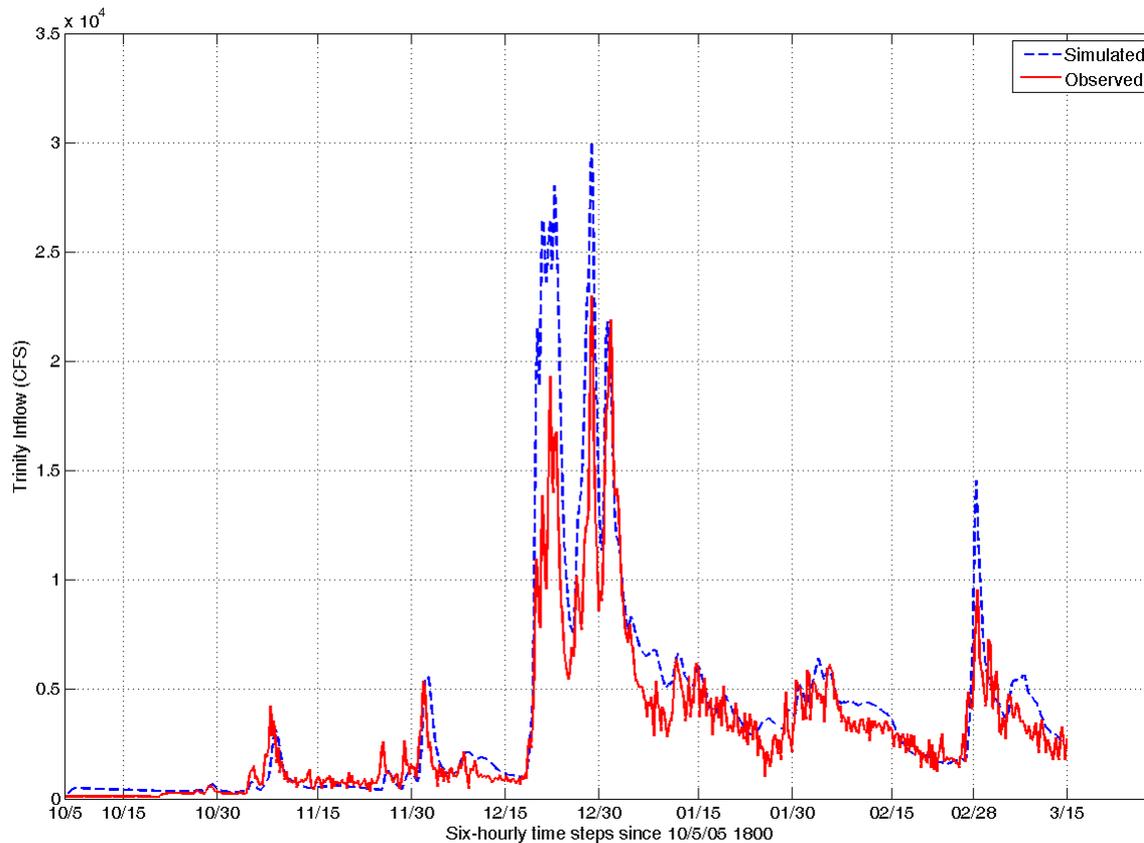
## Forecasts



Shasta  
Simulation

# Results and Assessments

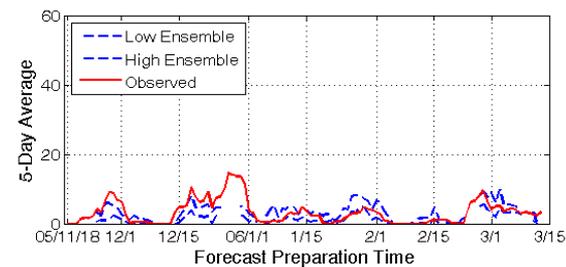
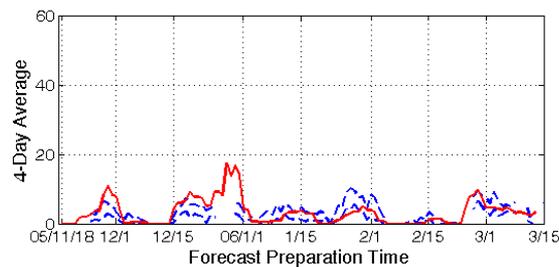
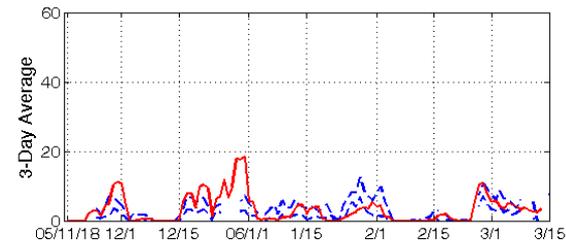
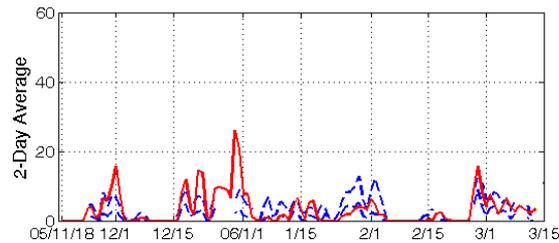
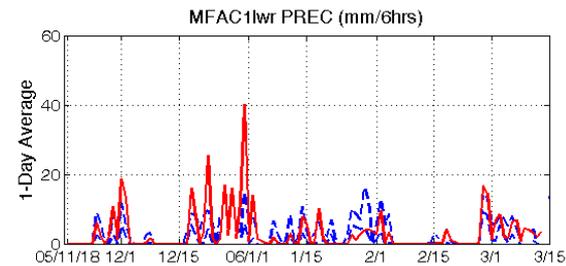
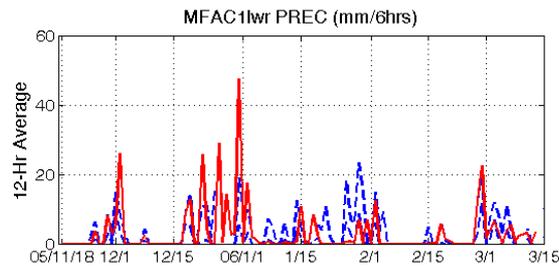
## Forecasts



Trinity  
Simulation

# Results and Assessments

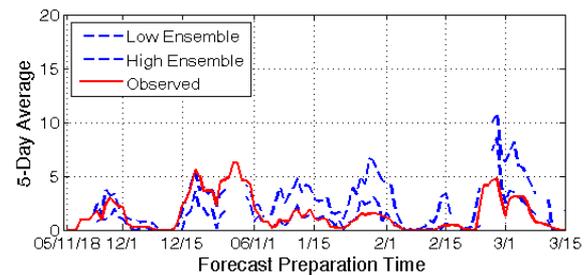
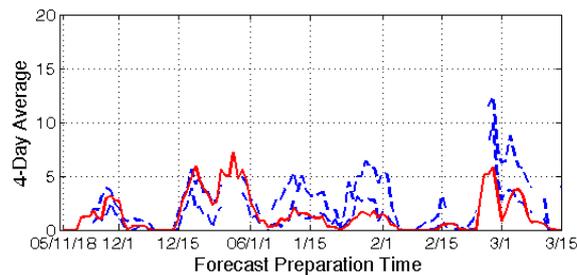
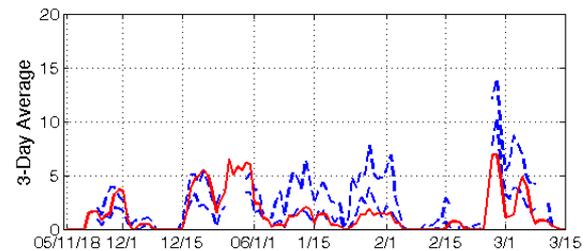
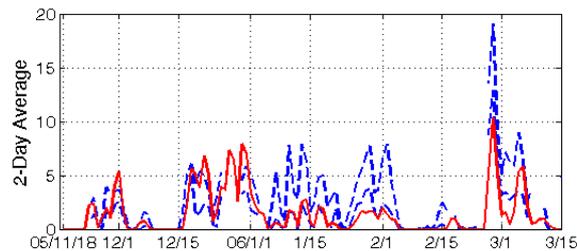
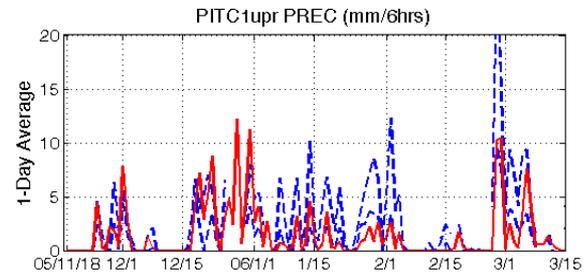
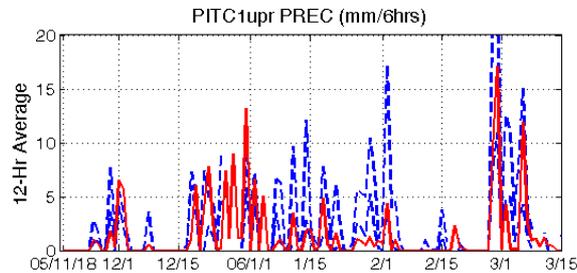
## Forecasts



MF  
American  
Lwr

# Results and Assessments

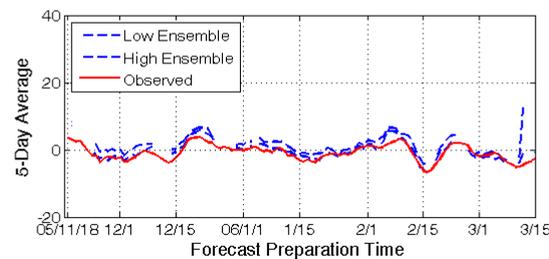
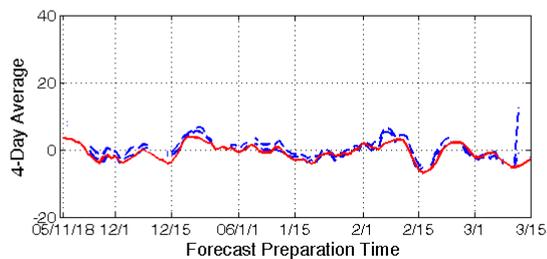
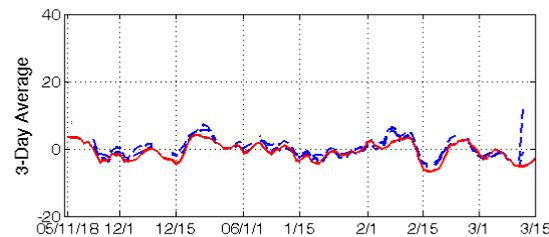
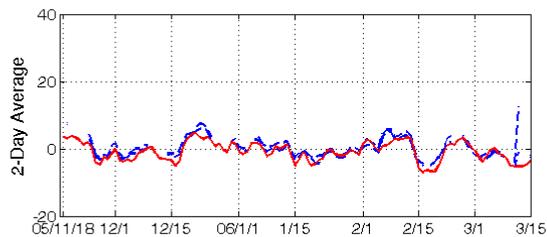
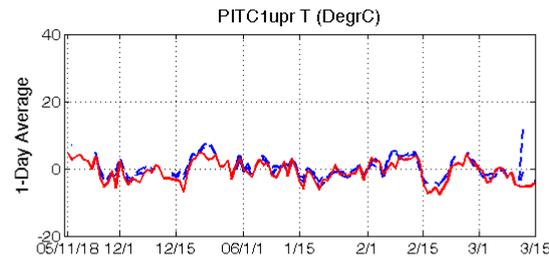
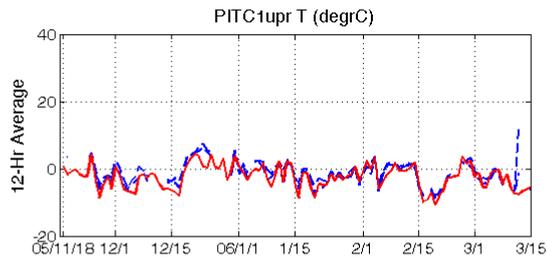
## Forecasts



Pit River  
Upr

# Results and Assessments

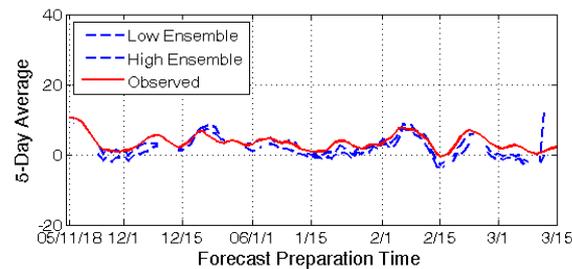
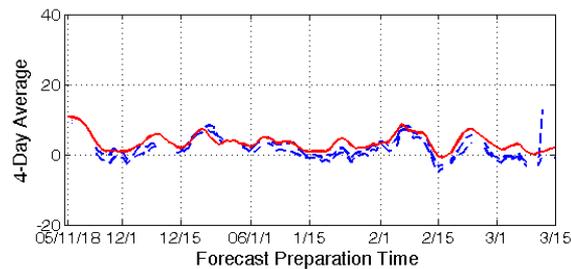
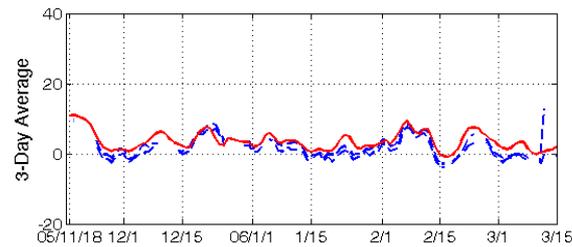
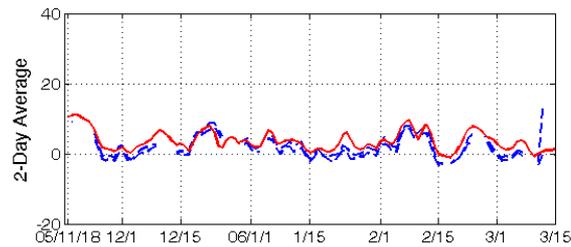
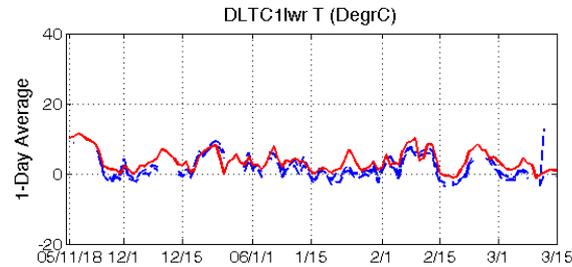
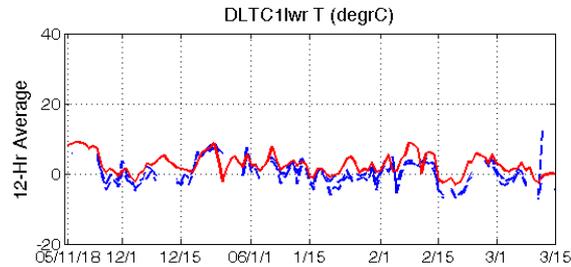
## Forecasts



Pit River  
Upr

# Results and Assessments

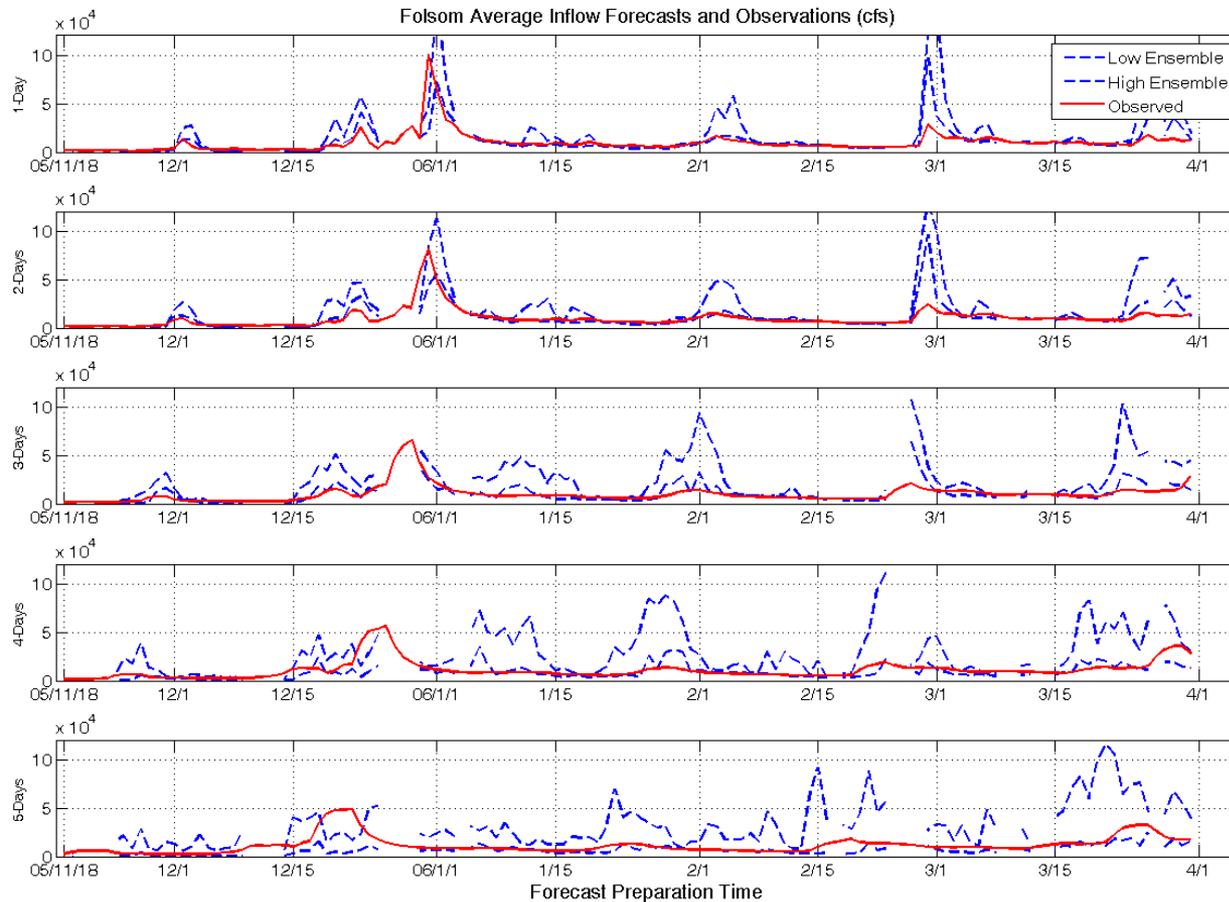
## Forecasts



Sacr. River  
@ Delta  
Lwr

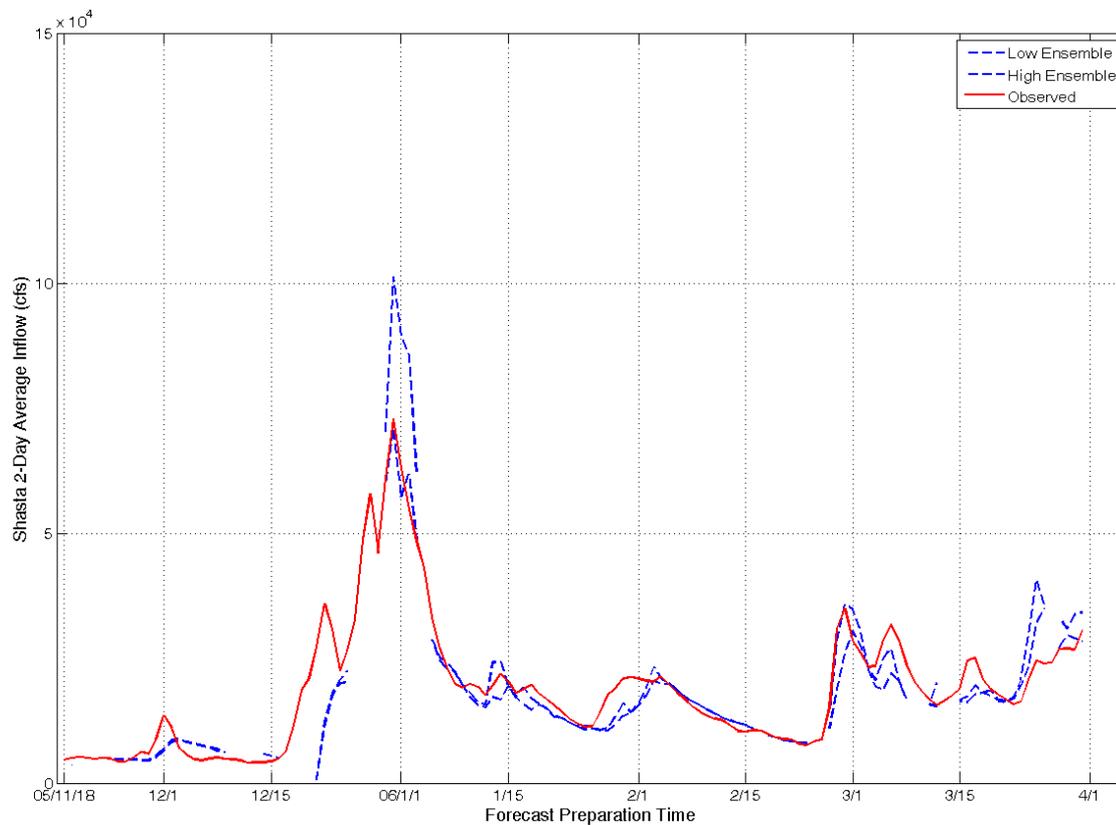
# Results and Assessments

## Forecasts



# Results and Assessments

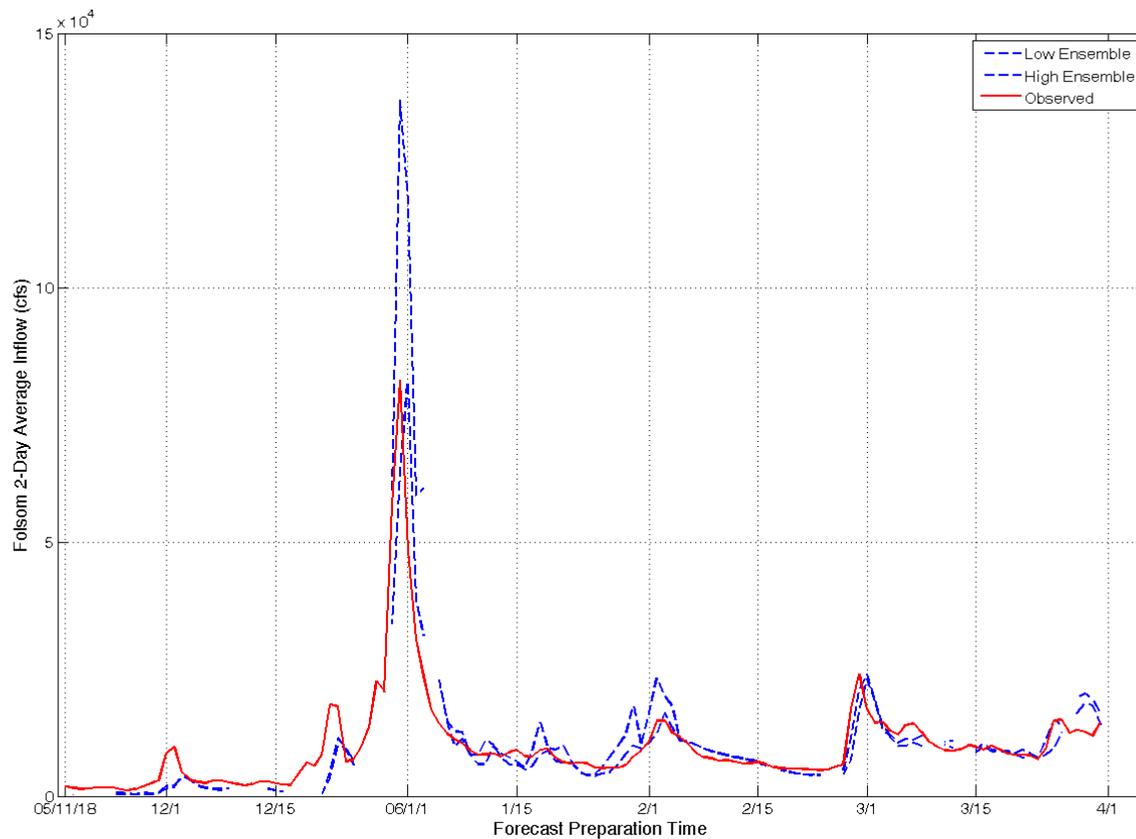
## Forecasts



Shasta Inflow

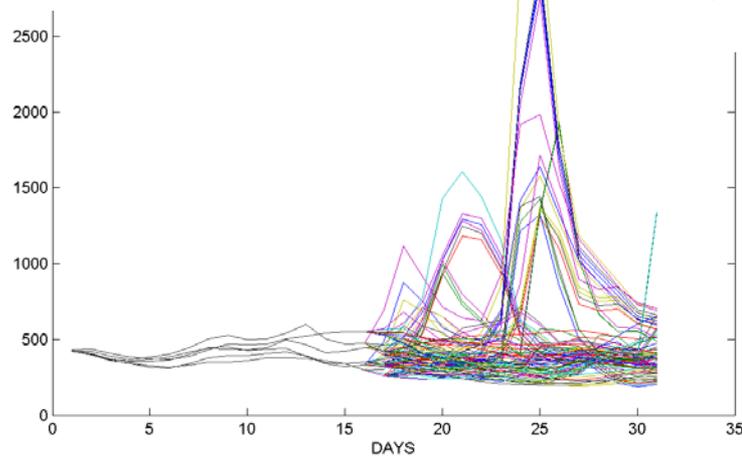
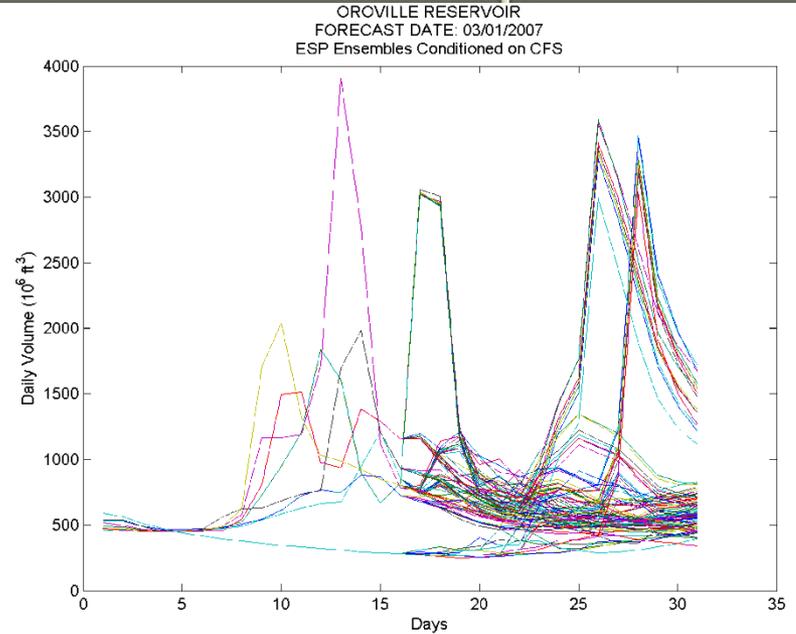
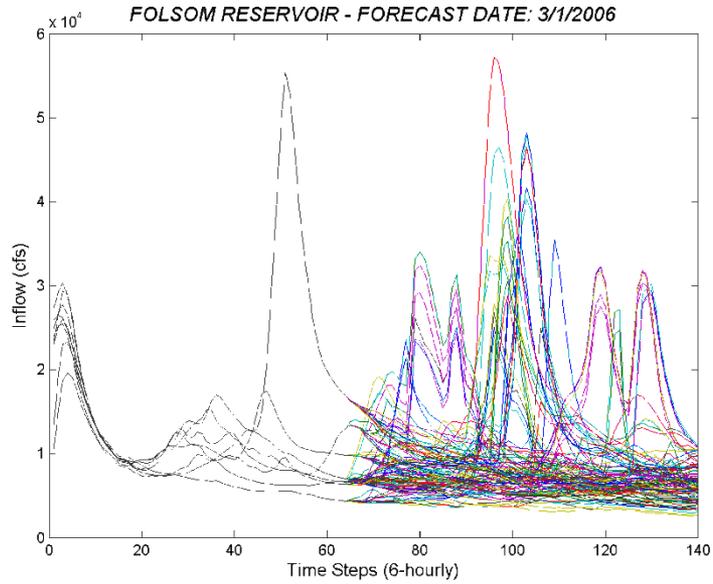
# Results and Assessments

## Forecasts



Folsom Inflow

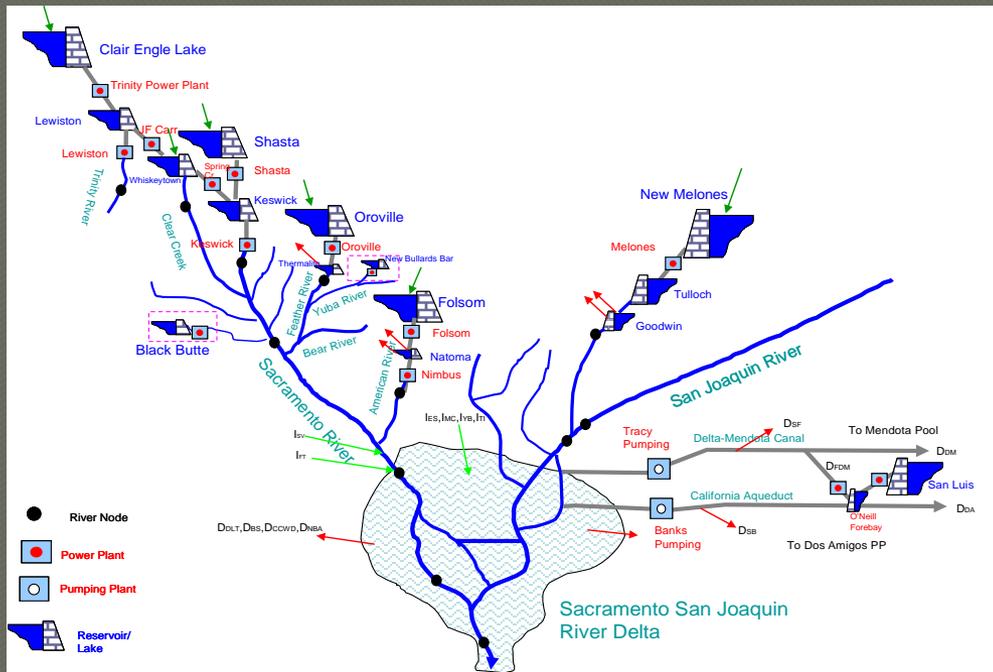
# Blending Short- and Long-Term Forecasts for Decision Component



# Results and Assessments

## Decision Support

### System Schematic



**Trinity River System** (Clair Engle Lake, Trinity Power Plant, Lewiston Lake, Lewiston Plant, JF Carr Plant, Whiskeytown, Clear Creek, and Spring Creek Plant);

**Shasta Lake System** (Shasta Lake, Shasta Power Plant, Keswick Lake, Keswick Plant, and the river reach from Keswick to Wilkins);

**Feather River System** (Oroville Lake, Oroville Power Plants, Thermalito Diversion Pond, Yuba River, and Bear River);

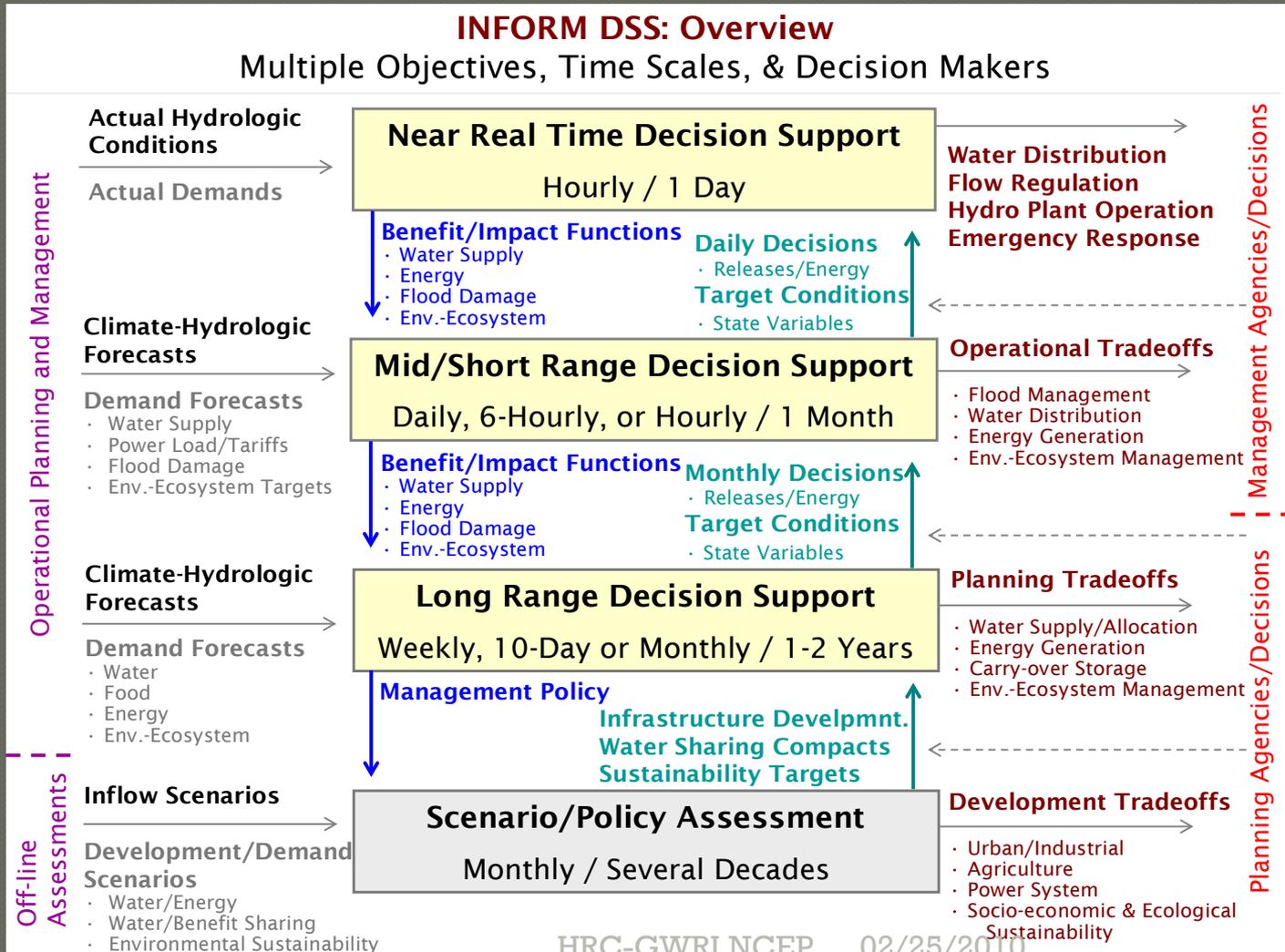
**American River System** (Folsom Lake, Folsom Plant, Natoma Lake, Nimbus Plant, Natoma Plant, and Natoma Diversions);

**San Joaquin River System** (New Melones Lake, New Melones Power Plant, Tulloch Lake, Demands from Goodwin, and Inflows from the main San Joaquin River); and

**Bay Delta** (Delta Inflows, Delta Exports, Coordinated Operation Agreement--COA, and Delta Environmental Requirements).

# Results and Assessments

## Decision Support



# Results and Assessments

## Decision Support

### Spring 2006, 2007, and 2008 Case Studies

#### Set- up:

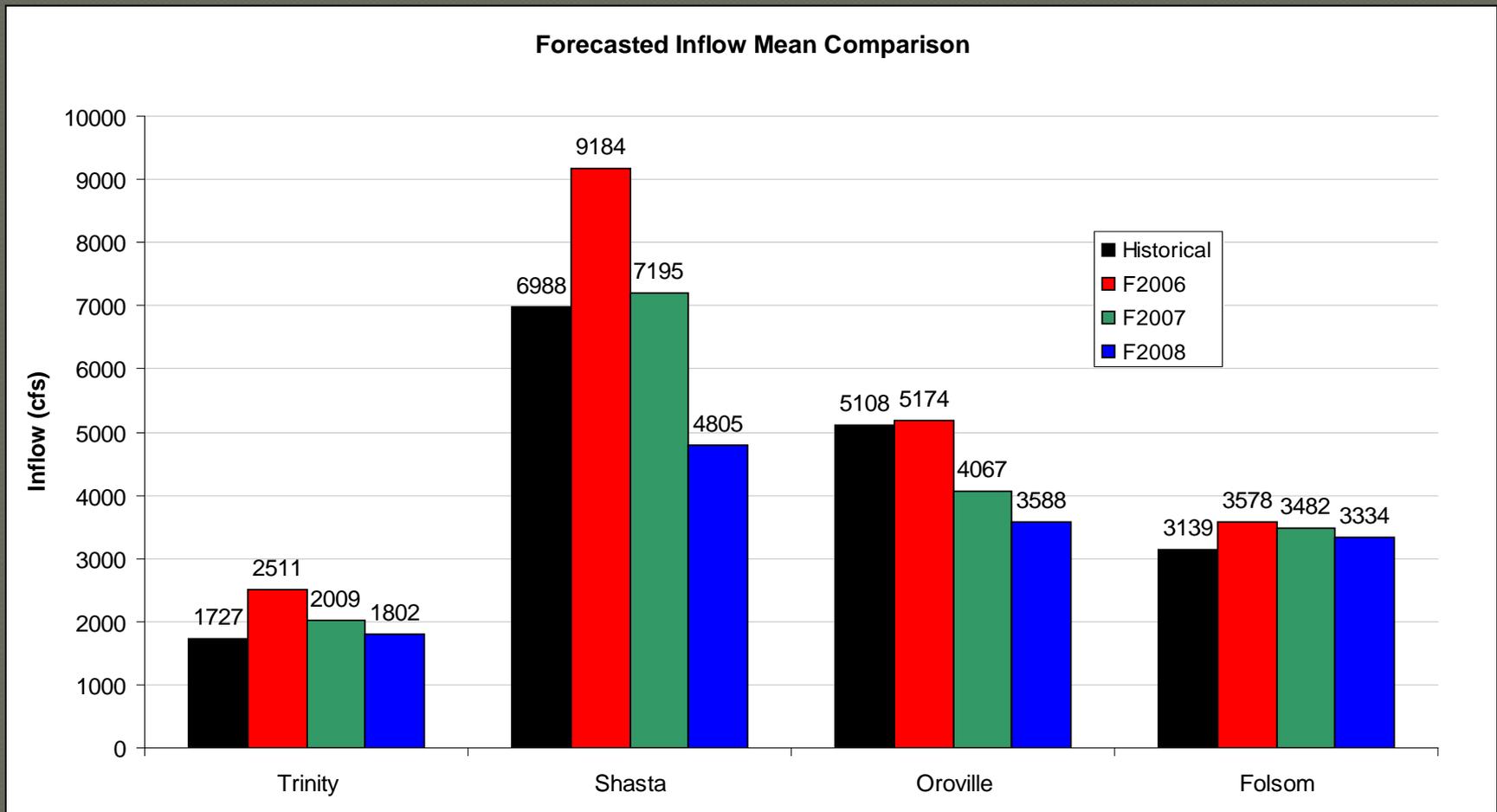
- Forecasted inflows were provided by HRC with start date March 1st (112 traces, 9 month horizon, and five locations: Clair Engle Lake, Shasta, Oroville, Folsom, and Yuba);
- Historical monthly average values are used for locations where forecasted inflows are not available;
- Monthly reservoir parameters and constraints (max, min, and target storage levels; evaporation rates);
- Minimum river flow and Bay Delta requirements; and
- Base monthly demands at all locations;

**DSS objective:** Develop the tradeoff between water supply deliveries and carry over storage that meets all other stated requirements.

# Results and Assessments

## Decision Support

### Mean 9- month Inflow Forecasts Comparison: 2006, 2007, 2008

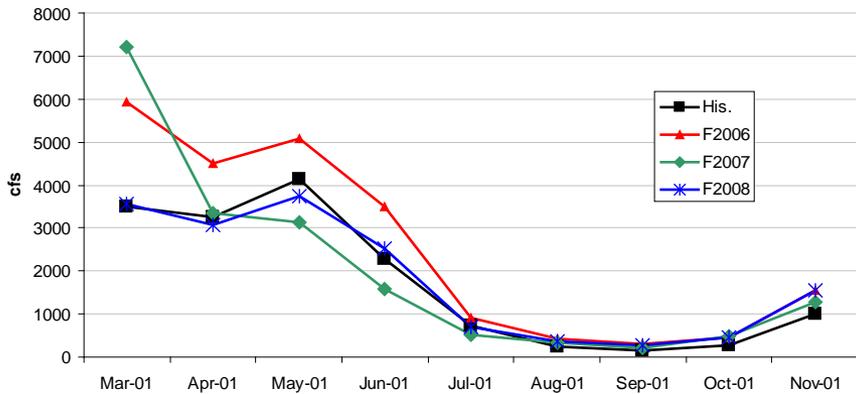


# Results and Assessments

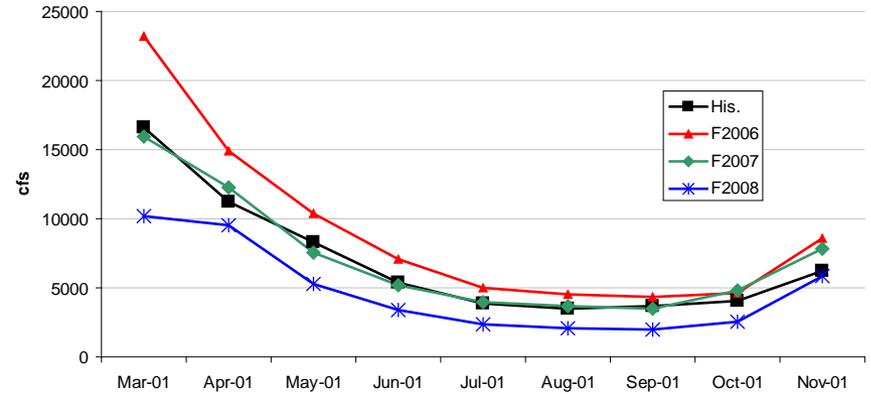
## Decision Support

### Mean Monthly Inflow Forecasts Comparison: 2006, 2007, 2008

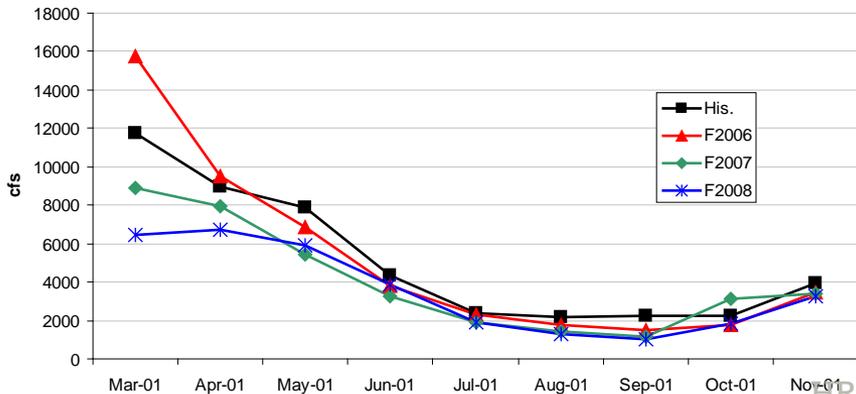
Forecasted Inflow Means - Trinity



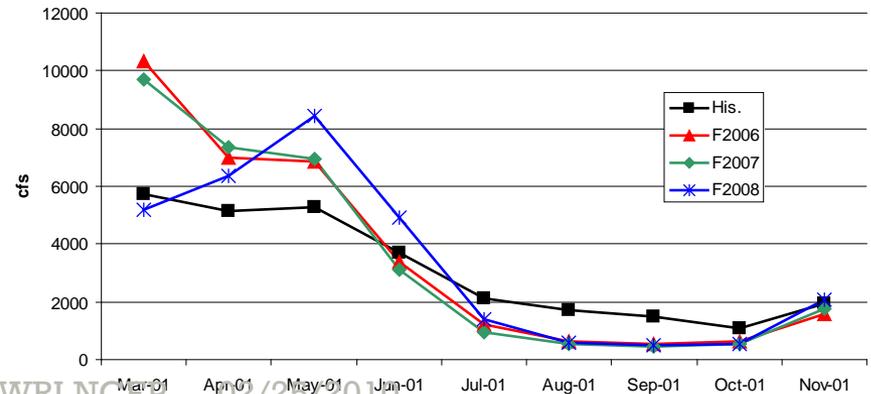
Forecasted Inflow Means - Shasta



Forecasted Inflow Means - Oroville



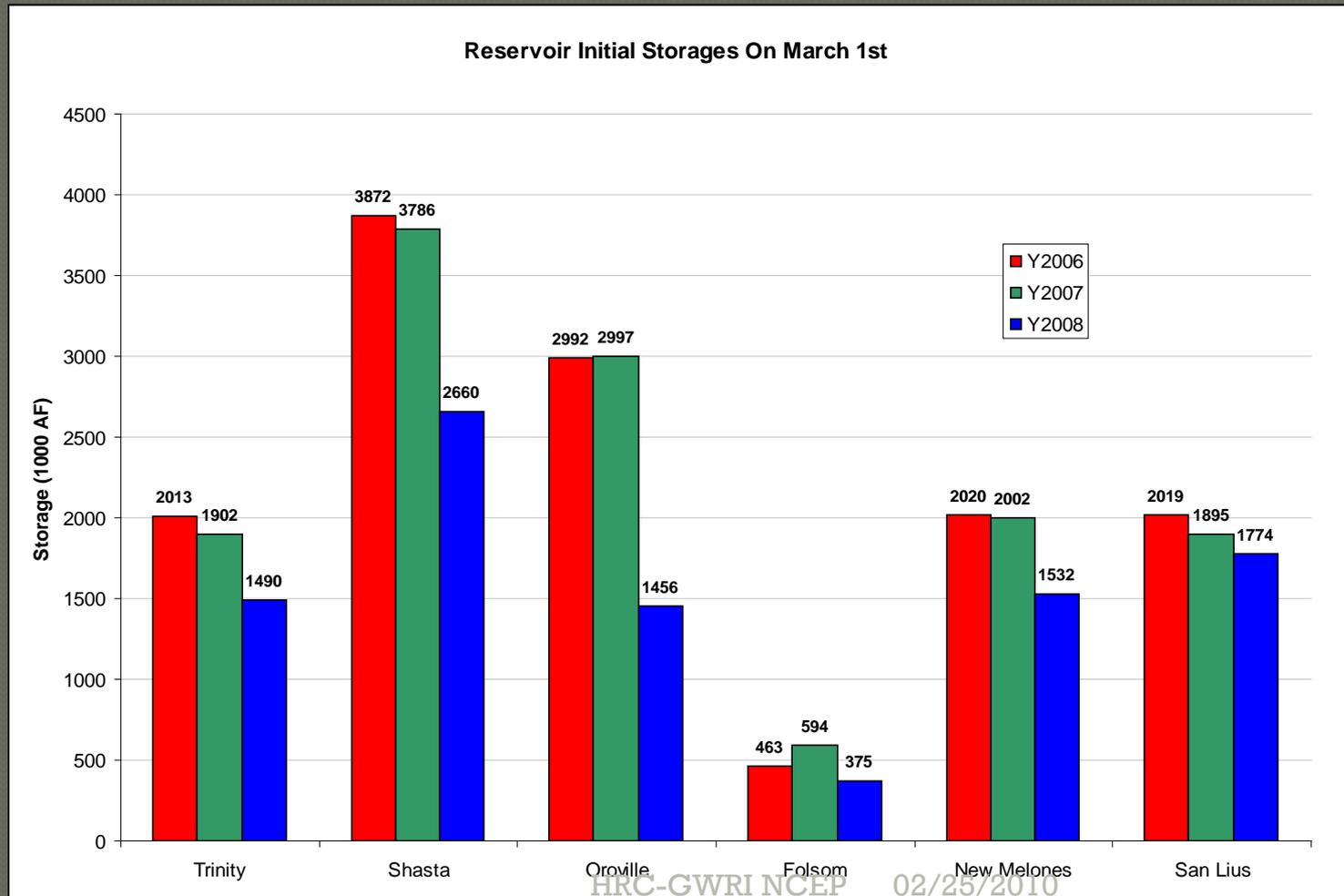
Forecasted Inflow Means - Folsom



# Results and Assessments

## Decision Support

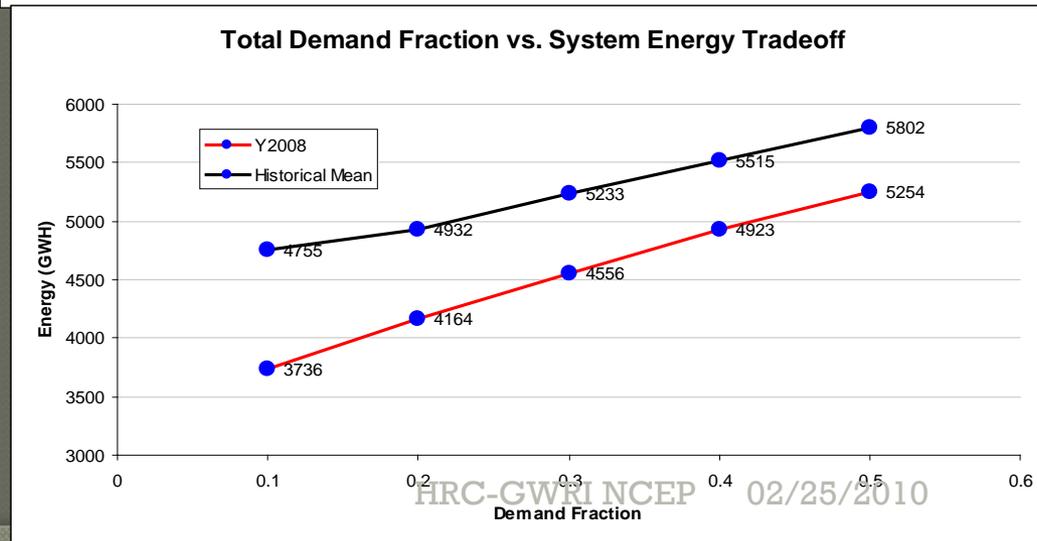
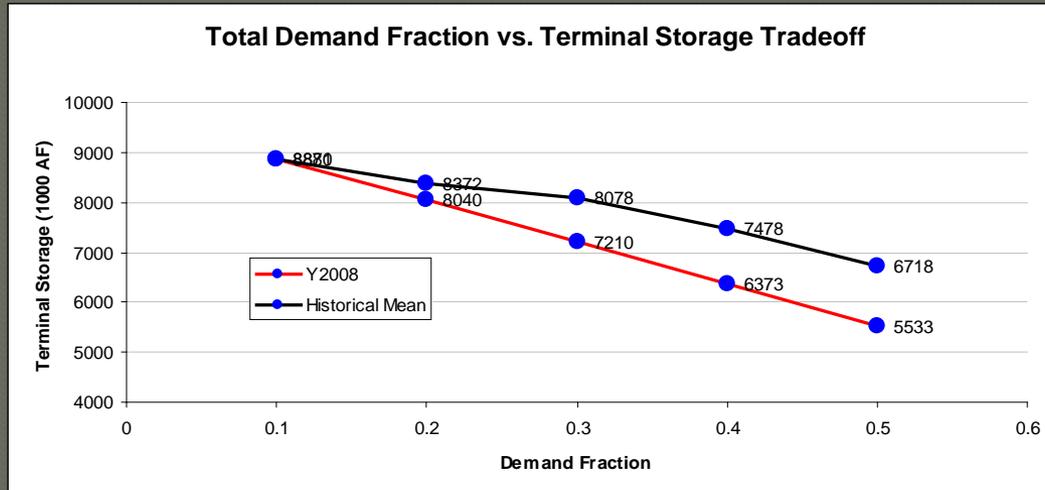
### March 1 Reservoir Storages: 2006, 2007, 2008



# Results and Assessments

## Decision Support

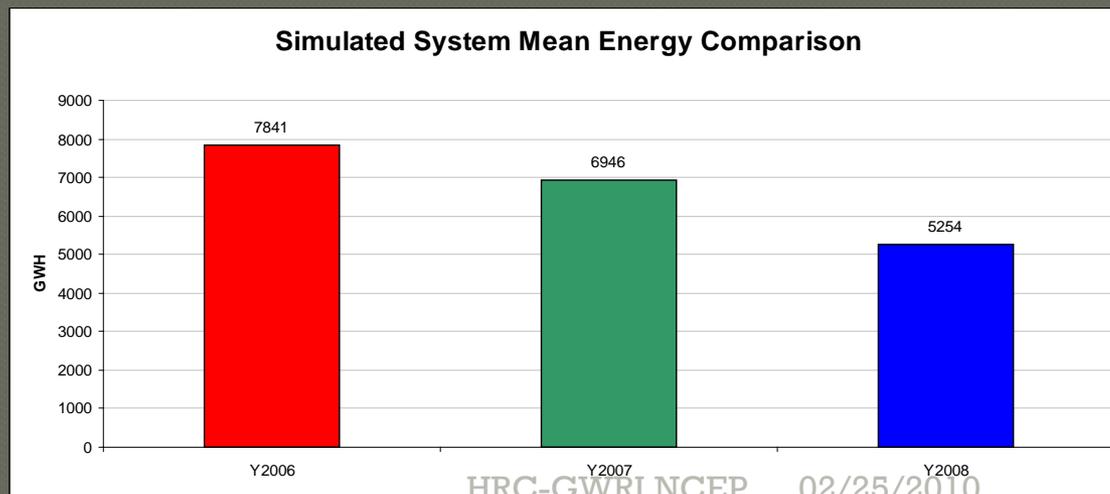
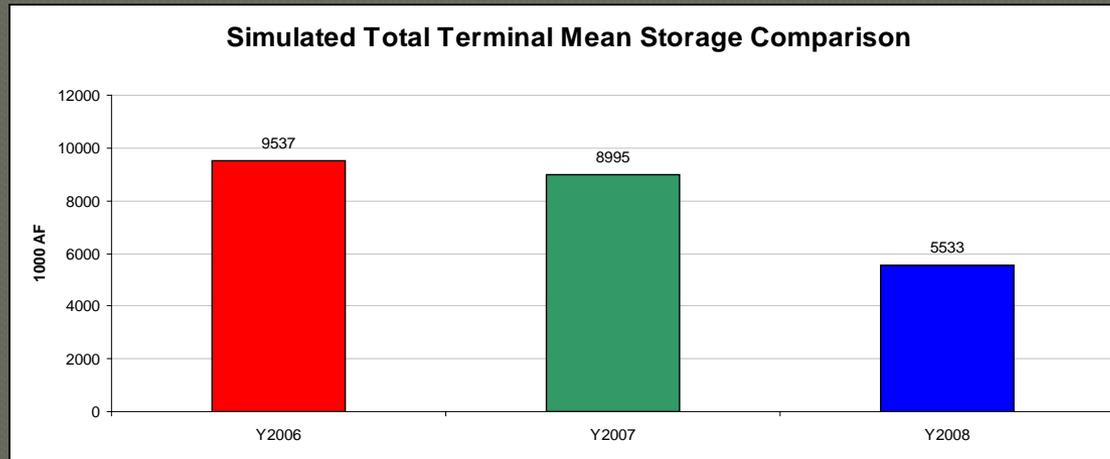
### Water Deliveries vs. Carry over Storage vs. Energy Tradeoffs



# Results and Assessments

## Decision Support

### Mean Carry Over Storage and Energy Comparisons: 50% Base Demand



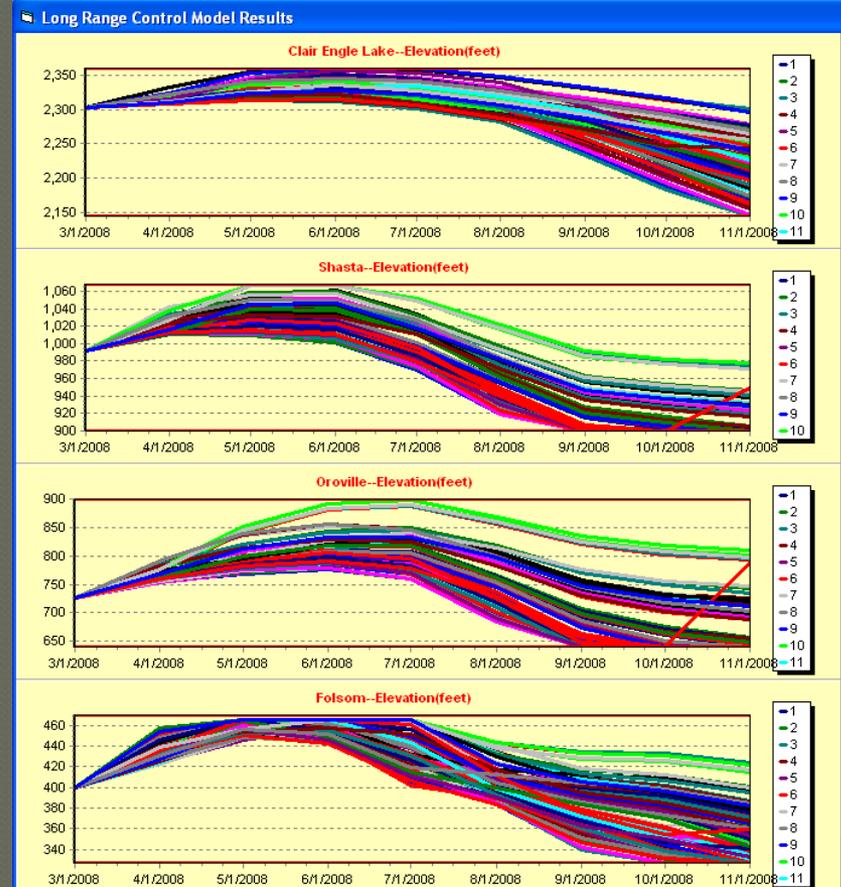
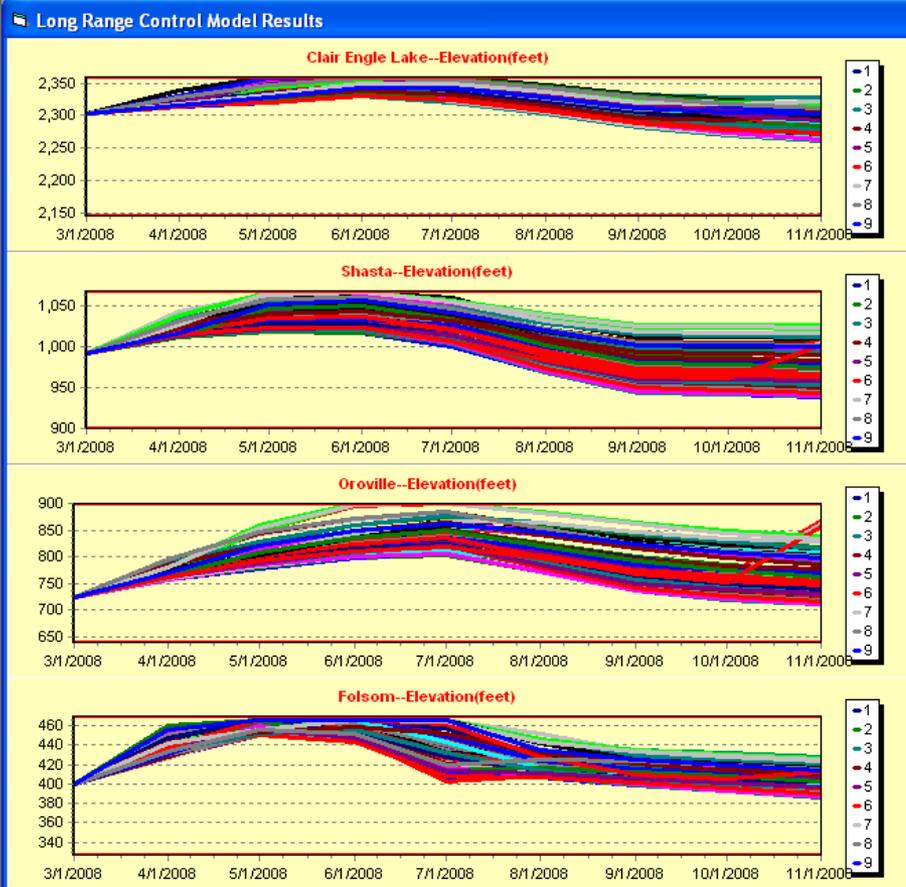
# Results and Assessments

## Decision Support

### Lake Level Forecast Ensembles: 2008

#### 10% Base Demand

#### 50% Base Demand

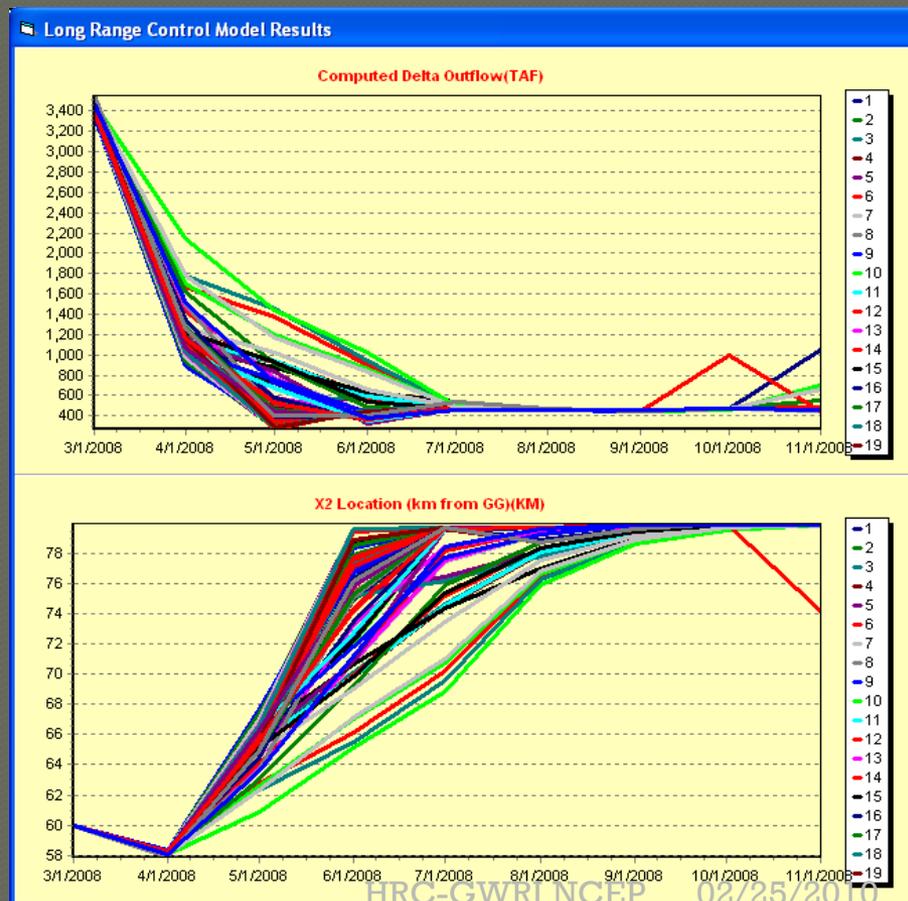


# Results and Assessments

## Decision Support

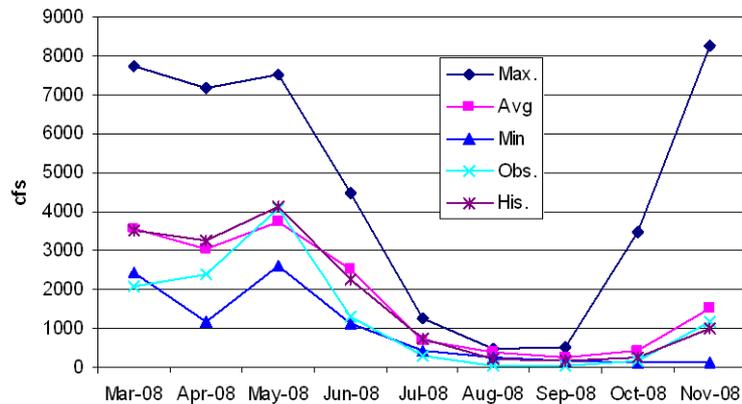
### X2 Location Forecast Ensembles: 2008

10% Base Demand

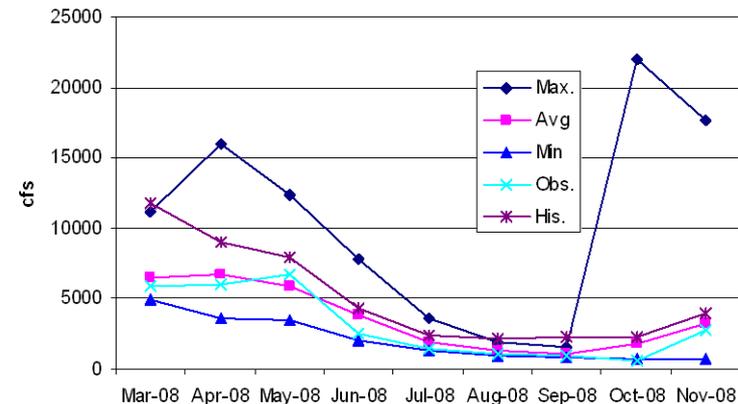


# Independent Evaluation by the California Energy Commission January 2009

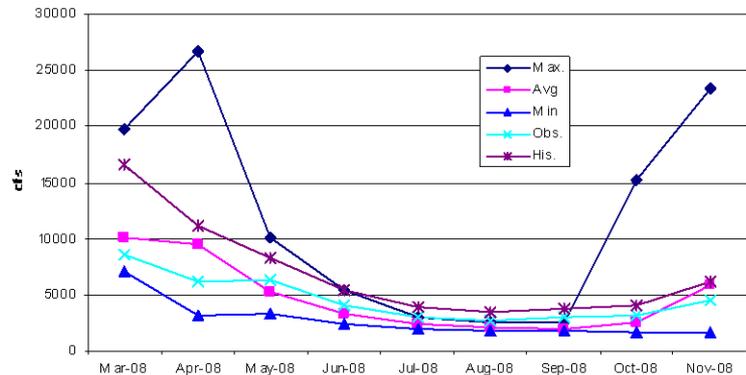
2008 Forecasts; Trinity



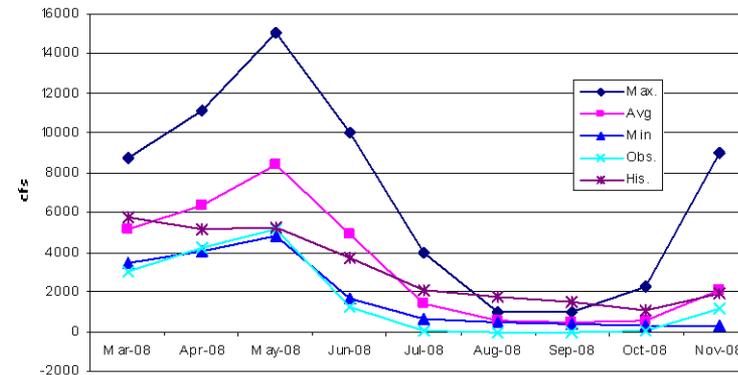
2008 Forecasts; Oroville



2008 Forecasts; Shasta

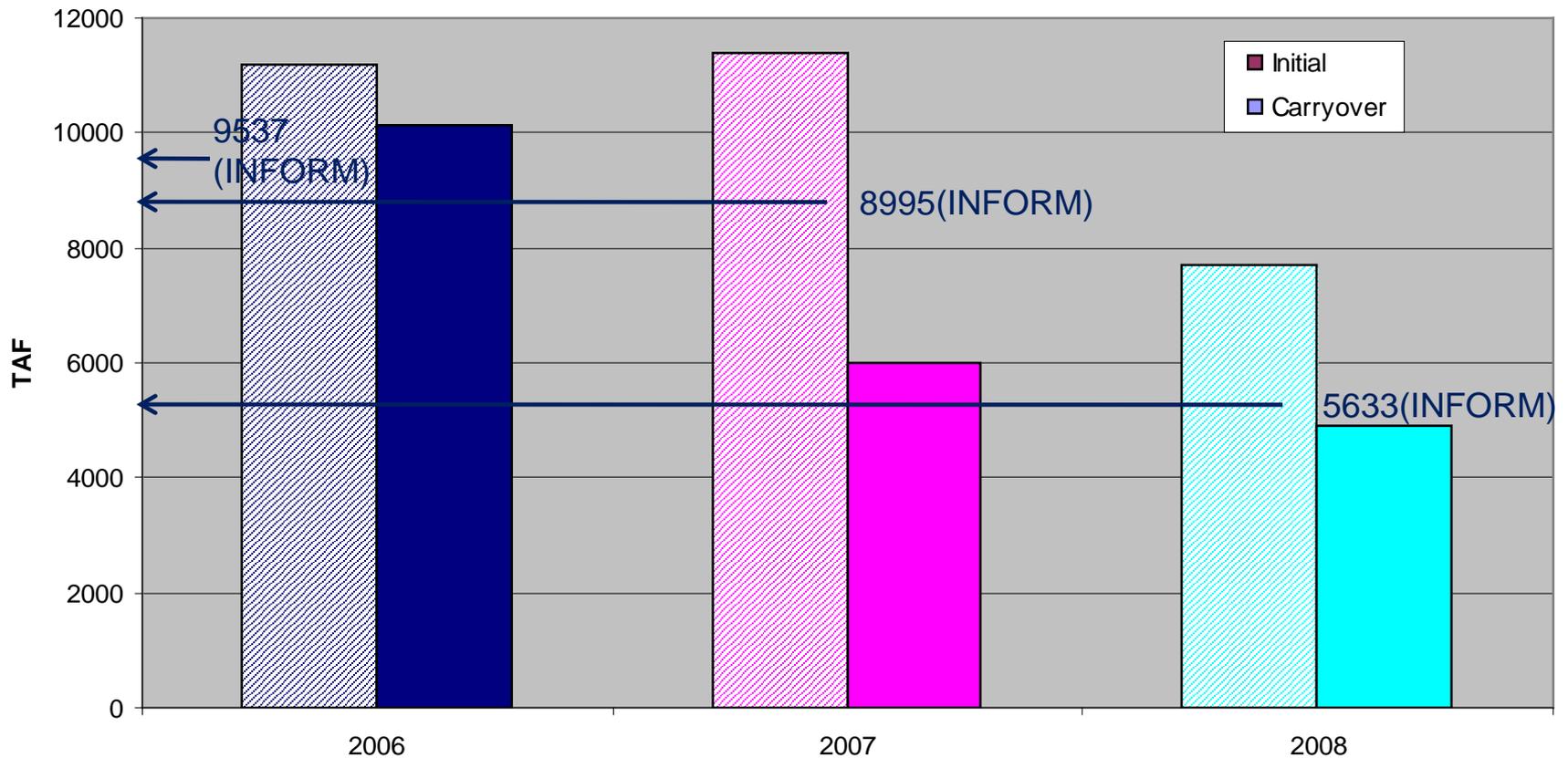


2008 Forecasts; Folsom



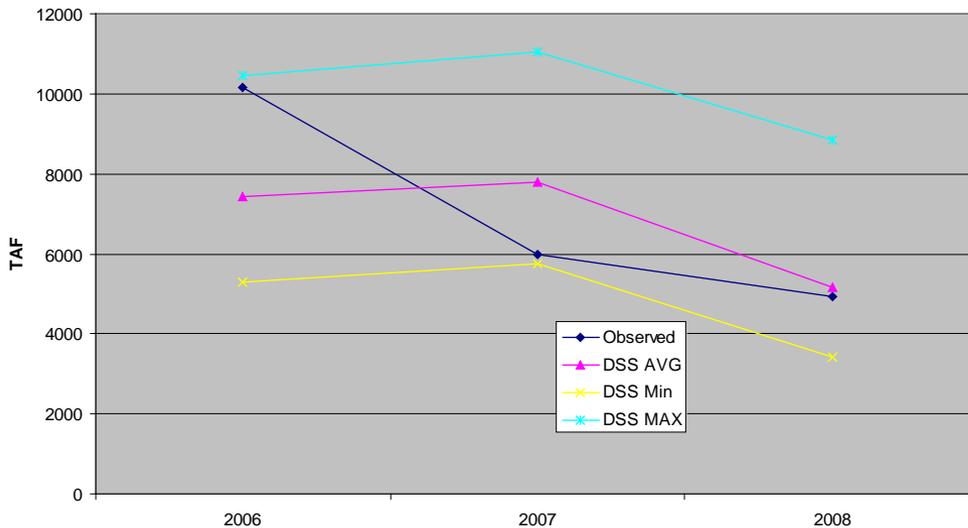
# Independent Evaluation by the California Energy Commission January 2009

## System Carryover Storages of Major Reservoirs

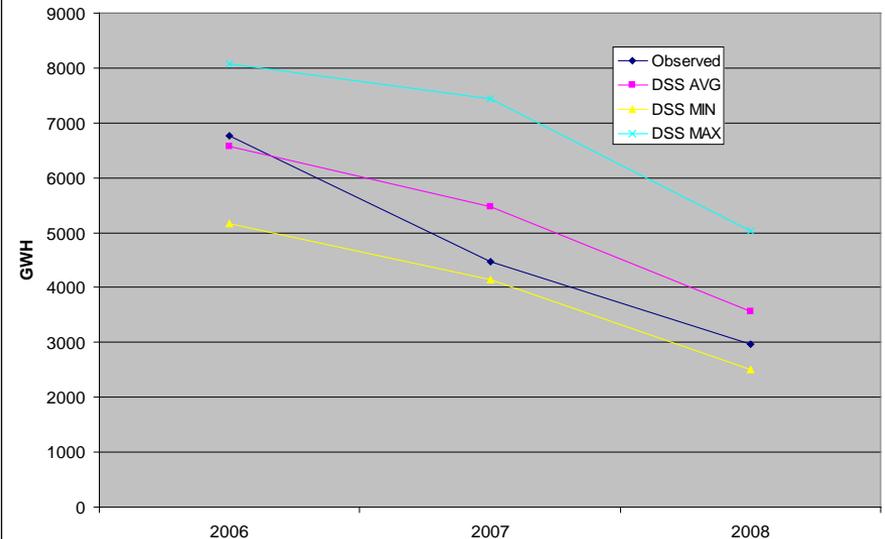


# Independent Evaluation by the California Energy Commission January 2009

Carryover Storage Comparisons



Energy Generation from Major Plants



Relevant and decision worthy – Energy Commission funded Phase II

High Visibility and Impact Project for Forecast and Management Agencies in California

# 3-D CFS Experiments - Rationale

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## **Objective:**

Test Utility of using dynamic downscaling beyond 16 days

## **Why?**

So that physically consistent and coherent events produced by the CFS are downscaled in a way that preserves significant precipitation or warming episodes in the watersheds of interest

## **Potential Benefit:**

Reduce uncertainty bounds for significant episodes for forecast lead times out to 30 – 45 days.

# 3-D CFS Experiments - Data

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NCEP Data (Ken Mitchell and Rongqian Yang – thank you):

*Two case studies:*

16 CFS runs with start dates at twelve-hourly intervals extending 45-days each

*Case A:*

CFS run period 12/02/2005-12/09/2005

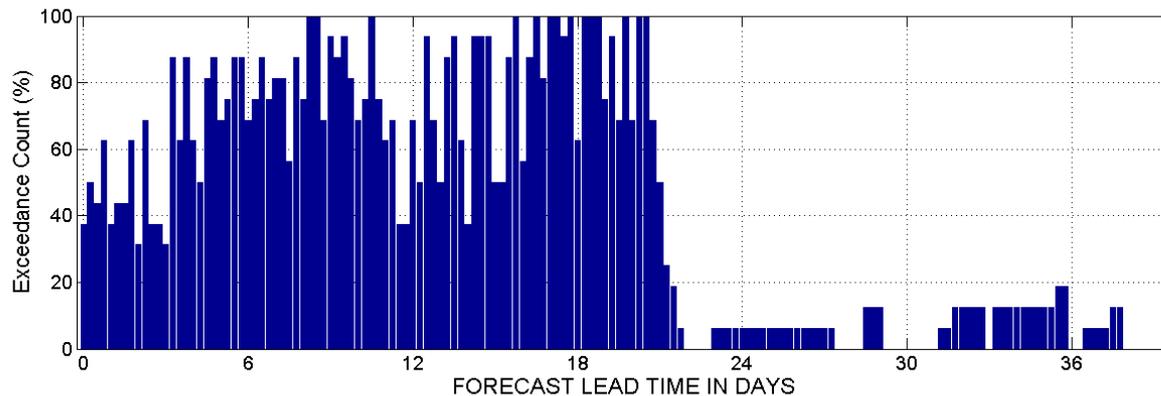
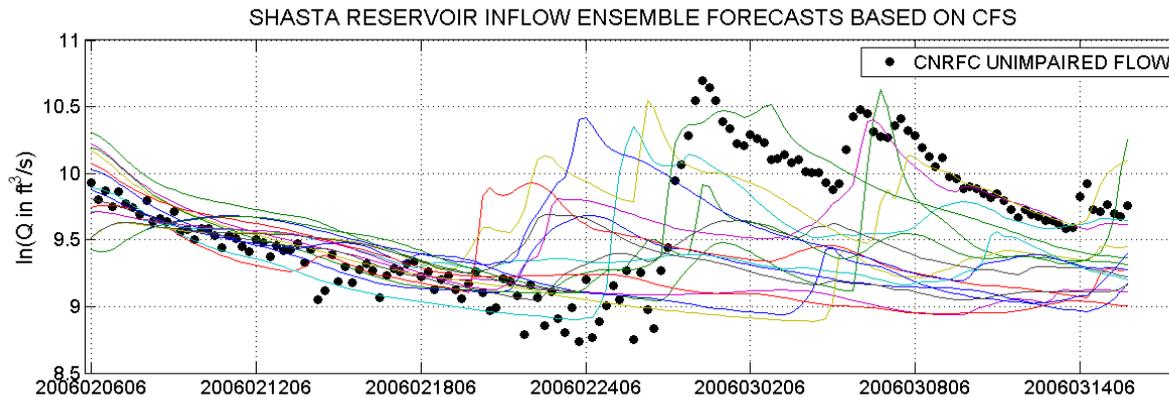
INFORM forecast evaluation period 12/09/2005 06Z – 01/16/2006 00Z

*Case B:*

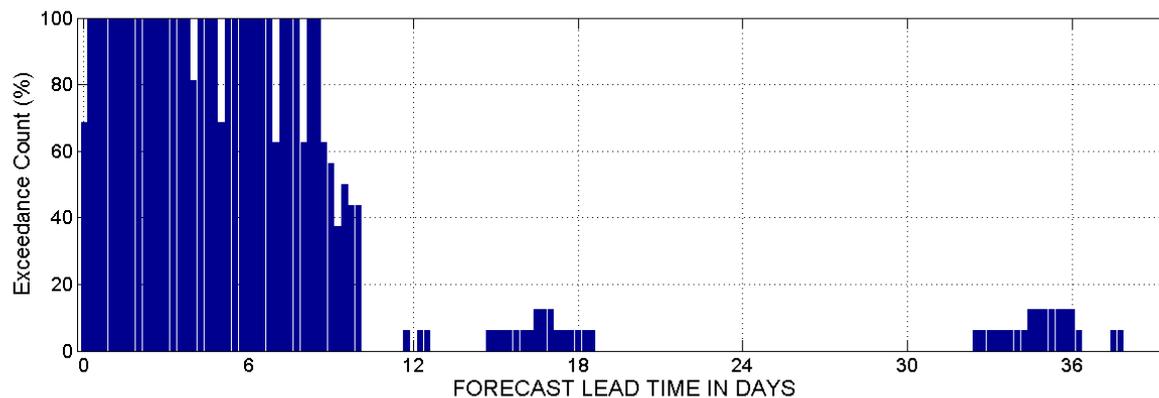
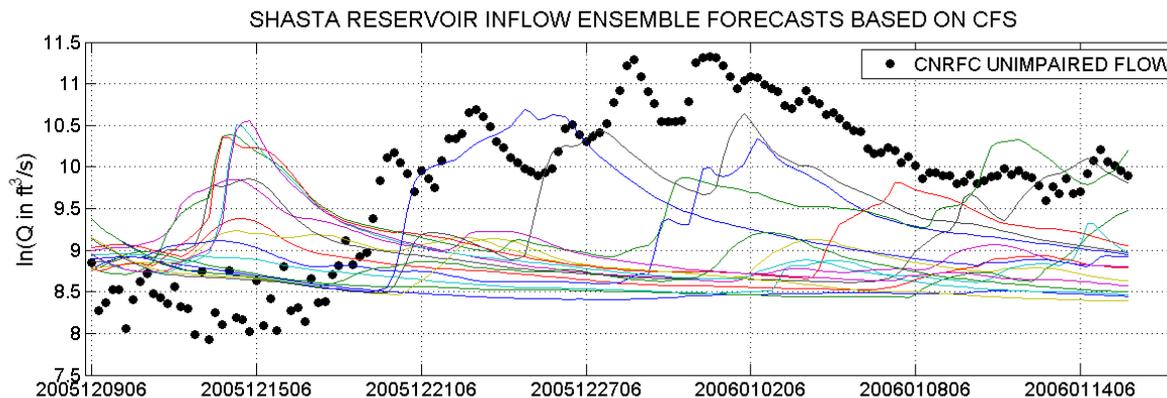
CFS run period 01/30/2006-02/06/2006

INFORM forecast evaluation period 02/06/2006 06Z – 03/16/2006 00Z

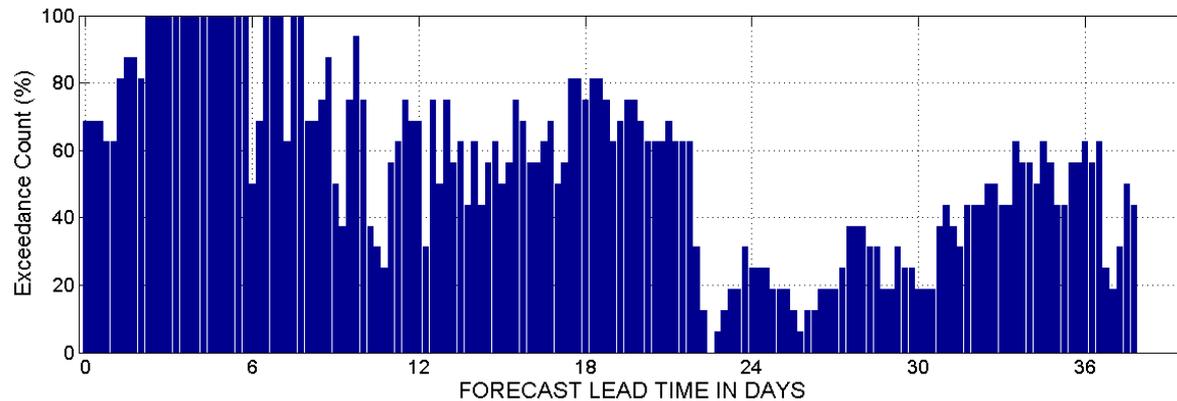
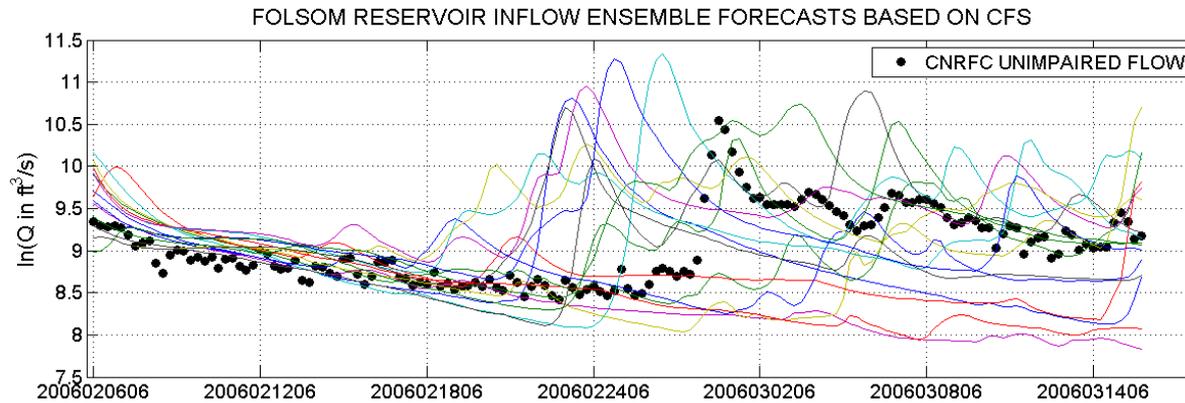
# 3-D CFS Experiments - Results



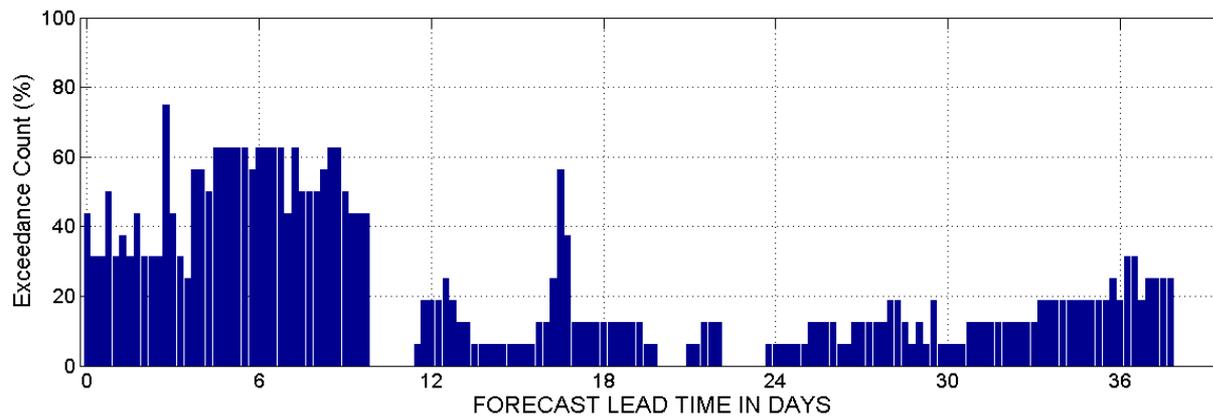
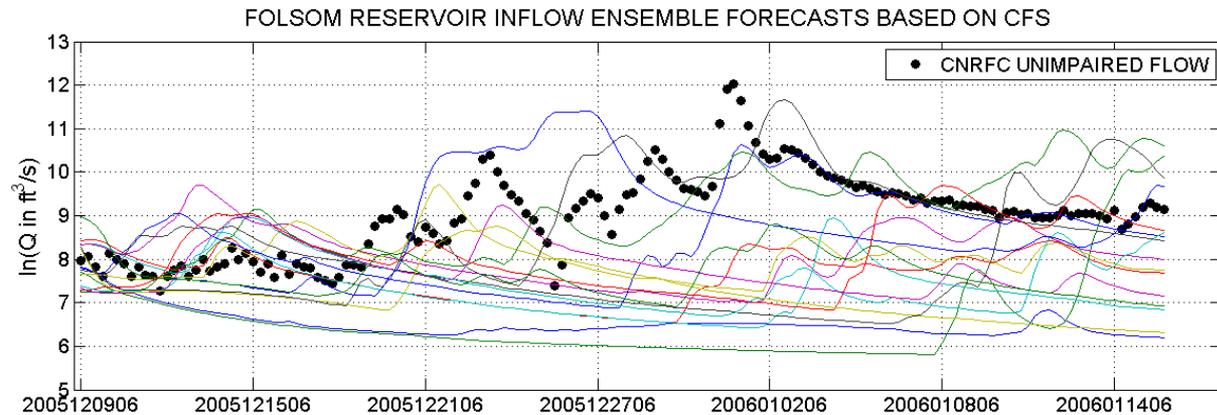
# 3-D CFS Experiments - Results



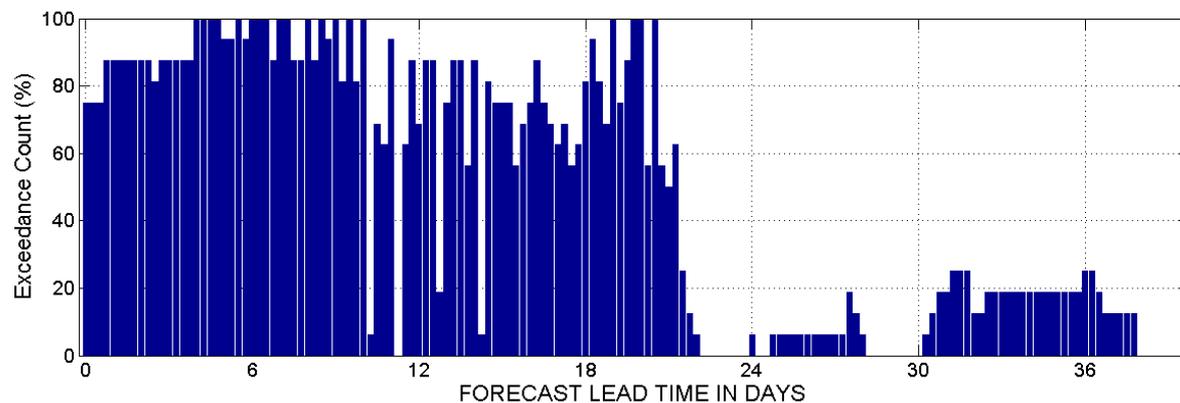
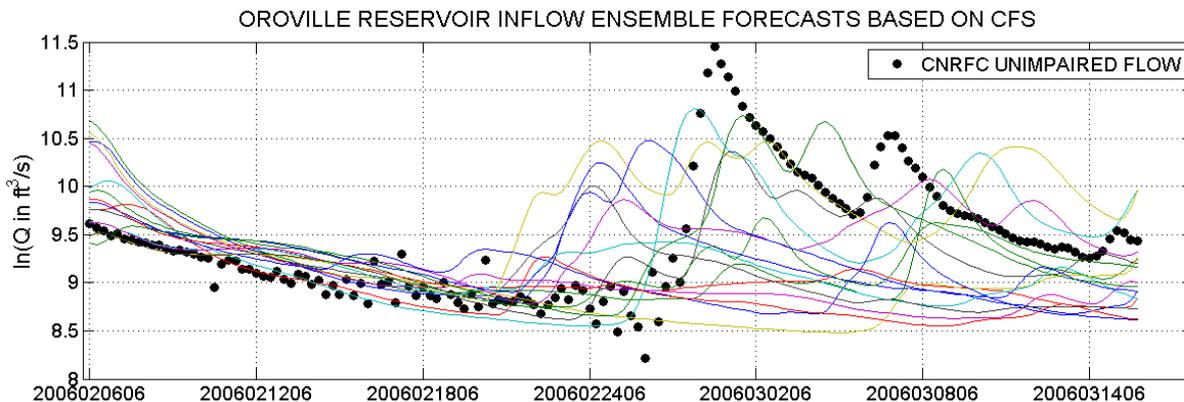
# 3-D CFS Experiments - Results



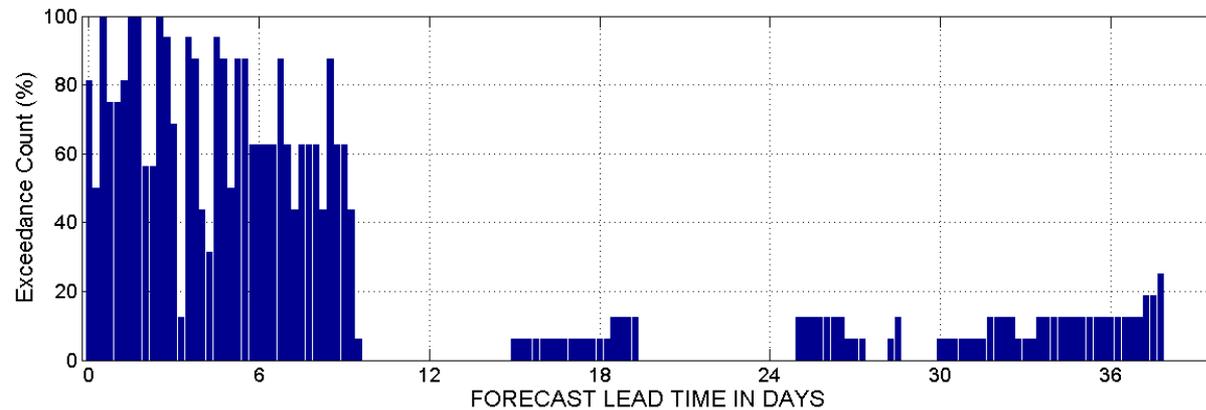
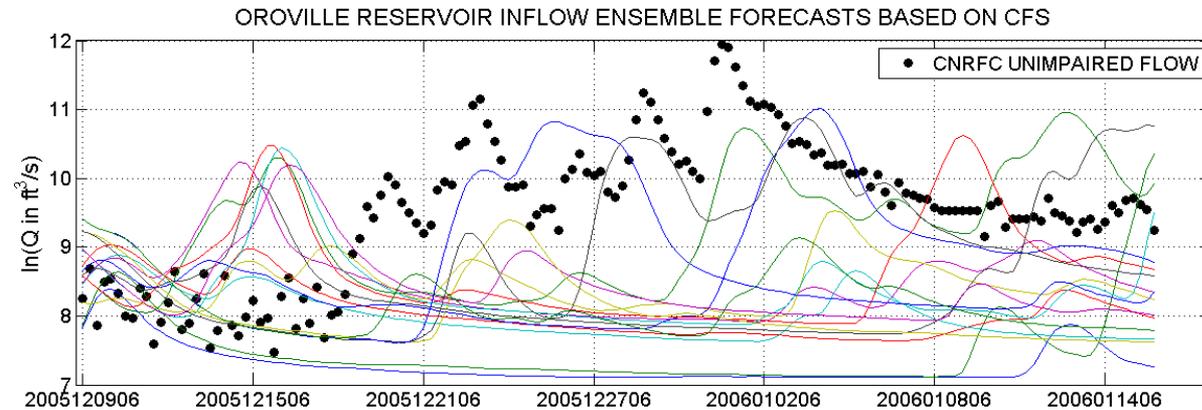
# 3-D CFS Experiments - Results



# 3-D CFS Experiments - Results



# 3-D CFS Experiments - Results



# Phase II Plans for Forecast Components

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- **Upgrade and implementation of INFORM multicomputer platform** to allow timely processing of 20 GFS ensembles for better statistical estimation of uncertainty
- Development of **bias adjustment procedures** that combine physical model improvements and statistical methodologies (benefits to all leads)
- **Utilization of 3-D CFS fields to produce downscaling of precipitation and temperature products commensurate with those from GFS (benefits to 16 – 30/45 day forecasts)**
- **Continued validation of system forecasts and demonstration assessments**

# Present Use of 3-D CFS Data

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Available data not directly usable for dynamic downscaling (e.g., only Precipitable water is available for downloading)

For INFORM we developed a post-processor to convert the available data to level data usable with INFORM dynamic downscaling models (very Approximate and temporary until 3-D CFS data becomes available)

Issues of transmission from NCEP to HRC and CNRFC in California

# OAKLAND RADIOSONDE DATA MONTHLY 1981-2004

$Y_{OB}$  as in CFS

$Z_{OB}$  (for downscaling)

	Z	U	V	P.WAT
1000	X			
850	X	X	X	
700	X	X	X	
500	X	X	X	
200	X	X	X	
N/A				X

  
 EOF > EOF  
 regression

	Z	T	Q	U	V
1000	X	X	X		
850	X	X	X	X	X
700	X	X	X	X	X
500	X	X	X	X	X
400	X	X	X	X	X
200	X	X		X	X

BY MONTH:

- CALCULATE & SAVE MONTHLY MEANS, STD. DEV.
- REMOVE MEANS, STANDARDIZE DATA ->  $Y^*$  &  $Z^*$
- CALCULATE EOFs OF  $Y_{OB}$  &  $Z_{OB}$
- GET  $\alpha, e$  s.t.  $Y^* = \alpha e^t$  and  $\beta, f$  s.t.  $Z^* = \beta f^t$

LINEAR REGRESSION:  $\hat{Z} = A Y^*$

with  $A = e^t C^t f$  and  $C = \langle \alpha \beta \rangle / (\langle \alpha^2 \rangle^{1/2} \langle \beta^2 \rangle^{1/2})$  (orthogonality)

SAVE A (monthly regression coefficients;

hindcast skill ~ 0.8-0.9 for Q 850 and 700

CFS DATA - MONTHLY 1981-2004  
LEAD TIMES OUT TO 60 days, 12 hourly

AVAILABLE CFS

	Z	U	V	P.WAT
1000	X			
850	X	X	X	
700	X			
500	X			
200	X			
N/A				X

GEOSTROPHY  
→

AUGMENTED CFS = Ycfs

	Z	U	V	P.WAT
1000	X			
850	X	X	X	
700	X	X	X	
500	X	X	X	
200	X	X	X	
N/A				X

BY MONTH:

- CALCULATE & SAVE MONTHLY MEANS, STD. DEV. OF Ycfs

Then, for each sounding out to 60 days lead time:

-REMOVE MEANS, STANDARDIZE -> Y\*cfs

- USE REGRESSION COEFFICIENTS  $\hat{Z}^*cfs = A Y^*cfs$

-TRANSFORM  $\hat{Z}^*cfs$  to observations using OBS means and STD DEVS

# Conclusions Relevant to NCEP

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Operational **GFS and CFS forecast** information is shown to have **beneficial impact** for regional water resources planning and management in Northern California **if used** within the integrated forecast and reservoir management procedures of INFORM

But there are **improvements** needed for **adoption in operational use**:

Availability of CFS forecasts out to 45 days **in form suitable for use with dynamic downscaling procedures**

Improved **method of delivery to CNRFC** of real-time ensemble forecast products (both GFS and CFS) for use in the INFORM system