



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

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The Means

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

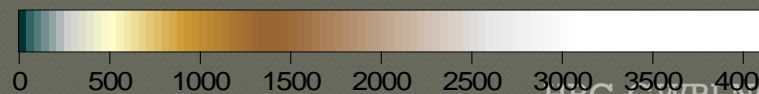
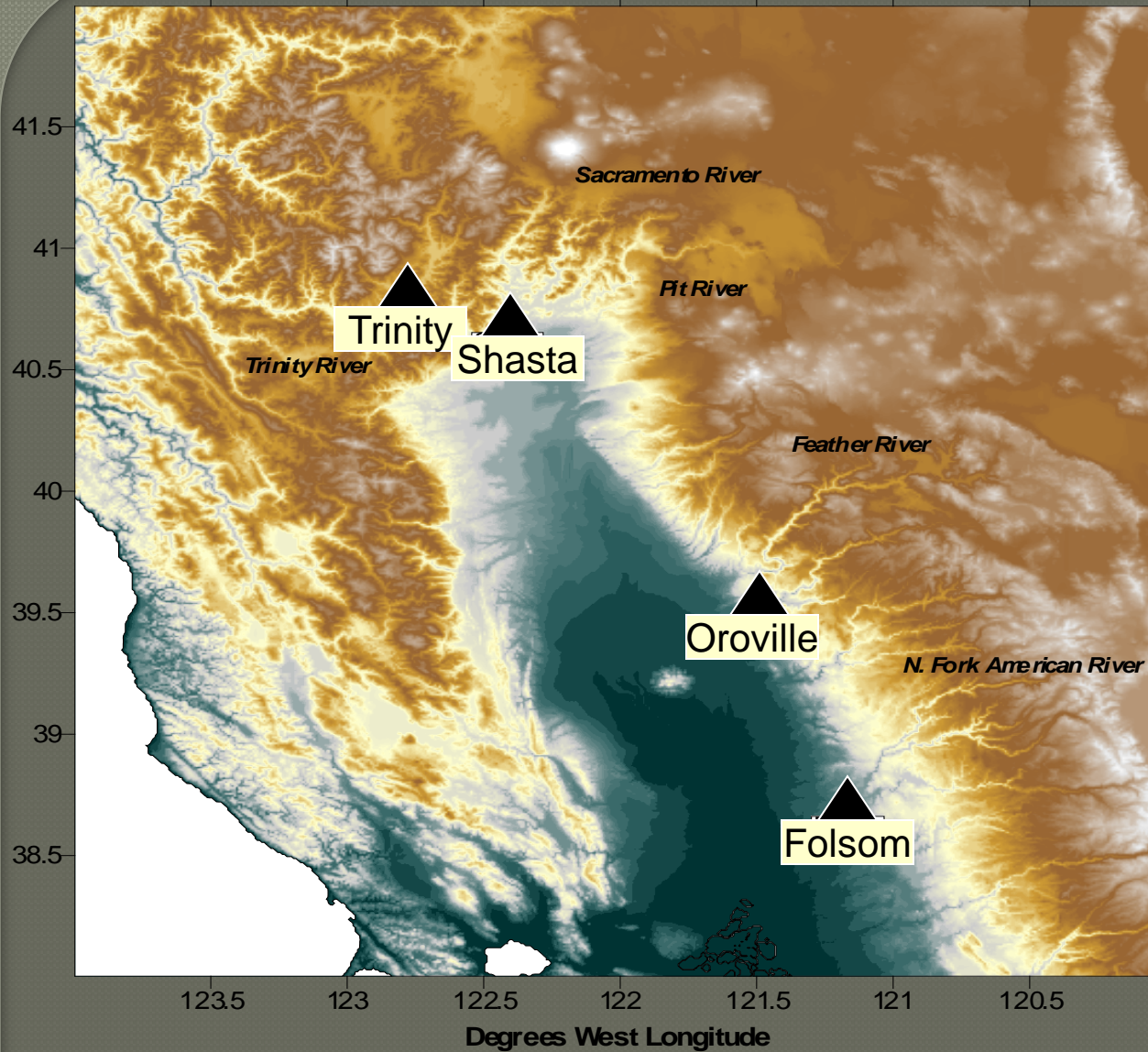
- Increase efficiency of water use in Northern California using climate, hydrologic and decision science

Goal and Objectives

- 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

Degrees North Latitude



Elevation (meters)

Application
Area

HRC-GWRINCEP

02/25/2010

SPONSORS-COLLABORATORS

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

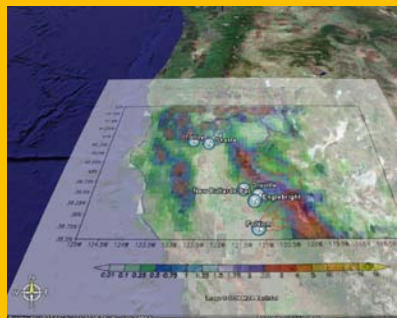
- HRC-GWRI, 2006. *Integrated Forecast and Reservoir Management (INFORM) for Northern California: System Development and Initial Demonstration*. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2006-109, 244pp. and 9 Appendices

http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2006-109.html

http://www.hrc-lab.org/projects/dsp_projectSubPage.php?subpage=inform

INFORM Modeling Framework

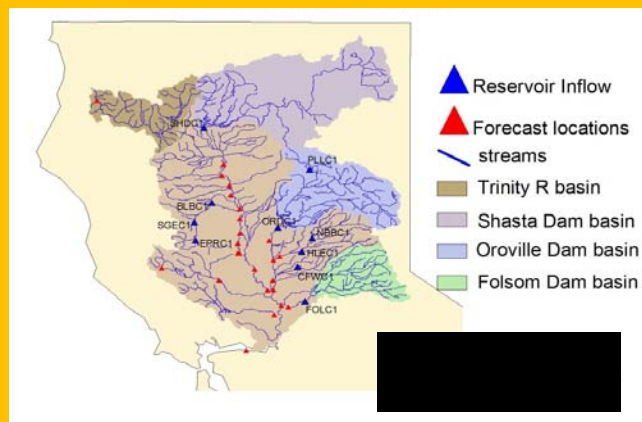
GFS & CFS INPUT Downscaling



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

Watershed Hydrology

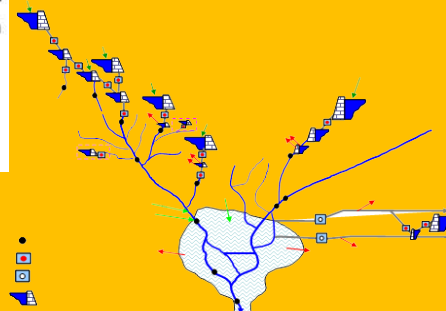
Simulate soil moisture, evapotranspiration, runoff, and streamflow.



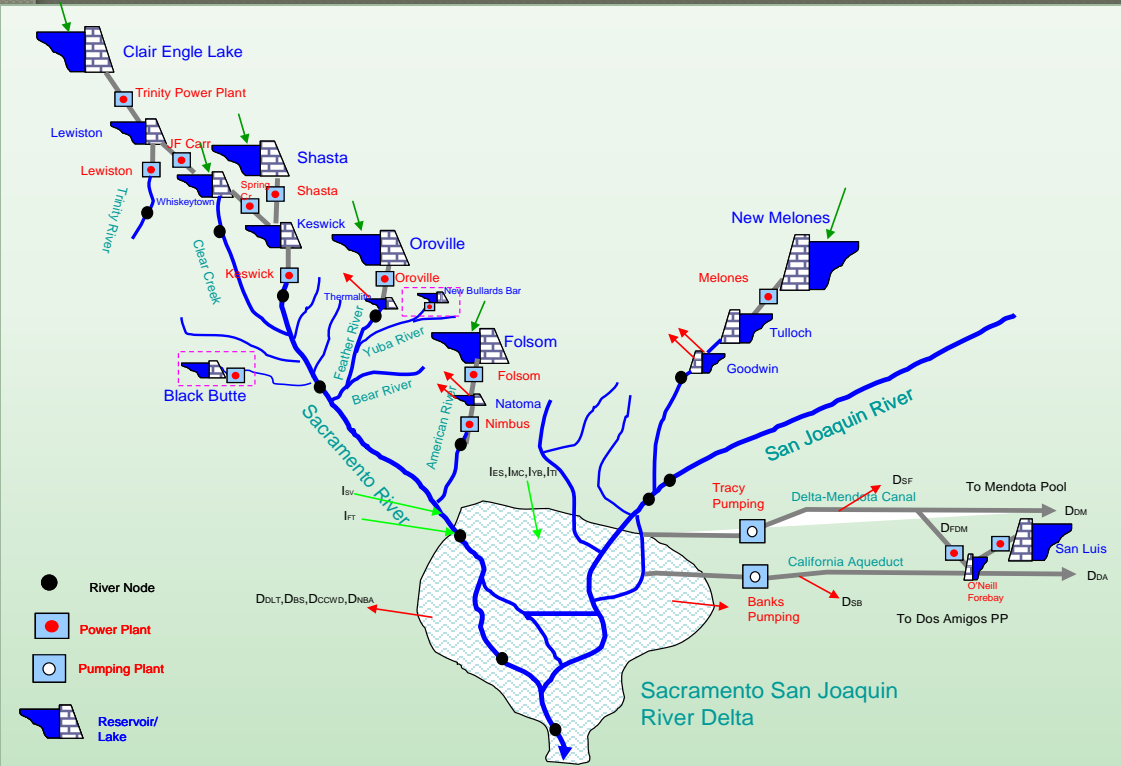
River/Reservoir Planning & Management

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

Economic and other benefits



Reservoir Modeling System



Objectives:
 Water Supply
 Energy Generation
 Environment
 Ecology
 Recreation

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

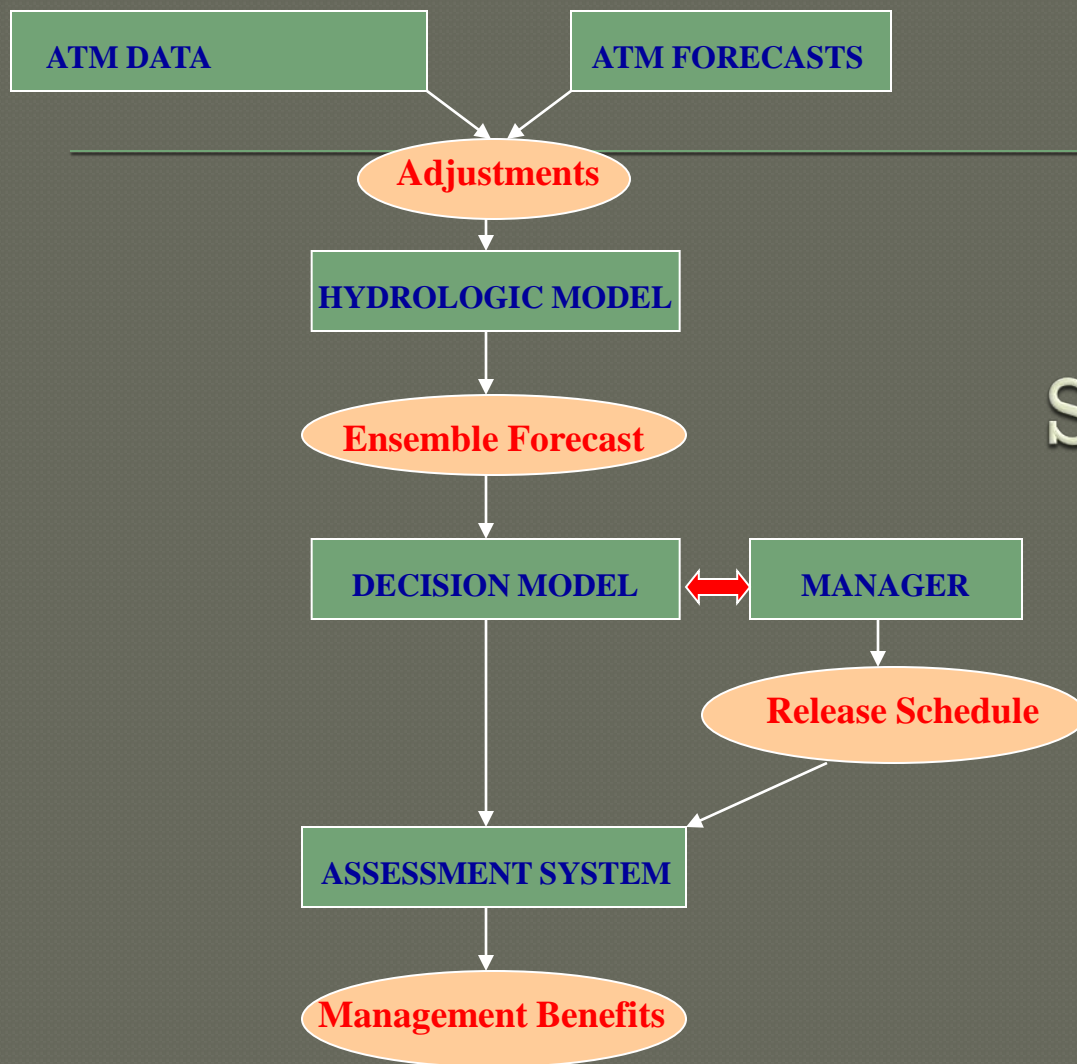
Shasta Lake System (Shasta Lake, Shasta Power Plant, Keswick Lake, Keswick Plant, and the river reach from Keswick to Wilkins);

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);

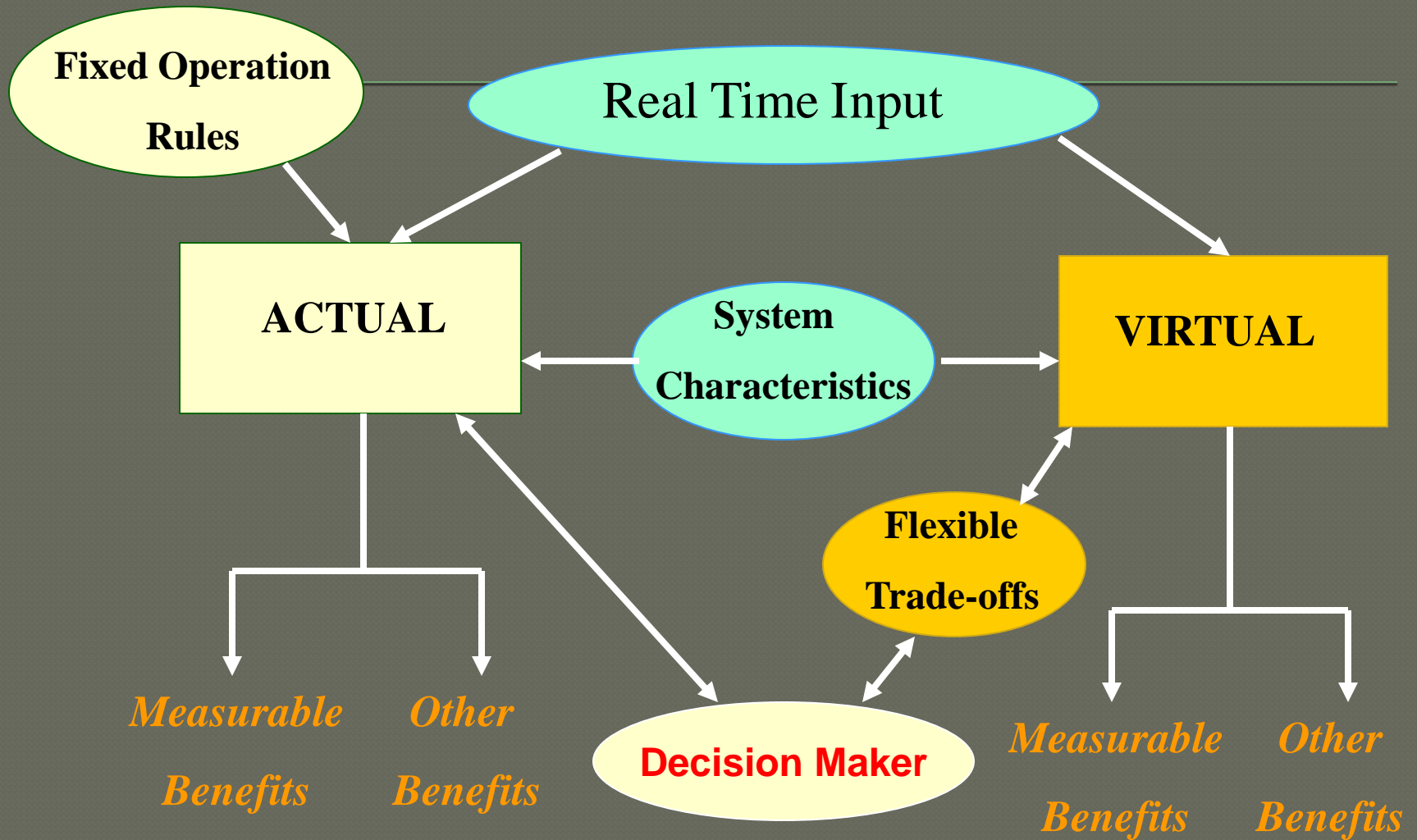
San Joaquin River System (New Melones Lake, New Melones Power Plant, Tulloch Lake, Demands from Goodwin, and Inflows from the main San Joaquin River); and

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

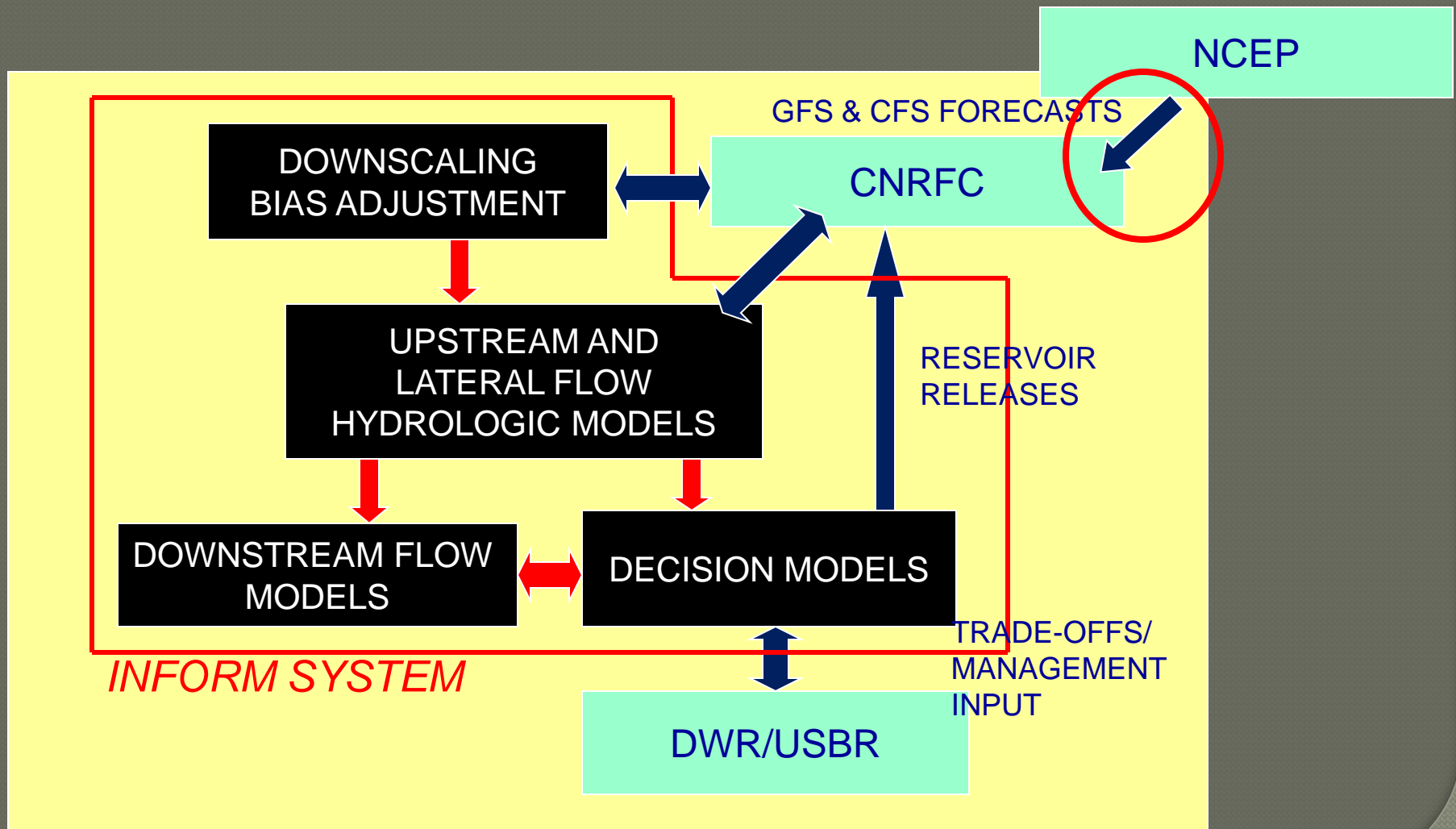


Integrated System Diagram

Demonstration Concept

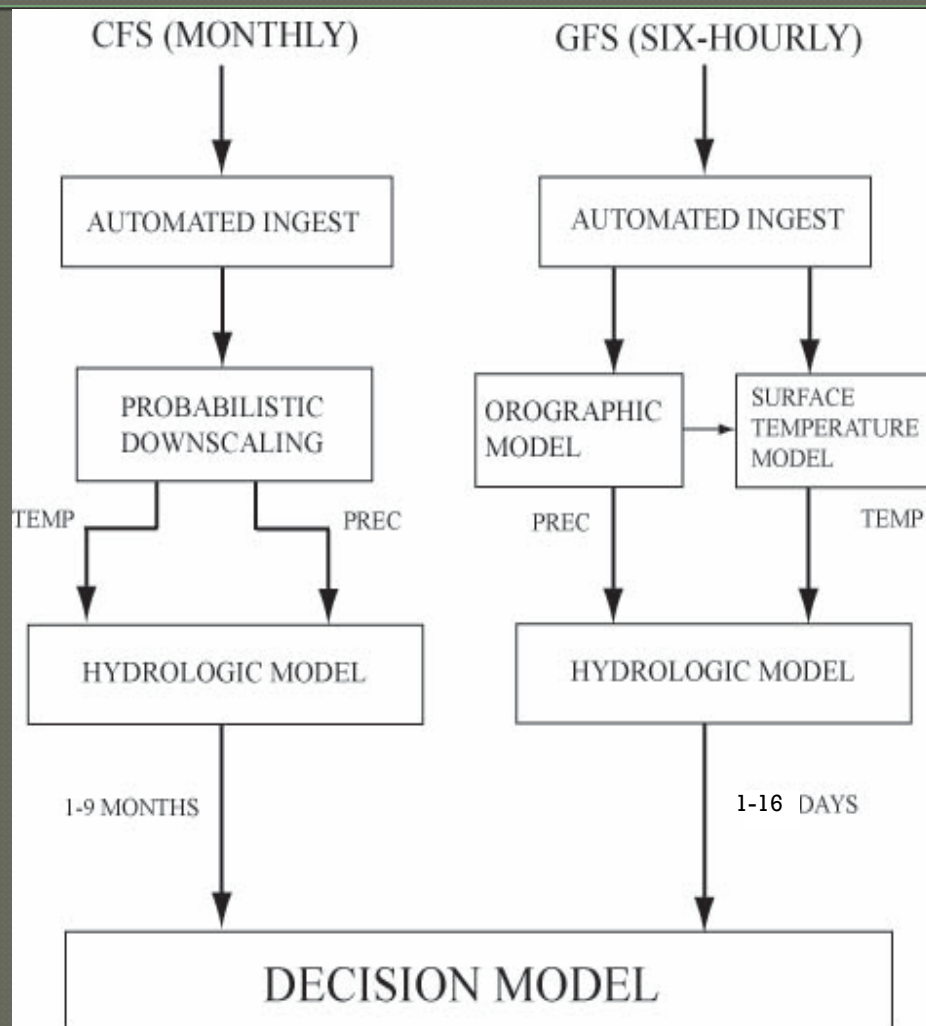


Operational Processing and Data Links



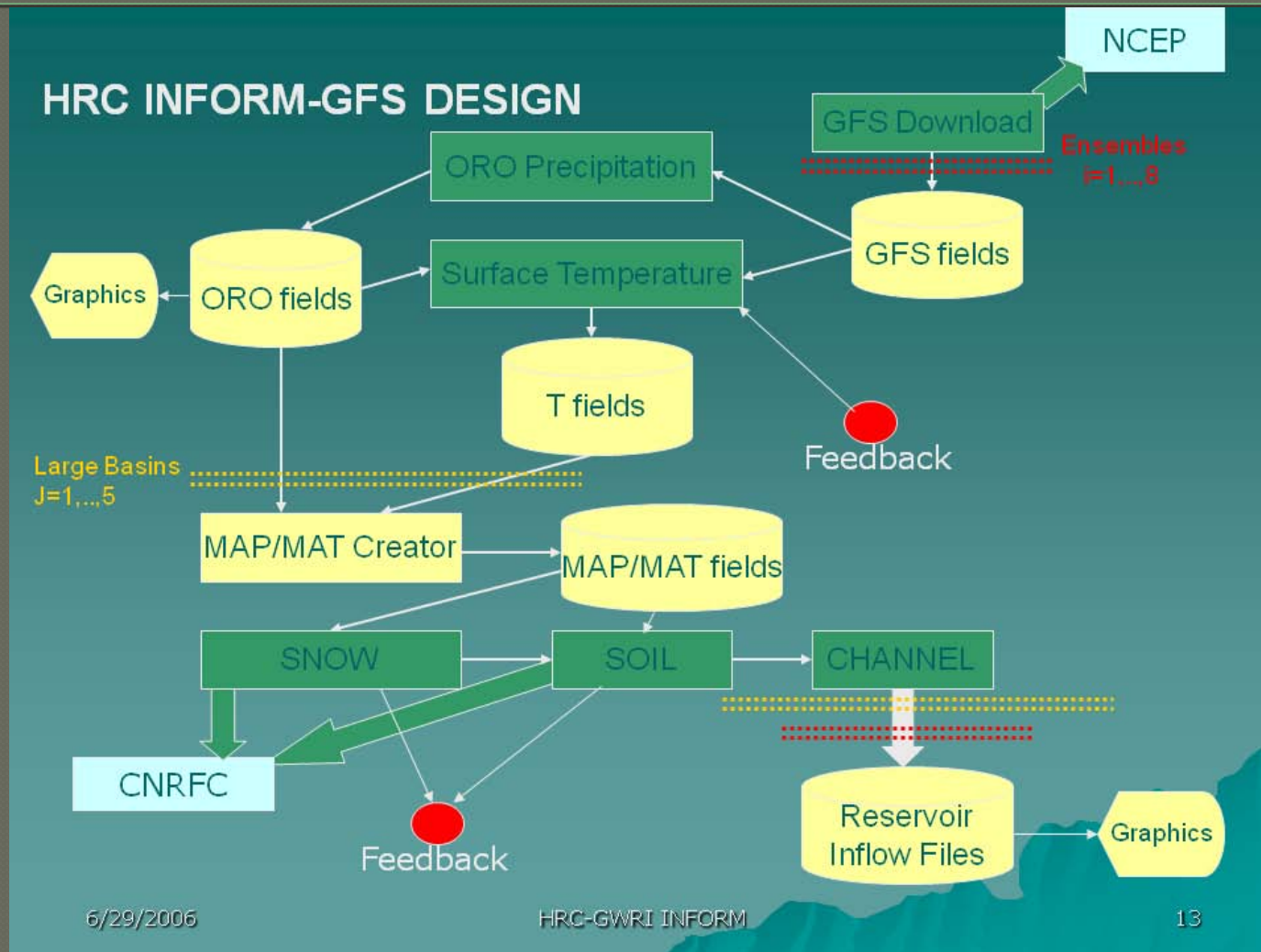
Results and Assessments

Forecasts



Results and Assessments

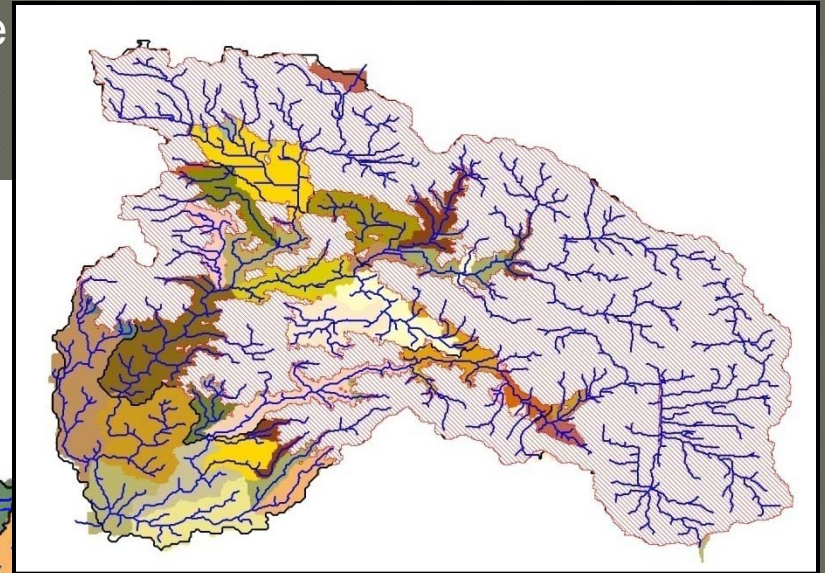
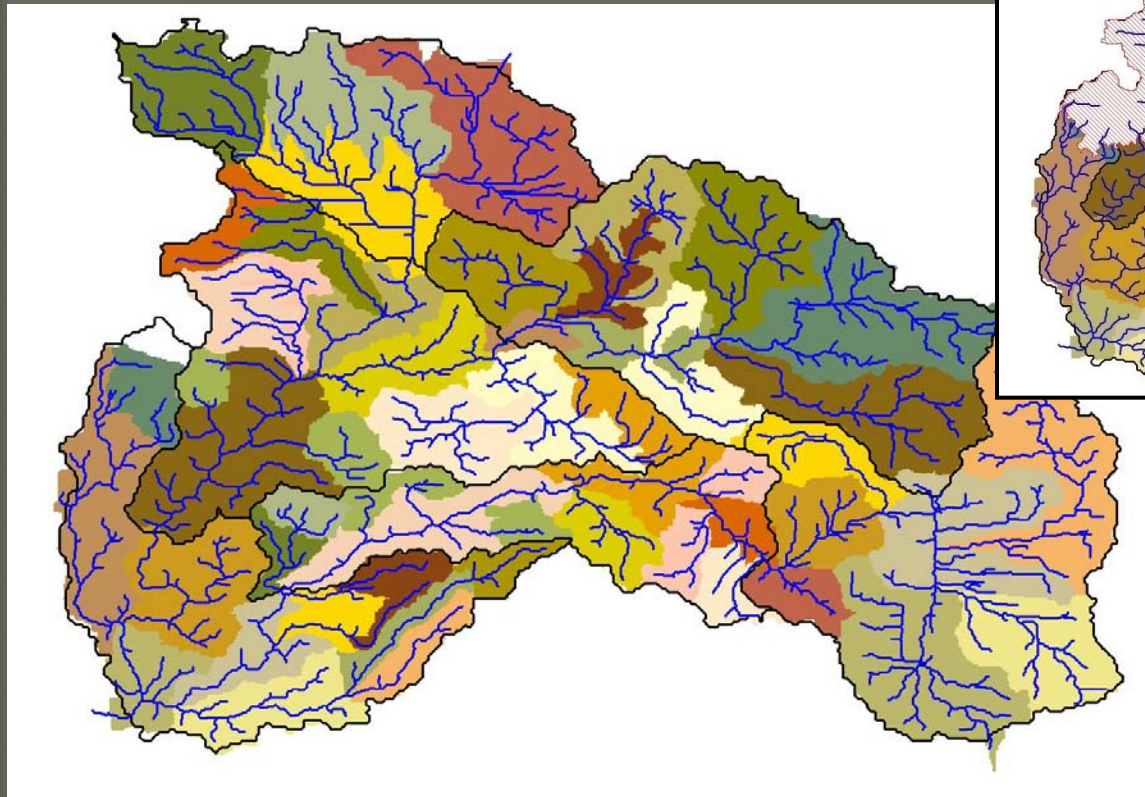
Forecasts



Results and Assessments

Forecasts

Distributed Tributary Basin System for Oroville
Example of INFORM Hydrology Modeling



Results and Assessments

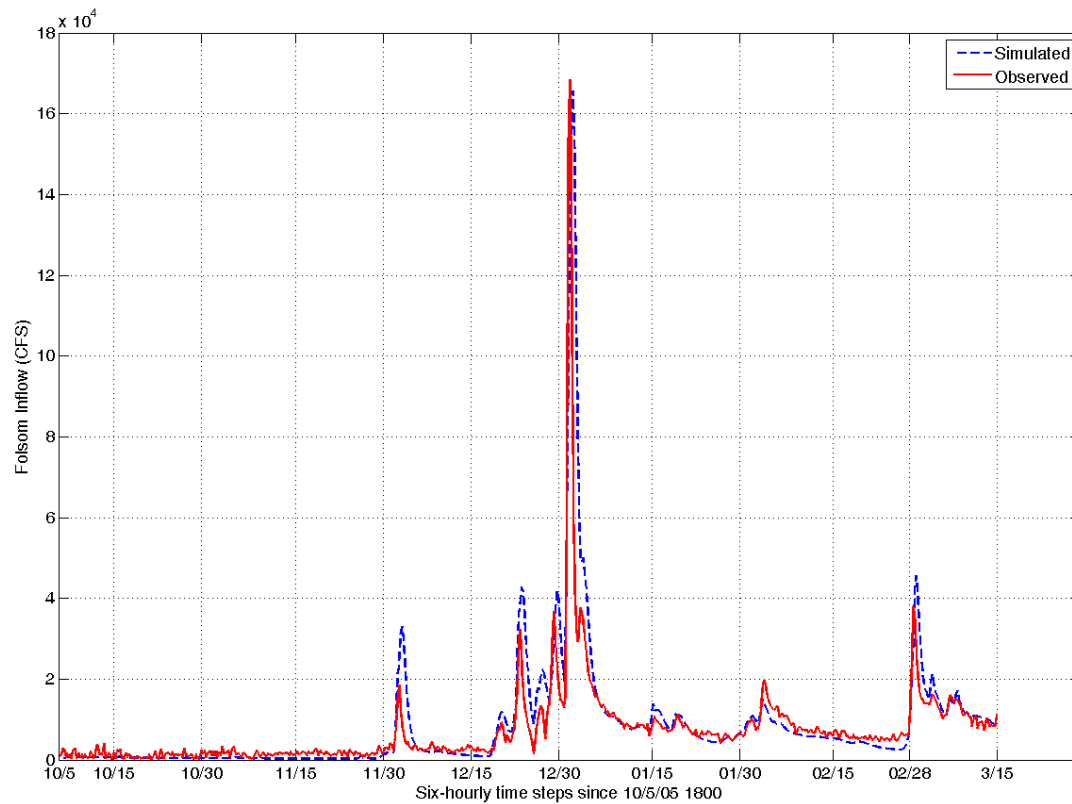
Forecasts

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

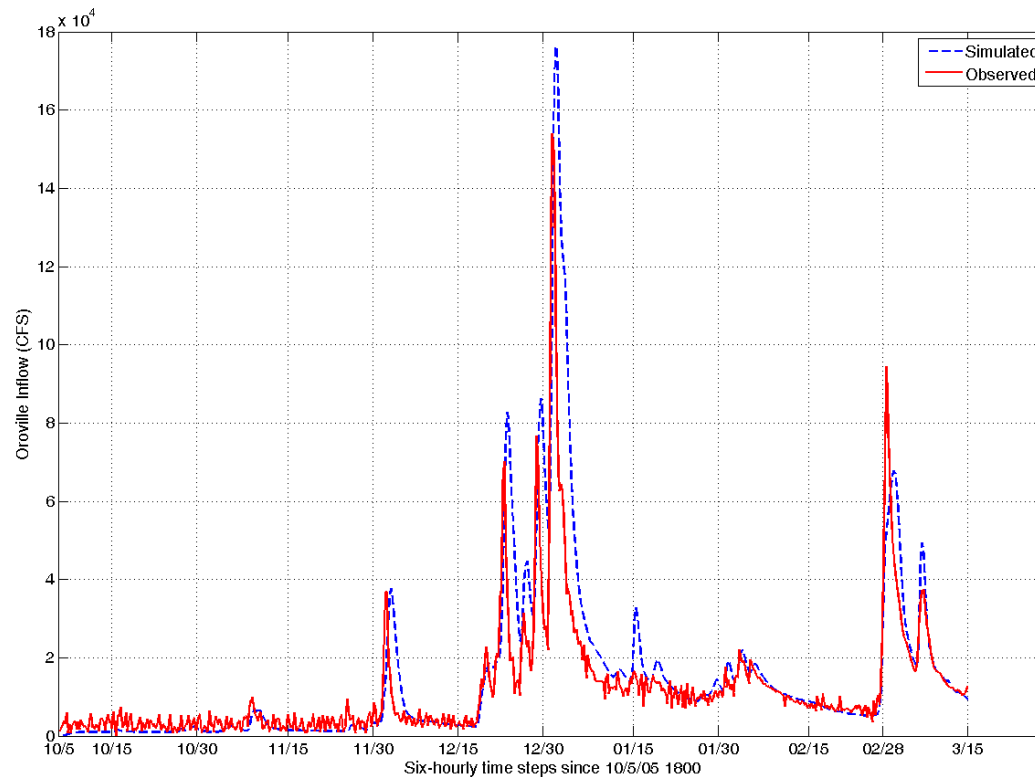
Forecasts



Folsom
Simulation

Results and Assessments

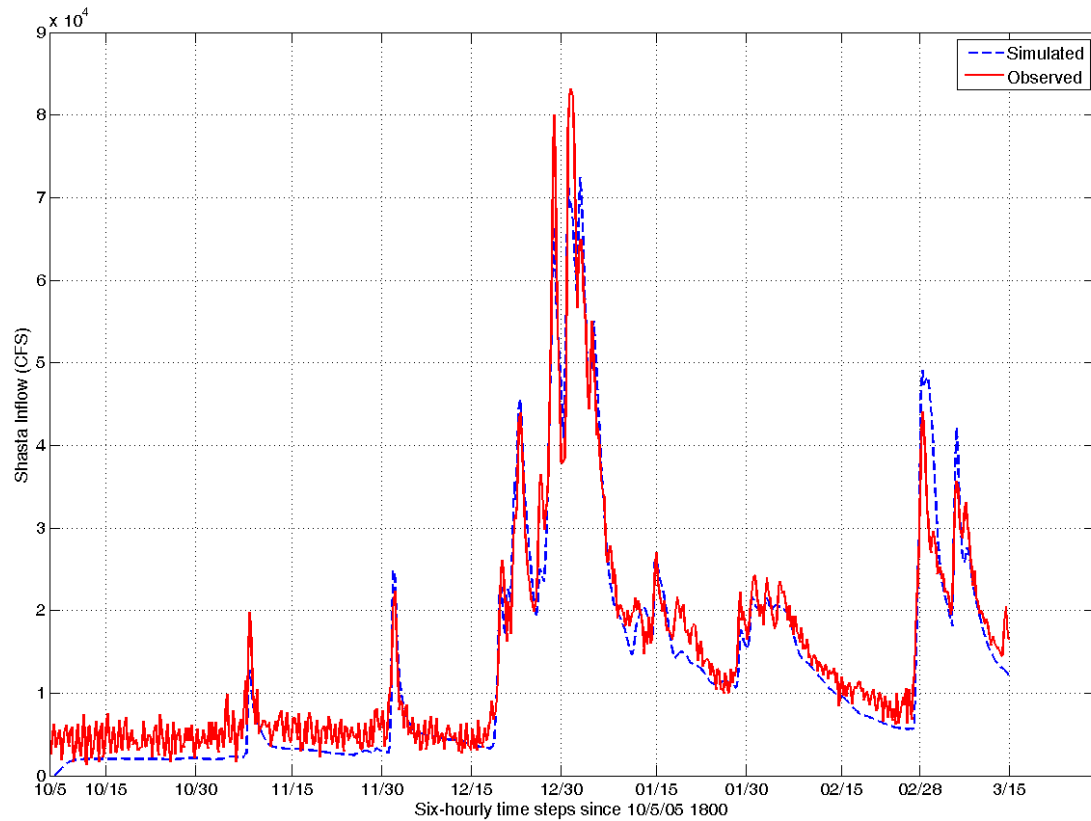
Forecasts



Oroville
Simulation

Results and Assessments

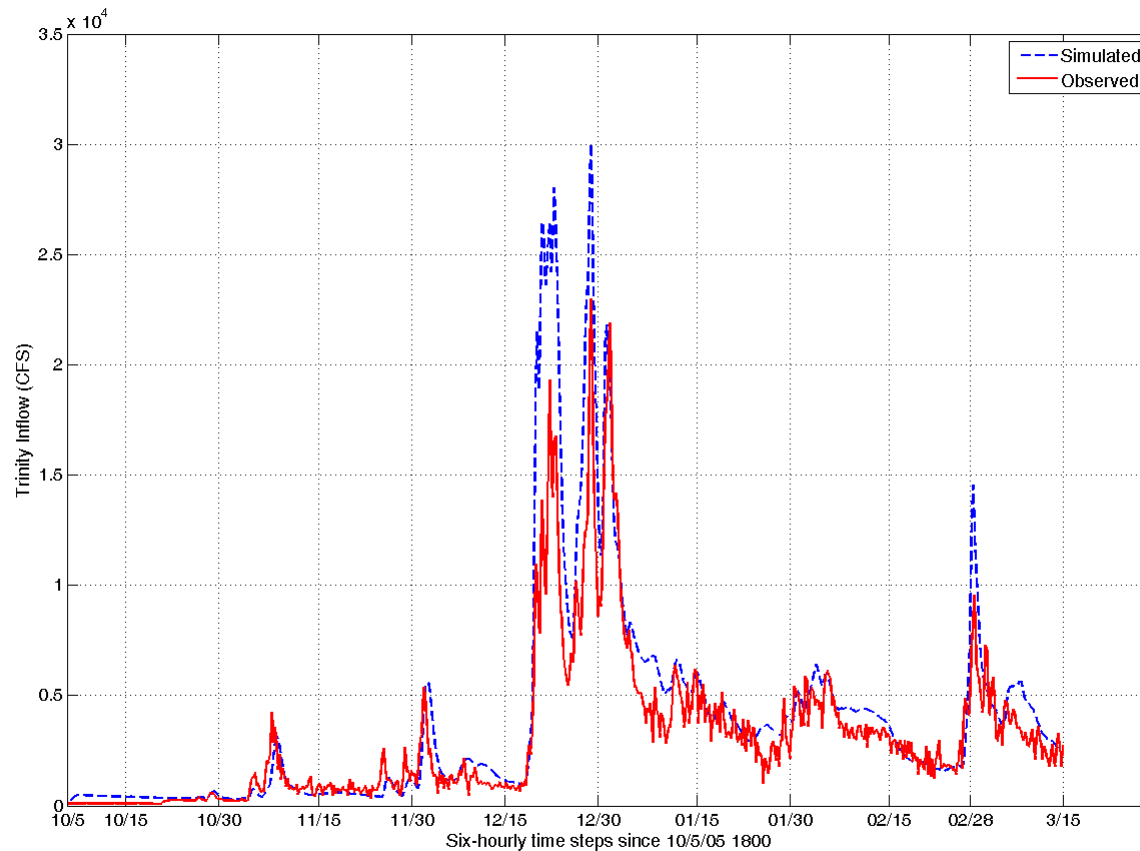
Forecasts



Shasta
Simulation

Results and Assessments

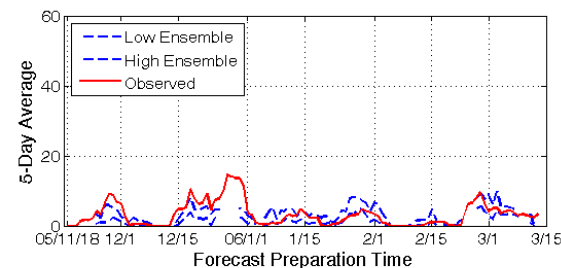
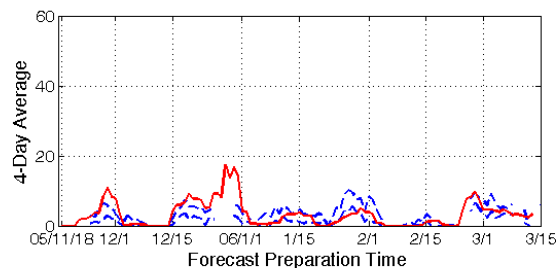
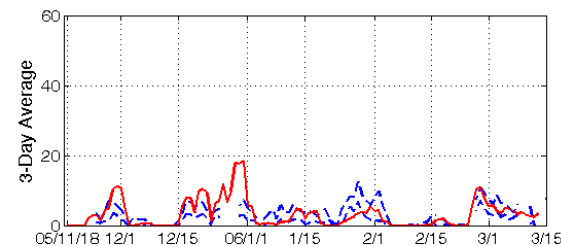
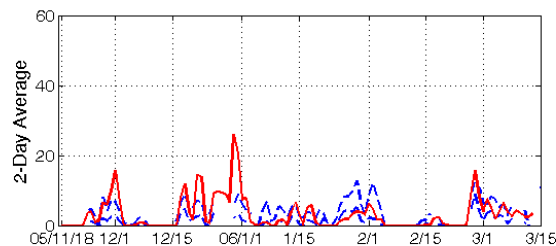
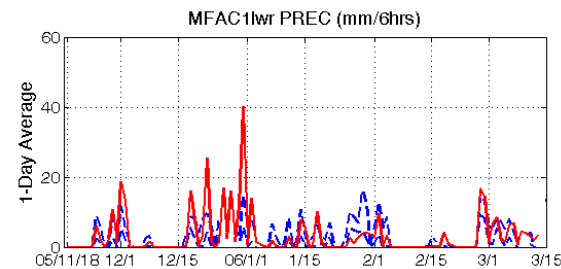
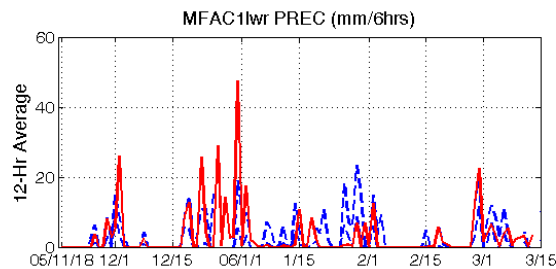
Forecasts



Trinity
Simulation

Results and Assessments

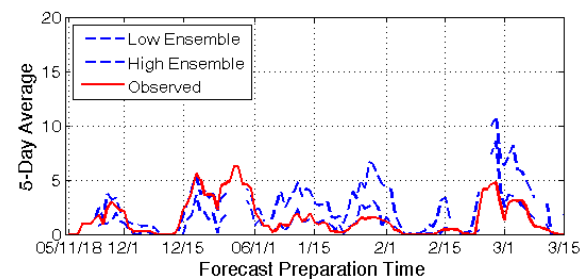
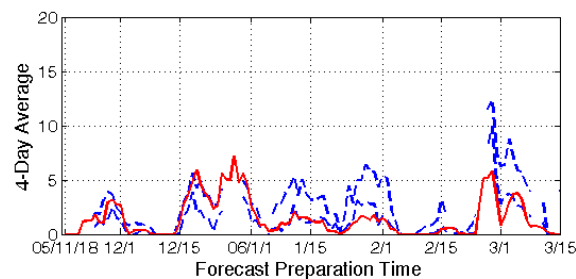
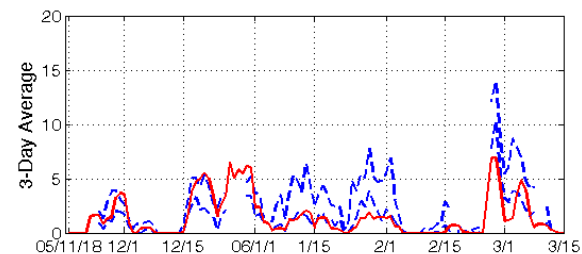
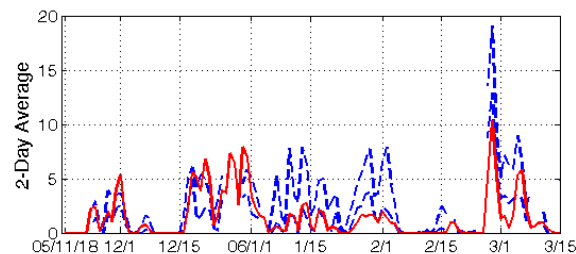
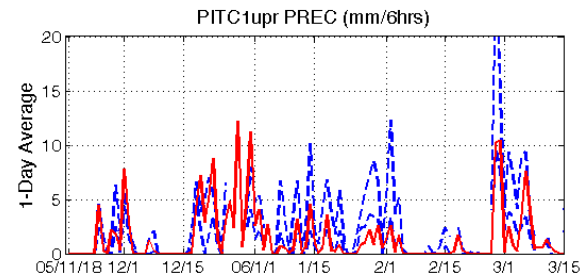
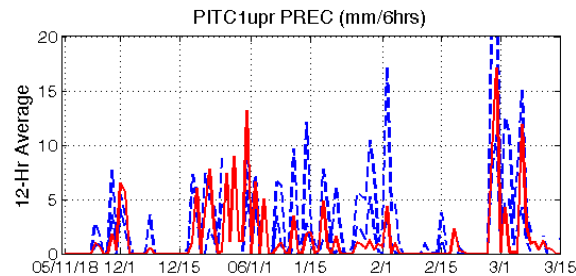
Forecasts



MF
American
Lwr

Results and Assessments

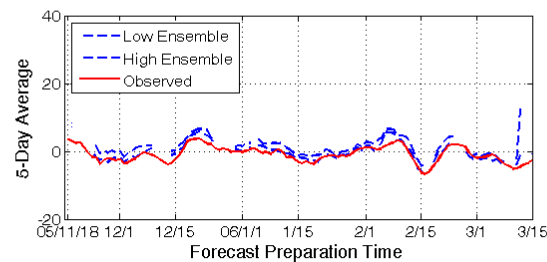
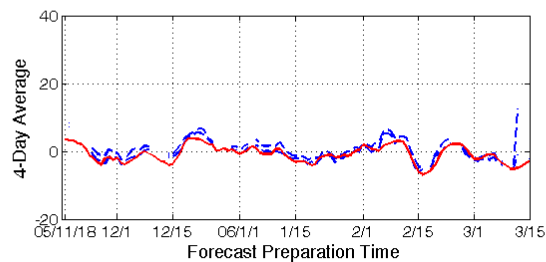
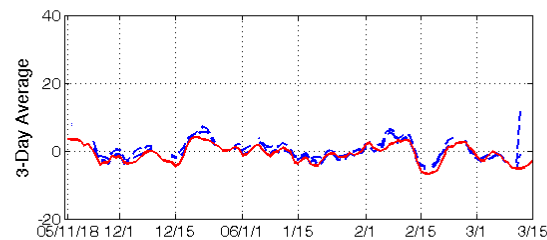
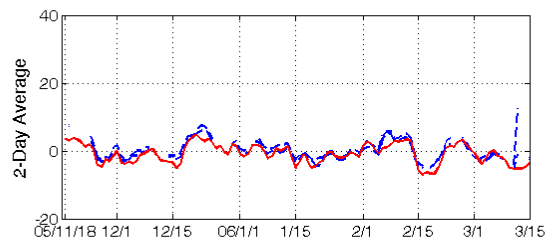
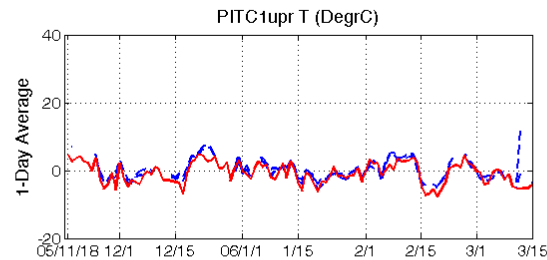
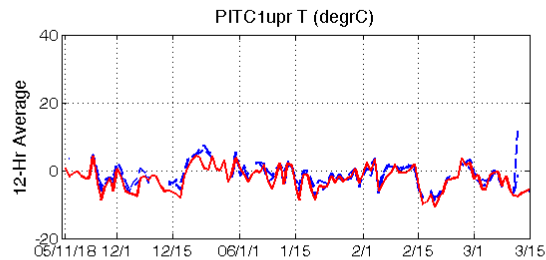
Forecasts



Pit River
Upr

Results and Assessments

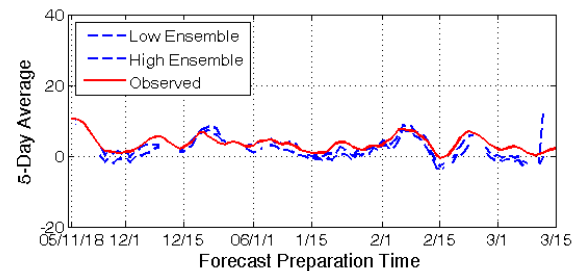
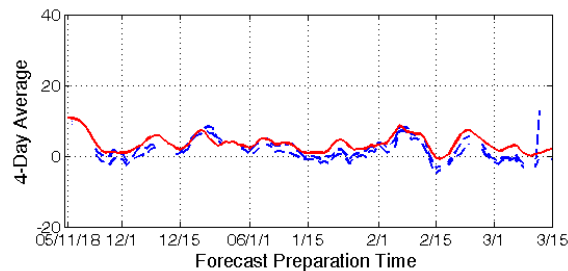
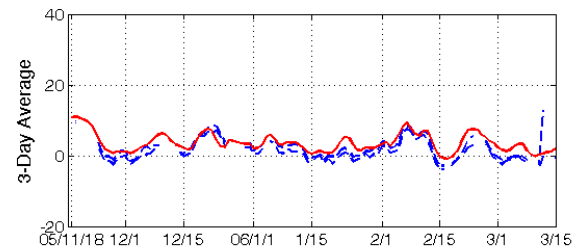
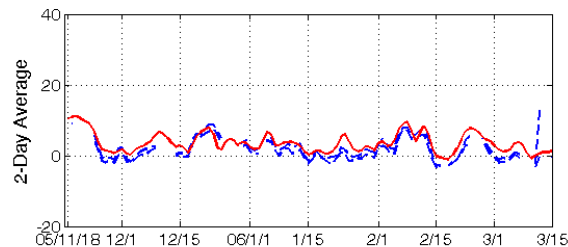
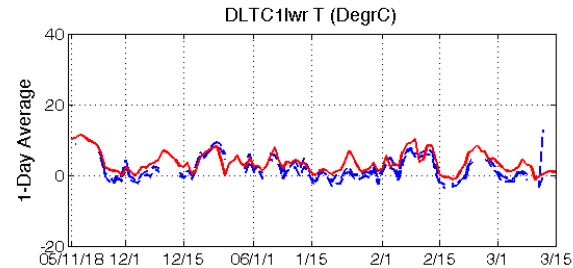
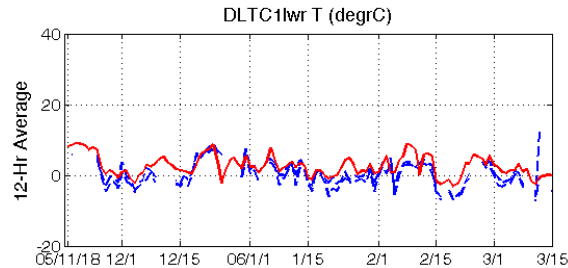
Forecasts



Pit River
Upr

Results and Assessments

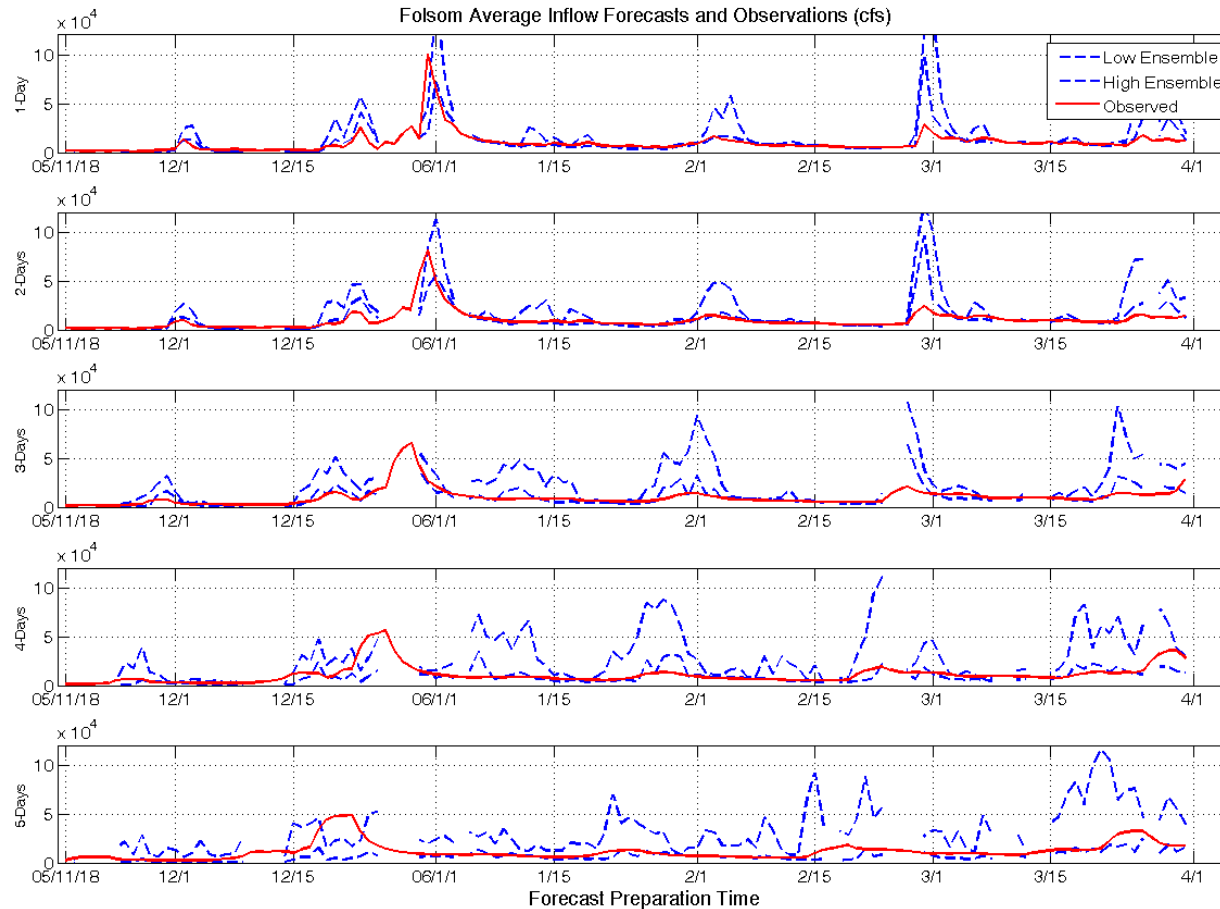
Forecasts



Sacr. River
@ Delta
Lwr

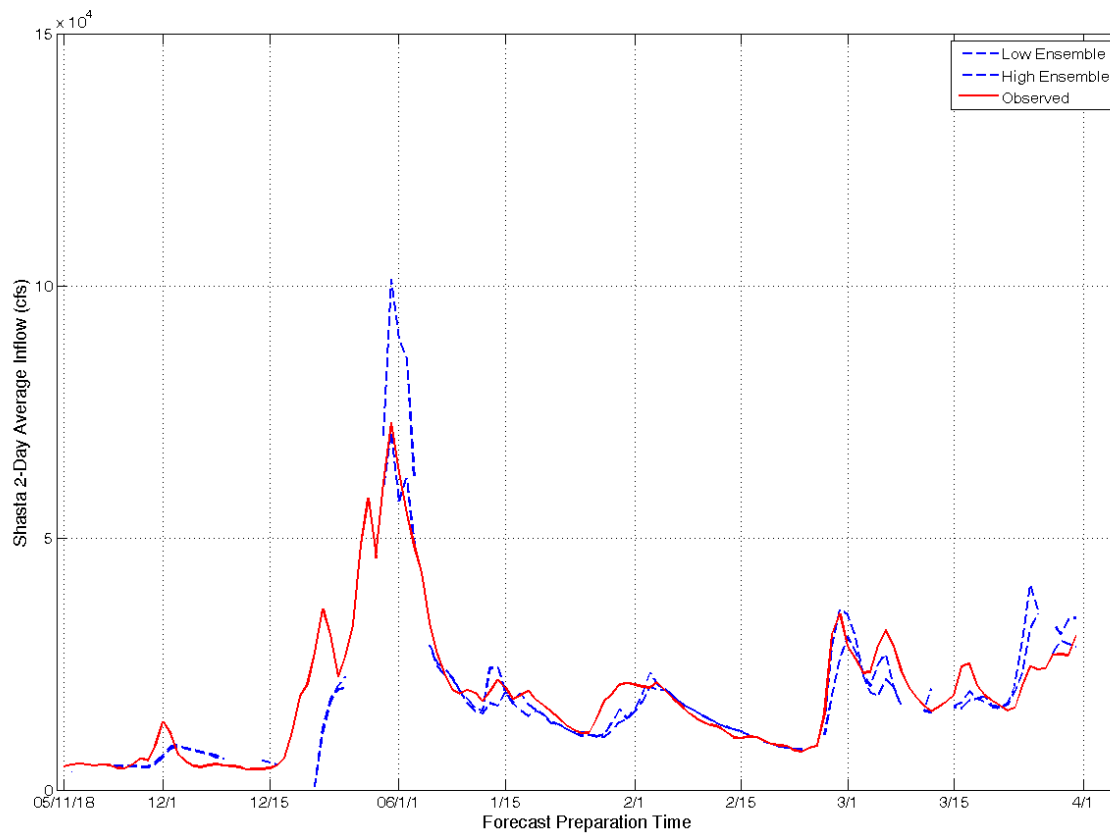
Results and Assessments

Forecasts



Results and Assessments

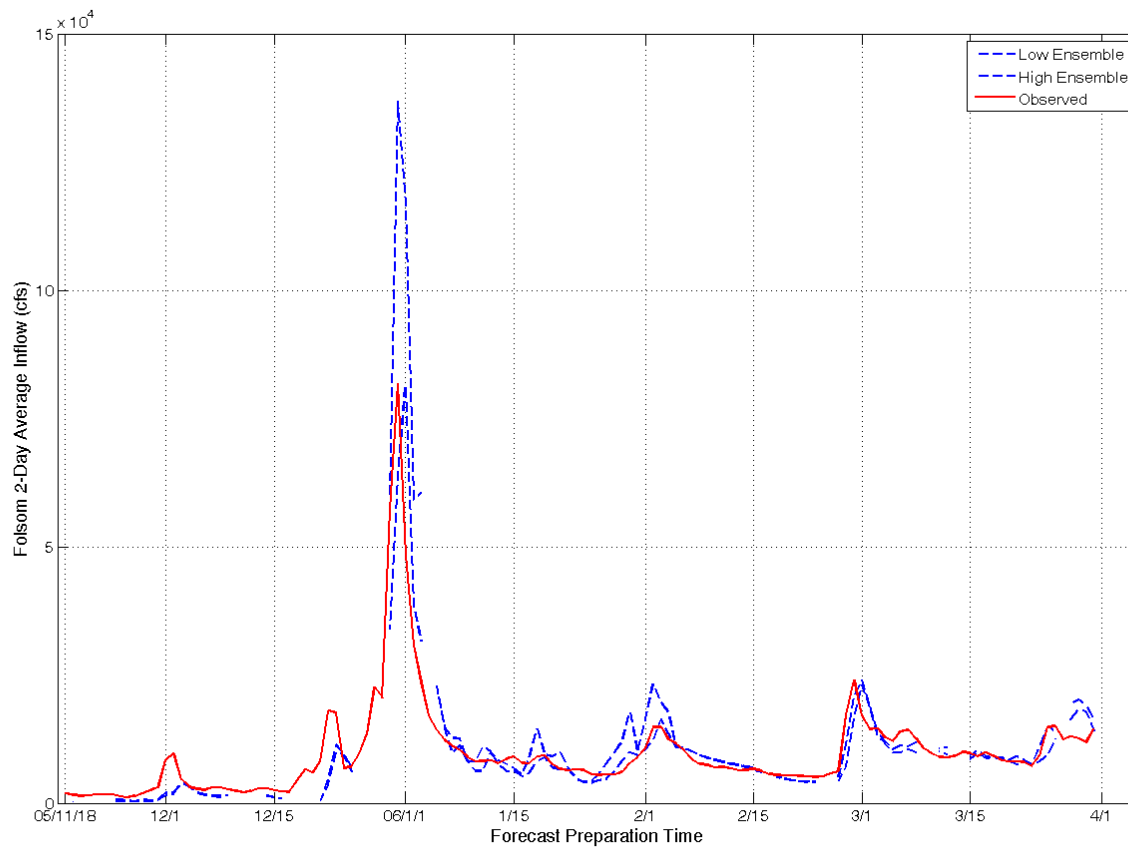
Forecasts



Shasta Inflow

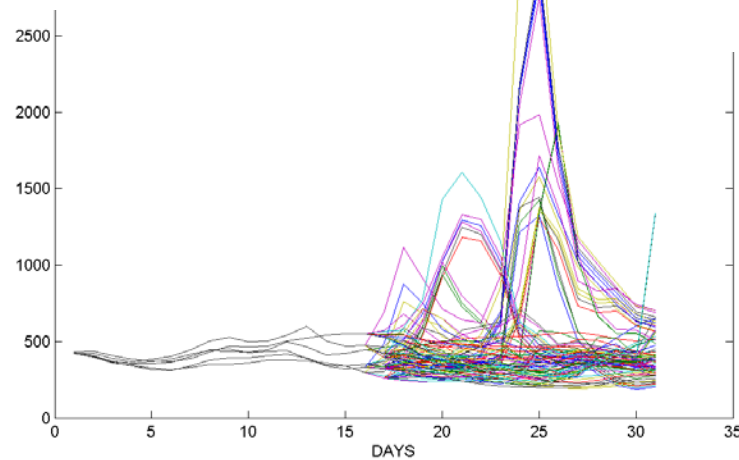
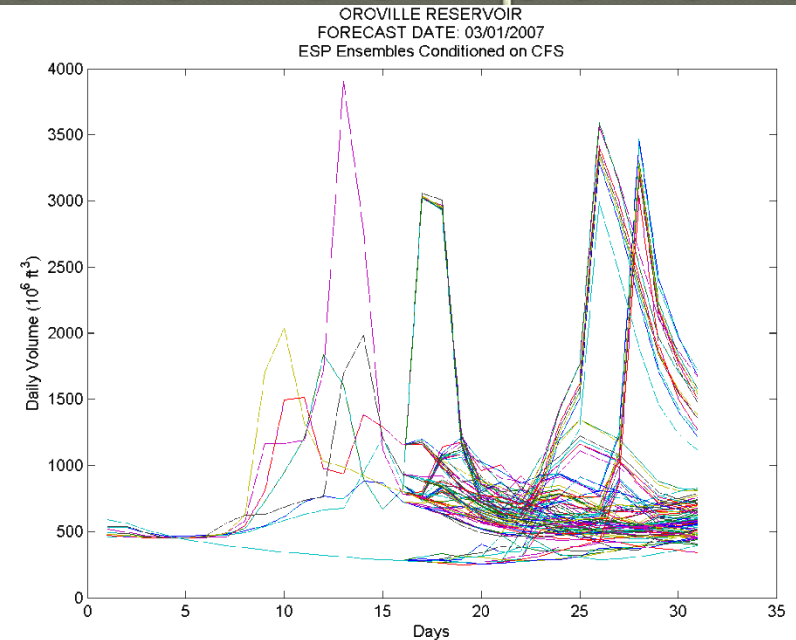
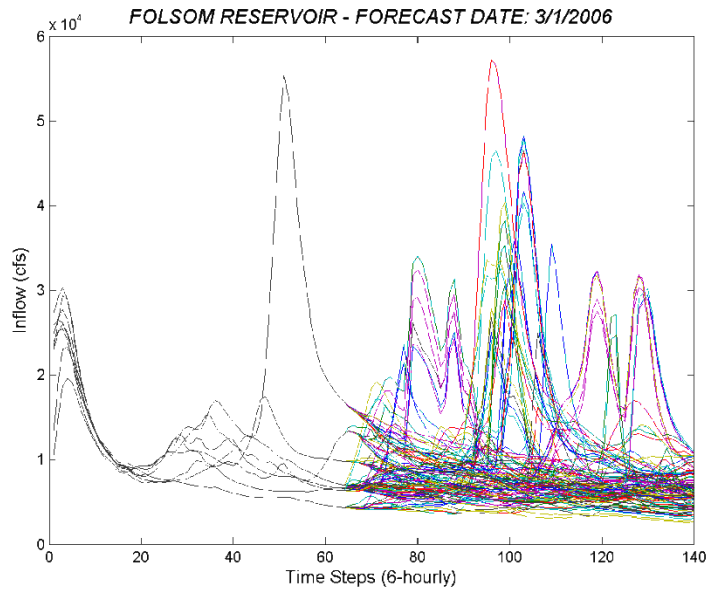
Results and Assessments

Forecasts



Folsom Inflow

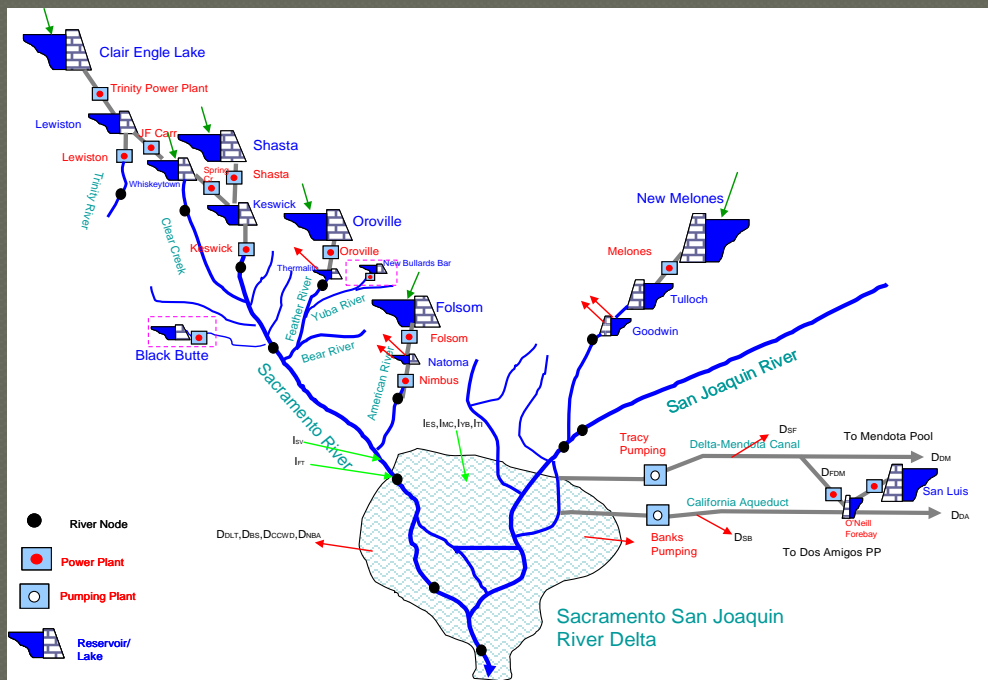
Blending Short- and Long-Term Forecasts for Decision Component



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);

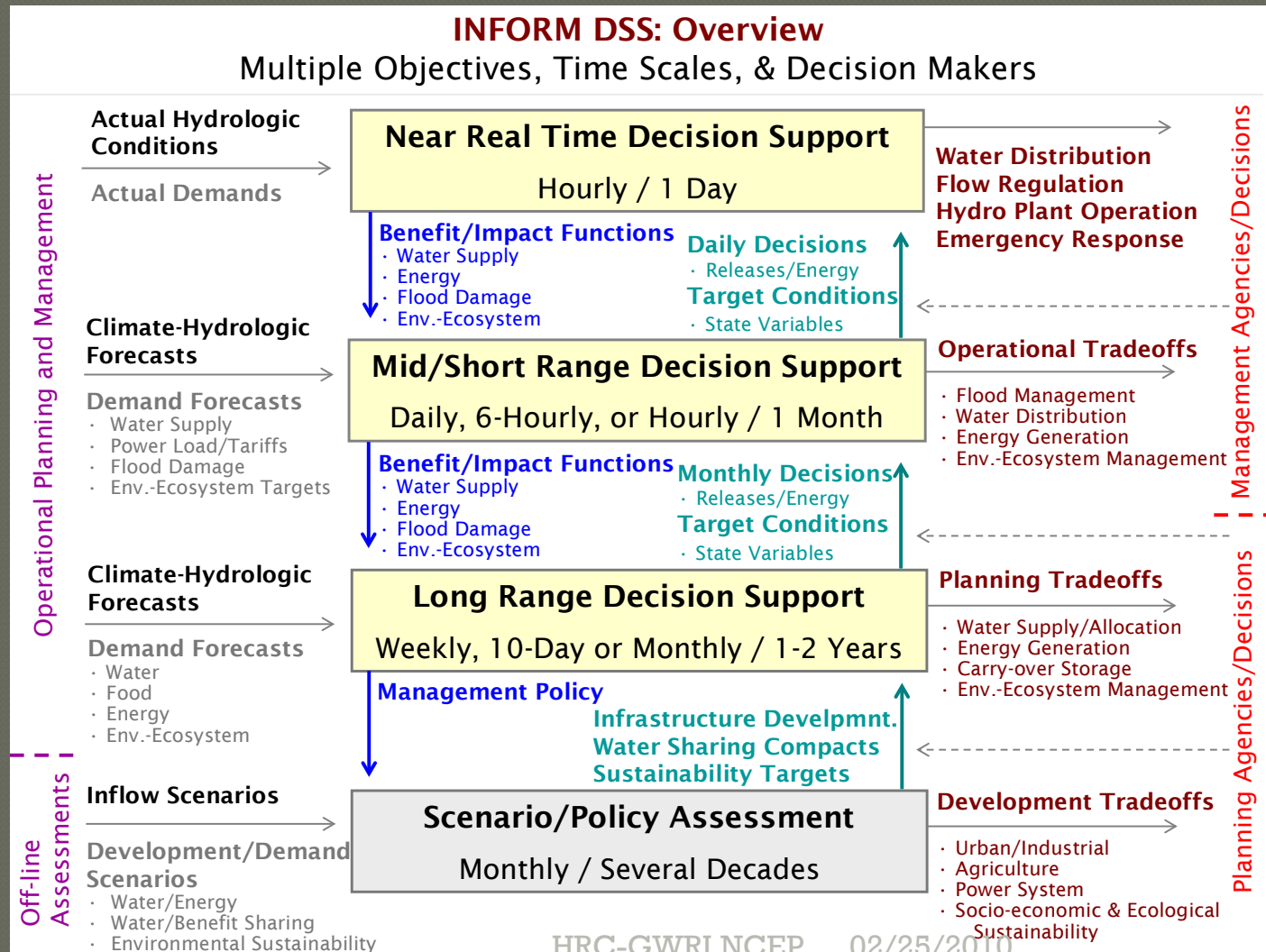
American River System (Folsom Lake, Folsom Plant, Natoma Lake, Nimbus Plant, Natoma Plant, and Natoma Diversions);

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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:

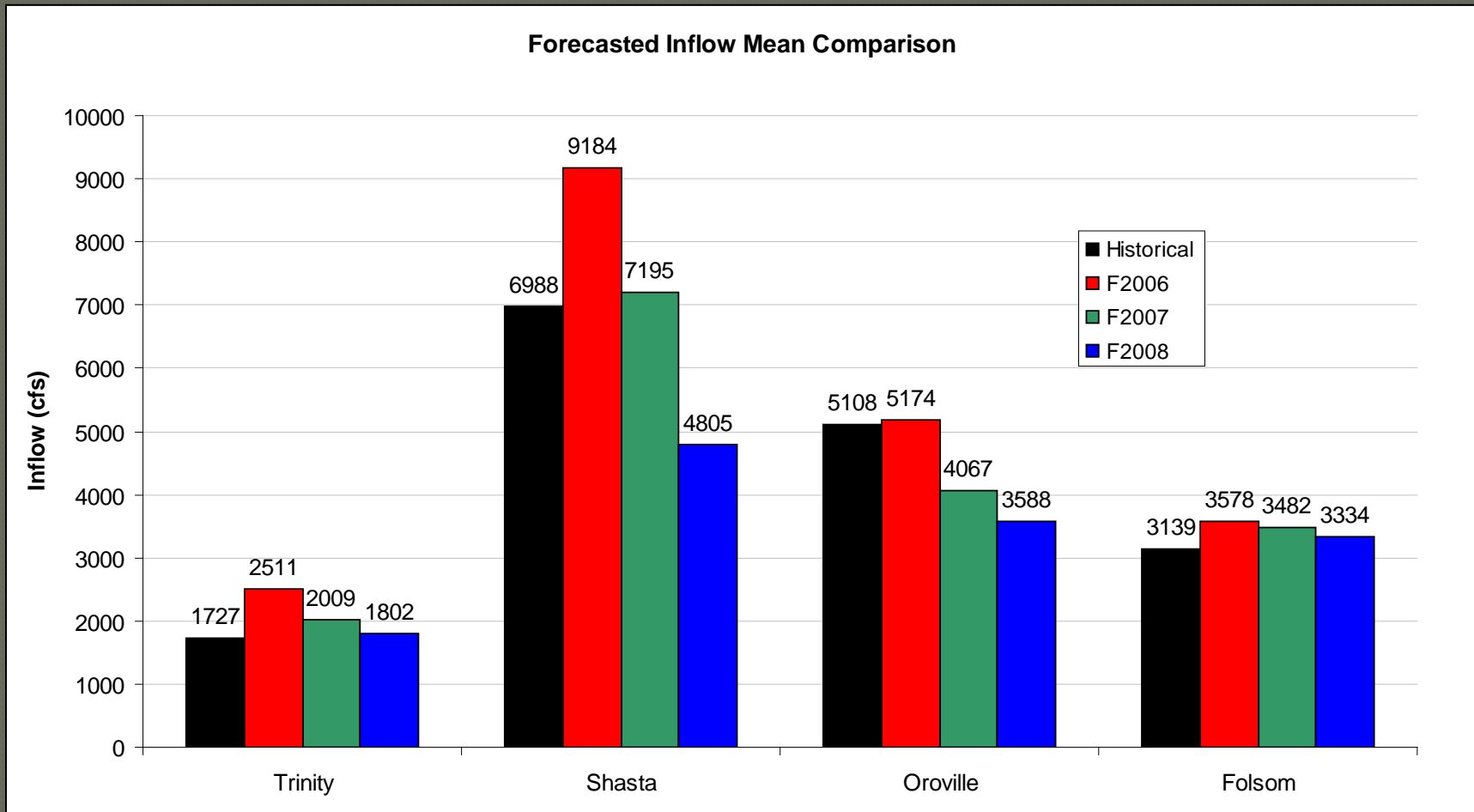
- Forecasted inflows were provided by HRC with start date March 1st (112 traces, 9 month horizon, and five locations: Clair Engle Lake, Shasta, Oroville, Folsom, and Yuba);
- Historical monthly average values are used for locations where forecasted inflows are not available;
- Monthly reservoir parameters 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

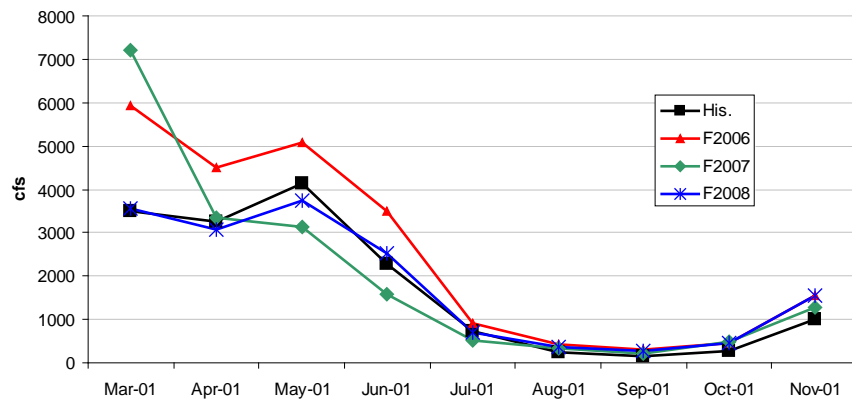


Results and Assessments

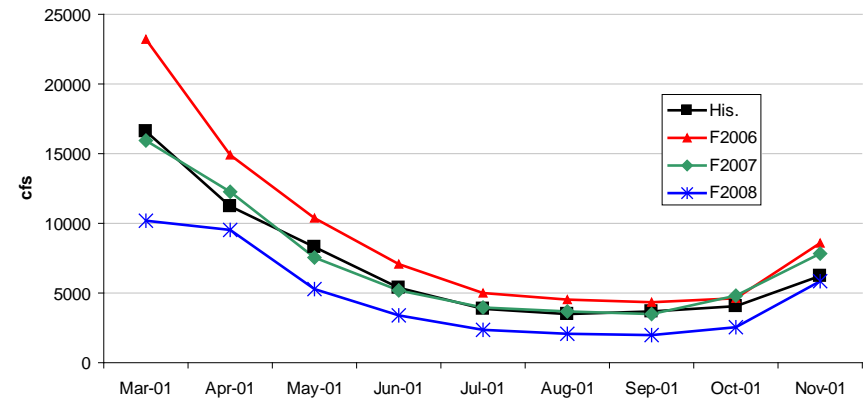
Decision Support

Mean Monthly Inflow Forecasts Comparison: 2006, 2007, 2008

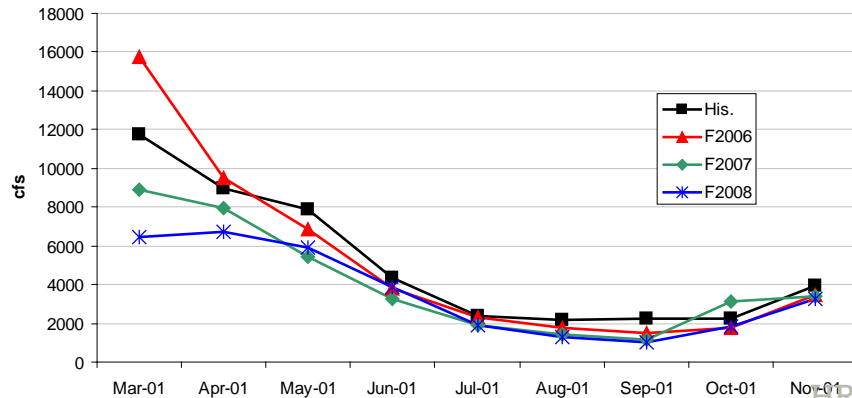
Forecasted Inflow Means - Trinity



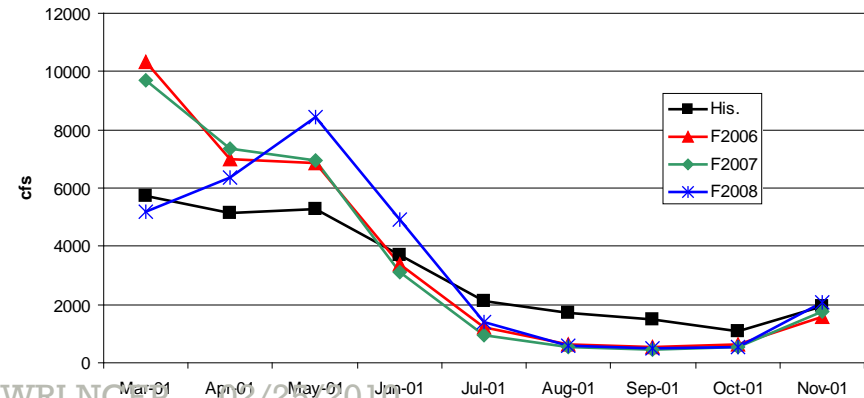
Forecasted Inflow Means - Shasta



Forecasted Inflow Means - Oroville



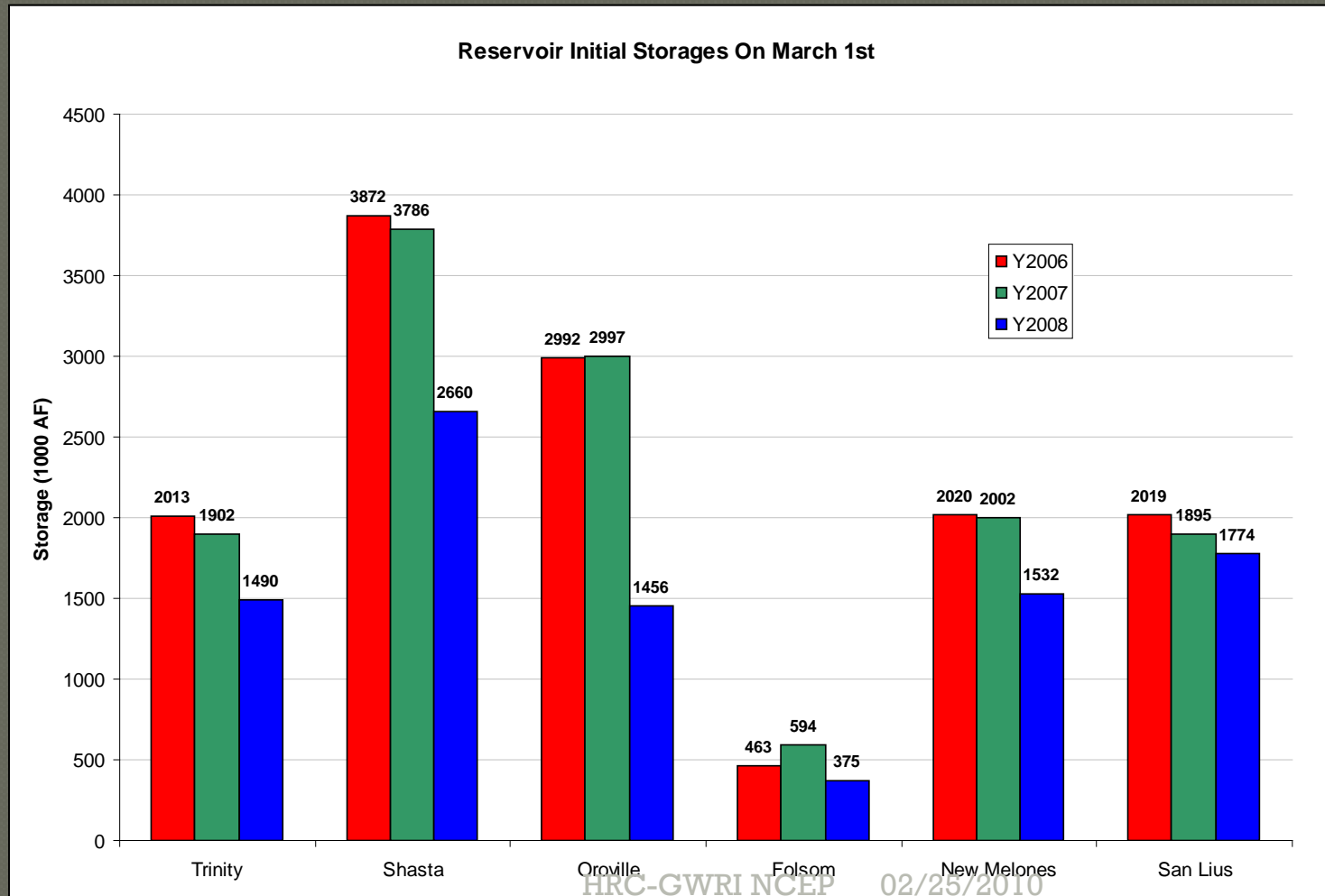
Forecasted Inflow Means - Folsom



Results and Assessments

Decision Support

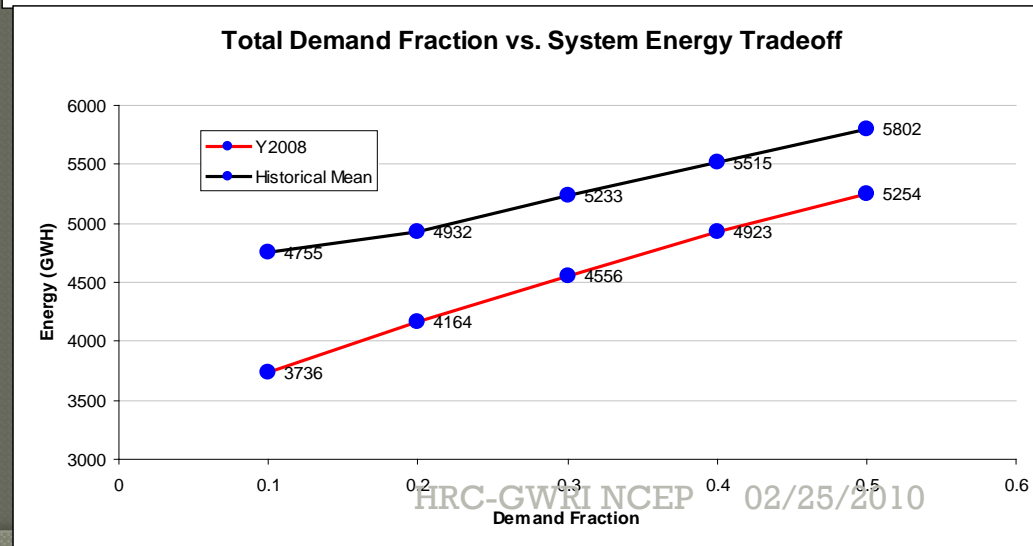
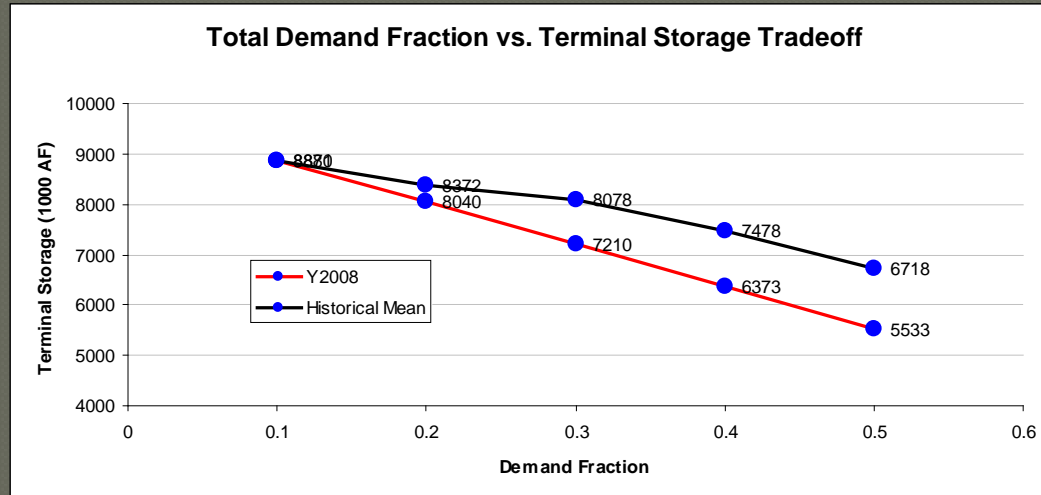
March 1 Reservoir Storages: 2006, 2007, 2008



Results and Assessments

Decision Support

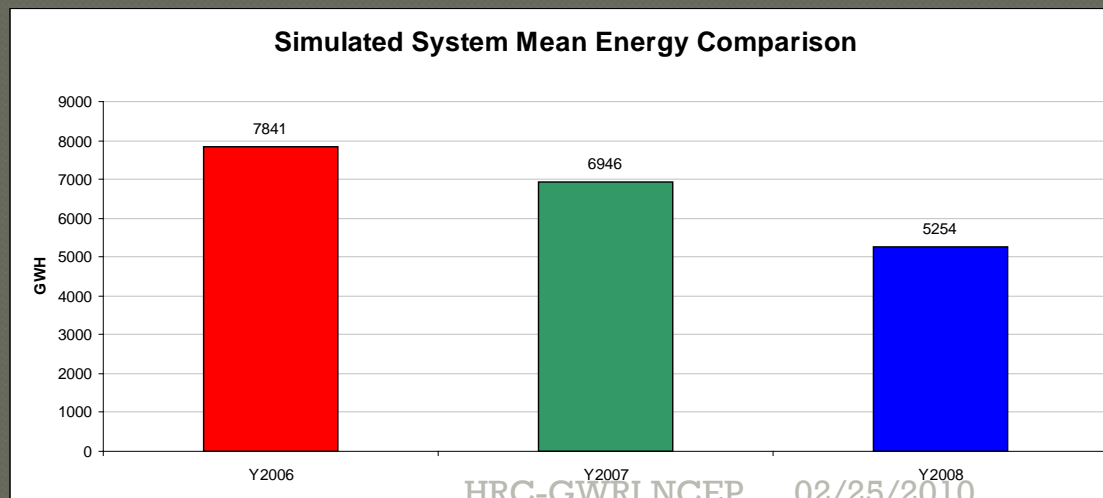
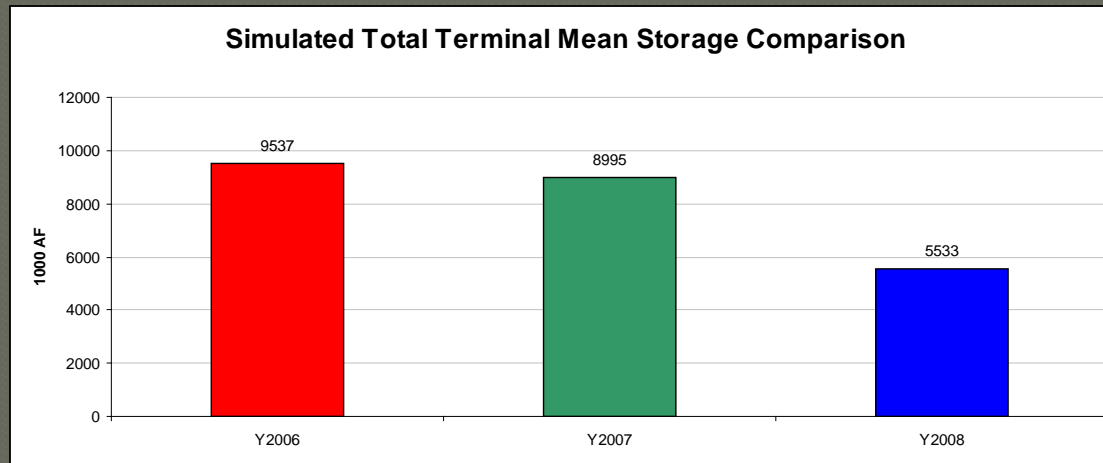
Water Deliveries vs. Carry over Storage vs. Energy Tradeoffs



Results and Assessments

Decision Support

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

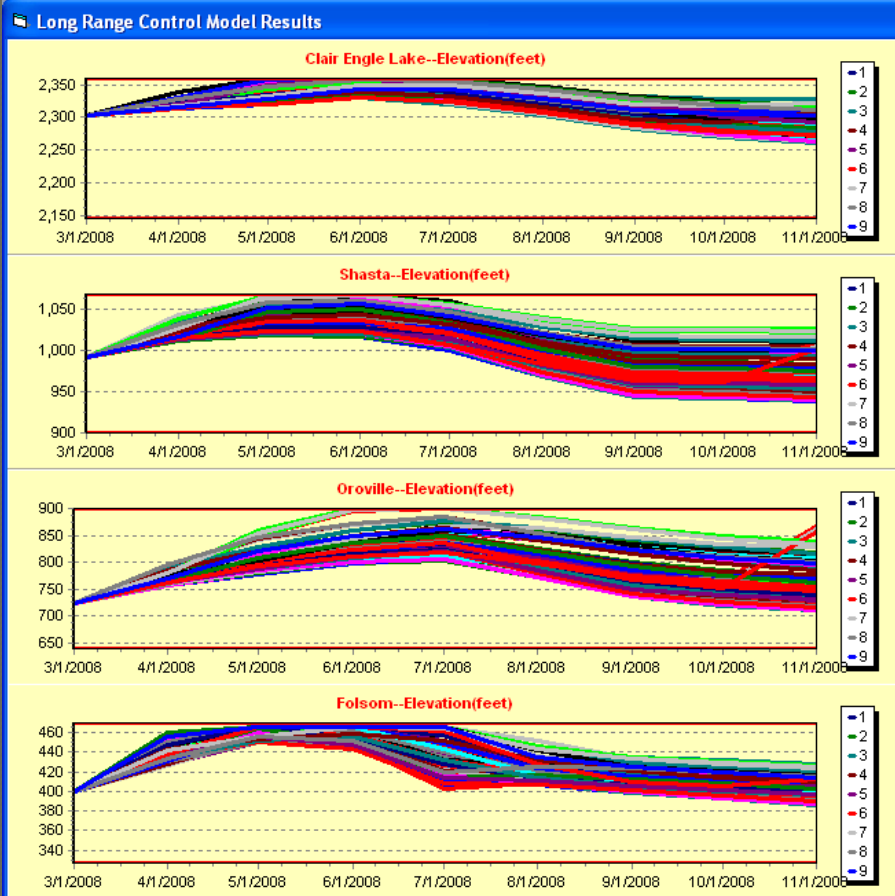


Results and Assessments

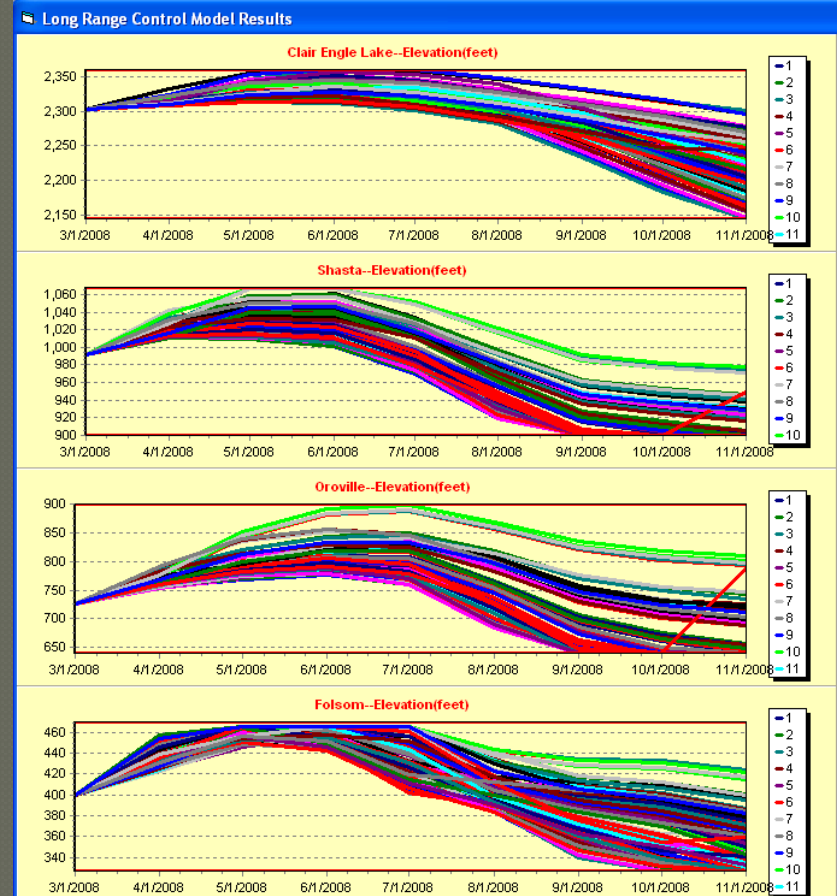
Decision Support

Lake Level Forecast Ensembles: 2008

10% Base Demand



50% Base Demand



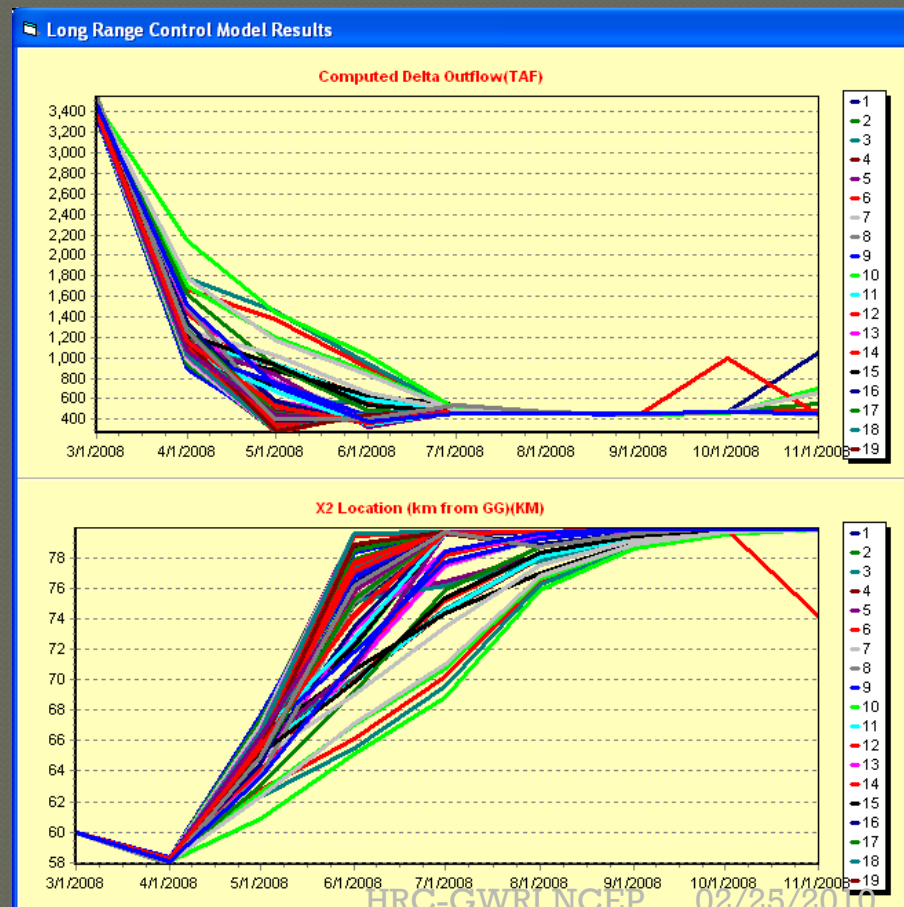
HYDROLOGIC MODEL 02/26/2008

Results and Assessments

Decision Support

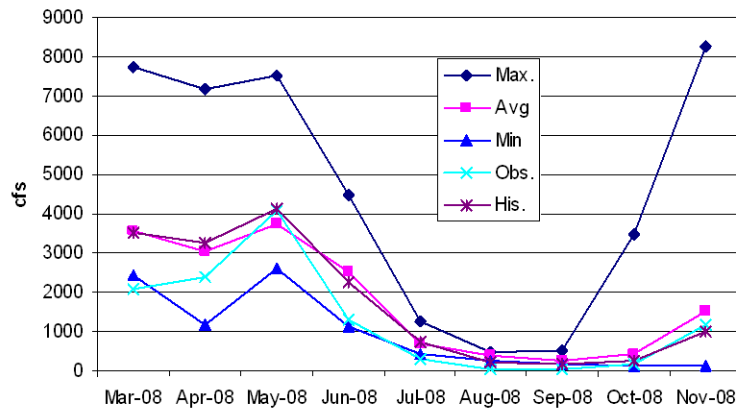
X2 Location Forecast Ensembles: 2008

10% Base Demand

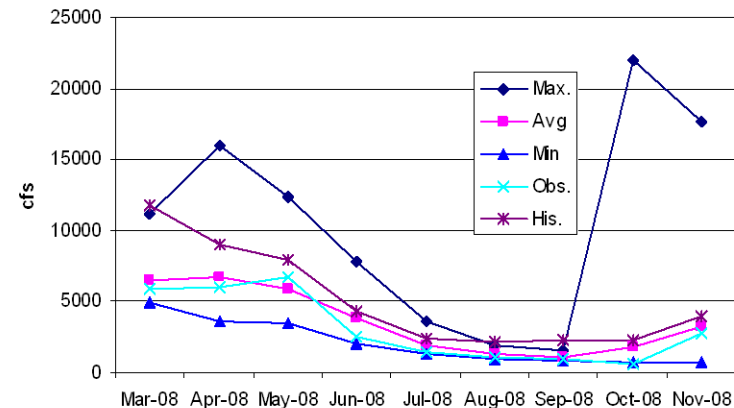


Independent Evaluation by the California Energy Commission January 2009

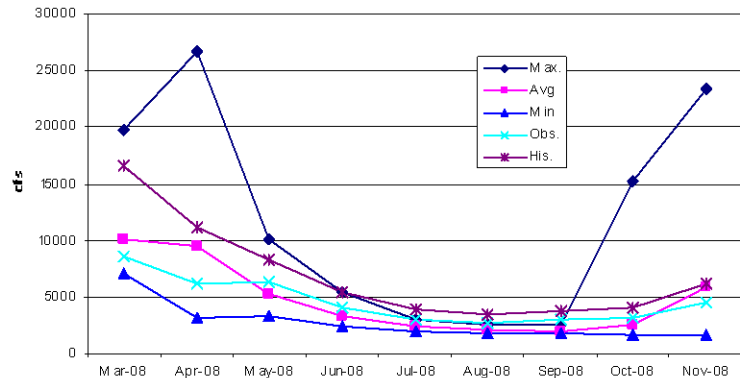
2008 Forecasts; Trinity



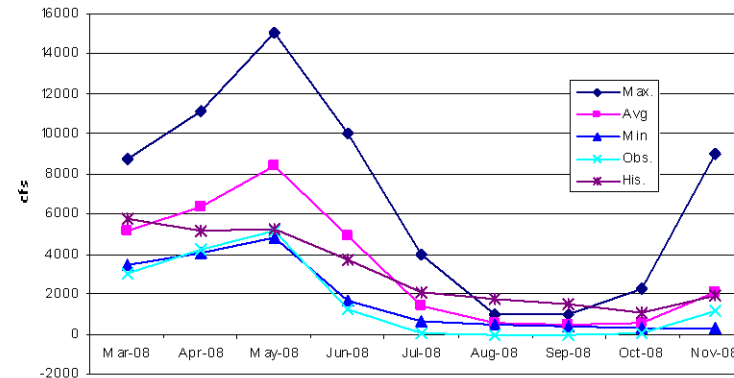
2008 Forecasts; Oroville



2008 Forecasts; Shasta

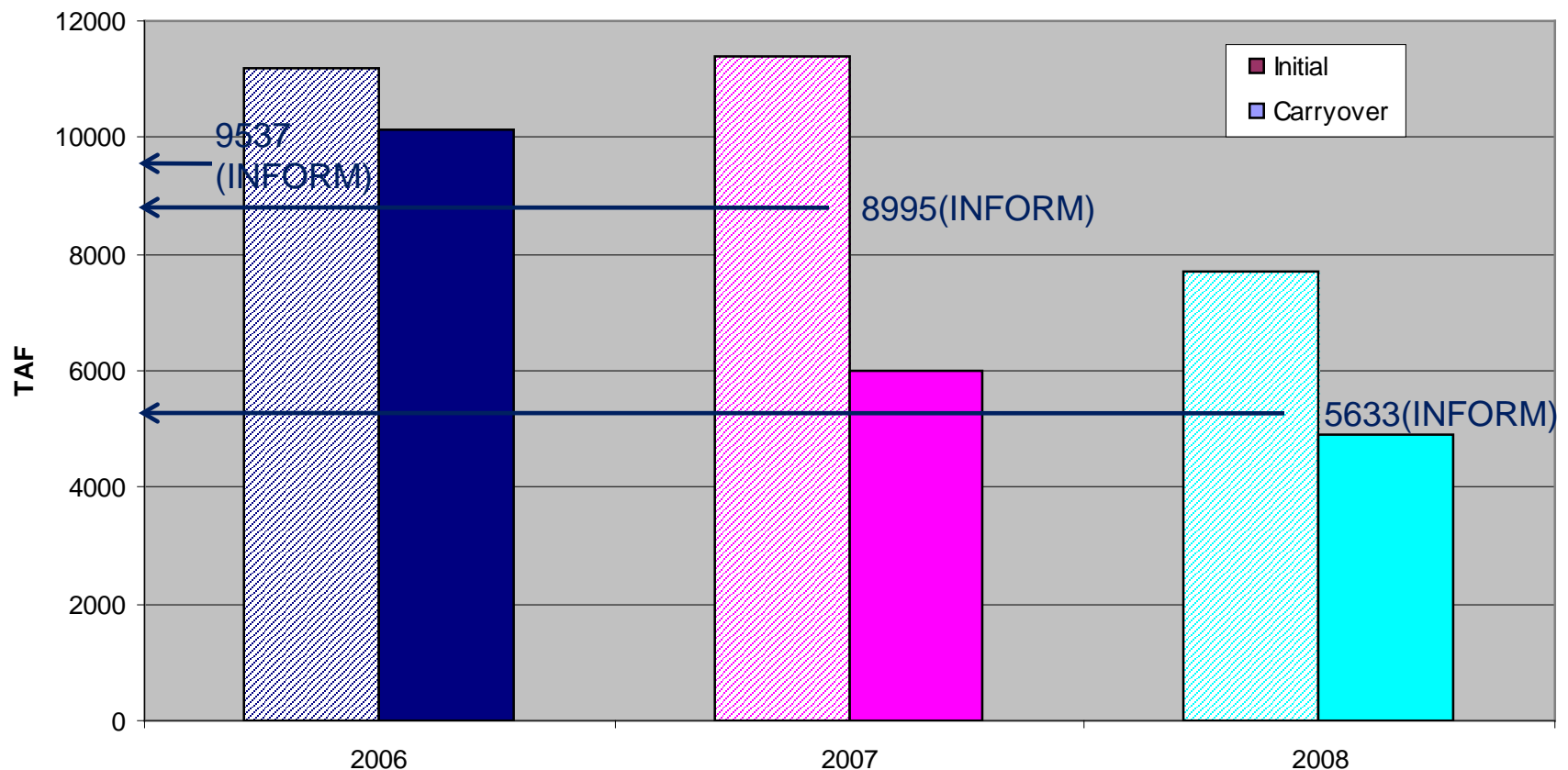


2008 Forecasts; Folsom



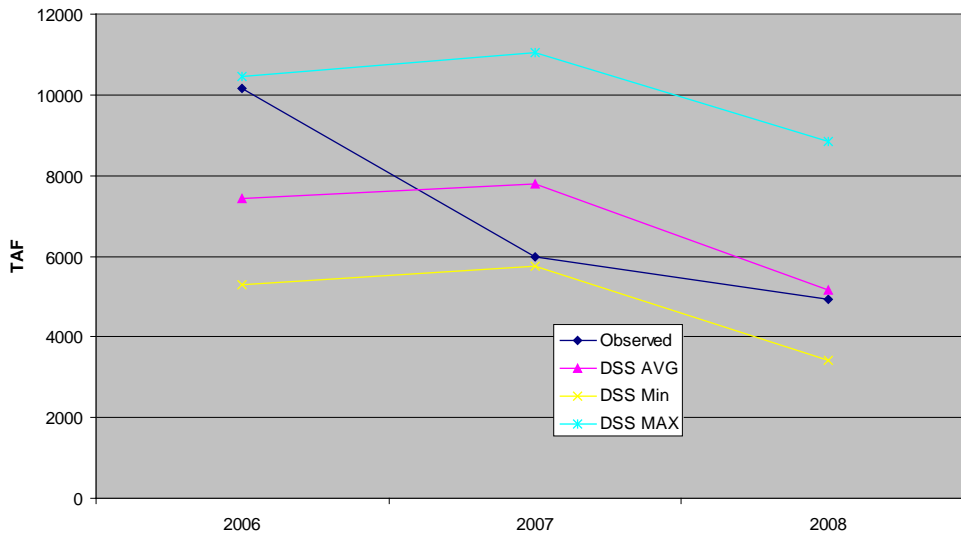
Independent Evaluation by the California Energy Commission January 2009

System Carryover Storages of Major Reservoirs

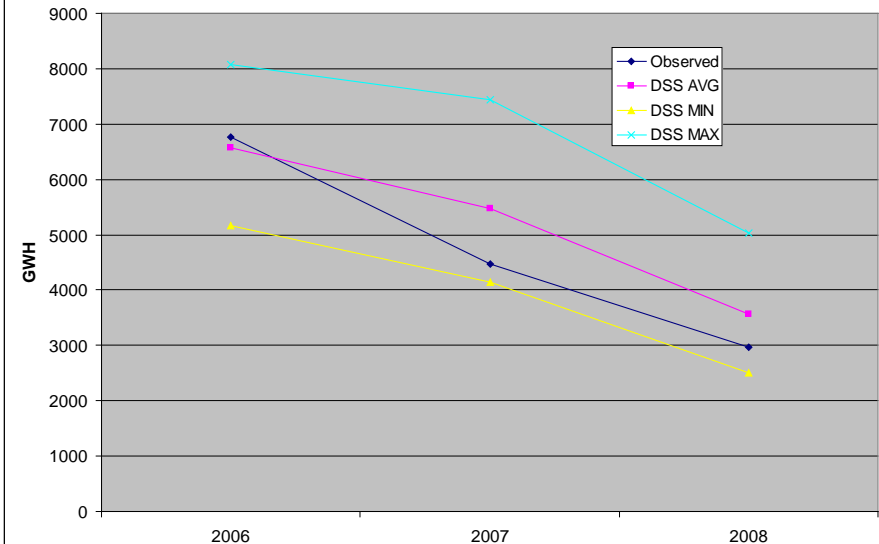


Independent Evaluation by the California Energy Commission January 2009

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

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

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

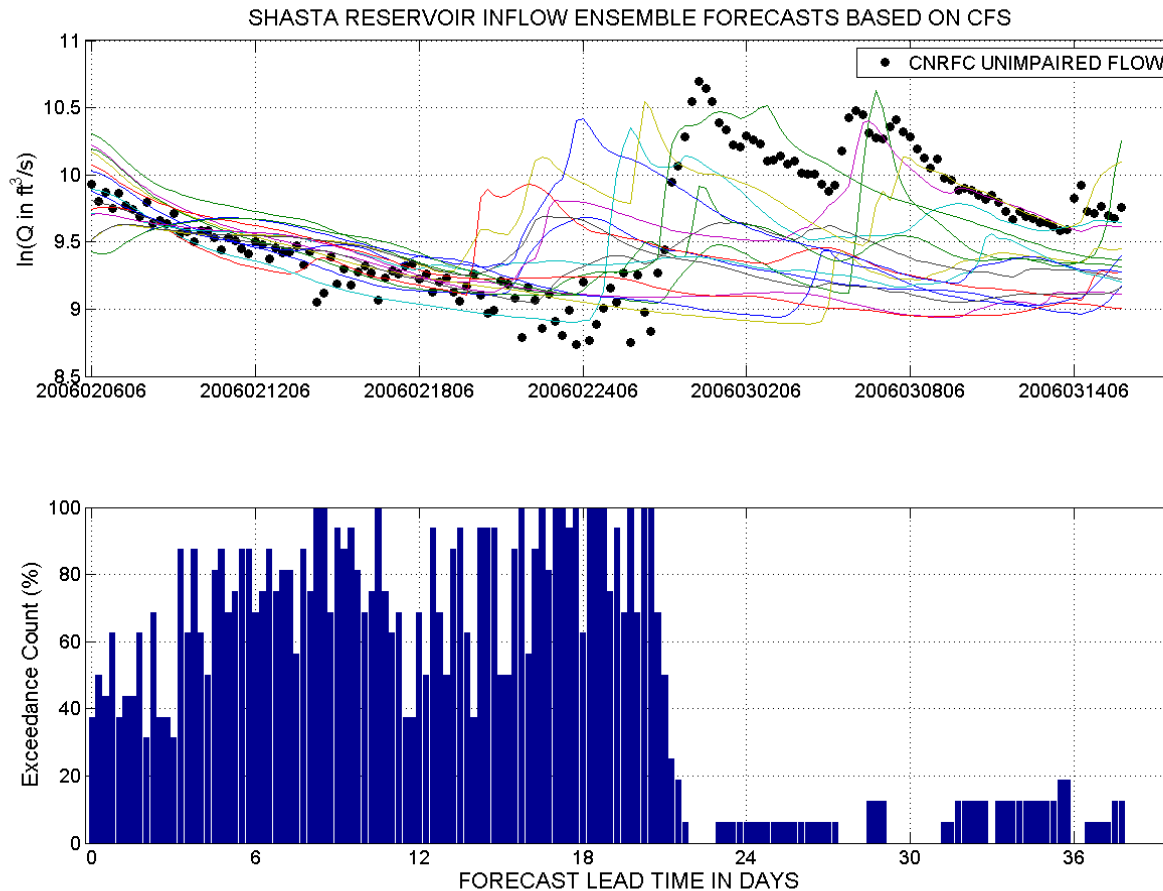
INFORM forecast evaluation period 12/09/2005 06Z – 01/16/2006 00Z

Case B:

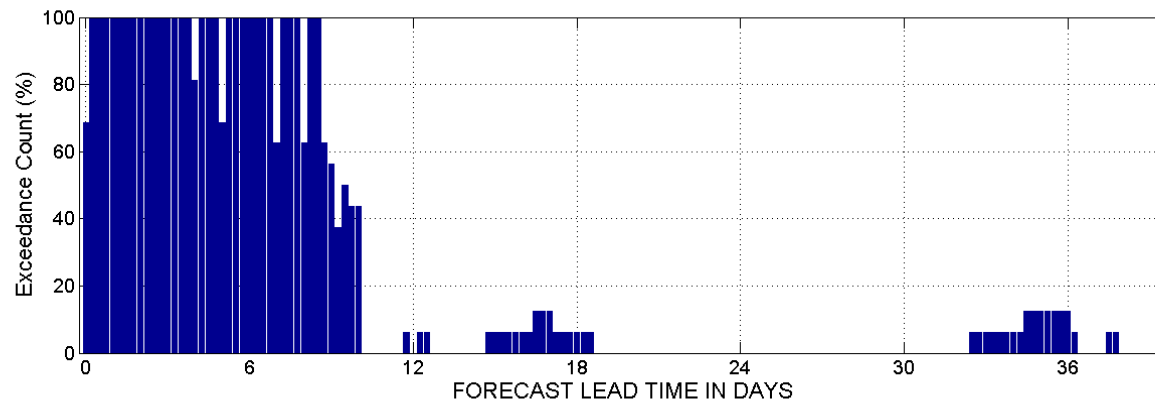
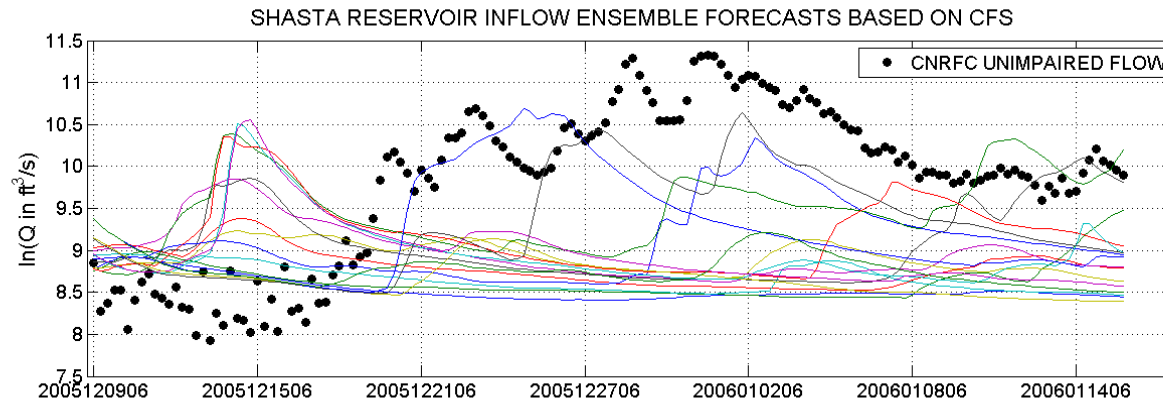
CFS run period 01/30/2006-02/06/2006

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

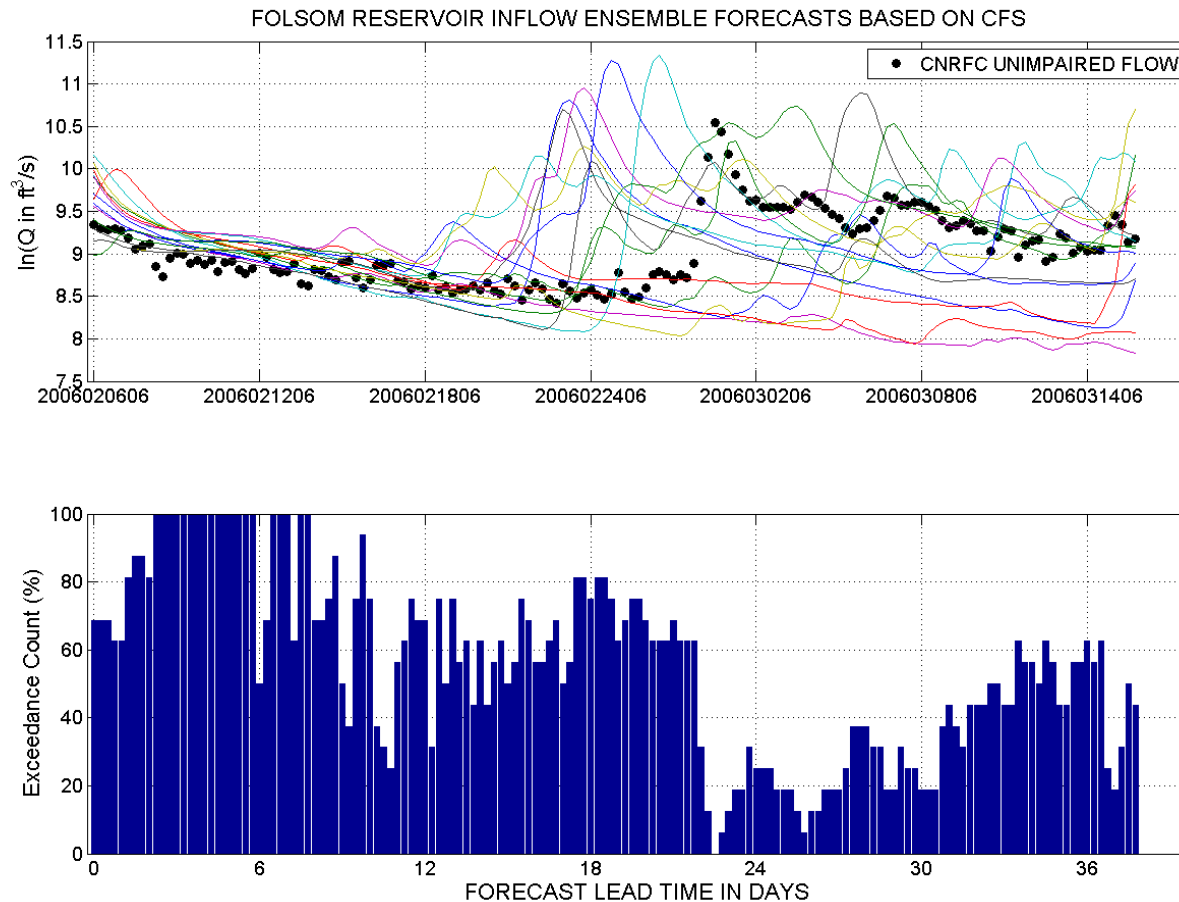
3-D CFS Experiments - Results



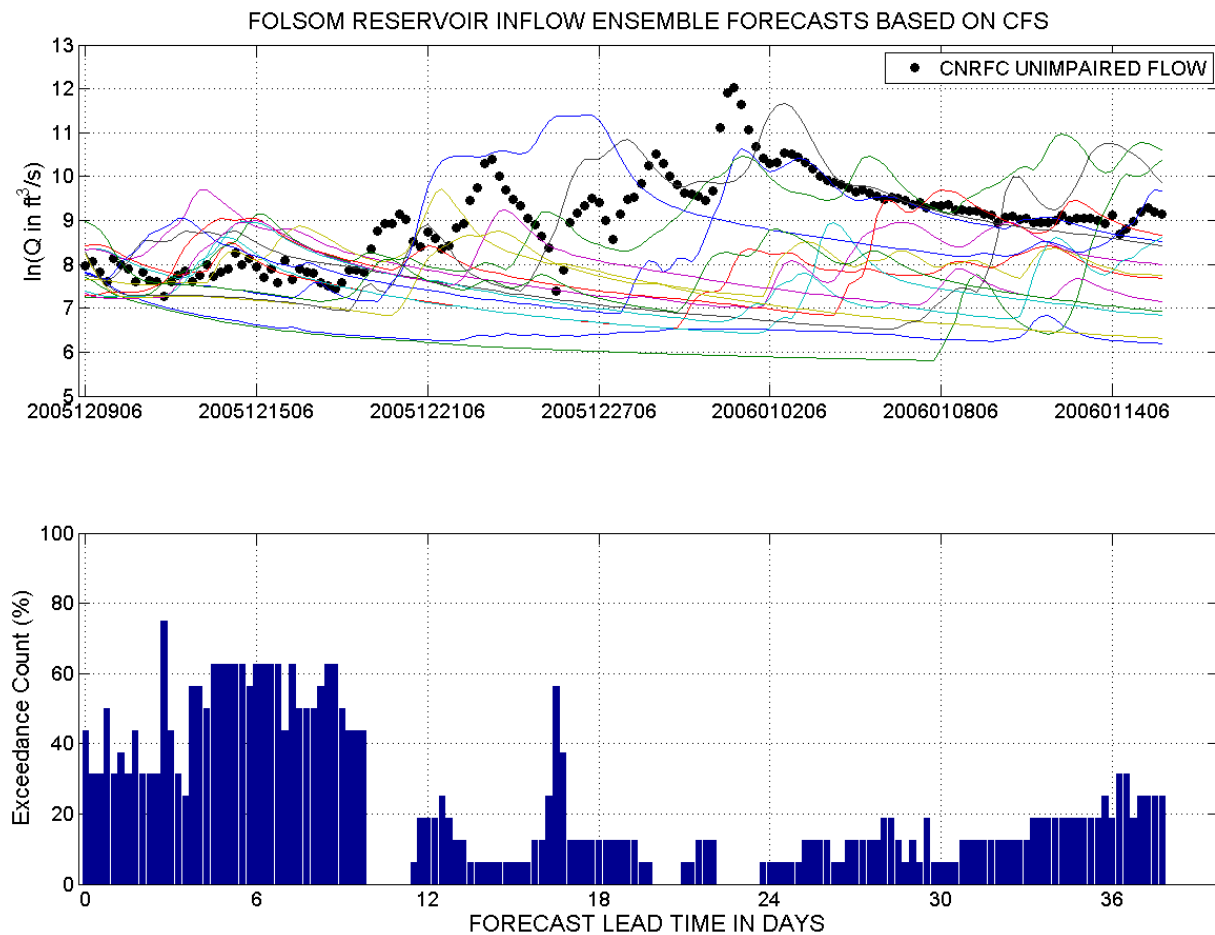
3-D CFS Experiments - Results



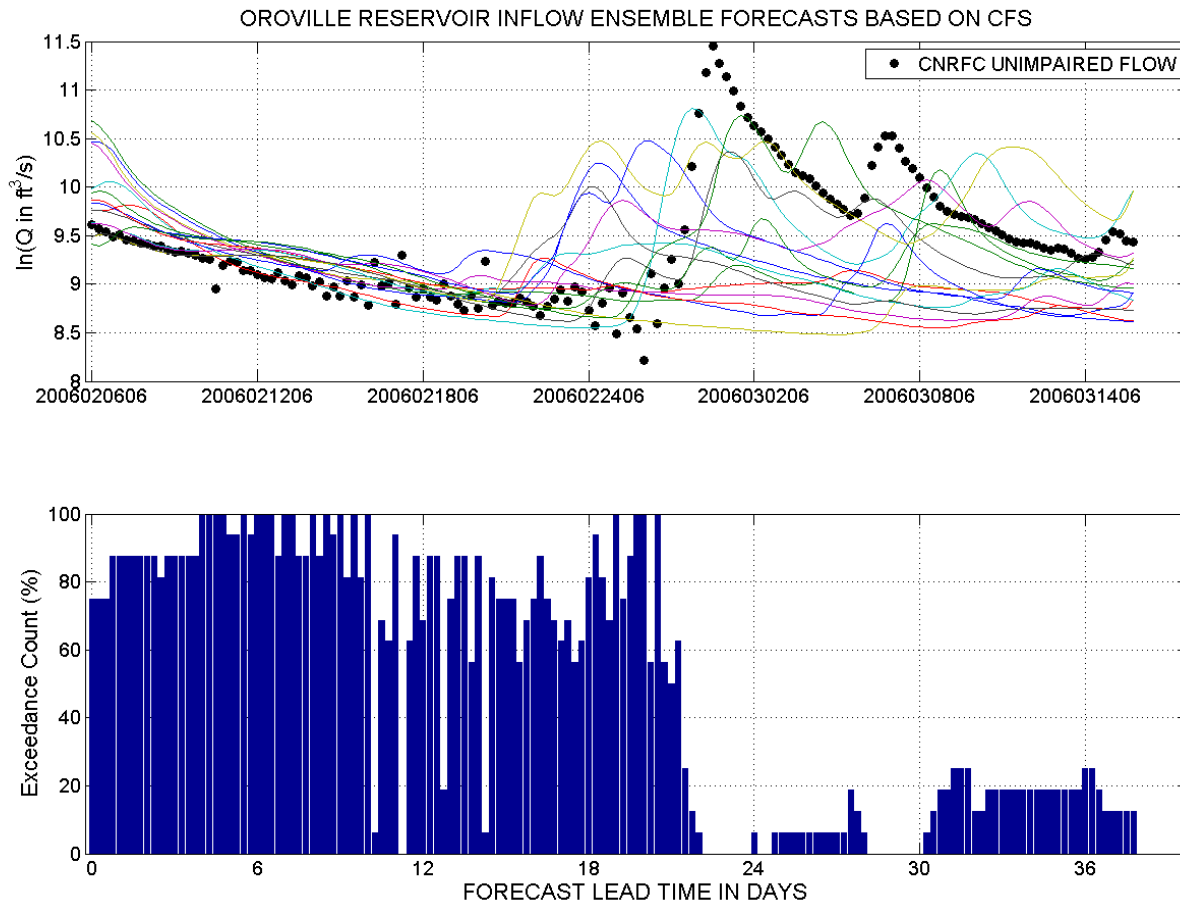
3-D CFS Experiments - Results



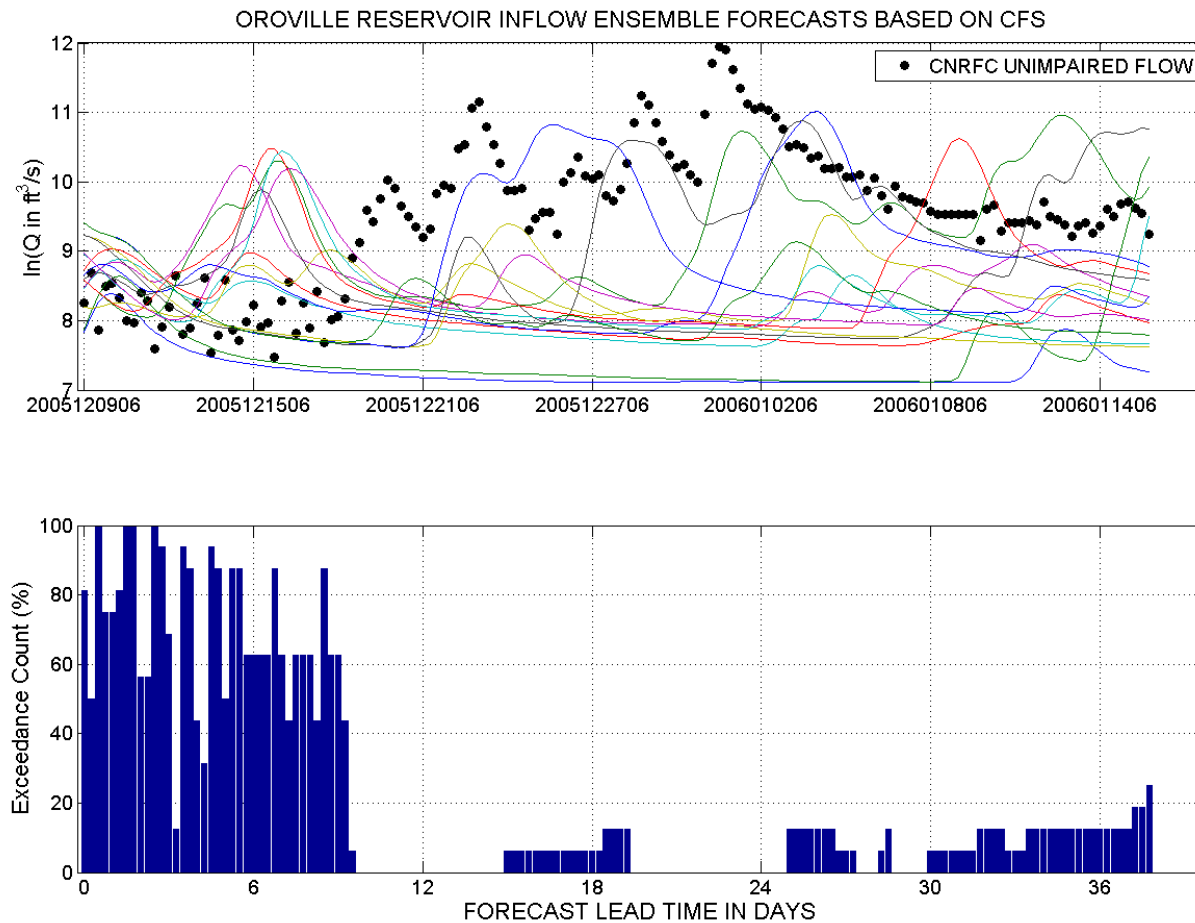
3-D CFS Experiments - Results



3-D CFS Experiments - Results



3-D CFS Experiments - Results



Phase II Plans for Forecast Components

- **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

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 α, e s.t. $Y^* = \alpha e^t$ and β, 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 = Y_{cfs}

| | 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 Y_{cfs}

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

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