

NOAA
River Forecast Center
Ensemble Streamflow Prediction

Kevin Werner

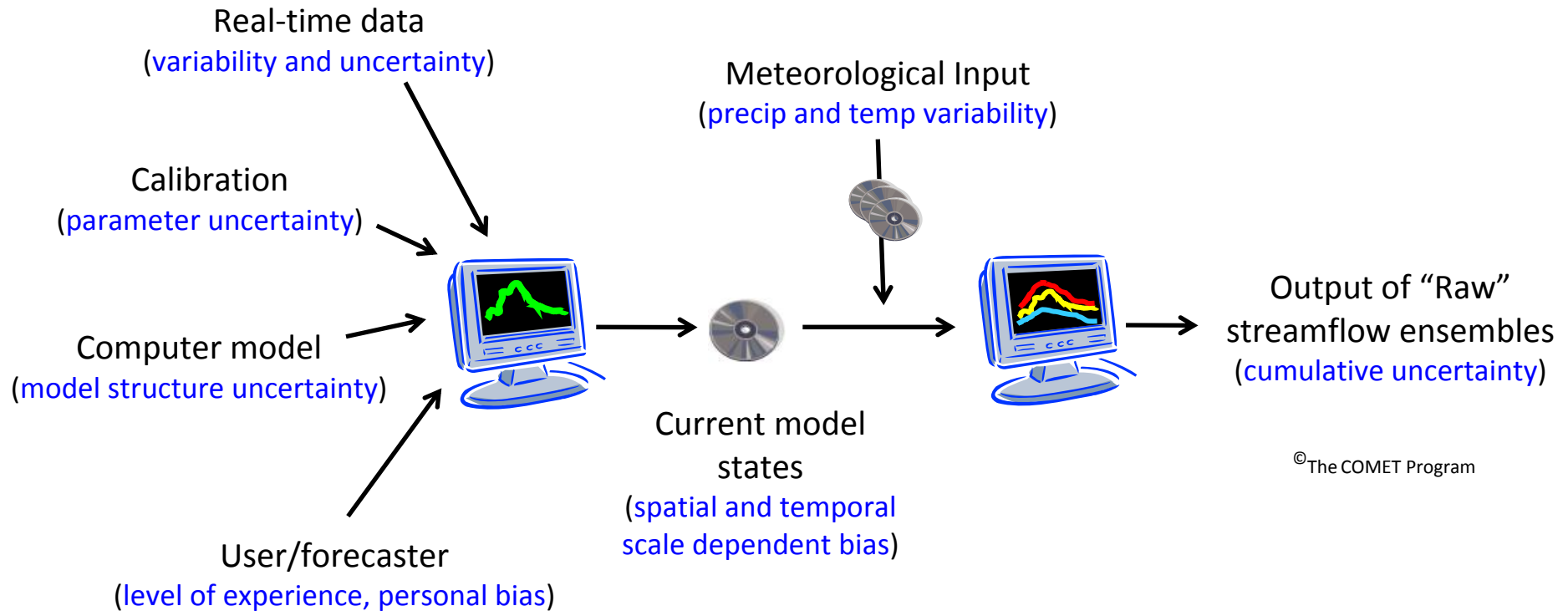
John Lhotak

CBRFC

Outline

- ESP overview and history
- New and ongoing research and development
- Forecast usage

Sources of uncertainty



ESP Technique

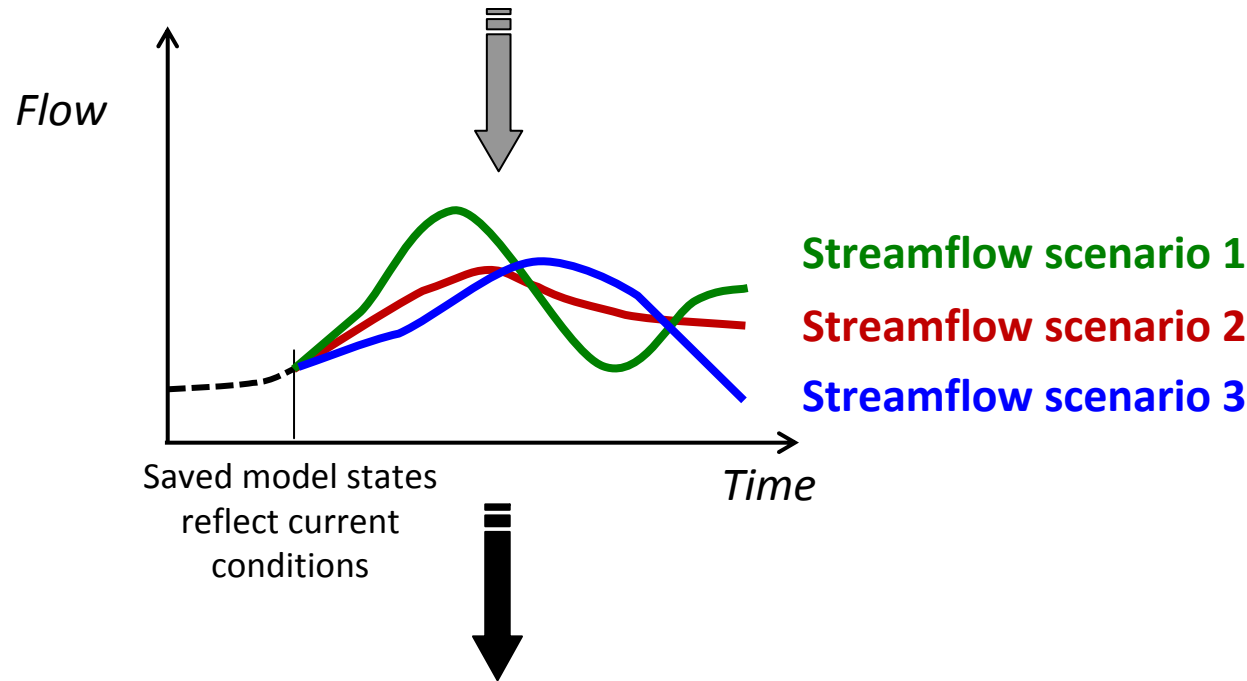
Meteorological scenario 1

Meteorological scenario 2

Meteorological scenario 3

Input weather conditions

*Forecast weather conditions or
Historic weather records or
Modified historic weather records*

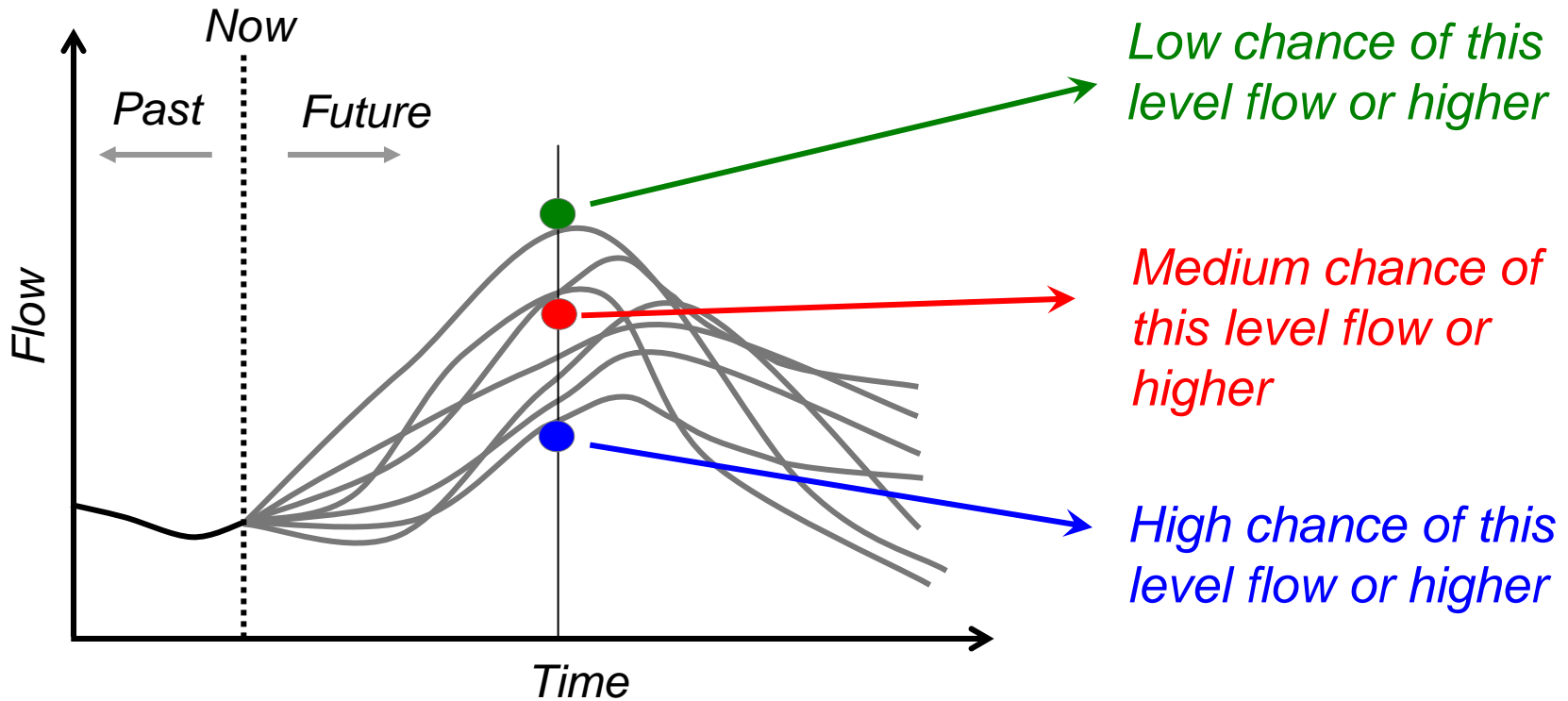


Results used in statistical analysis to produce forecasts with probabilistic values

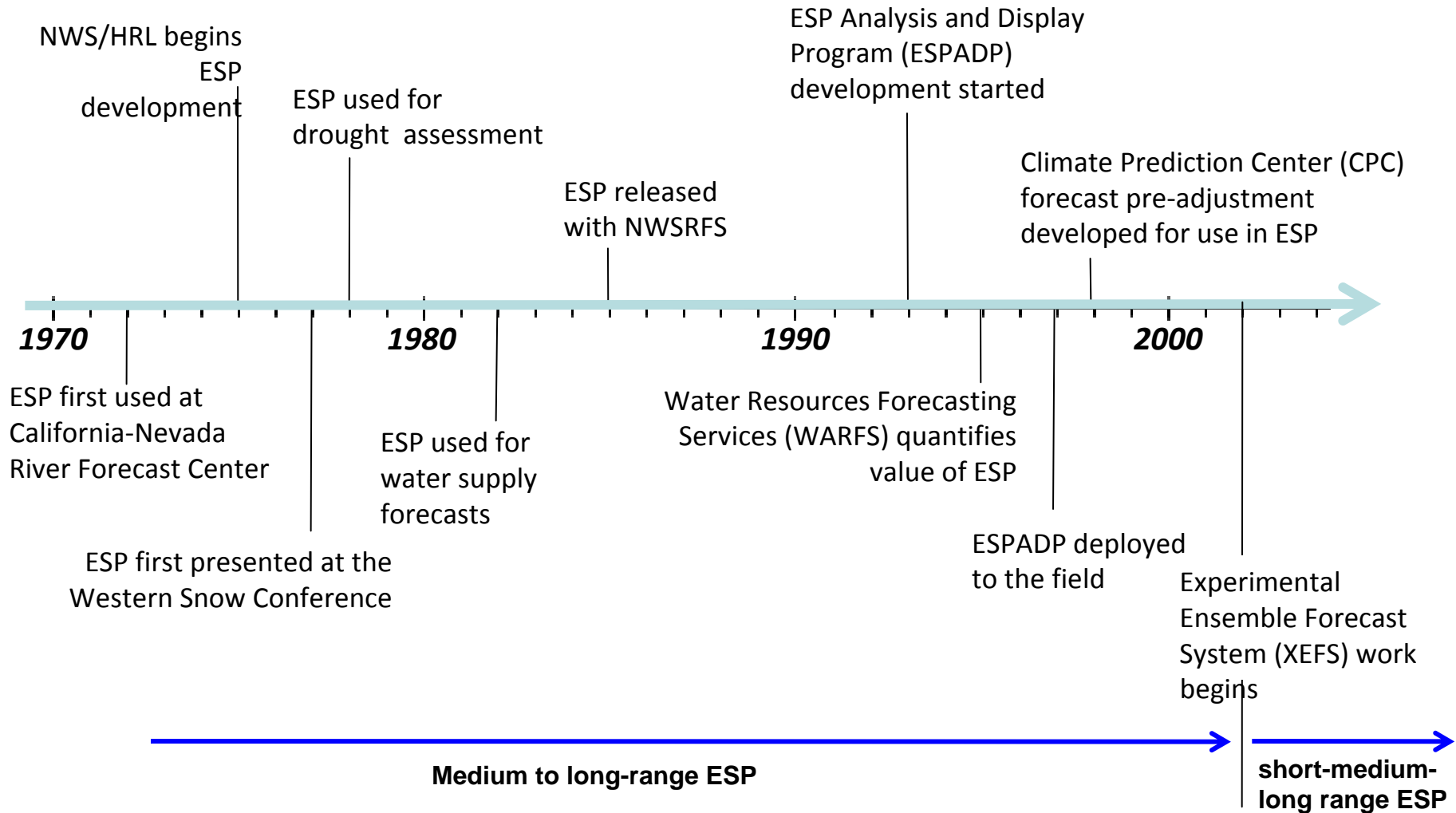
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ESP Technique



Historic development of ESP



Western Snow Conference paper, 1977

Twedt, et al, 1977

- “Many irrigation interests, reservoir operators, and other water management agencies now possess sufficient sophistication to demand and efficiently utilize water supply forecasts of a probabilistic nature for a variety of time periods.”
- “Because [ESP]... requires considerable amounts of historical data.. Perhaps requiring magnetic tape storage...”
- “Several final considerations involve the possible application of additional theoretical techniques such as quantitative precipitation forecasting.”

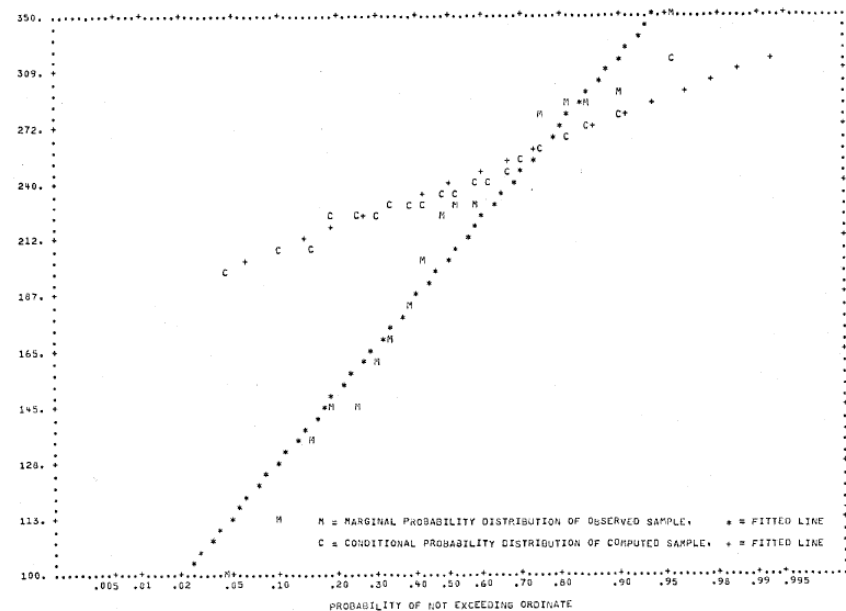
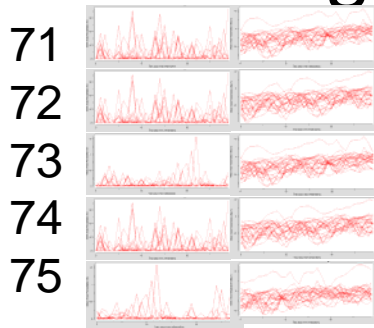


Figure 1. Marginal and conditional probability distribution plots for Eagle River total volume of flow (thousands acre-feet) during May and June 1971, predicted as of May 1, 1971.

Incorporating Climate Forecasts in ESP

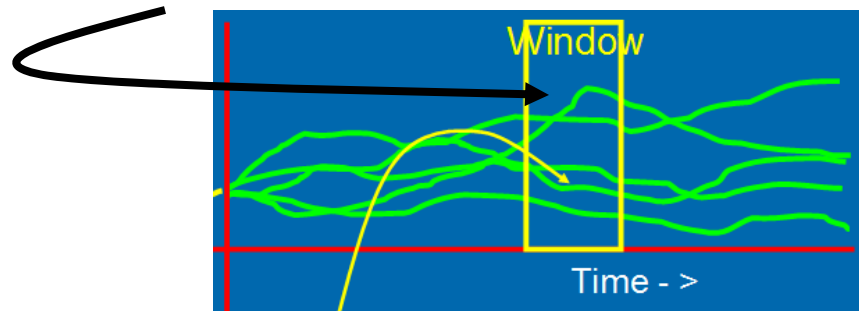
Pre -Adjustment Technique

Weight/Modify on Input Side

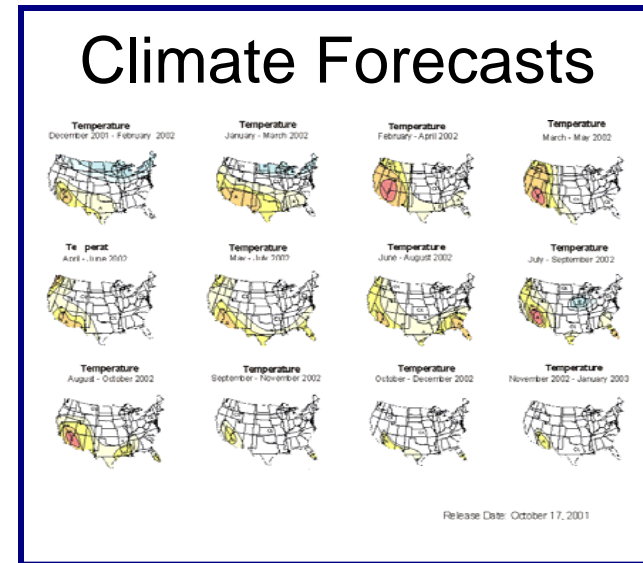
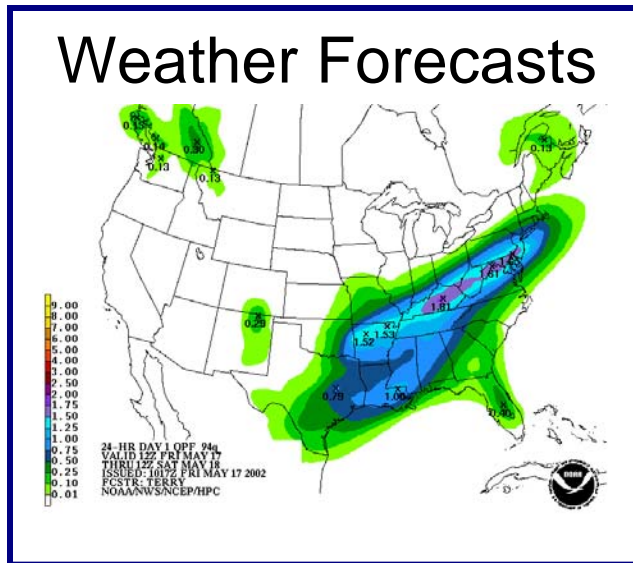
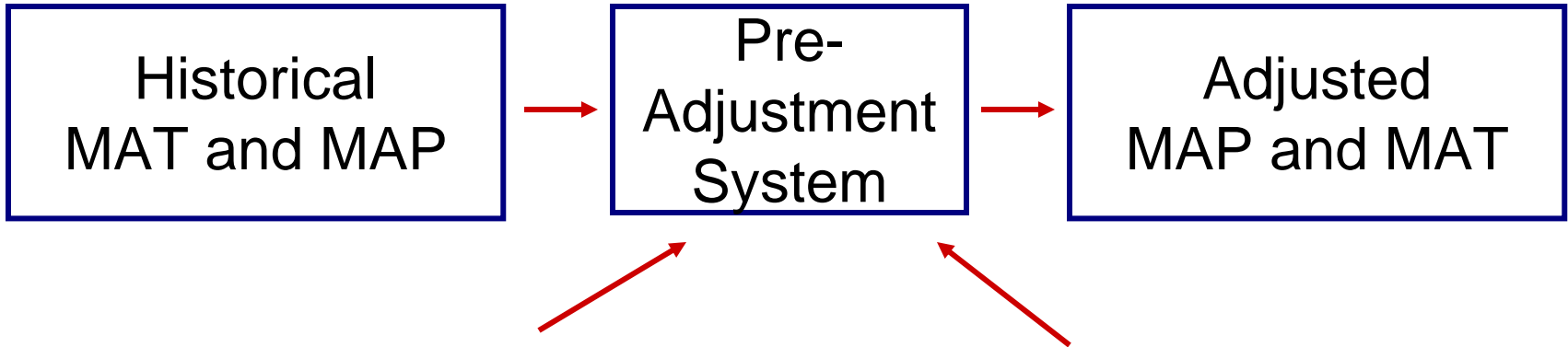


Post -Adjustment Technique

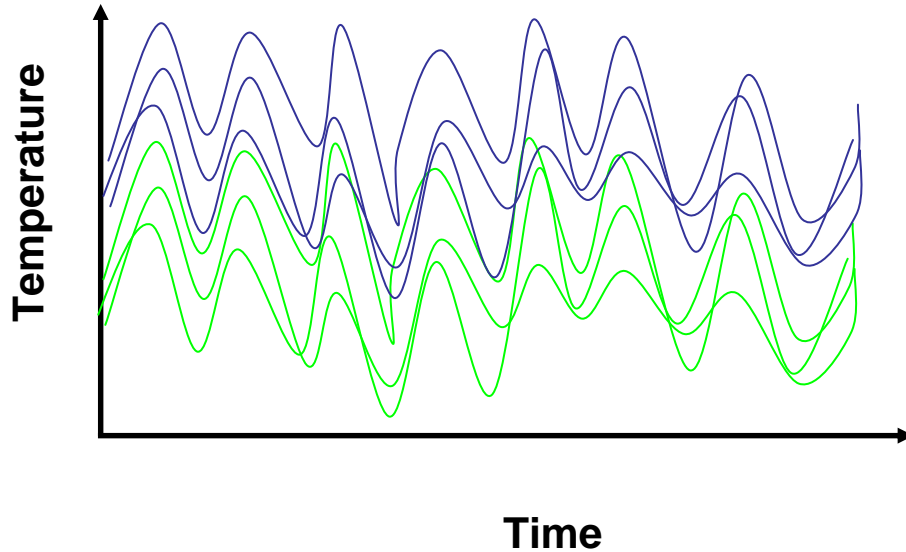
Weight On Output Side



Pre-adjustment System



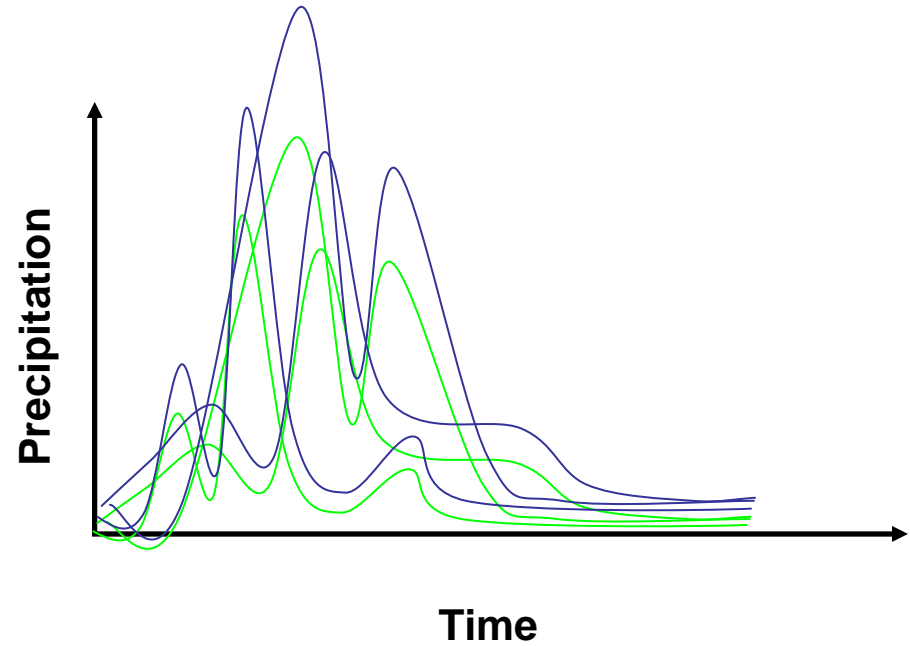
Pre-Adjustment Method



Temperature Ensemble

Adjusted Temperature ensemble based on a CPC “warm” probability shift.

Additive adjustment



Precipitation Ensemble

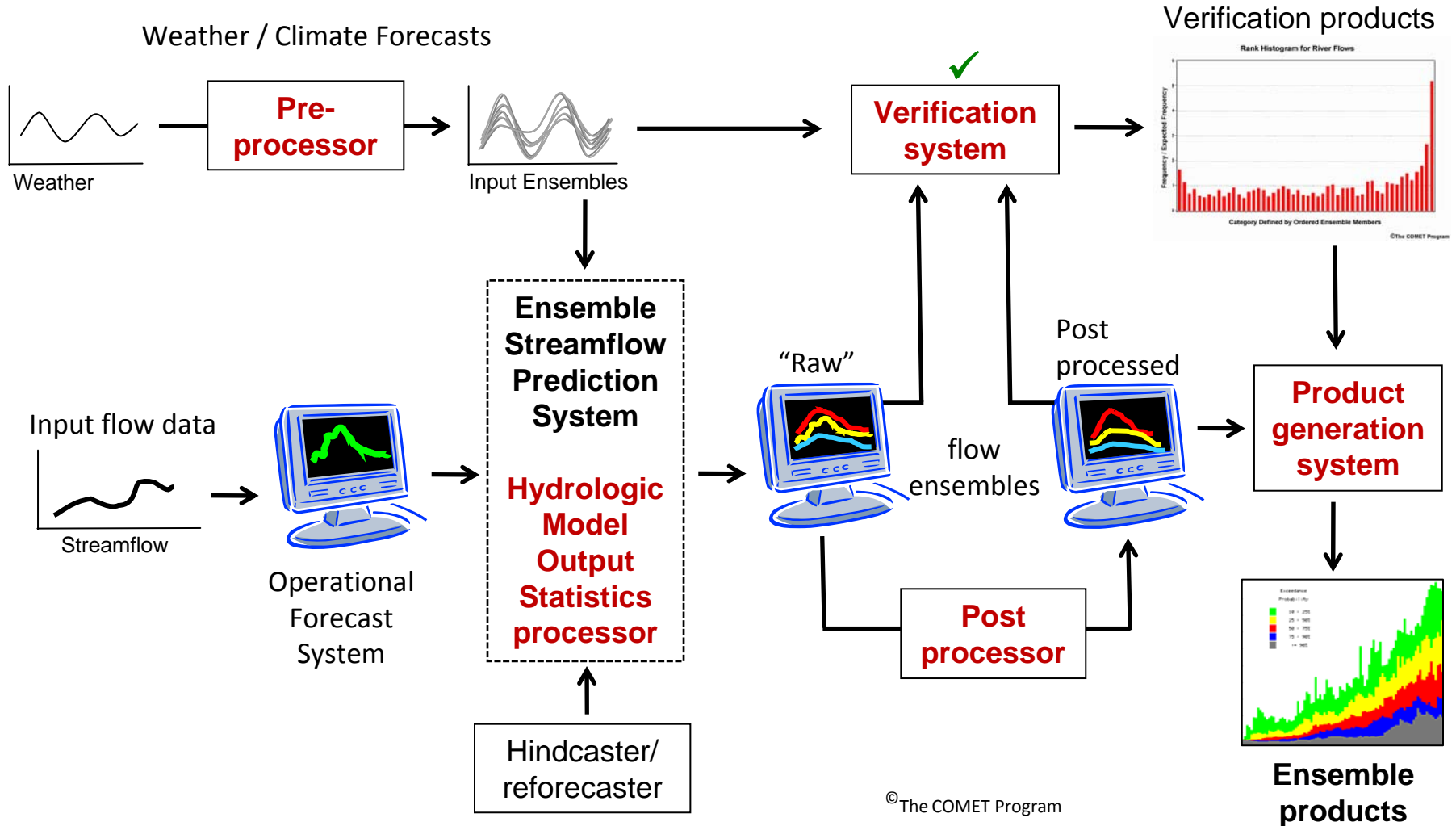
Adjusted Precipitation ensemble based on a CPC “wet” probability shift

Multiplicative adjustment

Research and Development

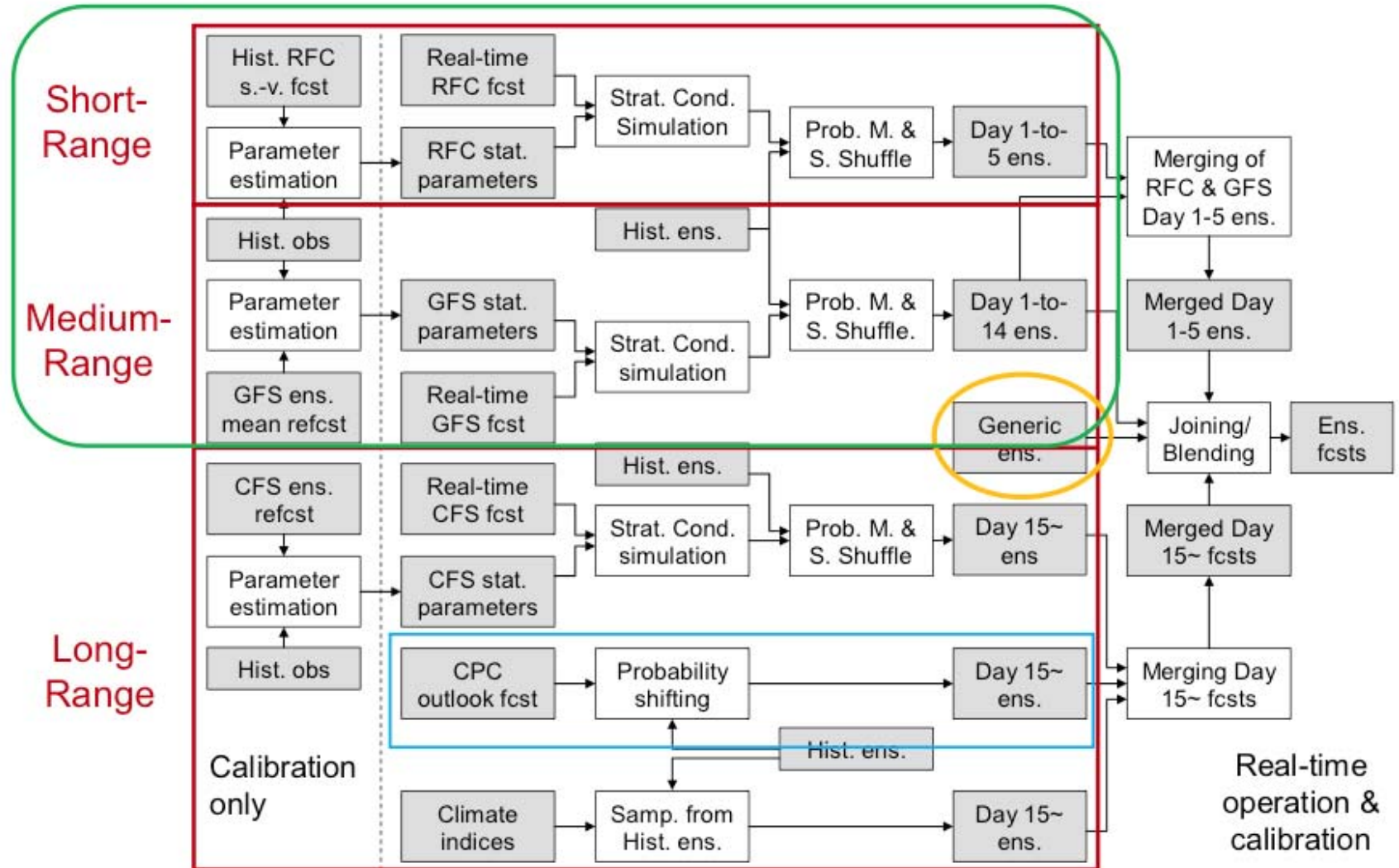
- Experimental Ensemble Forecast System
- CBRFC / CPC / OHD project
- Aptima project
- NWS CHPS Product generator

Hydrologic Ensemble Forecast System (HEFS / XEFS)





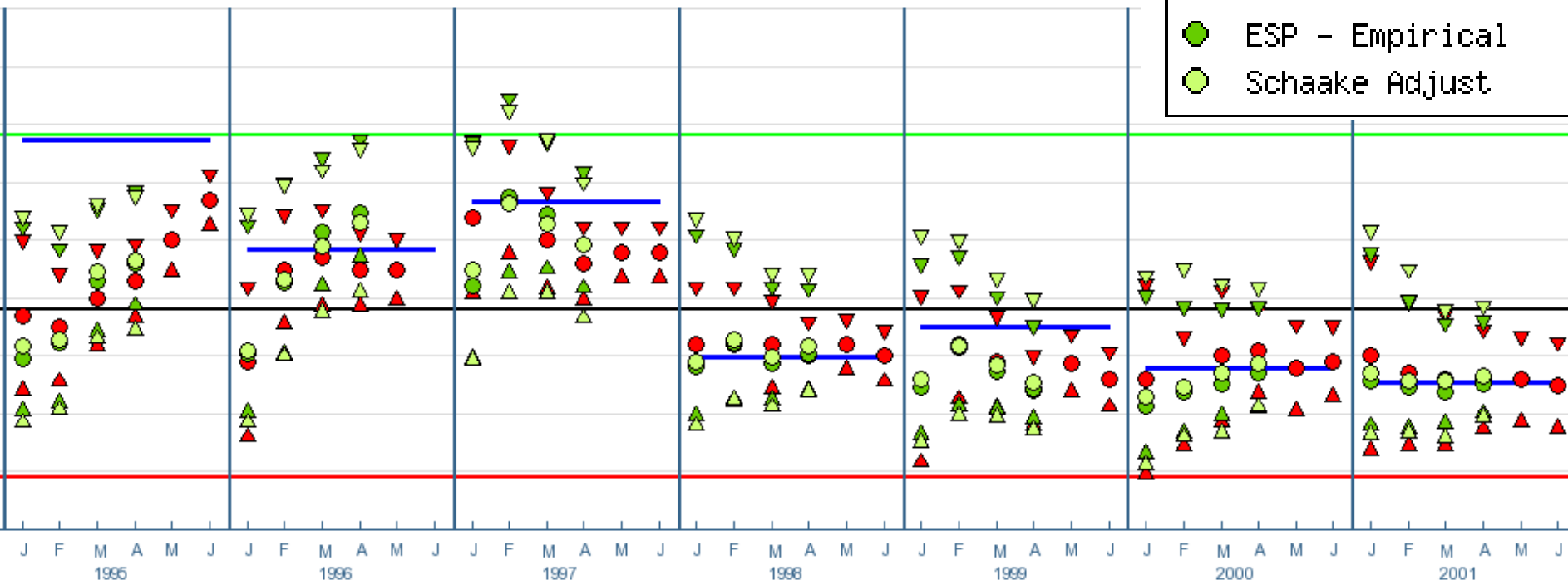
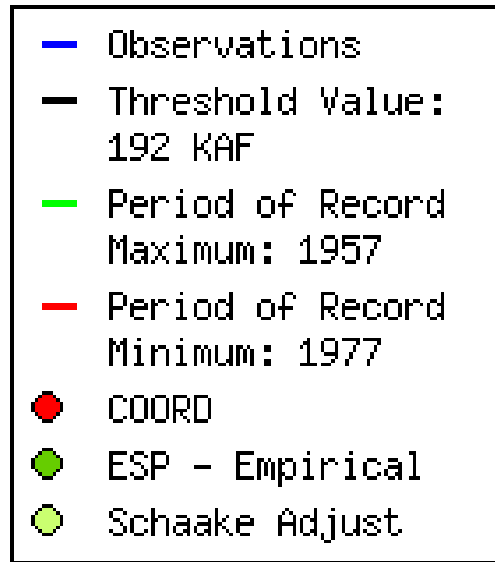
XEFS/Ensemble Pre-Processor III (EPP3)



From XEFS Design & Gap Analysis Report (NWS 2007)

Ensemble Post Adjuster

- Adjustment applied to ensemble forecasts to correct ensemble spread and mean biases
- CBRFC testing post adjusters for water supply forecasts:
 - CBRFC mean adjustment
 - ESPADP mean adjustment
 - Schaake transformed adjustment
- Example for East River at Almont

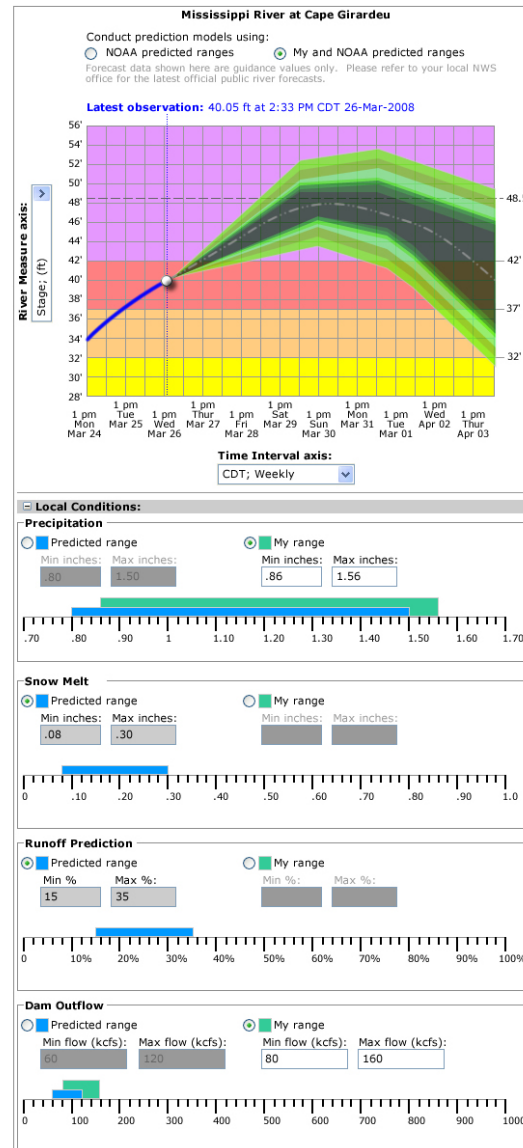
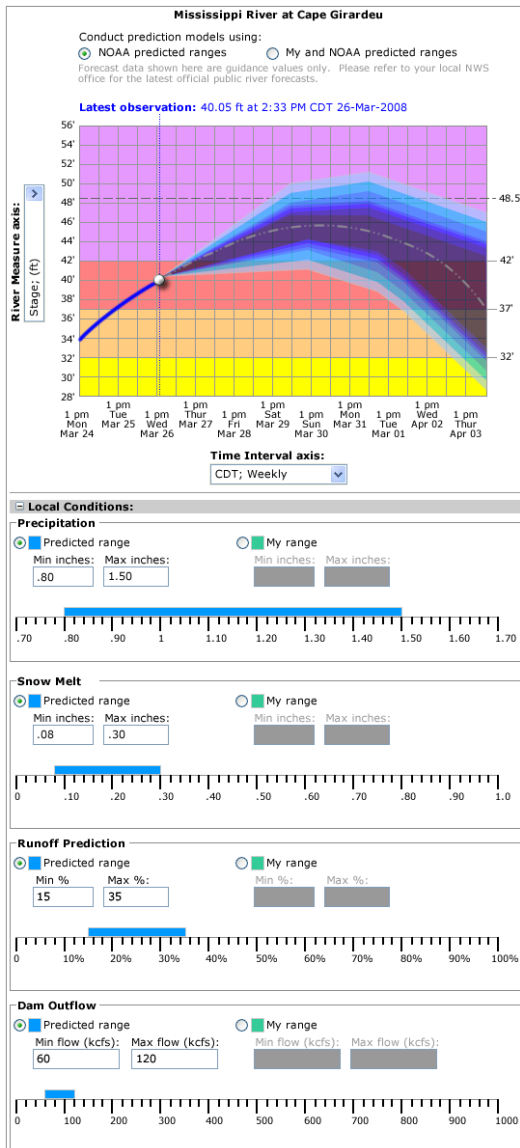


CBRFC / CPC / OHD Collaboration

- Goals:
 - Develop methodologies to include CFS forecasts in RFC forecasts
 - Improve RFC treatment of Evapotranspiration
- Funded one post doc position
 - ~1 year at CPC (FY10)
 - ~1 year at CBRFC (FY11)
- Collaborators: Kingtse Mo (CPC), John Schaake (OHD), DJ Seo (OHD), Kevin Werner (CBRFC)

NWS Hydrologic Forecast Uncertainty

Visual Display Design – River Height/Flow Forecast with Uncertainty



- Visual depiction of “river forecast” in terms of height / flow
 - Clear depiction of uncertainty with cone of uncertainty
- Provides the ability for users with local knowledge to adjust model parameters and visualize the alternative river forecast.

NWS CHPS Product Generator: Proposed GUI, Screen 1

Form Title

Selection

- Santiam Basin
 - Import data from OFSDE
 - Import data from SHEF
 - RRS processed data
 - Ensemble ENSPRE SQIN

- ▼ Detroit Dam
 - Detroit Dam Inflow Lower
 - Detroit Dam Inflow Middle
 - Detroit Dam Inflow Upper
- ▼ Foster Dam
 - Foster Reservoir Local Lower
 - Foster Reservoir Local Upper
- ▼ Green Peter Dam
 - Green Peter Inflow Lower

- River Discharge Observed Instantaneous
- Reservoir Inflow (Observed)
- Reservoir Outflow (Observed & Projected)
- River Discharge Observed Mean
- Reservoir Inflow Observed Mean
- River Stage Observed
- Reservoir Forebay Elevation (Observed)
- ✗ Precipitation Areal Mean
- Precipitation Areal Mean (Forecast)
- ✗ Gridded Precipitation Areal Mean
- ✗ Air Temperature Areal Mean
- Air Temperature Areal Mean (Forecast)

ID:

Reference:

Chart Series Calculators

#	Calculator Name	Input Time Series
1	Time Series	River at Place, QINE
2	Quantiles	River at Place, QINE, ENS POST

Input Series Provider Aggregator Calculator

Use Input Series From CHPS Time Series Selection Panel

Use Input Series Provider

< Back Next >

Current Chart Series

Chart Appearance Modifiers

Plot Title

Left-hand Y-Axis Title

Right-hand Y-Axis Title

X-Axis Title

Displayed Thresholds

Rating Curve

Times New Roman 12 **B** *I* U Color

Enter Text
Enter More Text

Little North Santiam

Discharge (CFS)

14,500
14,000
13,500
13,000
12,500
12,000
11,500
11,000
10,500
10,000
9,500
9,000
8,500
8,000
7,500
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500

12-14-2008 00:00:00 12-21-2008 00:00:00 12-29-2008 00:00:00

[1] SQIN (ENSPRE)

Using Probabilistic Forecasts

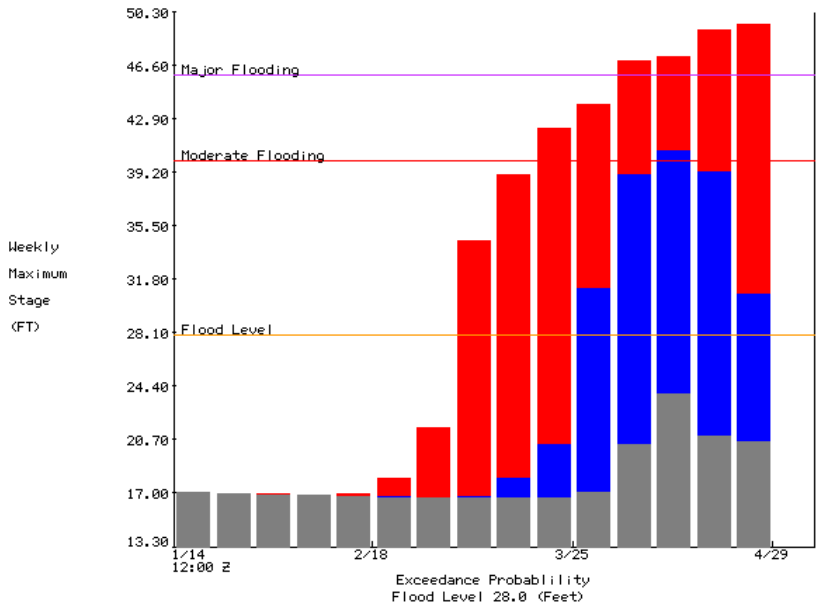
- AHPS long range products
- Western water supply
- Denver Water
- Others

NWS Hydrologic Forecast Uncertainty

Long-term Probabilistic Products

- Hydrograph
- River at a Glance
- Download
- Weekly Chance of Exceeding Levels**
- Chance of Exceeding Levels During Entire Period

1 Week Chances of Exceeding River Levels on the RED R at E GRAND FORKS MN
 Latitude: 47.6 Longitude: 96.8
 Forecast for the period 1/14/2009 - 4/29/2009
 This is a conditional simulation based on the current conditions as of 1/7/2009



About this graph

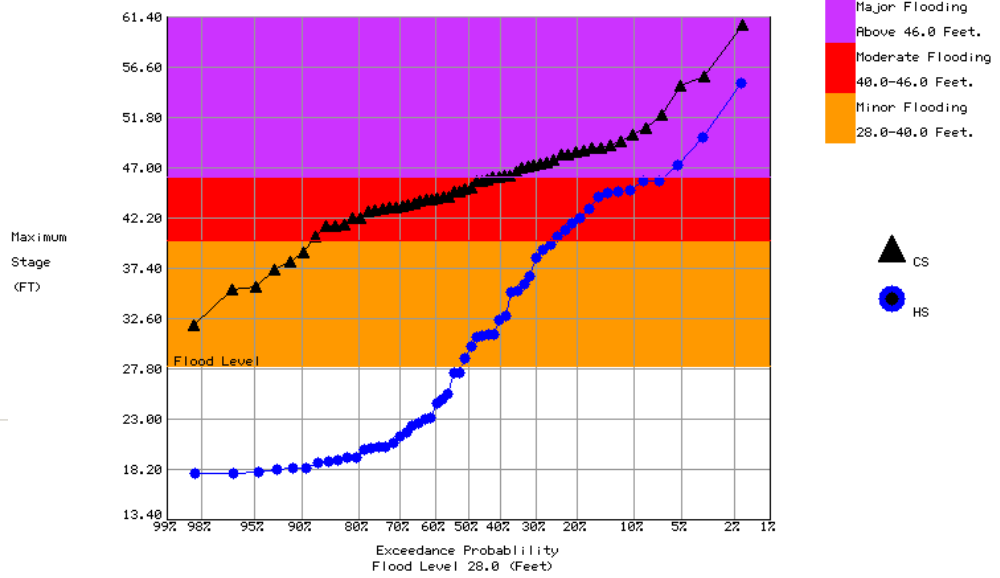
Forecasts for the Red River of the North at East Grand Forks are issued as needed during times of high water, but are not routinely available.

Stage - Weekly Chance of Exceeding Levels

[Return to Area Map](#)

- Hydrograph
- River at a Glance
- Download
- Weekly Chance of Exceeding Levels**
- Chance of Exceeding Levels During Entire Period

Chances of Exceeding River Levels on the RED R at E GRAND FORKS MN
 Latitude: 47.6 Longitude: 96.8
 Forecast for the period 1/14/2009 - 5/1/2009
 This is a conditional simulation based on the current conditions as of 1/7/2009



About this graph

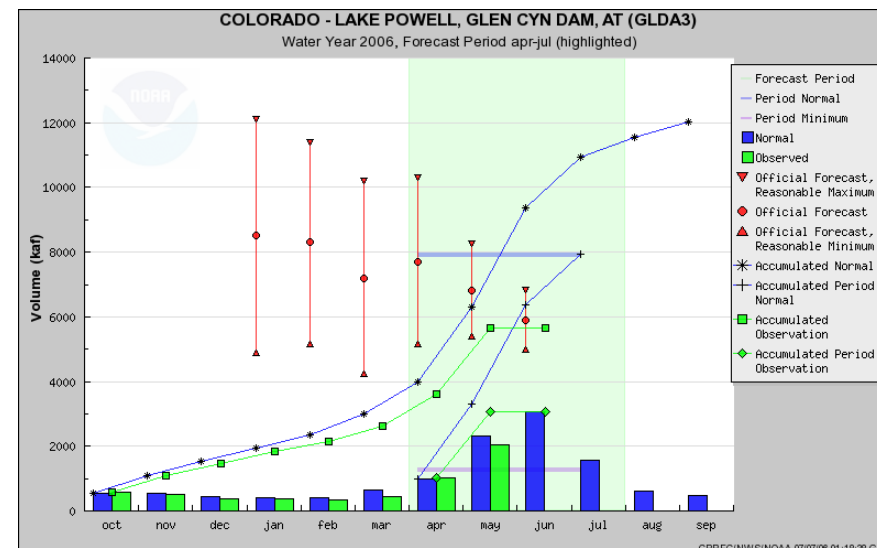
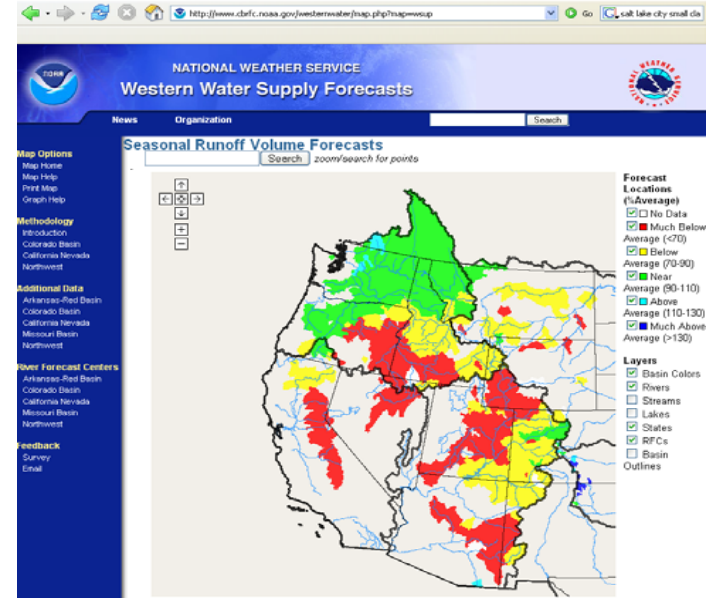
Forecasts for the Red River of the North at East Grand Forks are issued as needed during times of high water, but are not routinely available.

Stage - Chance of Exceeding Levels Entire Period

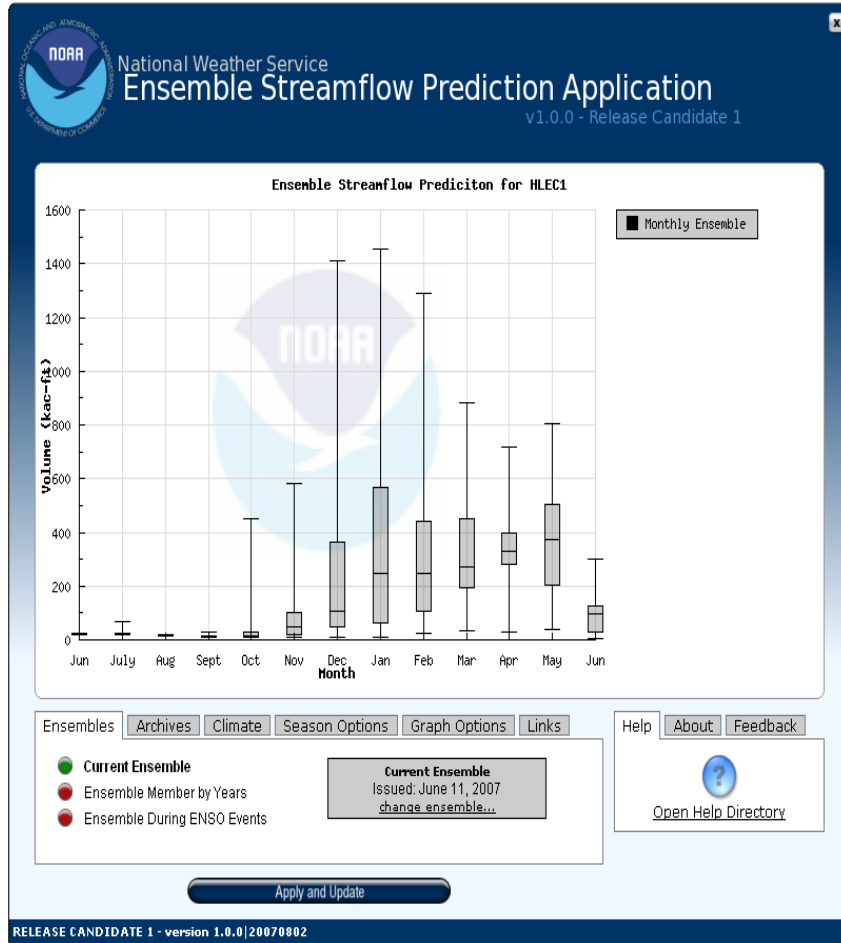
[Return to Area Map](#)

Western Water Supply Forecasts

- Forecasts for spring runoff amounts from snow melt dominated basins in western US
- Routinely produced at 6 RFCs and coordinated with other agencies
- NWS forecast program began in 1940s
- Primary forecast tools:
 - Ensemble Streamflow Prediction (described earlier)
 - Multivariate Linear Regression



Ensemble Services



RFC Ensemble Forecasts

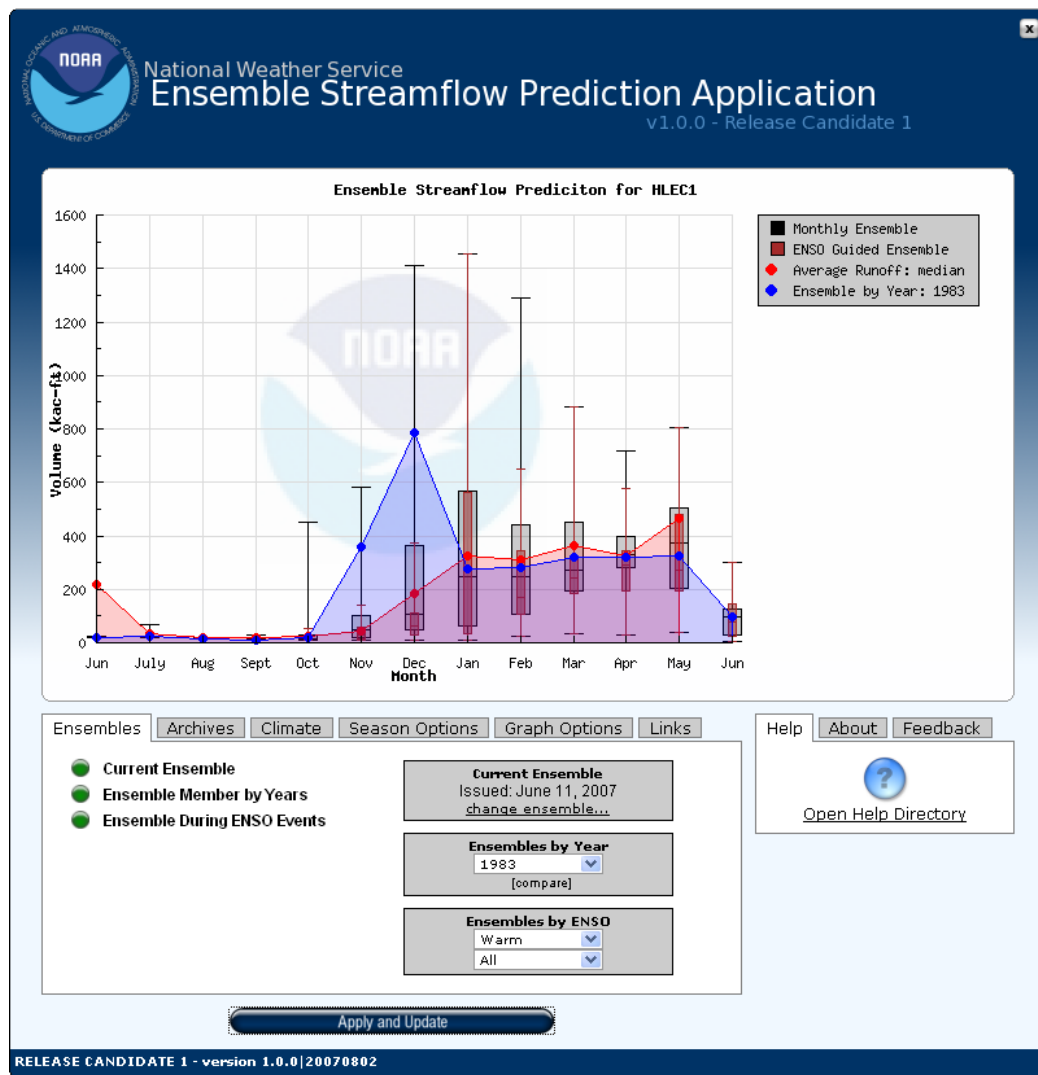
-Initially offered at NWS water supply points

-Display probability function for monthly volumes

-Tools included to query historical data and forecast ensemble members

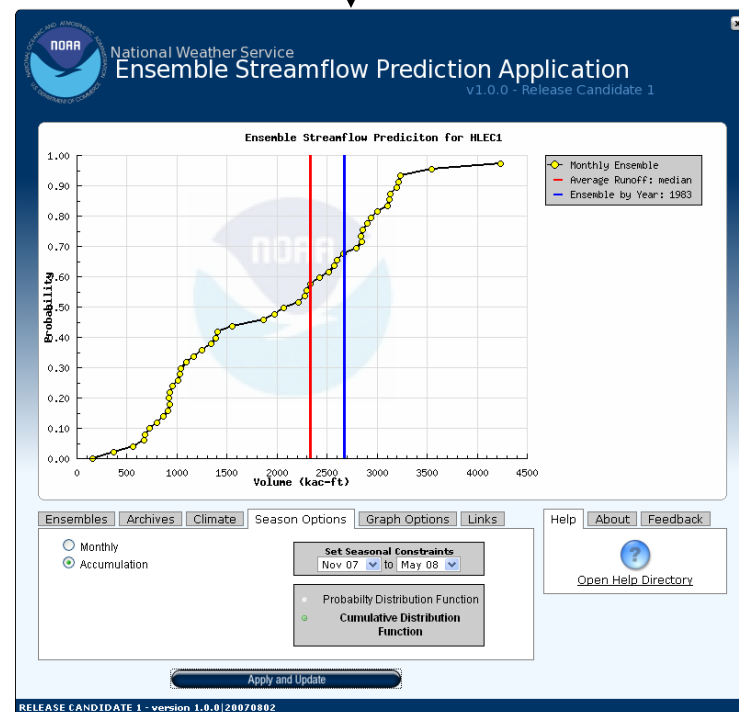
-User customizable plots

Ensemble Services



Median Historical Runoff
& 1983 ensemble member

November – May Seasonal
Runoff



Denver Water Application

RFC ESP
Forecasts

Results of Dillon ESP Simulations																		
Date of Traces: 4/7/08																		
Note: When elevations correspond to a specific date, the elevation occurs at the end of that date.																		
From May 26 - September 3.																		
Trace	Elev < 9002 Date	Elev > 9002 Date	# Days < 9002	Elev = 9011 Date	Elev = 9017 Date	Elev May 26	Elev June 30	Peak Comp Inflow		Peak Outflow		Days <450 out	Days 450-699	Days 700-1199	Days 1200-1399	Days >=1400 out		
								cfs	Date	cfs	Date							
6	1976	n/a	n/a	0	6/2	6/8	9006.60	9017.99	2266	6/6	1747	6/13	0	71	19	7	4	
7	1977	n/a	n/a	0	5/24	6/4	9011.70	9017.23	1990	6/6	1432	6/9	0	83	11	4	3	
8	1978	5/10	5/23	14	6/12	6/18	9002.70	9018.20	2539	6/15	1591	6/24	0	76	16	4	5	
9	1979	5/12	5/20	9	6/6	6/13	9004.30	9018.60	2735	6/15	2173	6/18	0	69	12	2	18	
10	1980	n/a	n/a	0	6/9	6/16	9004.40	9017.94	2226	6/12	1321	6/22	0	79	17	5	0	
11	1981	n/a	n/a	0	6/2	6/8	9006.80	9017.82	2857	6/9	2219	6/13	0	66	21	6	8	
12	1982	5/14	5/28	15	6/17	6/25	9001.10	9018.73	2033	6/18	1702	7/2	0	79	13	3	6	
13	1983	5/10	6/9	31	6/20	6/23	8999.00	9019.29	3384	6/24	2781	6/28	0	55	25	2	19	
14	1984	5/7	5/20	14	5/31	6/8	9006.10	9018.55	2549	6/15	2311	6/17	0	55	20	4	22	
15	1985	n/a	n/a	0	6/2	6/8	9006.30	9017.83	2877	6/9	1935	6/12	0	71	16	4	10	
16	1986	n/a	n/a	0	6/5	6/13	9005.70	9017.90	2349	6/9	1515	6/19	0	75	17	6	3	
17	1987	n/a	n/a	0	5/25	6/8	9011.10	9017.88	2107	6/8	1331	6/16	0	76	19	6	0	
18	1988	5/11	5/16	6	6/8	6/15	9003.80	9018.15	2357	6/9	1875	6/16	0	76	13	3	9	
19	1989	n/a	n/a	0	5/29	6/9	9008.80	9017.70	1912	5/30	1331	6/22	0	76	19	6	0	
20	1990	5/13	5/23	11	6/7	6/12	9002.80	9018.17	2926	6/10	1971	6/16	0	71	15	3	12	
21	1991	5/8	5/19	12	6/3	6/10	9005.40	9018.10	2395	6/10	1969	6/15	0	71	15	3	12	
22	1992	n/a	n/a	0	5/18	5/27	9016.20	9017.81	1875	5/21	1361	6/14	0	60	32	9	0	
23	1993	5/11	5/15	5	6/3	6/12	9005.10	9018.40	2789	6/18	2404	6/19	0	69	10	7	15	
24	1994	n/a	n/a	0	6/2	6/8	9006.50	9017.62	2241	6/7	1442	6/16	0	77	14	7	3	
25	1995	5/8	6/10	34	4/8	6/21	9000.00	9019.96	3843	7/9	3613	7/10	0	48	18	3	32	
26	1996	n/a	n/a	0	5/24	6/3	9012.60	9017.91	2273	5/25	1840	6/11	0	68	16	5	12	
27	1997	5/13	5/16	4	6/6	6/12	9004.30	9018.52	2535	6/19	2311	6/23	0	69	11	4	17	
28	1998	n/a	n/a	0	6/2	6/13	9005.40	9017.89	2122	6/3	1054	6/24	0	72	29	0	0	
29	1999	5/12	5/23	12	6/6	6/12	9003.70	9019.05	2854	6/21	2559	6/22	0	56	19	2	24	
30	2000	n/a	n/a	0	5/22	5/28	9014.60	9017.46	2736	5/31	2334	6/2	0	72	14	3	12	
31	2001	n/a	n/a	0	5/25	6/1	9011.40	9017.64	2292	6/3	1759	6/5	0	70	17	3	11	
32	2002	n/a	n/a	0	5/31	6/8	9006.20	9017.24	2465	6/1	1169	6/13	0	87	14	0	0	
33	2003	5/11	5/21	11	5/30	6/3	9005.10	9018.26	3180	5/31	2139	6/19	0	62	13	6	20	
34	2004	n/a	n/a	0	5/27	6/6	9010.40	9017.52	1836	6/8	1311	6/11	0	85	13	3	0	
35	2005	5/12	5/20	9	6/29	6/8	9007.80	9017.89	2074	5/24	1679	6/21	0	72	18	4	7	
36	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
37	Min	5/7	5/15	0	4/8	5/27	8999.00	9017.23	1836	5/21	1054	6/2	0	48	10	0	0	
38	Max	5/14	6/10	34	6/20	6/25	9016.20	9019.96	3843	7/9	3613	7/10	0	87	32	9	32	
39	Avg	5/10	5/23	6	5/31	6/9	9006.53	9018.11	2487	6/9	1873	6/17	0	71	17	4	9	
40																		
41	90% Ex	8-May	16-May	0	5/23	6/2	9002.54	9017.51	1983	5/29	1320	6/10	0	56	12	2	0	
42	70% Ex	10-May	19-May	0	5/29	6/8	9004.37	9017.83	2236	6/5	1493	6/13	0	69	14	3	3	
43	50% Ex	11-May	20-May	0	6/2	6/8	9005.90	9017.93	2376	6/9	1799	6/17	0	71	16	4	9	
44	30% Ex	12-May	23-May	10	6/9	6/12	9007.10	9018.22	2736	6/12	2149	6/21	0	76	18	5	12	
45	10% Ex	13-May	5-Jun	14	6/9	6/18	9011.79	9018.76	2951	6/19	2420	6/24	0	79	21	7	20	
46																		
47	Assumed RT off until June 1 and April "normal" operating plan thereafter. Took HT from April "normal" plan.																	
48	Assumed Fernandez' suggestion and then held the 470 release.																	
49																		
50	Raffable flows approx 450 - 1800 cfs. Optimum for commercial approx 700 - 1400 cfs.																	
51	Good stream fishing approx 450 cfs and below. Marginal fishing 450 - 700 cfs.																	
52																		

Reservoir
Management

Other Applications

- Pacificcorps operation on Bear River (UT and ID)
- BPA and USACE operation on Columbia River
- INFORMS project in CA

Summary

- ESP overview and history
- New and ongoing research and development
- Forecast usage