Colorado River Water Availability Study
Alternate Hydrology Development

Colorado Climate Technical Advisory Group

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Agenda

- Overview of approach
- Status
- Description of principal elements
- PRELIMINARY Results
- Discussion

Colorado River Water Availability Study

- Study Purpose:

  "How much water from the Colorado River Basin System is available to meet Colorado's current and future water needs?"

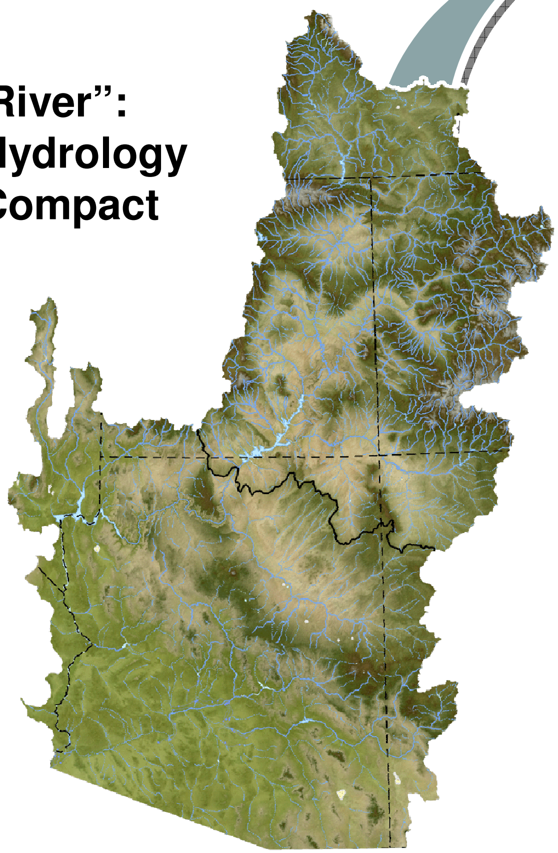
- Phase I – Water Availability under current water supply infrastructure, currently perfected water rights, and current levels of consumptive and non-consumptive water demands

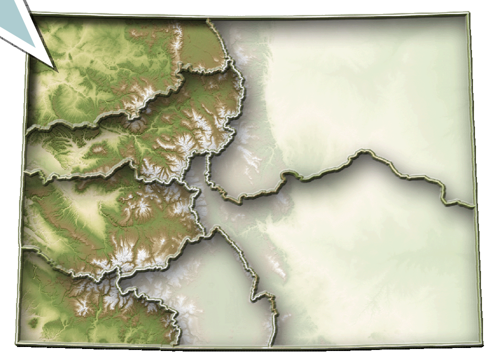
- Phase II – Water Availability under projected demands from existing, conditional and new water rights and for additional consumptive and non-consumptive water uses

Two Scales

Colorado River Basin

"Big-River":
Hydrology
Compact





State of Colorado

Intra-state:
Hydrology
Water rights

Study Approach – Three Step Hydrologic Analysis

Historical Hydrology

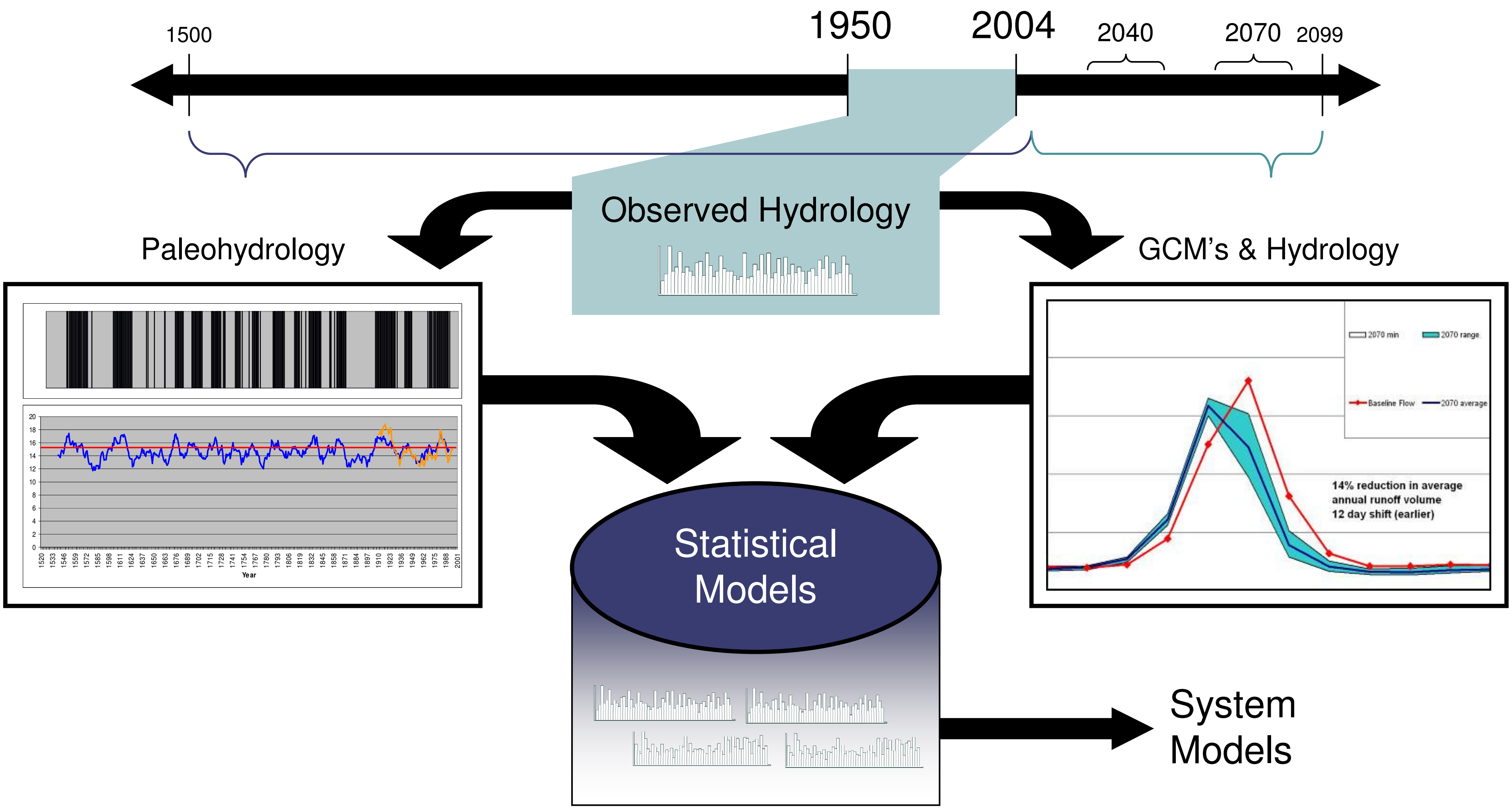
- To be used for comparative analysis
- Focus on 1950s forward, most reliable data

Alternate Historical Hydrology

Extend Records with Tree-Rings & Stochastic Methods

Climate Change and Forest Change

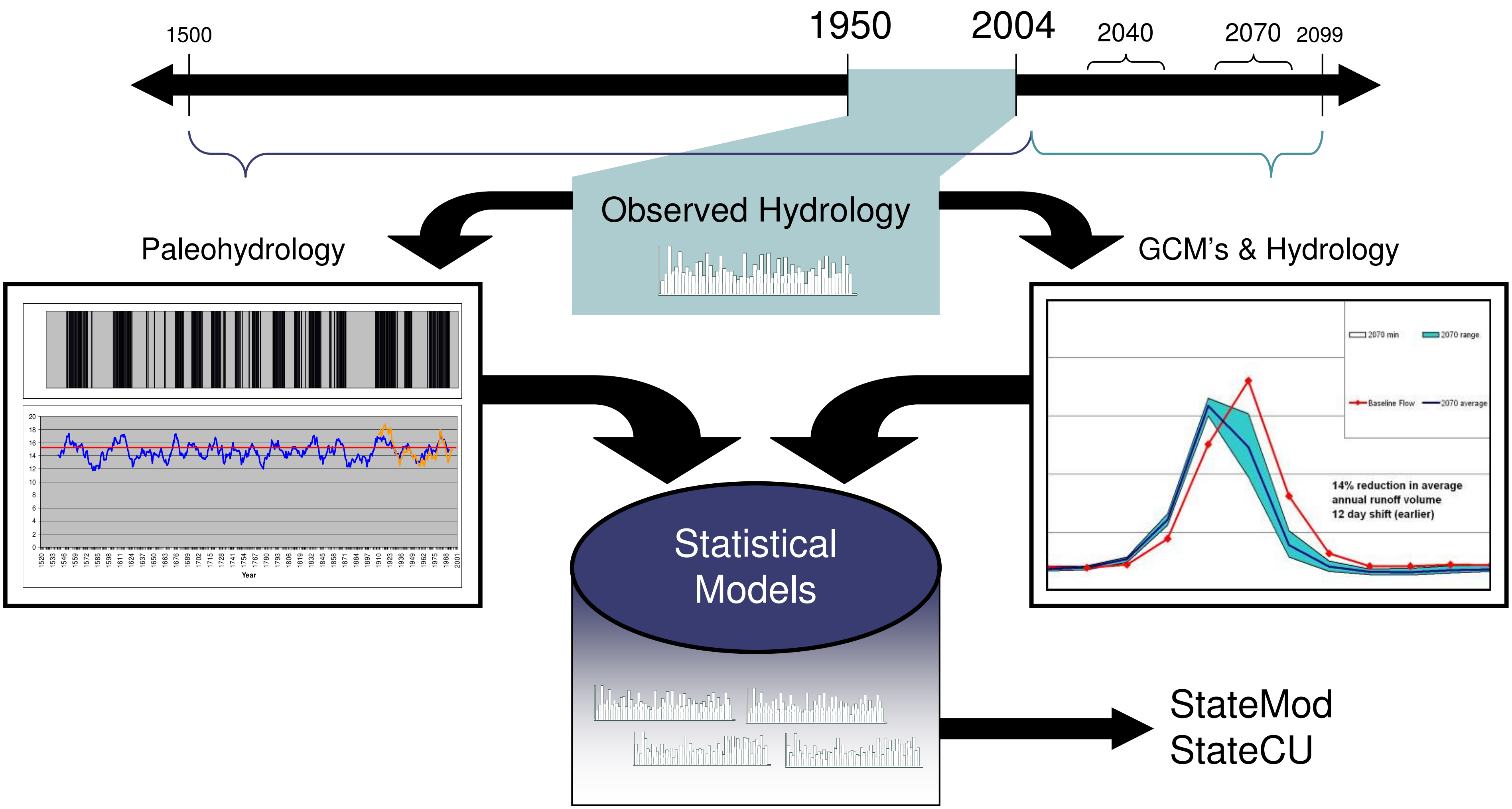
Overall Hydrology Approach



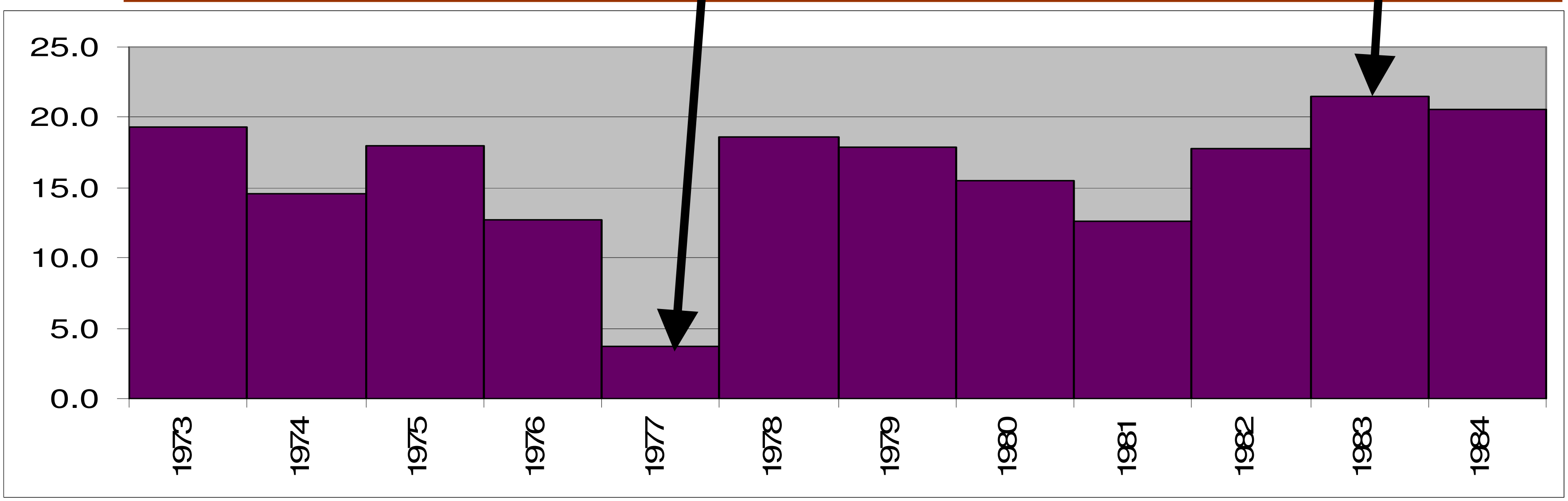
Observed Hydrology

- Use commonly accepted flows
- Colorado River
  - CRSS natural flows (Big River)
  - CDSS natural flows (Intra-state)

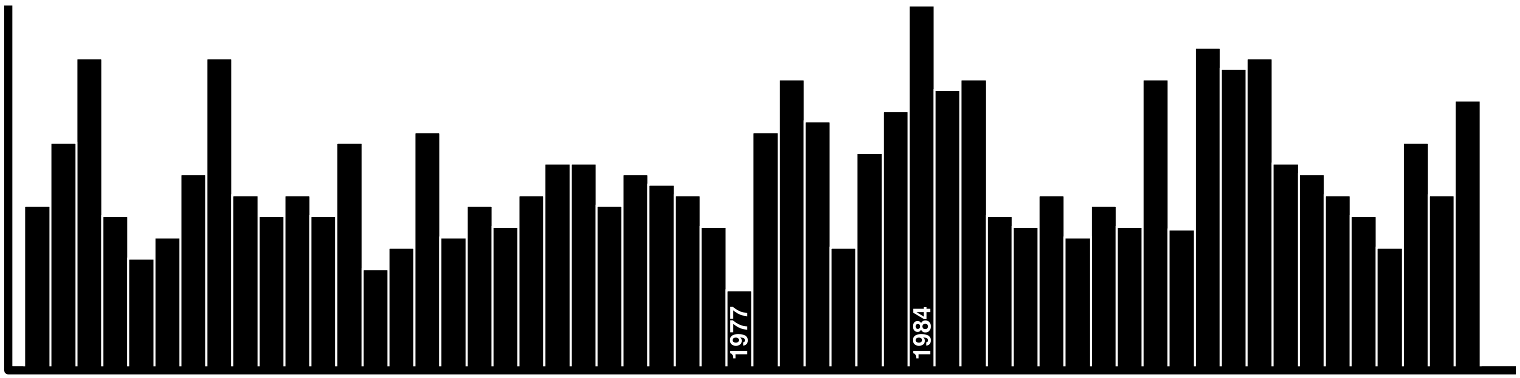
Overall Hydrology Approach



Paleohydrology – Tree Ring Data



Resequencing –
Alternate Historical Hydrology



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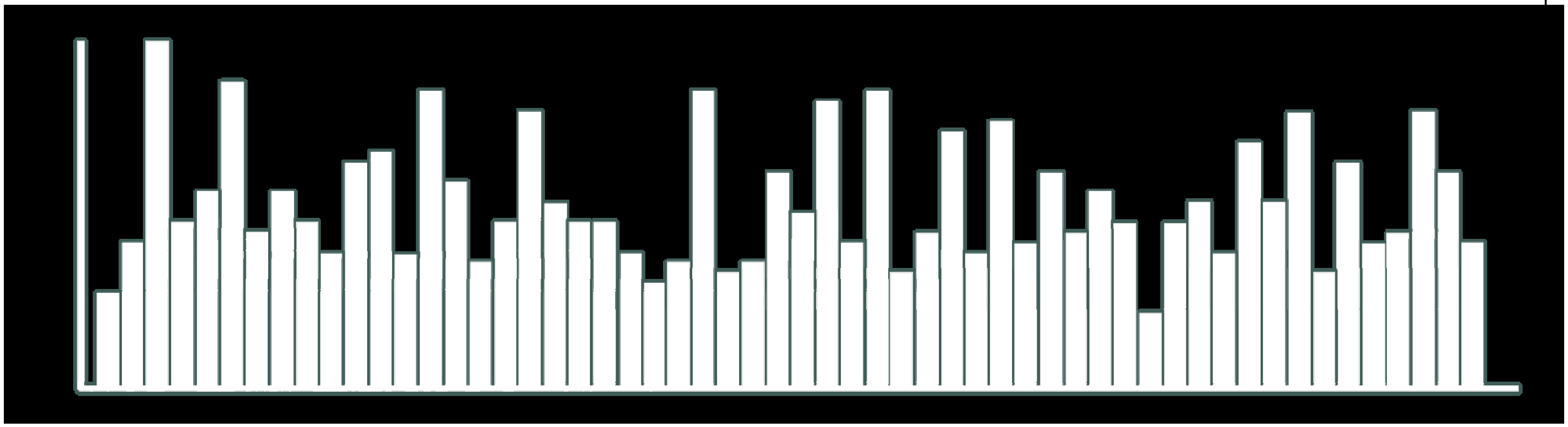
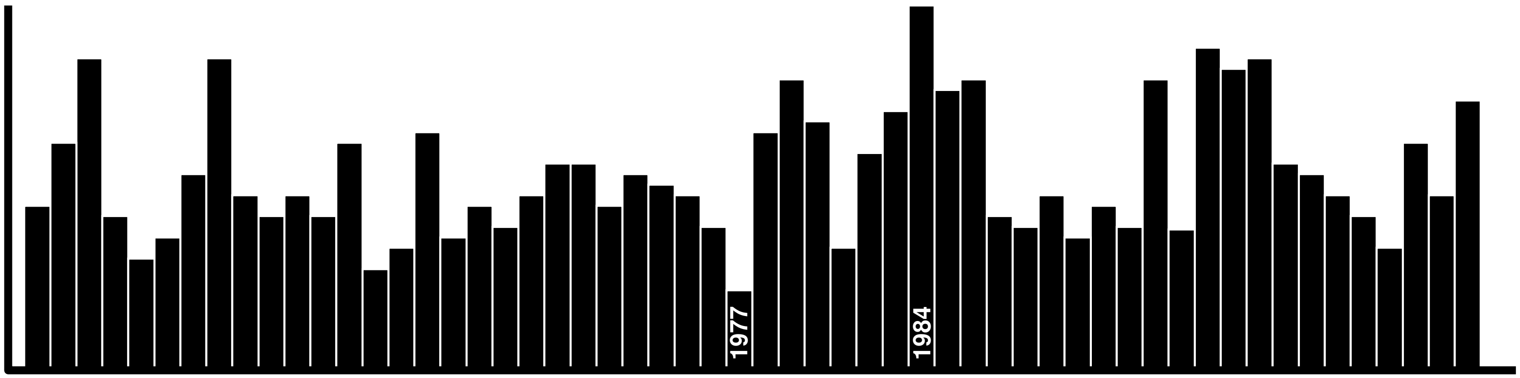
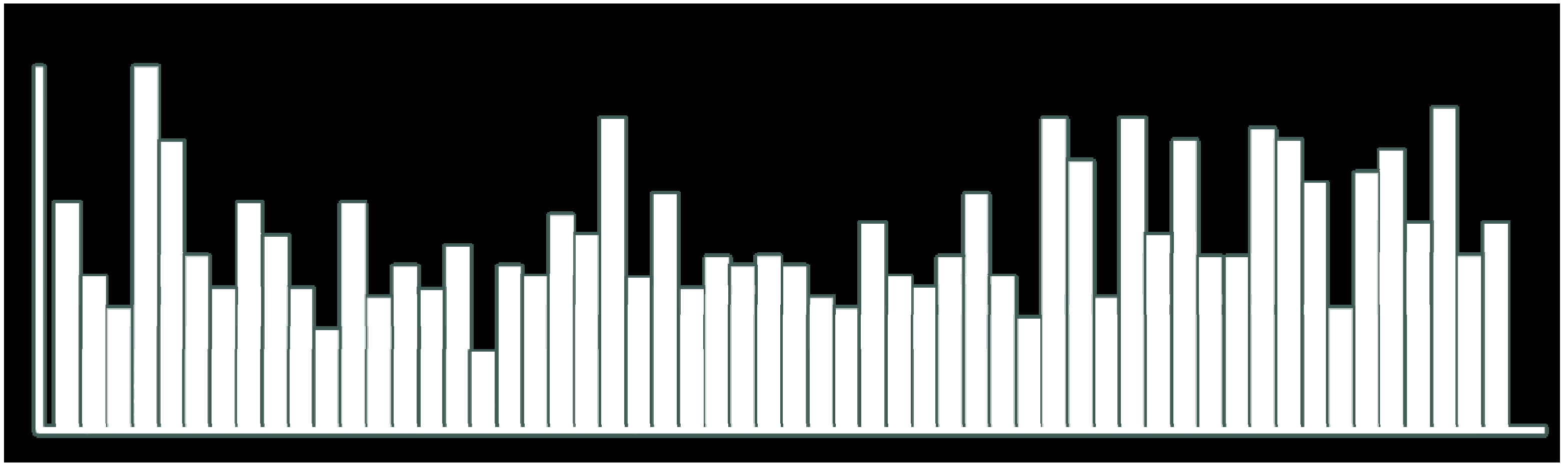


Resequencing –
Alternate Historical Hydrology



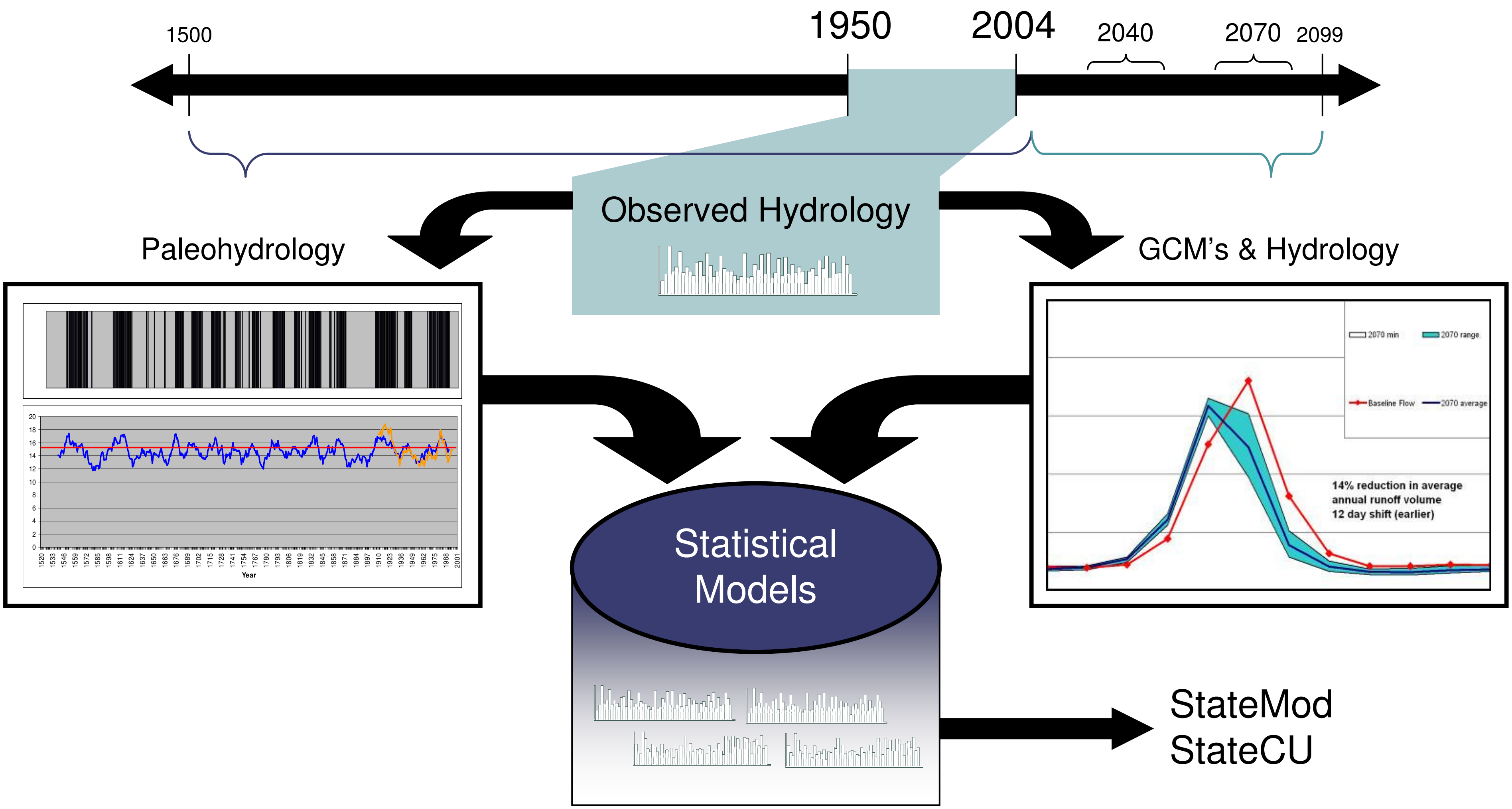


2.

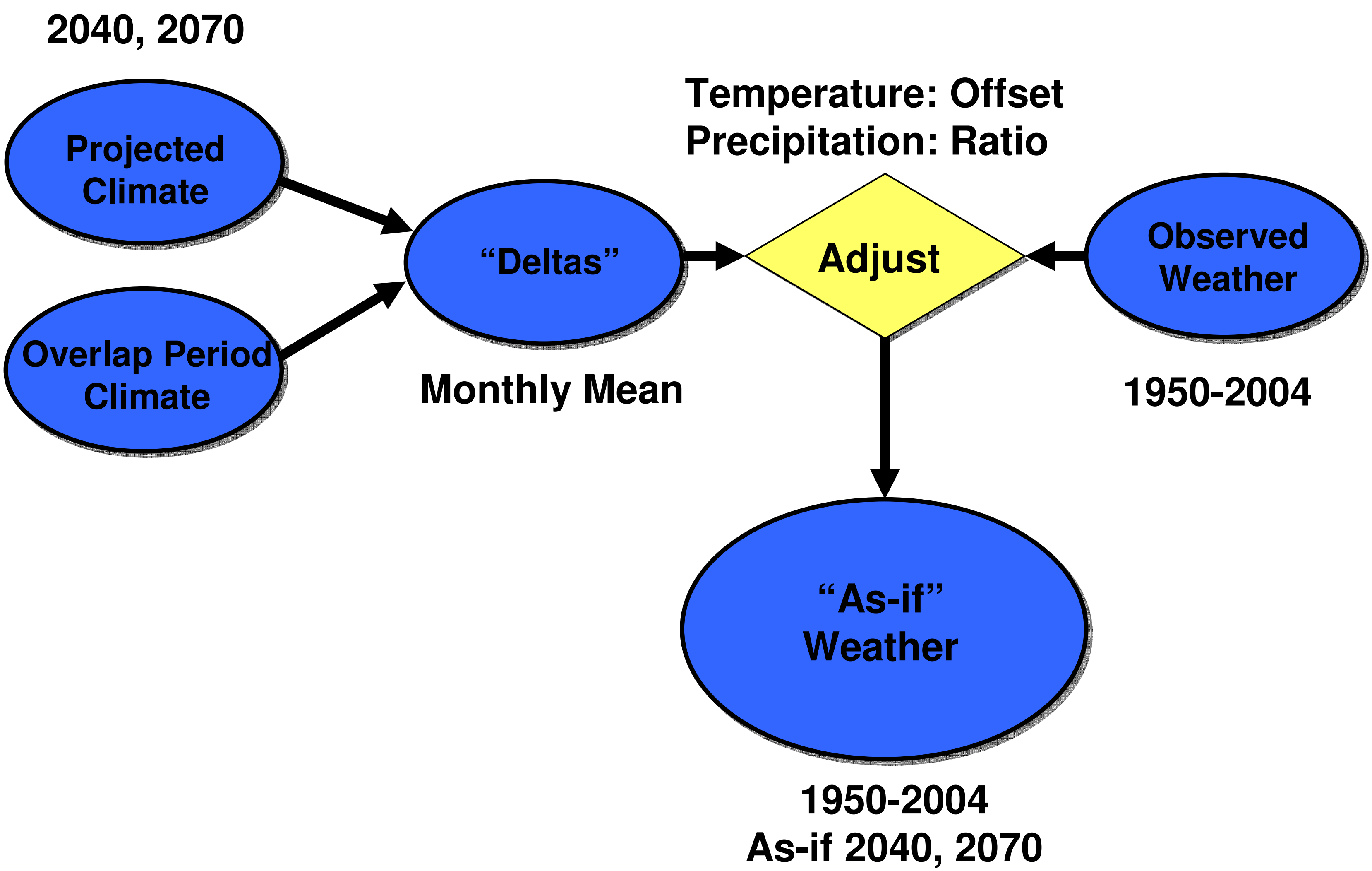
...

Repeat 100x

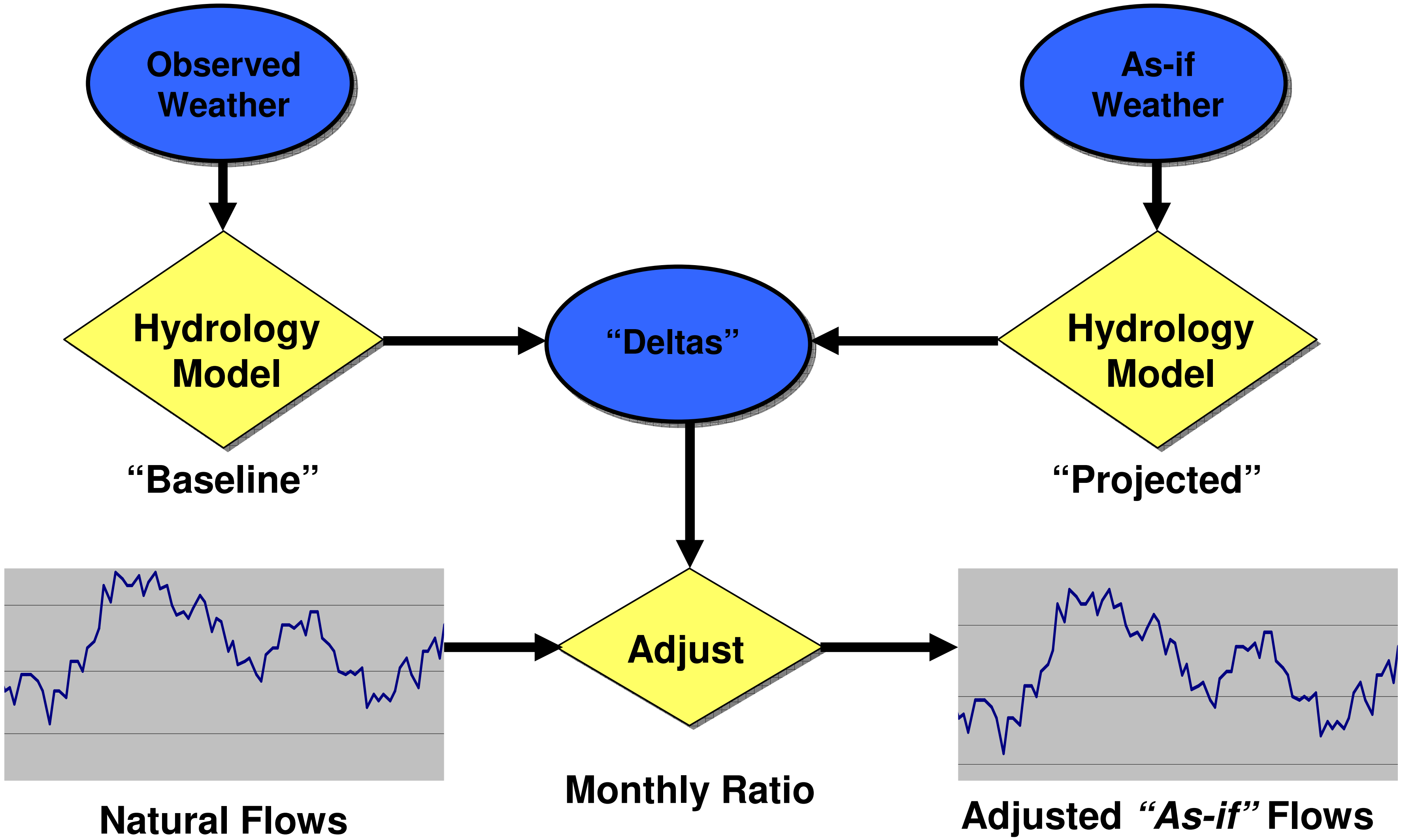
Overall Hydrology Approach



Alternate Weather



Alternate Hydrology

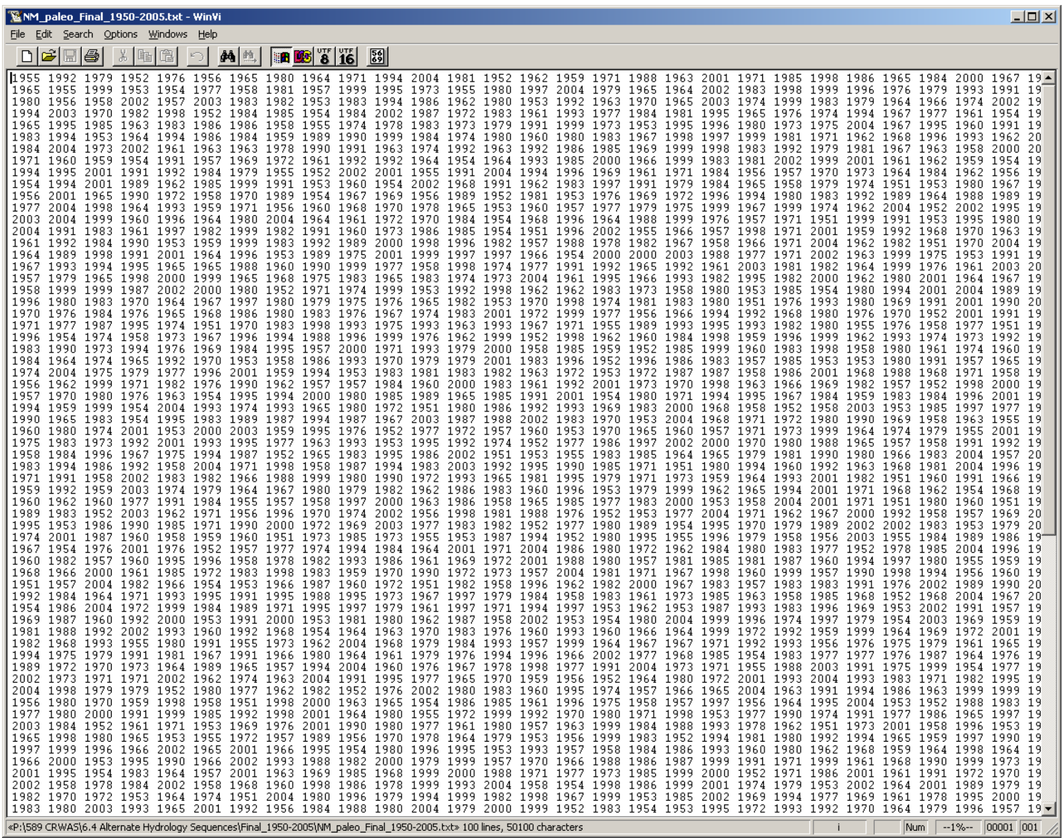


Work Completed to Date

- Built the "infrastructure"
- Obtained all data
- Developed the paleo stochastic model
- Obtained and evaluated Christensen & Lettenmaier VIC calibrated soil file
- Made initial VIC runs and produced PRELIMINARY as-if hydrology
  (presented later)
- Evaluated routing methods
- Implemented MOCOM automated calibration method
- Refined calibrations (ongoing)

Paleohydrology Methodology

Prairie et al. (2008) paper [Prairie, J., K. Nowak, B. Rajagopalan, U. Lall, and T. Fulp (2008), A stochastic nonparametric approach for streamflow generation combining observational and paleoreconstructed data, Water Resour. Res., 44, W06423, doi:10.1029/2007WR006684.]



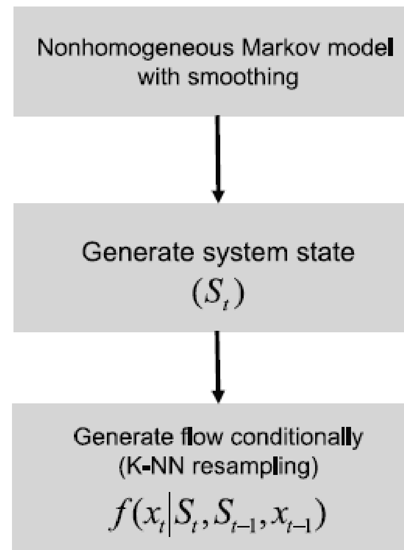
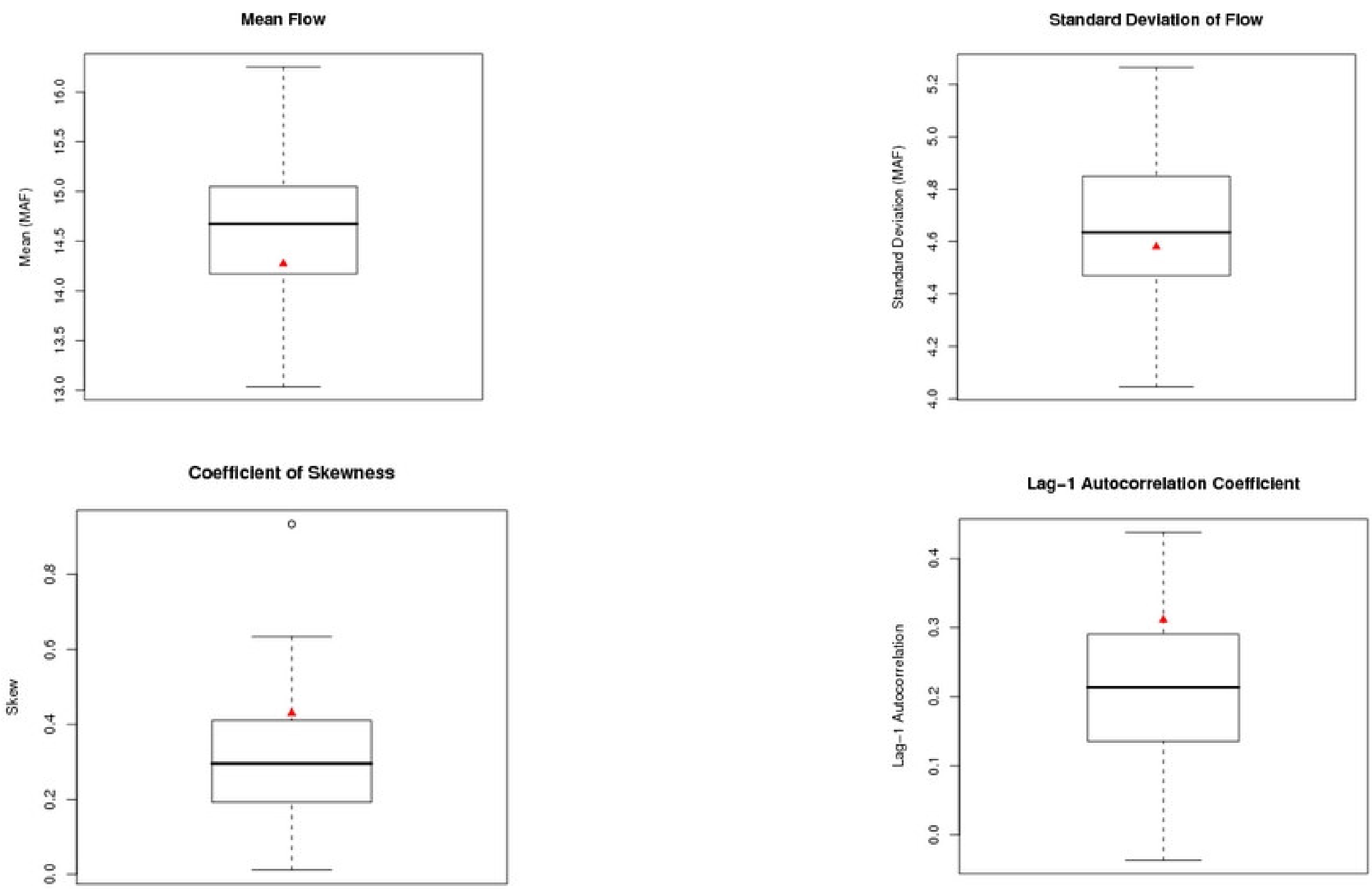


Figure 4. The nonparametric paleoconditioning (NPC) modeling framework description.

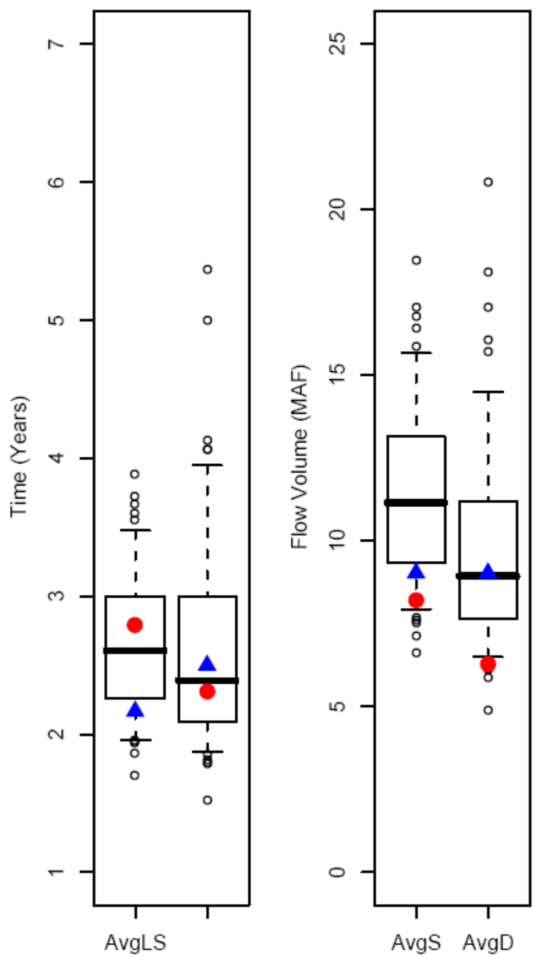
Source: Prairie et al (2008)

Paleohydrology Results – Basic Statistics



100 simulations each of length 100 years; Meko et al. (2007) reconstruction; resampling period, WY 1950-2005

Paleohydrology Results – Drought Statistics

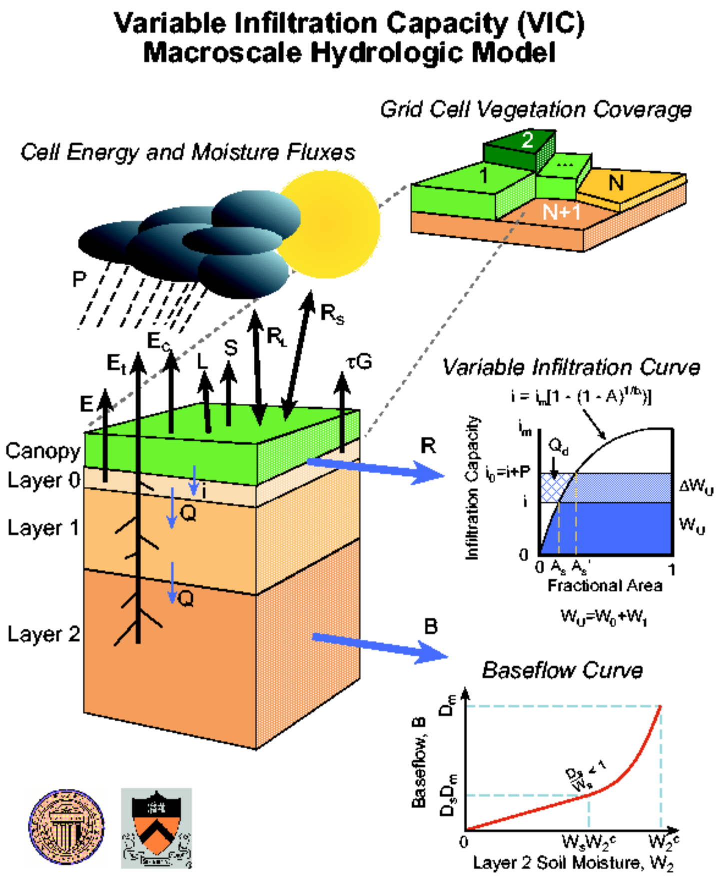


Statistics of the observed period are shown as blue triangles, and those of the paleo-simulations are shown as red circles.

Hydrology Modeling

- Use VIC model
- Land Surface, Vegetation and Soil Data
  - From Christiansen and Lettenmaier (C&L data)
- Refined calibration
  - Maurer/Wood gridded weather
  - CRDSS natural flows
  - MOCOM automated calibration (multi-objective SCE)
- Routing
  - Daily
  - Monthly
  - Annual
- Sum to monthly

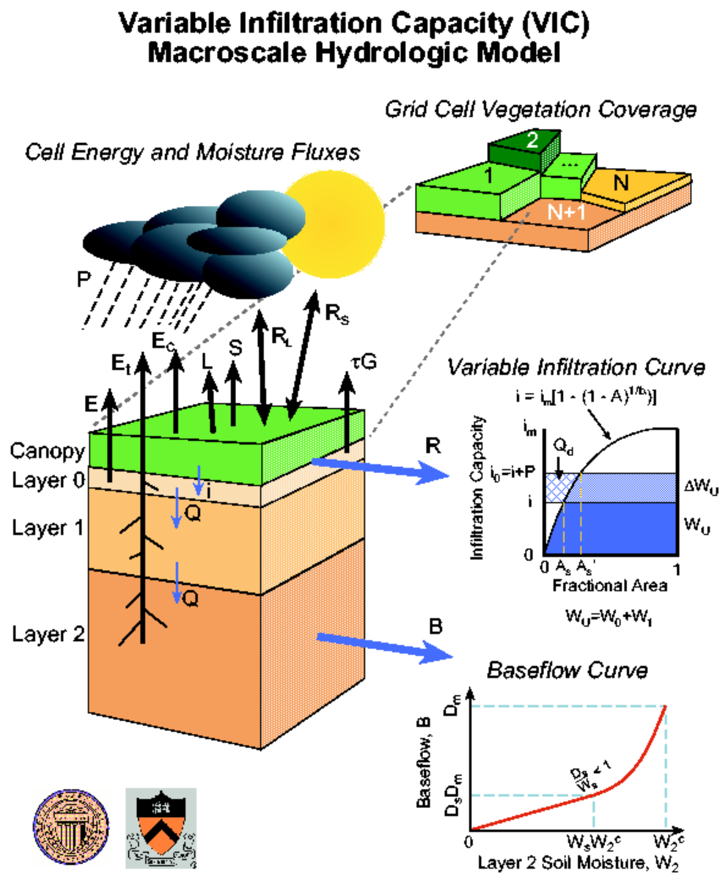
Land Surface, Vegetation, Soils Data



- Land cover tiles (vegetation)
- Elevation zones (topography)
- Snow model solved for each tile
- Snow state variables and fluxes averaged (area weighted)

Source: Kostas Andreadis, 2007

Land Surface, Vegetation, Soils Data

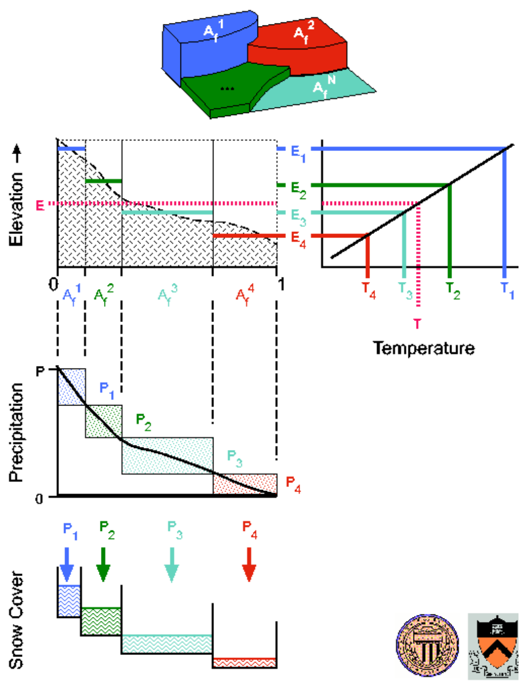


• Land surface processes – “advanced” physical representation – “complex”

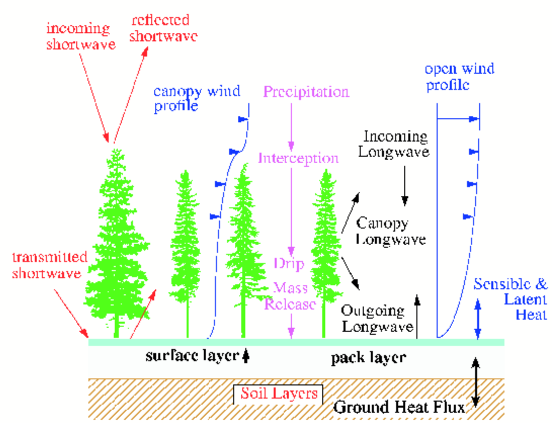
• Subsurface processes – “conceptual”

Snow Model

VIC Snow Elevation Bands

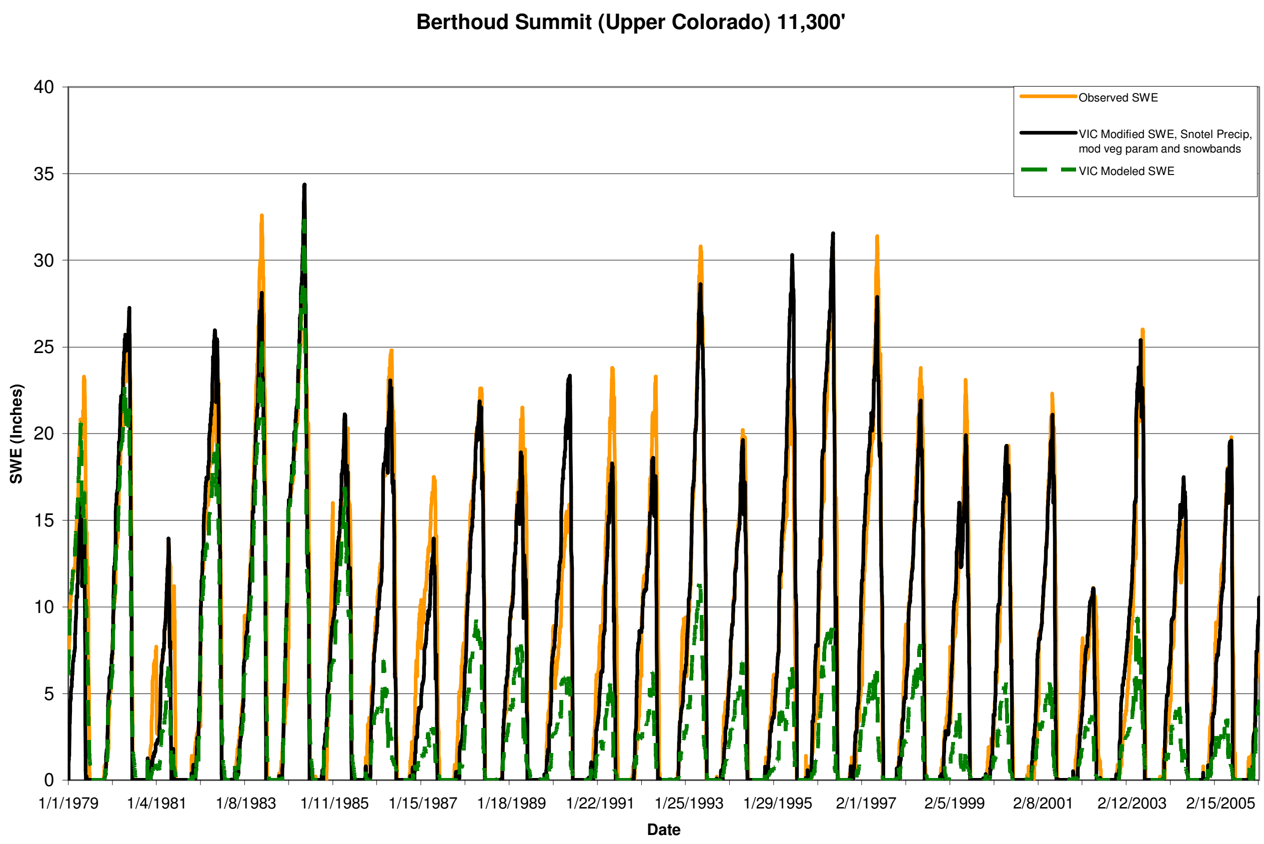


VIC Snow Algorithm



- 5 snow-bands
- fractional-area
- “2-layer” formulation
- ground snow pack
- snow interception and canopy processes
- energy balance approach

Snow Model Validation

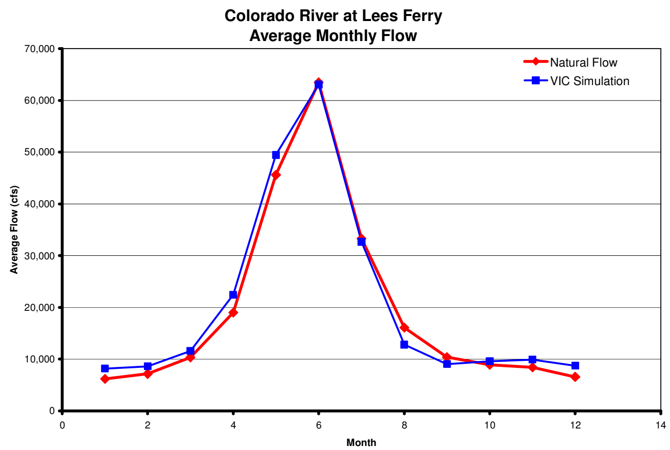


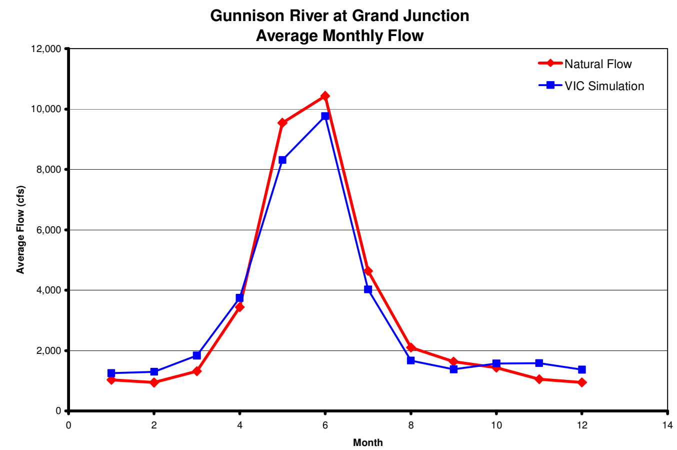
- SNOTEL precipitation
- set VIC cell elevation to SNOTEL site elevation
- vegetation set to grassland

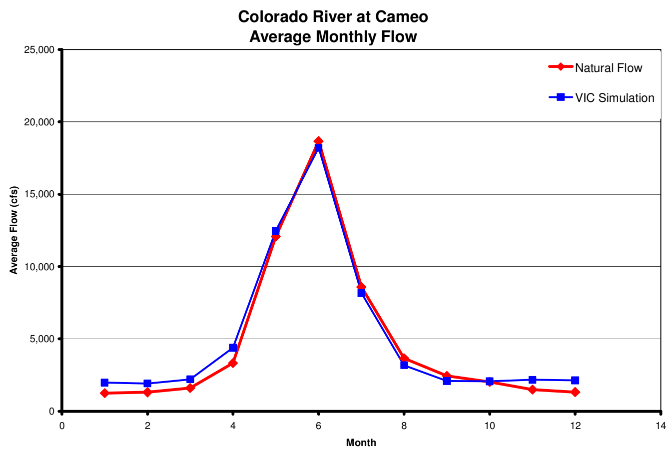
Observed Weather/Forcings

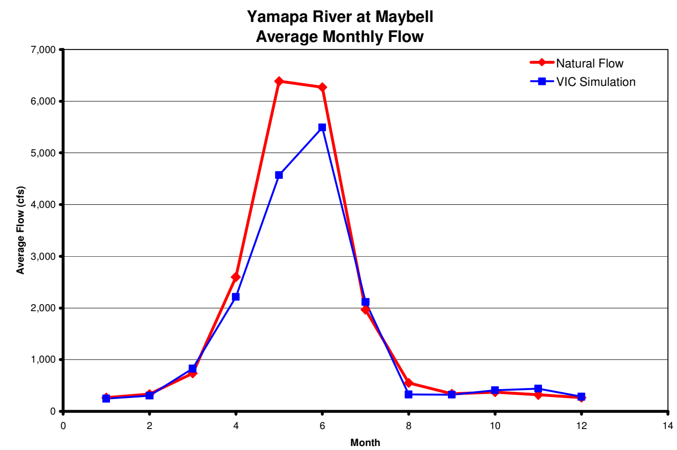
- Andy Wood – west wide forecast datasets, 1950-2005, daily
  - Precipitation
  - Maximum temperature
  - Minimum temperature
  - Wind
- Spatial resolution - 1/8-degree ~7.5-mile grid

Simulation Results CY 1950-2004 using C&L Parameters – soil, vegetation, land surface

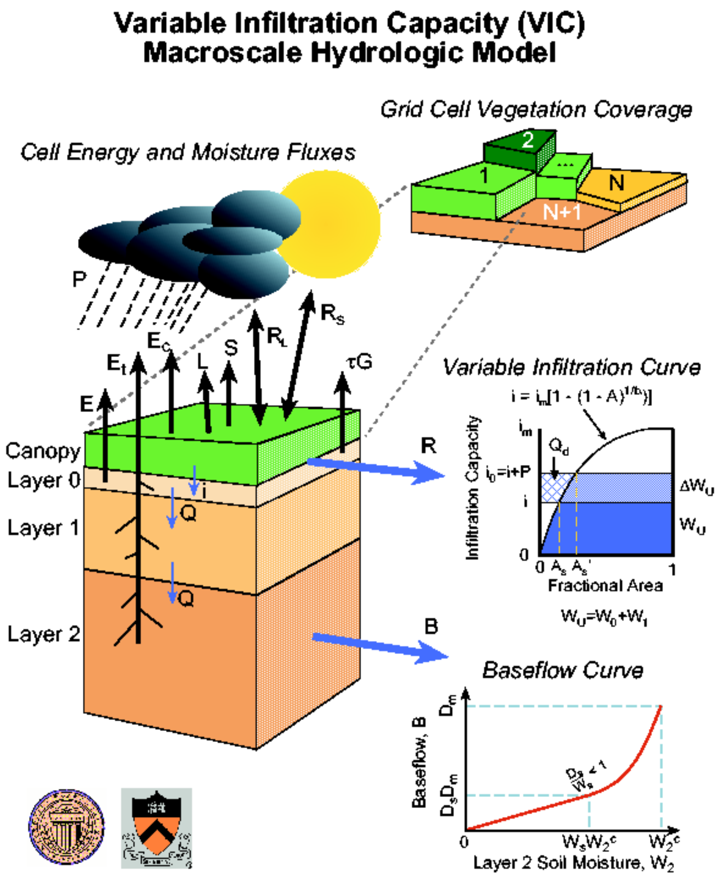








Calibration



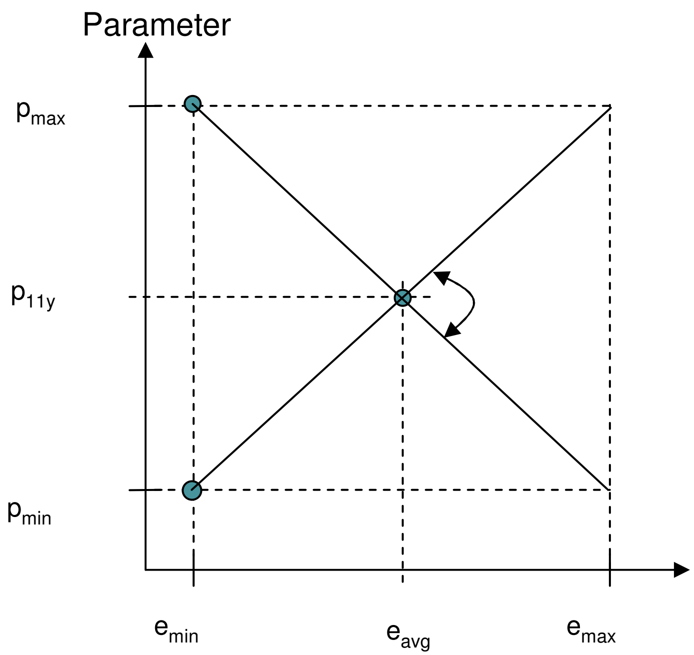
- Land surface processes – “better” physical representation – “complex”
- Subsurface processes – “conceptual”
  1. Dsmax – maximum baseflow that can occur from the lowest soil layer (mm/d).
  2. Ds – fraction of Dsmax where non-linear baseflow begins.
  3. Ws - fraction of maximum soil moisture in lowest soil layer where non-linear baseflow occurs.
  4. Layer 1 soil depth (D_2).
  5. Layer 2 soil depth (D_3).
  6. binf – shape of the variable infiltration capacity curve – control for infiltration versus surface runoff.

Calibration Approach - Autocalibration

- MOCOM
- Three-stage approach
  - Scalar values – let the 6 subsurface parameters vary within [min, max]
  - Slope sensitivity analysis – ‘will explain details in next slide
  - Hybrid slope/scalar calibration
- Periods
  - Parameter estimation 1950 – 1984
  - Validation 1985 – 2004 (spin up with 1983 and 1984)

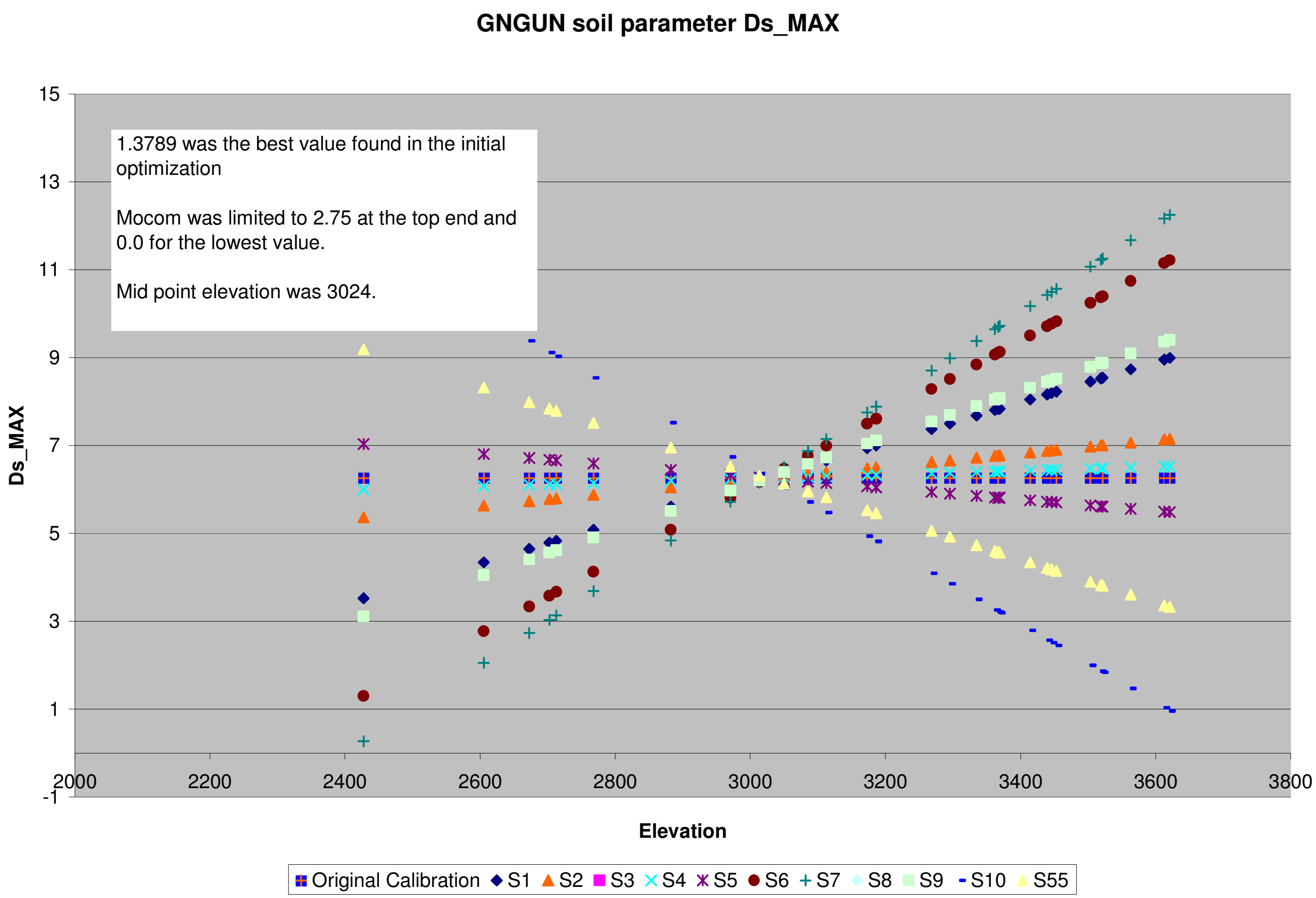
Slope Sensitivity Analysis

- Scalar MOCOM run using [min, max] parameter bound for all the 6 subsurface parameters for the 11-year period, 1950-1960.
- Select the “best” parameter values from the 11-year run -> “effective” parameter for the basin.

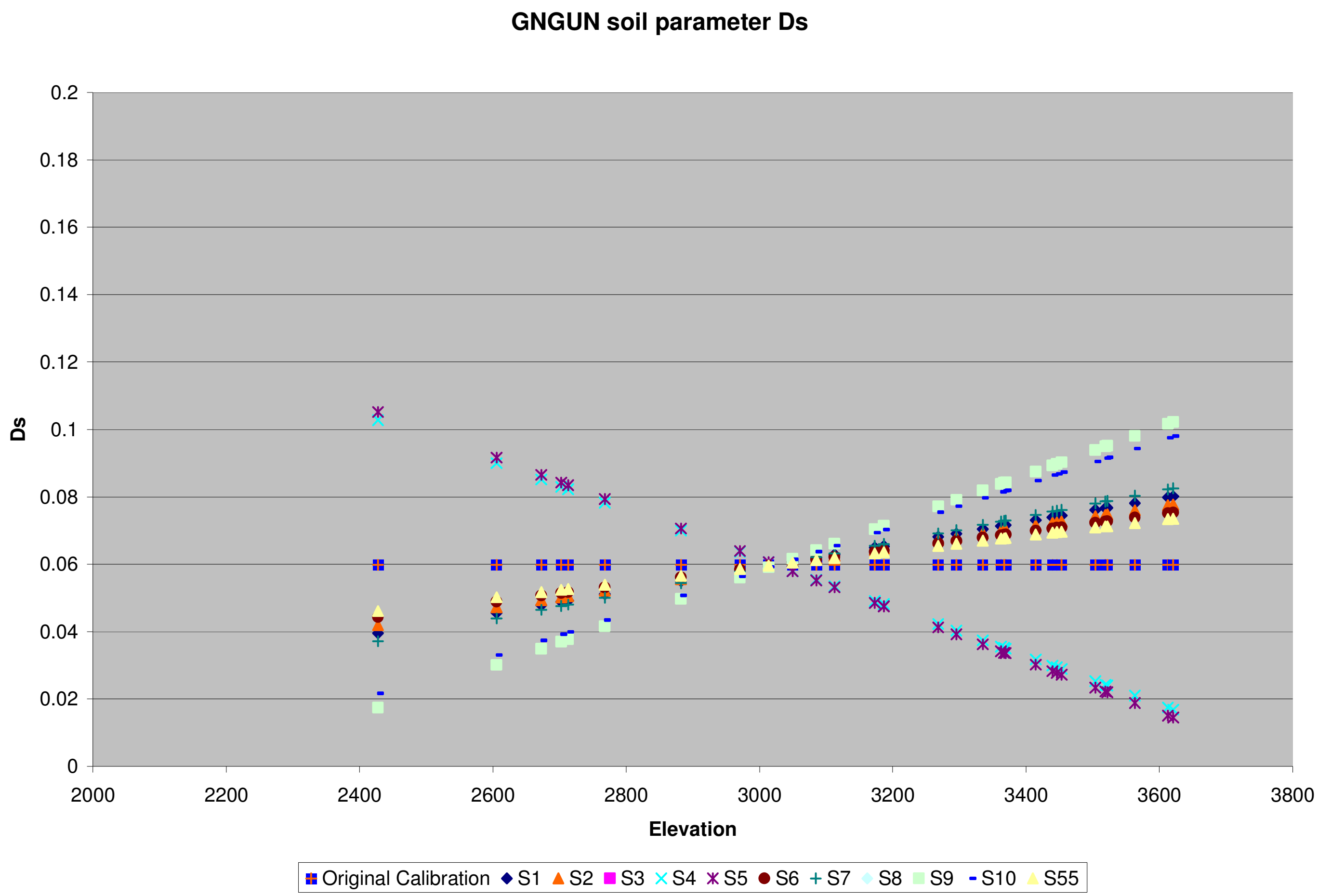


$$p_n = m(e_n - e_{avg}) + p_{11y}$$

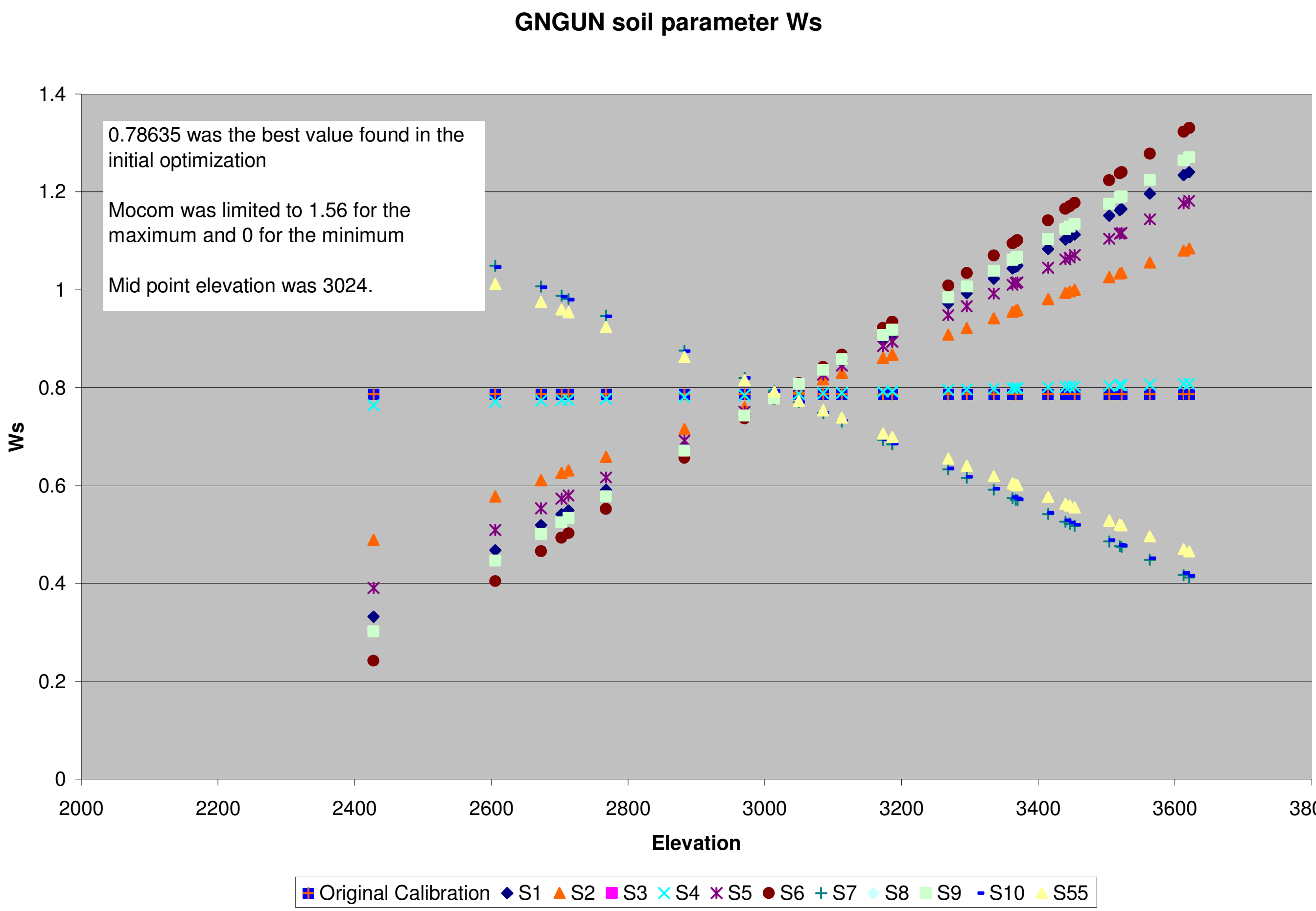
Dsmax – Gunnison at Gunnison



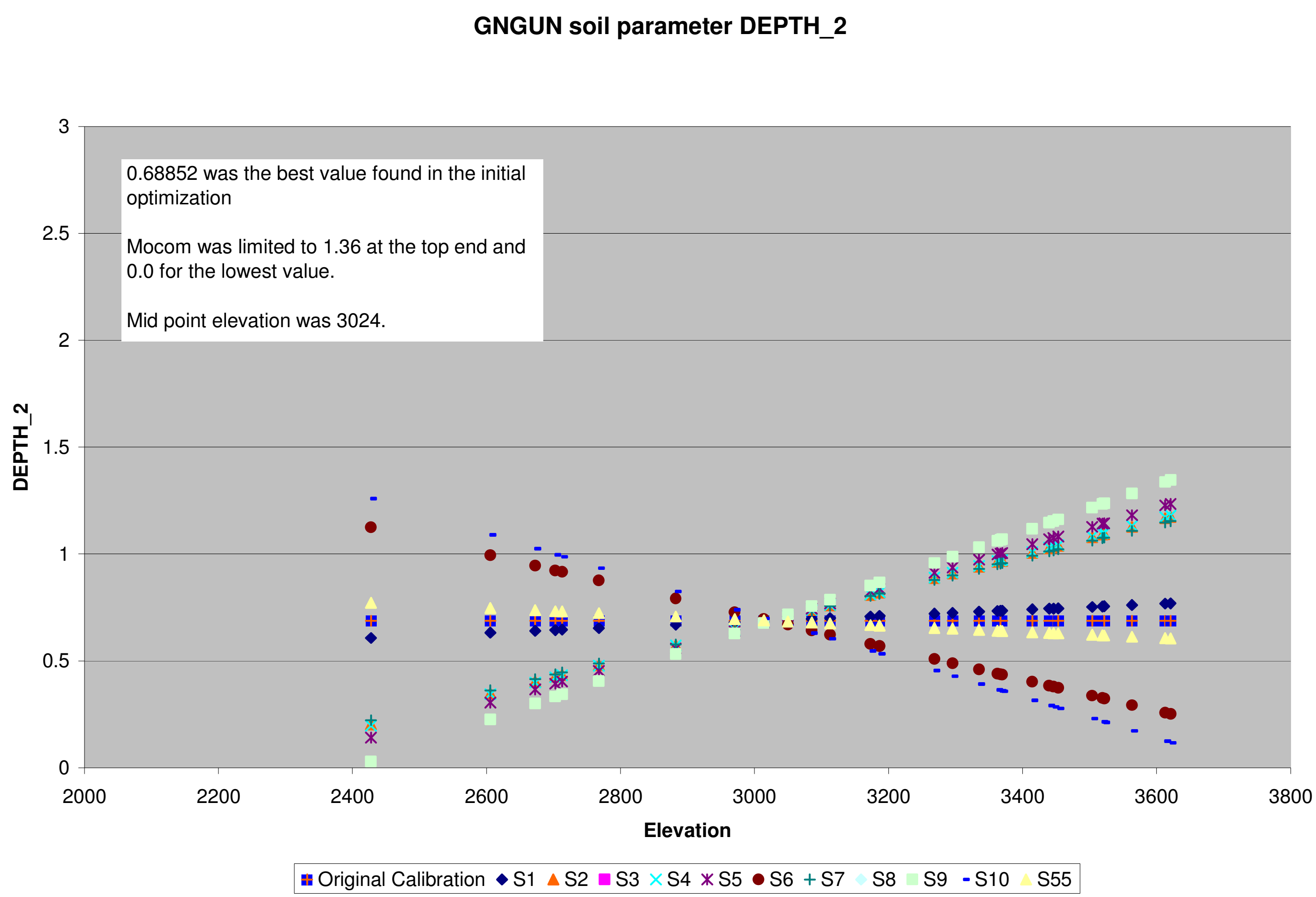
Ds – Gunnison at Gunnison



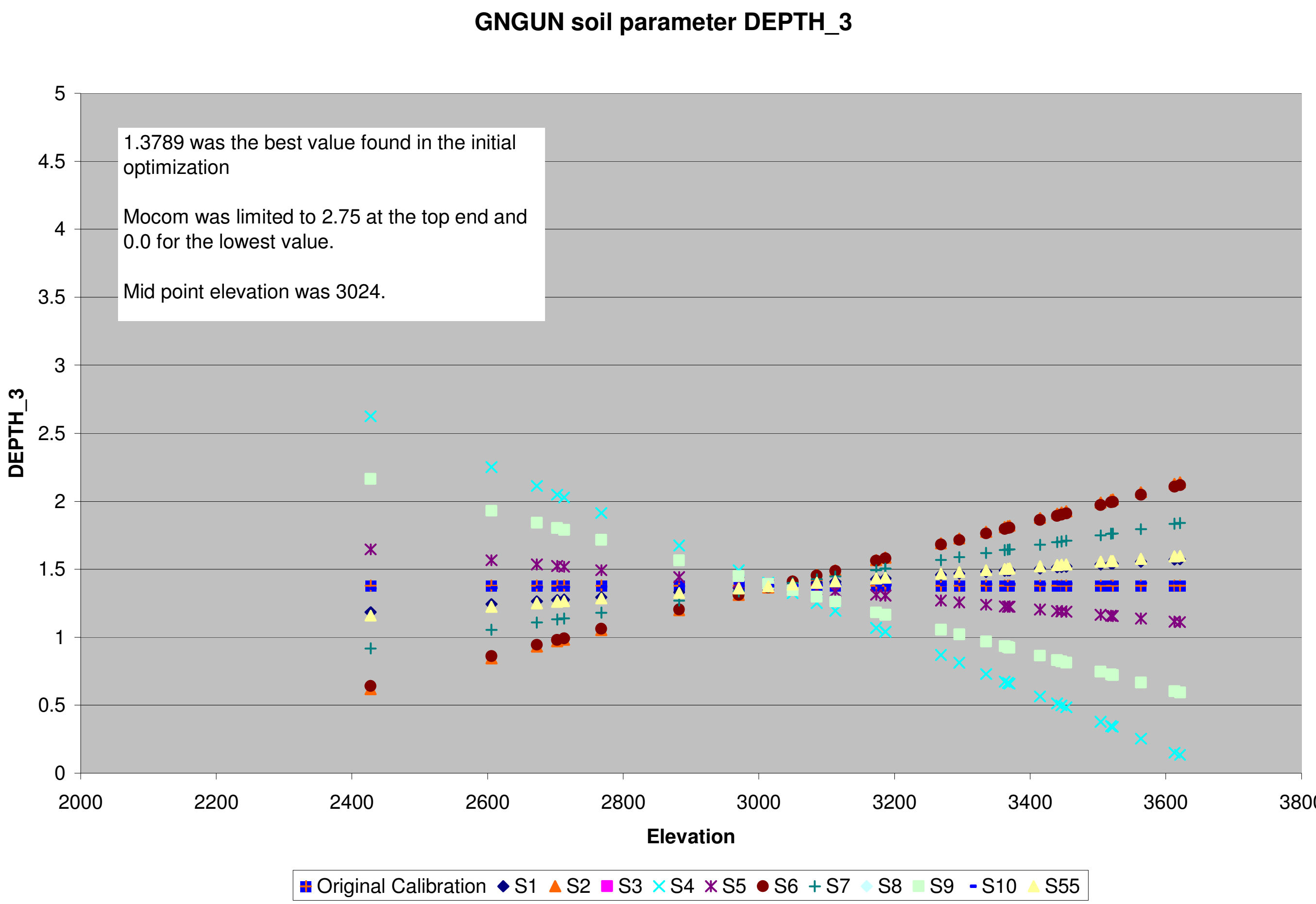
Ws – Gunnison at Gunnision



Layer 1 soil depth (D_2) – Gunnison at Gunnison

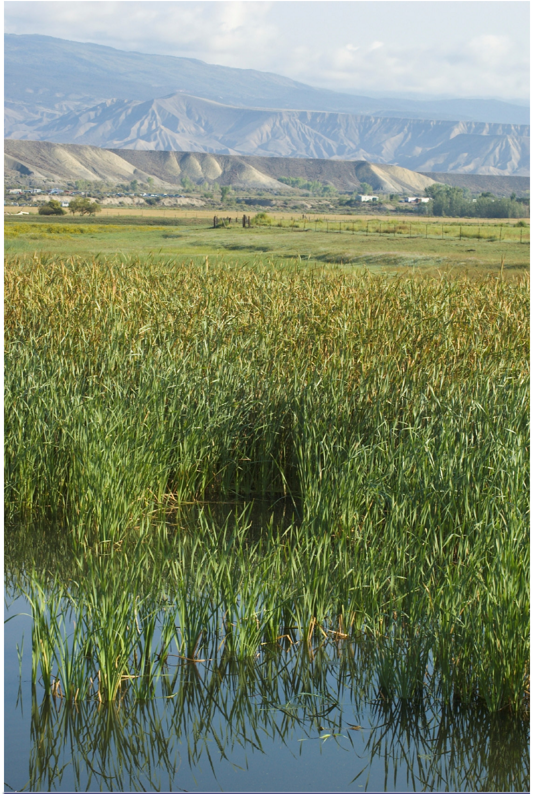


Layer 2 soil depth – Gunnison at Gunnison

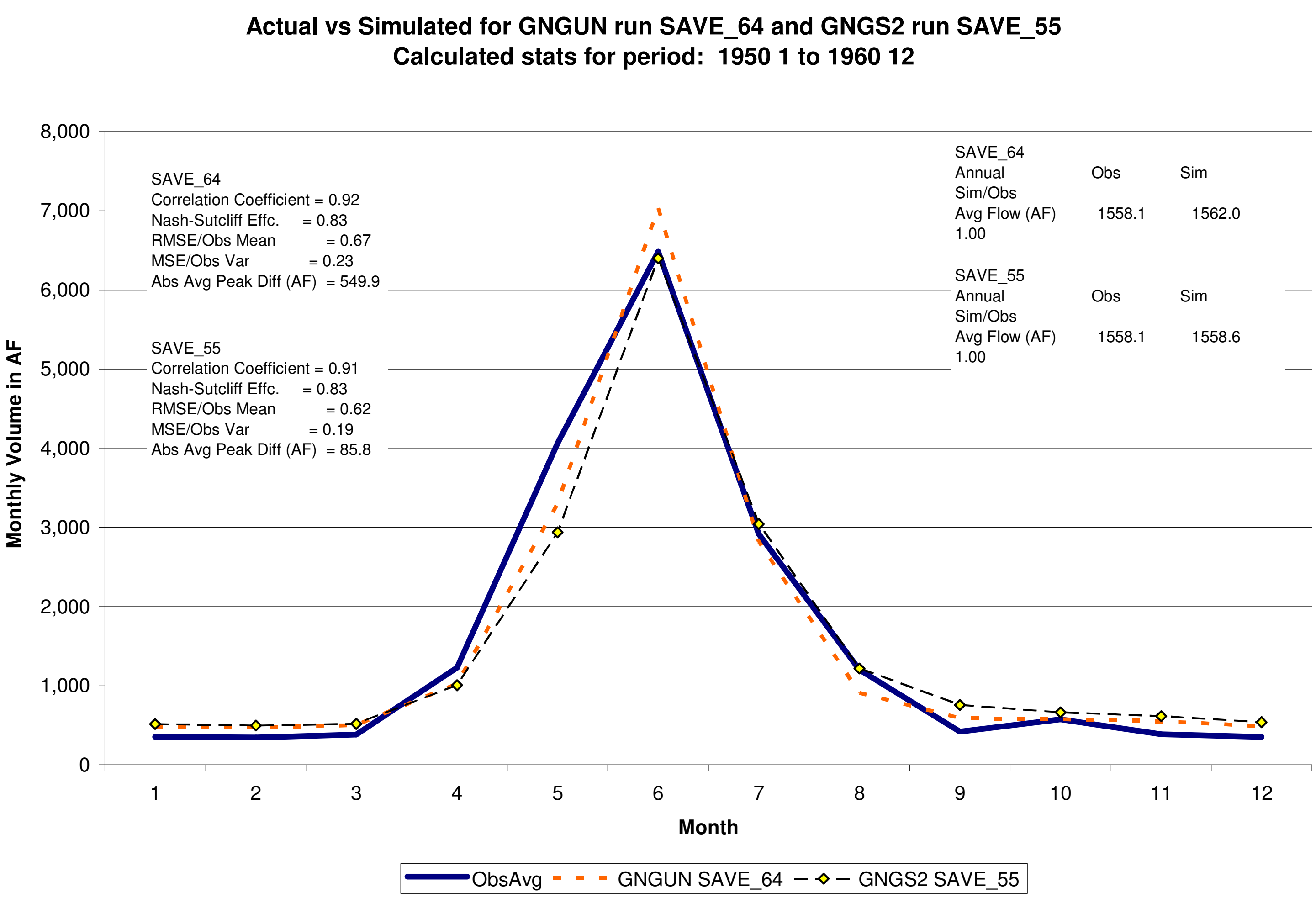


Calibration Results

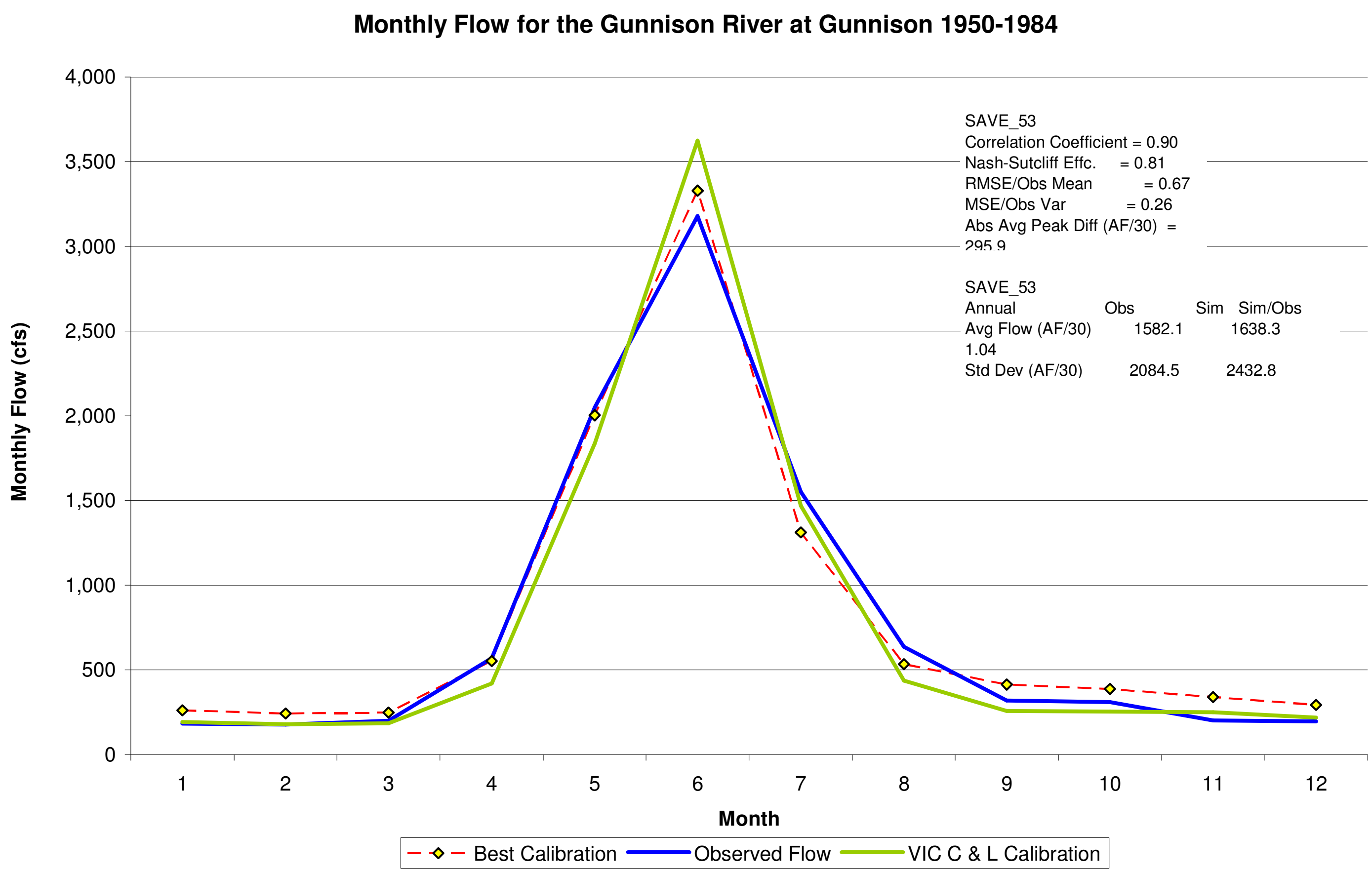
- 2-most sensitive parameters are:
  - Dsmax
  - Ws



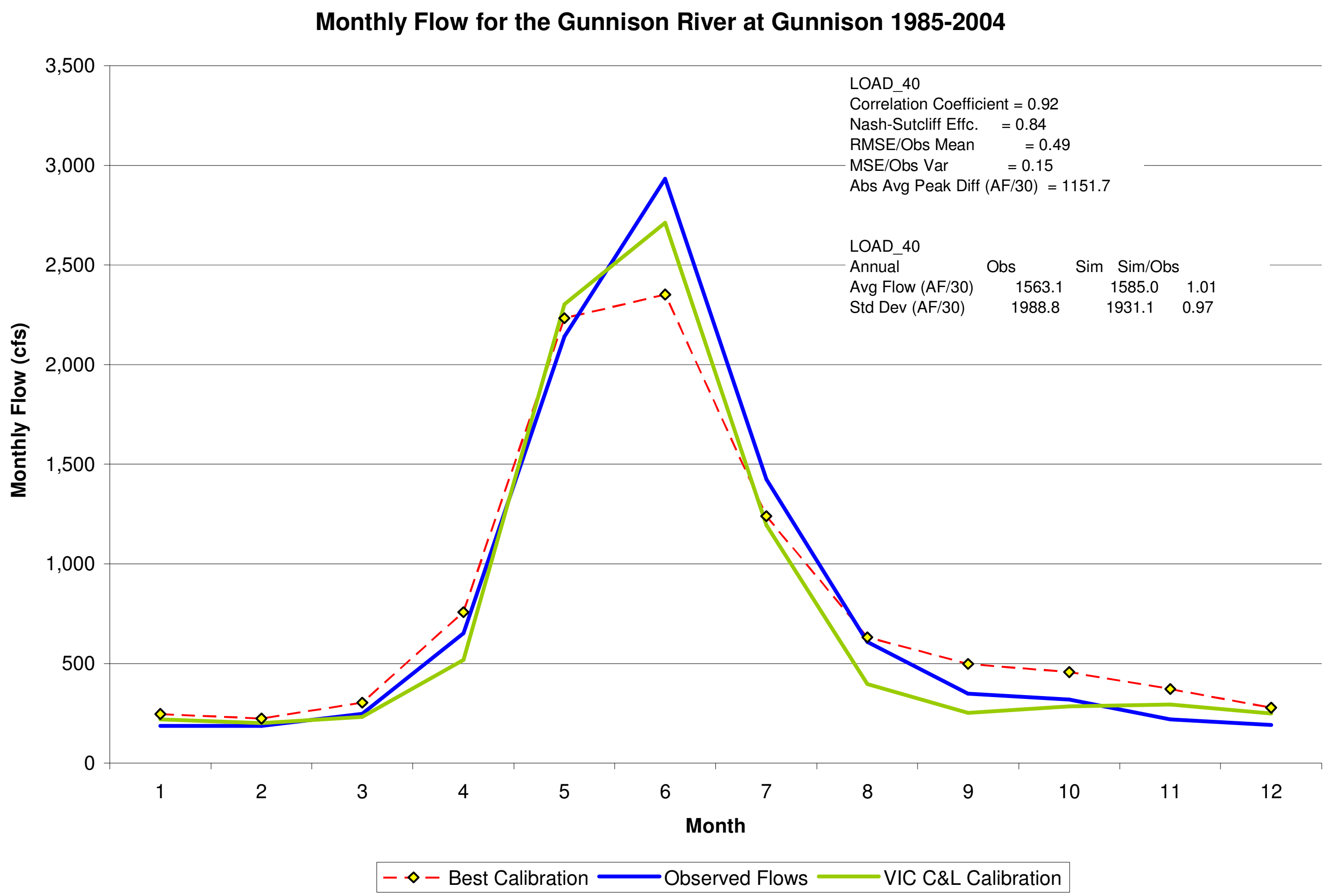
Calibration Results – Gunnison at Gunnison



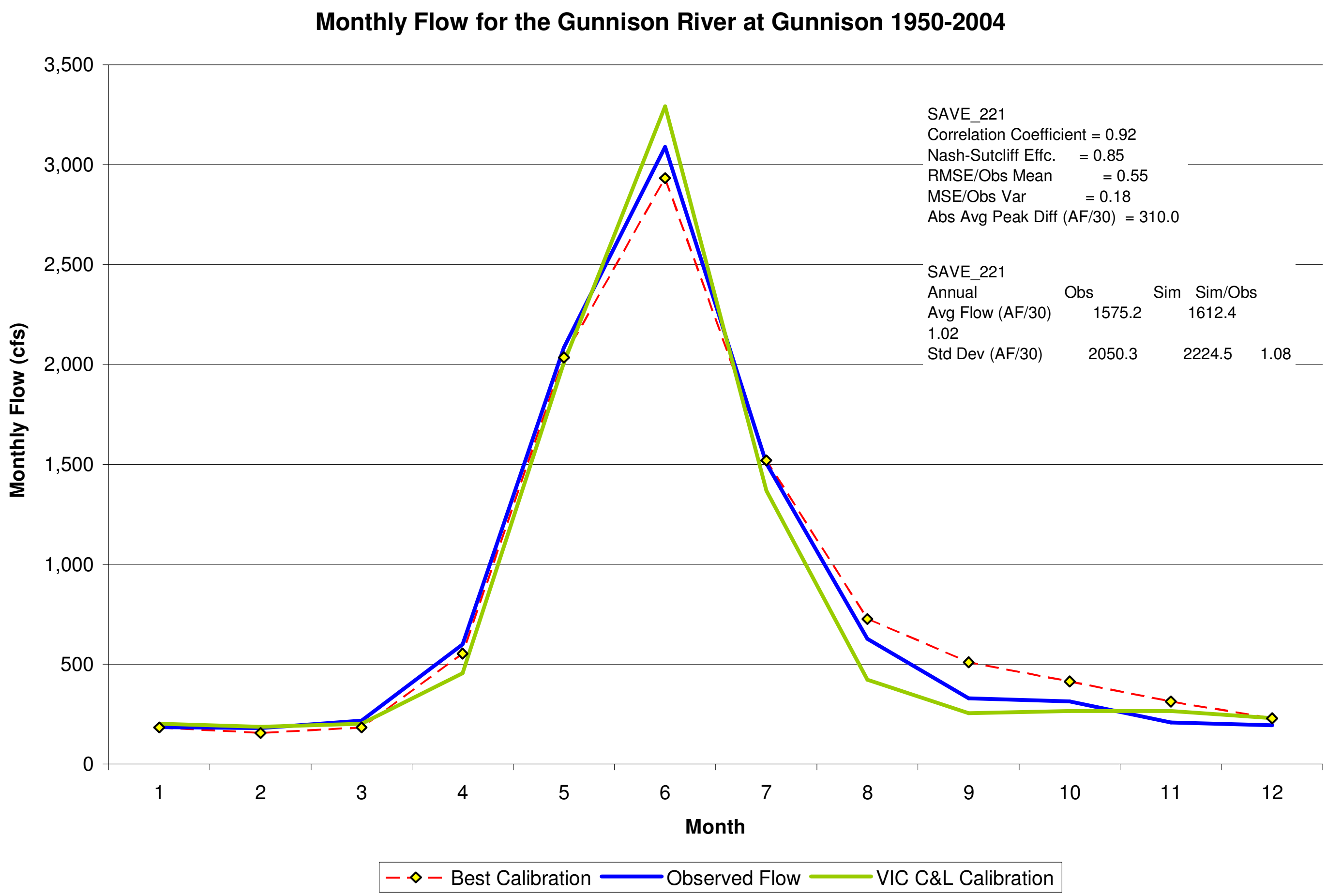
Calibration Results, 1950-1984, Calibration Period



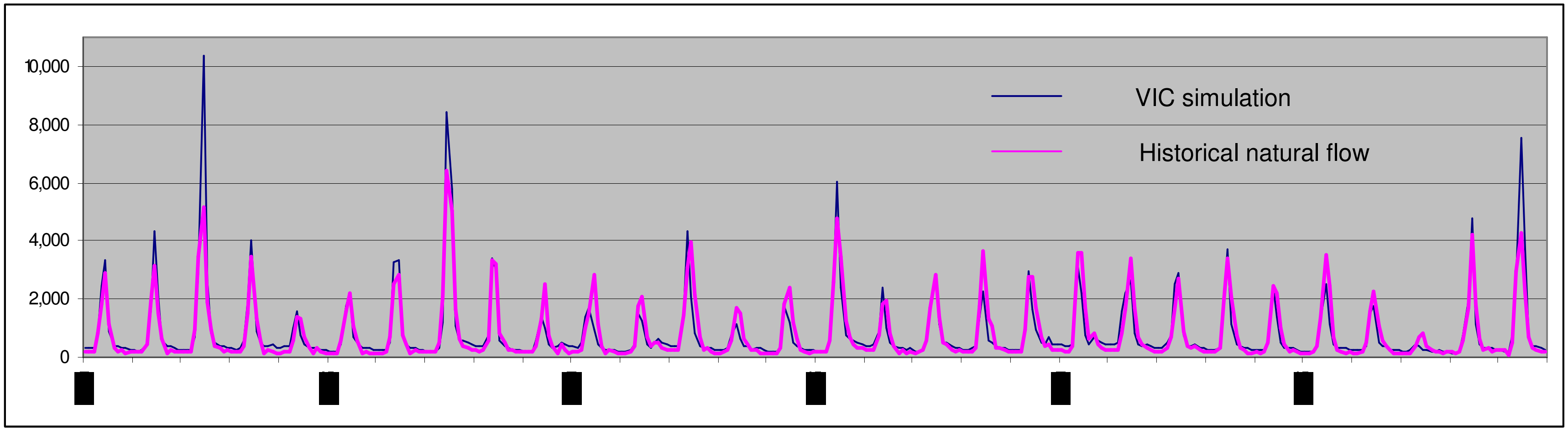
Calibration Results, 1985-2004, Validation Period

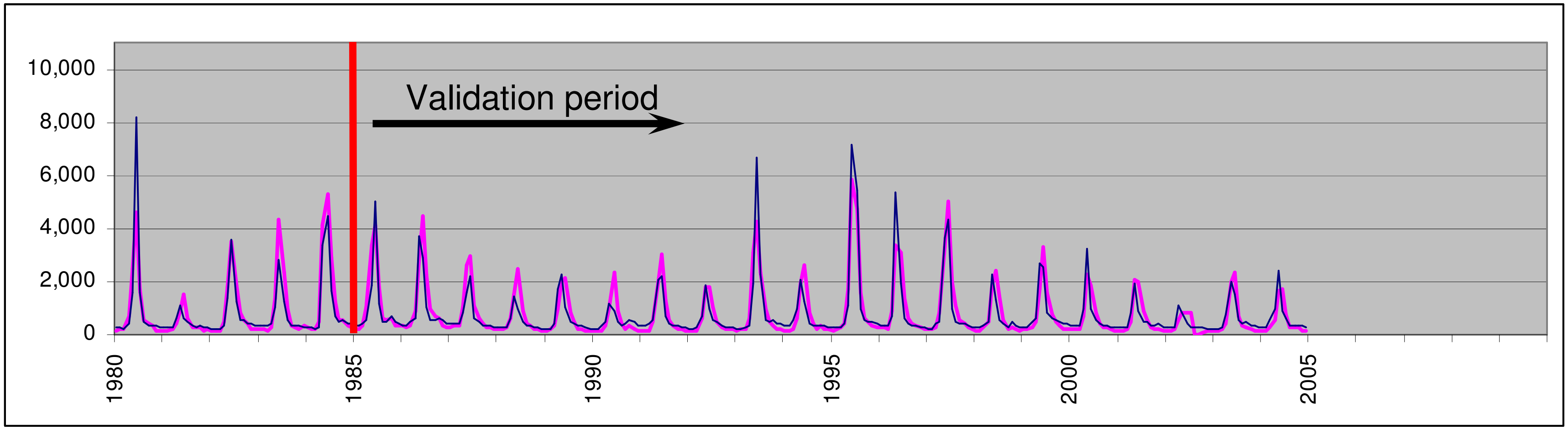


Calibration Results, 1950-2004



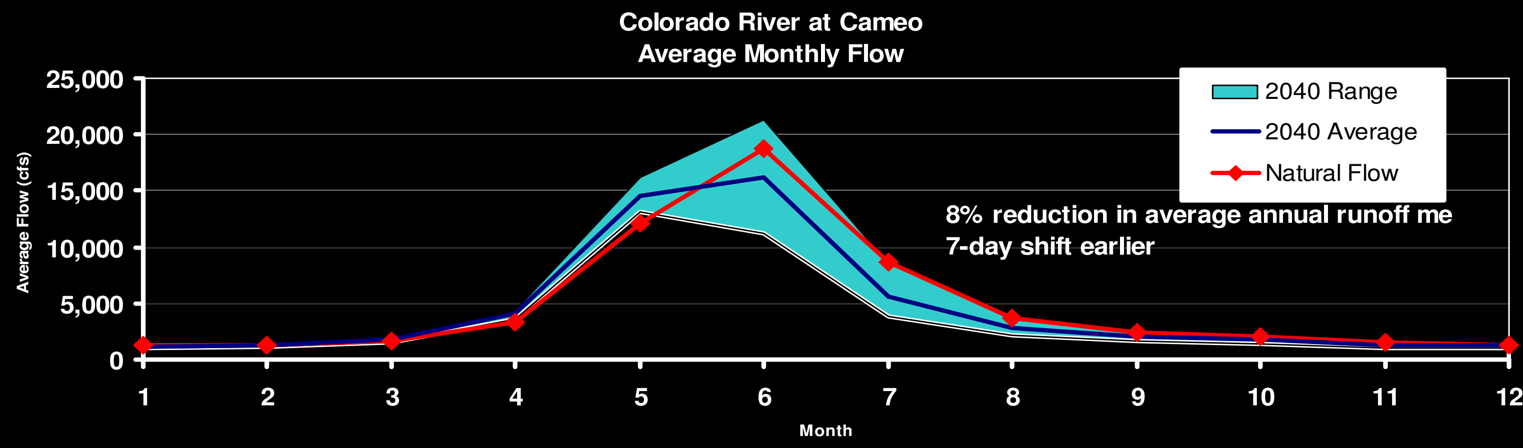
Time-series Comparison

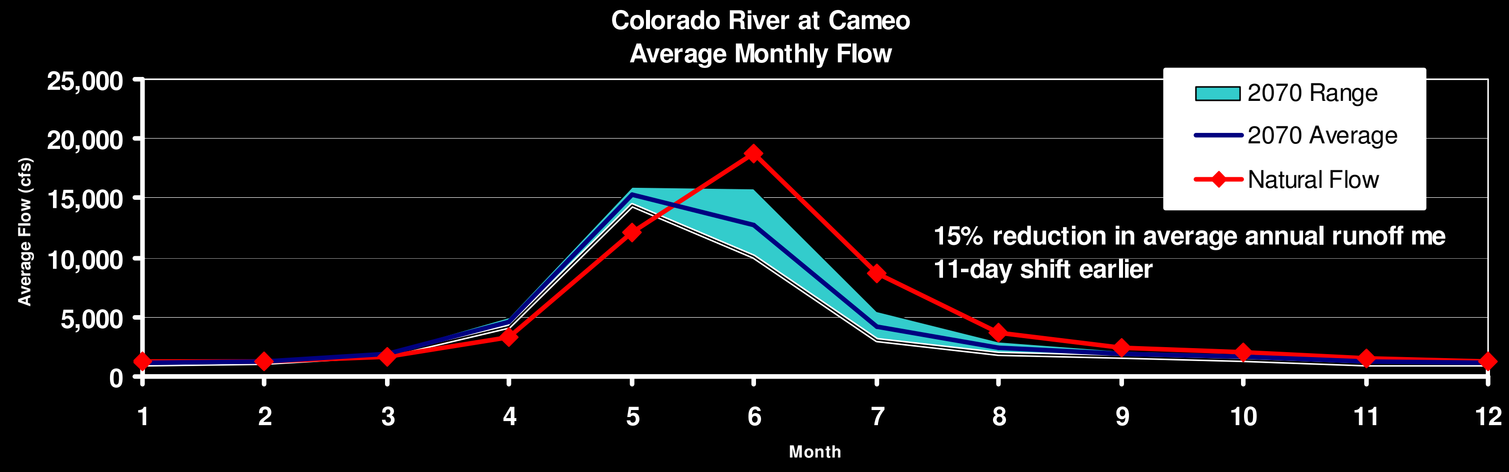




GCM Results – Colorado – Cameo

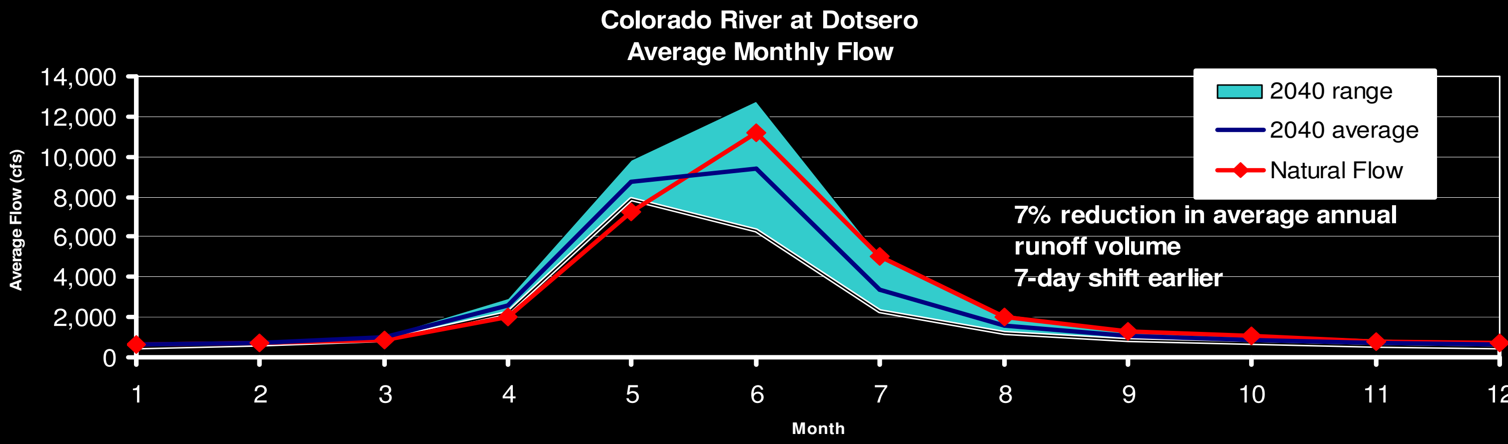
PRELIMINARY RESULTS—Not for citation.

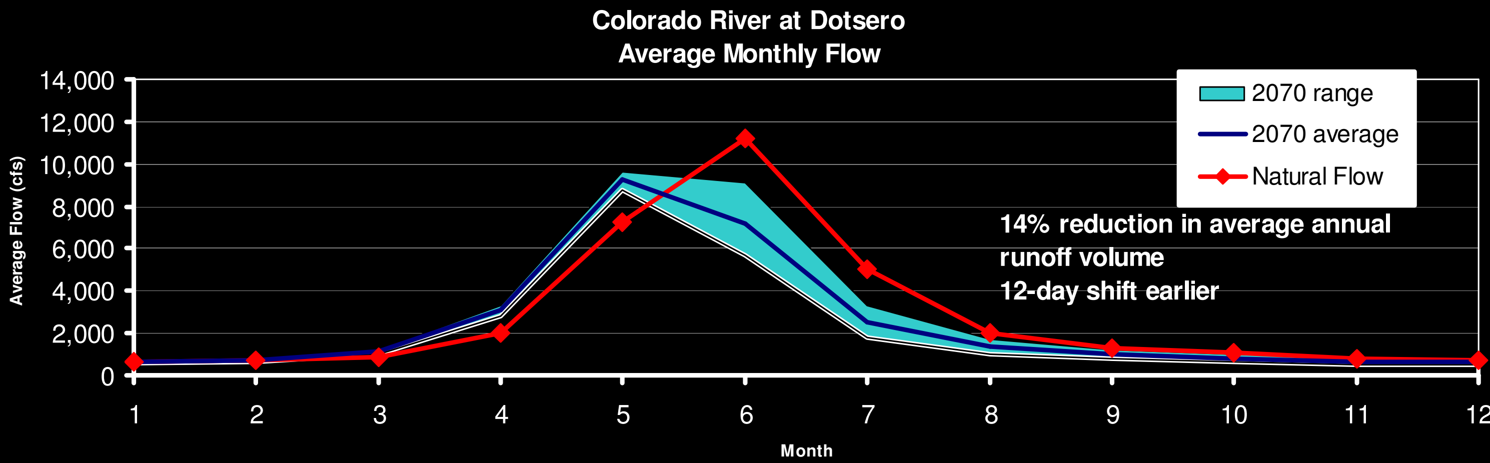




GCM Results – Colorado – Dotsero

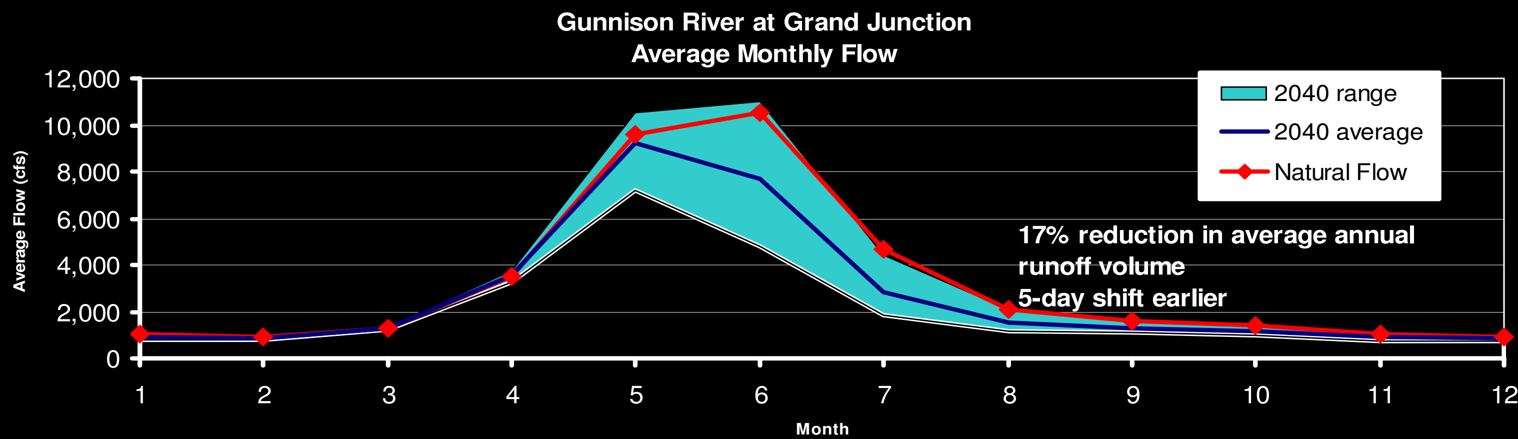
PRELIMINARY RESULTS—Not for citation.

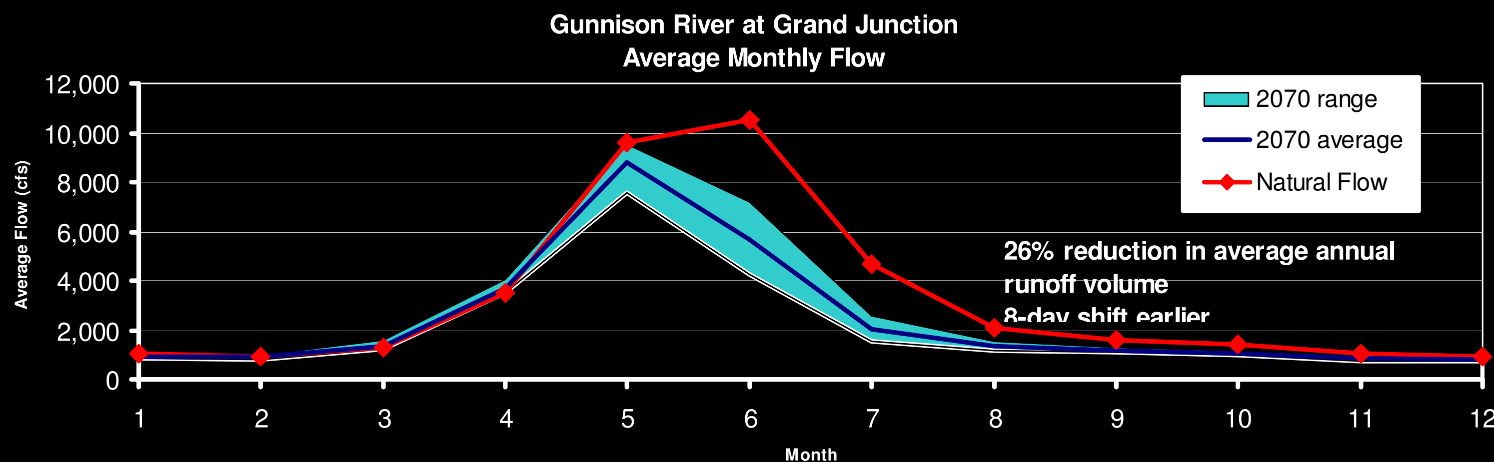




GCM Results – Gunnison – G. Junction

PRELIMINARY RESULTS—Not for citation.





GCM Results – Gunnison – Gunnison

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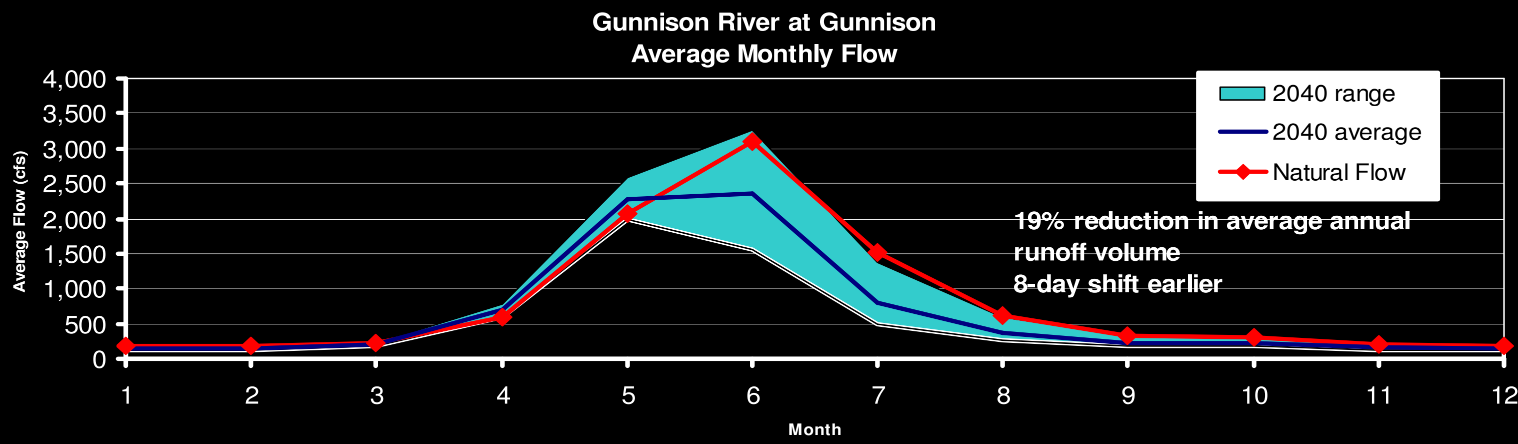

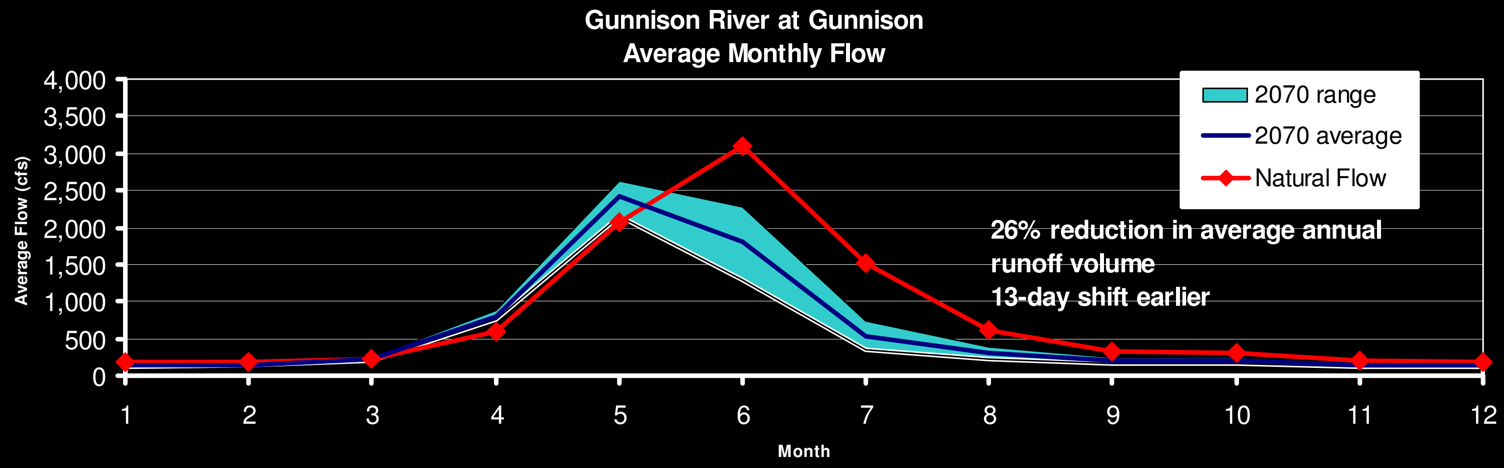

GCM Results – Yampa – Maybell

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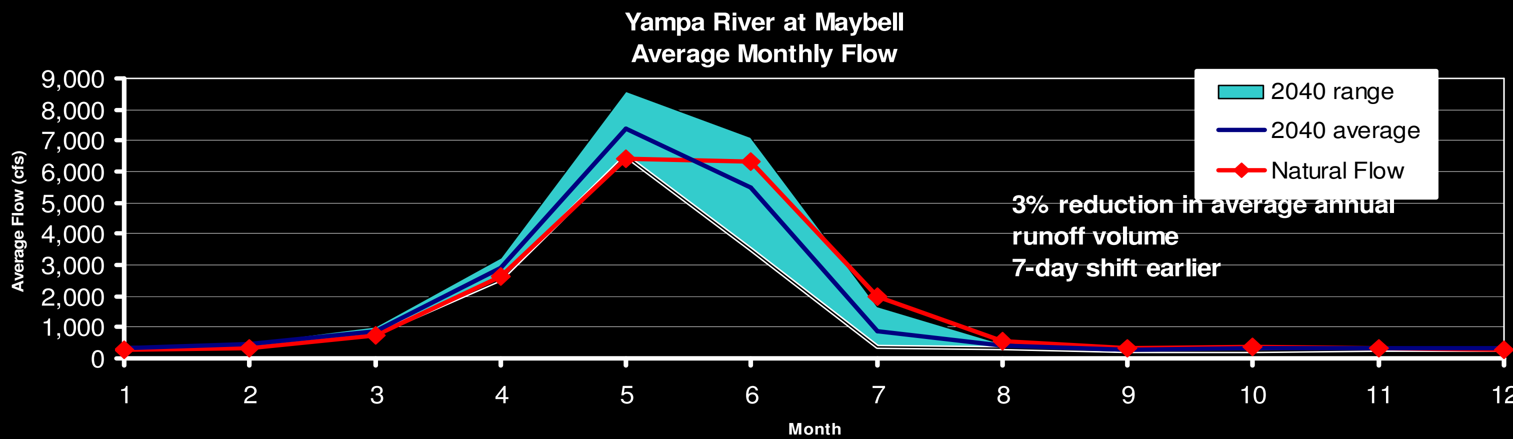
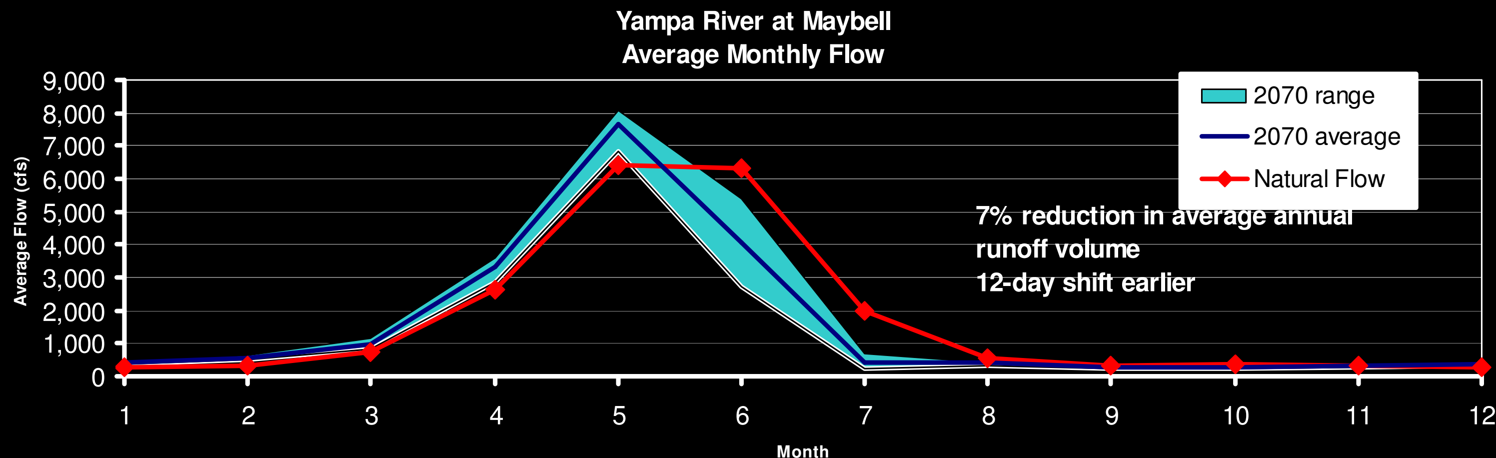
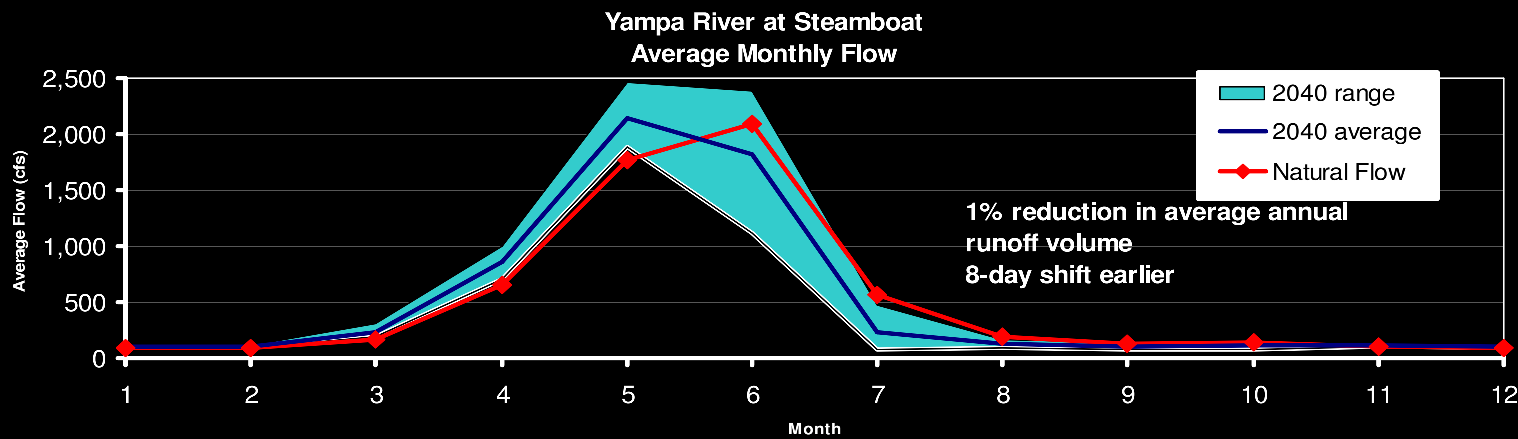
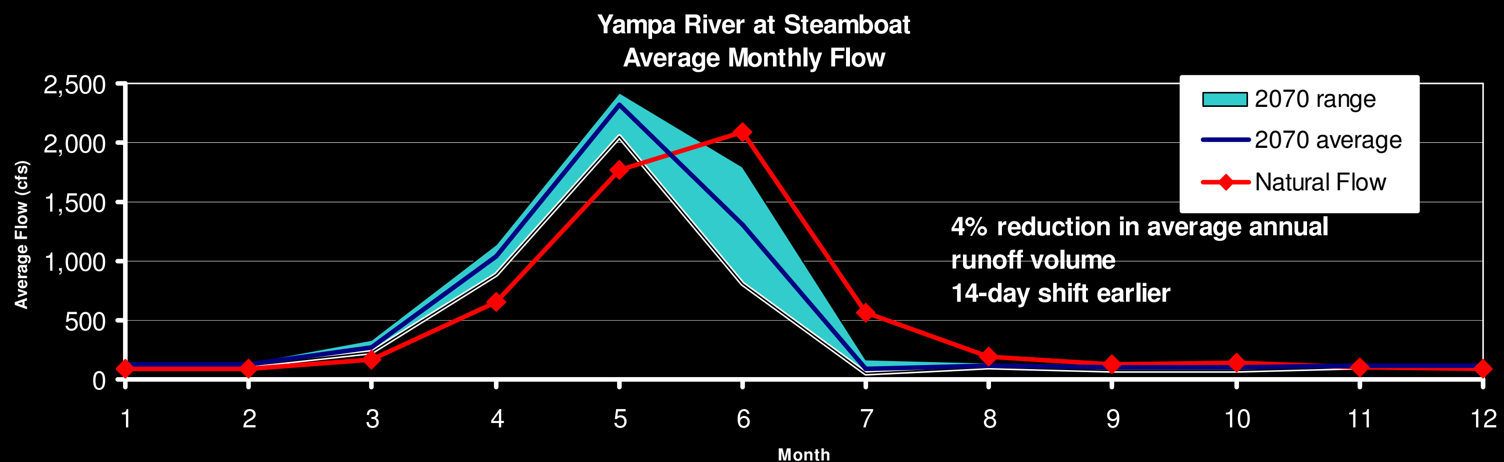




GCM Results – Yampa – Steamboat

PRELIMINARY RESULTS—Not for citation.





GCM Results – White – Meeker

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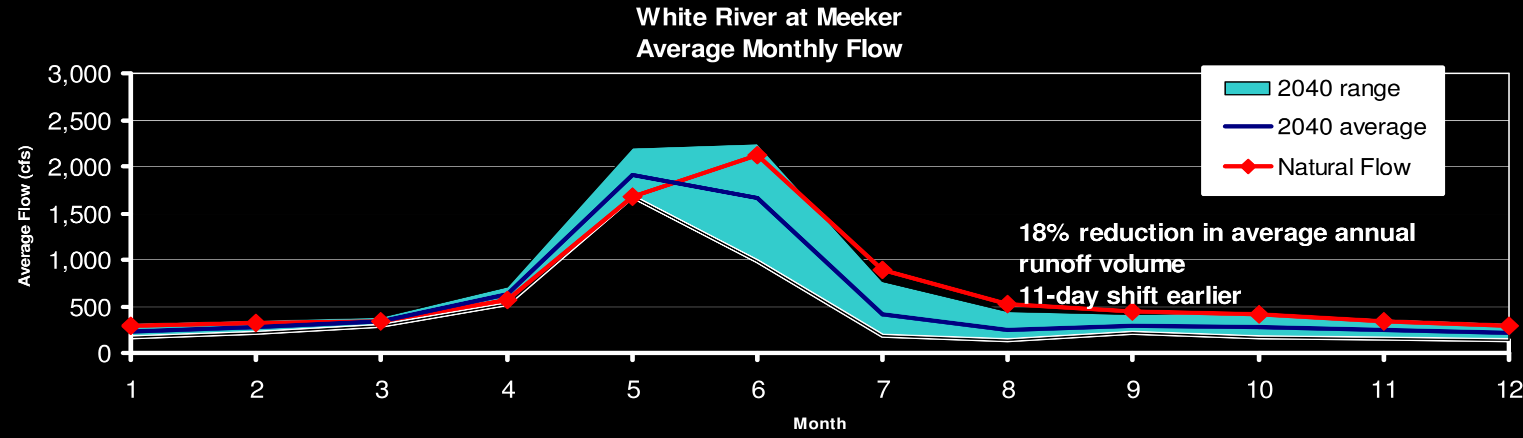
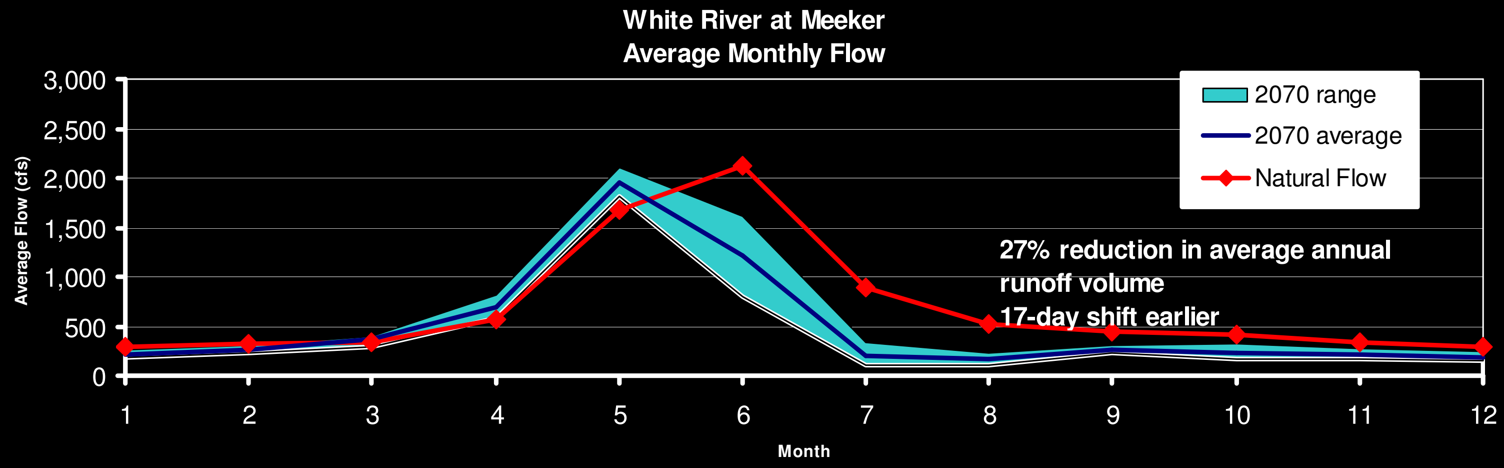
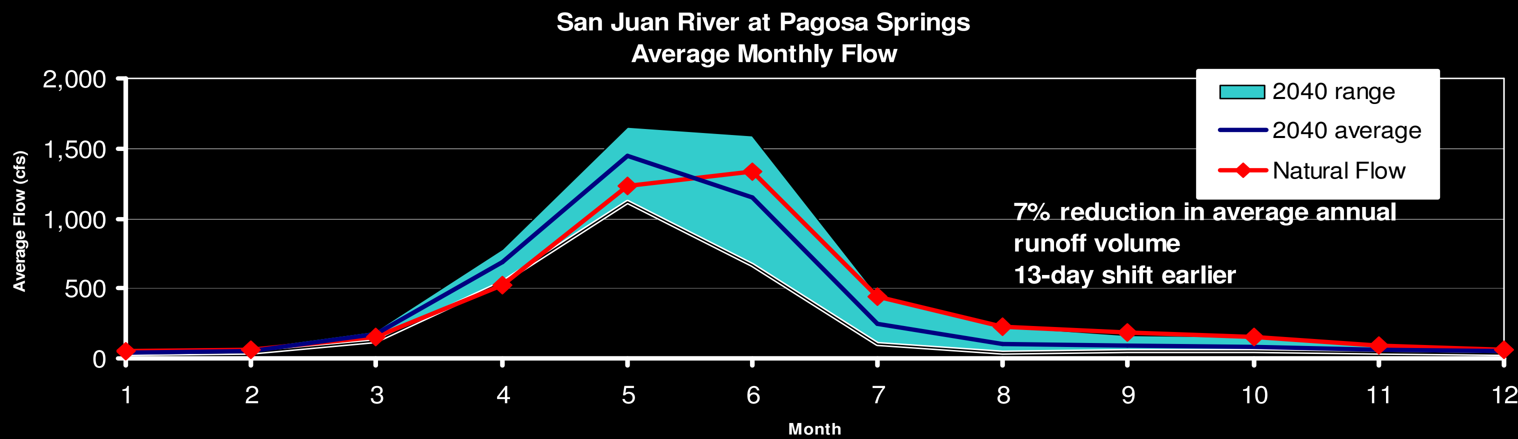
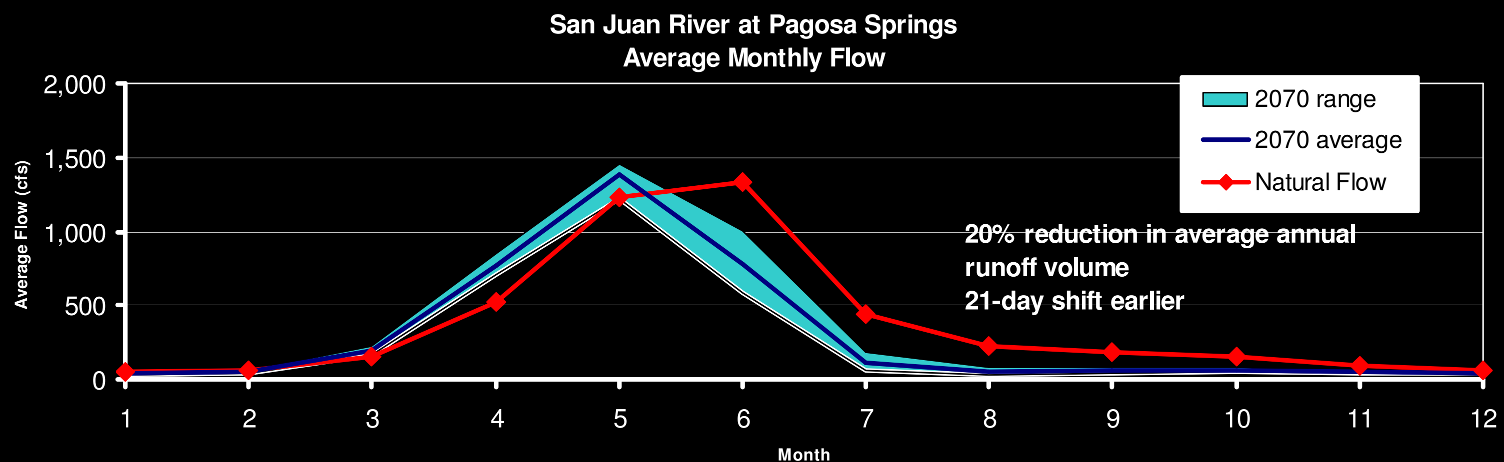




GCM Results – San Juan – Pagosa Springs

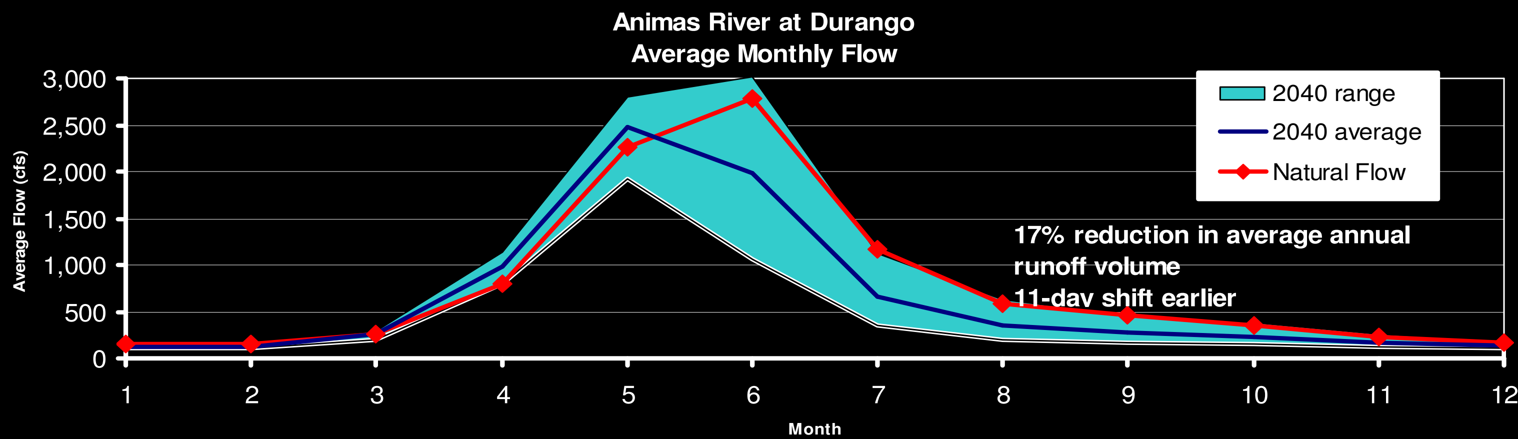
PRELIMINARY RESULTS—Not for citation.

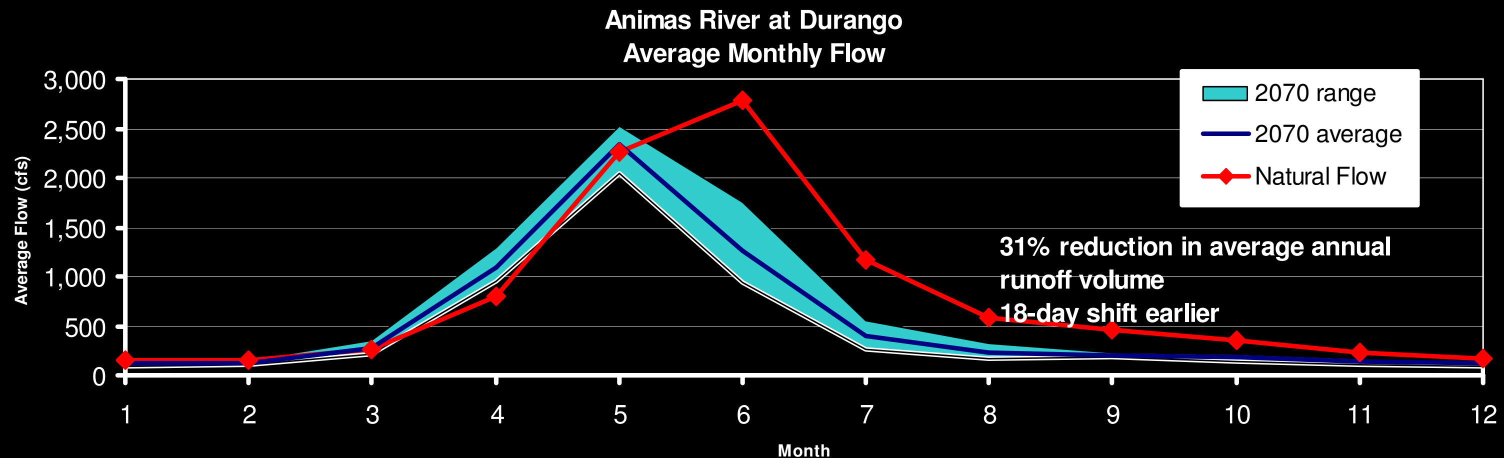




GCM Results – Animas – Durango

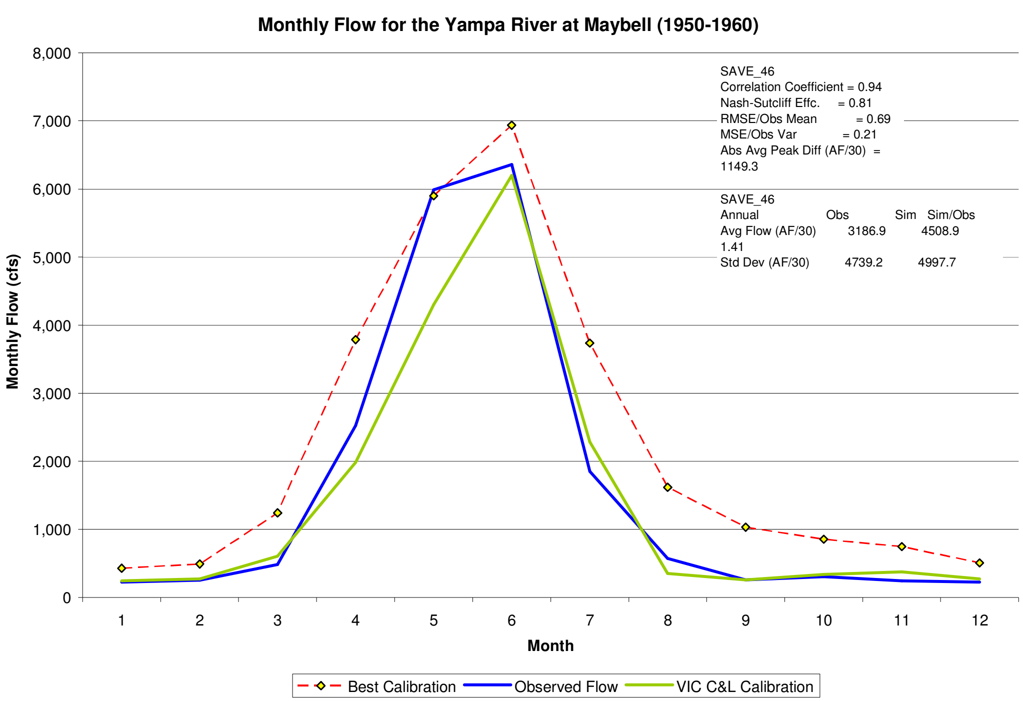
PRELIMINARY RESULTS—Not for citation.





Questions/Uncertainties

- Temperature adjustment
- Routing parameters
- Observed forcings
- MOCOM non-convergence



To-Do

- Wrap up calibration
- Develop REVIEW as-if hydrology
- Conduct review of as-if hydrology
- Re-sequence as-if hydrology to develop alternate hydrology of climate change
- Document methods and results