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Managing Water in the West

Evaluating the Value of Information provided by Airborne Snow Observatory products in support of Reclamation Snowmelt Management

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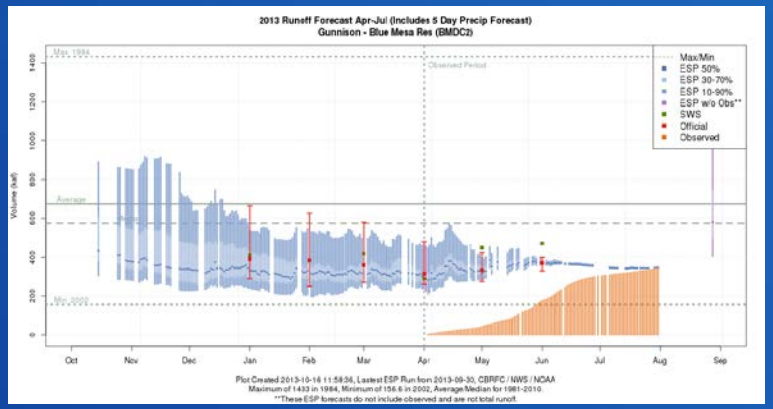
U.S. Department of the Interior
Bureau of Reclamation

Evaluating the Value of Information provided by Airborne Snow Observatory products in support of Reclamation Snowmelt Management

Gap(s) Addressed

Reclamation recognizes technology for improved measurement and estimation of snow water equivalent (SWE), snow covered area (SCA), and snow surface albedo is being developed by NASA JPL with the Airborne Snow Observatory (ASO) and is investigating whether or not these advances will potentially lead to significantly improved operating

Graphic



Research Question(s)

What is the value of the information provided by ASO products and associated improved forecasting in Reclamation's snowmelt management and spring runoff operations?

Can Reclamation operate reservoir systems more efficiently and better meet our operation goals with improved forecast products?

Collaborators/Schedule/Source of Support

- NASA JPL, NOAA-NWS CBRFC, USBR Upper Colorado Region, TSC, Research and Development
- Operation models and synthetic forecasts currently in development, results and analysis in June-September
- Funding: USBR Research and Development Office

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Project Background

- Reclamation's spring reservoir operations (i.e. snowmelt management) depend largely on runoff forecasting to set targets and make decisions including reservoir release volumes and timing to make room for snowmelt runoff
- Operational goals include minimizing reservoir spill, maximizing irrigation deliveries, maximizing hydropower production, meeting environmental flow requirements, etc…
- Reclamation dam/reservoir operators frequently revisit operational outlooks and inflow forecasts during the snowmelt season of (March) April-July
- These forecast products largely provided by NOAA NWS River Forecasting Centers

Project Background

- Reclamation recognizes technology for improved measurement and estimation of snow water equivalent (SWE), snow covered area (SCA), and snow surface albedo is being developed by NASA JPL with the Airborne Snow Observatory (ASO)

- It is expected that better data should lead to better snowmelt forecasting, both in runoff volumes and timing

Major Research Questions

- What is the value of the information provided by ASO products and associated improved forecasting in Reclamation's snowmelt management and spring runoff operations?

- Essentially, can we operate our reservoir systems more efficiently and better meet our operation goals with these potentially improved forecast products?

- Two systems selected: Aspinall Unit on the Gunnison River, Navajo Unit on the San Juan River
- Two major units of the Colorado River Storage Project, vast majority of runoff as spring snowmelt

Gunnison Basin – Aspinall Unit

- 3 dams/reservoirs with hydropower plants operated holistically as one system
- Blue Mesa Reservoir– 941 TAF, main storage reservoir
- Morrow Point Reservoir – 117 TAF, highest head (413') major peaking hydropower producer
- Crystal Reservoir – 26 TAF, operated to re-regulate the highly fluctuating flows from Morrow Point
- Black Canyon Tunnel Diversion – up to 1300 cfs, ~365 TAF annually, and other water right demands
- Environmental Flow Requirements in the Black Canyon and newly near Grand Junction depend on snowmelt runoff forecasts
- Flooding constraints

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Gunnison River Environmental Flows Depend Directly on April-July Forecast Volumes

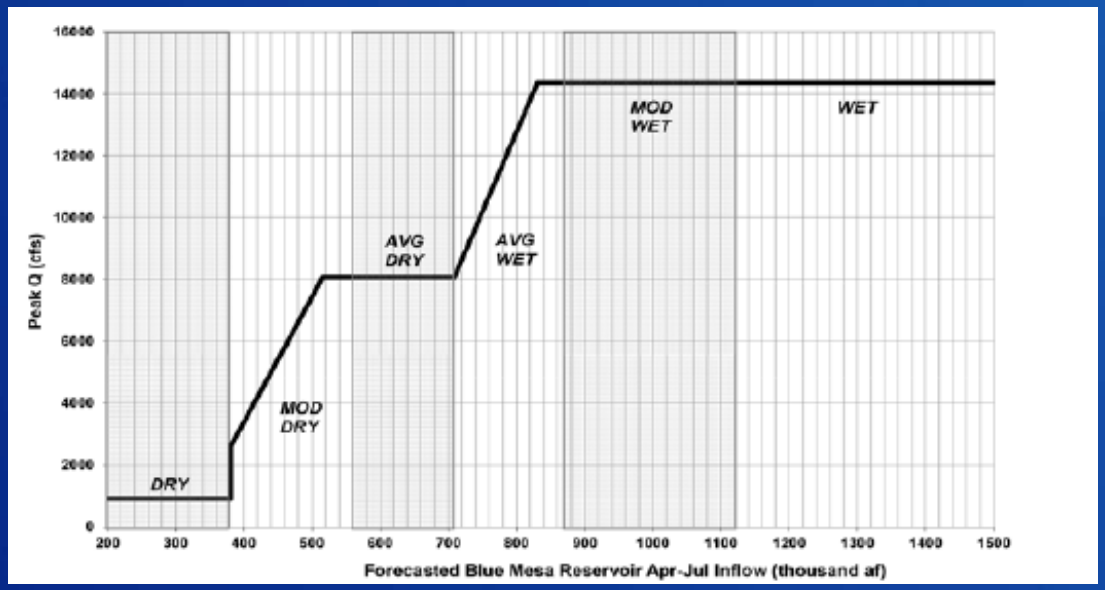

Table 2. Base flow targets at Whitewater Gage by year type and month (cfs)*

Year Type	Jan. and Feb.	Mar.	Apr. and May	Jun. and July	Aug.	Sep.	Oct. and Nov.	Dec.
Wet	1050	1050	1050	1500	1500	1050	1050	1050
Mod Wet	1050	1050	1050	1500	1500	1050	1050	1050
Avg Wet	1050	1050	1050	1500	1050	1050	1050	1050
Avg Dry	1050	1050	1050	1500	1050	1050	1050	1050
Mod Dry*	750	750-790	750-890	1050	1050	750-890	750-790	750
Dry*	750	750-790	750-890	1050	750-890	750-890	750-790	750

*During March through November in Moderately Dry and Dry type years, additional releases will be made as necessary to provide flows above the 750 cfs anticipated to be diverted by the Redlands Diversion Dam, for the fish ladder and fish screen as shown.

Goal to time peak res. releases with forecasted tributary peaks for efficient operations

Year Type dependent on runoff has big effects on base flow release volumes required

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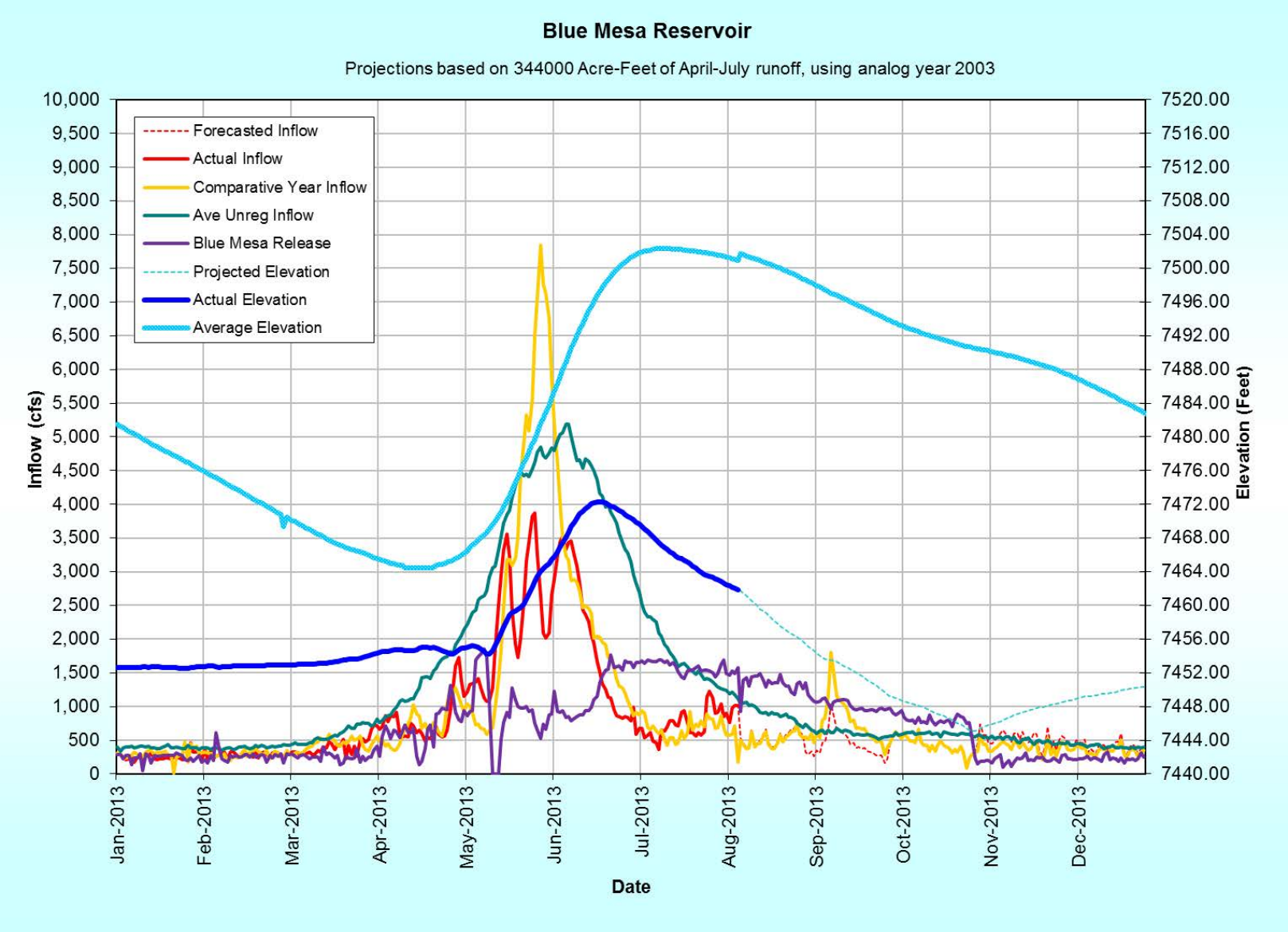
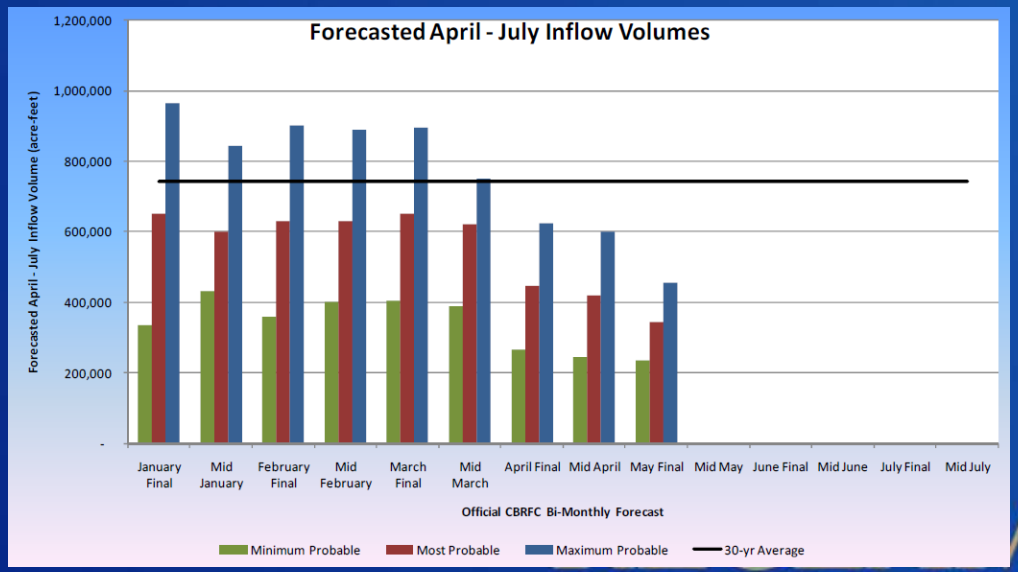
Example Aspinall Operations 2013

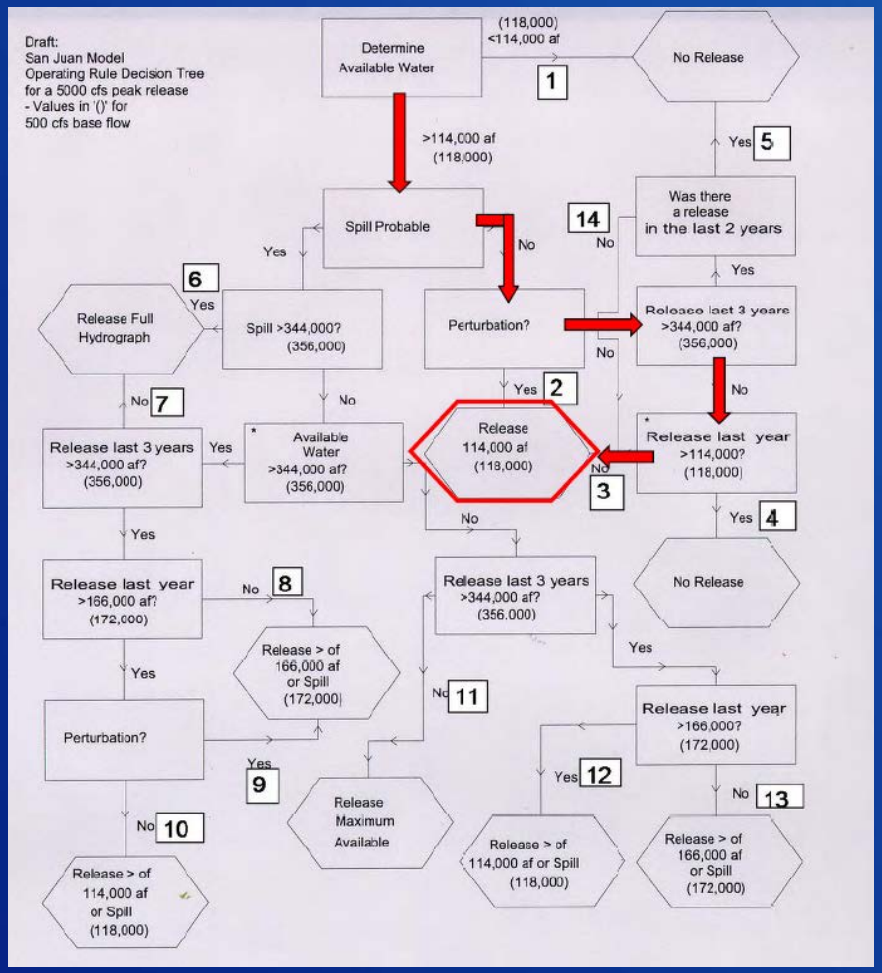


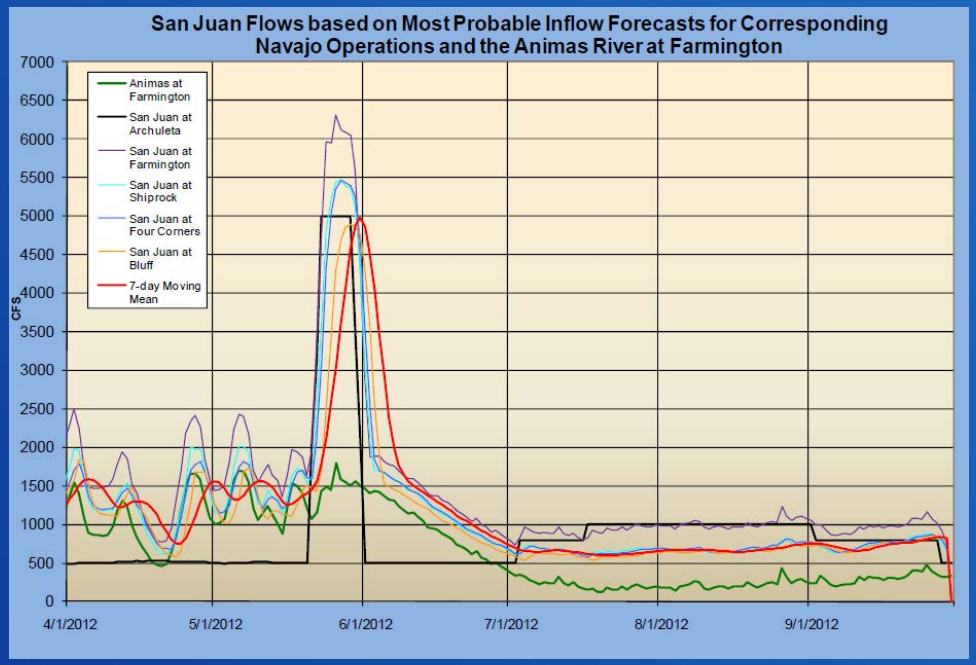
San Juan Basin – Navajo Unit

- Vallecito Reservoir (Pine River) – 130 TAF, irrigation storage
- Navajo Reservoir (San Juan River) – 1708 TAF, major CRSP storage reservoir
- Recovery Implementation Program (RIP) Flows – In stream flow requirements for Colorado pikeminnow, razorback sucker
- San Juan-Chama diversion to Rio Grande Valley, 110 TAF



2012 RIP Releases





Numerous decision points depend on forecast volumes

Timing of releases with forecasted tributary peaks for efficient operations

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CBRFC – Current Forecast Methods

- Statistical Water Supply (SWS)
  - Develops/applies principal component regression equations
  - Predictor variables can include: Observed Precip, Existing Snow Water Equivalent, Observed Streamflow Volumes, Climate Signal Indices (e.g. ENSO index)
  - Easier to calibrate, maintain, and run
  - Provides 10%, 50%, 90% exceedance values for seasonal volume
  - Can only run at certain times and for pre-defined forecast periods (e.g. April-July volume)
- Coordinate with NRCS forecasts, developed with similar methods to SWS
- NWS River Forecast System ESP (next slide)
- Produce Official seasonal runoff forecasts, 2x/month
- Short-term flows, <10 days

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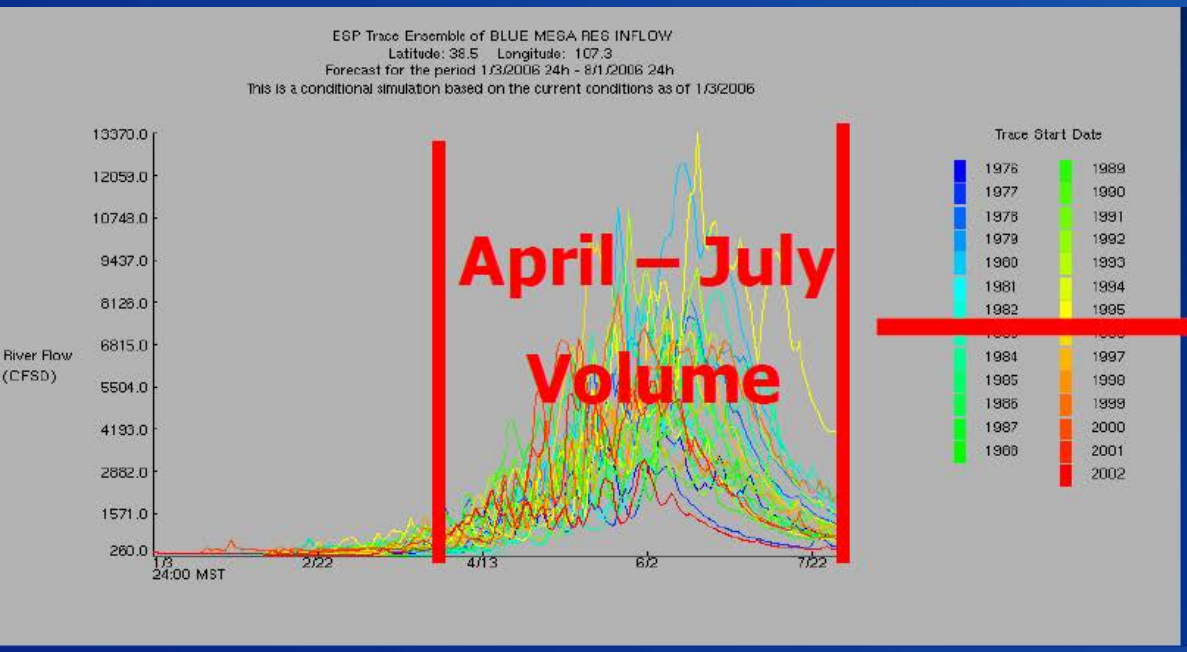
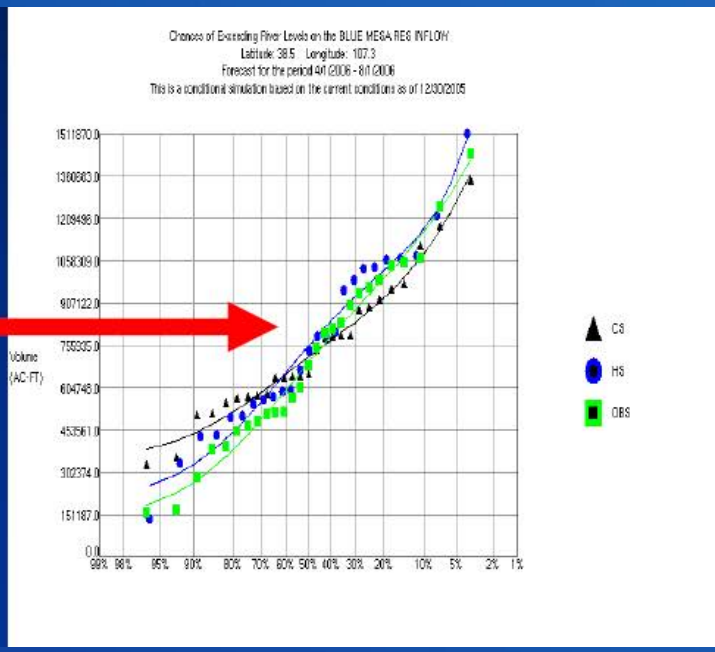
CBRFC – Current Forecast Methods

- **NWS River Forecast System**
  - **Sacramento Soil Moisture Accounting (SacSMA) with SNOW-17**
  - **Operational Forecast System generates short-term deterministic river forecasts with observed meteorological data and forecasted precip (5-day) and temp (10-day)**
  - **Continuously tracks and maintains current model states, including soil moisture and snowpack**
  - **Snow states are informed and updated with SNOTEL site data (point measurements) and compared with model simulated snowpack, adjustments are made**
  - **Ensemble Streamflow Prediction (ESP) models into the future with historic met data traces as potential future weather scenarios to create ensembles of forecast flow hydrographs and create statistical distributions**

Example ESP Results





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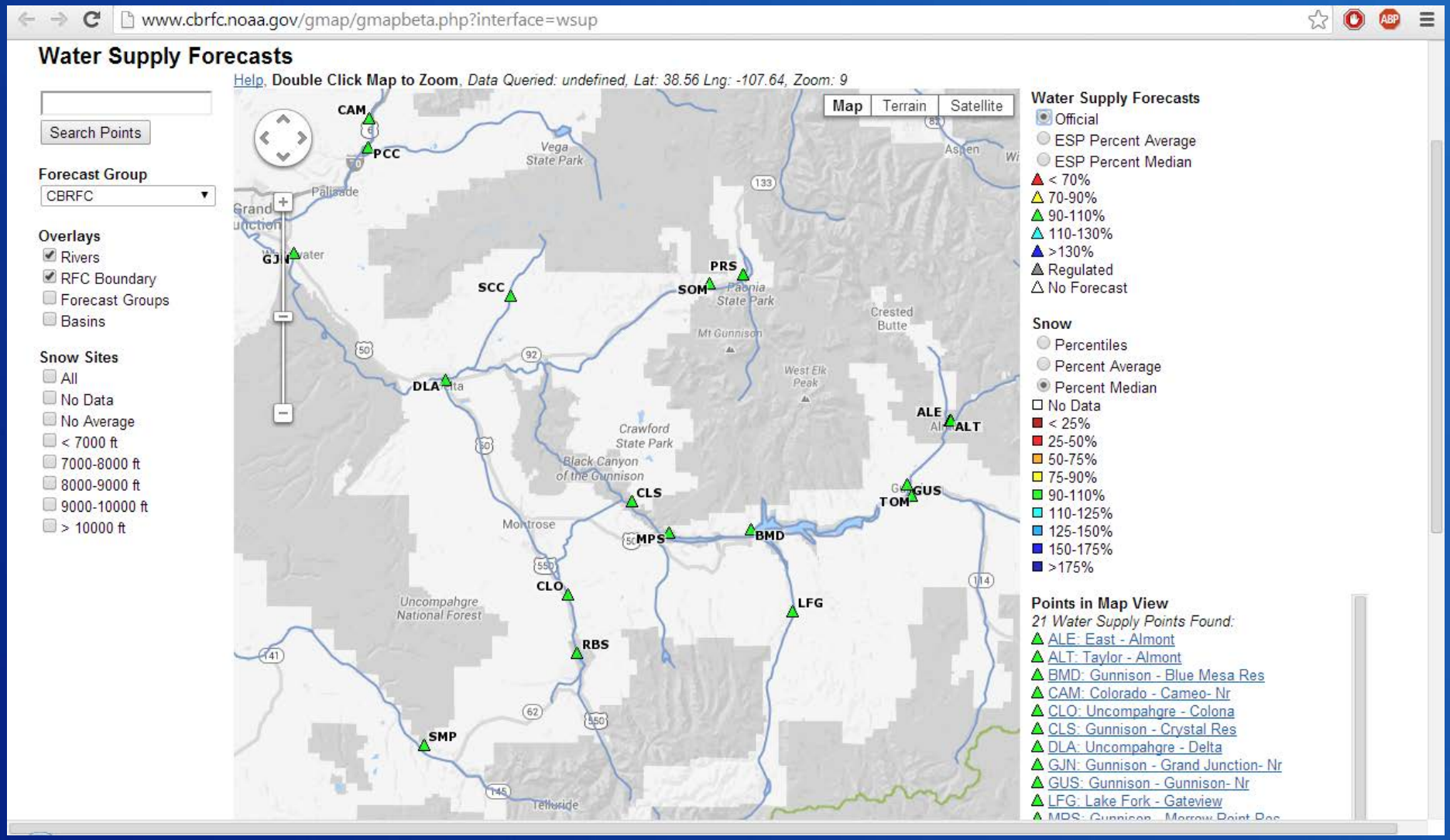
Gunnison Basin RFC Forecasts



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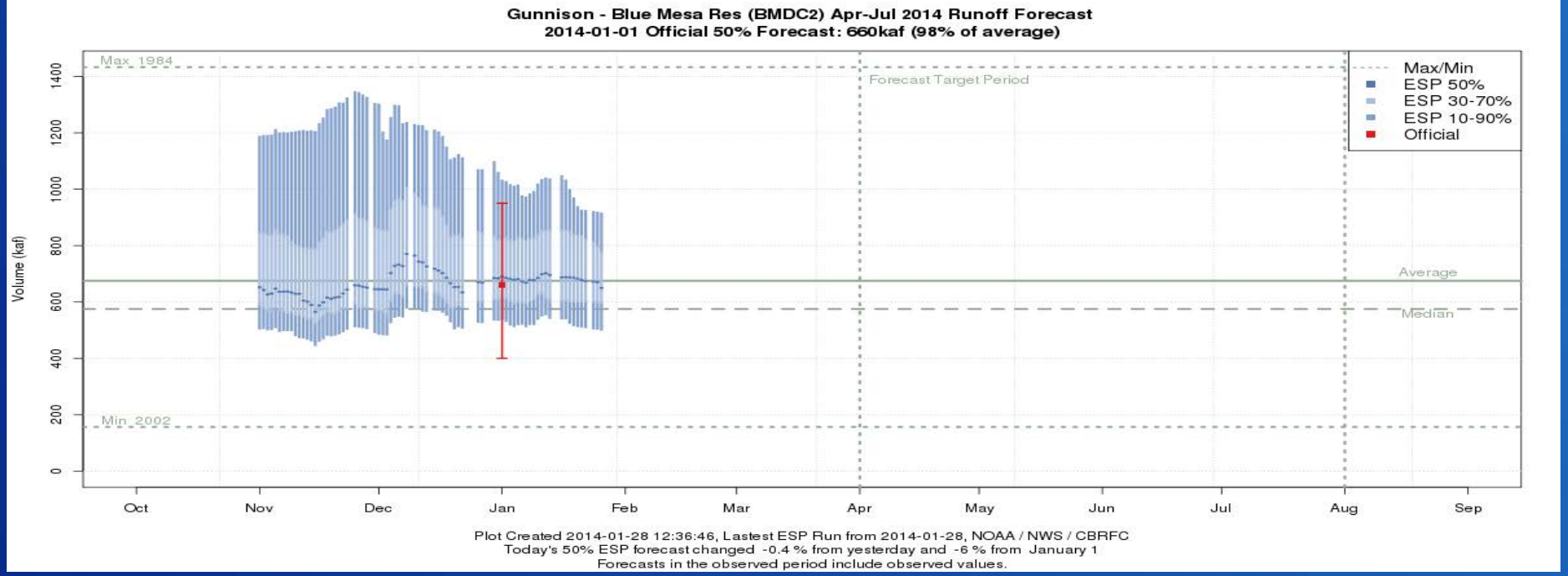
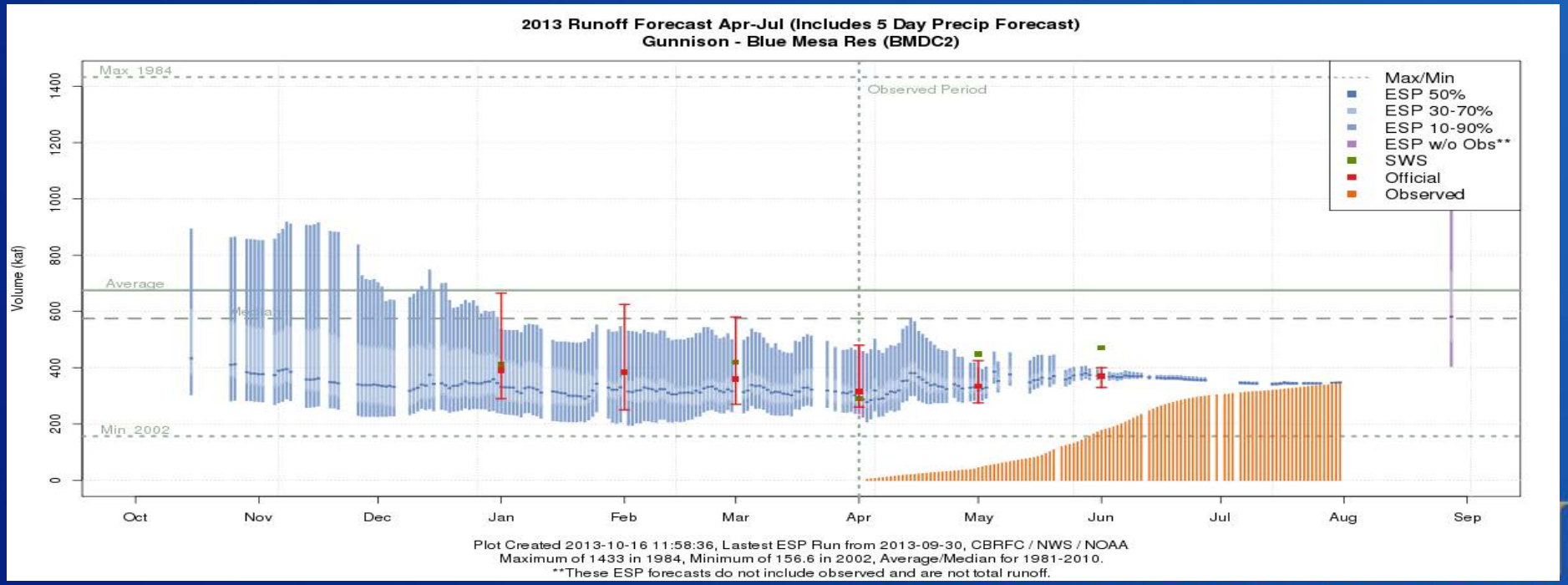

Gunnison - Blue Mesa Res (BMDC2) Apr-Jul 2014 Runoff Forecast
2014-01-01 Official 50% Forecast: 660kaf (98% of average)
Max 1984
Forecast Target Period
Max/Min
ESP 50%
ESP 30-70%
ESP 10-90%
Official
Average
Median
Min 2002
Volume (kaf)
0
200
400
600
800
1000
1200
1400
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Plot Created 2014-01-28 12:36:46, Lastest ESP Run from 2014-01-28, NOAA / NWS / CBRFC
Today's 50% ESP forecast changed -0.4 % from yesterday and -6 % from January 1
Forecasts in the observed period include observed values.


2013 Runoff Forecast Apr-Jul (Includes 5 Day Precip Forecast)
Gunnison - Blue Mesa Res (BMDC2)
Max 1984
Observed Period
Max/Min
ESP 50%
ESP 30-70%
ESP 10-90%
ESP w/o Obs**
SWS
Official
Observed
Average
Median
Min 2002
Volume (kaf)
0
200
400
600
800
1000
1200
1400
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Plot Created 2013-10-16 11:58:36, Lastest ESP Run from 2013-09-30, CBRFC / NWS / NOAA
Maximum of 1433 in 1984, Minimum of 156.6 in 2002, Average/Median for 1981-2010.
**These ESP forecasts do not include observed and are not total runoff.

3+ Forecast Alternatives

Base

- Current Model, SacSMA + SNOW-17
- Current Snow Monitoring SWE/SCA, Point Measurements (SNOTEL)

Alternative 1

- New Model, DHSVM (Distributed Hydrology Soils and Vegetation Model)
- Current Snow Monitoring SWE/SCA, Point Measurements

Alternative 2

- New Model, DHSVM
- Airborne Snow Observatory informed SWE, SCA, Albedo

NASA is developing synthetic forecasts for each alternative for operational analysis (described next)

Operations Modeling Plan

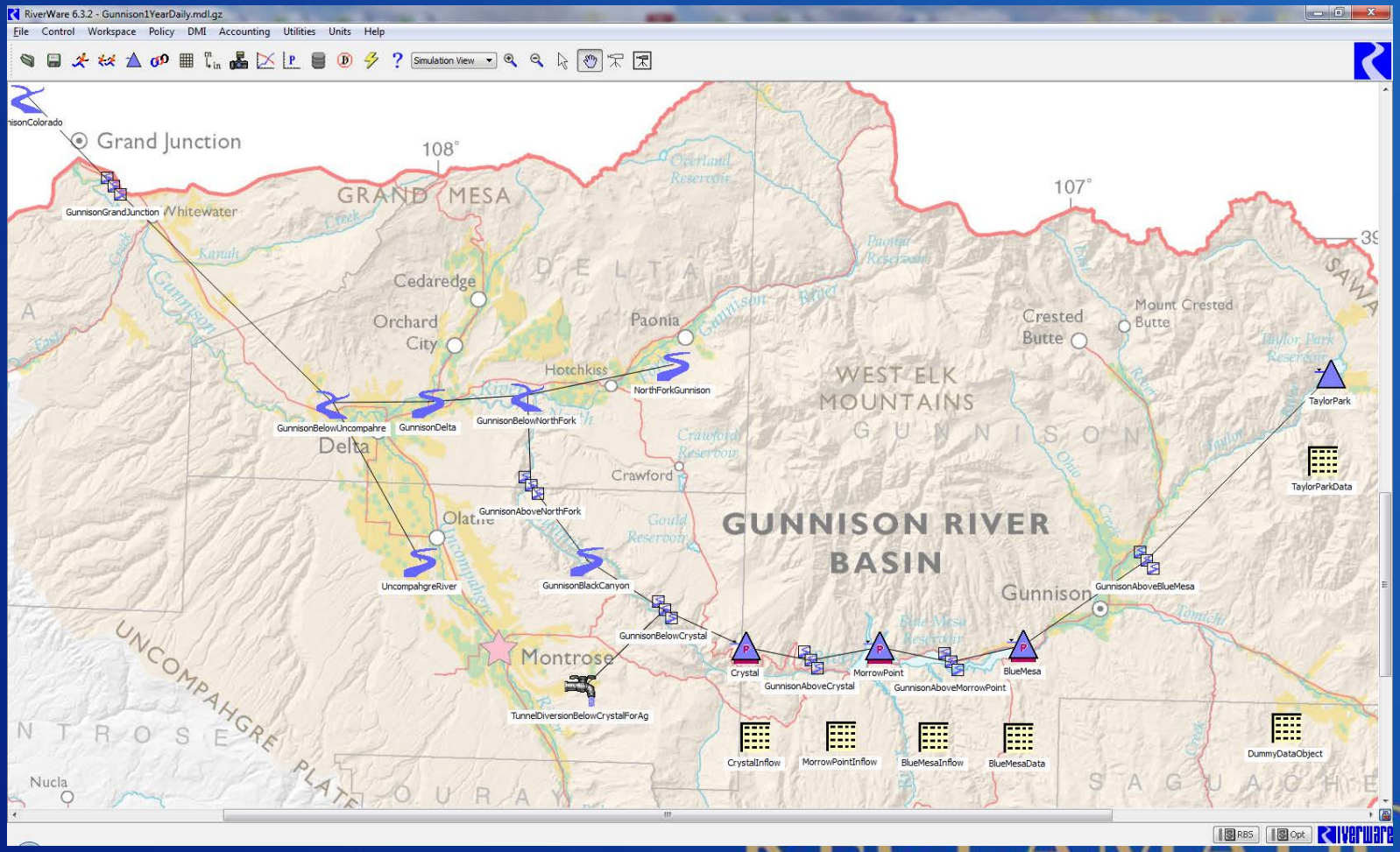
- Emulate basin snowmelt operations with RiverWare annual operation models at a daily timestep
- Focus on snowmelt operational look ahead and decision making due to forecasted seasonal runoff
- Run individual Water Years 2001-2012 (12 years)
- Initialize on Mar 1st with observed historic conditions
- Run 1 year at a time, 3 runs per year with Alts
- Look ahead with each forecast and mimic actual operational decisions, release planning, etc.
- Advance/run the model with actual observed data
- Incrementally compare operational targets vs operational error (deviations) due to forecast error

RiverWare

- Developed and maintained by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at University of Colorado Boulder (CU)
- Developed with substantial support from Reclamation, US Army Corps of Engineers, and Tennessee Valley Auth.
- Notable applications:
  - Reclamation's Colorado River Simulation System (CRSS) long term planning and Mid Term Operations Models
  - TVA's 6-hr timestep daily scheduling optimization model of >40 reservoirs and hydroelectric plants
- RiverWare provides a construction kit for hydrologic operations modeling: river/reservoir network setup, "Rules" language for simulations, modeling algorithms, solvers, etc…

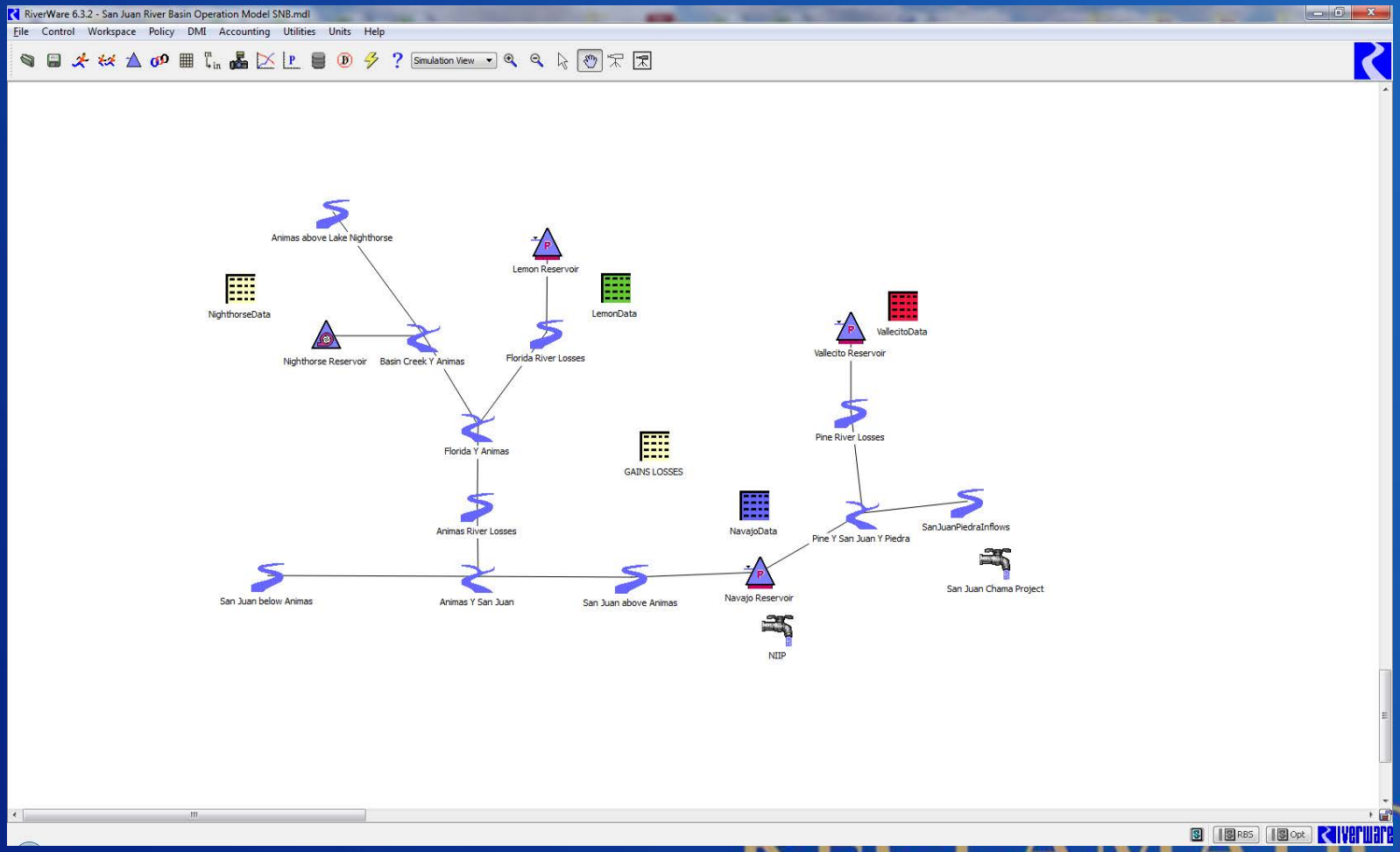
Gunnison Operations Model

Developing for this project at TSC, to be hopefully adopted for use in annual ops by UC region operators



San Juan Operations Model

In development by Susan Behery, USBR, Durango, CO for use in annual operations. Adapted for this study



Evaluation of Forecast Value of Info

Potential Evaluation Variables:

- **Spill volumes, reservoir levels, target storages**
- **Environmental flows/goals**
- **Demands/deliveries made**
- **Hydropower production**
- **Other requirements**

- **How do deviations between actual operations and goals and targets vary across forecast types?**
- **What are the "real impacts" of these deviations? (Qualitative or quantitative, economics, etc…)**

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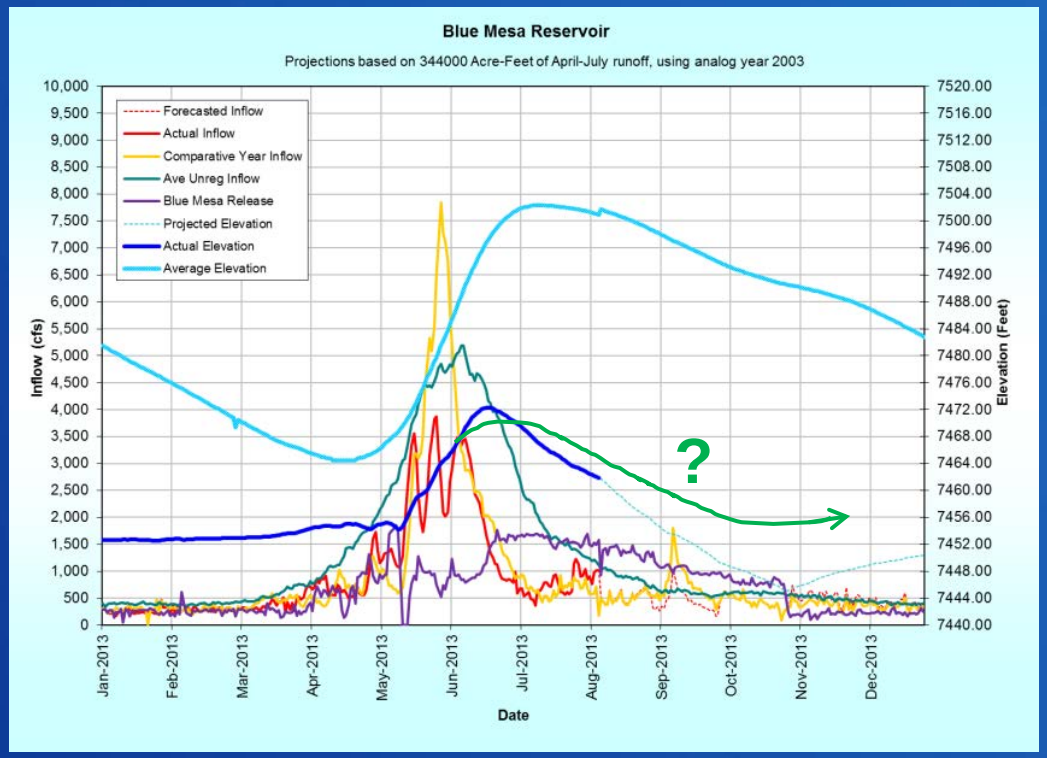
Task Summary

1. Develop operation models in RiverWare
2. Develop "Synthetic Forecasts" for Baseline and Alternatives
3. Run operation models with different forecast alternatives
4. Compare/evaluate operations differences, target meeting, etc due to different forecast alternatives
5. Assign Value to the Deviations



Potential gains from better monitoring and forecasting??

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Questions?

To NASA to Describe Synthetic Forecast Development

Assessing the Value of Information from advanced hydrologic modeling and ASO for forecasting and water resources management

Kostas Andreadis[1], Tom Painter[1], Jeff Deems[2,3], Ben Livneh[3]

[1]NASA Jet Propulsion Laboratory

[2]National Snow and Ice Data Center

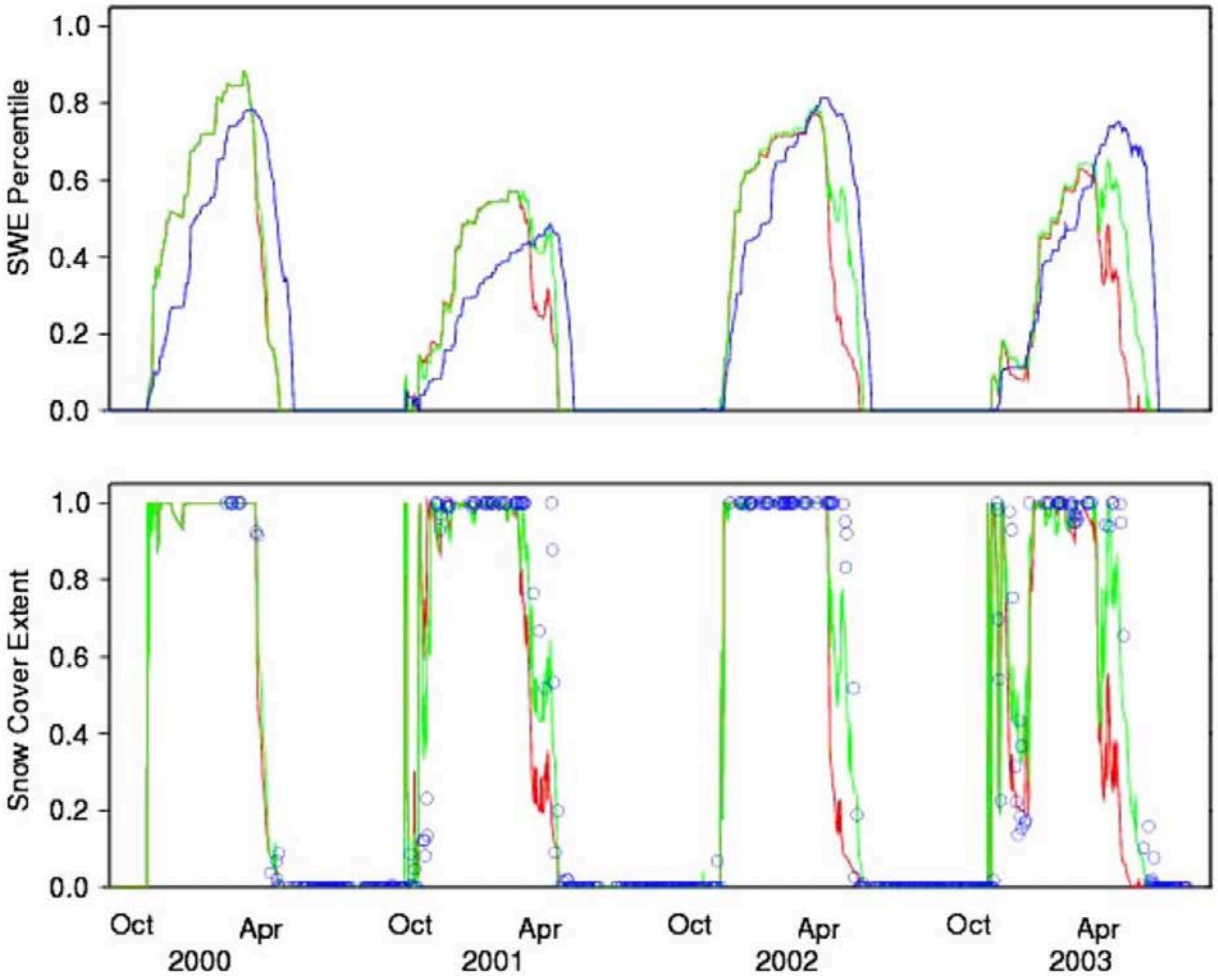
[3]National Oceanic and Atmospheric Administration

Background

- Streamflow (and therefore reservoir inflow) forecasting relies on snow mass estimates
- Usually taken from SNOTEL measurements
- Point measurements cannot capture spatial variability of SWE
- ASO can provide synoptic information on snow properties at unprecedented spatial scales
- ASO observations can be merged with snow models via data assimilation
- *Data assimilation can provide the optimal estimates for forecast initial conditions*

Assimilation of snow cover extent

- Example from assimilation of MODIS fractional snow cover over the Snake River basin



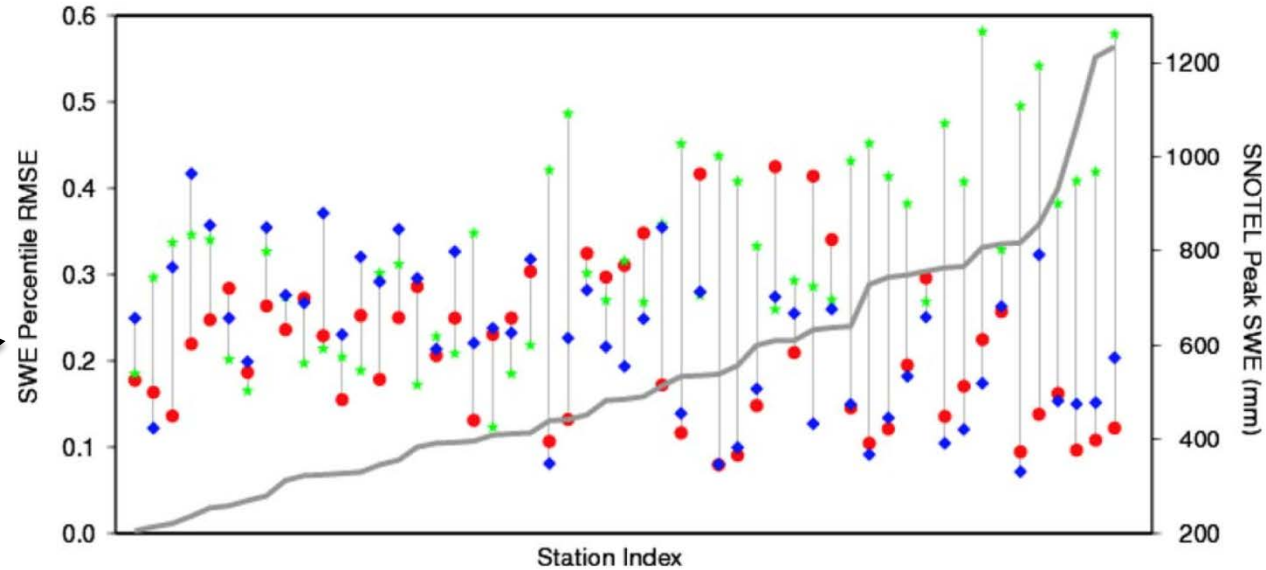
SNOTEL/MODIS

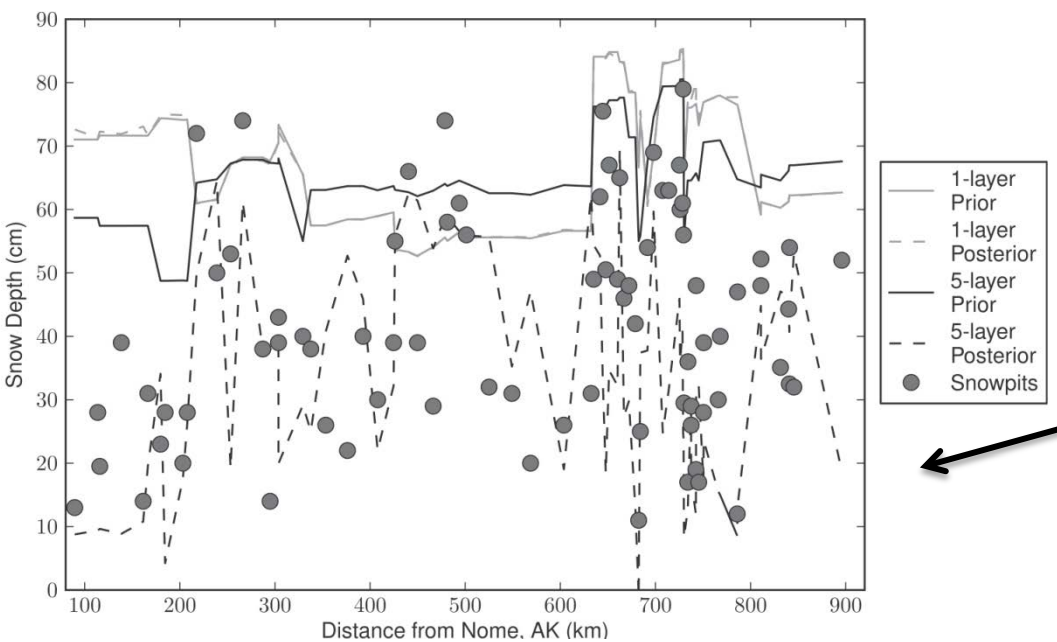
NO ASSIMILATION

ASSIMILATION

Assimilation of SWE and T_B

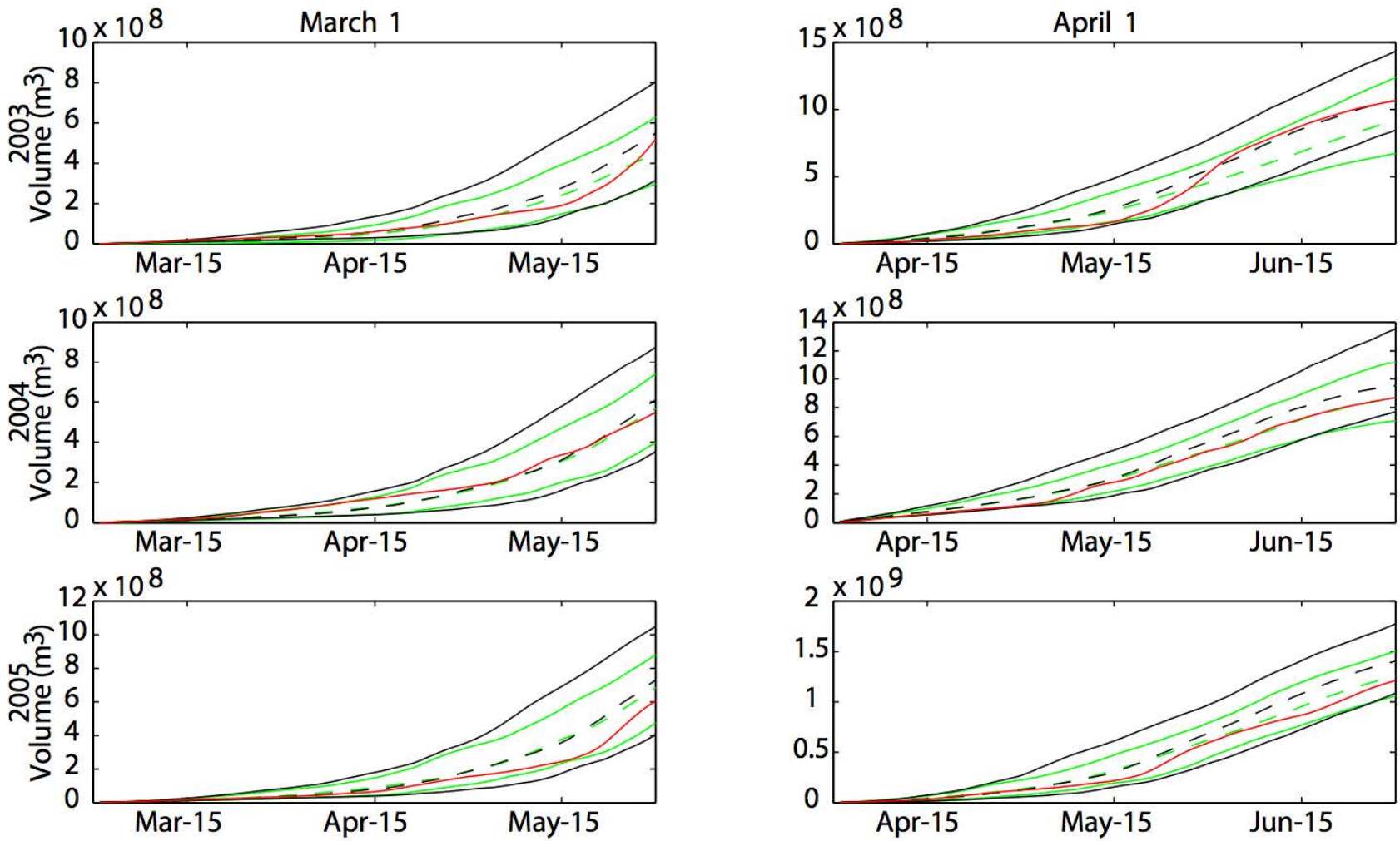
- Example from assimilation of AMSR-E SWE over the Snake River basin





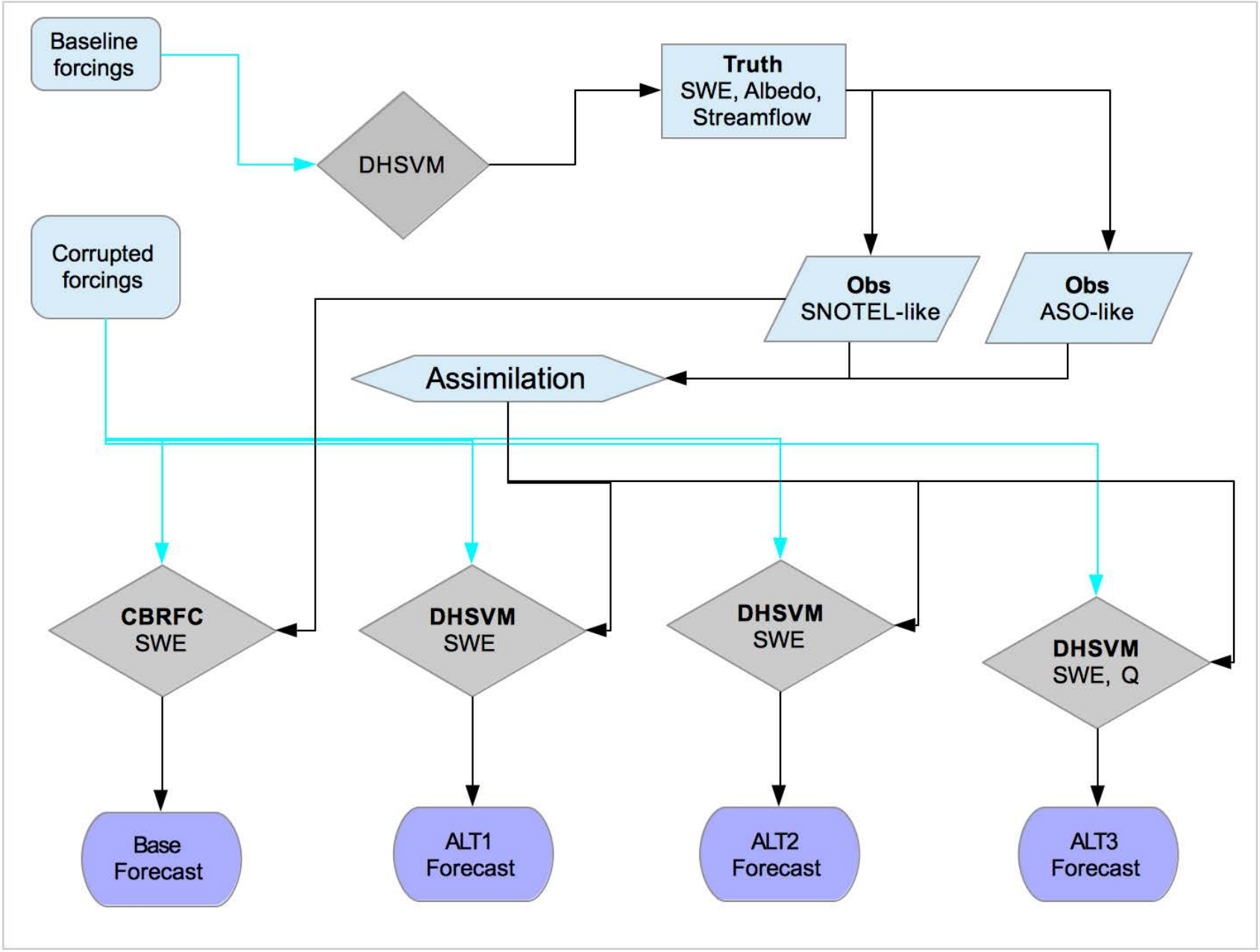
- Example from assimilation of AMSR-E T_B over Alaska transect

Streamflow from snow assimilation



95% ESP ESP Mean 95% ESPDA ESPDA Mean Observed

Experimental design



Overview of tasks

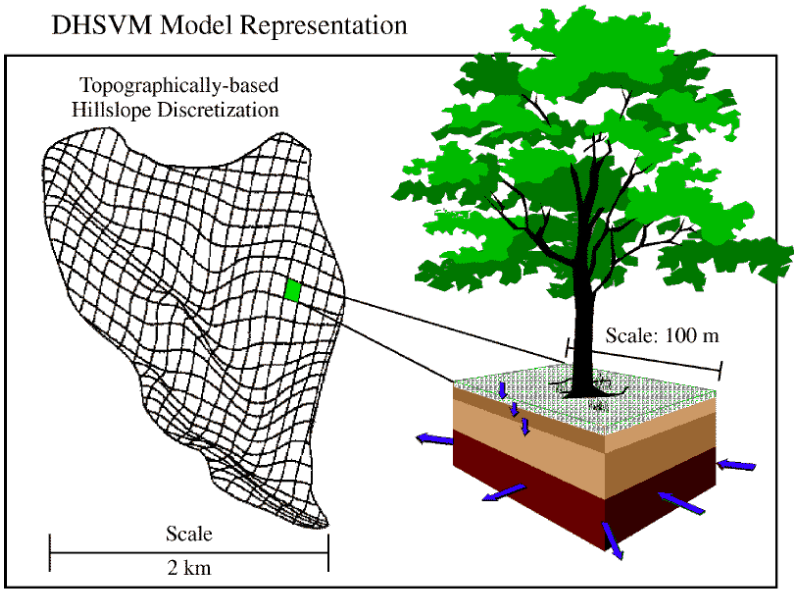
- Develop “Truth” hydro-meteorological simulations
- Extract meteorology for ESP forecasting
- Generate synthetic observations (SNOTEL & ASO)
- Produce runoff forecast series
  - Baseline: SaCSMA using SNOTEL SWE
  - ALT1: SaCSMA using SWE IC (SNOTEL assimilated into DHSVM)
  - ALT2: SaCSMA using SWE IC (ASO assimilated into DHSVM)
  - ALT3: DHSVM using SWE IC (ASO assimilated into DHSVM)
- IC: Initial Conditions

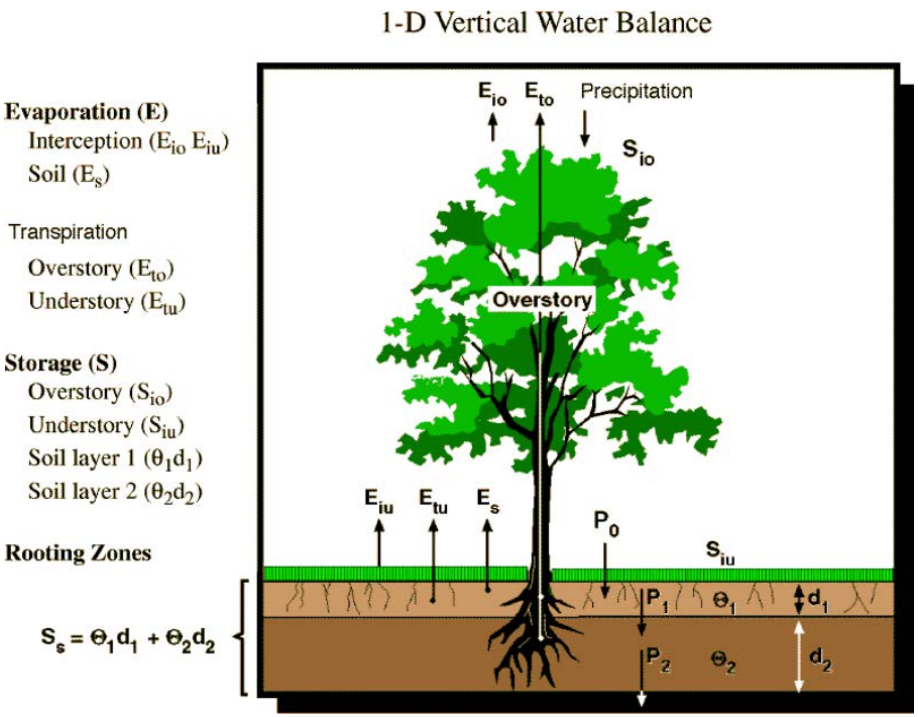
Study areas

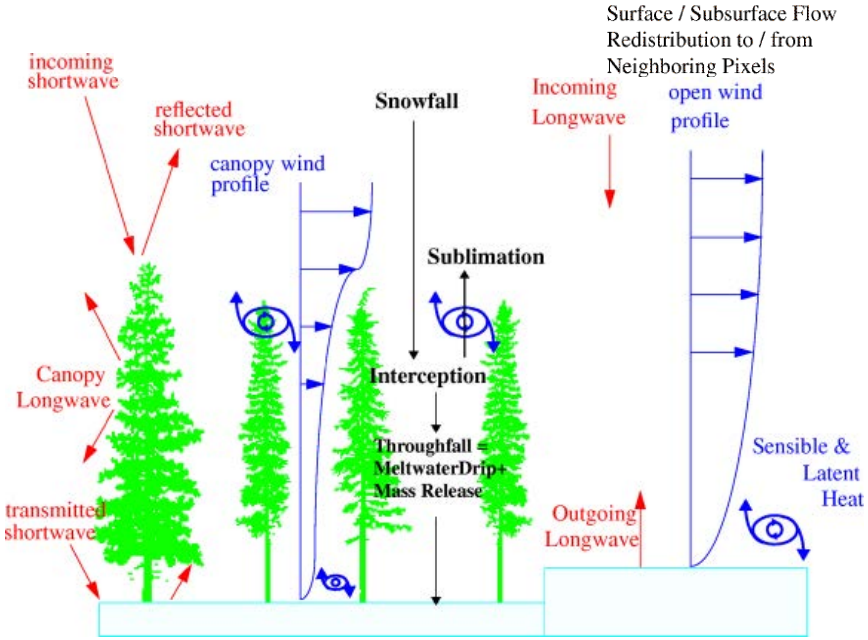
- Uncompahgre River (above Ridgway Dam)
- Gunnison River (above Crystal Dam)
- San Juan River (above Navajo Dam)

Model description

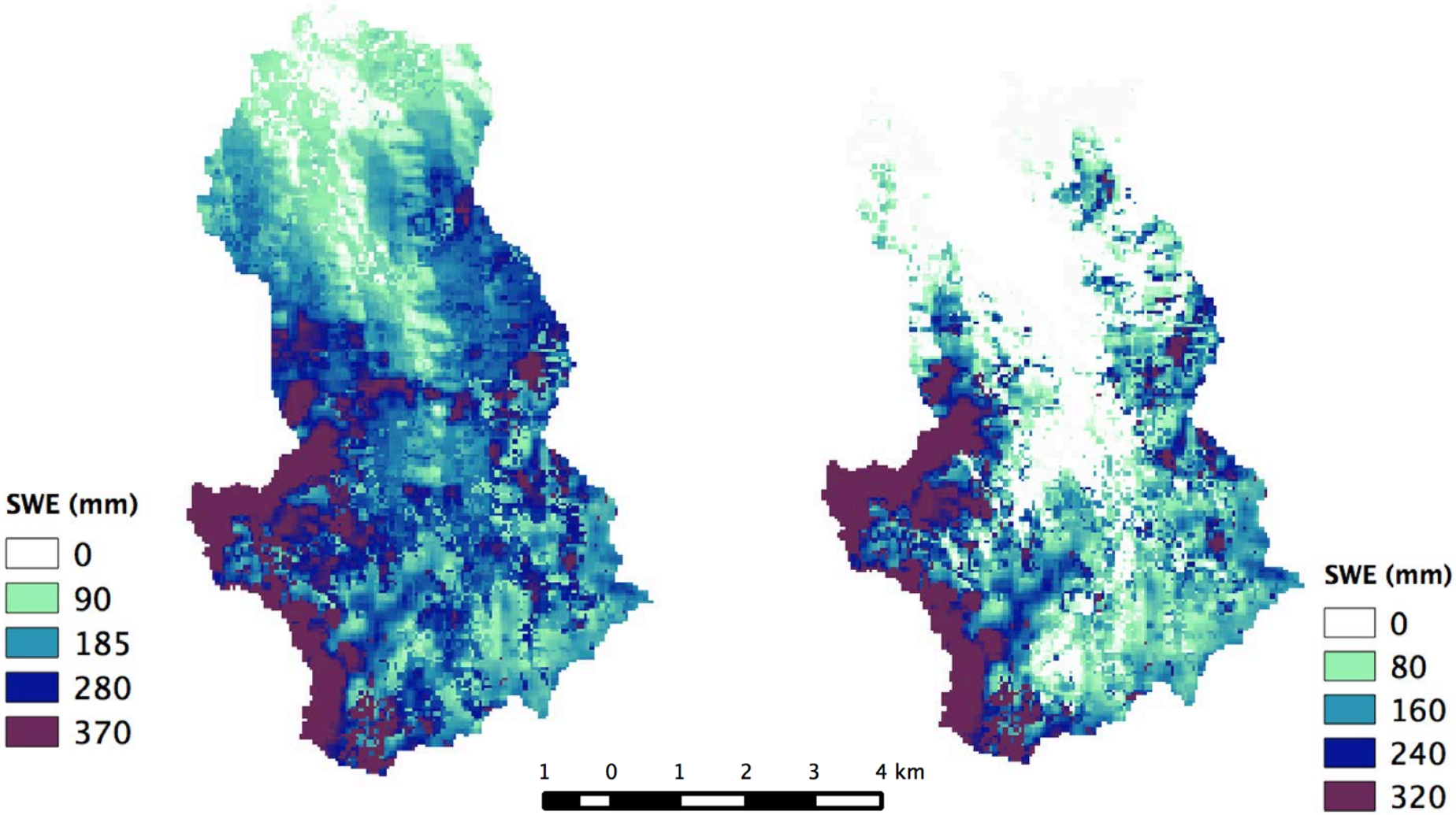
- Distributed hydrology-soil-vegetation model (DHSVM)
- Physically-based model that represents effects of
  - Topography, soil, vegetation
- Detailed snow modeling component







Example simulations



1 April 2002

1 May 2002