Hydrologic Model Review

CBRFC Fourth Annual Stakeholder Forum

February 25 – 26, 2014

Salt Lake City, UT

Overview

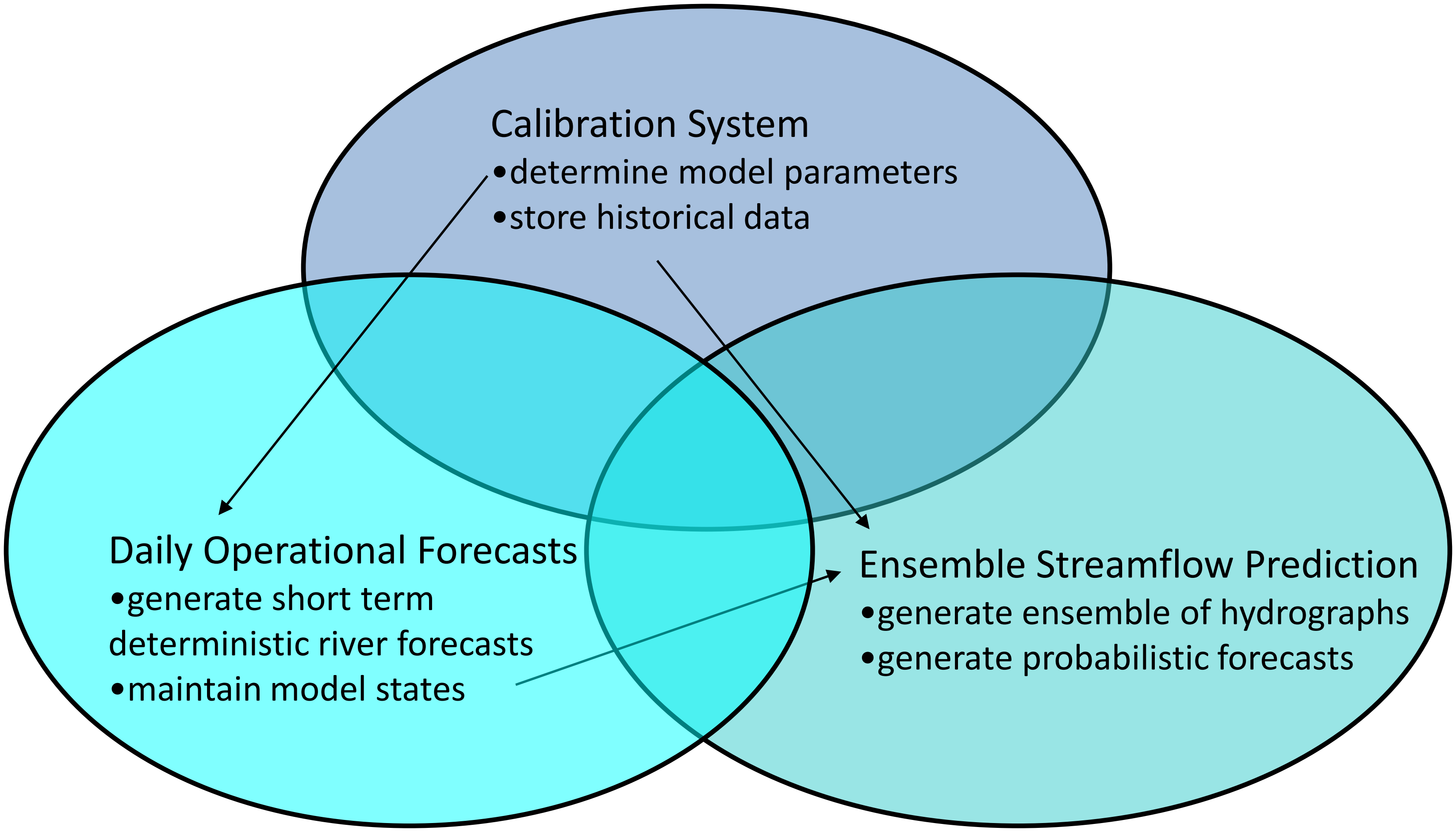
- Model Description
- Calibration
- Operations (current and planned methods)
  - Daily deterministic forecast mode
  - Ensemble Streamflow Prediction (ESP) mode
    - Unregulated
    - Regulated
- Statistical Water Supply (SWS)

NWS River Forecast Model

- Same model we have always run, but moved within the Community Hydrologic Prediction System (CHPS) framework at the start of Water Year 2012.
  - More/better graphics.
  - Provides ability to plug in new model modules.
- Continuous – meant to be run all the time, not just during events.
- Conceptual – physically based, but uses parameters in place of hard-to-get data.
- Lumped – uses mean areal inputs; not distributed.

NWS River Forecast Model

Composed of three major interrelated components.

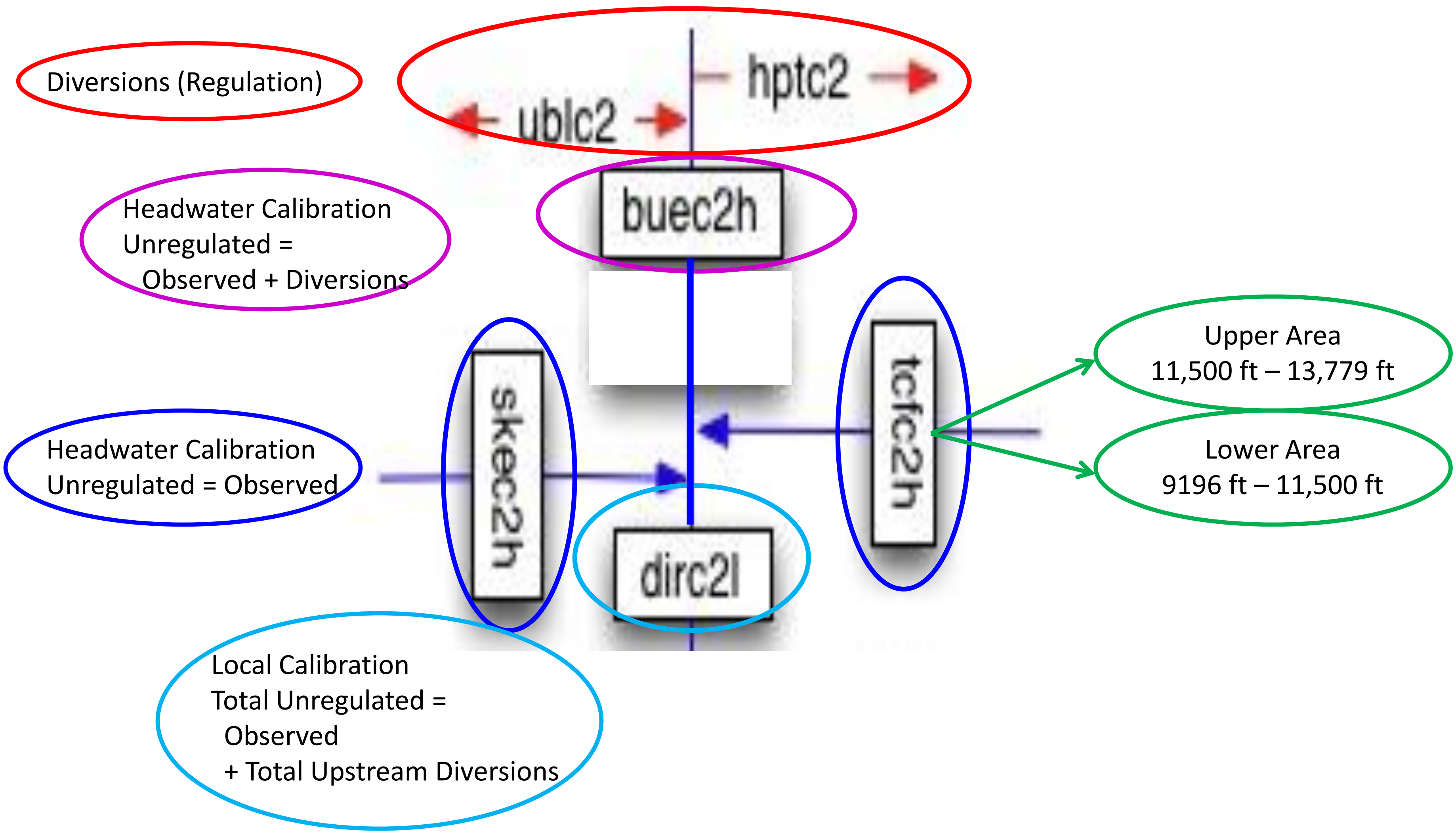


CBRFC Model Setup

- Each river point in the model is called a segment.
  - There are 181 segments above Lake Powell
  - There are 486 total segments in the CBRFC area.
- Segments are calibrated to the unregulated flow.
  - Remove effects of known diversions and reservoirs.
- Individual segment areas only include the contributing area between it and any upstream point(s).
  - Headwater calibration: All water comes from this segment alone.
  - Local calibration: Upstream water is routed downstream and added to the local water to get the total.
- Each segment is broken into 2-3 subareas by elevation.
  - These subareas should have similar soil, land cover, and snow accumulation/melt characteristics.
  - Because it is a lumped model each of these subareas is represented by a single point.
- Model inputs needed to simulate unregulated river flow:
  - Precipitation
  - Temperature
  - Freezing level – calculated from temperature when not available.

CBRFC Model Setup

Blue River Basin



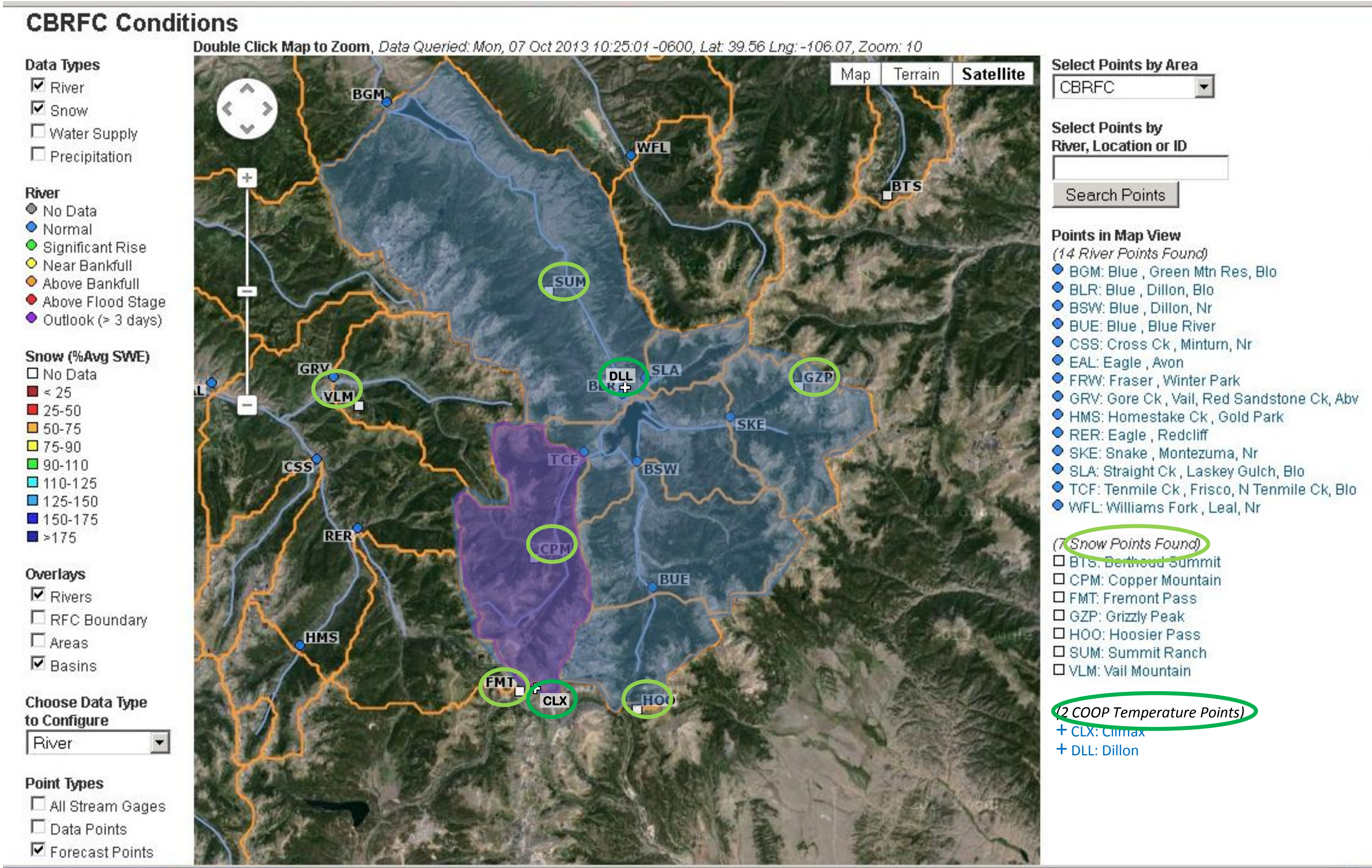
Calibration – Basics

- Initial conditions are not important.
- Evaporation is determined through water balance and is regionalized.
- Forced by 30 years (1981-2010) of 6 hourly precipitation and temperature.
  - Mean Areal Precipitation (MAP) for each subarea is calculated using pre-determined station weights.
  - Mean Areal Temperature (MAT) for each subarea is calculated similarly to MAP.
  - Operationally MAP and MAT are calculated in a similar way to ensure our forecasts will have similar quality/characteristics to 30 years of calibration.

Calibration – Basics

- The accuracy of the results are mostly dependent upon the quality of our temperature and precipitation network (mostly SNOTEL).
  - This network is not expected to change much in the next several years.
- Therefore, improvements in the calibration process must come from:
  - Model improvement (e.g. , a higher resolution model physically based). However, any chance for significant improvement is strongly bound by the temperature and precipitation network!
  - Remote sensing (e.g. , areal extent of snow). Relating to SWE is not obvious.

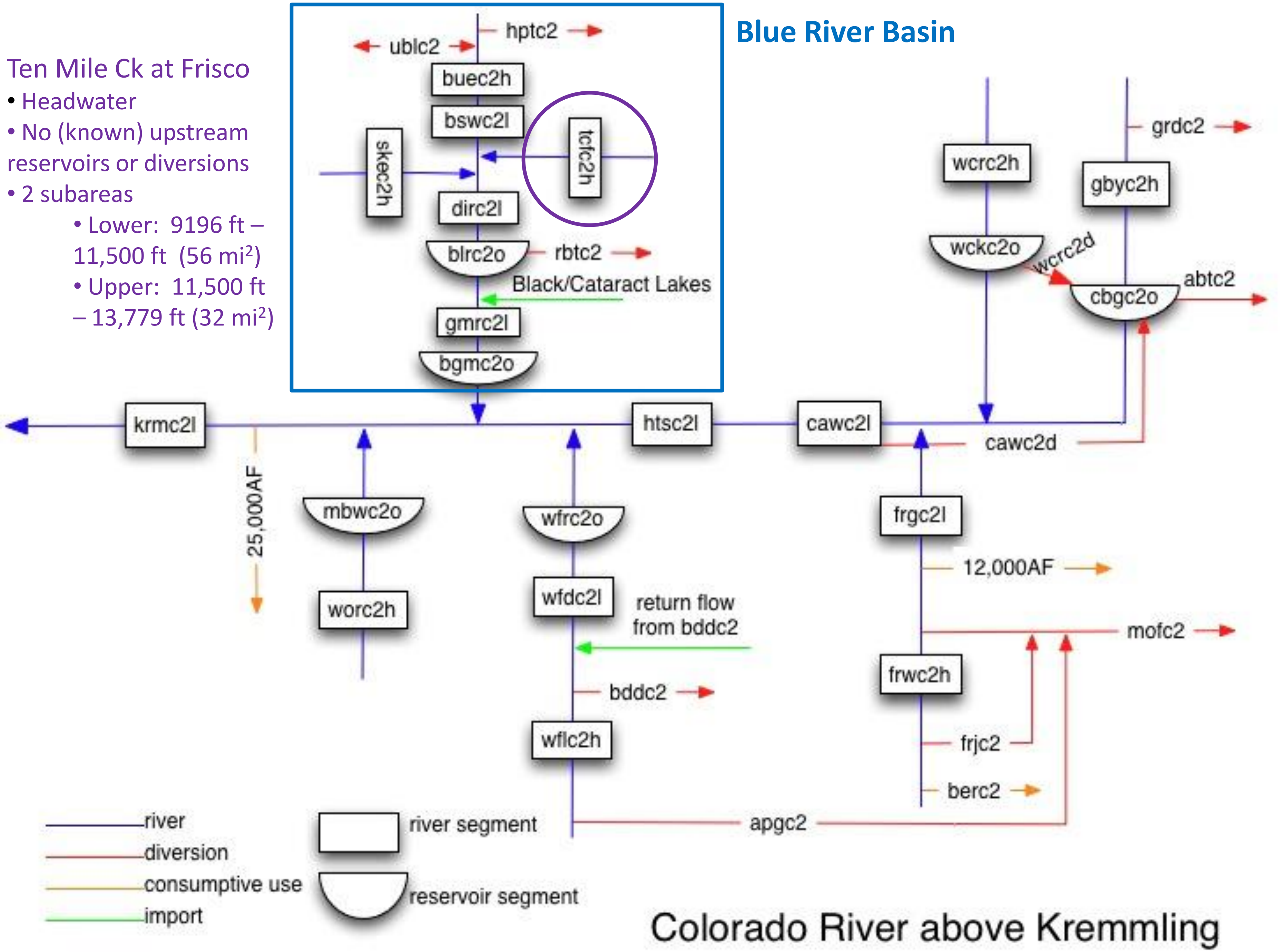
Blue River Basin Data Points



Ten Mile Ck at Frisco

- Headwater
- No (known) upstream reservoirs or diversions
- 2 subareas
  - Lower: 9196 ft – 11,500 ft (56 mi^2)
  - Upper: 11,500 ft – 13,779 ft (32 mi^2)

Blue River Basin



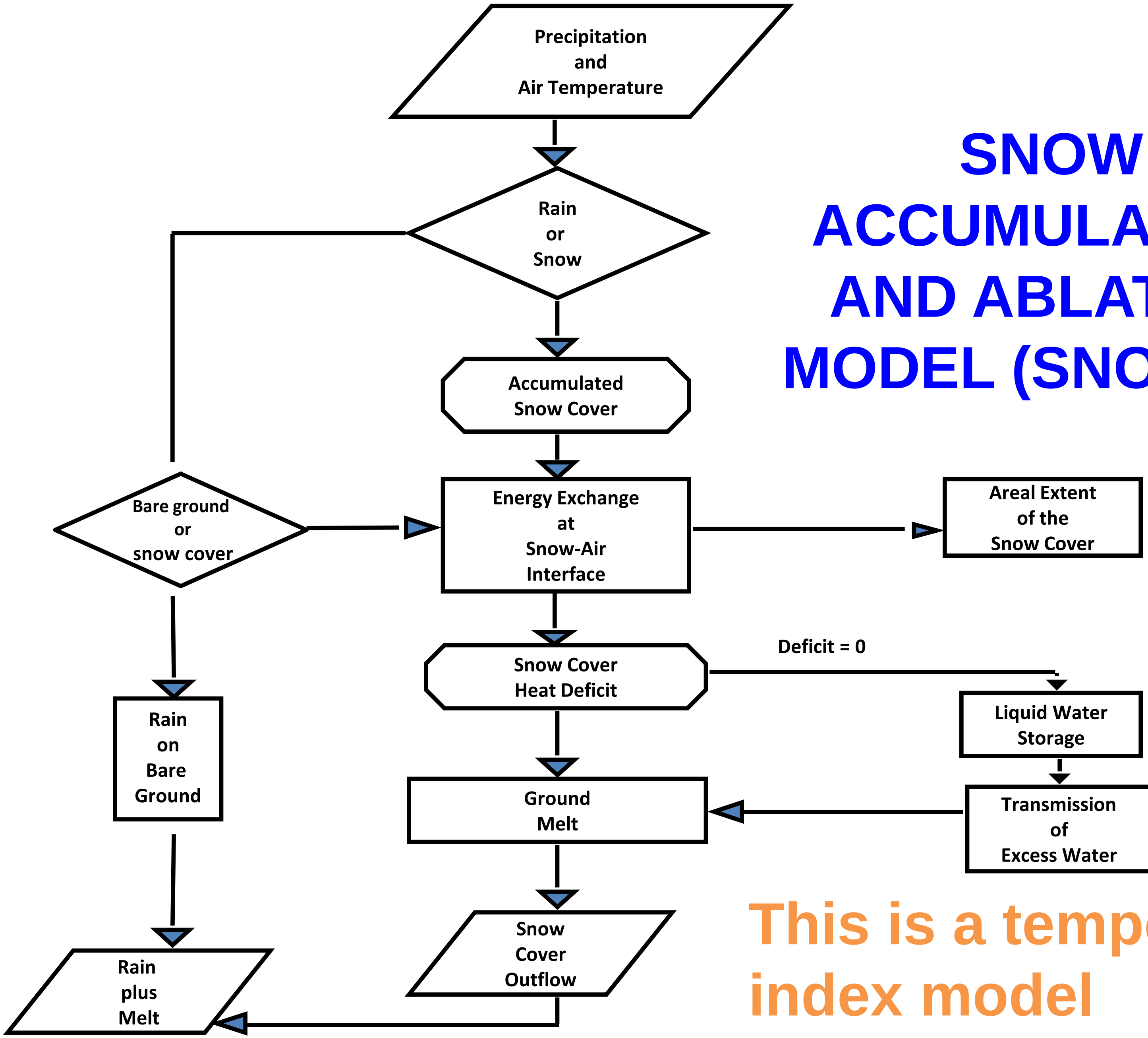
Calibration – Precipitation

- Each subarea MAP is calculated using precipitation stations that (hopefully) have similar characteristics to that area.
- Weights are chosen to guarantee water balance in each area.
  - The water balance is calculated using the PRISM sets.
- Station weights for TCFC2:
  - Upper area – Fremont Pass .67, Copper Mountain .67
  - Lower area – Fremont Pass .52, Copper Mountain .52

Calibration – Temperature

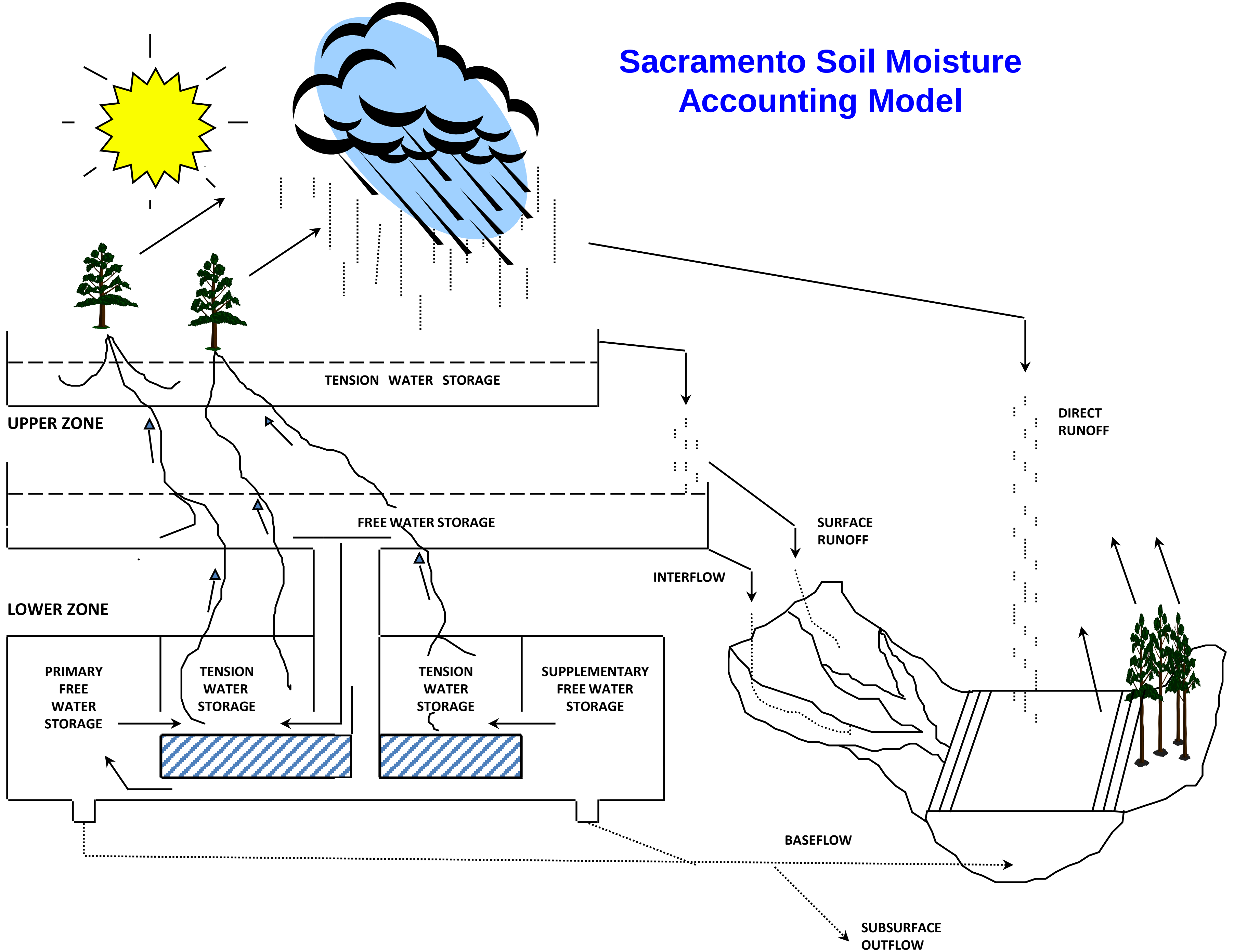
- Each subarea MAT represents the mid-point elevation of the area.
  - Nearby stations (whose climatologies are known) are used to calculate the temperature of the MAT (whose climatology is calculated using the climatologies of the nearby stations).
- Temperature is calculated by using the ratio between the station and area climatologies.
- Temperature stations used by TCFC2:
  - Dillon COOP
  - Climax COOP
  - Vail SNOTEL

SNOW ACCUMULATION AND ABLATION MODEL (SNOW-17)



This is a temperature index model

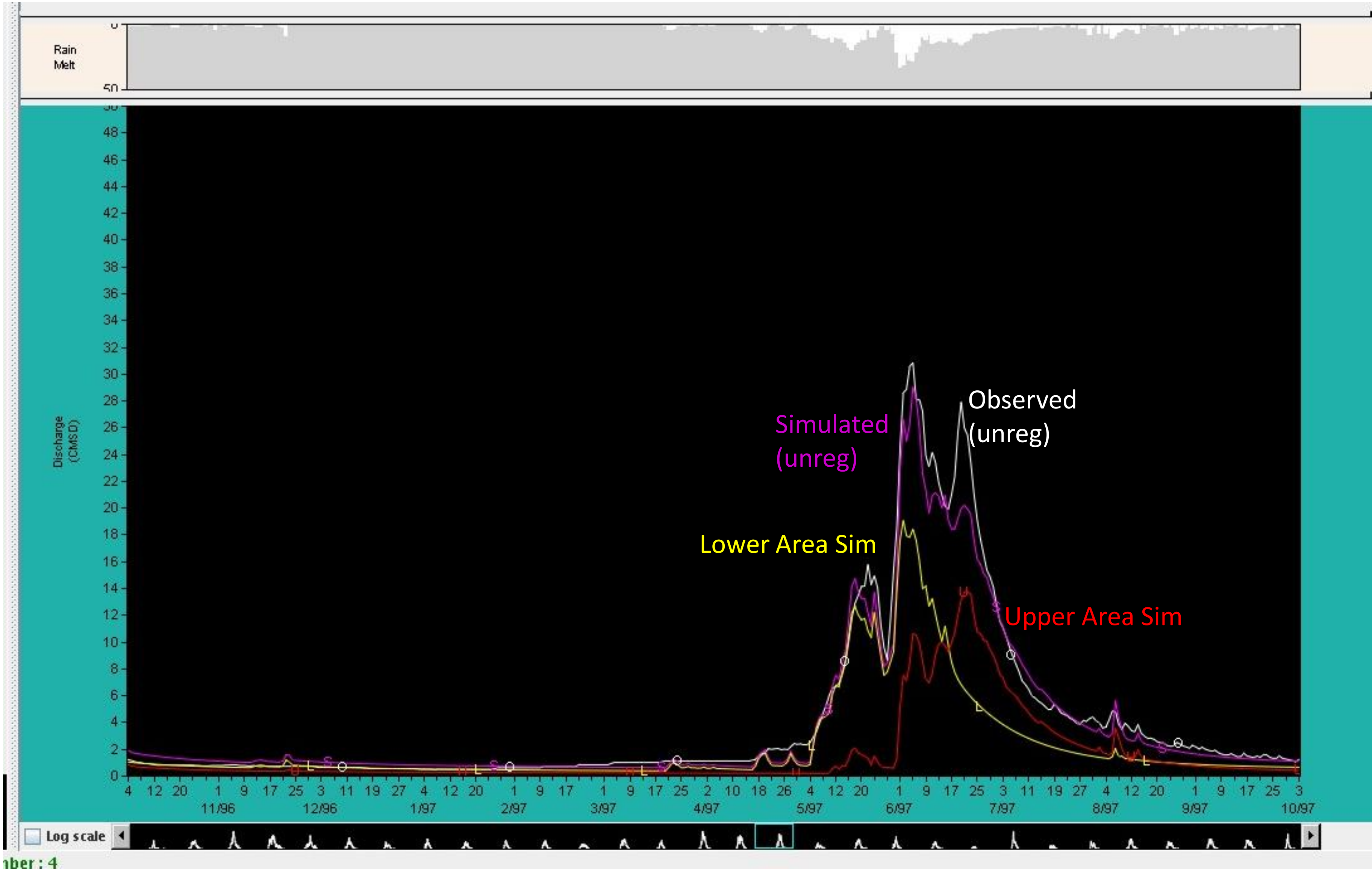
Sacramento Soil Moisture Accounting Model



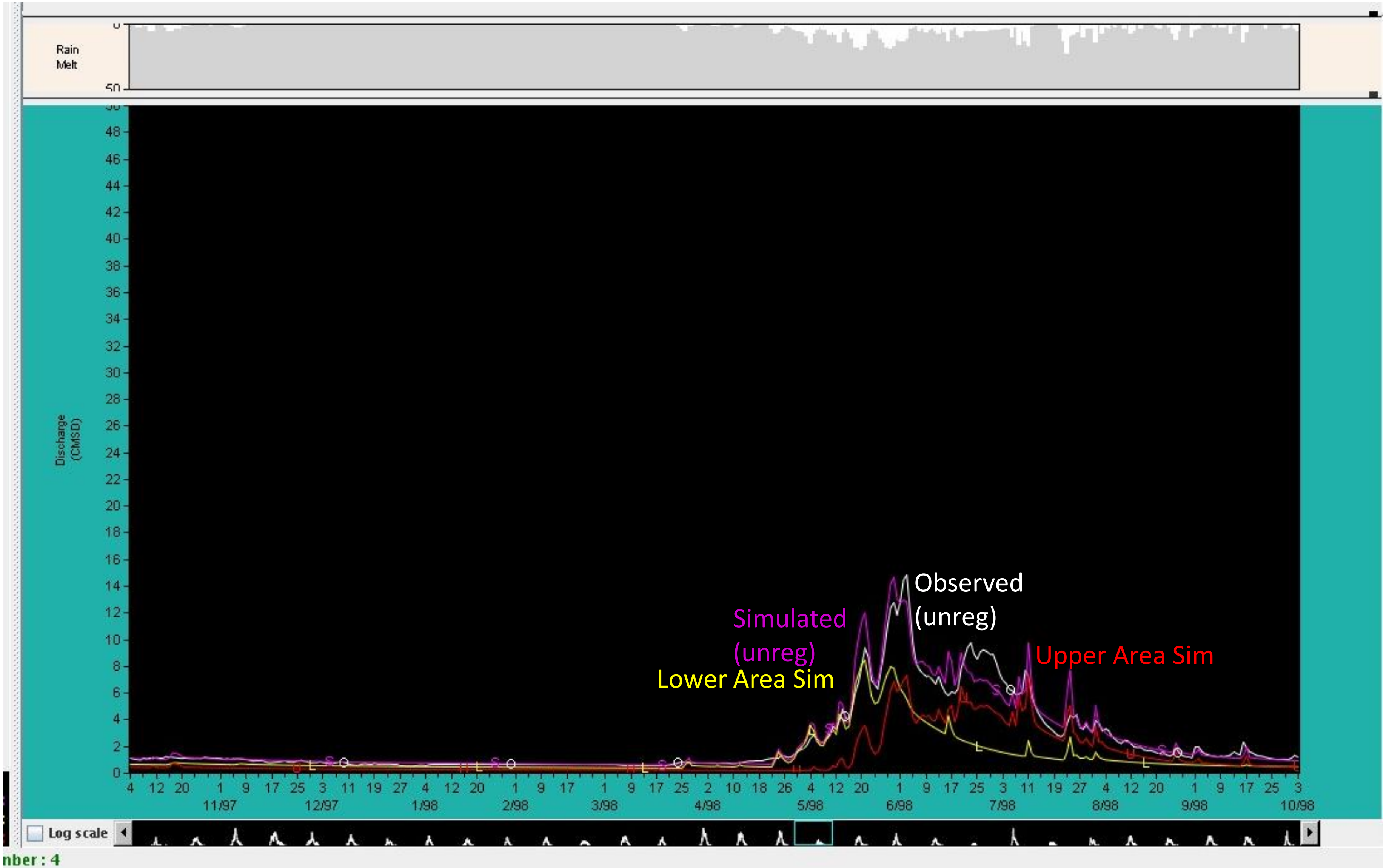
Calibration – Parameters

- Determine calibration parameters for each subarea
  - SNOW-17
    - 5 Major
      - Snow Correction Factor, Max and Min Melt Factors, Wind Function, Snow Cover Index, Areal Depletion Curve
    - 5 Minor
      - Temperature indexes and minor melt parameters
  - SAC-SMA
    - 11 Major
      - Tank sizes (5) and rates of drainage (interflow, percolation)
    - 5 Minor
      - Impervious area, Riparian Vegetation effects
- For TCFC2 this is done for 2 areas: Upper and Lower

Calibration – Results



Calibration – Results



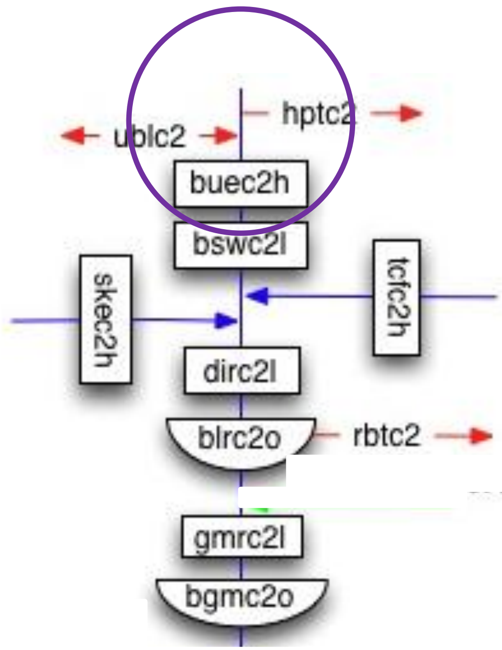
Calibration – Techniques

The segment is calibrated using the total unregulated flow:

buec2unreg = buec2obs
+ublc2+hptc2

The simulated flow resulting from the calibration should be similar to this unregulated flow:

buec2sim ~ buec2unreg



Blue River

We need to account for the diversions (ublc2, hptc2) at buec2. We add the daily diversion at ublc2 and hptc2 to the observed daily flow at buec2 to get the unregulated flow at buec2.

Calibration – Techniques

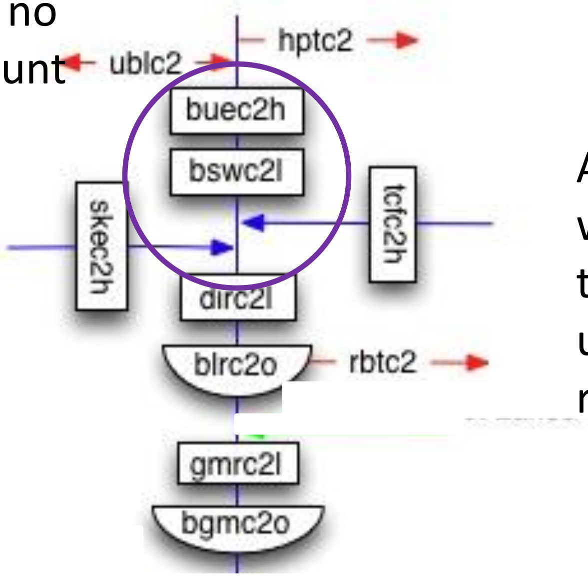
We have to send the buec2unreg and buec2sim downstream to the next segment, bswc2l. Although there are no diversions at bswc2, we need to account for the diversions upstream. So the total unregulated flow is:

bswc2unreg = bswc2obs
+total upstream diversions

And the total simulated flow is:

bswc2sim=buec2sim+bswc2locsim

where bswc2locsim is the model simulation of the 'local' flow – the water from the area between buec2 and bswc2 only.



Blue River

As we move downstream, we always make sure the total simulation and total unregulated flows have reasonably good balance.

Calibration – Techniques

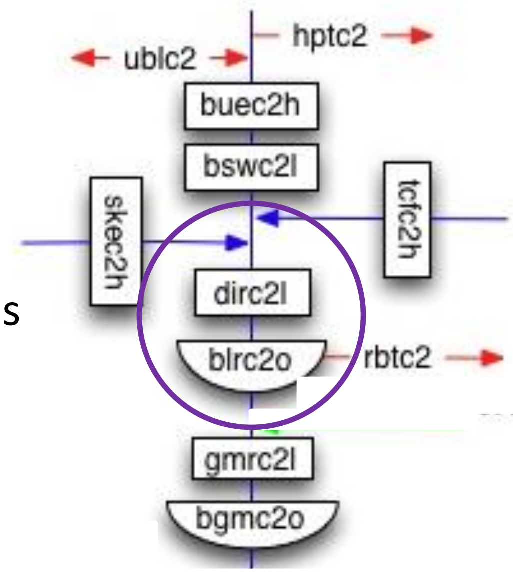
Finally, we need to calibrate the Dillon Reservoir inflow. The total unregulated flow for Dillon is:

dirc2unreg = dirc2outflow
+dirc2storage
+rbtc2
+total upstream diversions

We sum up all the simulations upstream:

dirc2sim=bswc2sim+tcfc2sim+skec2sim
+dirc2locsim

As before, the total simulation and the total unregulated flow are always checked: dirc2unreg ~ dirc2sim



Blue River

For unregulated flow, all reservoirs are removed from the calculations. So the entire dirc2 unregulated flow and dirc2 simulated flow are passed downstream to the next segment, gmrc2l, which is the Green Mountain Reservoir inflow.

Calibration – Techniques

- This process is continued for all basins above Lake Powell, for instance.
  – When we reach the Lake Powell inflow point, we have the total simulation and total unregulated flow for the entire area.
- In-stream diversions (consumptive use) are accounted for internally but not added back into the unregulated flow.
  – This is why we call our simulations and forecasts ‘unregulated’ vs. ‘natural’ flow.

Operations

Daily Deterministic Forecasts

- Regulated
- INITIAL CONDITIONS ARE VERY IMPORTANT
  - Soil moisture
  - SWE
  - Reservoir elevations/releases
  - Diversions
- Forcings are deterministic
  - Five days of forecast precipitation (QPF)
    - Zero beyond this
  - 10 days of forecast temperature (QTF)
    - Climatological average beyond this
- Creates and saves model states that become starting point for ESP

ESP Probabilistic Forecasts

- Unregulated or Regulated
- INITIAL CONDITIONS ARE VERY IMPORTANT
  - Soil moisture
  - SWE
  - Current reservoir and diversion information *not used in Unregulated mode*.
- Forcings are probabilistic
  - Uses 30 years of MAP and MAT from calibration to create 30 hydrologic traces/scenarios.
  - QPF and QTF
    - Deterministic QPF (5 days) and QTF (10 days)
    - Can use ensemble QPF and QTF from weather and/or climate models (test mode this year)

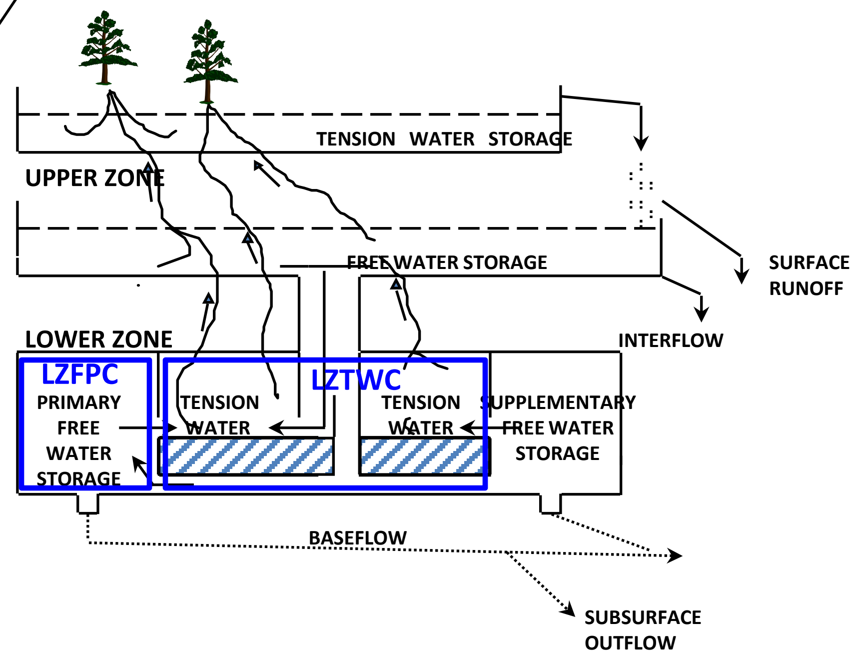
Operations
Initial Conditions – Soil Moisture

LZFPC (baseflow or free water)
1. Carryover from previous season
2. Affected some by fall precipitation
3. Adjusted by flow observations in fall/early winter

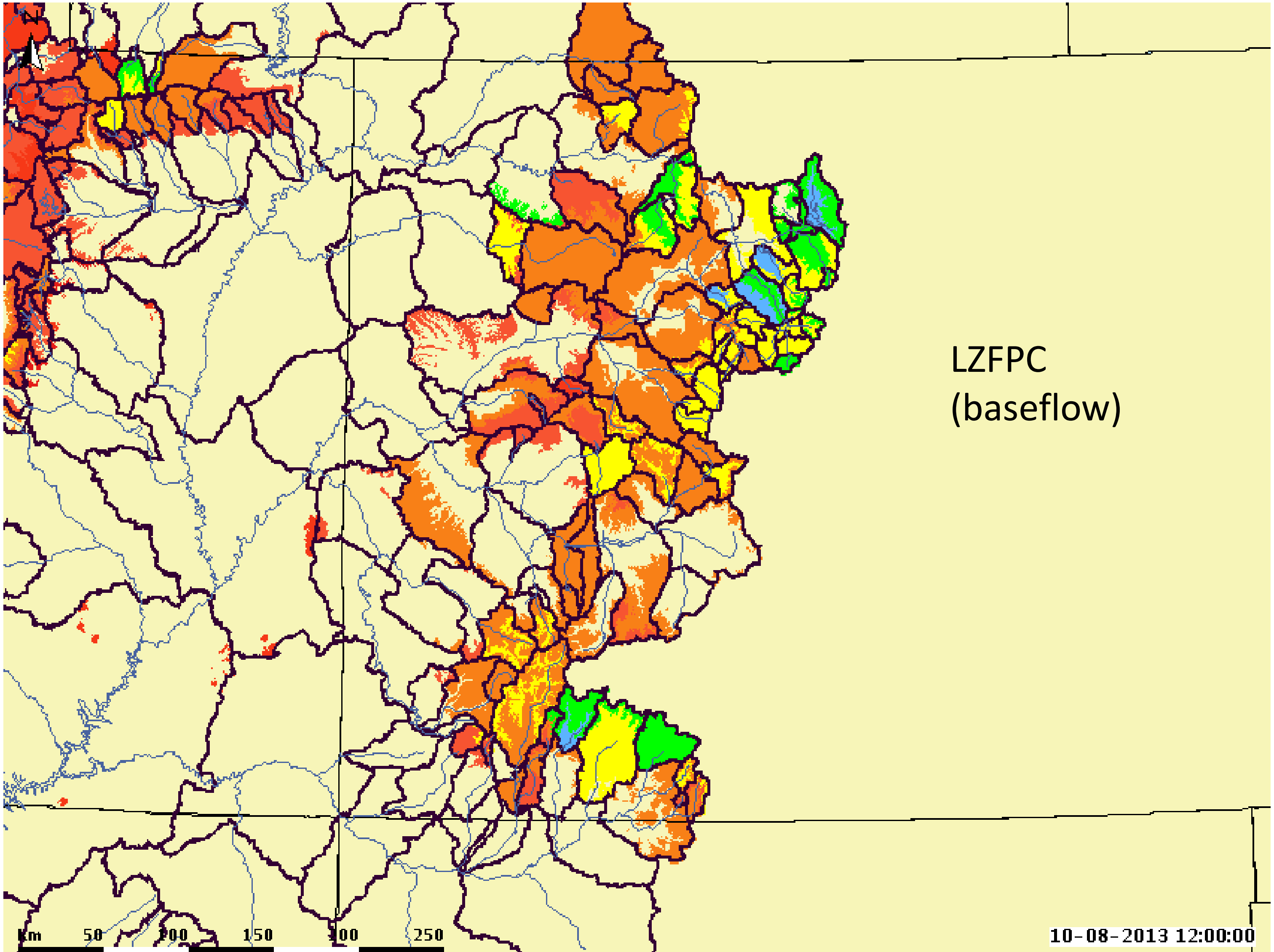
LZTWC (tension water)
1. Little carryover from previous season
2. Affected strongly by fall precipitation
3. Regionally adjusted

NRCS soil moisture observations

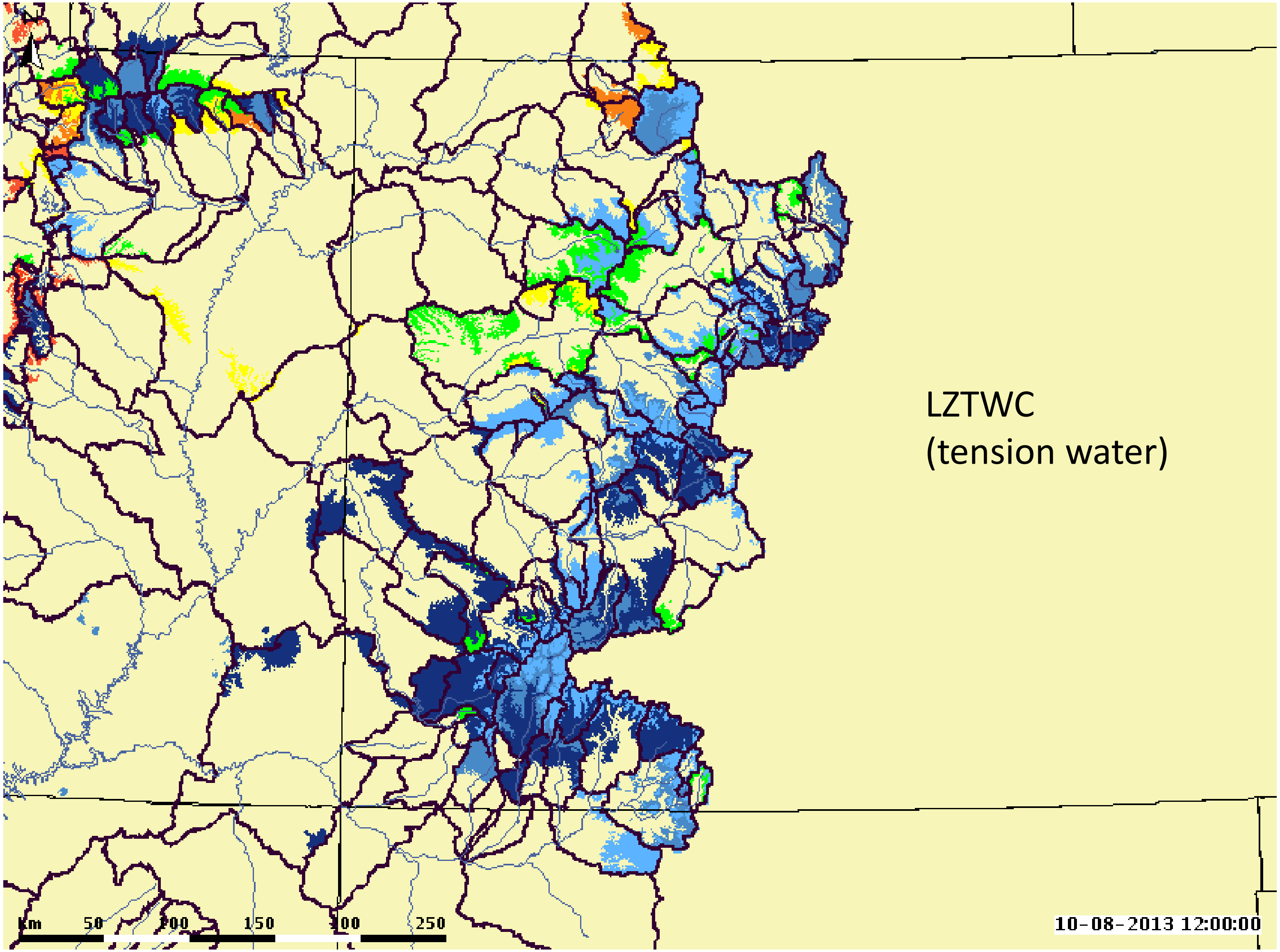
Initial fall soil moisture
1. Can have a moderate impact on spring runoff (+/- 5-10 %)
2. Typical Capacity of LZTWC+LZFPC ~ 15 inches



Operations
Initial Conditions – Soil Moisture

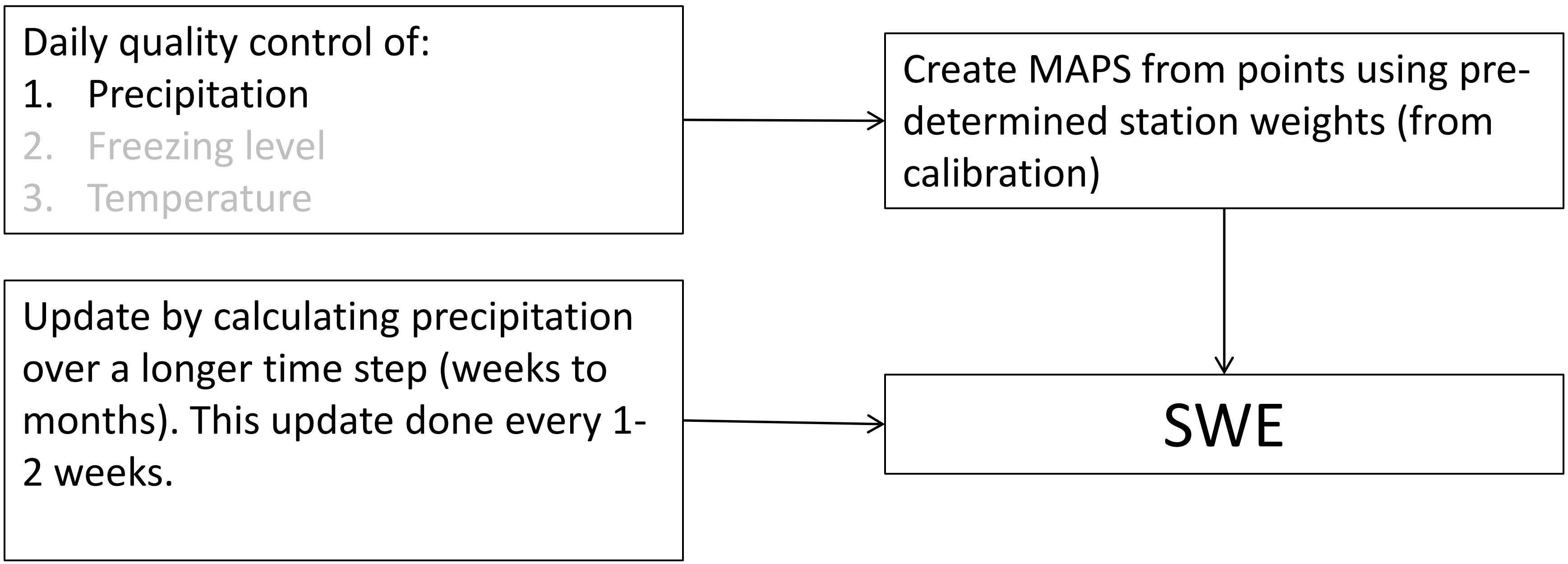


Initial Conditions – Soil Moisture

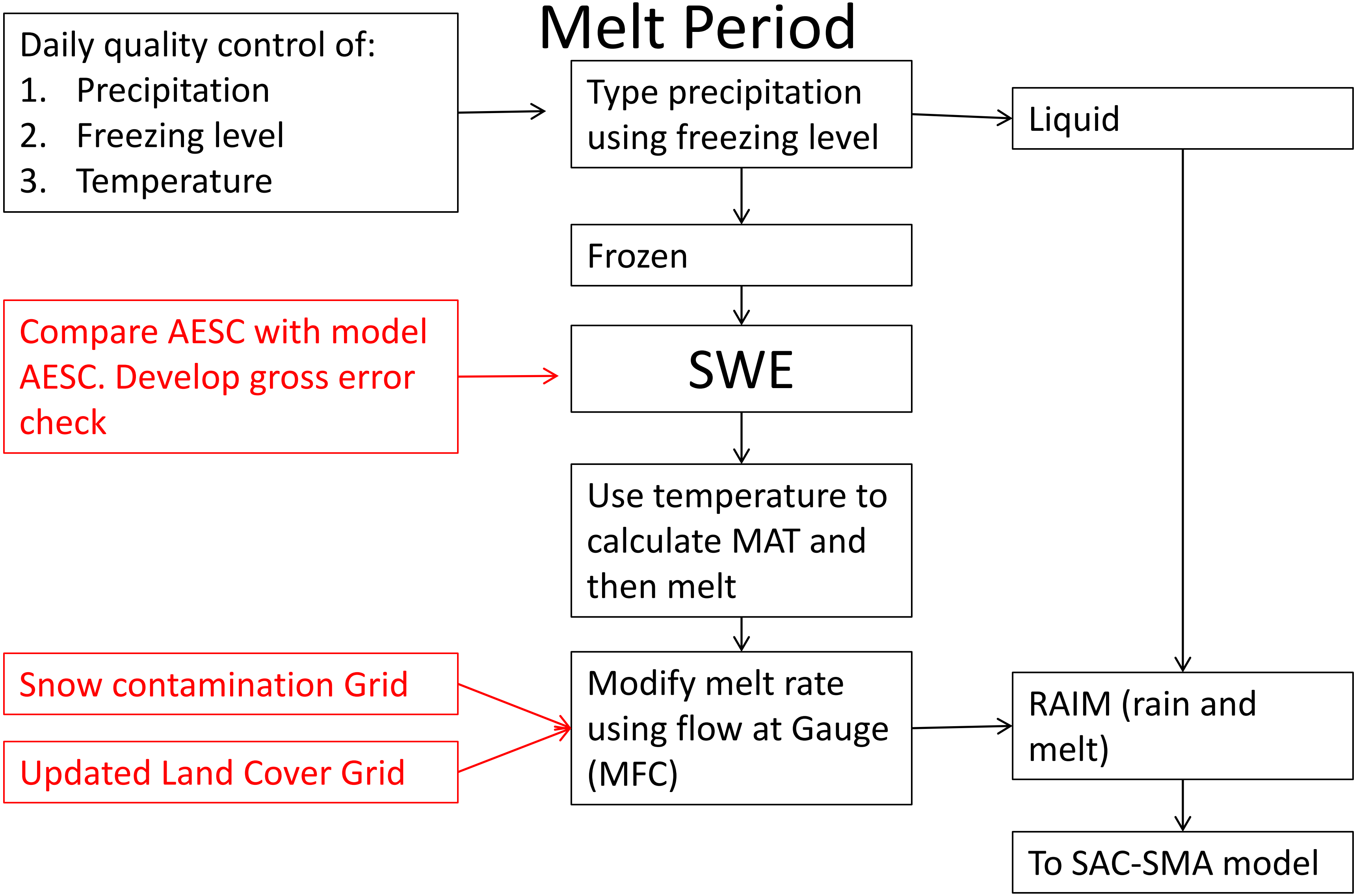


LZTWC
(tension water)

Operations
Initial Conditions – SWE
Accumulation Period



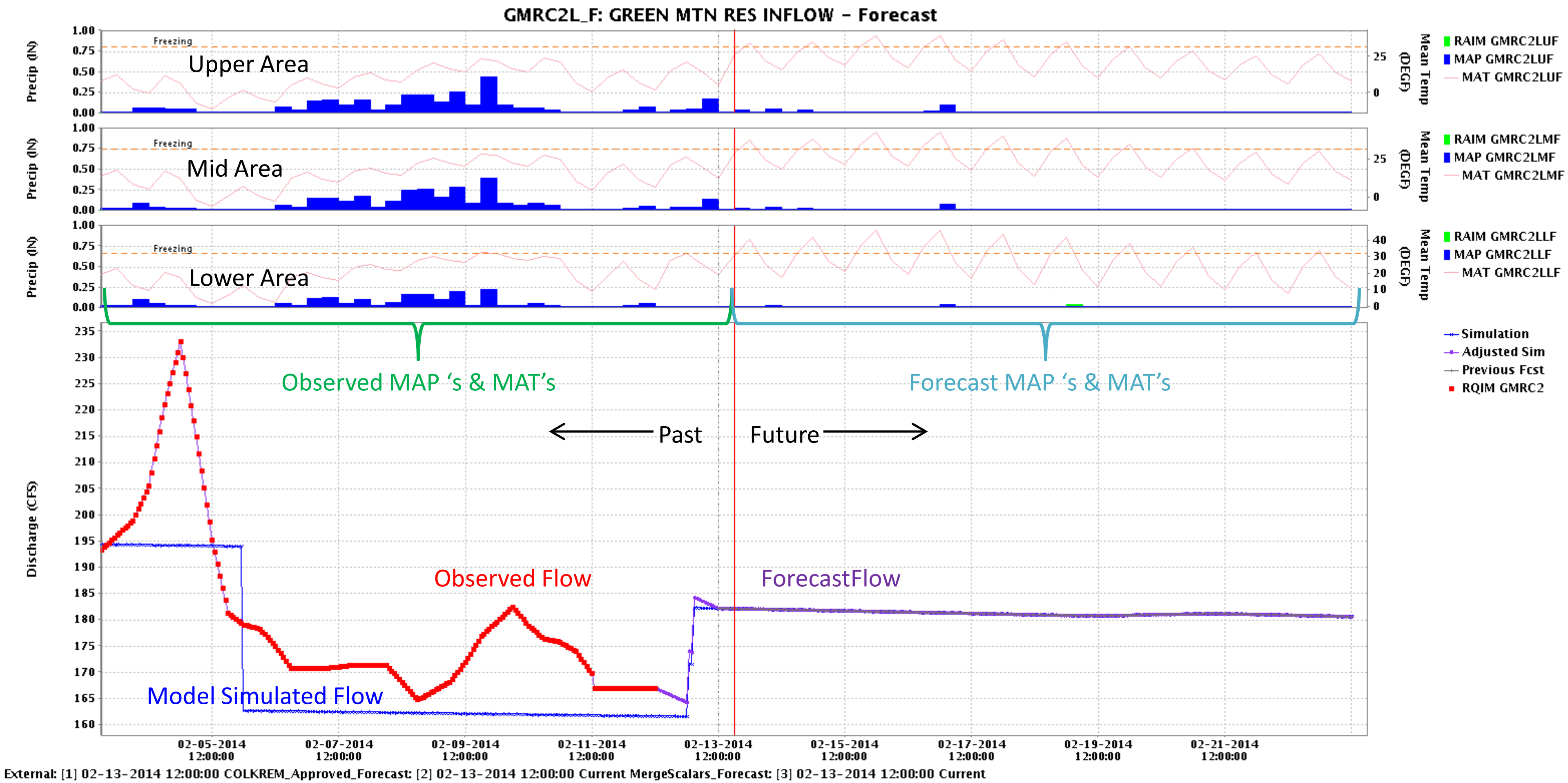
Operations
Initial Conditions – SWE
Melt Period



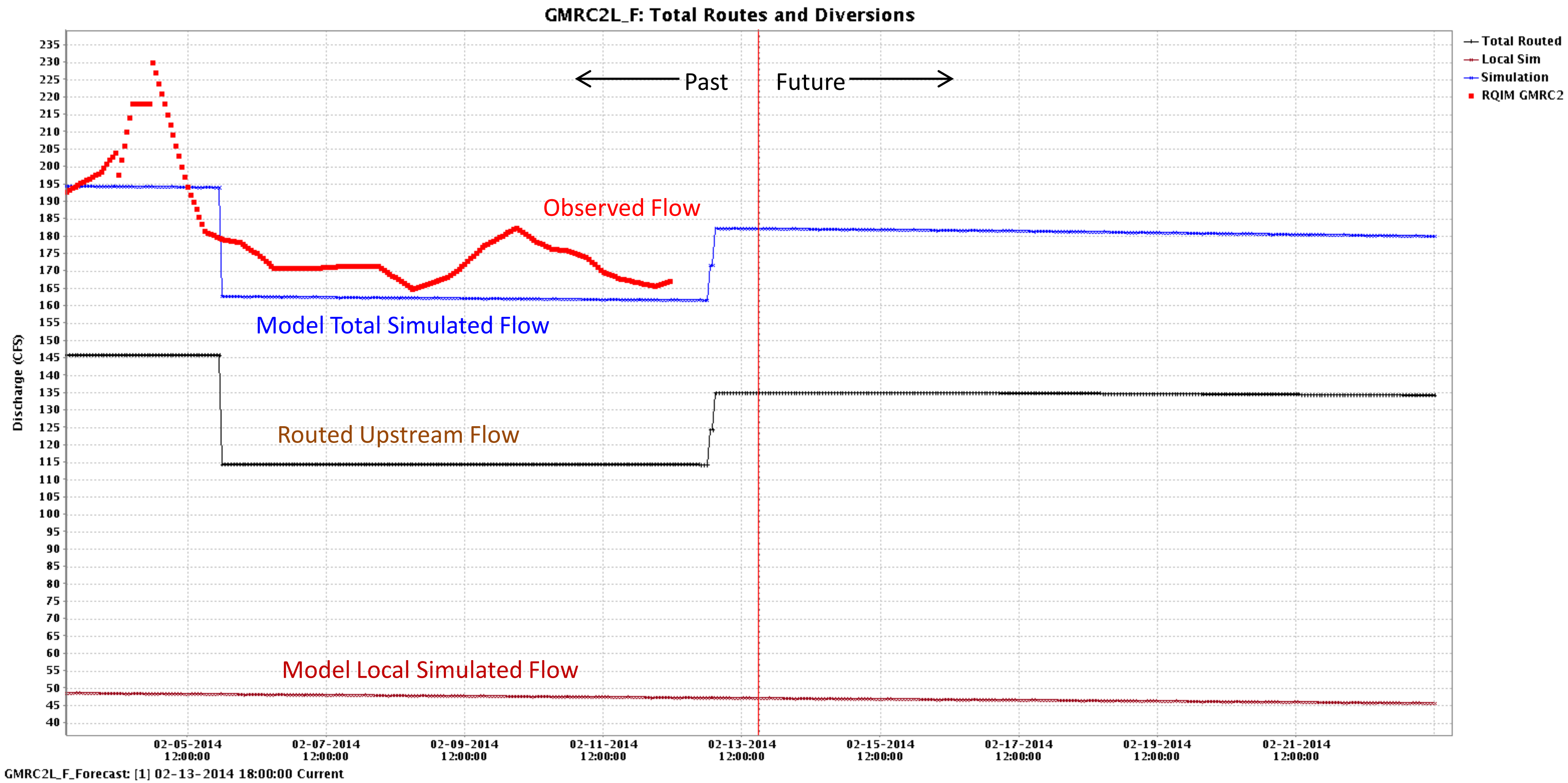
Daily Deterministic Forecasts

- Start run 10 days back so can see how model simulation compares to observed flows
  - Make sure inputs and forcings are correct
- End 10 days into the future
  - Upper Colorado (above Powell) and Great Basin run on a 6 hour timestep
  - Lower Colorado (below Powell) and Sevier Basin run on a 1 hour timestep
- Regulated (trying to match observed flow in river)
  - Future diversions:
    - Set to current
    - Specified
    - Best guess
  - Future reservoir releases:
    - Set to current
    - Specified
    - Spill
- 5 day deterministic precipitation forecast
  - 6 hour timestep (evenly divided for 1 hour segments)
  - Zero beyond 5 days
- 10 day deterministic temperature forecast
  - Max/Min forecasts converted to 6 hour timestep

Daily Deterministic Forecasts

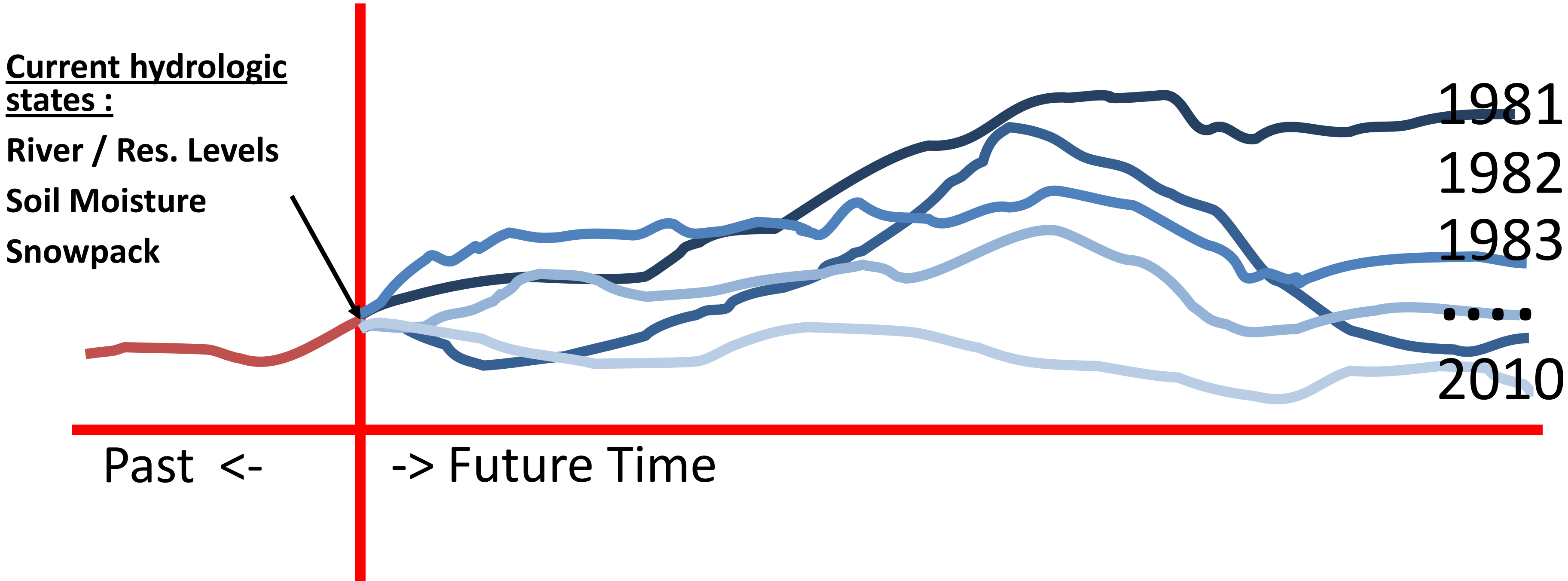


Daily Deterministic Forecasts

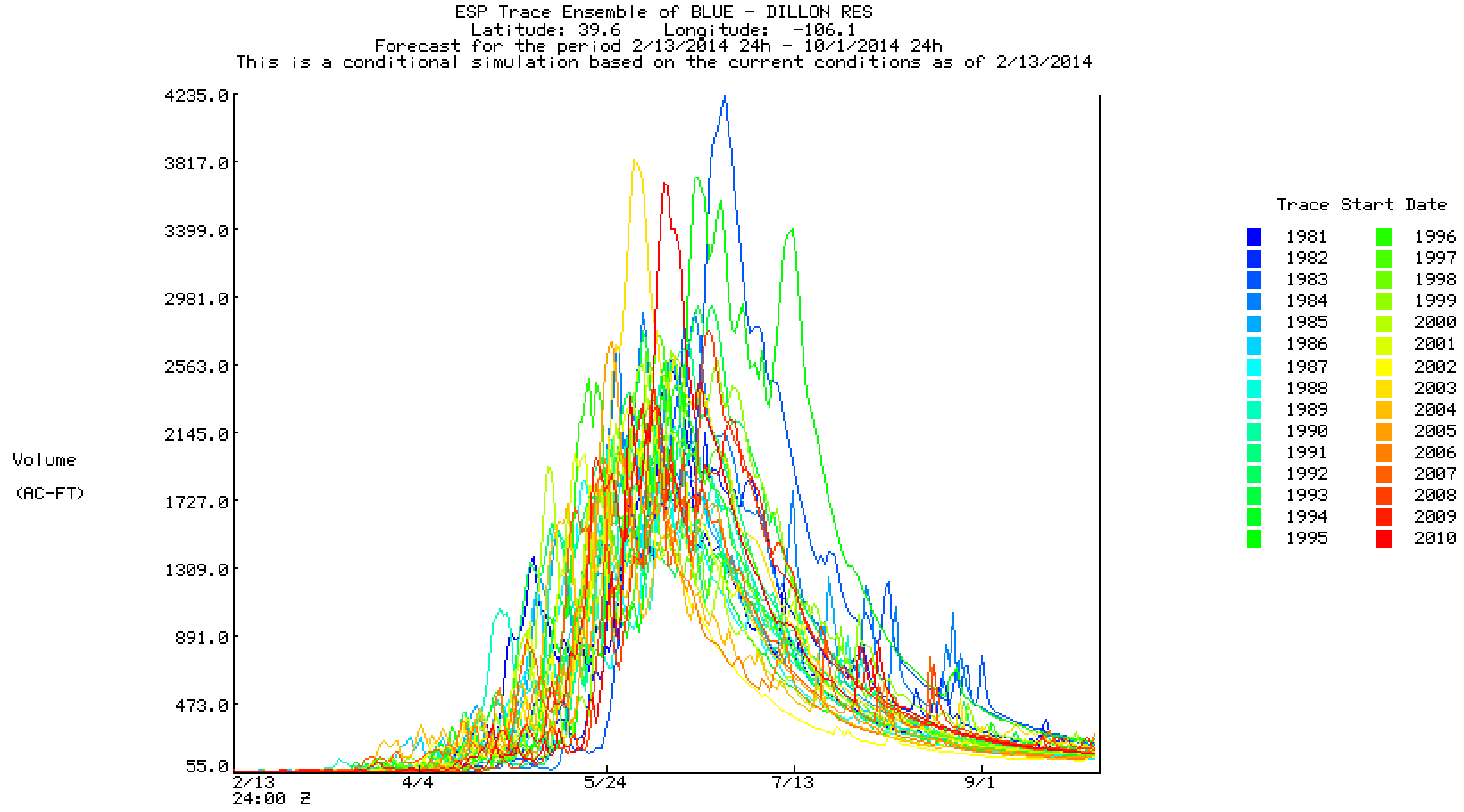


Ensemble Streamflow Prediction
Probabilistic Forecasts

- •Start with current conditions
- •Apply precipitation and temperature from each historical year (1981-2010) *going forward*
- •A forecast is generated for each of the years (1981-2010) *as if, going forward,* that year will happen
- •This creates 30 possible future streamflow patterns. Each year is given a 1/30 chance of occurring



ESP Probabilistic Forecasts



ESP Probabilistic Forecasts

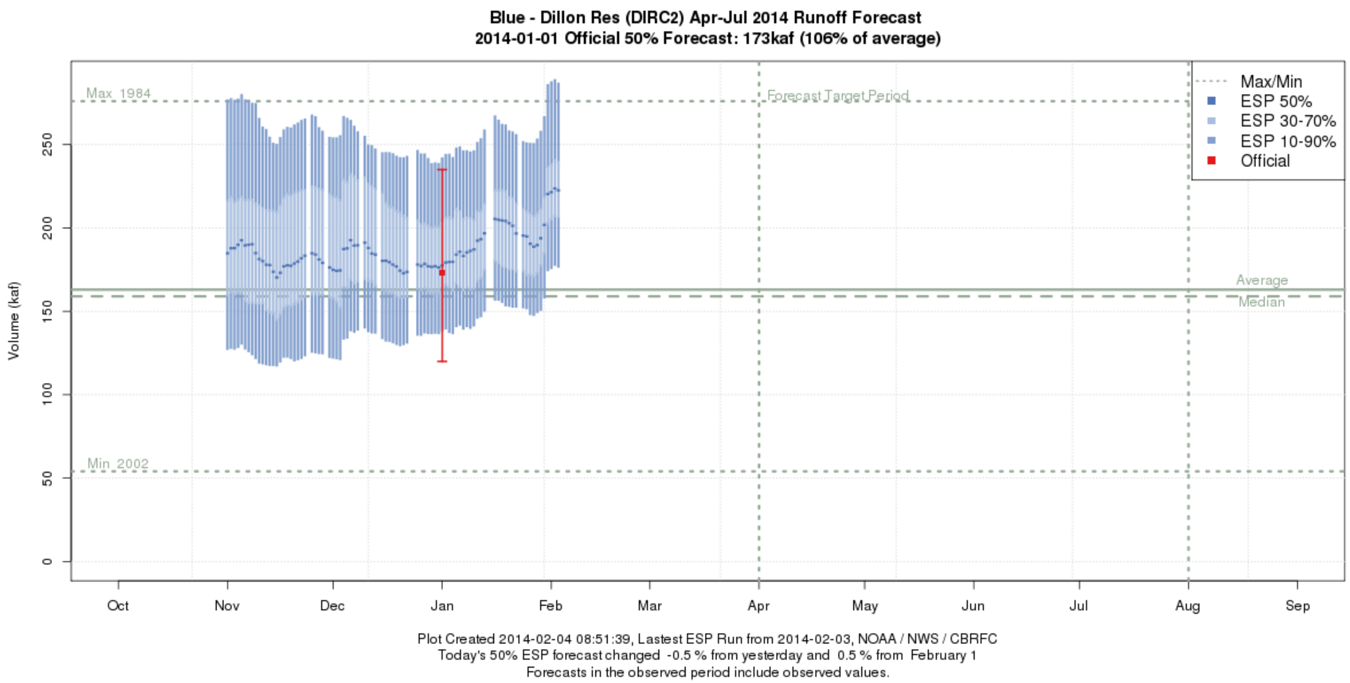
The flows are summed into volumes for the period of interest (typically 4/1-7/31)

#Trace # year	Year Weight	Cond. Data Point	Exceed. Prob.
1981	0.033	177211.438	0.645
1982	0.033	176045.719	0.677
1983	0.033	264999.438	0.065
1984	0.033	221810.359	0.258
1985	0.033	203260.516	0.419
1986	0.033	206865.734	0.355
1987	0.033	160108.203	0.839
1988	0.033	170150.953	0.742
1989	0.033	202772.094	0.452
1990	0.033	189682.000	0.581
1991	0.033	202233.734	0.484
1992	0.033	169767.188	0.774
1993	0.033	260266.516	0.097
1994	0.033	173539.250	0.710
1995	0.033	332482.281	0.032
1996	0.033	237575.438	0.161
1997	0.033	201420.719	0.516
1998	0.033	160373.312	0.806
1999	0.033	237255.172	0.194
2000	0.033	217391.062	0.290
2001	0.033	204273.781	0.387
2002	0.033	109645.195	0.968
2003	0.033	240024.969	0.129
2004	0.033	151270.719	0.903
2005	0.033	156270.141	0.871
2006	0.033	145418.188	0.935
2007	0.033	181728.625	0.613
2008	0.033	212733.891	0.323
2009	0.033	222155.312	0.226
2010	0.033	192733.172	0.548

The statistics are simplified

# Exceedance # Probabilities	Conditional Simulation
0.900	151770.656
0.800	162252.078
0.700	174291.188
0.600	184909.969
0.500	201827.219
0.400	203868.469
0.300	215993.891
0.200	234235.078
0.100	258242.141

And formatted for the web



ESP Probabilistic Forecasts

Unregulated Mode

- Reservoirs ignored
  - Water is just passed through them.
- Diversions ignored
  - All measured diversions into and out of the basin are set to zero.
- Consumptive Use water still removed
- Used for Water Supply volume forecasts
  - Some exceptions in Sevier and Great Basin

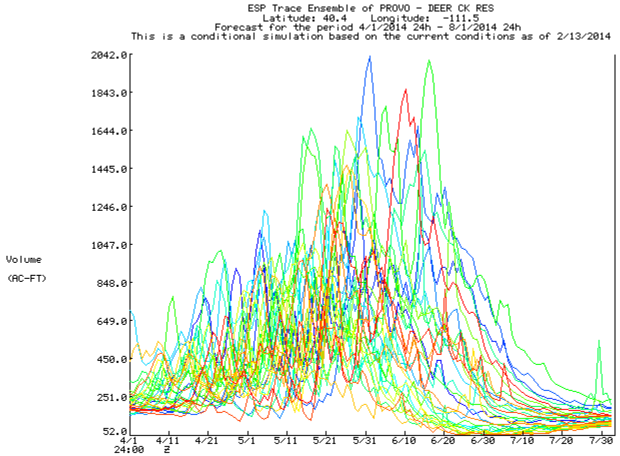
Regulated Mode

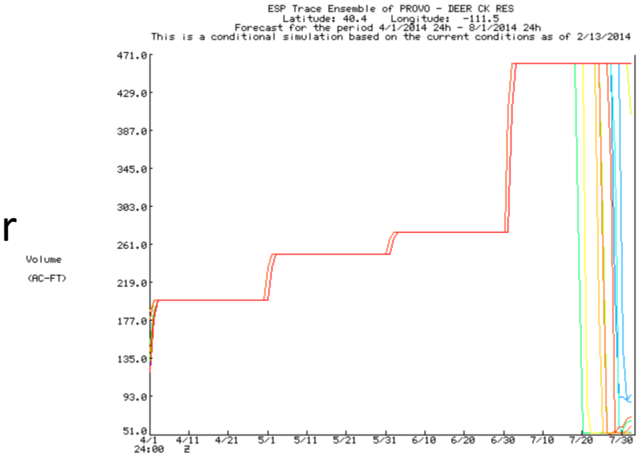
- Reservoirs use rules defined in model
  - Releases set based on time of year or simulated elevation of reservoir.
  - Spill, pass flow.
  - Can input a single release schedule if known that far into future.
- Diversions use historical data
  - Trace that uses 1995 MAP/MAT also uses 1995 diversions.
- Consumptive Use water still removed
- Used mostly for mean daily Peak Flow forecasts

ESP Probabilistic Forecasts

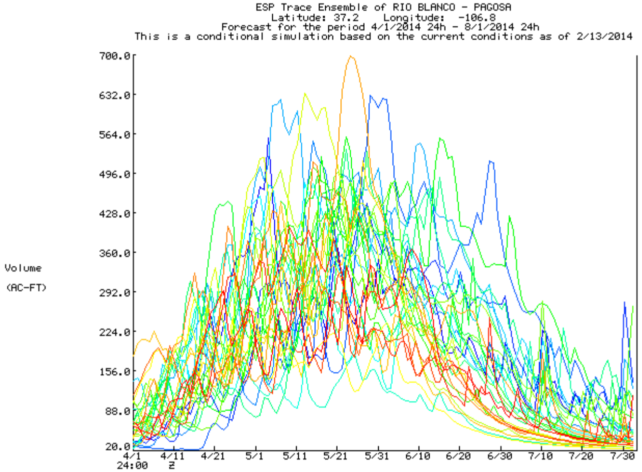
Unregulated Mode

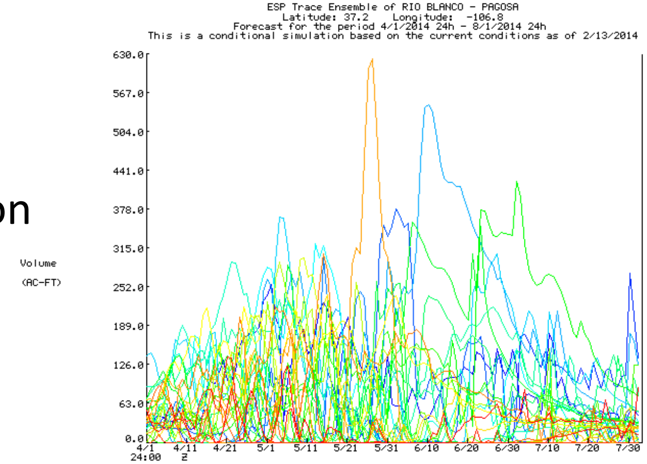
Regulated Mode





Reservoir



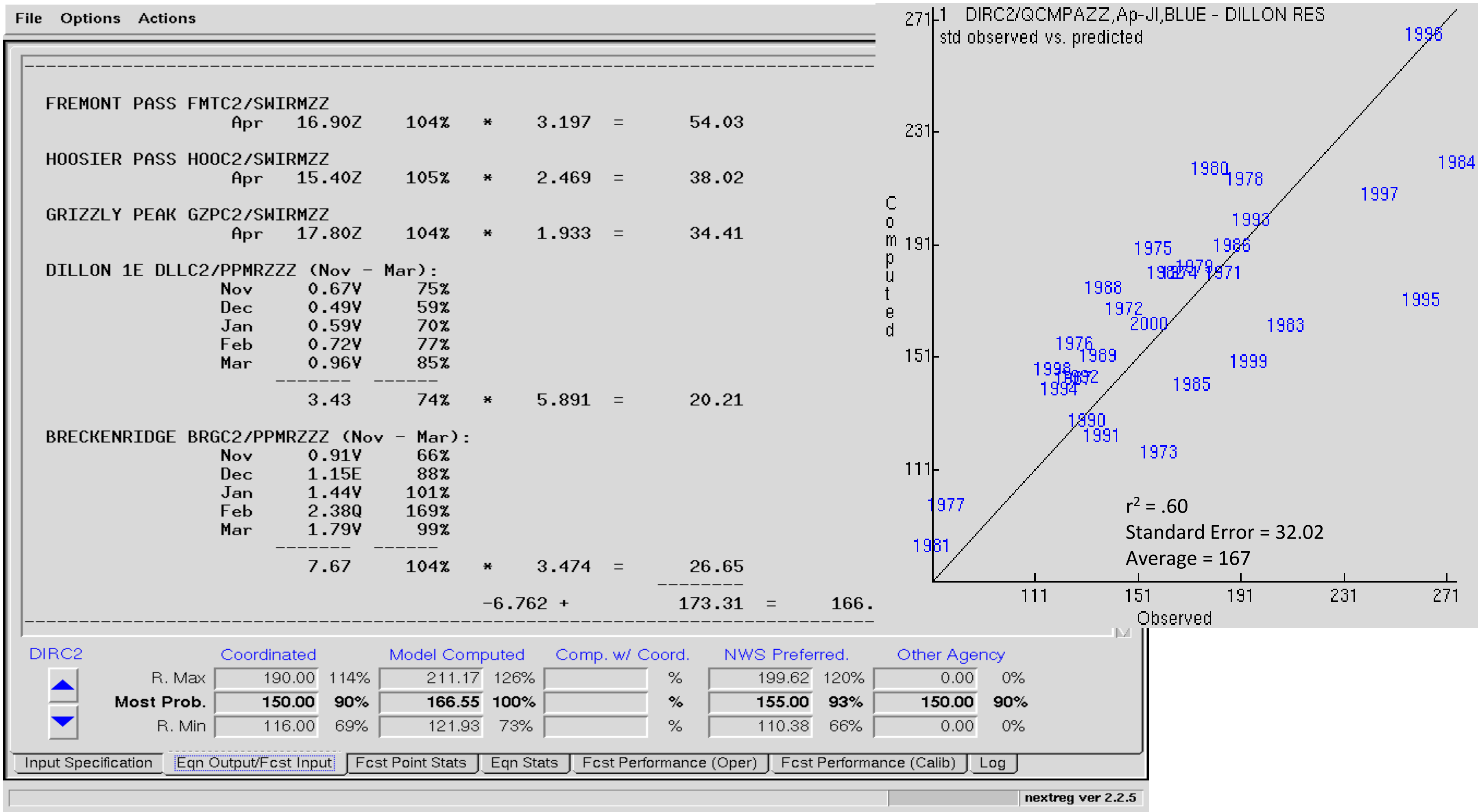


Diversion

Statistical Water Supply (SWS)

- Regression equations that relate observed data to future seasonal streamflow volume.
- Inputs are monthly values.
  - Total precipitation (can be multiple months)
  - First of month snow water equivalent
  - Monthly flow volume
- Output is a seasonal volume (i.e. April-July).
  - It is really a conditional probability distribution, not a single value; the equation result is the 50% exceedance.
  - Other exceedance levels (10%, 90%, etc.) can be calculated by using the standard error.

Statistical Water Supply (SWS)



Sources of Error

- Data
  - Undetected errors in historical as well as current observations
    - Errors in streamflow measurements due to poor channel ratings/controls
  - Data density
  - Ungaged/unknown diversions (especially in low years)
    - Consumptive use estimation
  - Distribution of snow vs. point measurements
- Model
  - Initial conditions (see data errors)
  - Calibration error (bias)
- Future weather
  - QPF (accuracy, distribution in space & time)
  - Spring temperatures affect melt/runoff pattern
  - Climate outlooks

Questions

- Was this presentation helpful and what additional information would you like on CBRFC modeling techniques?
- During low flow conditions, the consumptive use (largely unknown) can be larger than the observed flow and is the largest source of error in the forecast. What additional information would be useful during these conditions?

Simulated Unregulated=Natural-Consumptive use

Observed Unregulated=Regulated Observed + Known Diversions

Calibration attempts to make Simulated Unregulated =Observed Unregulated

Since Consumptive Use is not known, Neither is Natural