Colorado River Water Availability Study

Technical Outreach Workshops
September 22 and 23, 2009

Consulting Team

AECOM Water
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BOYLE | AECOM

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IBCC-Basin Roundtables

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Ben Harding	Paleo, Stochastic, and Big River hydrology / operations
Erin Wilson	CDSS applications
Meg Frantz	StateMod refinements / execution
Jim Pearce	Review - Water Management issues
Joel Smith	Guidance - Climate Change approaches

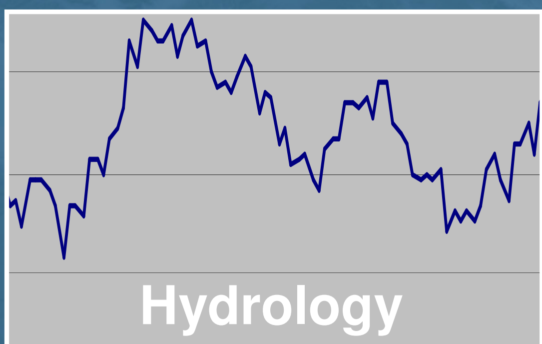
Agenda

- PRELIMINARY Results
  - Drought Frequency
  - Hydrologic impact of projected climate
  - Climate change impacts on current Consumptive Use
- Details of Technical Approaches
- Discussion (throughout)

Phases

- 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 demands

Hydrology → Water Availability



CDSS Models
in-state & CRSS for "Big River" ops

Results for Decision Makers

- ***Water Availability***
- ***Reservoir Conditions***
- ***Instream Flows***

Three Part Hydrologic Assessment Process

1) **Historical Hydrology**

- For comparative analysis
- 1950's forward (most reliable data)

2) **Alternate Historical: Paleohydrology** | **Extend Records with Tree-Rings & Stochastic Methods**

3) **Climate Change and Forest Change**

Colorado River at Dotsero

Observed Maximum Length of Drought (years)	6
Paleo Average Maximum Length of Drought (years)	6.3
Paleo Worst-case Maximum Length of Drought (years)	13

Colorado River at Cameo

Observed Maximum Length of Drought (years)	6
Paleo Average Maximum Length of Drought (years)	6.6
Paleo Worst-case Maximum Length of Drought (years)	12

Gunnison River at Gunnison

Observed Maximum Length of Drought (years)	5
Paleo Average Maximum Length of Drought (years)	6.8
Paleo Worst-case Maximum Length of Drought (years)	15

Gunnison River at Grand Junction

Observed Maximum Length of Drought (years)	5
Paleo Average Maximum Length of Drought (years)	6.7
Paleo Worst-case Maximum Length of Drought (years)	15

Yampa River at Steamboat Springs

Observed Maximum Length of Drought (years)	6
Paleo Average Maximum Length of Drought (years)	6.0
Paleo Worst-case Maximum Length of Drought (years)	12

Yampa River at Maybell

Observed Maximum Length of Drought (years)	6
Paleo Average Maximum Length of Drought (years)	6.2
Paleo Worst-case Maximum Length of Drought (years)	14

White River at Meeker

Observed Maximum Length of Drought (years)	6
Paleo Average Maximum Length of Drought (years)	7.0
Paleo Worst-case Maximum Length of Drought (years)	15

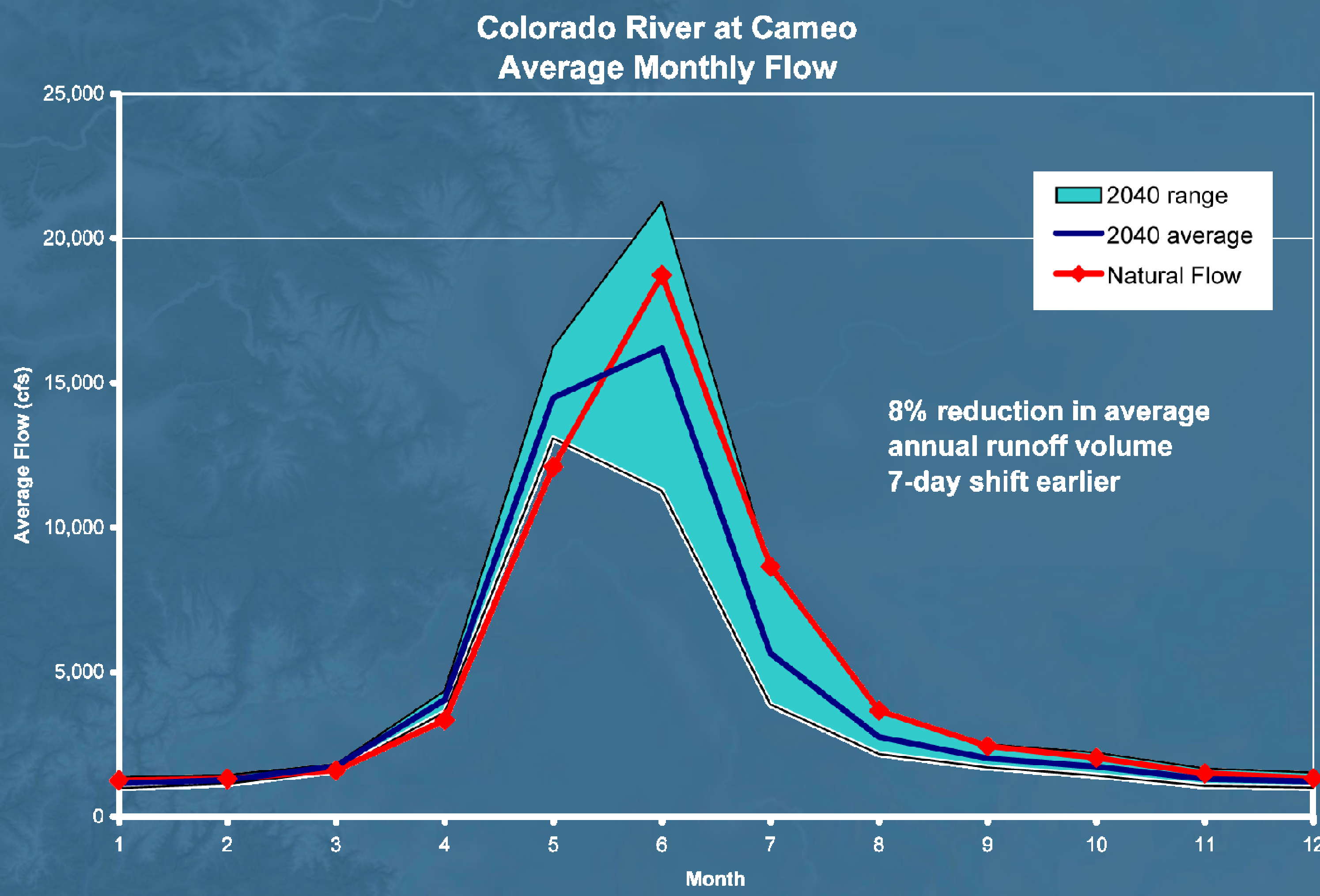
San Juan River at Pagosa Springs

Observed Maximum Length of Drought (years)	4
Paleo Average Maximum Length of Drought (years)	5.1
Paleo Worst-case Maximum Length of Drought (years)	11

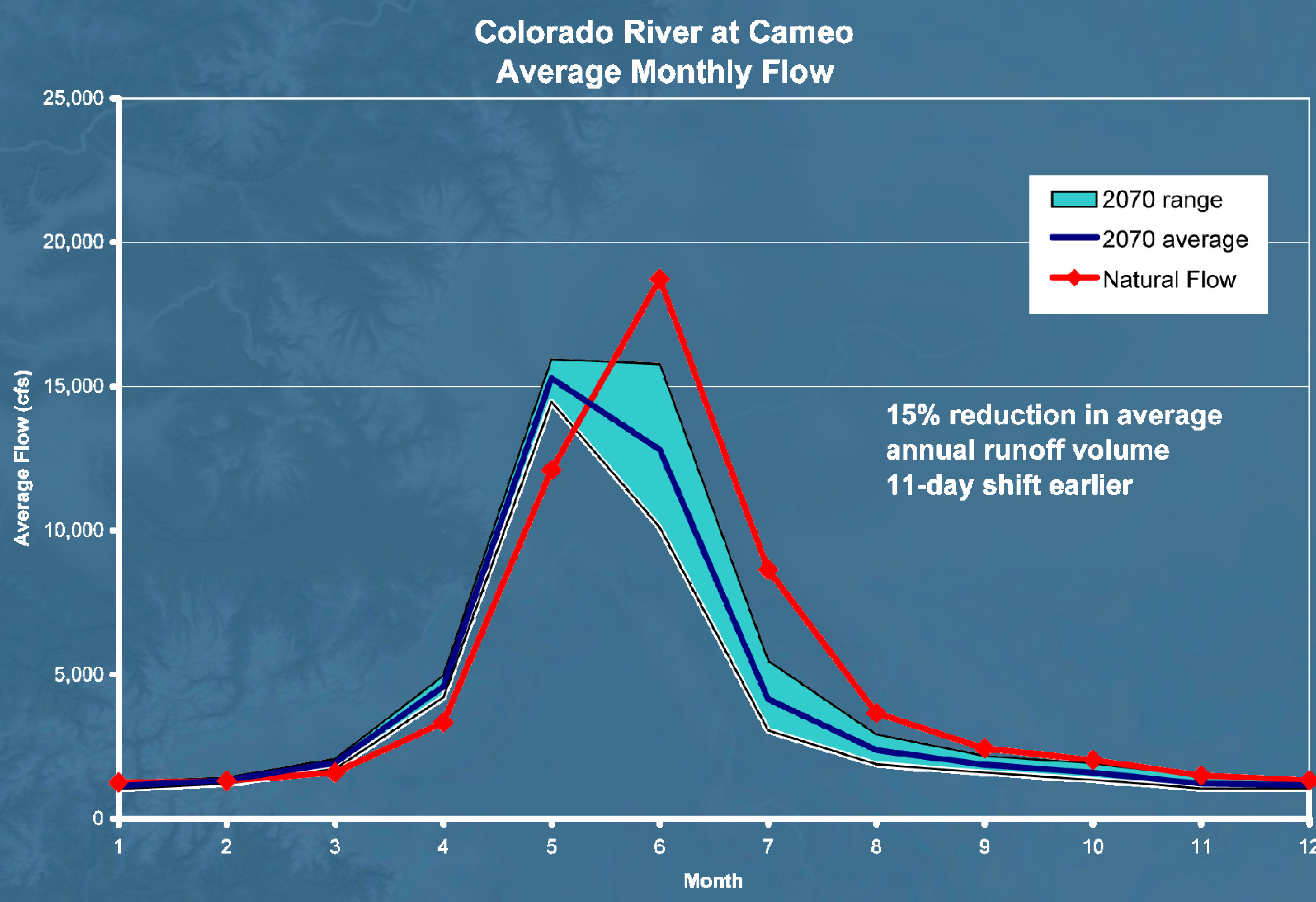
Animas River at Durango

Observed Maximum Length of Drought (years)	5
Paleo Average Maximum Length of Drought (years)	6.1
Paleo Worst-case Maximum Length of Drought (years)	14

GCM Results – Cameo 2040

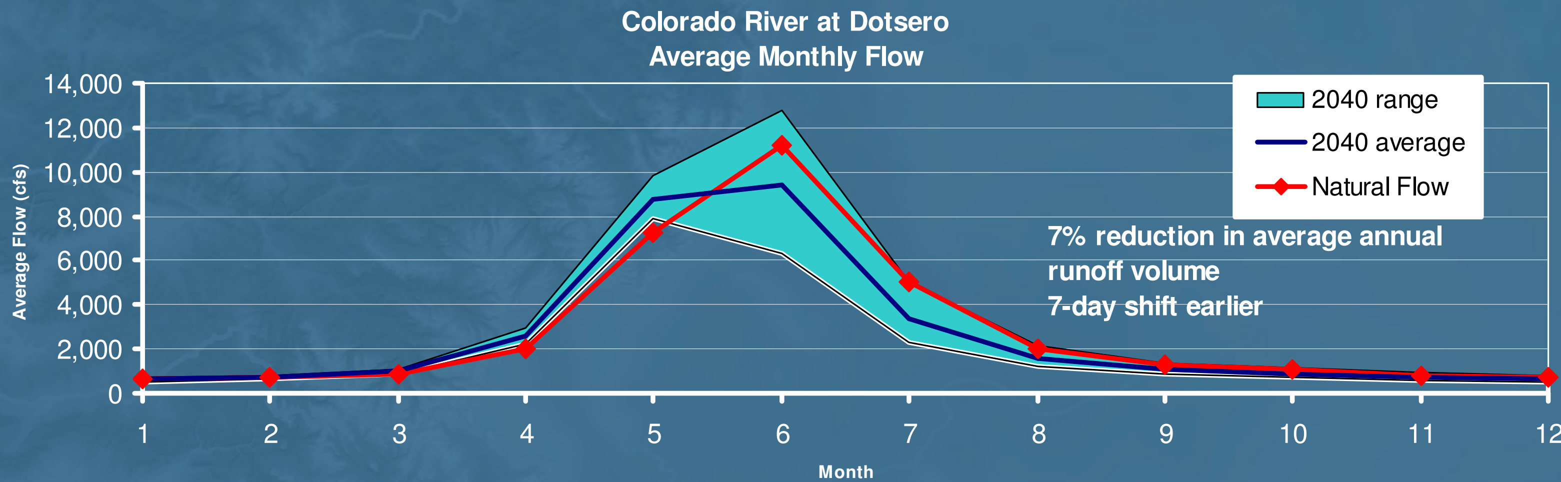


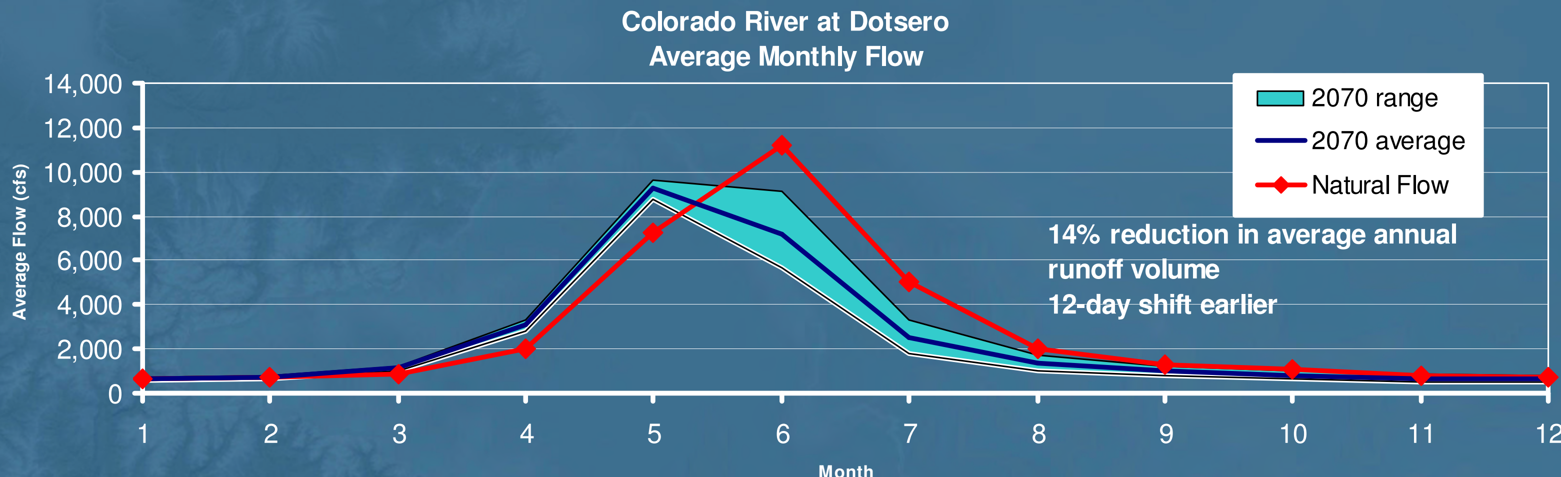
GCM Results – Cameo 2070



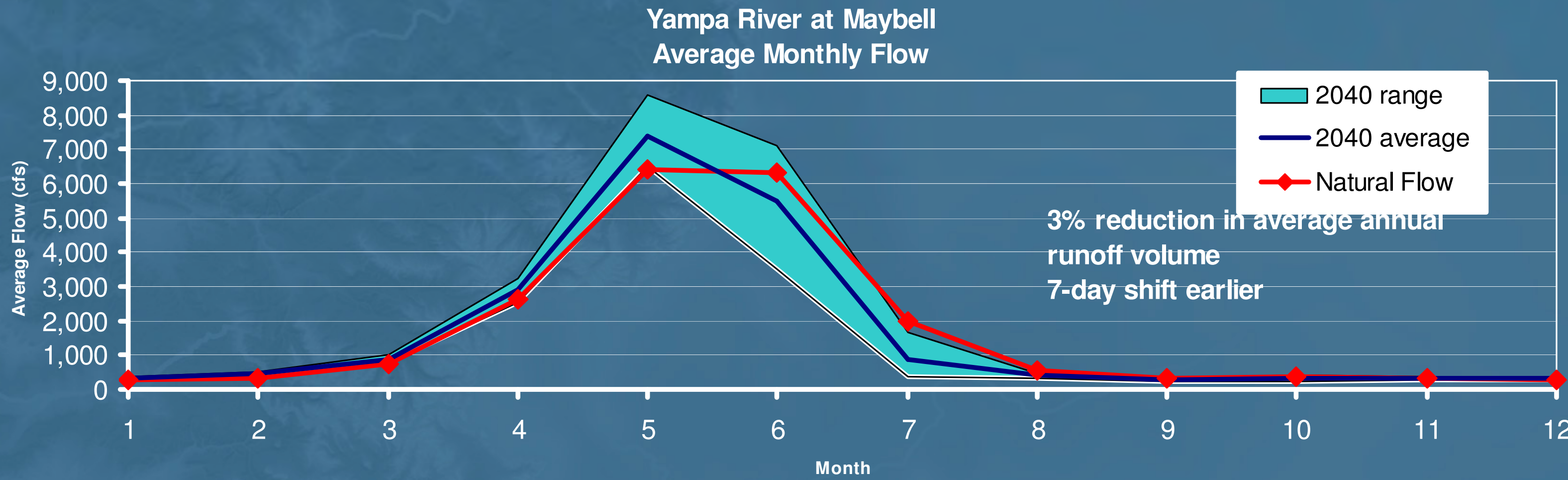
PRELIMINARY RESULTS – UNDER REVIEW

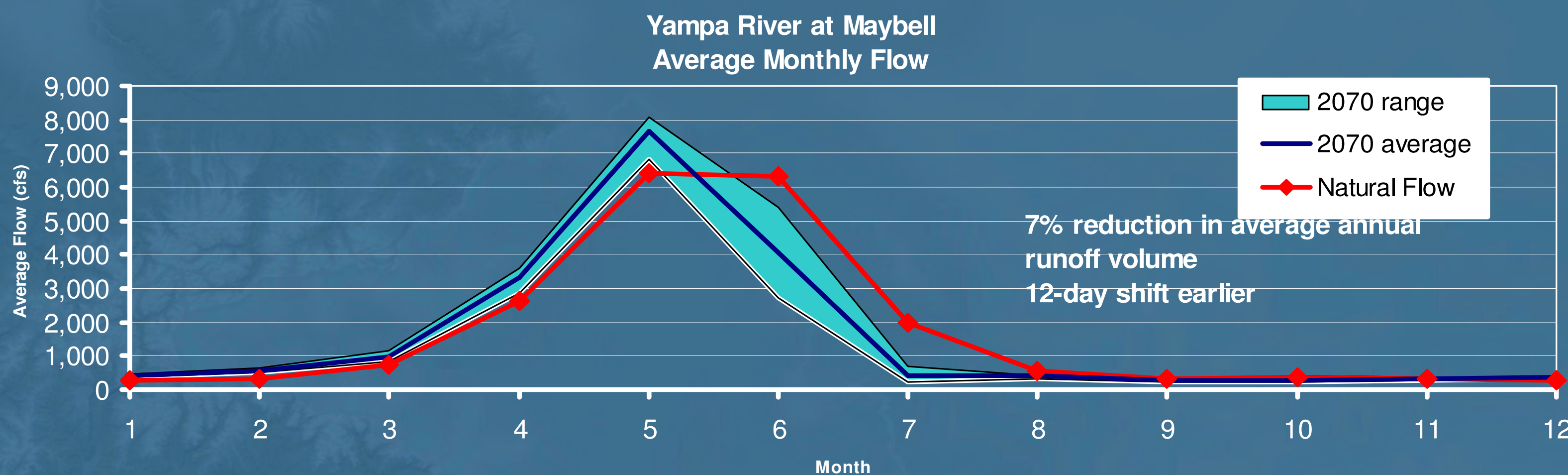
GCM Results – Colorado – Dotsero



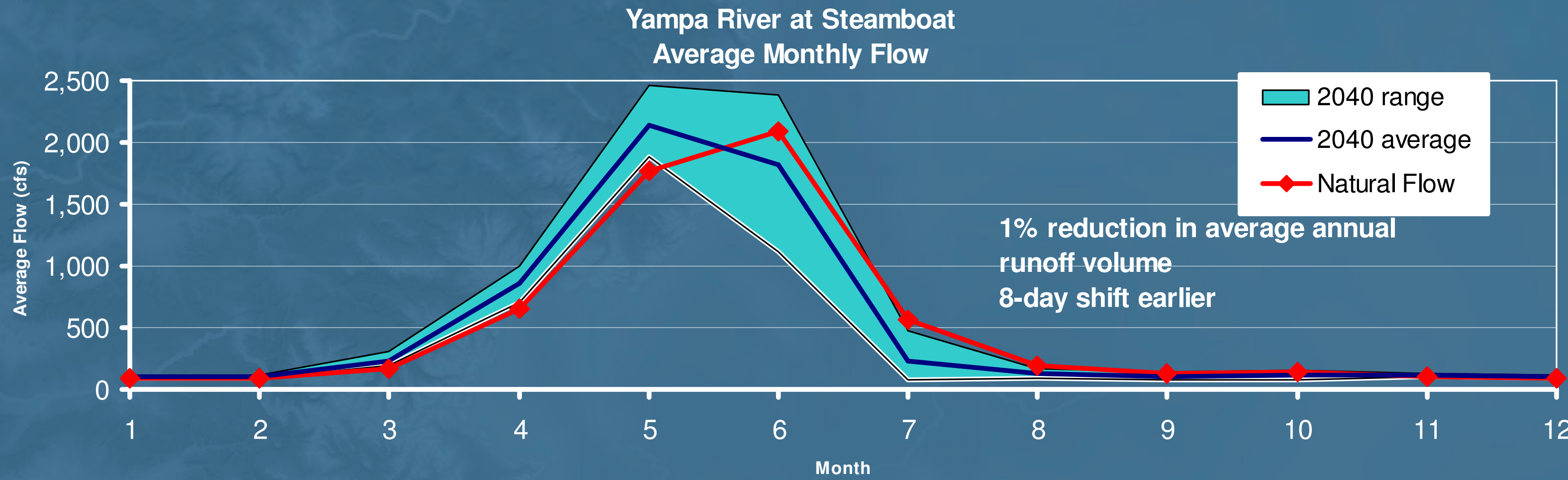


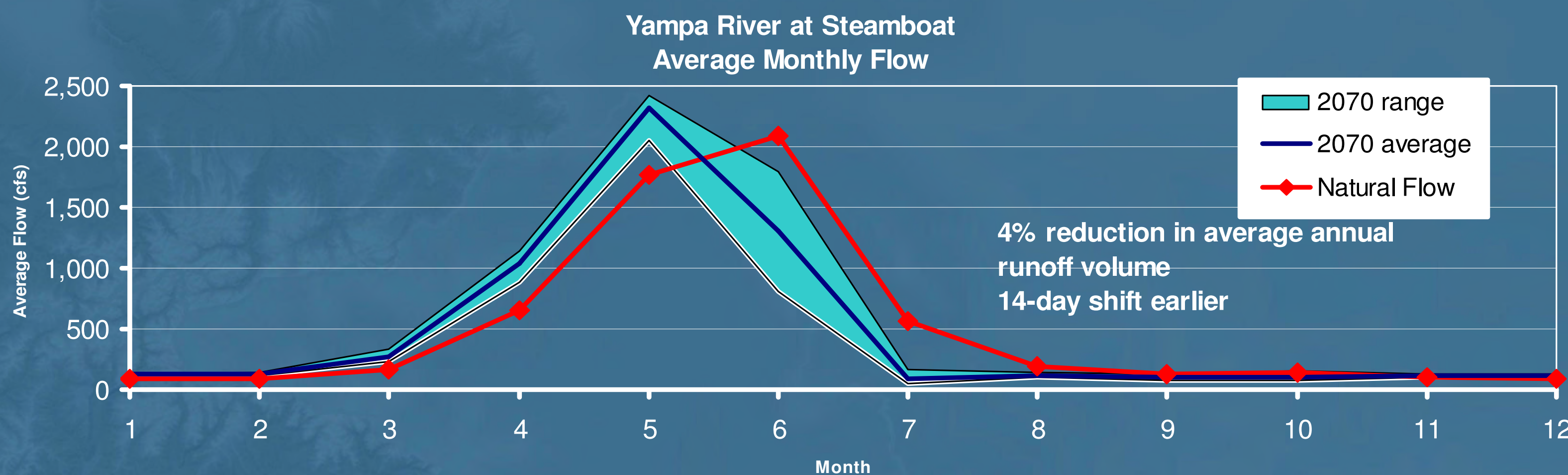
GCM Results – Yampa – Maybell



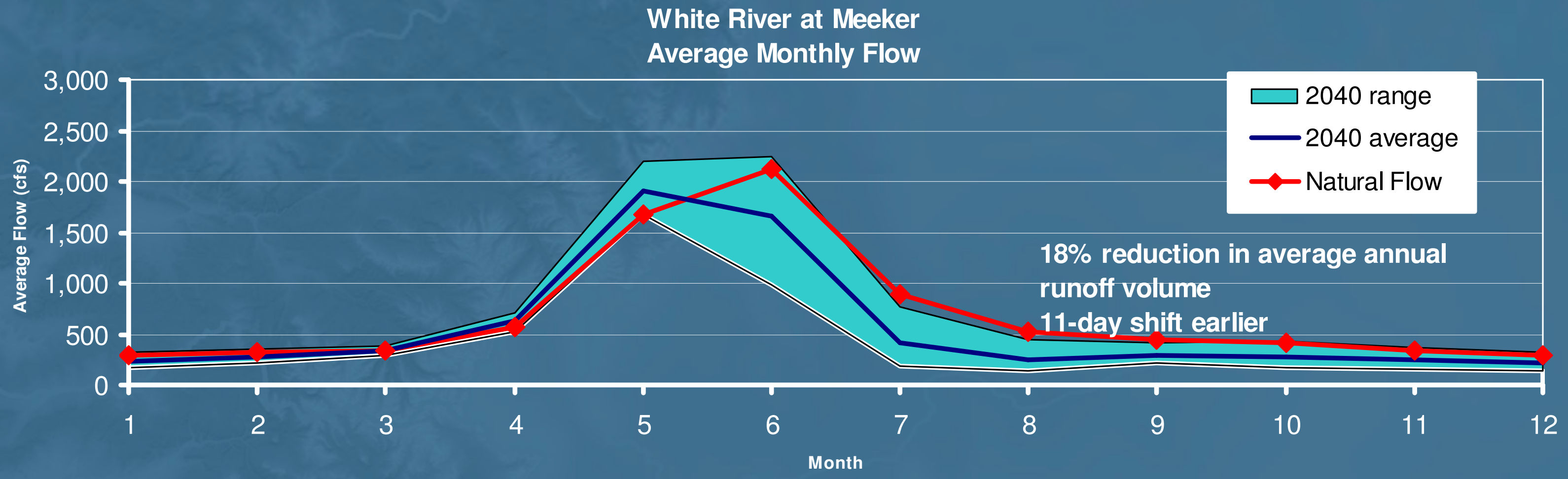


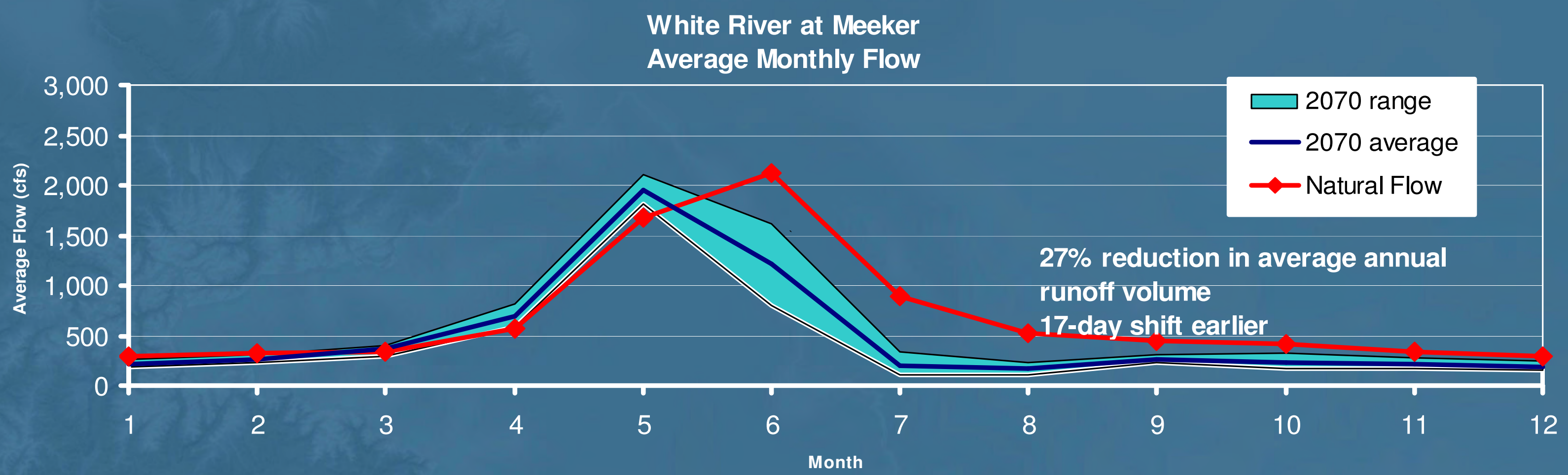
GCM Results – Yampa – Steamboat



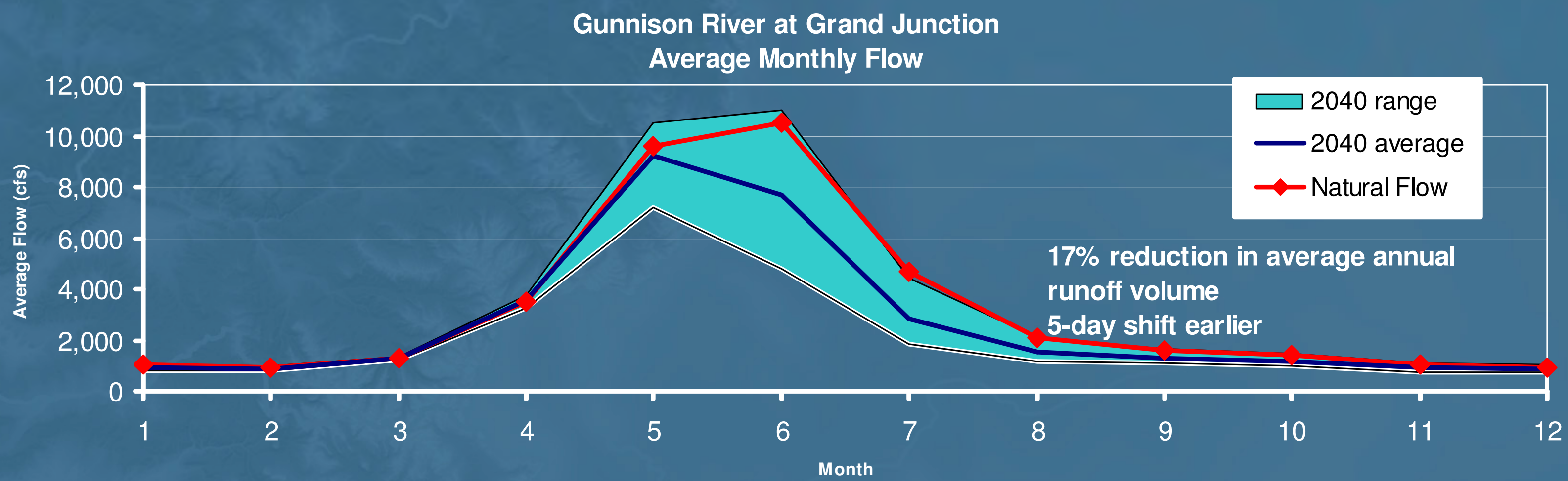


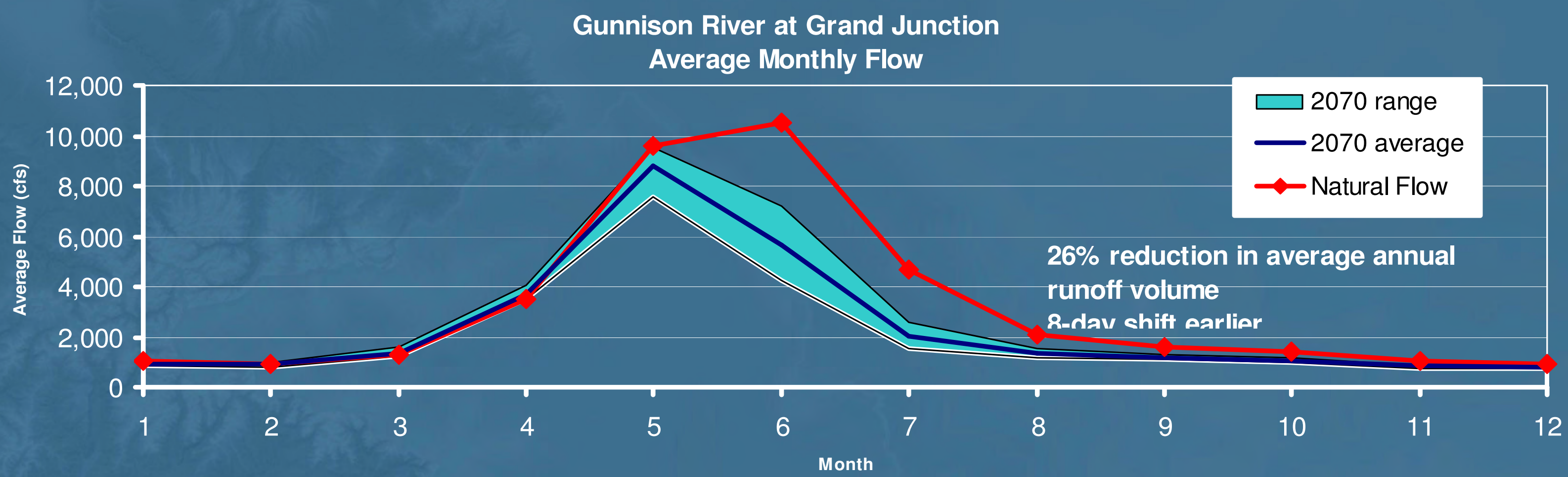
GCM Results – White – Meeker



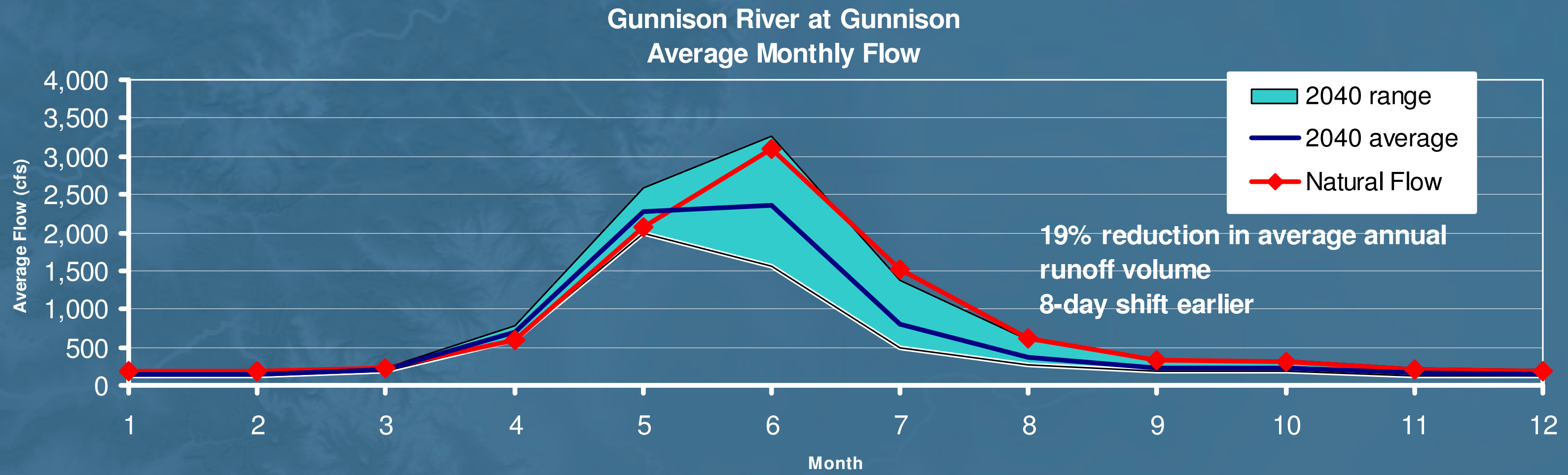


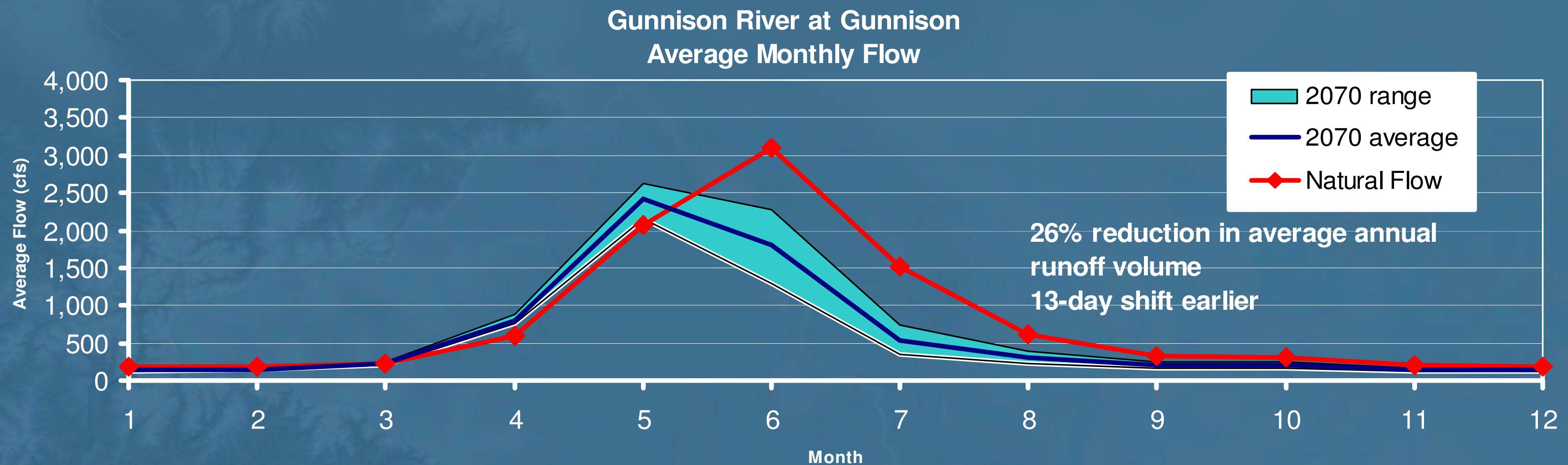
GCM Results – Gunnison – G. Junction



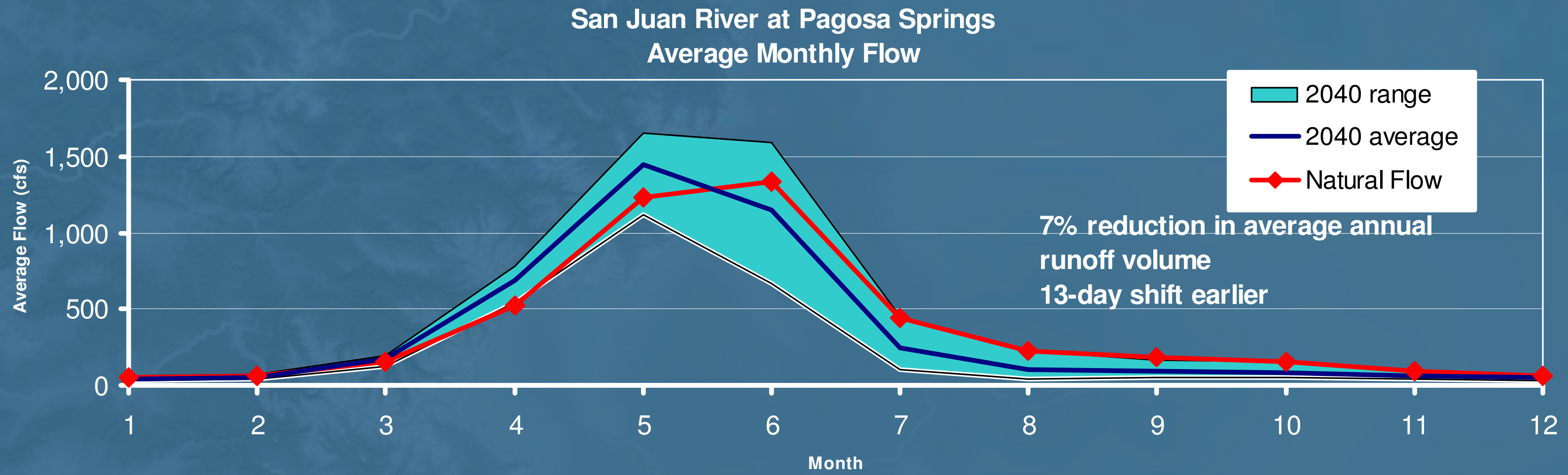


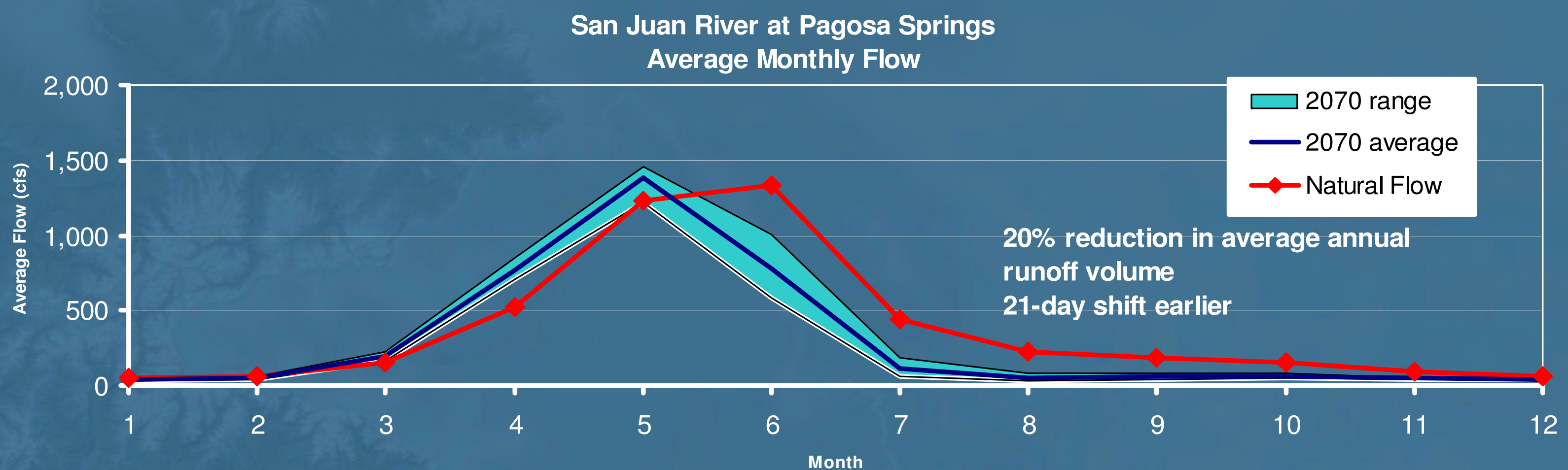
GCM Results – Gunnison – Gunnison



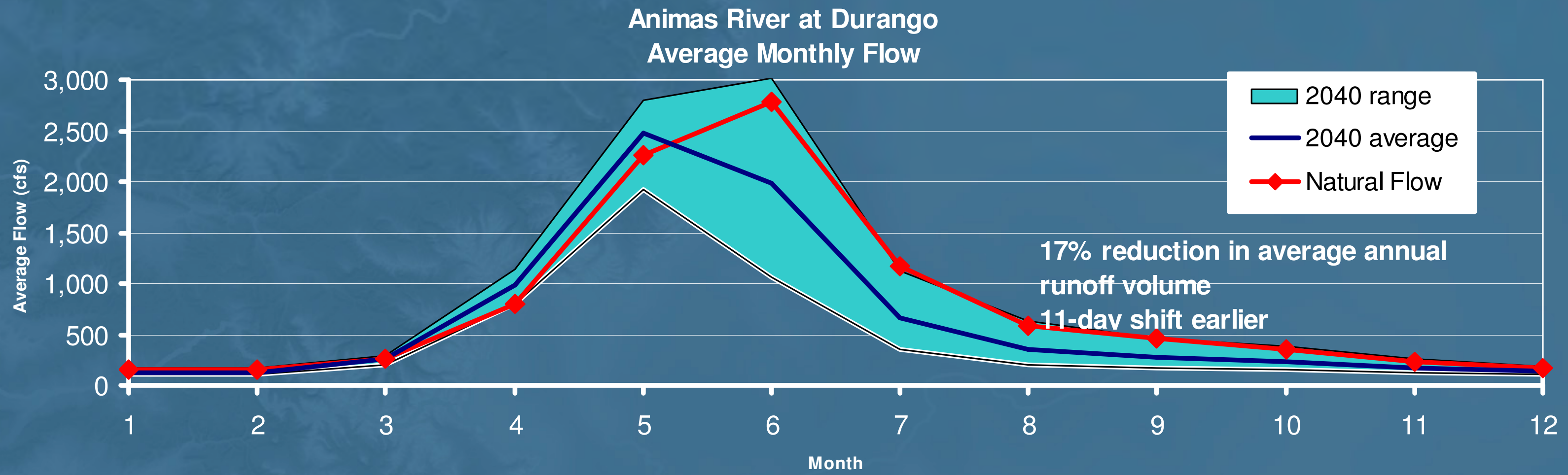


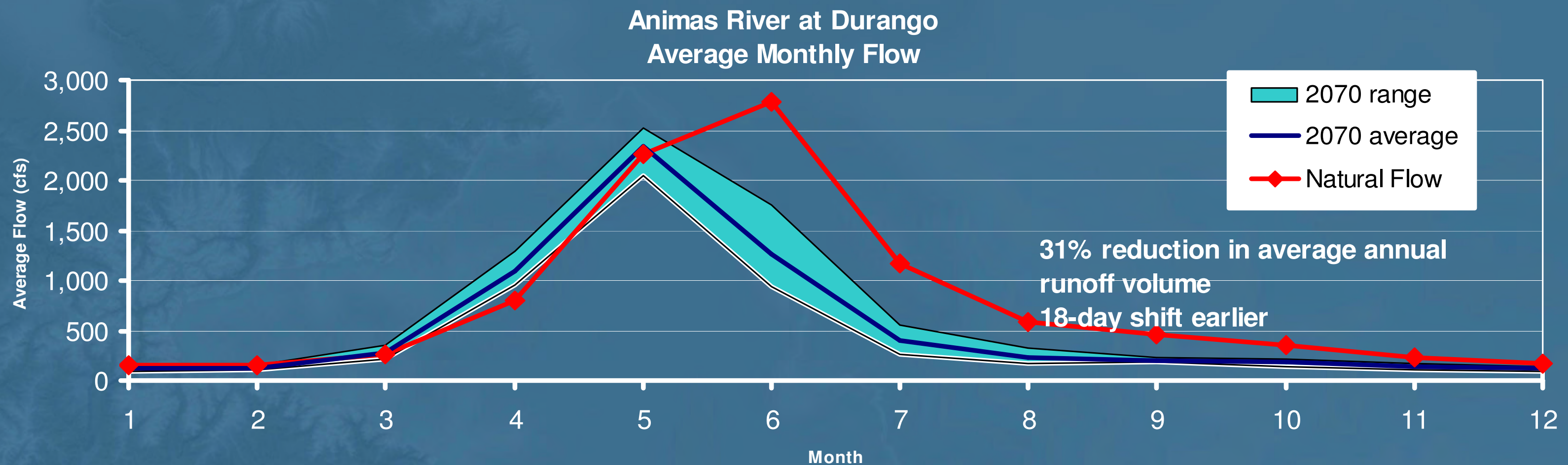
GCM Results – San Juan – Pagosa Springs



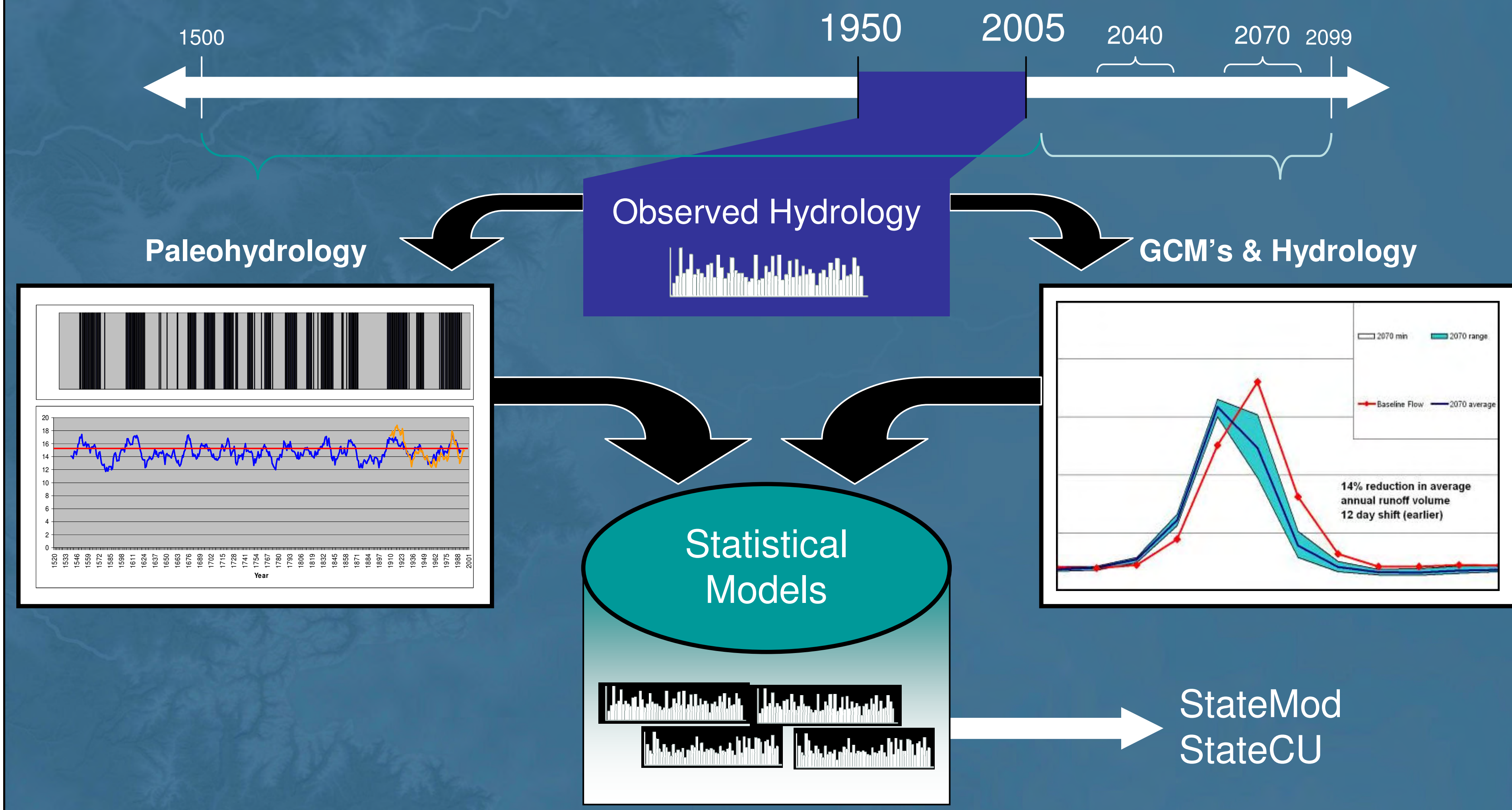


GCM Results – Animas – Durango





Overall Hydrology Approach

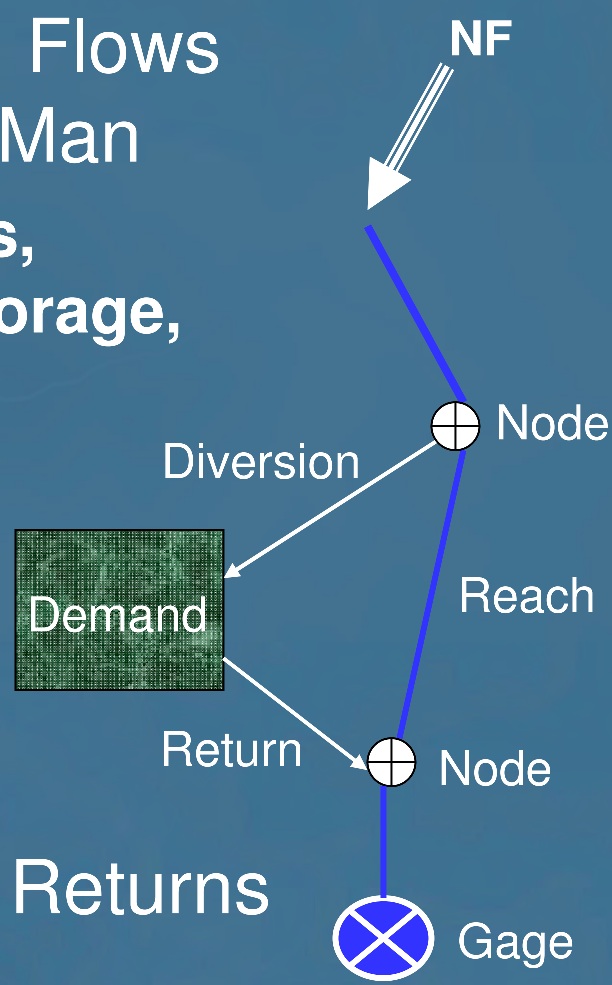


Observed Hydrology

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

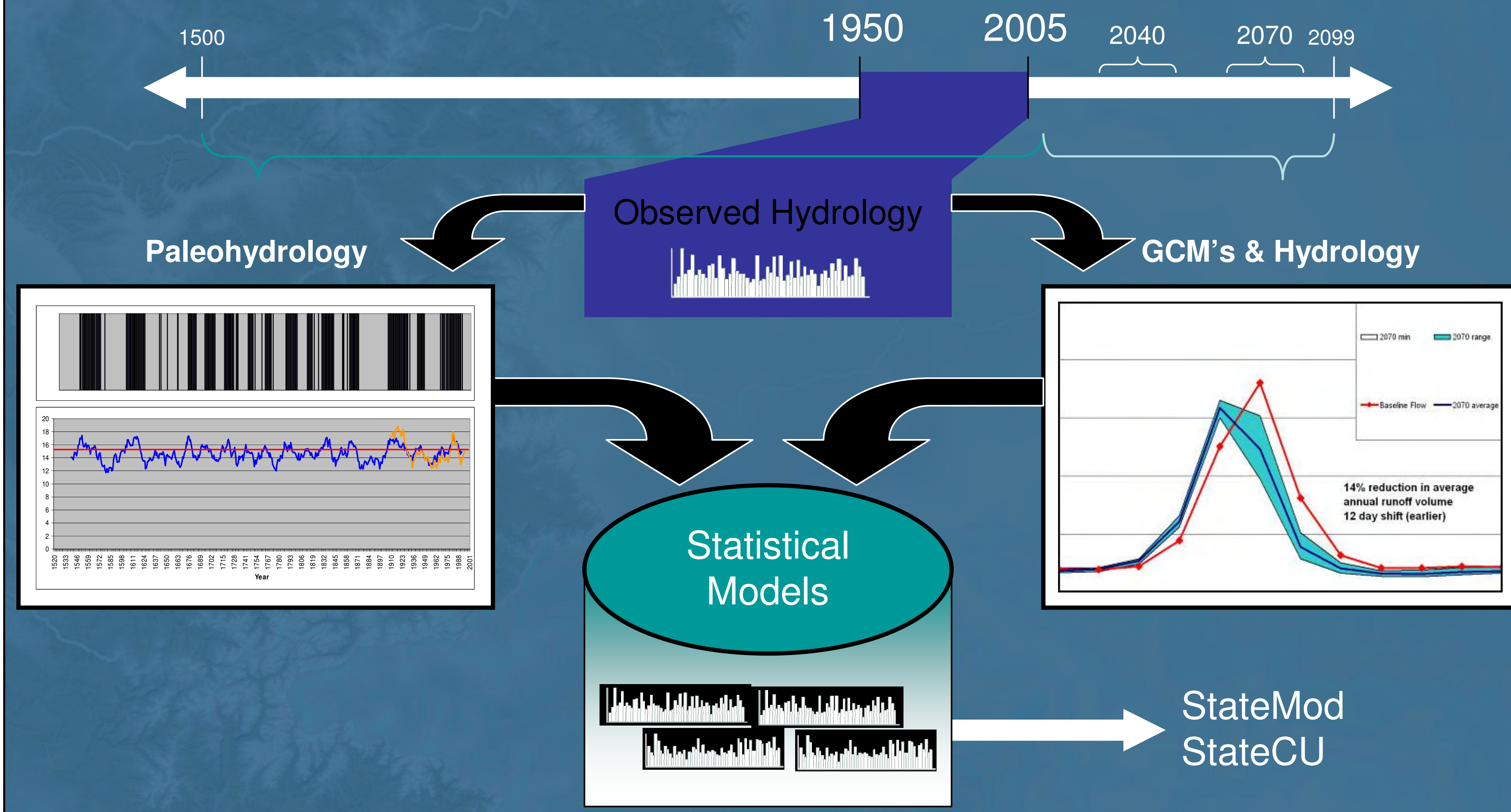
Observed Hydrology – Natural Flow Development

- StateMod estimates Natural Flows by Removing the Effects of Man
  - **Diversions, Return Flows, Changes in Reservoir Storage, Evaporation**

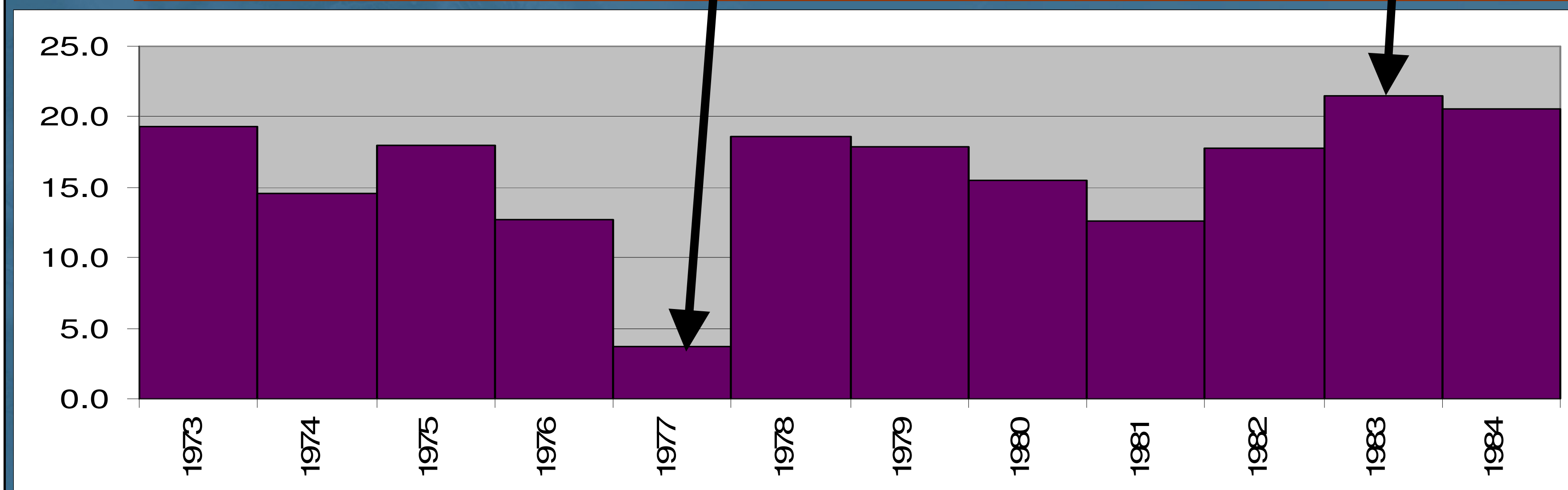


- NF = Gaged + Diversions – Returns +/- change in storage

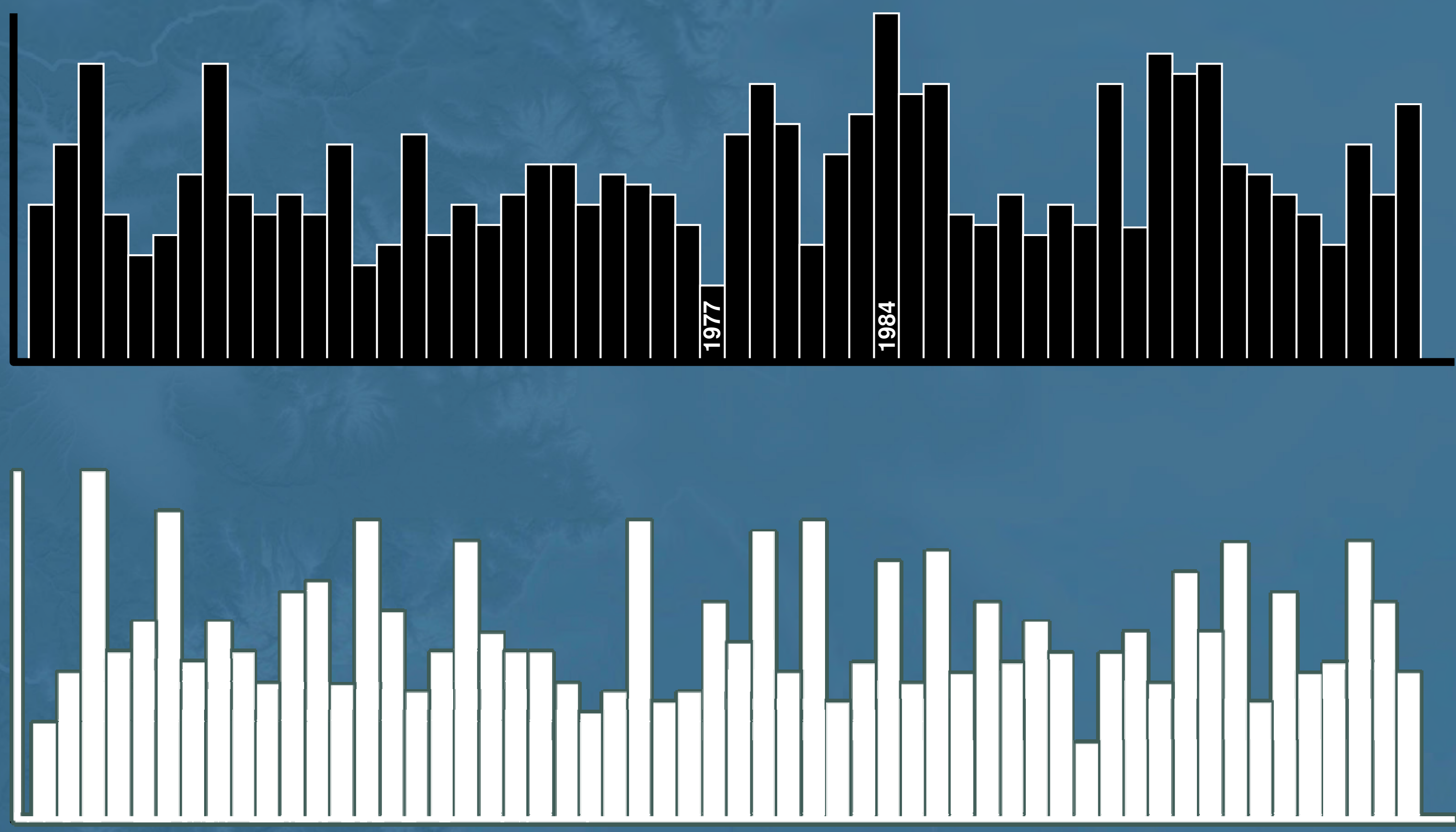
Overall Hydrology Approach



Paleohydrology – Tree Ring Data



Resequencing – Alternate Historical Hydrology

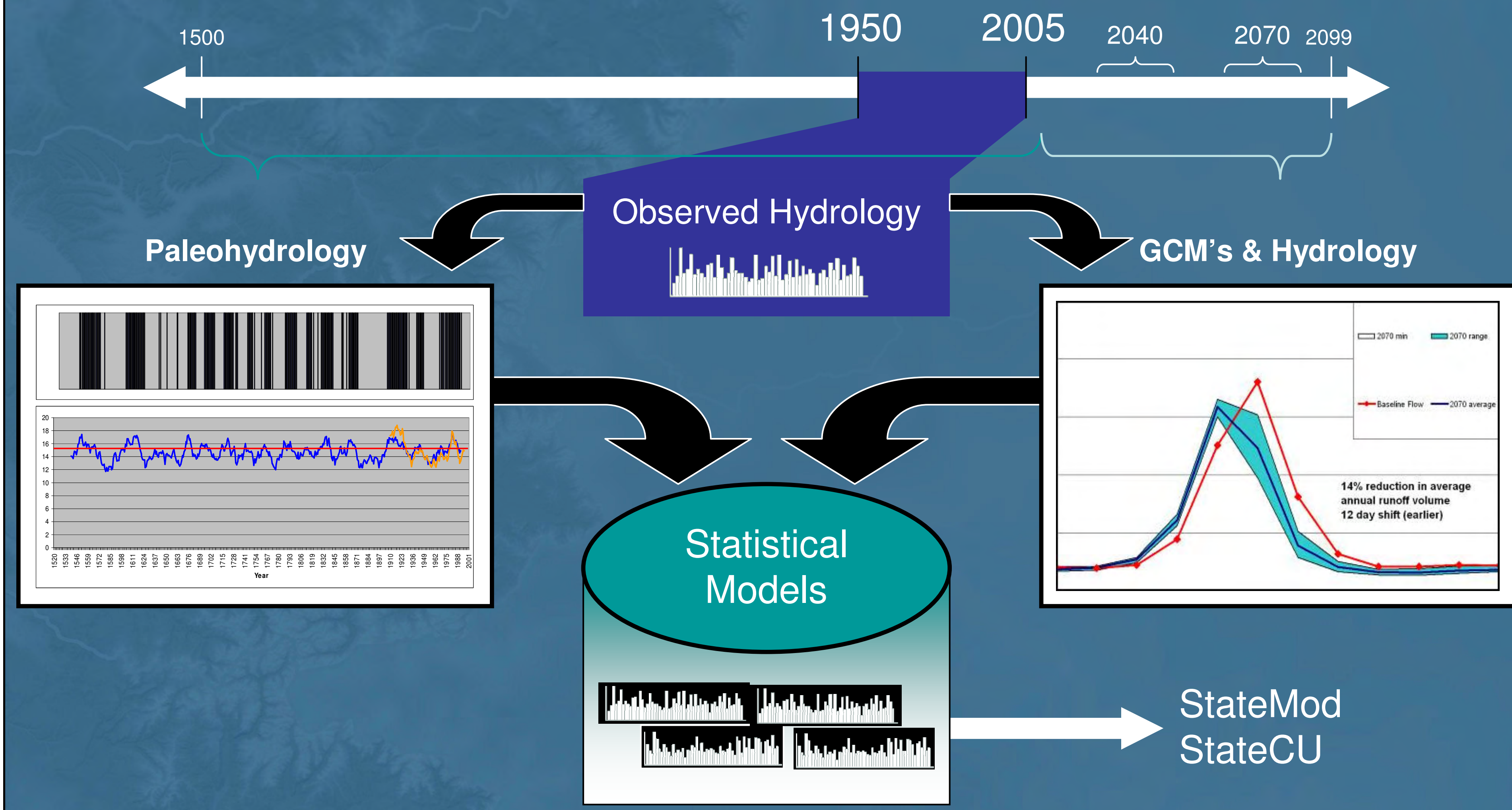


1.

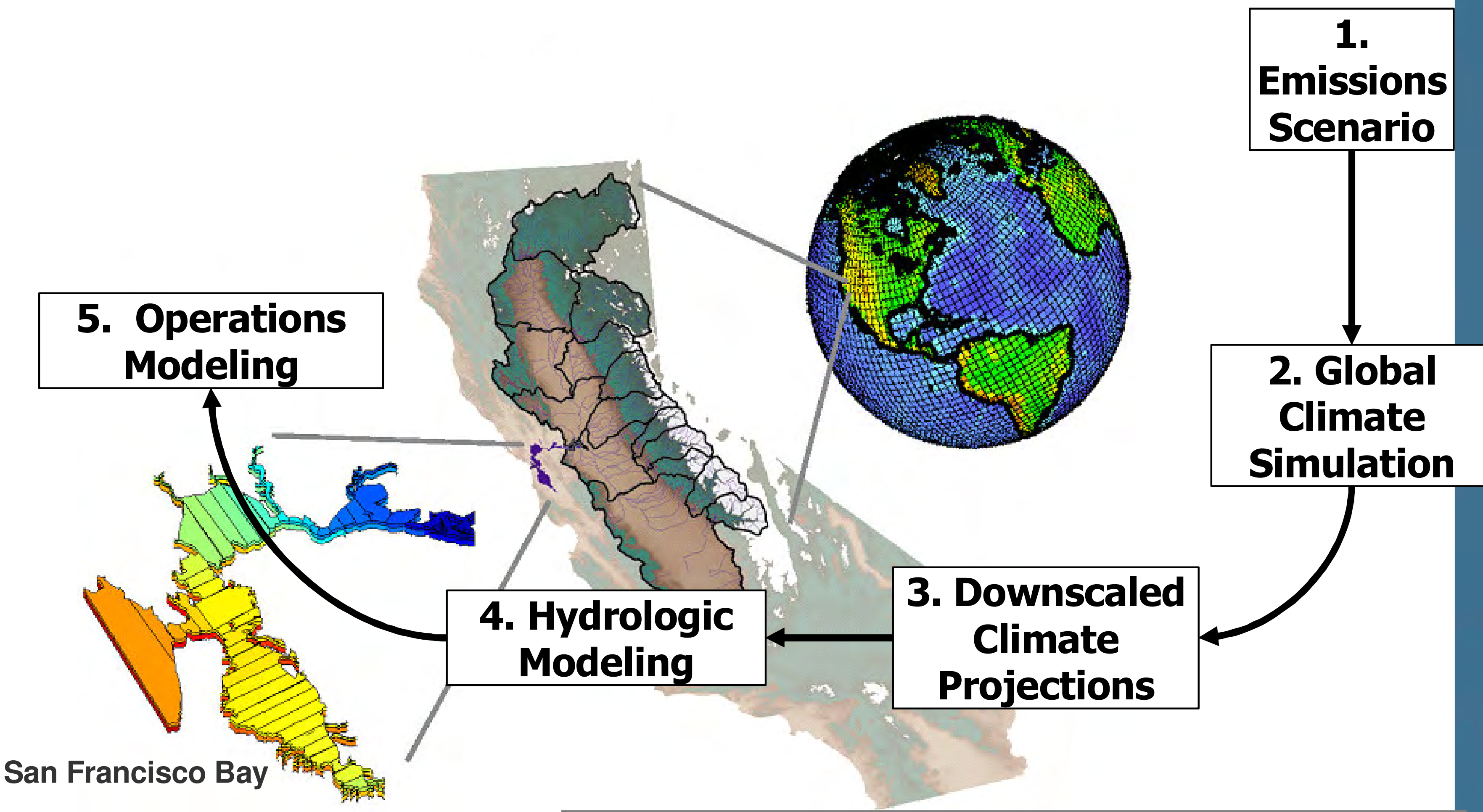
...

Repeat 100x

Overall Hydrology Approach



Quantifying Future Water Availability



Adapted from Cayan and Knowles, SCRIPPS/USGS, 2003

Climate Change & Down - Scaling

Earth

- Emissions Scenarios
- Global Climate Models

Result: *Altered Temperature and Precipitation*

Colorado River Basin

- "Down-Scaled" Projections
- Revised Basin-Wide Hydrology

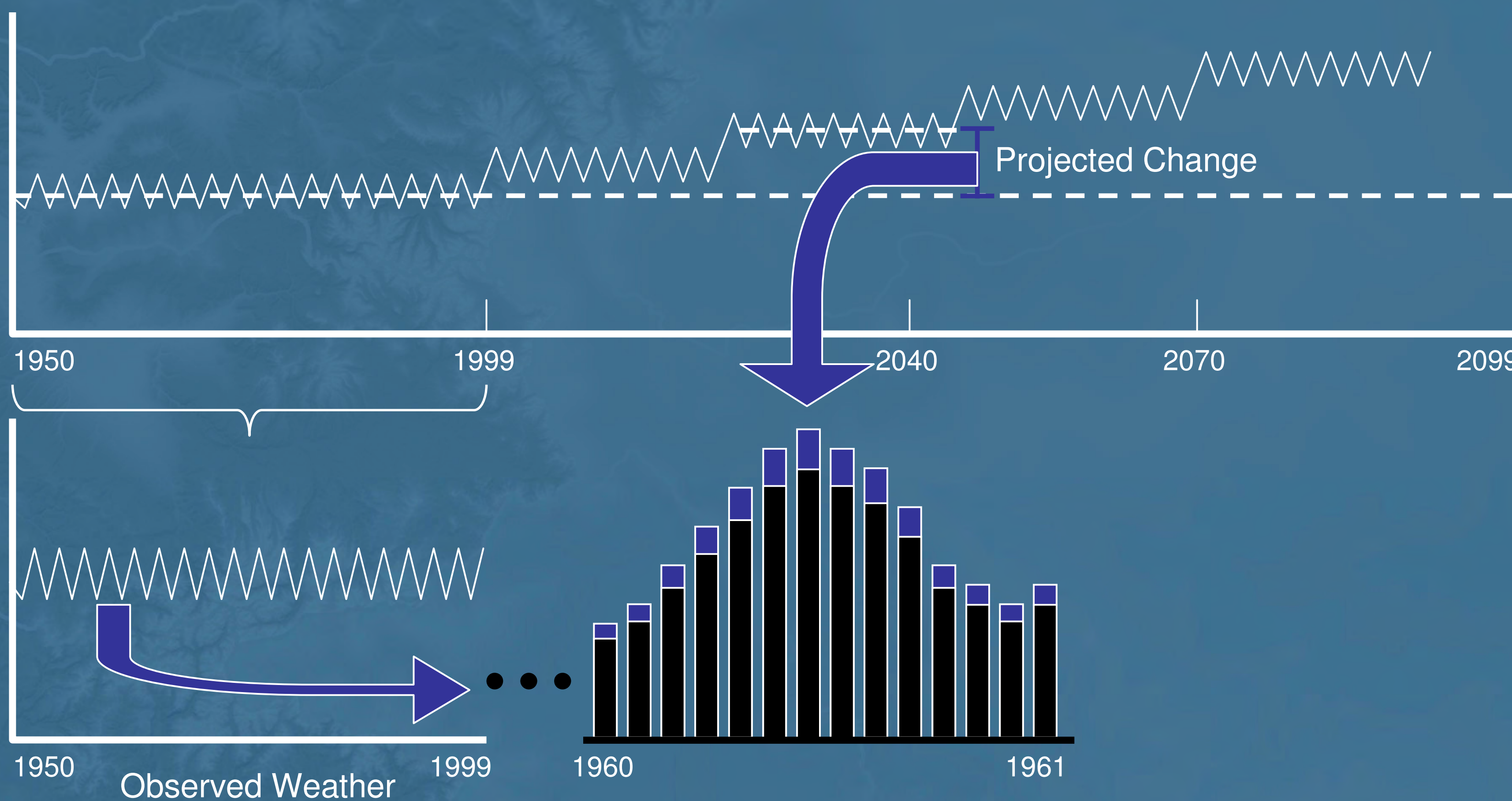
Result: *Altered Stream Flows*

State of Colorado

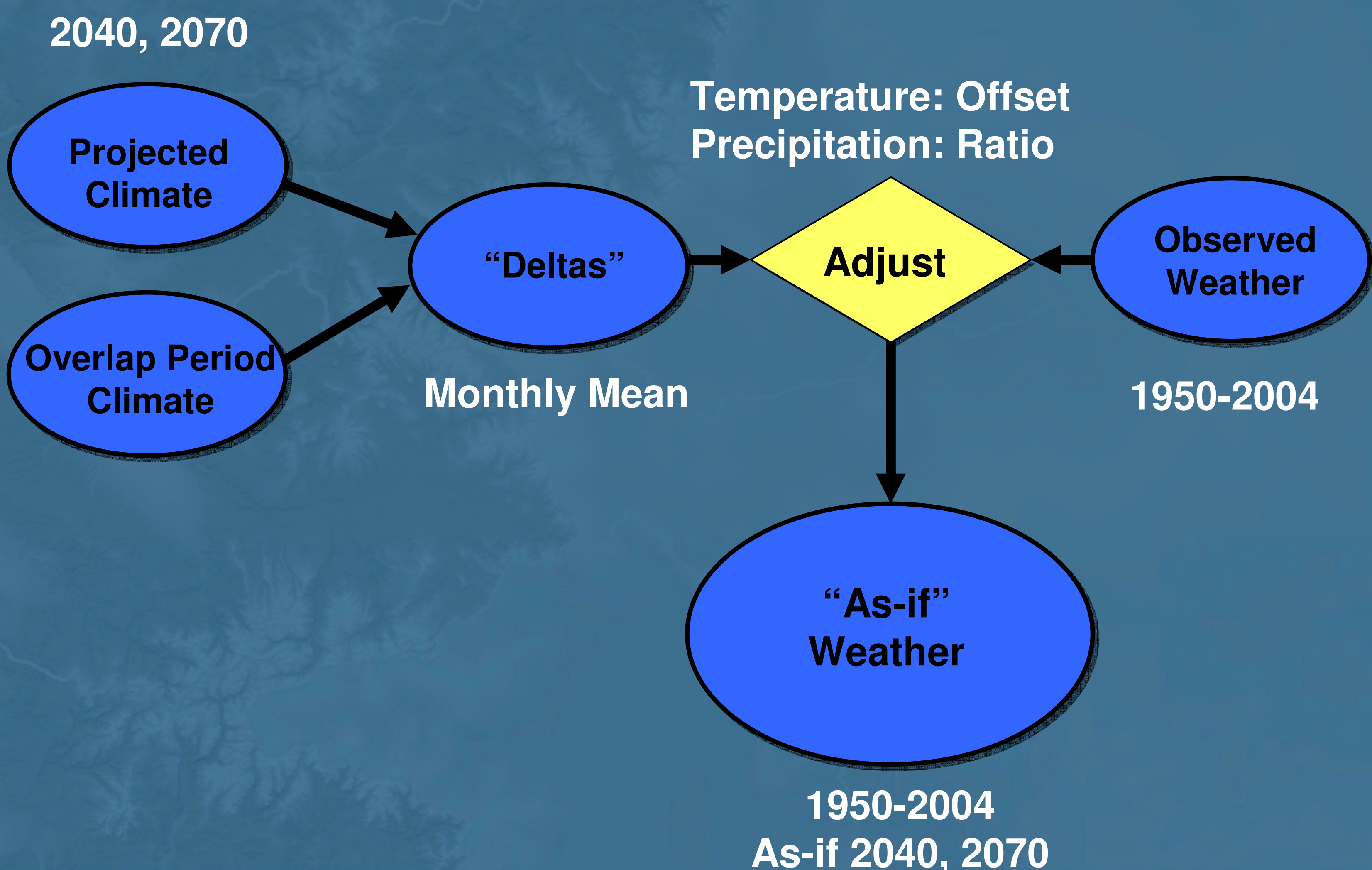
- CDSS Modeling

Result: *Water Availability*

GCM's & Hydrology – As-if Weather

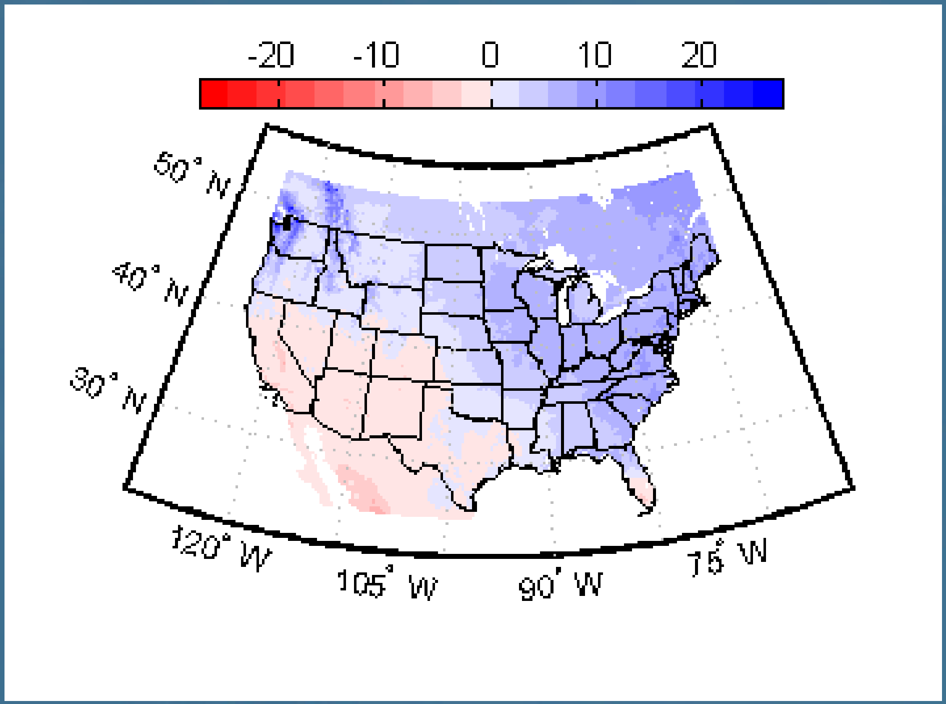


Alternate Weather



Observed Weather/Forcings

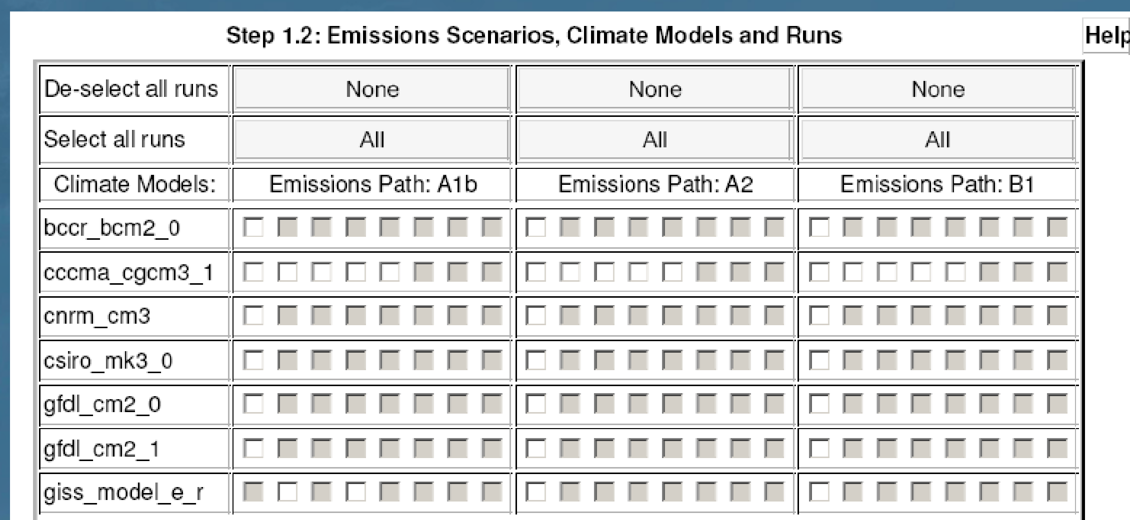
- Andy Wood – west wide forecast datasets, 1950-2005, daily
  - Precipitation
  - Maximum temperature
  - Minimum temperature
  - Wind
- Spatial resolution
  - 1/8-degree
  - ~7.5-mile grid



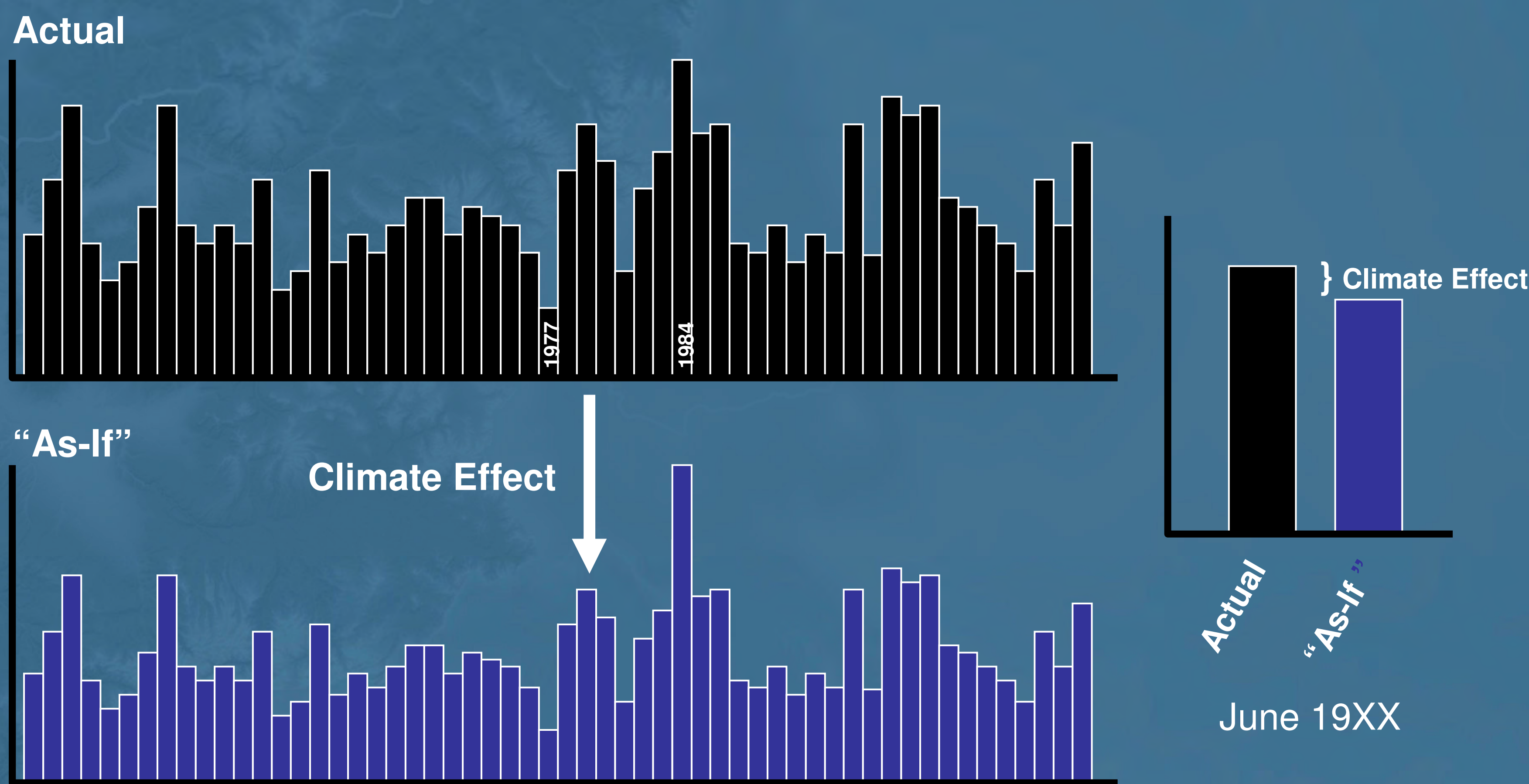
Downscaled Projections

USBR/Santa Clara College/LLNL Archive

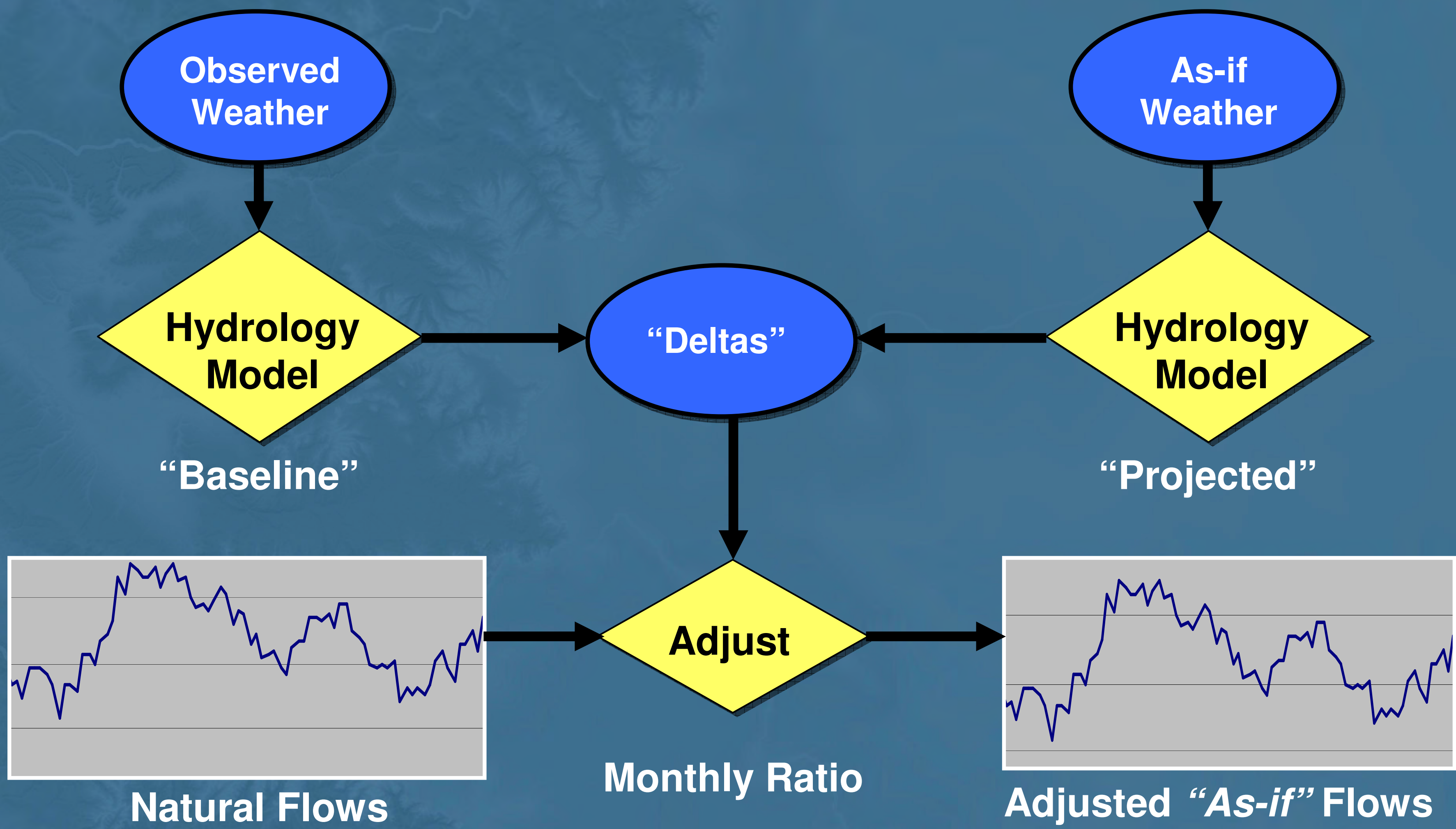
- 112 Projections
  - Tavg, Precip
  - Downscaled to 1/8th degree
  - 3 SRES Scenarios (B1, A1B, A2)
  - 16 GCMs
  - 1950 - 2099



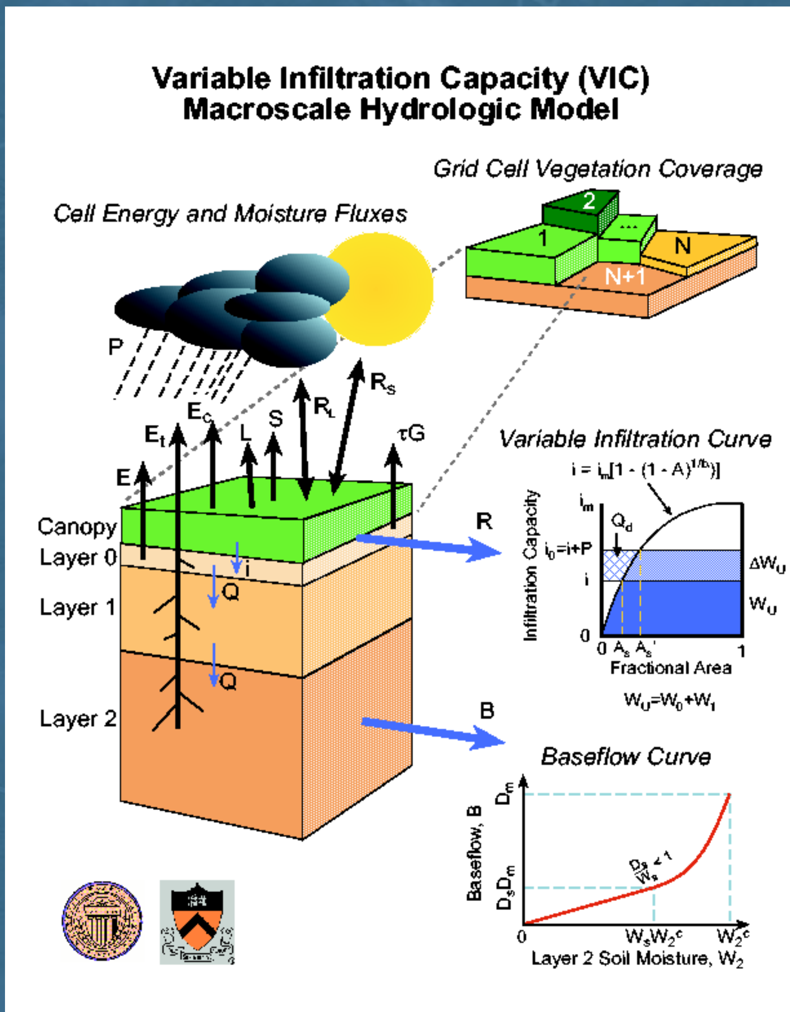
GCM's & Hydrology – Process



Alternate Hydrology



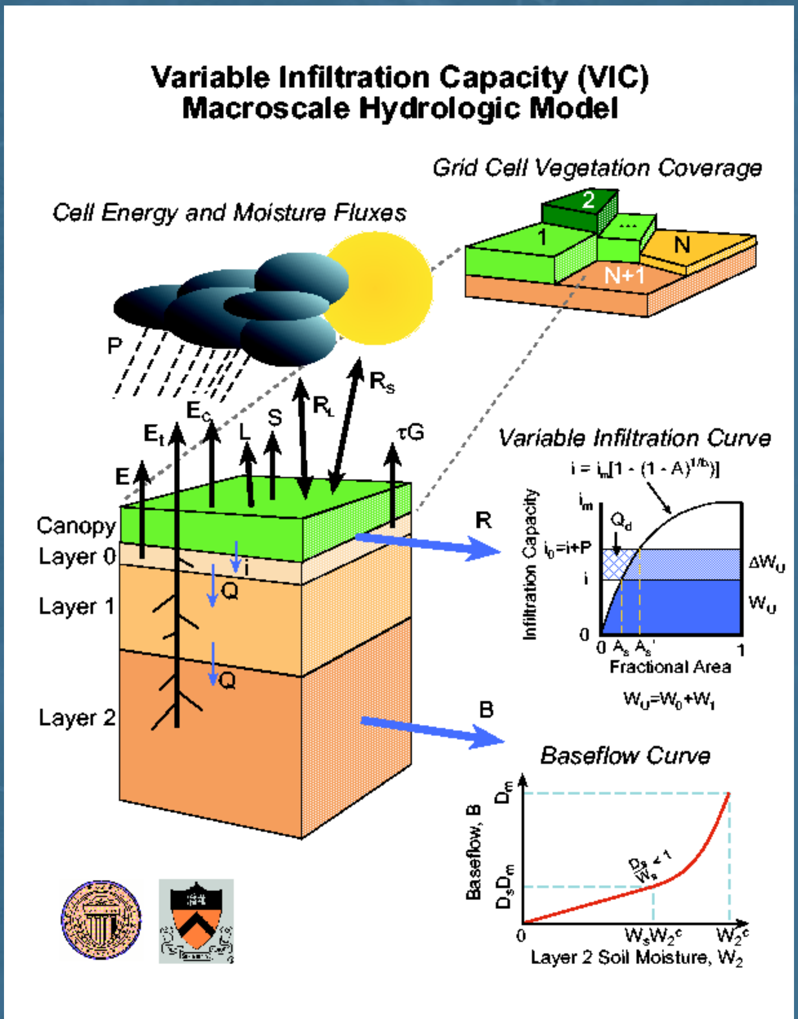
Land Surface, Vegetation, Soils Data



- 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

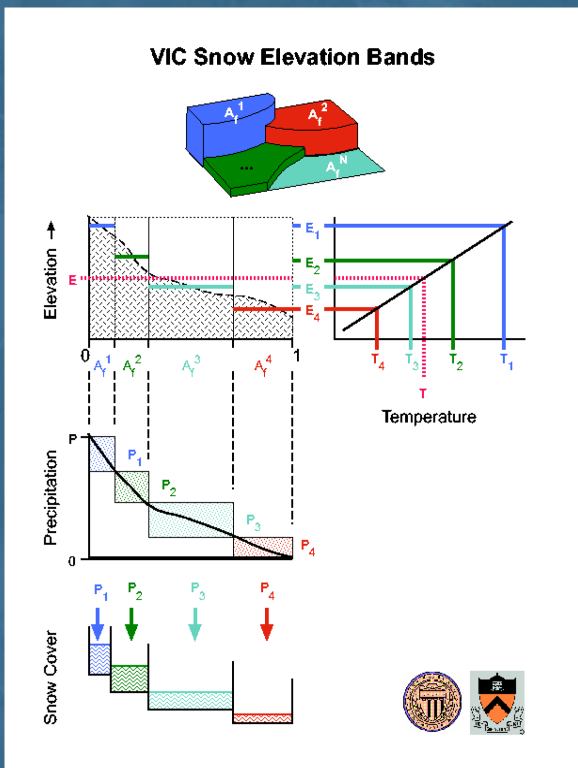
Land Surface, Vegetation, Soils Data

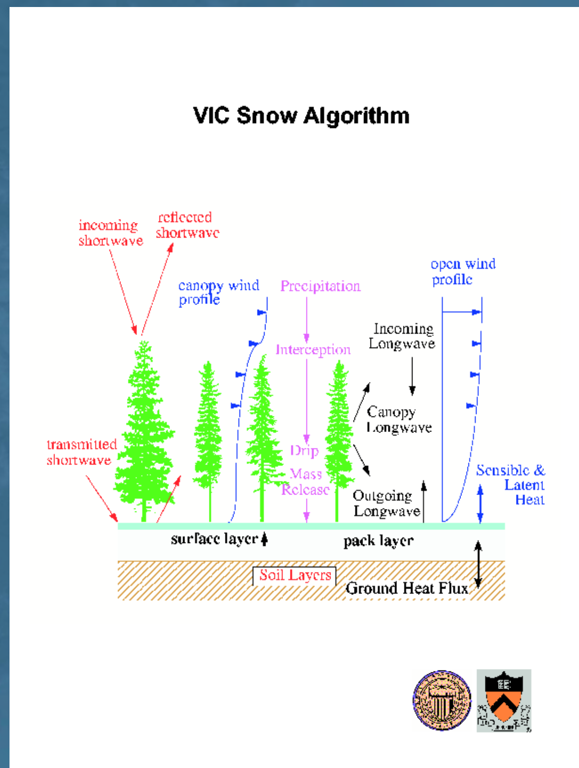


- Land surface processes – "advanced" physical representation – "complex"

- Subsurface processes – "conceptual"

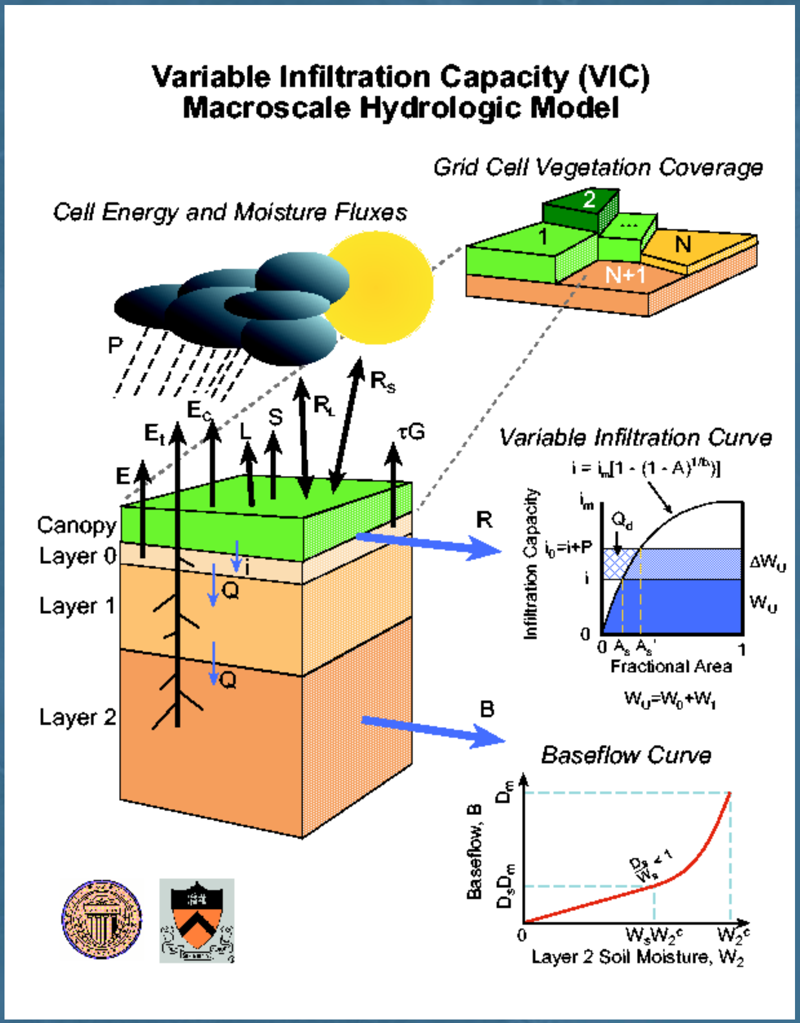
Snow Model





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

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.

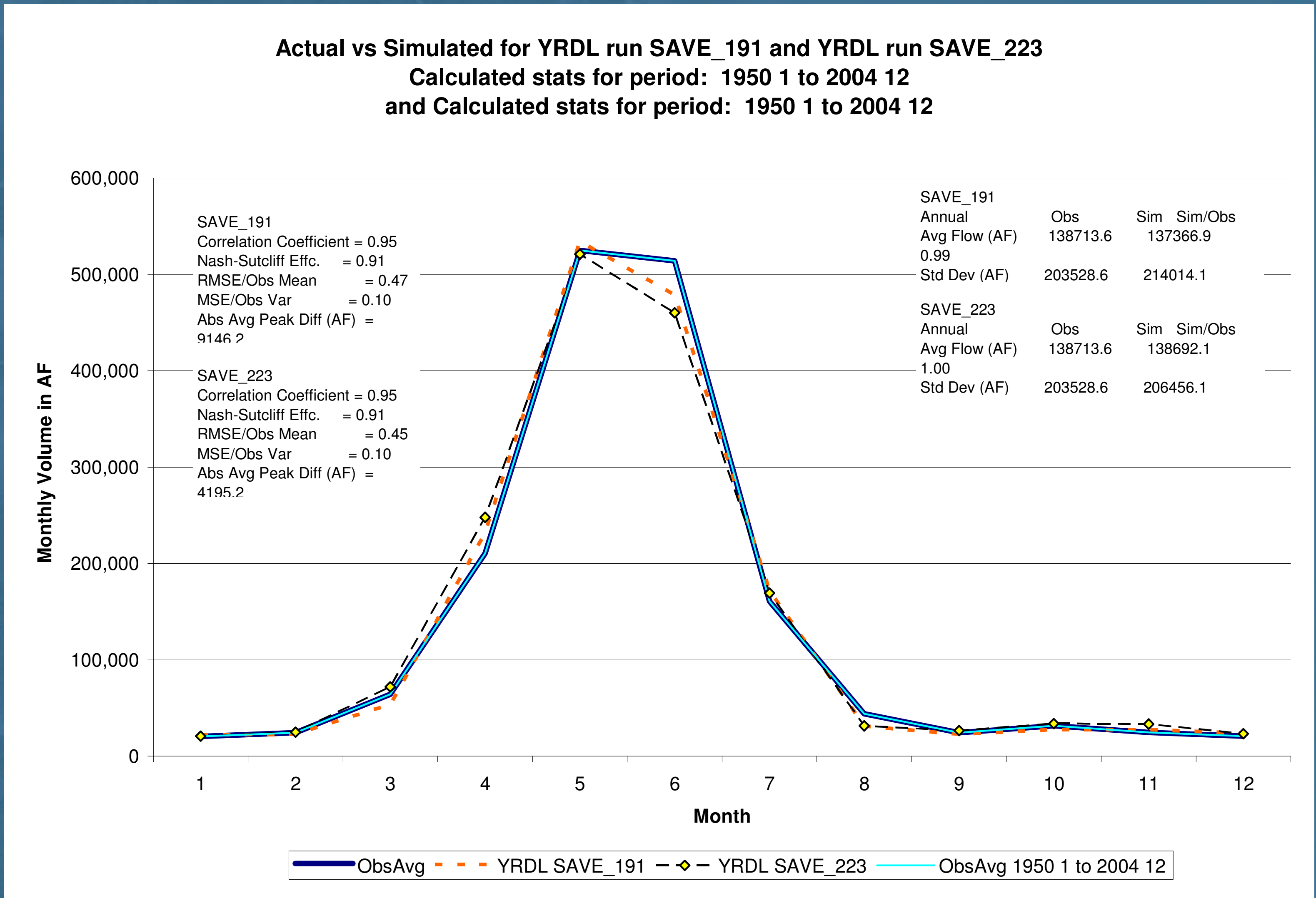
Calibration Objectives

- Represent response to change
  - Temperature, Precipitation
  - More important than absolute values due to use of differencing approach
- Calibration “knobs” affect transport
  - Temporal mapping of land-surface forcing to flow
  - Land-surface forcing uses binf, but is otherwise a physical representation
- Shape of hydrograph is most important

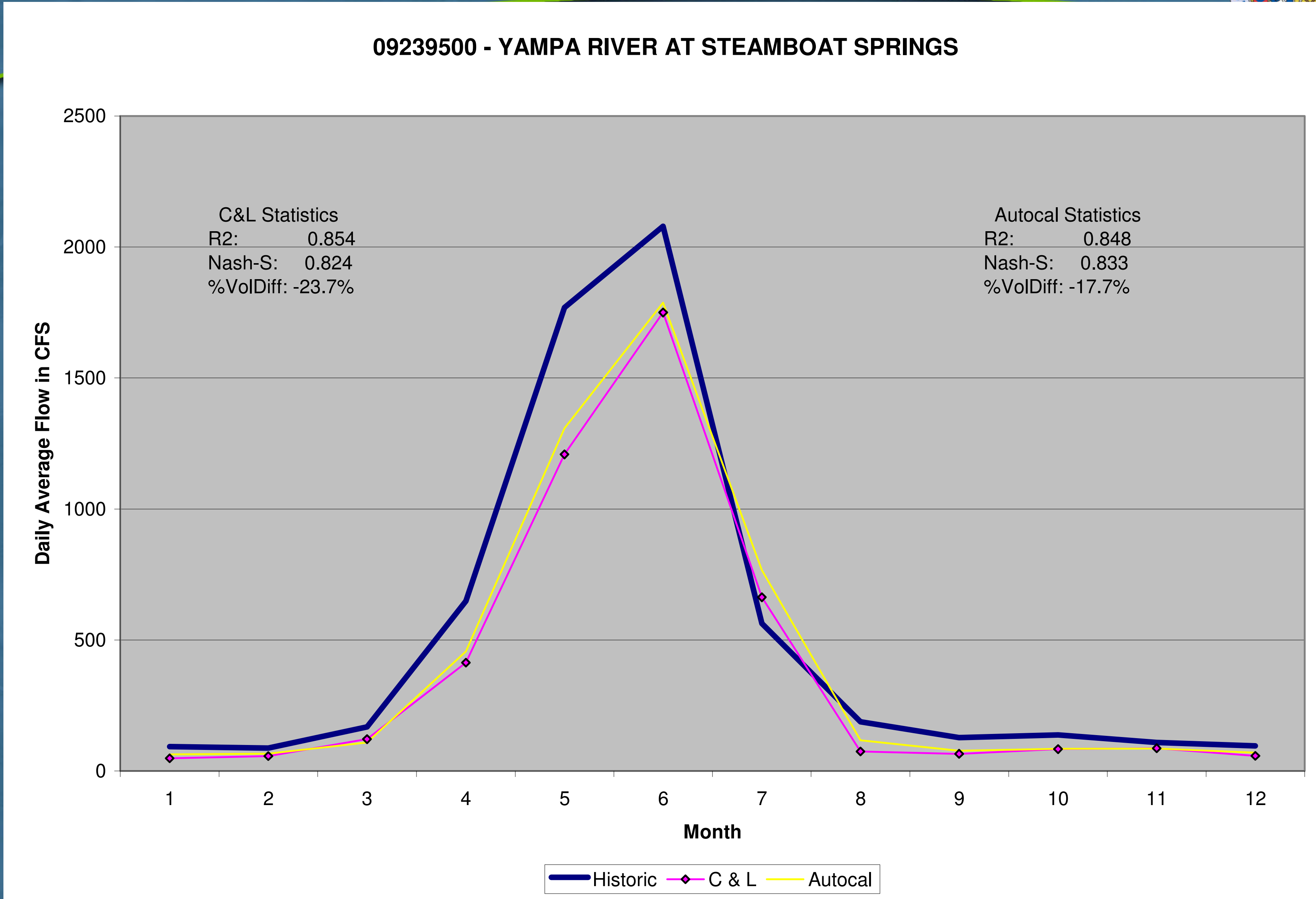
Calibration Approach - Autocalibration

- MOCOM
- Three-stage approach
  - Scalar values – let the 6 subsurface parameters vary within [min, max]
  - Slope sensitivity analysis
  - Hybrid slope/scalar calibration
- Periods
  - Parameter estimation 1950 – 1984
  - Validation 1985 – 2004 (spin up with 1983 and 1984)
  - Final calibrations use 1950 - 2004
- Most sensitive parameters:
  - Dsmax
  - Ws

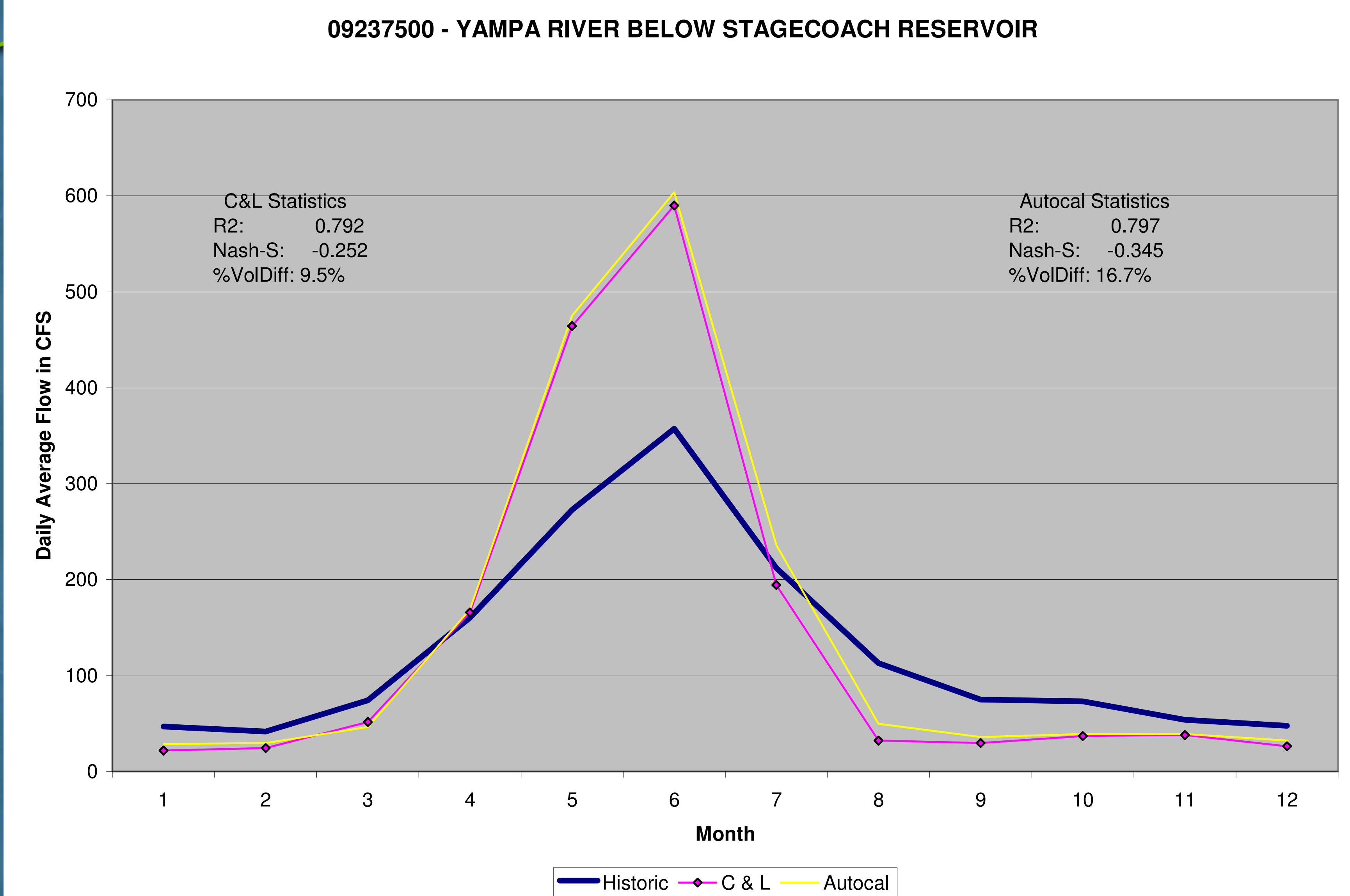
Calibration Results—Yampa at Deerlodge



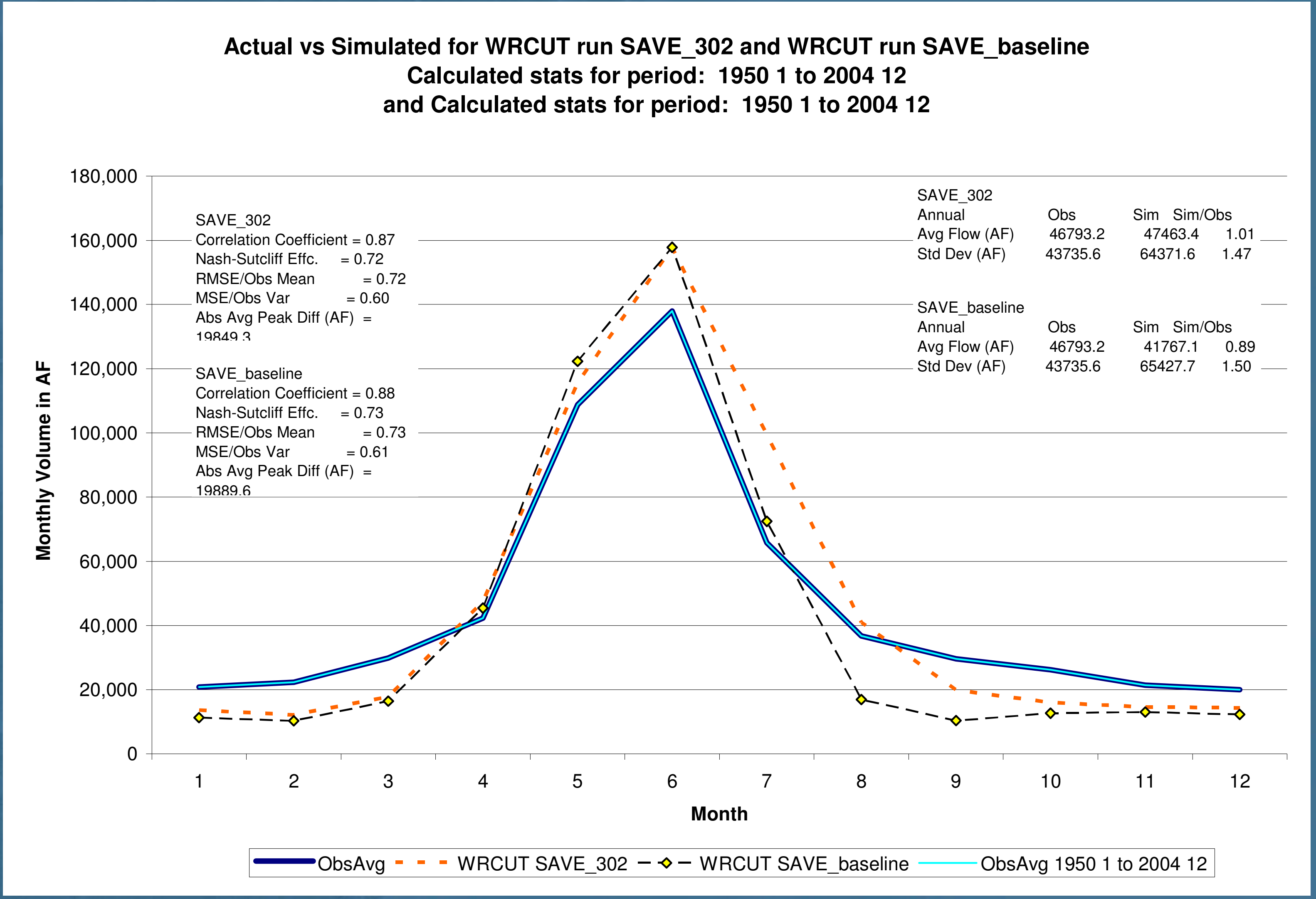
Calibration Results—Yampa at Steamboat Springs



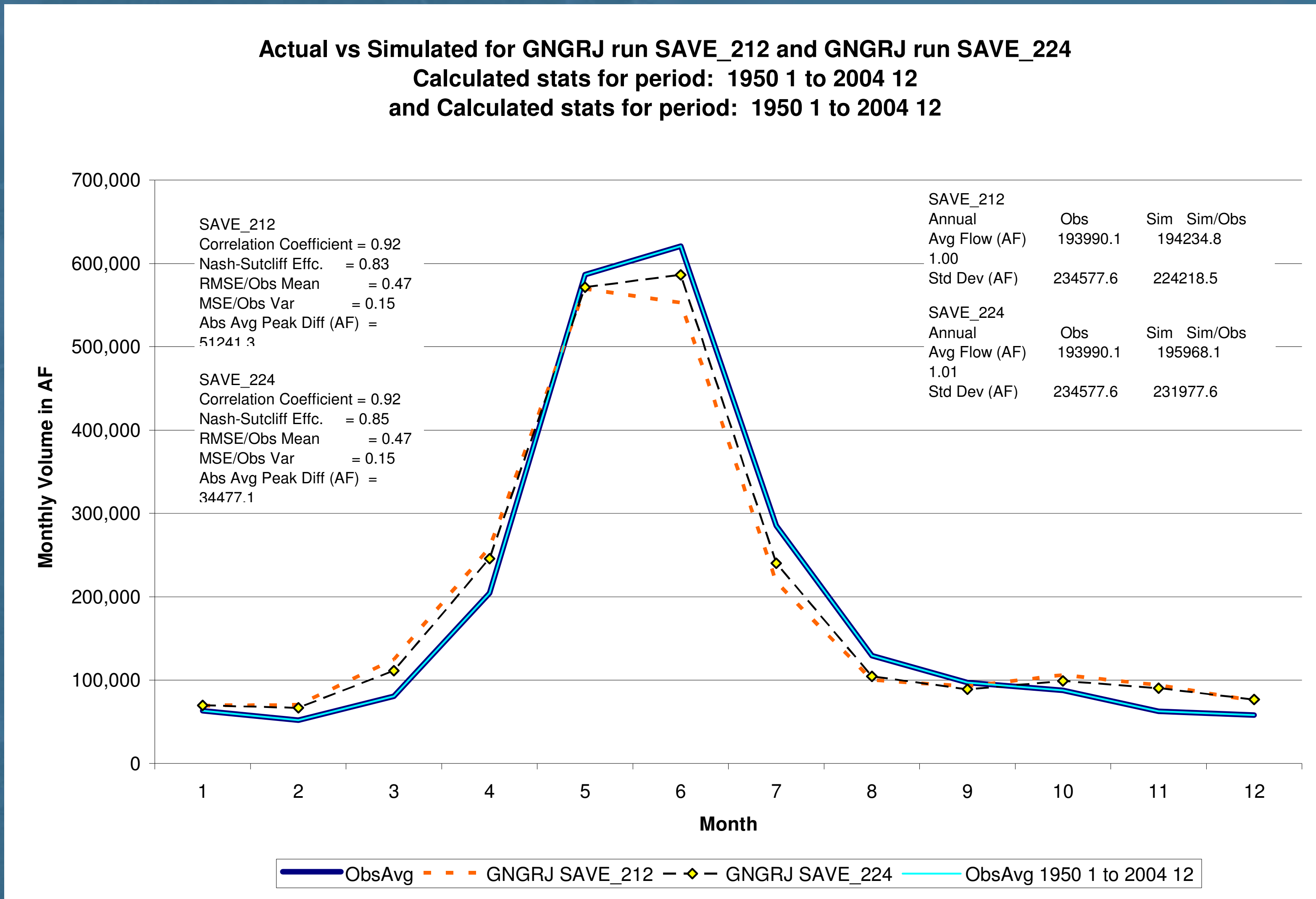
Calibration Results—Yampa Below Stagecoach



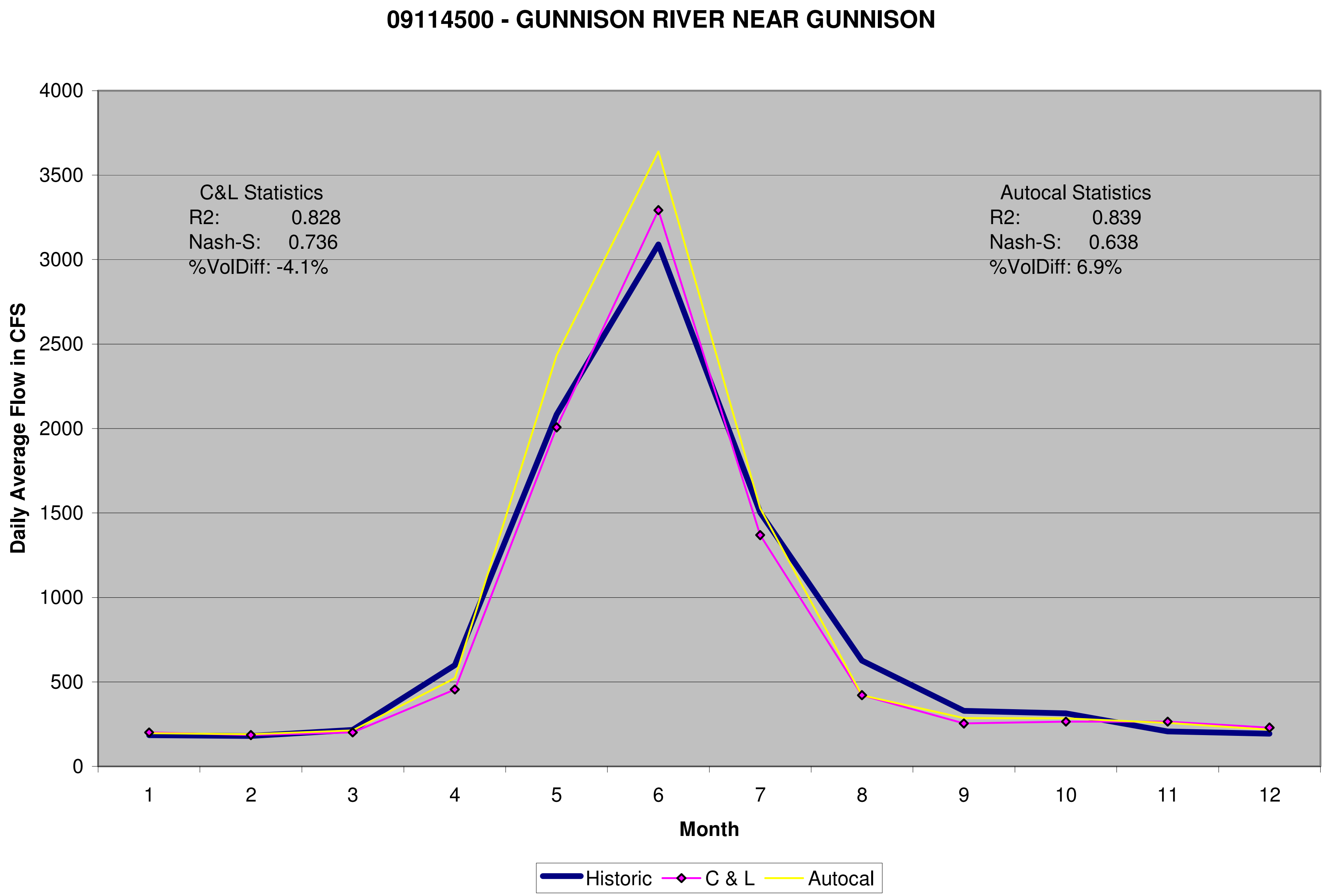
Calibration Results—White River NR CO/UT SL



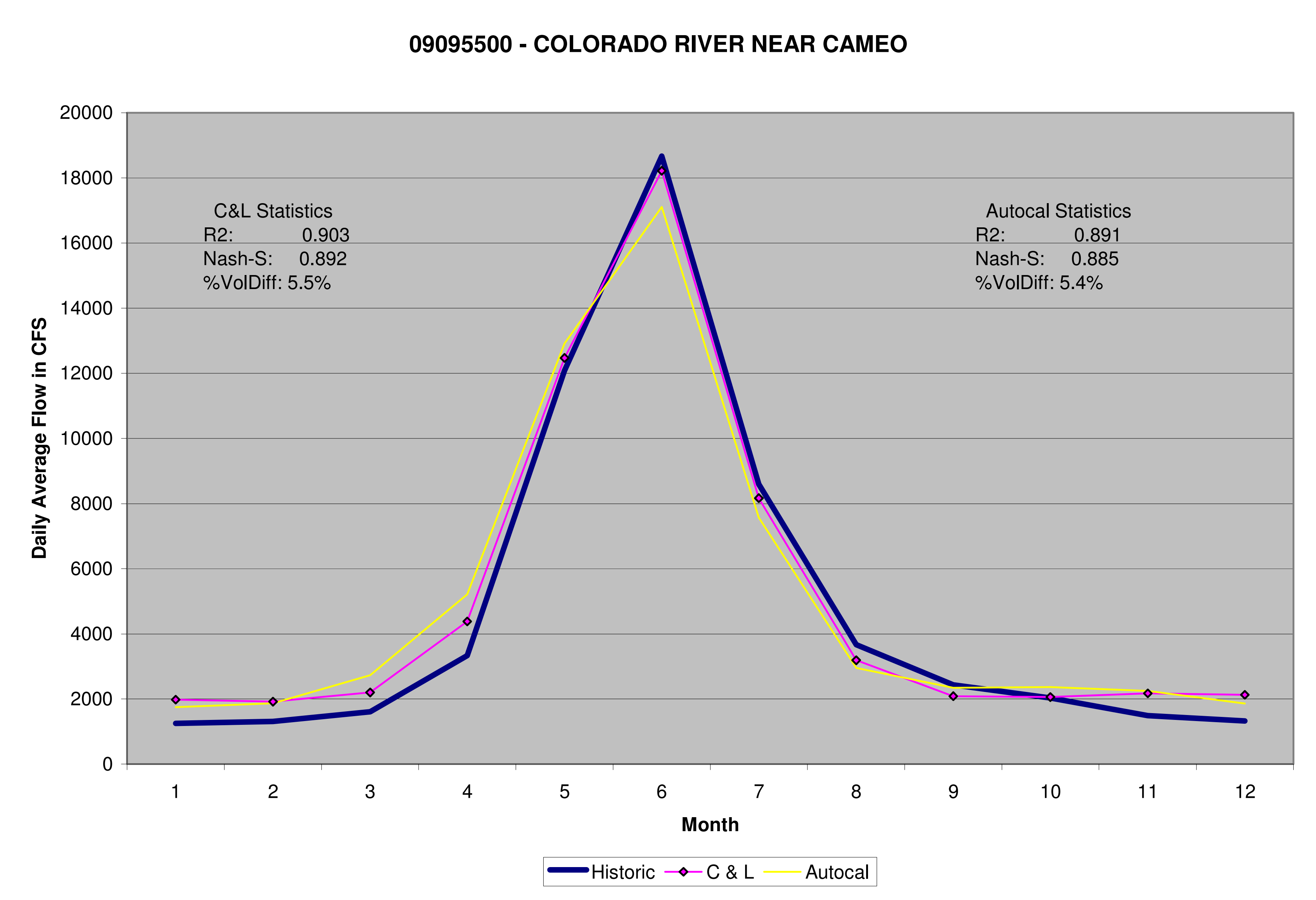
Calibration Results—Gunnison River at Grand Junction



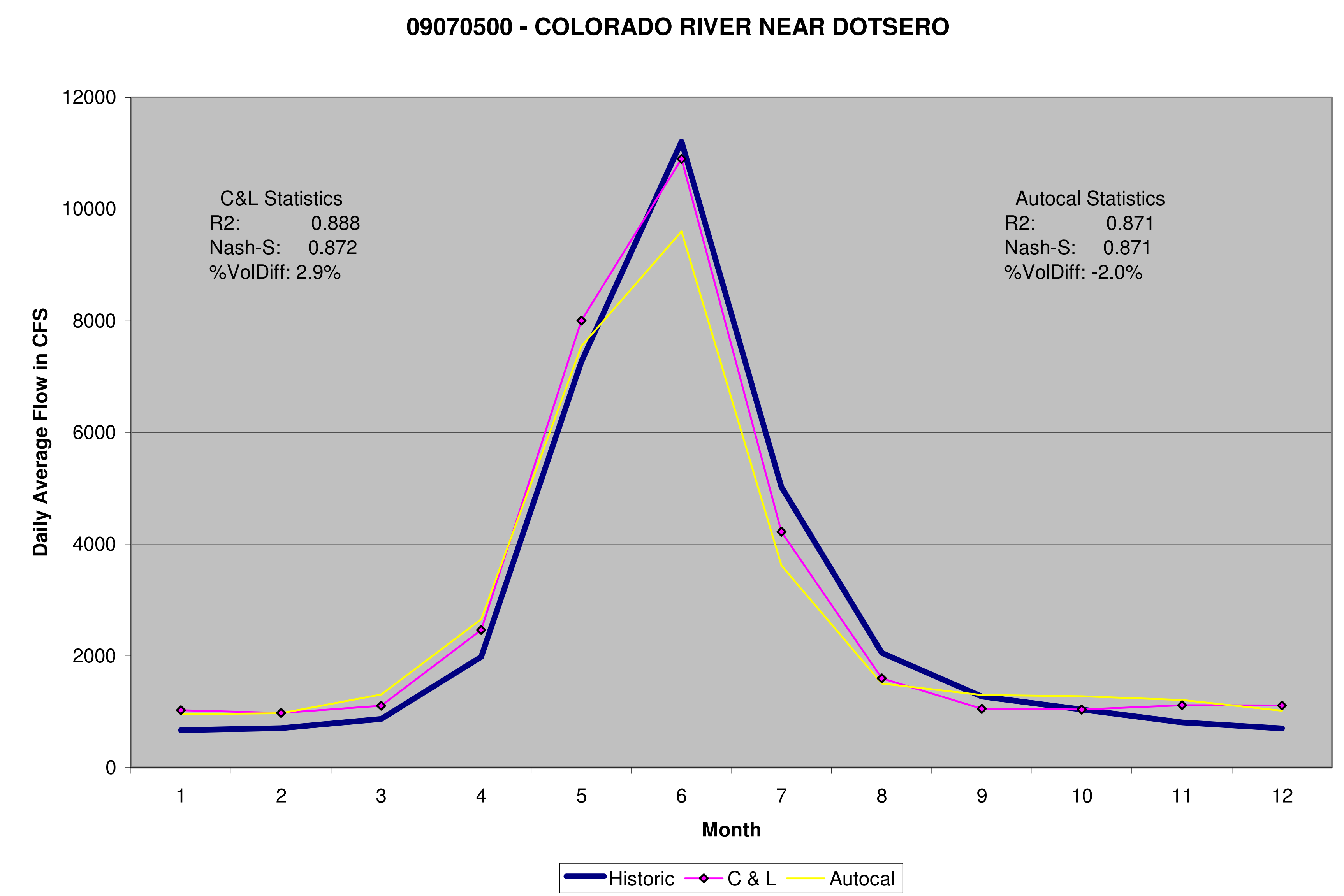
Calibration Results—Gunnison at Gunnison



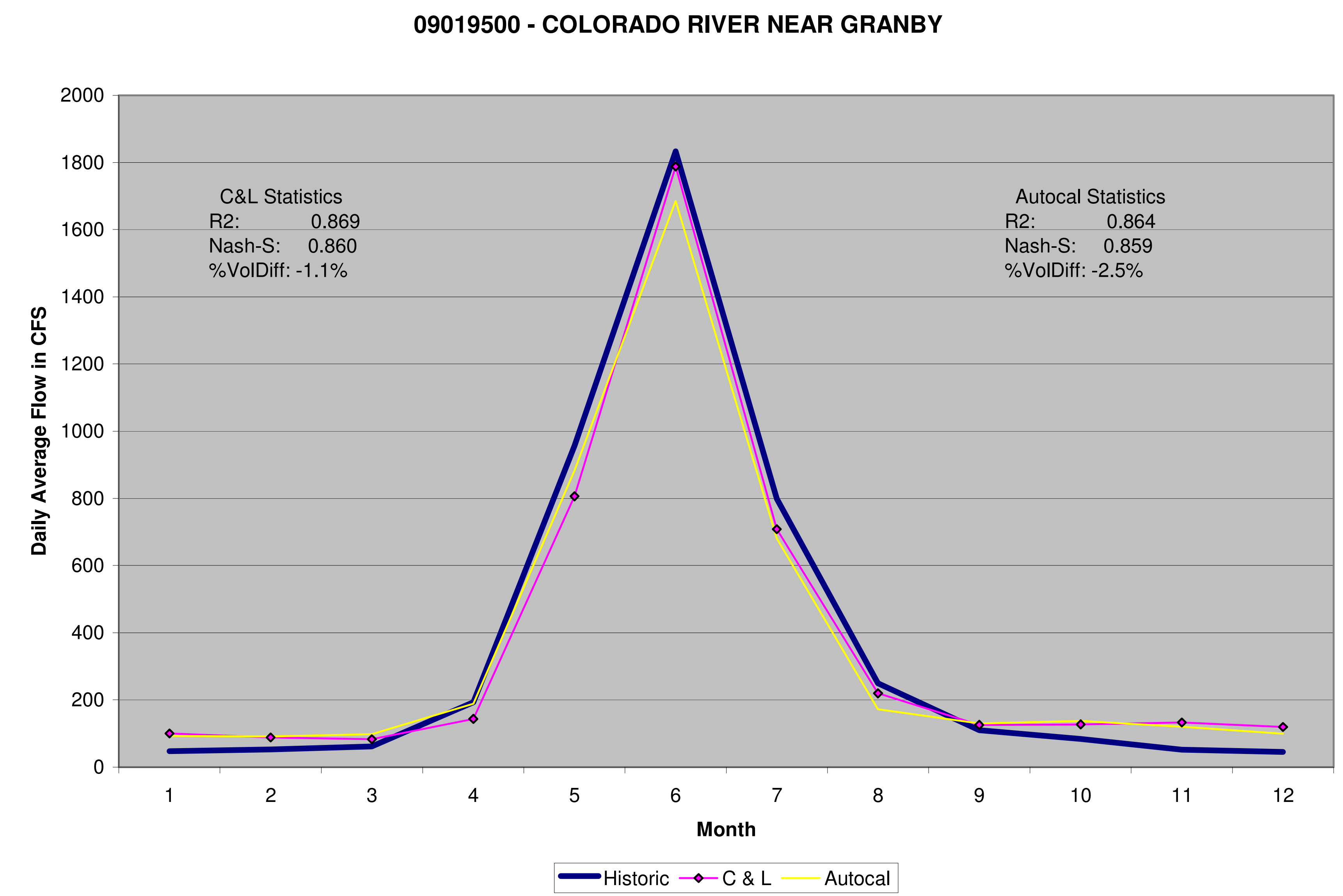
Calibration Results—Colorado River Near Cameo



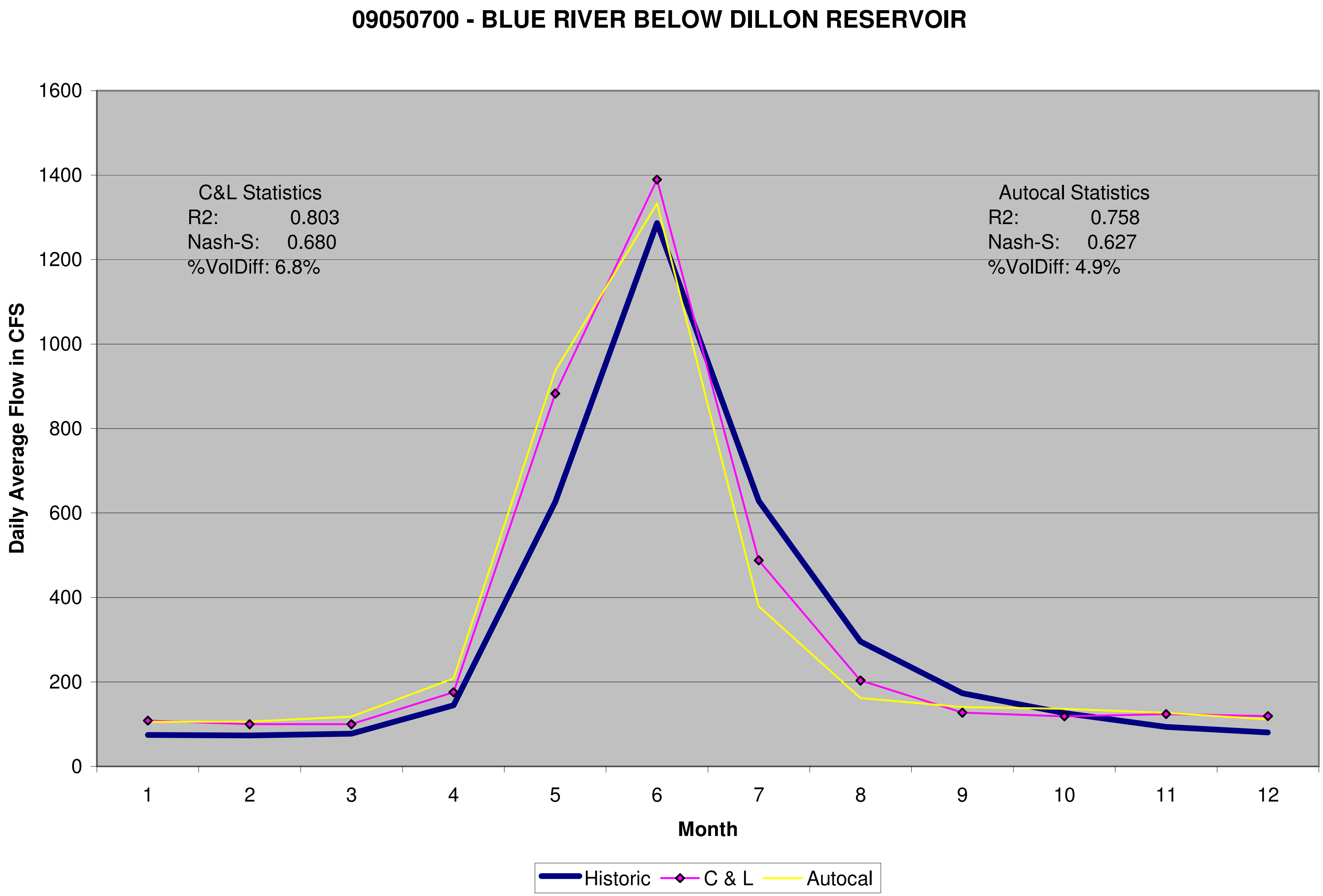
Calibration Results—Colorado River Near Dotsero



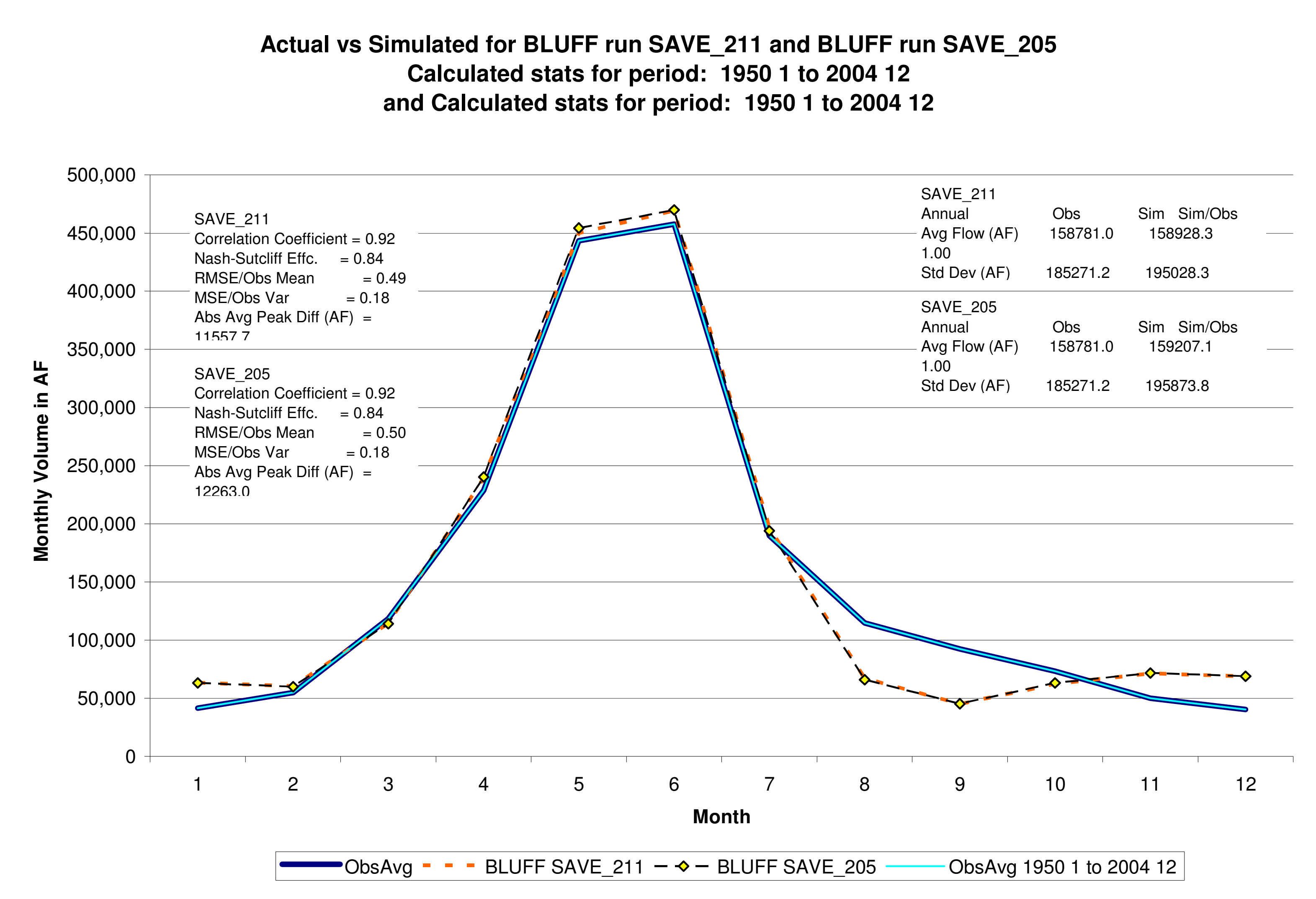
Calibration Results—Colorado River Near Granby



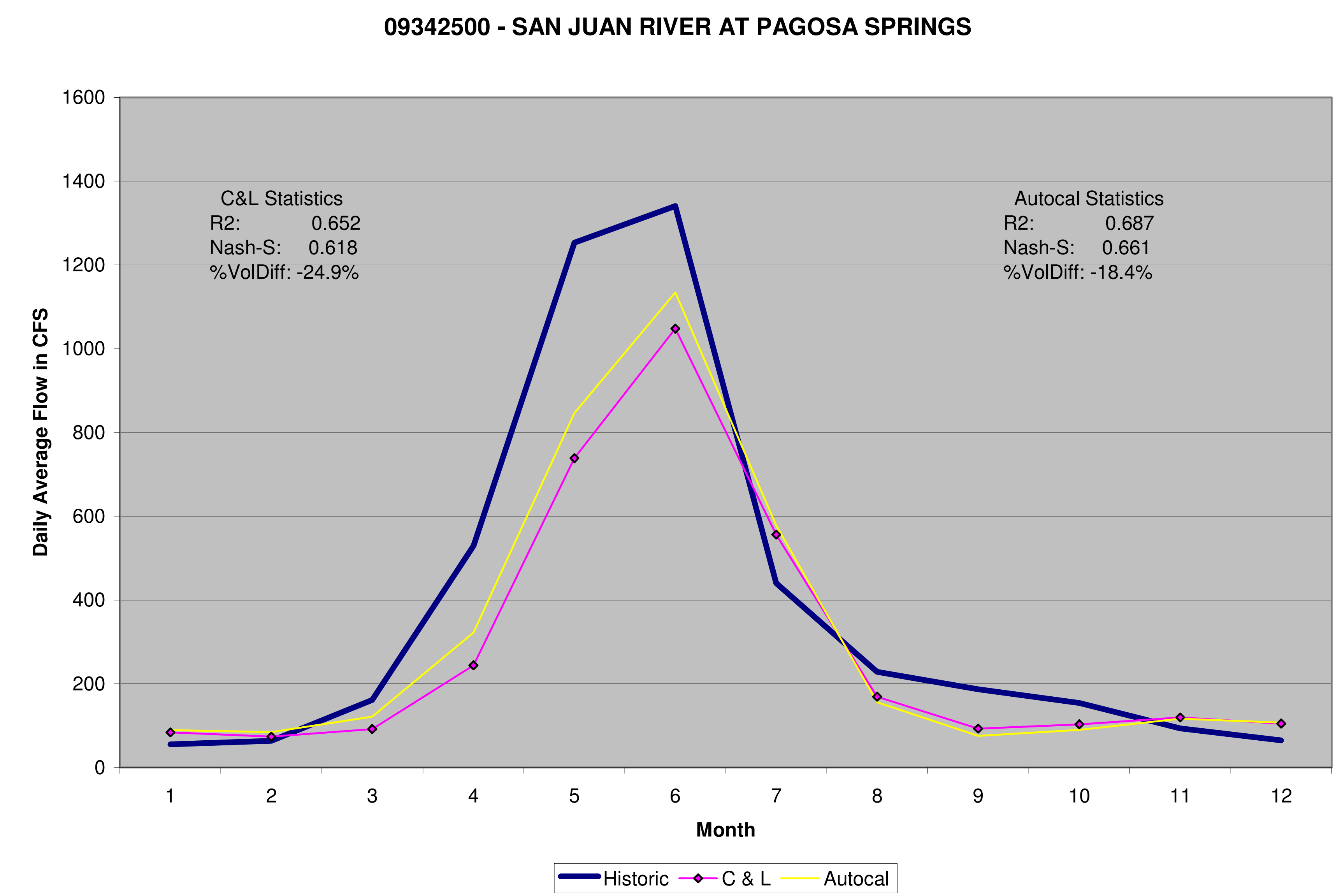
Calibration Results—Colorado River Below Dillon Res.



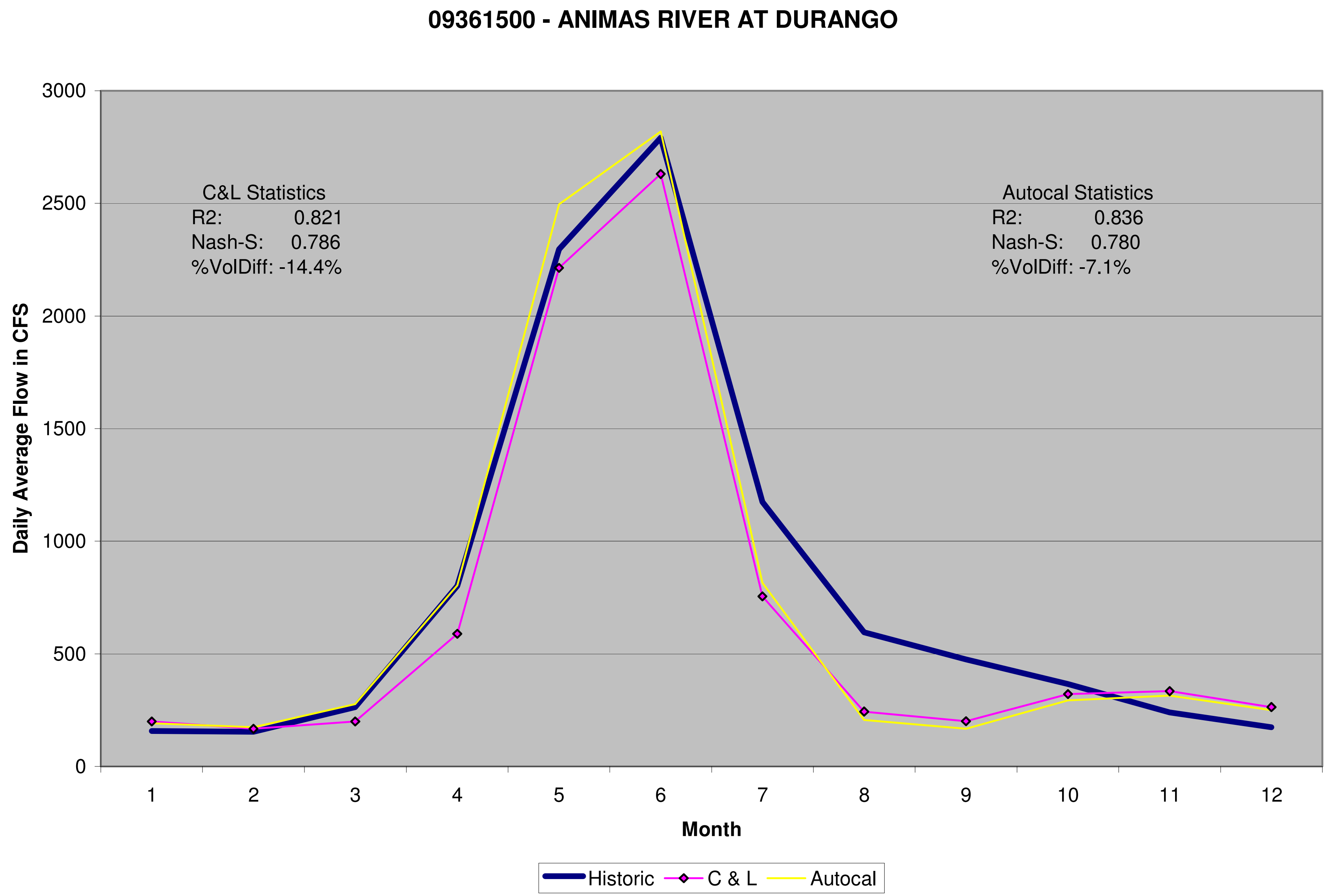
Calibration Results—San Juan River at Bluff



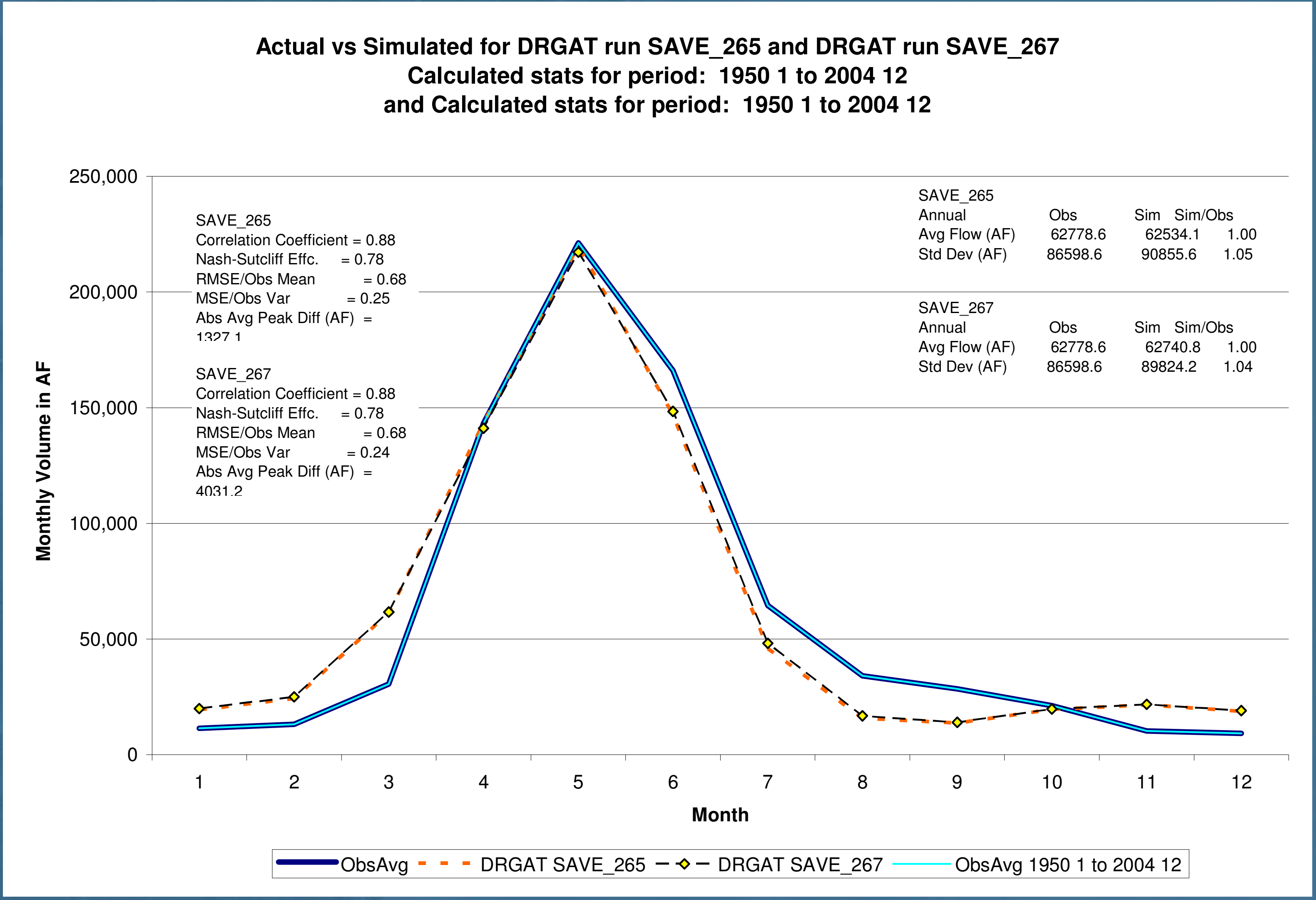
Calibration Results—San Juan River at Pagosa Springs



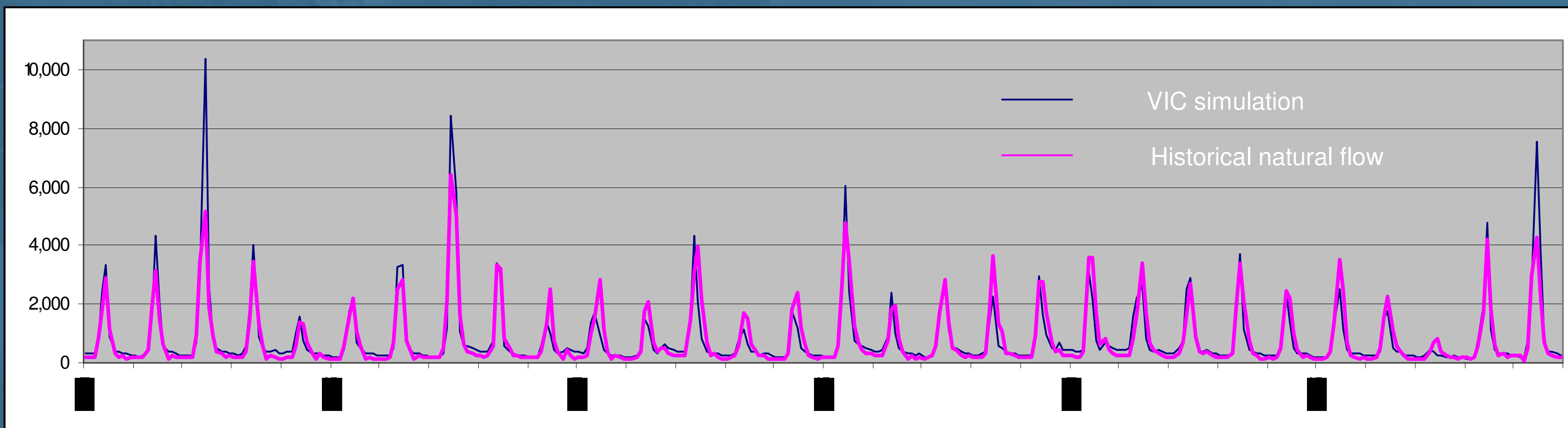
Calibration Results—Animas River at Durango

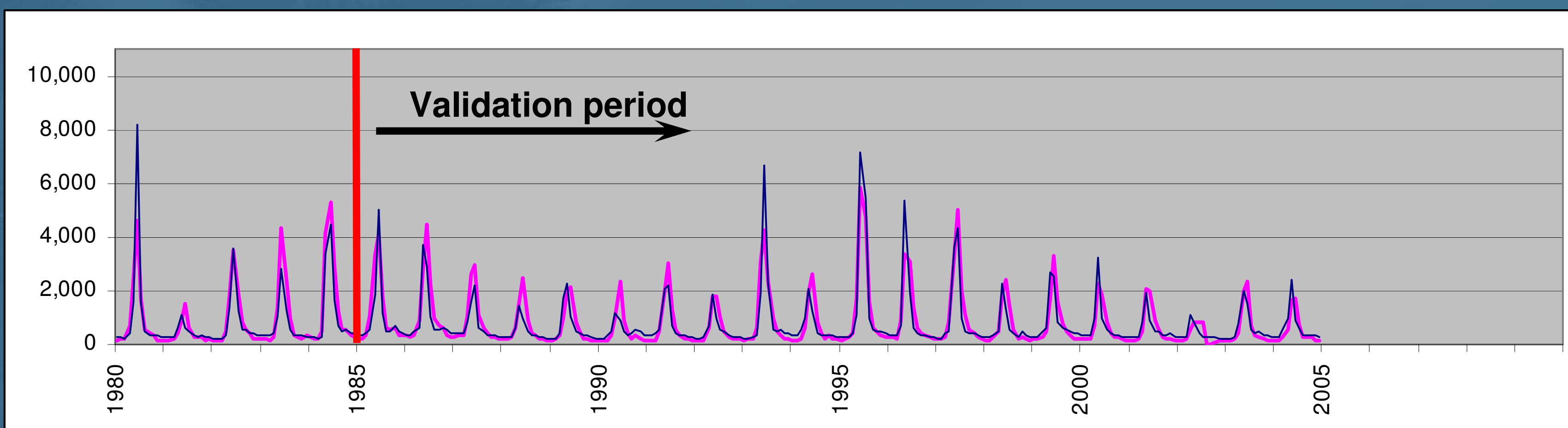


Calibration Results—Dolores River at Gateway

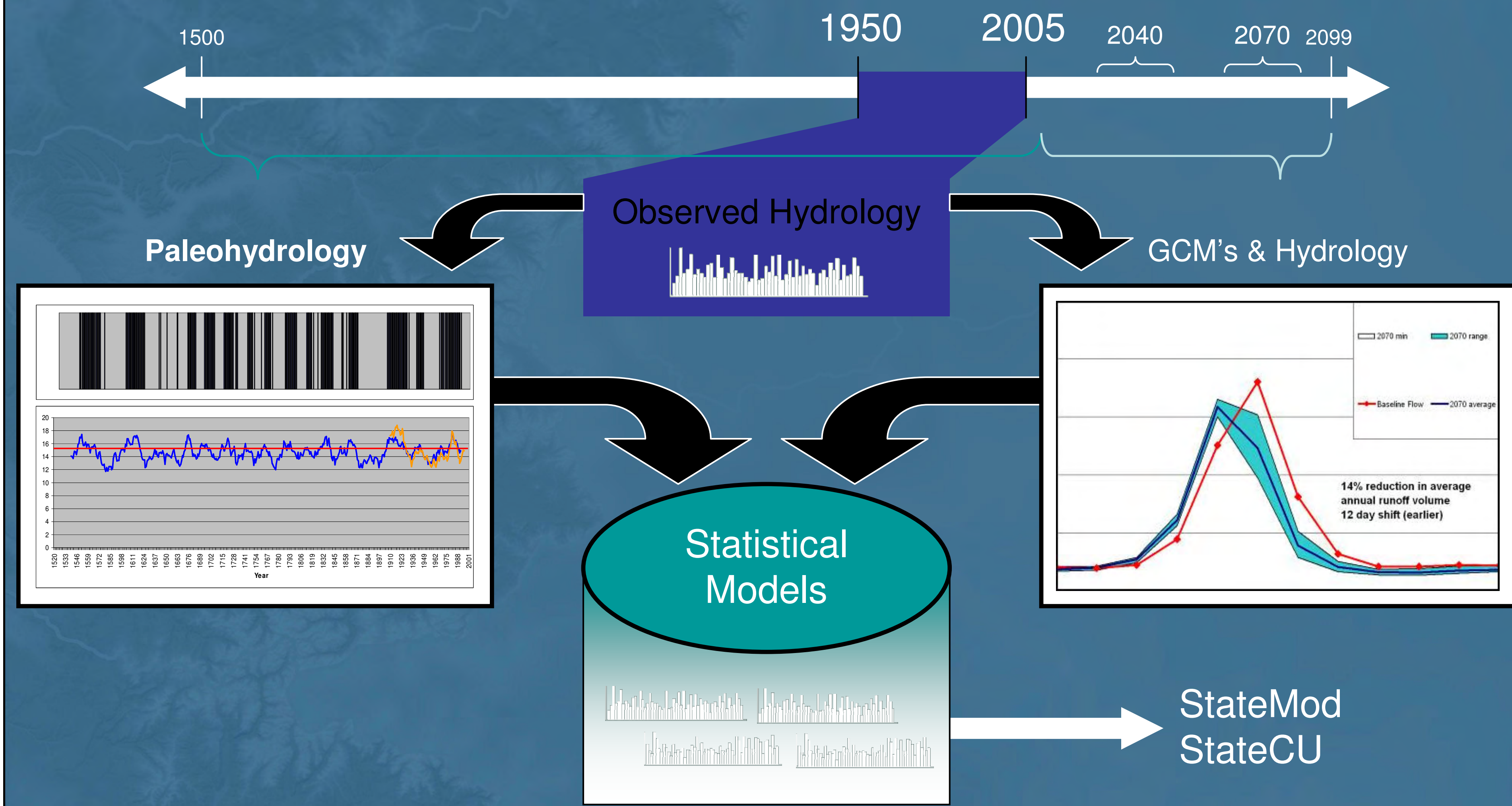


Time-series Comparison—Gunnison at Gunnison





Overall Hydrology Approach



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
- Evaluated routing methods
- Developed final routing model
- Implemented MOCOM automated calibration method
- Refined calibrations

Comments and Questions?

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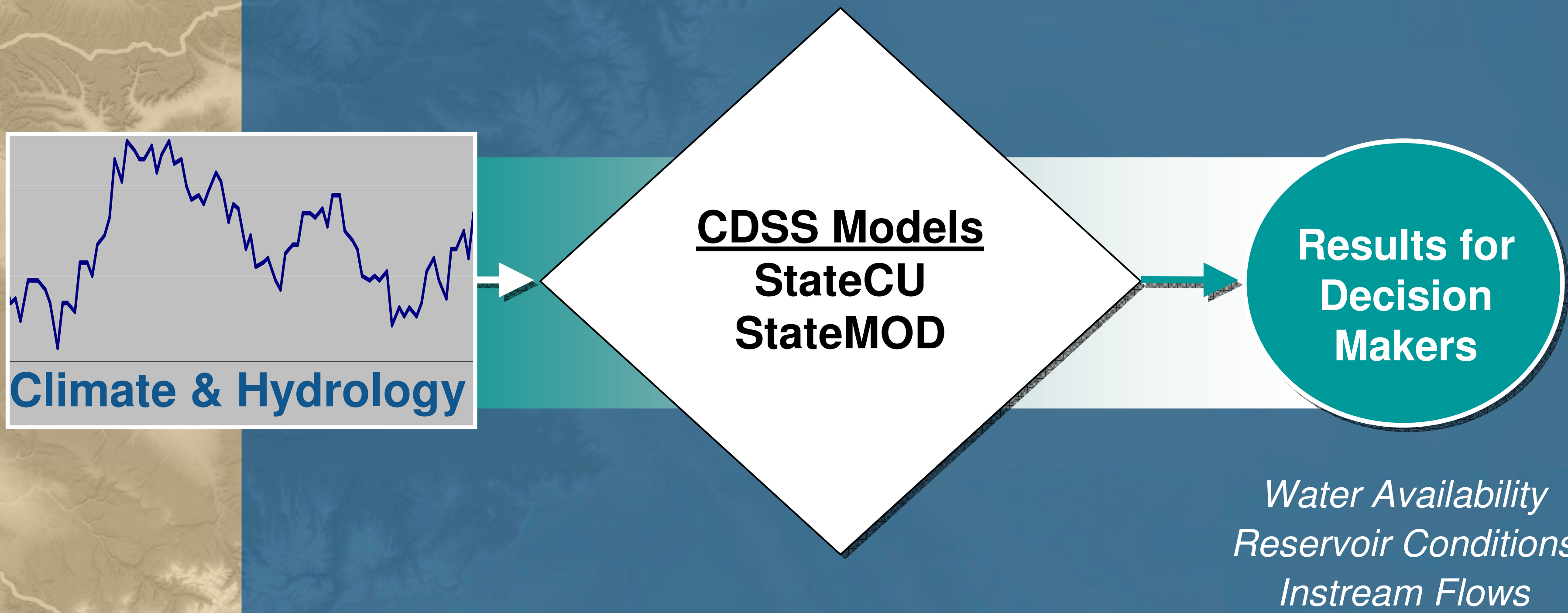
Website:

http://cwcb.state.co.us/WaterInfo/CRWAS

Colorado Decision Support System



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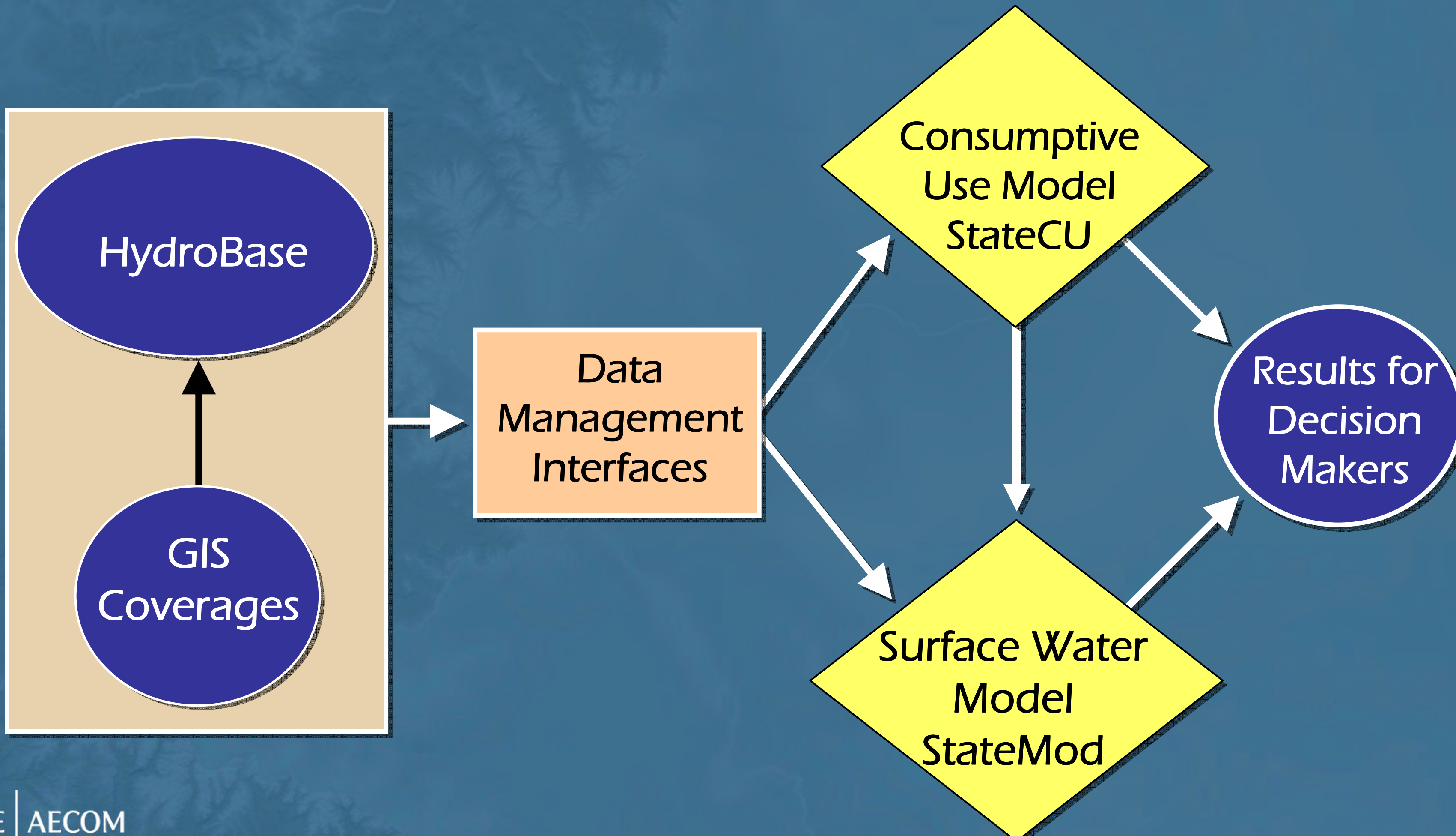
Historical Hydrology – Data Centered CDSS



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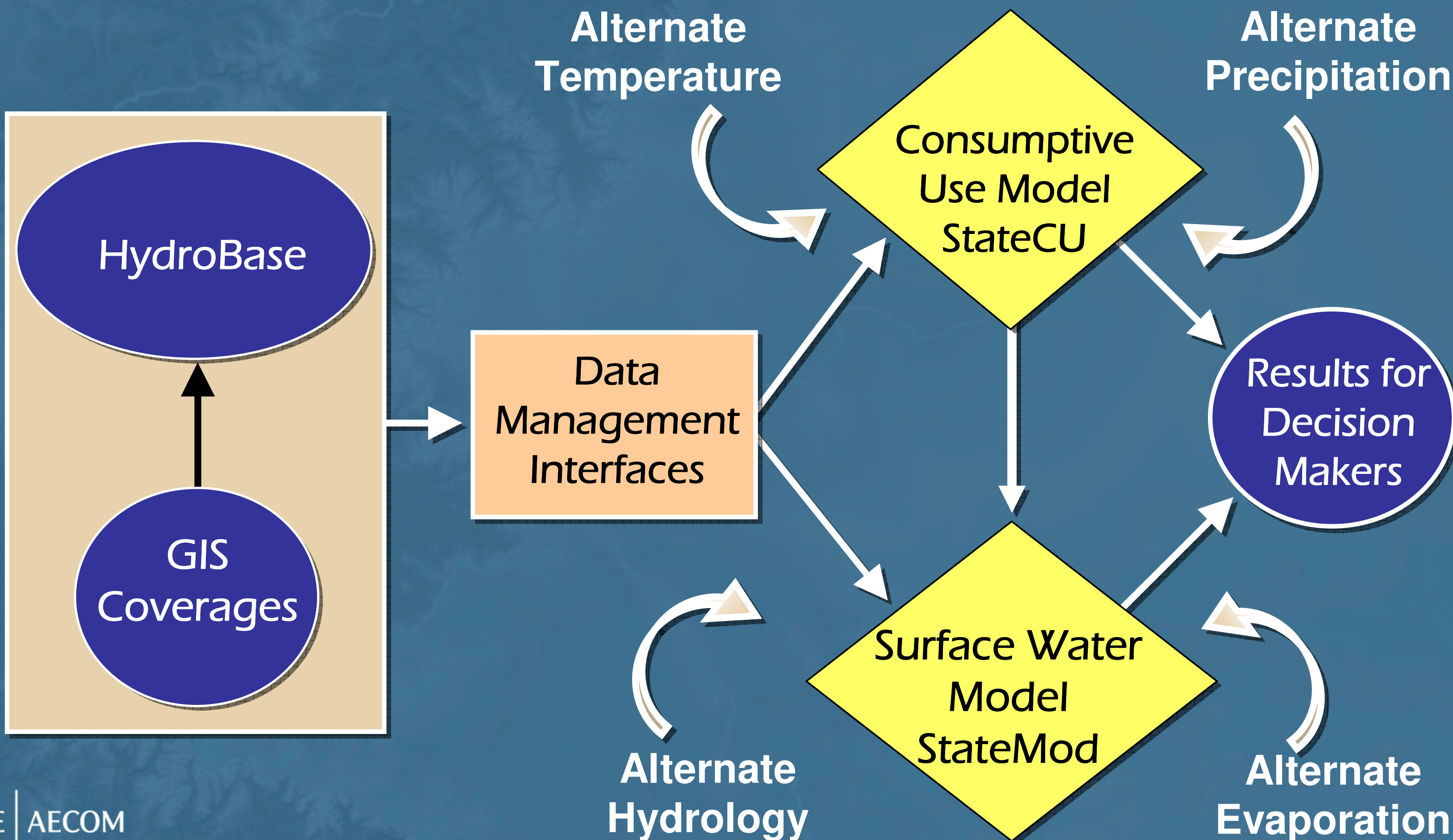
Historical Hydrology – Data Centered CDSS



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2040 GCM's Effect On Temperature

Lower Elevations Show Largest Increase

Basin Wide 2040 Average Increase = 3.6 Deg F

Increase is Consistent Each Month

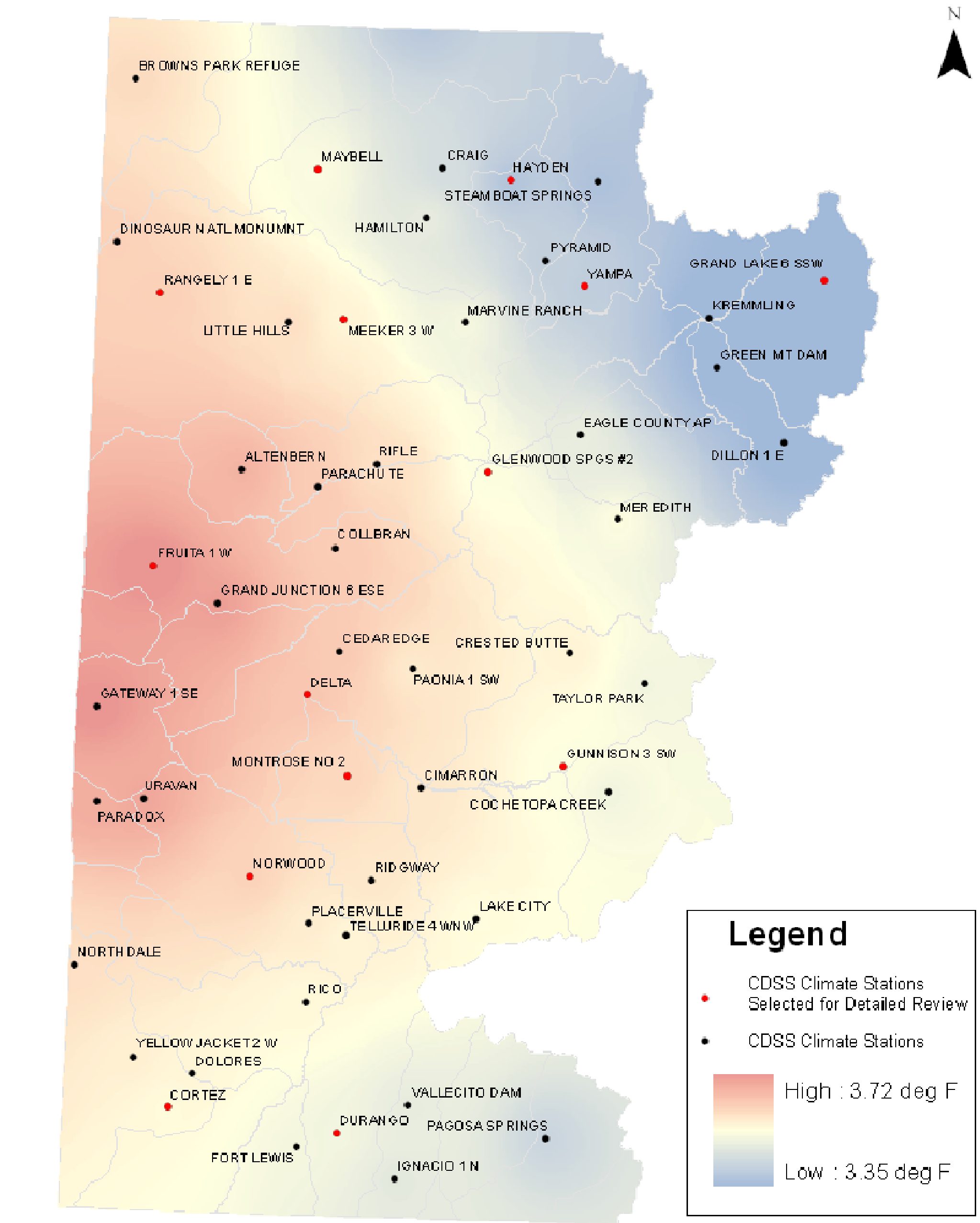

Figure 1 - 2040 Average Annual Temperature Increase from Historical (deg F)

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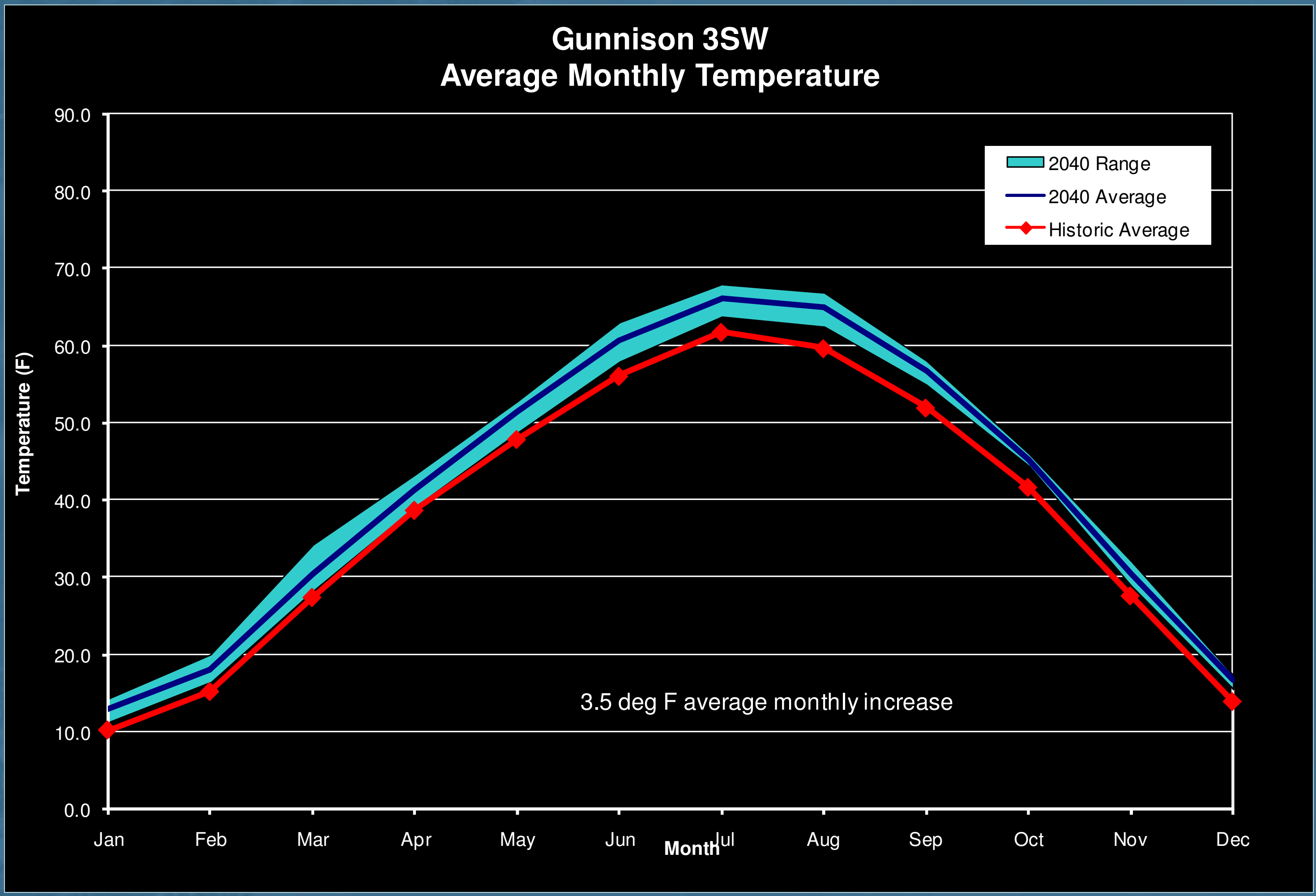
2040 GCM Temperature Results



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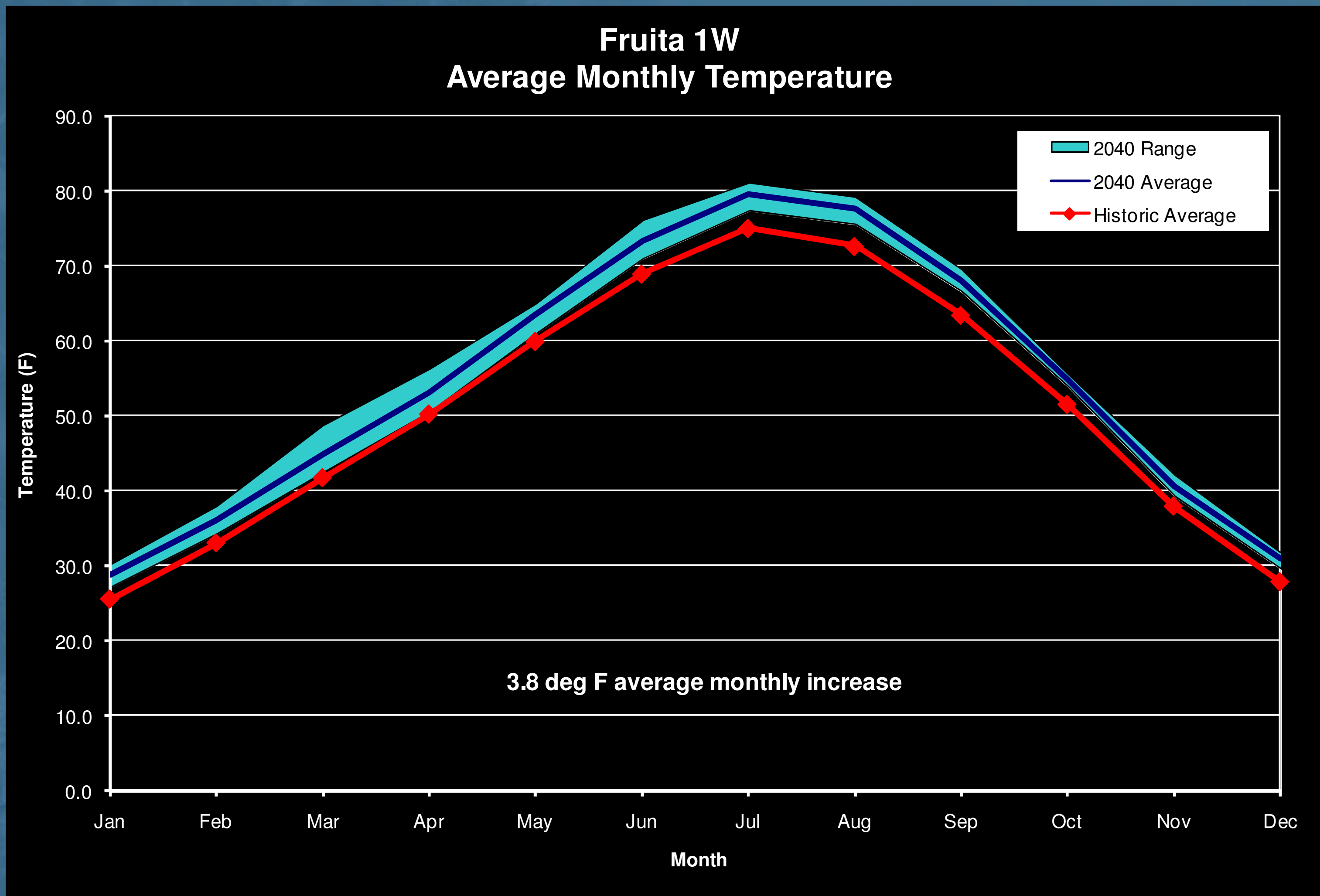
2040 GCM Temperature Results



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2070 GCM's Effect On Temperature

Lower Elevations Show Largest Increase

Basin Wide 2070 Average Increase = 5.8 Deg F

Northern Colorado Shows More Variation Between Five GCMs

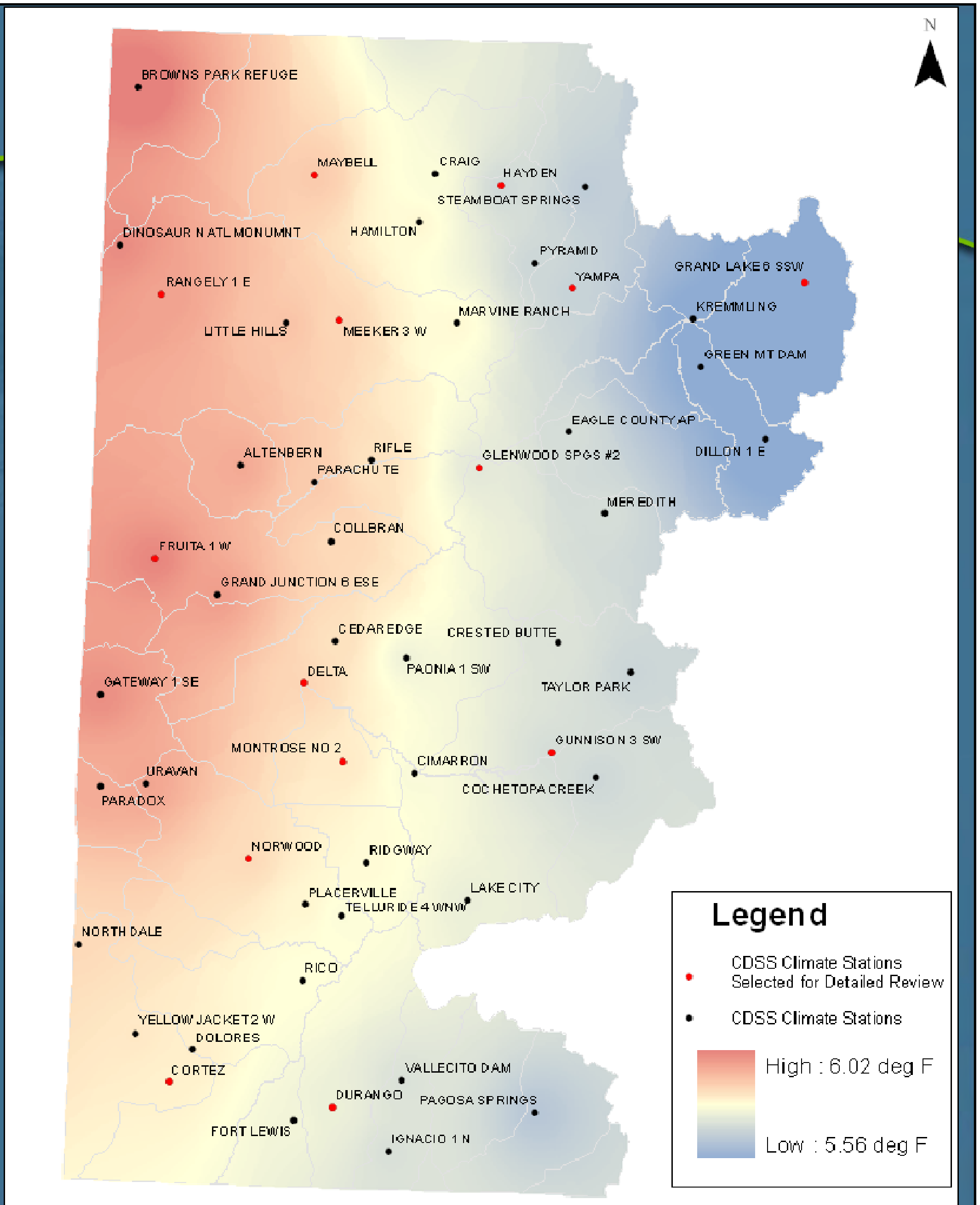

Figure 2 - 2070 Average Annual Temperature Increase from Historical (deg F)

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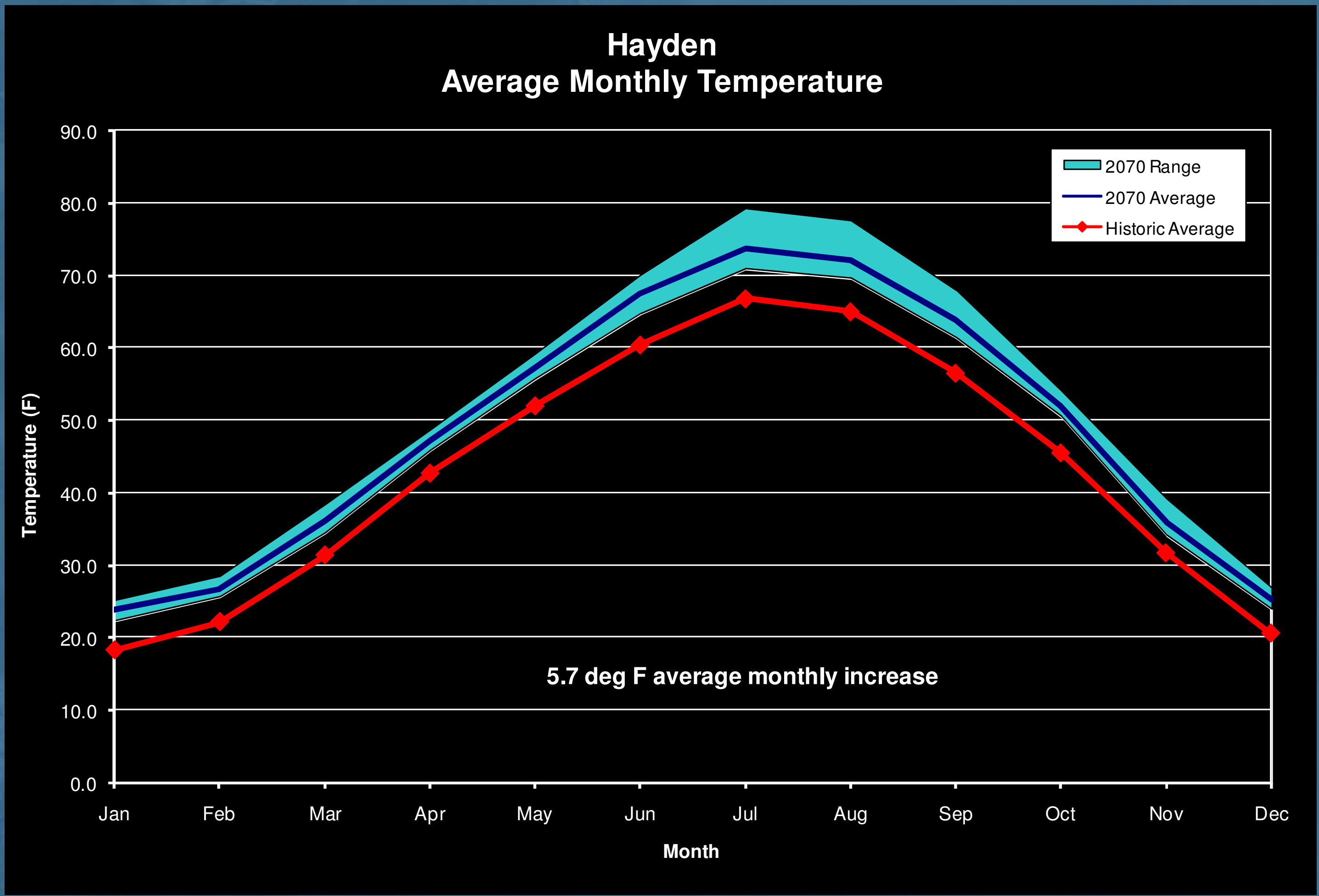
2070 GCM Temperature Results



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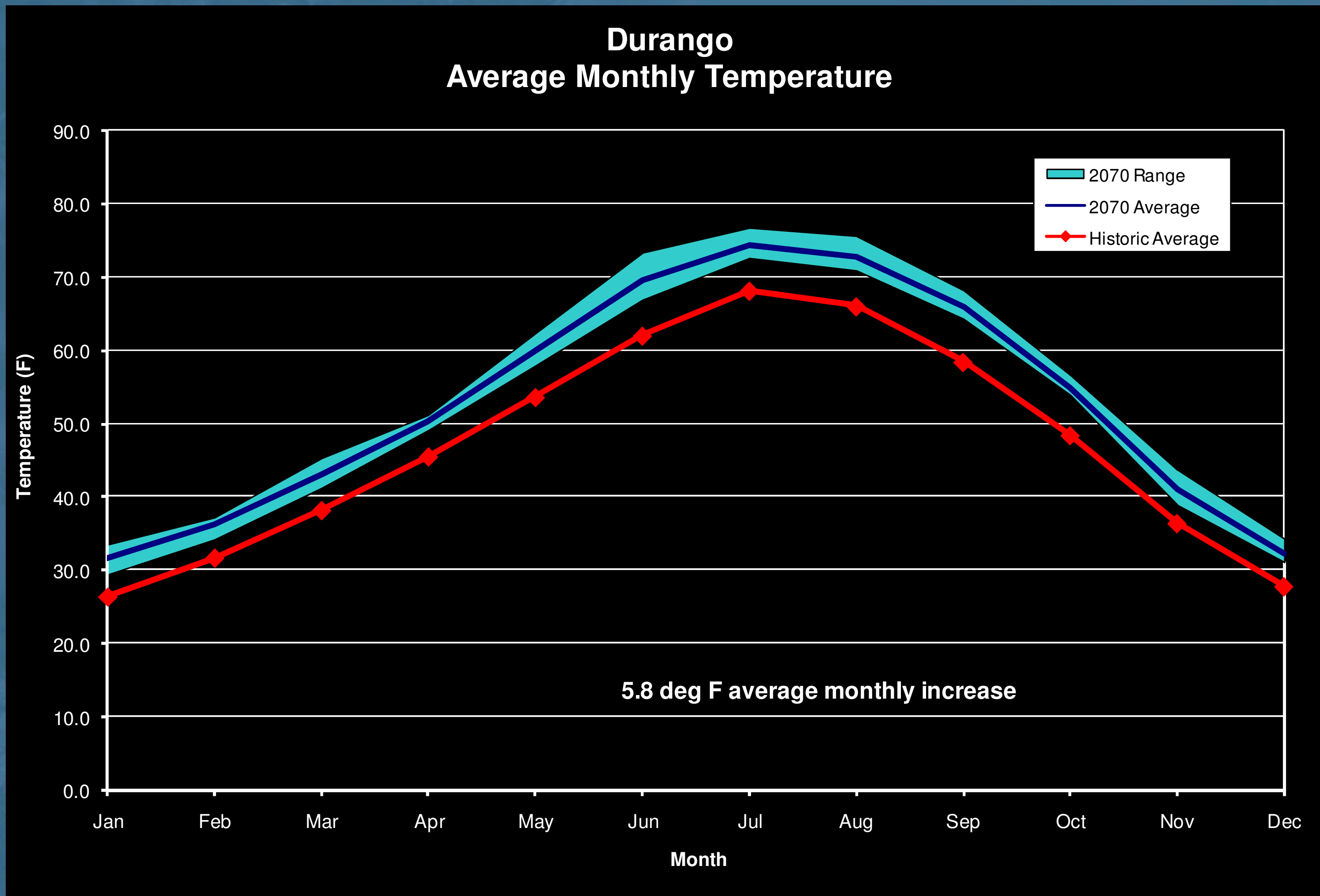
2070 GCM Temperature Results



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2040 and 2070 Effect On Temperature

Average Annual Projected Temperature Compared to Historic

Climate Station	Elevation	Designation	Location	Delta Temperature Degree Fahrenheit	
				2040	2070
Fruita 1W	4480	Lower	North	3.8	6.0
Glenwood Springs No 2	5880	Mid	North	3.5	5.8
Grand Lake 6SSW	8288	Higher	North	3.3	5.5
Rangely 1E	5290	Lower	North	3.6	6.0
Meeker 3W	6180	Mid	North	3.6	5.9
Maybell	5908	Lower	North	3.5	5.9
Hayden	6440	Mid	North	3.4	5.7
Yampa	7890	Higher	North	3.5	5.8
Delta 3E	5010	Lower	South	3.7	5.9
Montrose No 2	5785	Mid	South	3.6	5.9
Gunnison 3SW	7640	Higher	South	3.5	5.7
Cortez	6153	Lower	South	3.6	5.9
Durango	6592	Mid	South	3.5	5.8
Norwood	7020	Higher	South	3.6	5.9
Basin-wide Average				3.6	5.8

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2040 GCM's Effect On Precipitation

Winter Precipitation
Increases Basin-wide

Precipitation Increases
More in Northern CO

Precipitation Increases
More at Higher
Elevations

Historical Average
Generally Falls within
Range of GCMs

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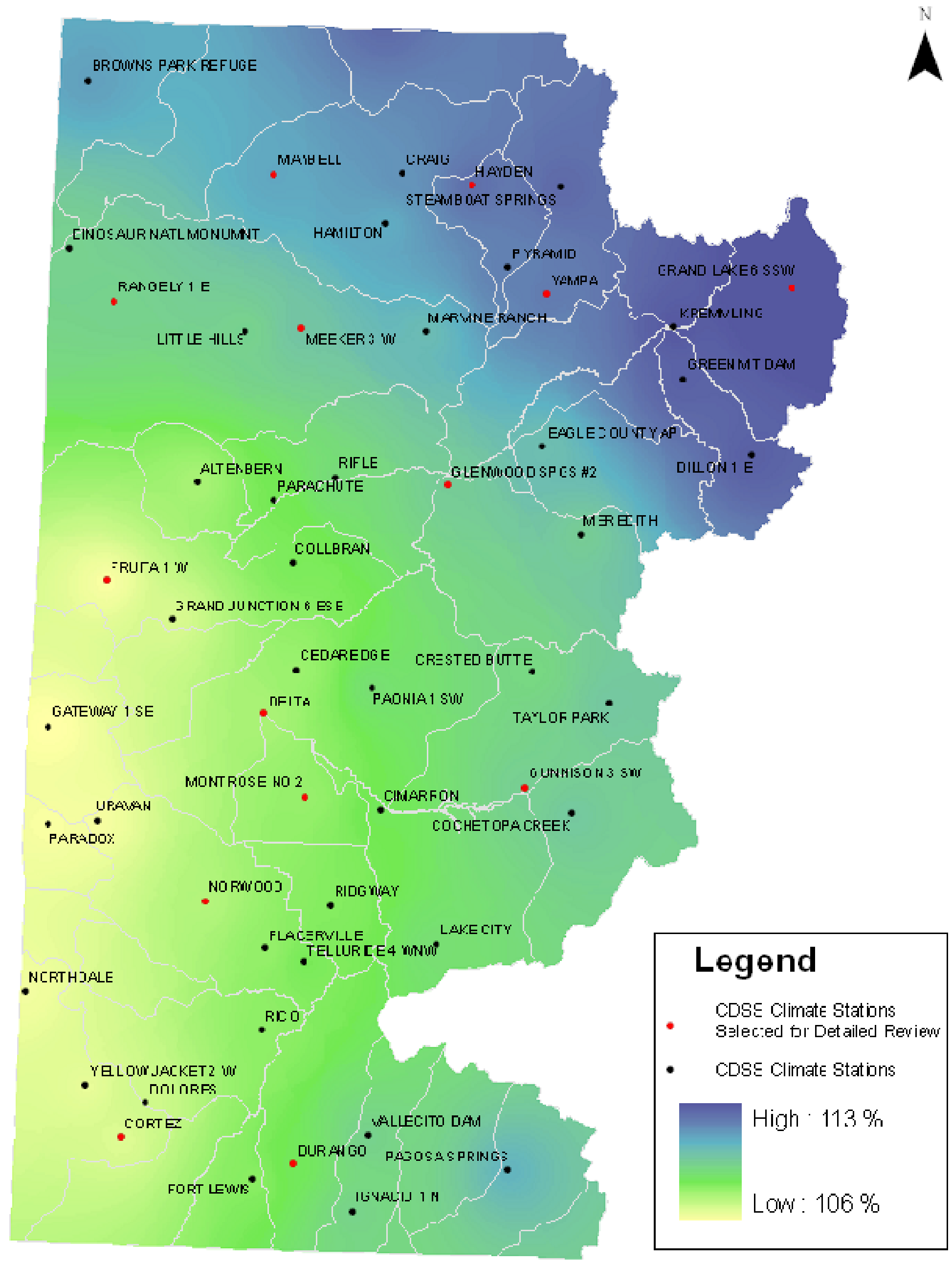

Figure 3 - 2040 Percent of Historical Winter (Nov - Mar) Precipitation

2040 GCM's Effect On Precipitation

Summer Precipitation
Decreases Basin-wide

Precipitation Decreases
More in Southern CO

Precipitation Decreases
Less at Higher
Elevations

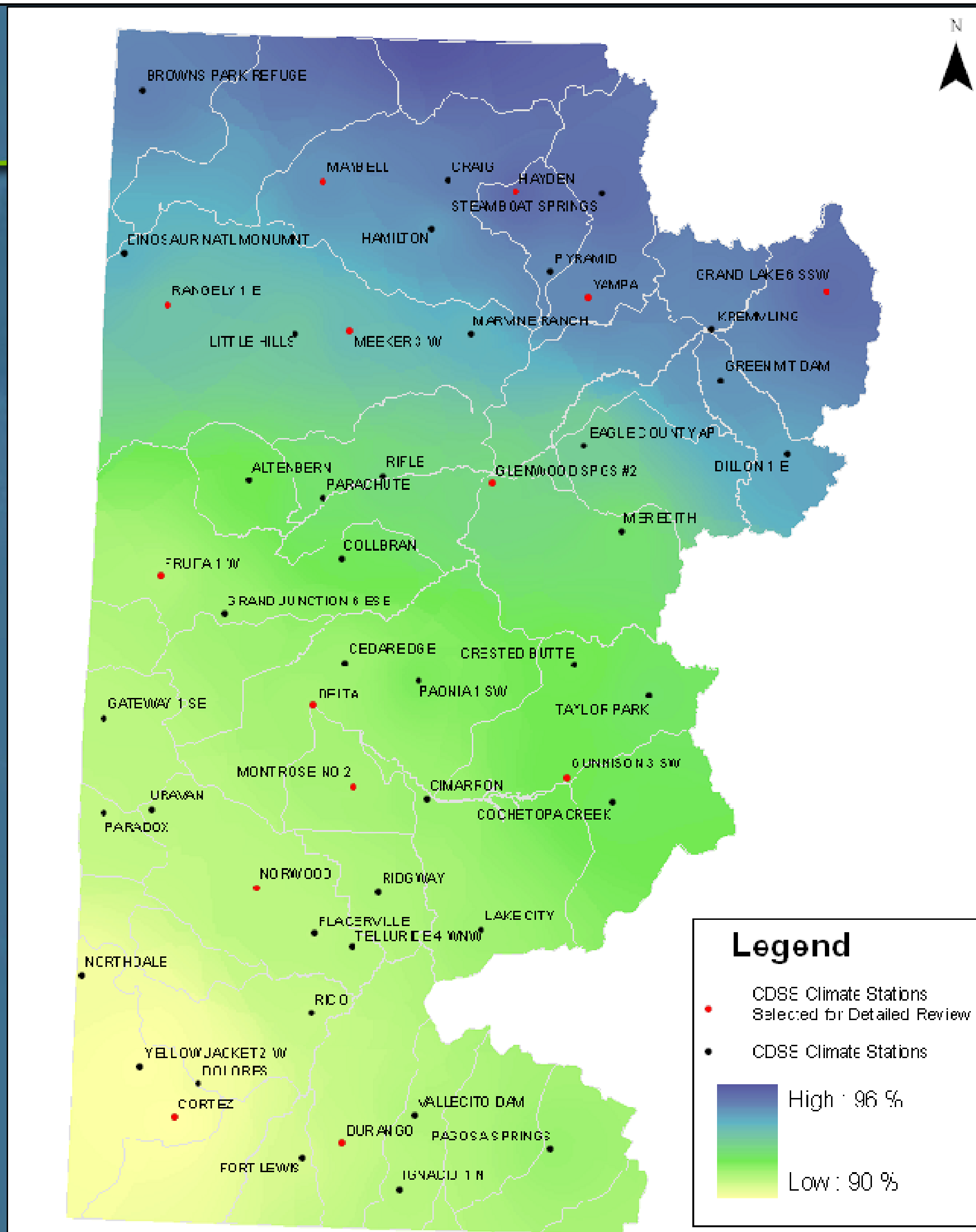

Figure 5 - 2040 Percent of Historical Irrigation Season (Apr-Oct) Precipitation

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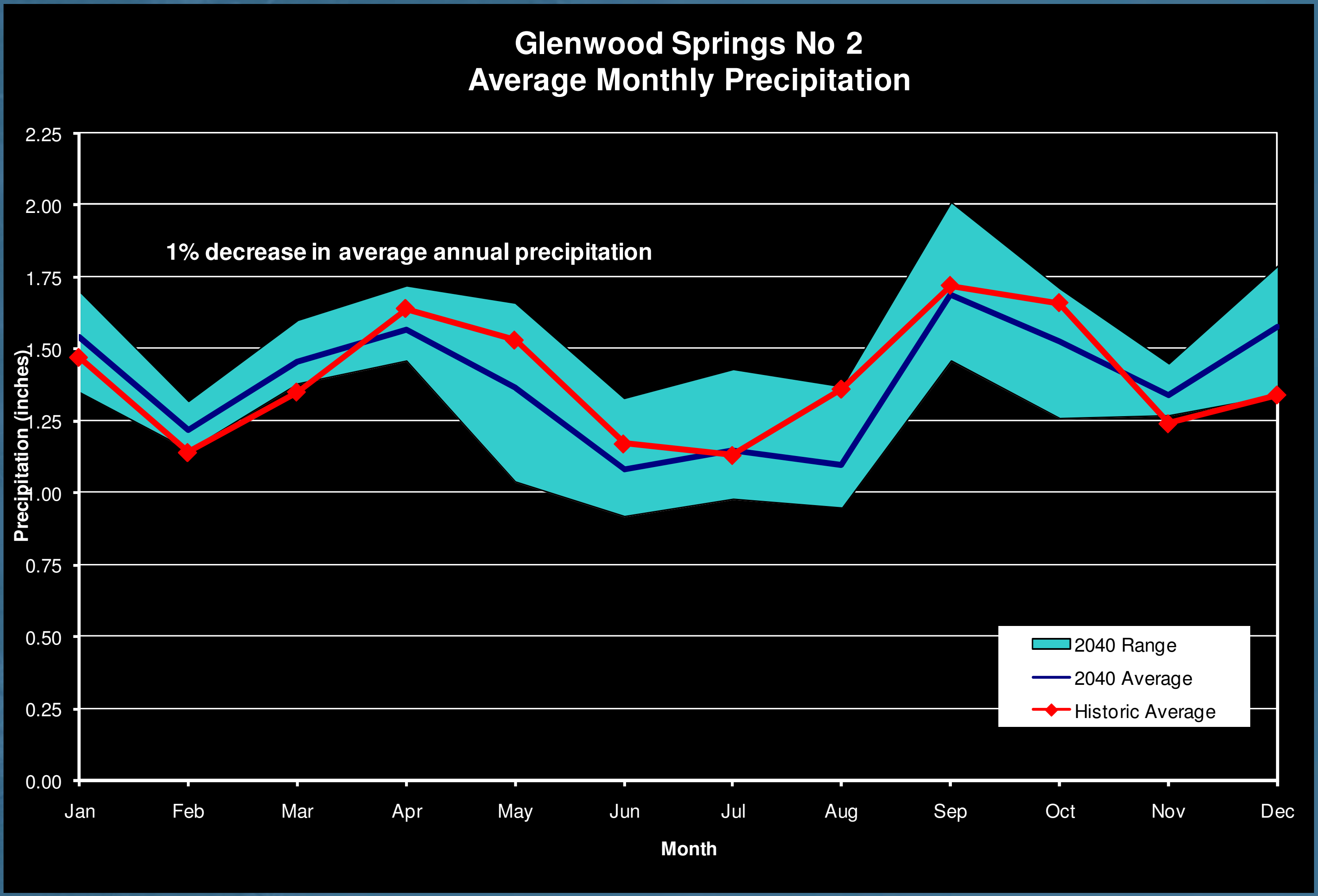
2040 GCM Precipitation Results



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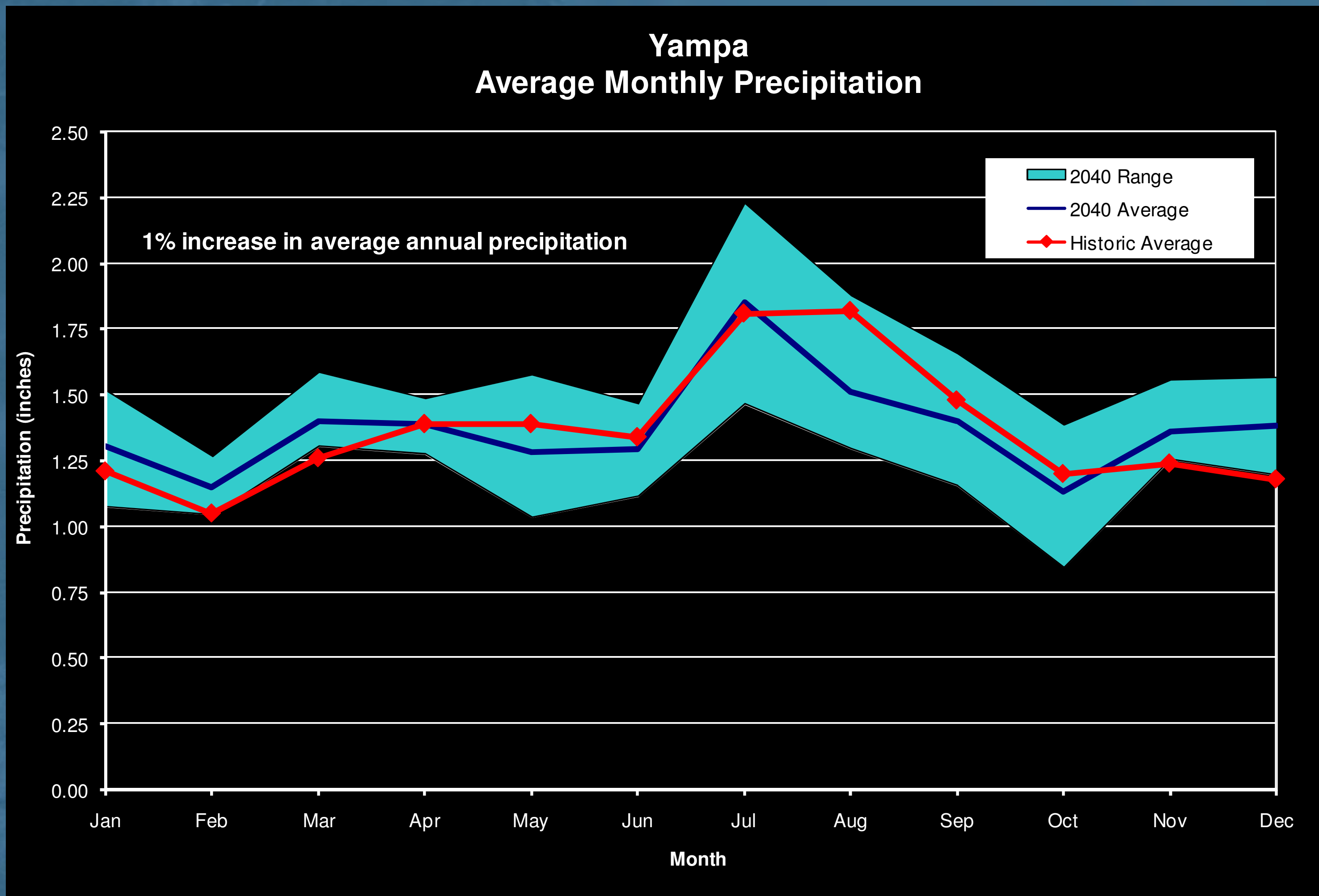
2040 GCM Precipitation Results



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2070 GCM's Effect On Precipitation

Winter Precipitation
Increases in Northern CO

Precipitation Increases
More at Higher Elevations

Winter Precipitation Does
Not Increase in Southern CO

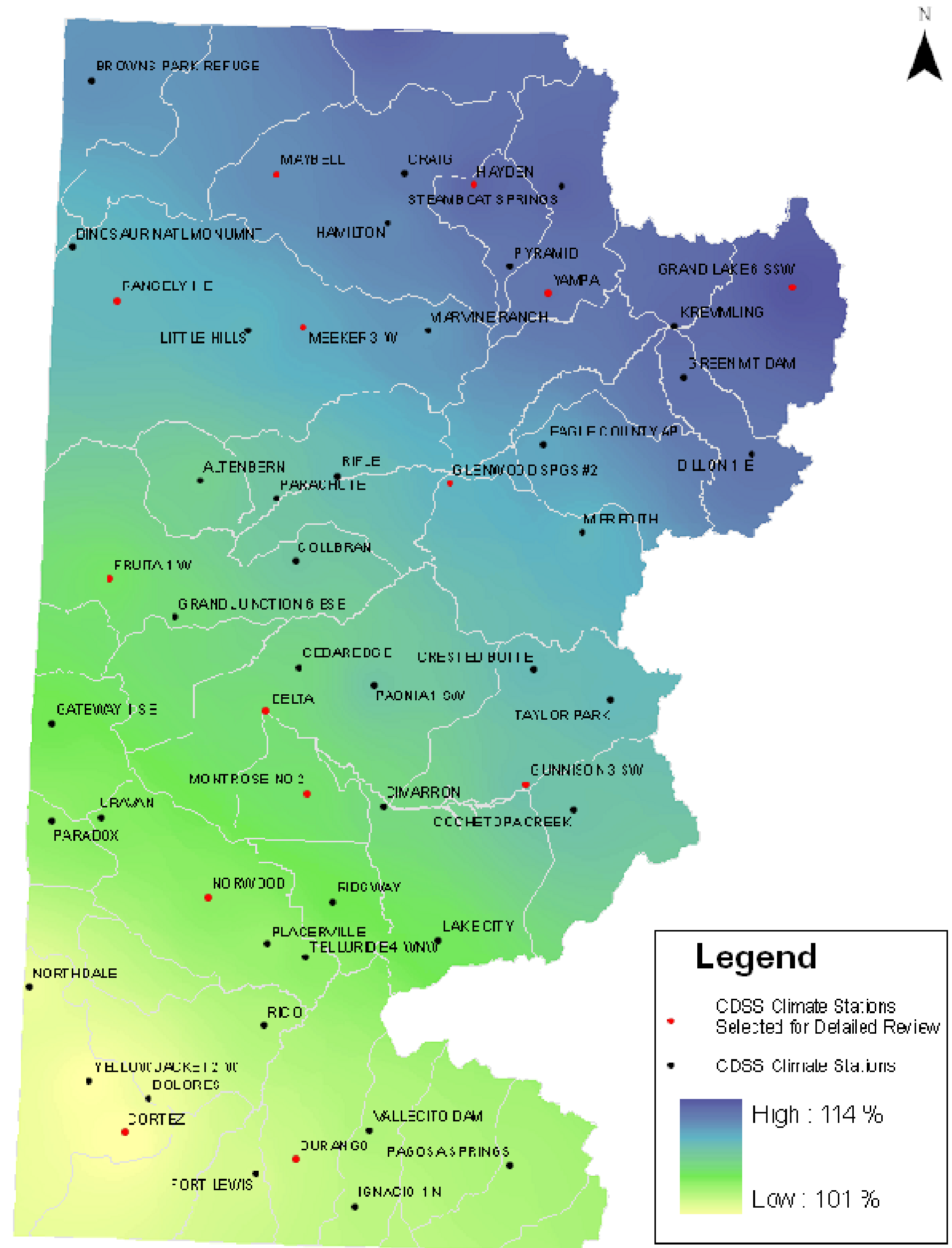

Figure 4 - 2070 Percent of Historical Winter (Nov - Mar) Precipitation

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2070 GCM's Effect On Precipitation

Summer Precipitation
Decreases Basin-wide

Precipitation Decreases
More in Southern CO

Precipitation Decreases
Less at Higher
Elevations

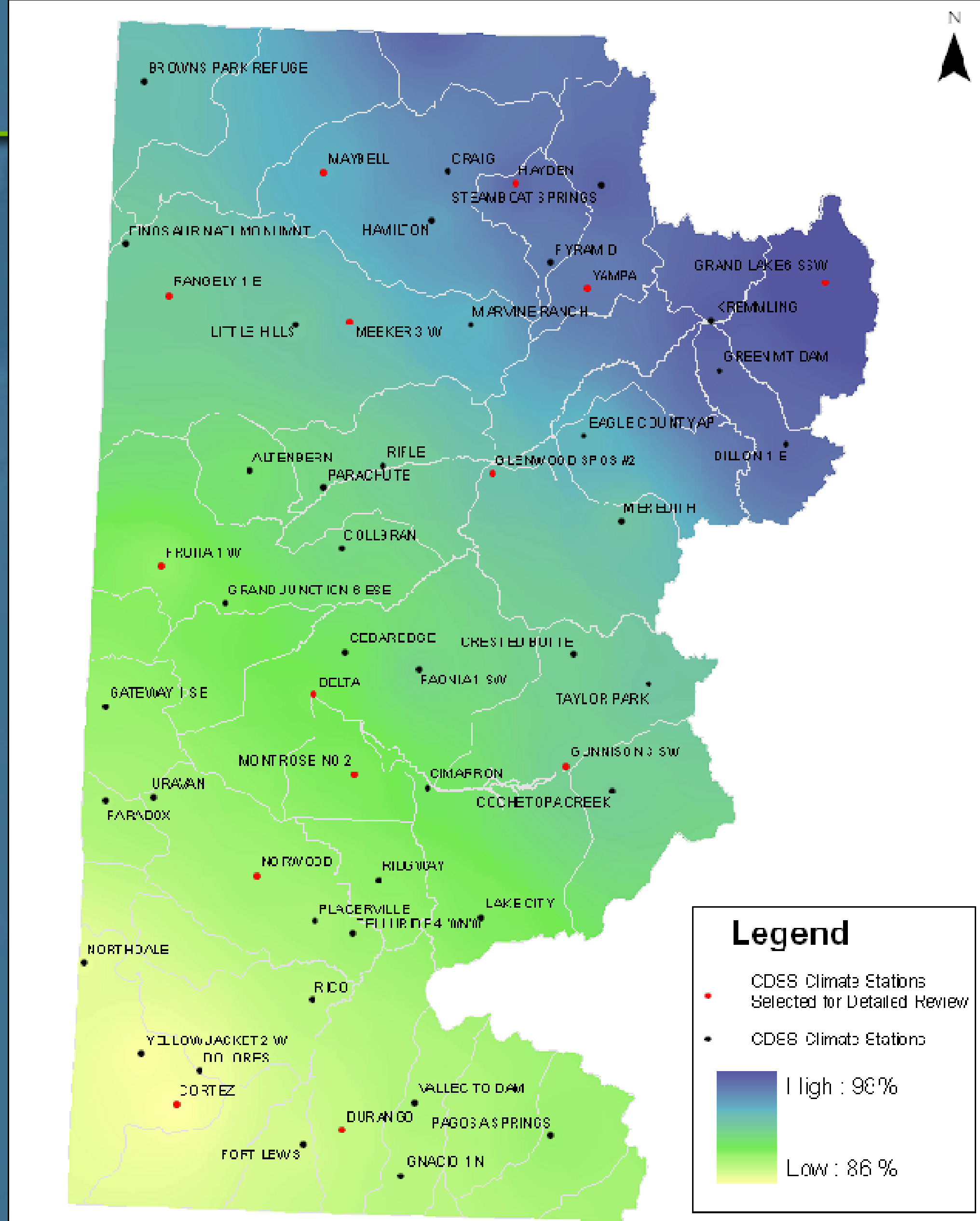

Figure 6 - 2070 Percent of Historical Irrigation Season (Apr-Oct) Precipitation

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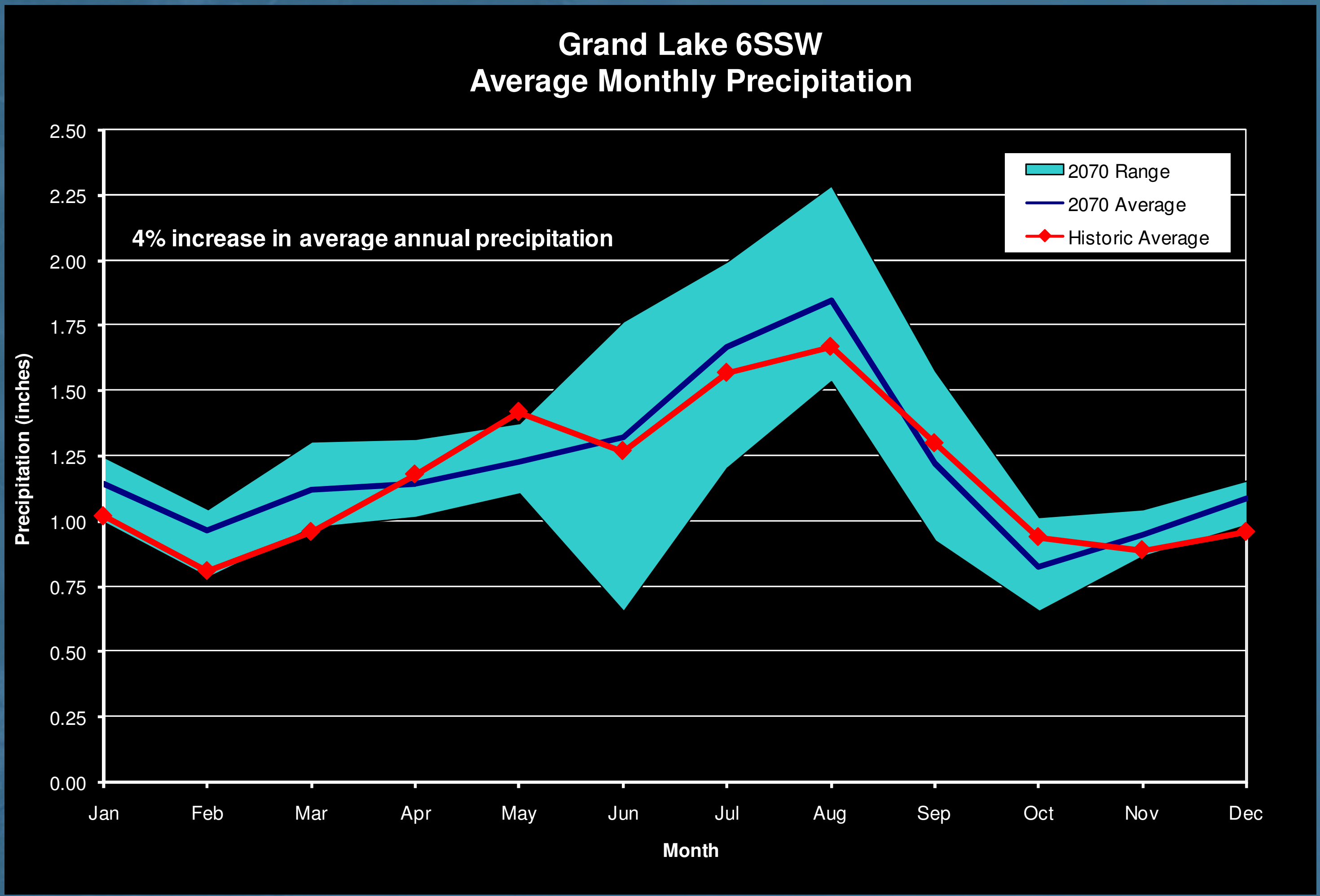
2070 GCM Precipitation Results



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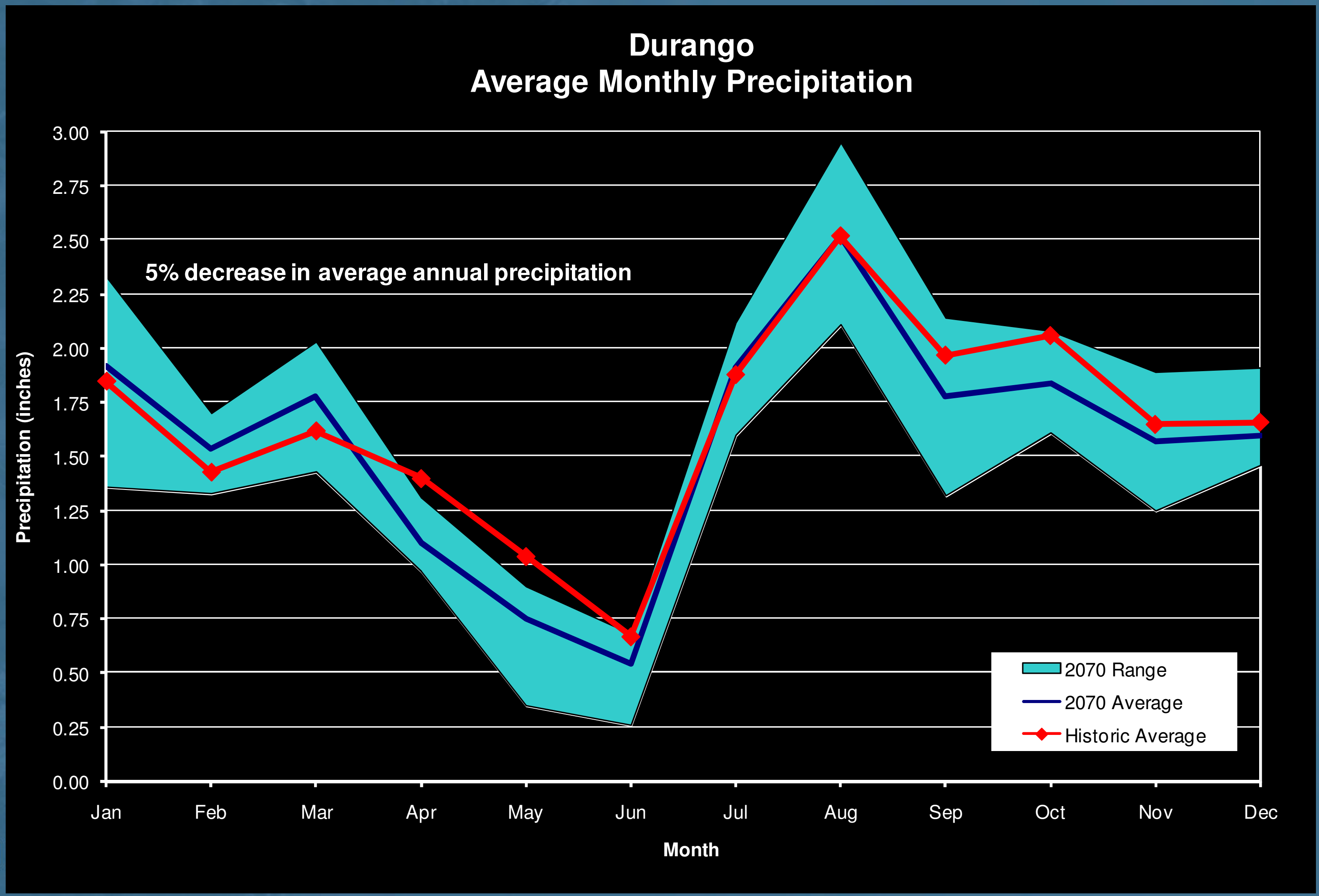
2070 GCM Precipitation Results



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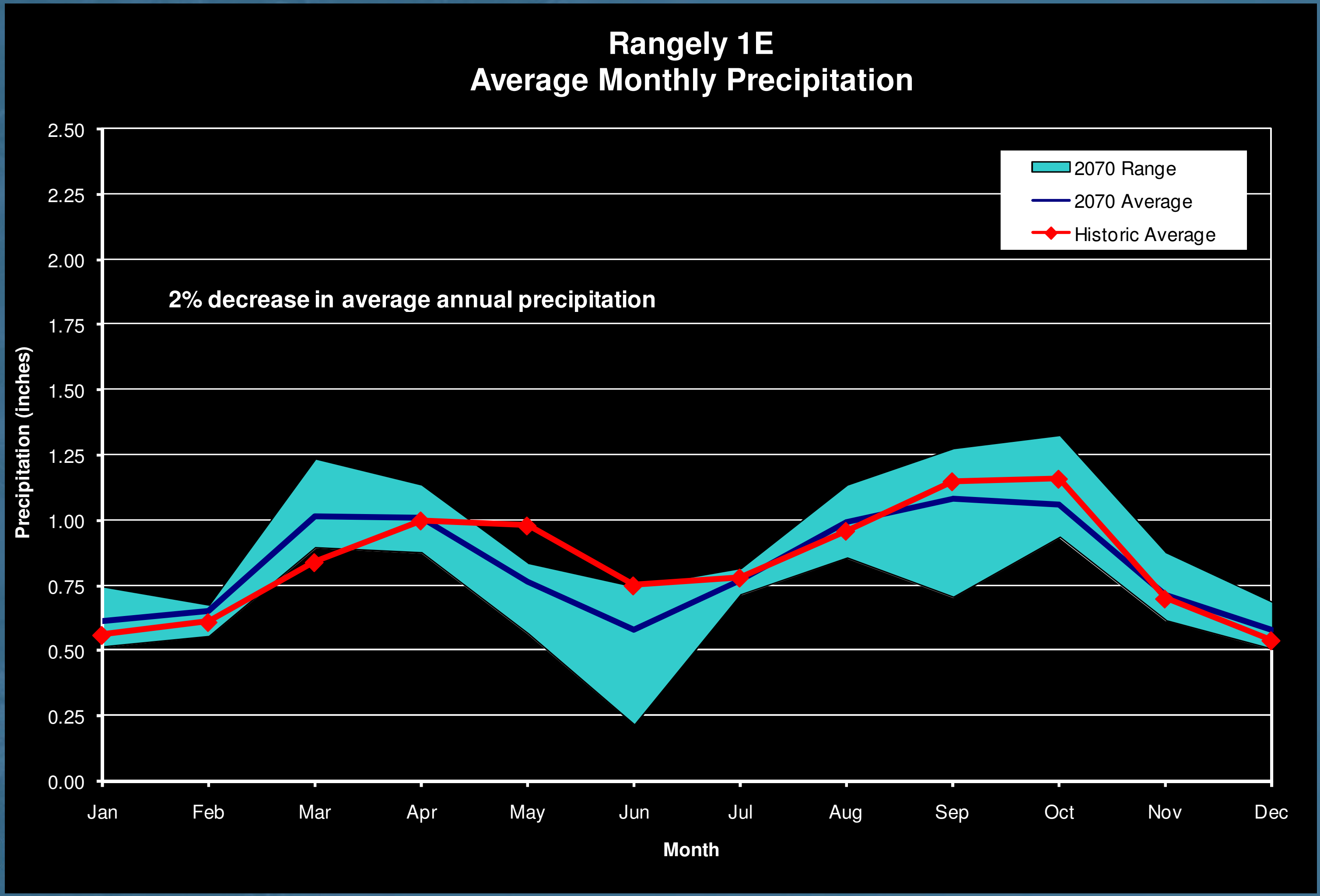
2070 GCM Precipitation Results



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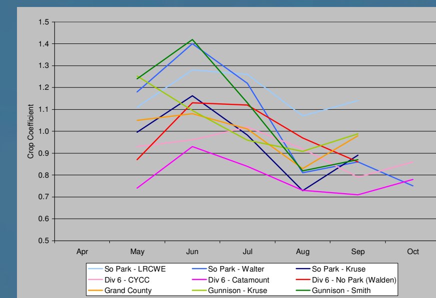
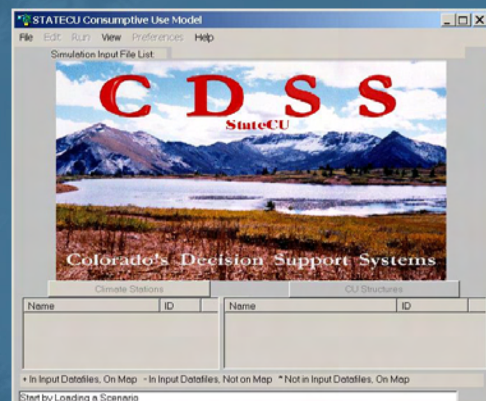
Historical Consumptive Use Analysis Overview

Supplemental Sources User Info

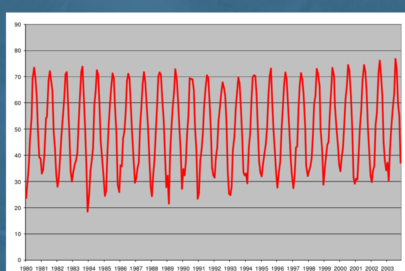
Irrigated Acreage, Crop Type, Irrigation Method



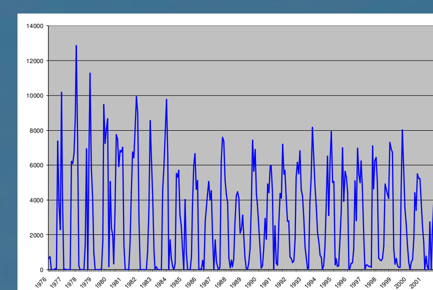
CU Method Review and Selection



Climate Data



Water Supply Data



Irrigation Efficiencies

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Basin Representation Enhancements

- Objective is to Enhance Representation of Current Uses and Operations
- Opportunity to Supplement Documentation
- Provides Basis for Representing the Effects of Alternate Historical Hydrology and Climate Projection
- Enhancements were recommended and incorporated into both StateCU and StateMod Datasets

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Consumptive Use Analysis Enhancements

- Revised Blaney-Criddle Method to incorporate Standard Recommended Elevation Adjustment
  - Grass Pasture above 6500 feet continues to be estimated using High-altitude coefficients
  - Elevation adjustment applied to other crops above 6500, and all crops below 6500 feet

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Consumptive Use Analysis Enhancements

- Maximum Irrigation System Efficiencies Revised
  - Revised in Upper Gunnison to match Subordination Report estimates
  - Revised throughout Colorado Basin to better represent operations
- Incorporate Current Redlands Canal Irrigation Demands (Revise Acreage and Irrigation Practices)

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Consumptive Use Analysis Enhancements

- Used Revised CU Estimates to Update Consumptive Uses and Loses Report required by the Colorado River Basin Project Act of 1968
- Developed Stand-Alone Historical Crop Consumptive Use Documentation for each Basin
  - Acreage estimates
  - Diversion records
  - Crop irrigation Requirements
  - Actual (supply-limited) consumptive use

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Consumptive Use Analysis – Updated Historical

Basin	Previous CIR	New CIR	Previous CU	New CU
Yampa	172,900	183,900	130,400	139,700
White	40,200	46,400	38,000	42,500
Upper Colorado	503,900	574,500	436,600	485,600
Gunnison	555,900	618,900	448,400	513,600
San Juan/Dolores	481,000	518,500	346,400	358,200
Total	1,753,800	1,942,200	1,399,800	1,539,600

- Basin-wide CIR Increased by 10 percent with Enhancements
- Supply-Limited (Actual) CU increased by 9 percent

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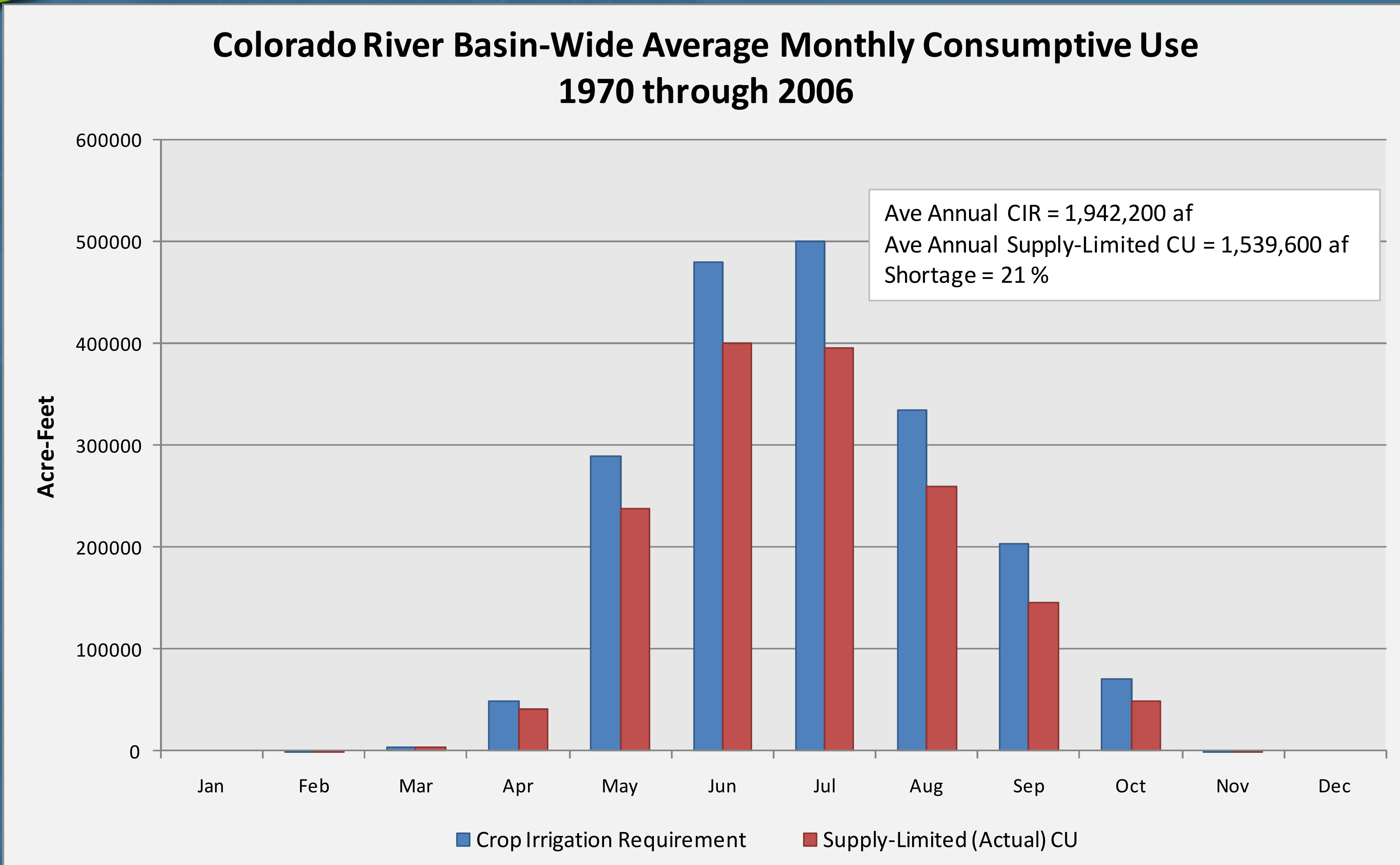
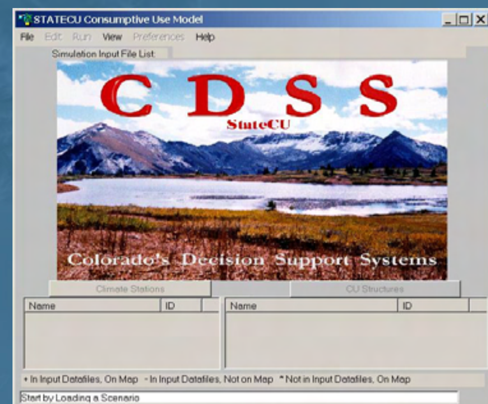
Consumptive Use Analysis – Updated Historical

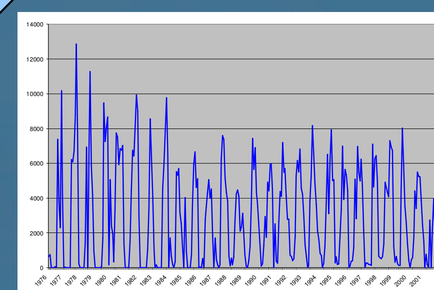


Crop Irrigation Requirements – Climate Variability

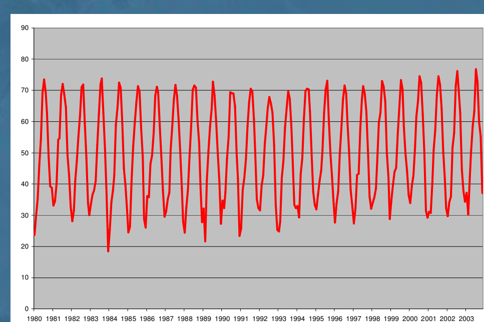
Current Irrigated Acreage, Crop Type



2040 and 2070 Projected Temperature and Precipitation Data



Re-sequenced Historical (Paleo) Temperature and Precipitation



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Climate-Based Crop Irrigation Requirement

Climate Variation Affects

- Growing Season
  (Warmer Spring = Earlier Growth)
  (Warmer Fall = Extended Season)

- Monthly Irrigation Requirements
  (Warmer Temperature = Higher CIR)

- Monthly Effective Precipitation
  (Less Precipitation = Higher CIR)

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2040 Climate-Based Crop Irrigation Requirement

Percent Increase CIR is Less at Higher Elevations

Increase is Primarily Temperature Driven

2040 Average Annual Crop Irrigation Requirement (CIR) and Growing Season Length Compared to Historical

Climate Station	% Difference CIR	Increase in CIR (inches)	# Days Increase Start Growing Season	# Days Increase End Growing Season	# Days Increase Growing Season
Fruita 1W	21%	6.38	11	7	18
Glenwood Springs	25%	5.81	11	8	19
Grand Lake 6SSW	16%	3.67	9	9	18
Rangely 1E	22%	6.02	9	7	16
Meeker 3W	28%	5.47	10	8	18
Maybell	26%	5.16	9	7	16
Hayden	25%	4.75	8	7	15
Yampa	13%	3.29	9	8	17
Delta 3E	21%	6.43	11	7	18
Montrose No 2	23%	6.36	12	8	20
Gunnison 3SW	13%	3.5	9	7	16
Cortez	24%	6.24	14	8	22
Durango	10%	2.81	13	8	21
Norwood	10%	2.74	9	8	16
Average	20%	4.90	10.5	7.6	18.1

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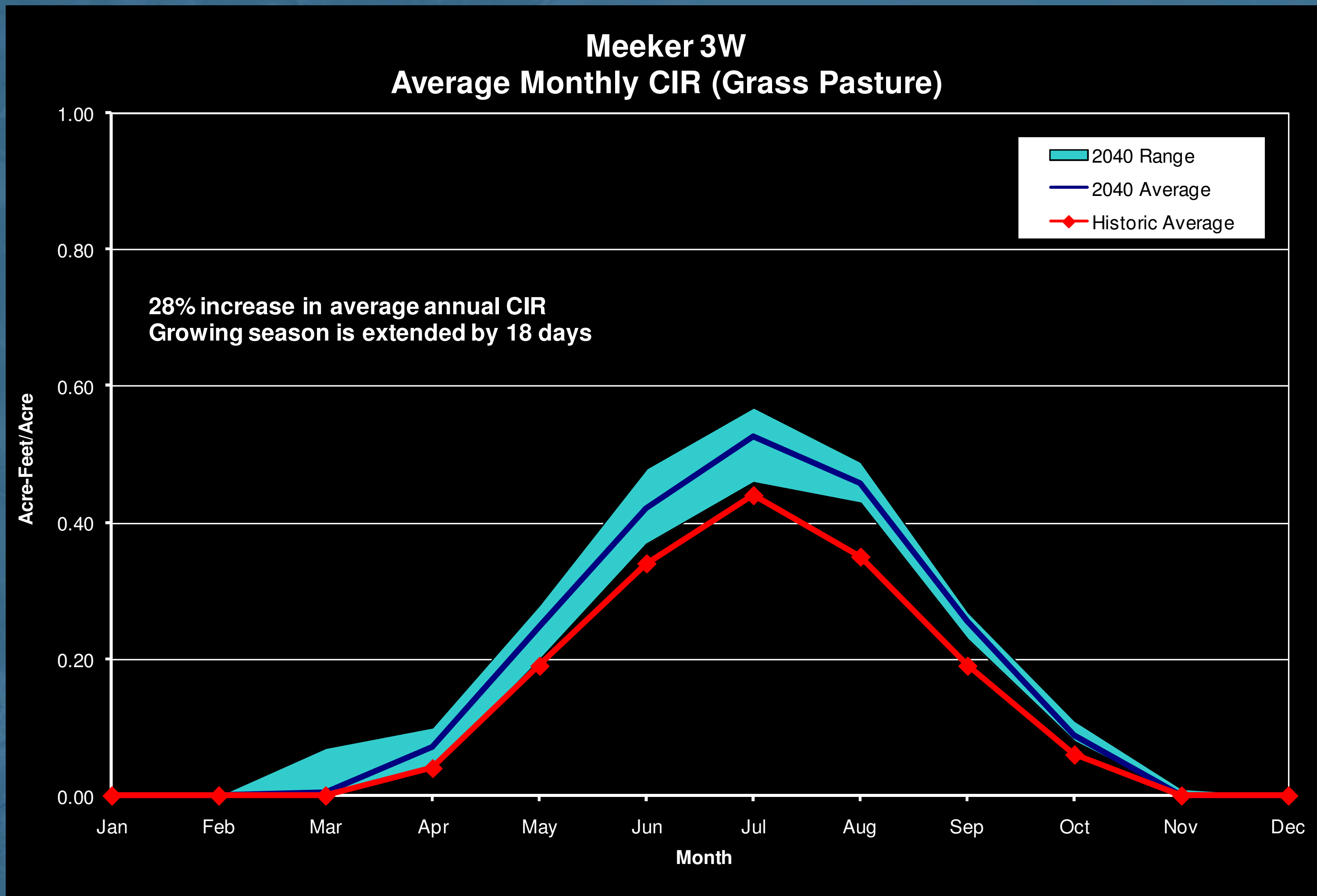
2040 Climate-Based Crop Irrigation Requirement



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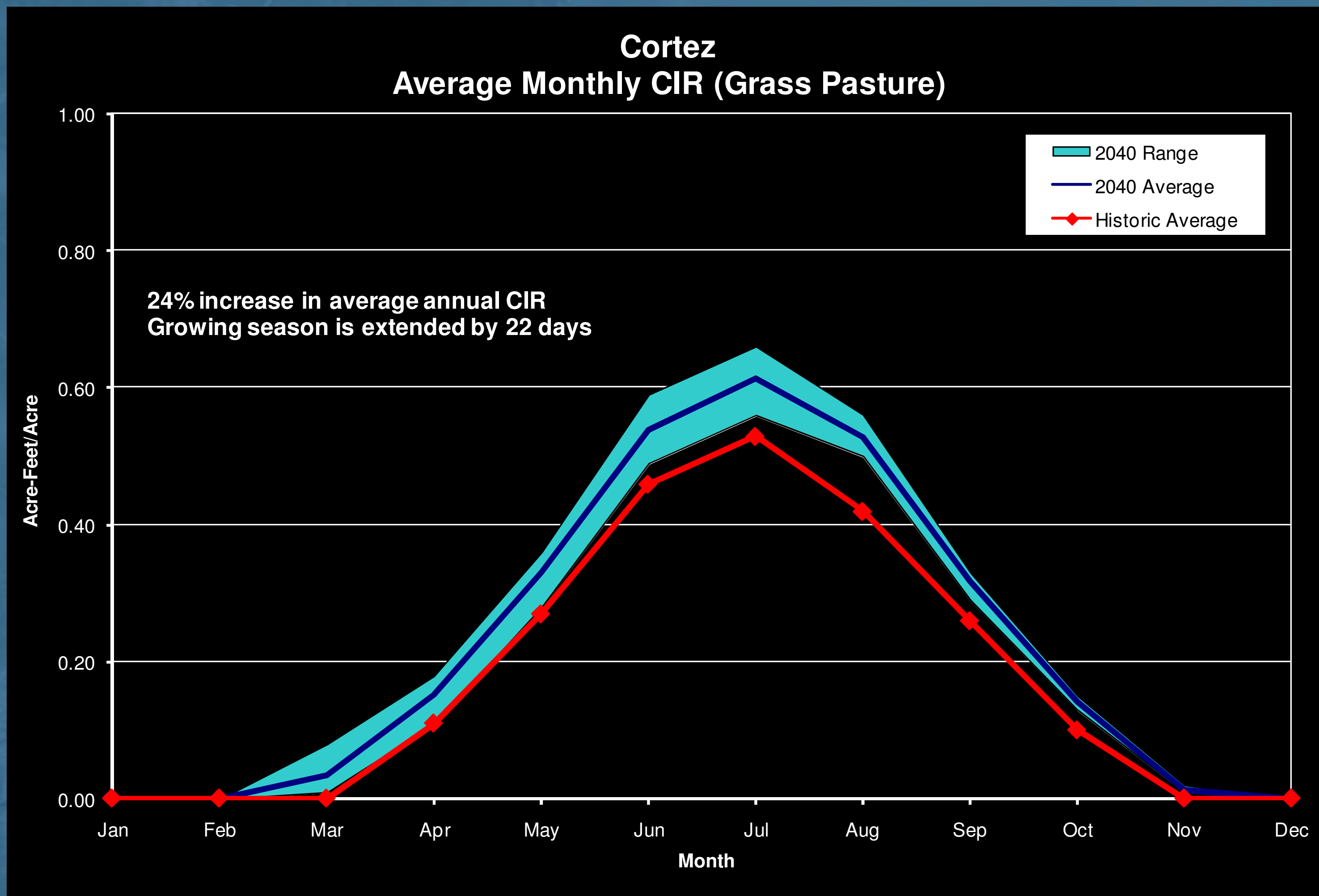
2040 Climate-Based Crop Irrigation Requirement



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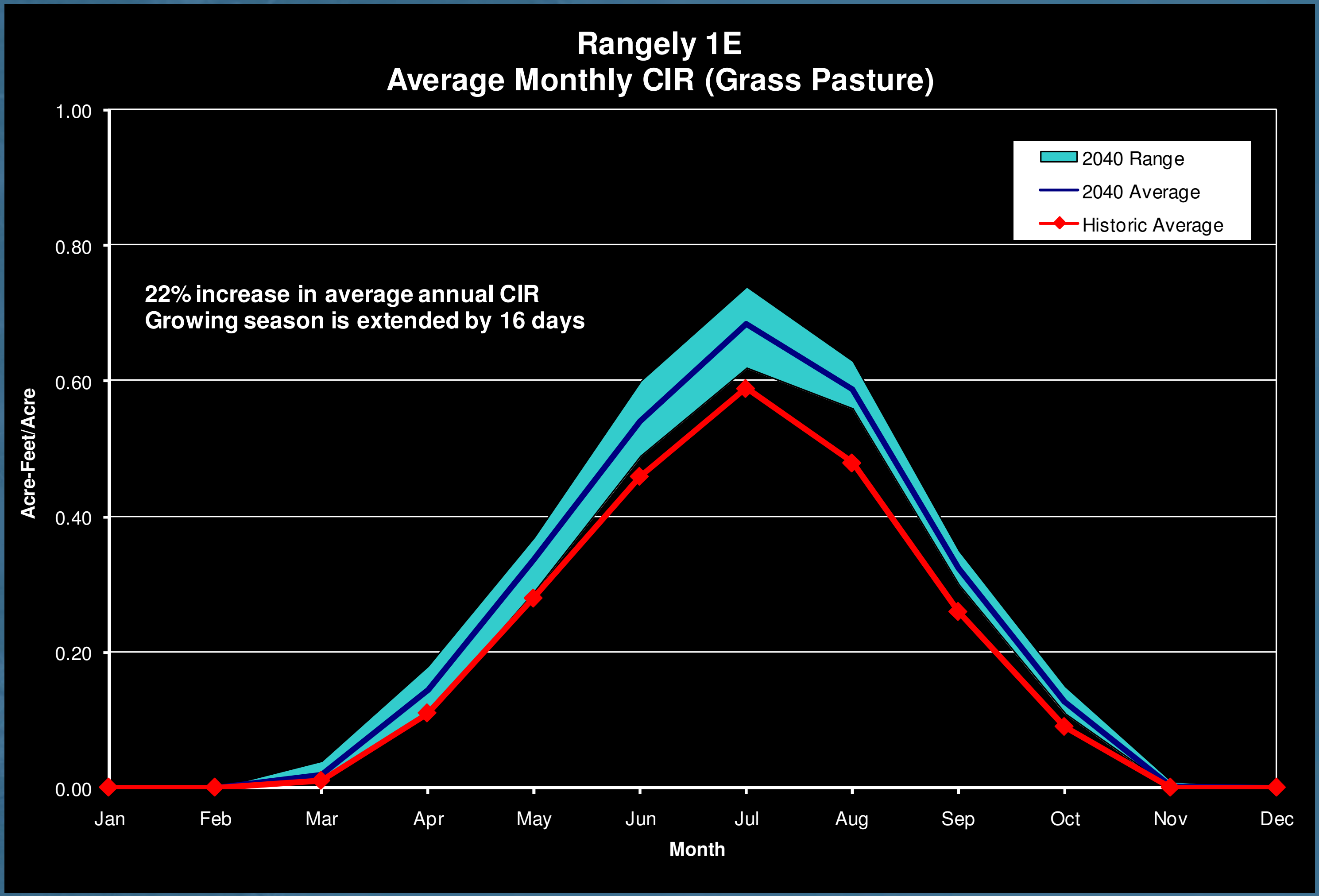
2040 Climate-Based Crop Irrigation Requirement



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2070 Climate-Based Crop Irrigation Requirement

Percent Increase CIR is Less at Higher Elevations

Increase is Primarily Temperature Driven

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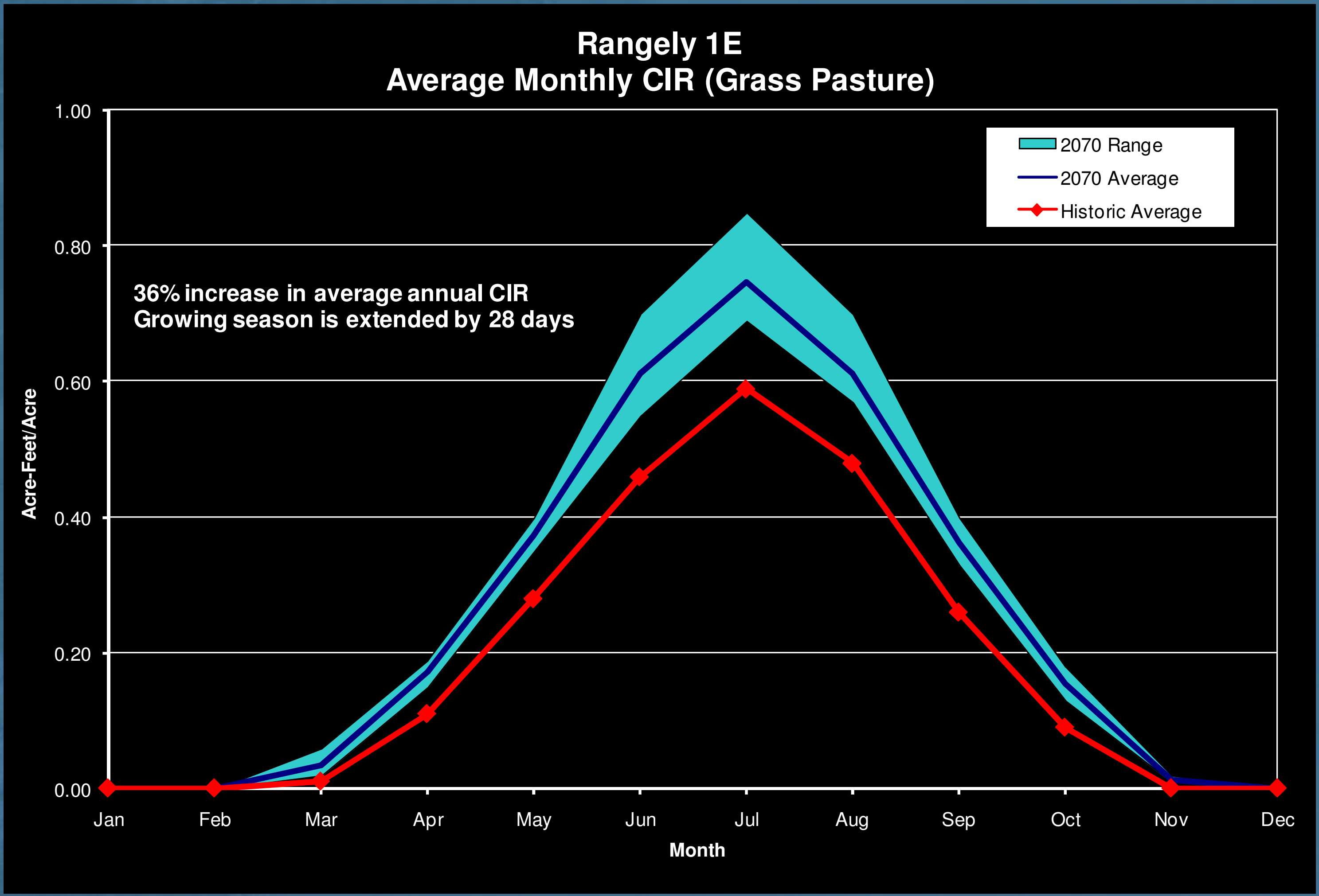
2070 Average Annual Crop Irrigation Requirement and Growing Season Length Compared to Historical

Climate Station	% Difference CIR	Increase in CIR (inches)	# Days Increase Start Growing Season	# Days Increase End Growing Season	# Days Increase Growing Season
Fruita 1W	34%	10.15	18	12	30
Glenwood Springs	40%	9.14	19	13	32
Grand Lake 6SSW	24%	5.47	15	15	30
Rangely 1E	36%	9.67	16	12	28
Meeker 3W	44%	8.59	17	14	31
Maybell	42%	8.45	15	13	28
Hayden	42%	8.11	14	13	27
Yampa	20%	4.87	14	13	27
Delta 3E	34%	10.18	17	12	28
Montrose No 2	36%	10.01	18	13	31
Gunnison 3SW	19%	5.09	14	13	27
Cortez	38%	9.89	21	13	34
Durango	15%	4.15	20	13	23
Norwood	14%	4.08	19	13	32
Average	31%	7.7	17.0	13.0	29.0

2070 Climate-Based Crop Irrigation Requirement



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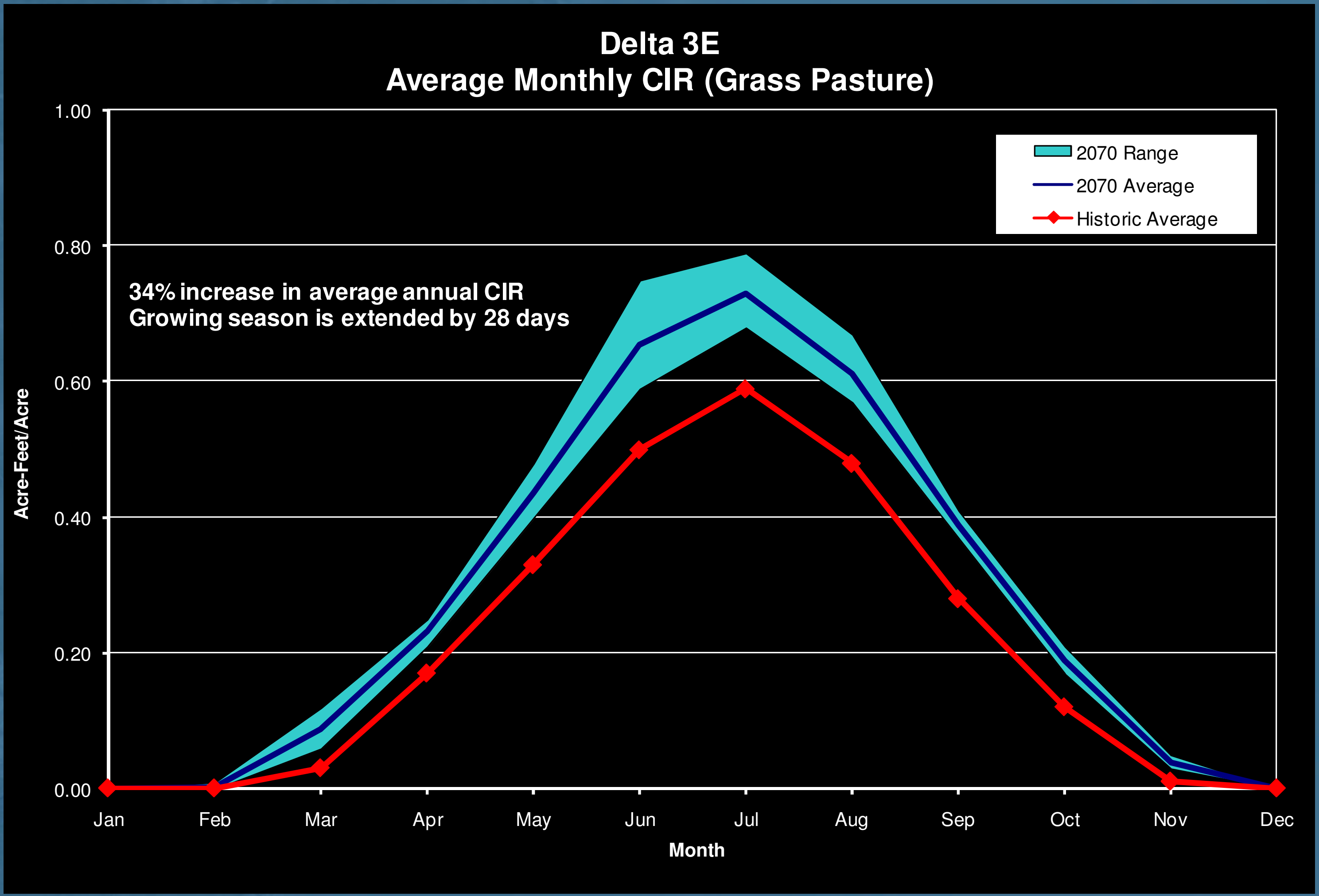
2070 Climate-Based Crop Irrigation Requirement



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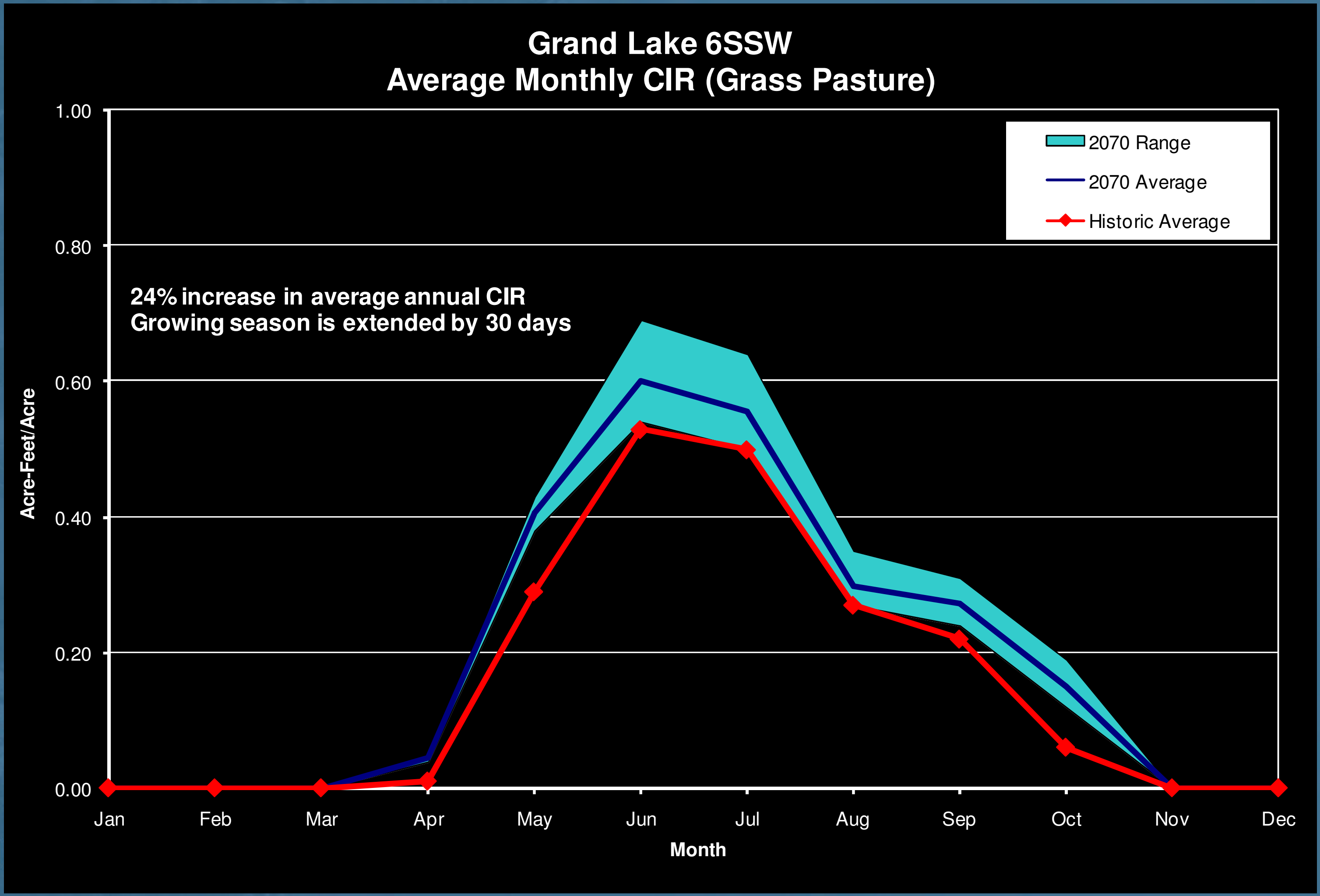
2070 Climate-Based Crop Irrigation Requirement



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Consumptive Use Analysis Input to StateMod

- StateCU determines Agricultural Demands that Reflect Alternative Temperature and Precipitation based on climate projection scenarios
- StateMod Determines how Climate-Based Demands and Projected Hydrology Affect Water Availability
  - Physical water limitation
  - Legal limitation (downstream senior right)

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StateMod Overview

- Generic Water Allocation Model
- Can be Adapted to Any River Basin through Unique Data Sets
- Data Sets Define Basin
- StateMod Operates Based on Colorado's Water Right System

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StateMod Overview

- Linked-Node Model
- Nodes are Locations Where you Have or Need Information
  - Stream Gages
  - Diversion Locations
  - Reservoirs
  - Beginning/End of Instream Flow Segments
  - Return Flow/Discharge Locations

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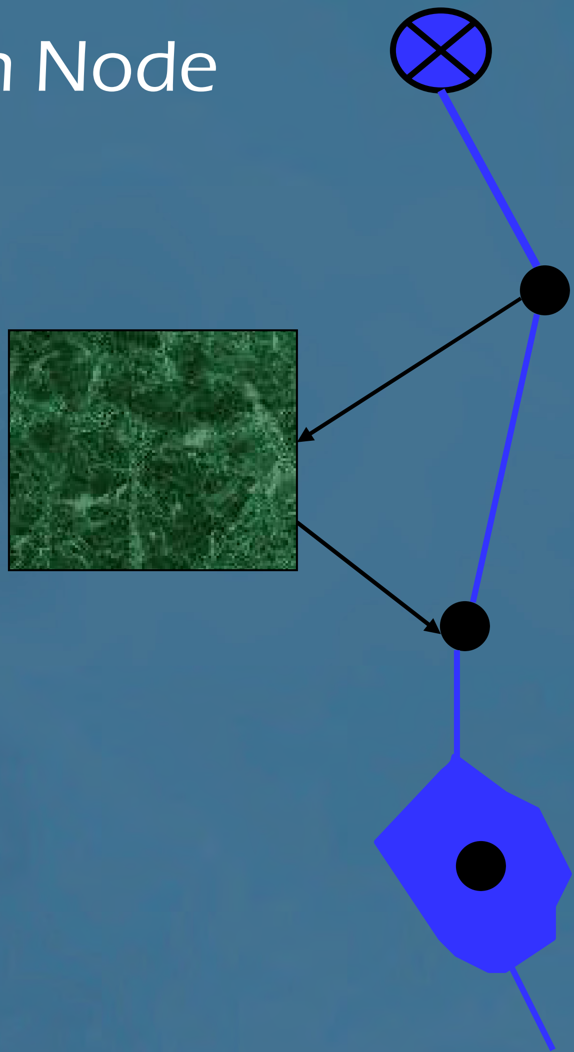
StateMod Overview

- Water is Carried from Node to Node via
  - Rivers
  - Canals
  - Pipelines



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StateMod Model Components

- Inflow Hydrology
- Physical Systems
- Water Demands
- Administrative Conditions

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Inflow Hydrology

- CRWAS Model Period - 1950 through 2005
  - Represents Wet/Dry/Average Periods
  - Minimized Data Filling
  - Sufficiently Long to look at Water Availability over time
- Five Models Represent more than 310 Tributaries

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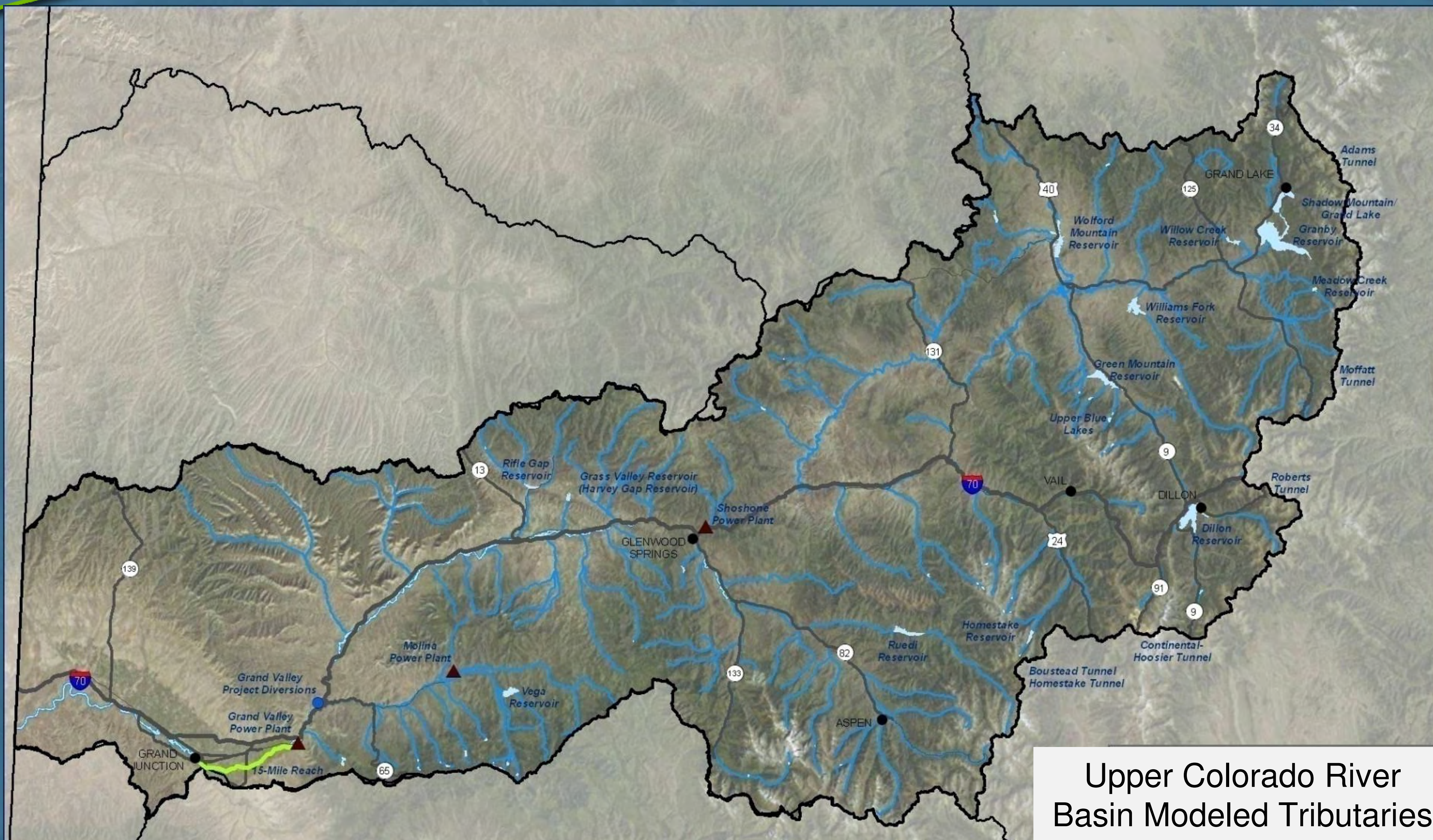
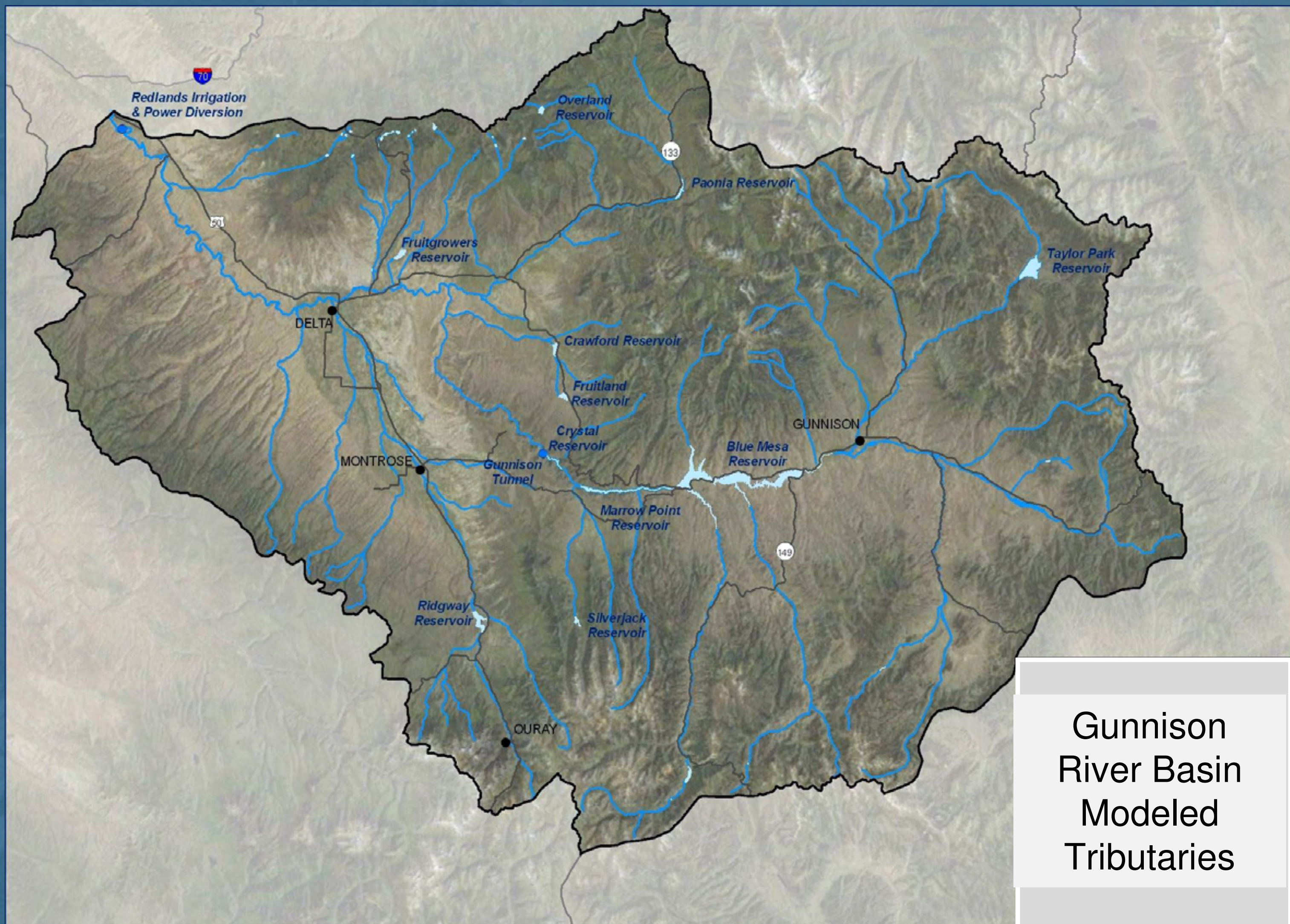
Inflow Hydrology



Upper Colorado River Basin Modeled Tributaries

Inflow Hydrology



Gunnison River Basin Modeled Tributaries

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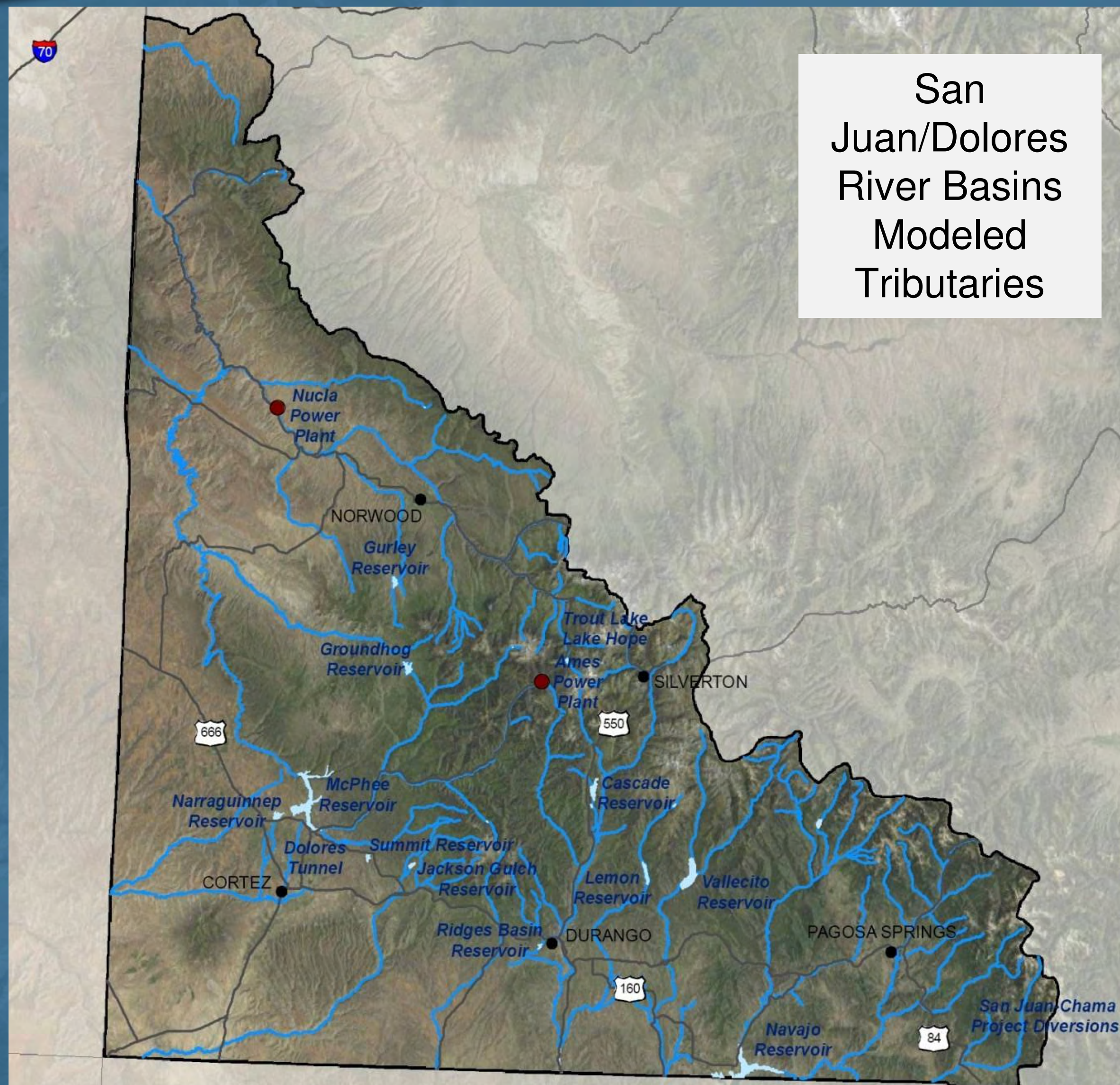
Inflow Hydrology

San Juan/Dolores River Basins Modeled Tributaries



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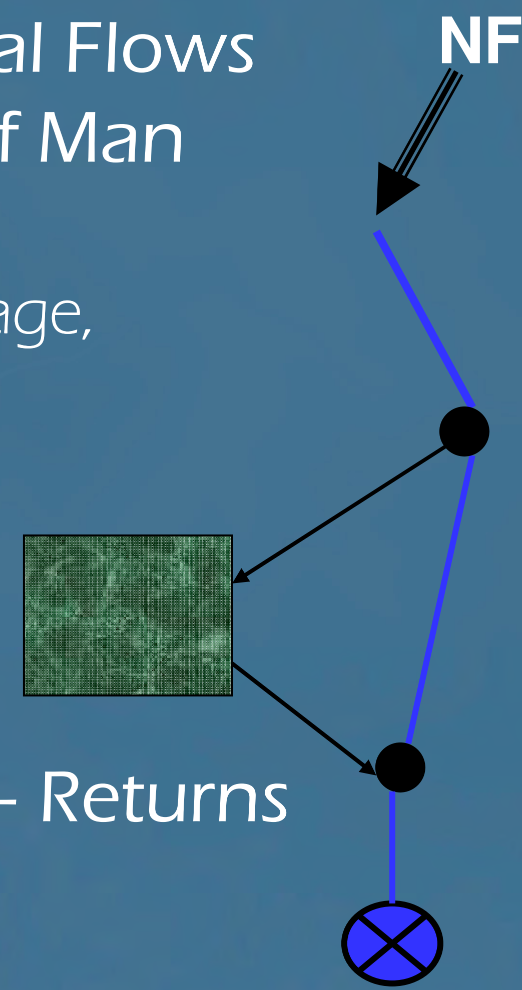
Inflow Hydrology – Natural Flow Development

- StateMod estimates Natural Flows by Removing the Effects of Man
  - Diversions, Return Flows, Changes in Reservoir Storage, Evaporation



- NF = Gaged + Diversions – Returns +/- change in storage

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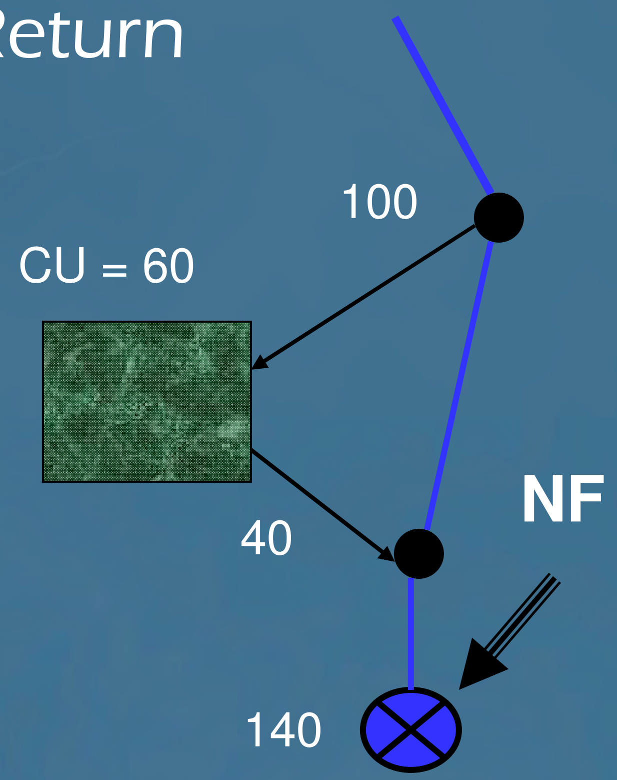
Inflow Hydrology – Natural Flow Development

- Develop NF at Gaged Locations
- NF = Gaged + Divert – Return



NF = 140 + 100 – 40

NF = 200

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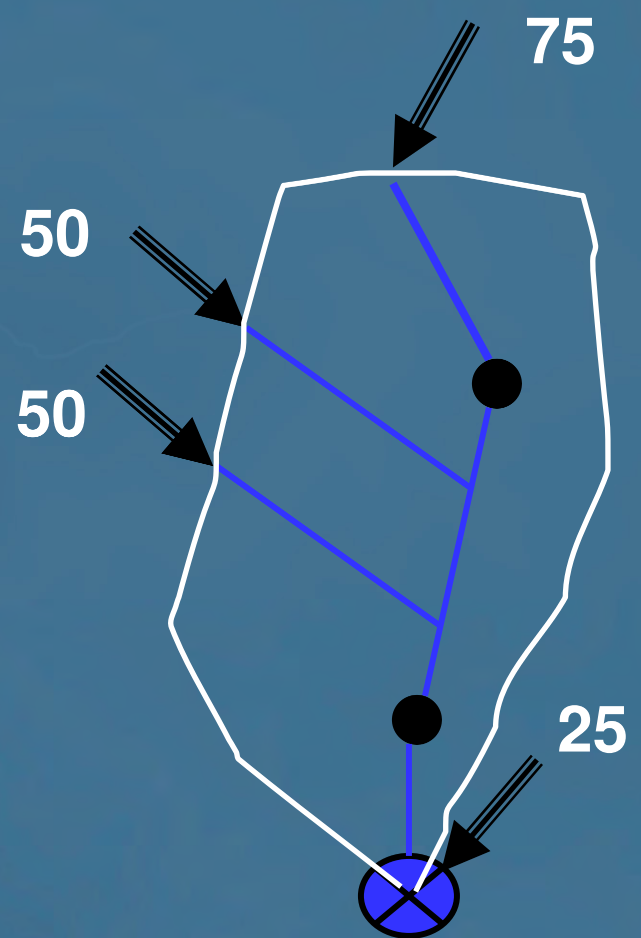
Inflow Hydrology – Natural Flow Development

- Distribute Natural Flow Gains to ungaged tributaries

Overall Gain = 200



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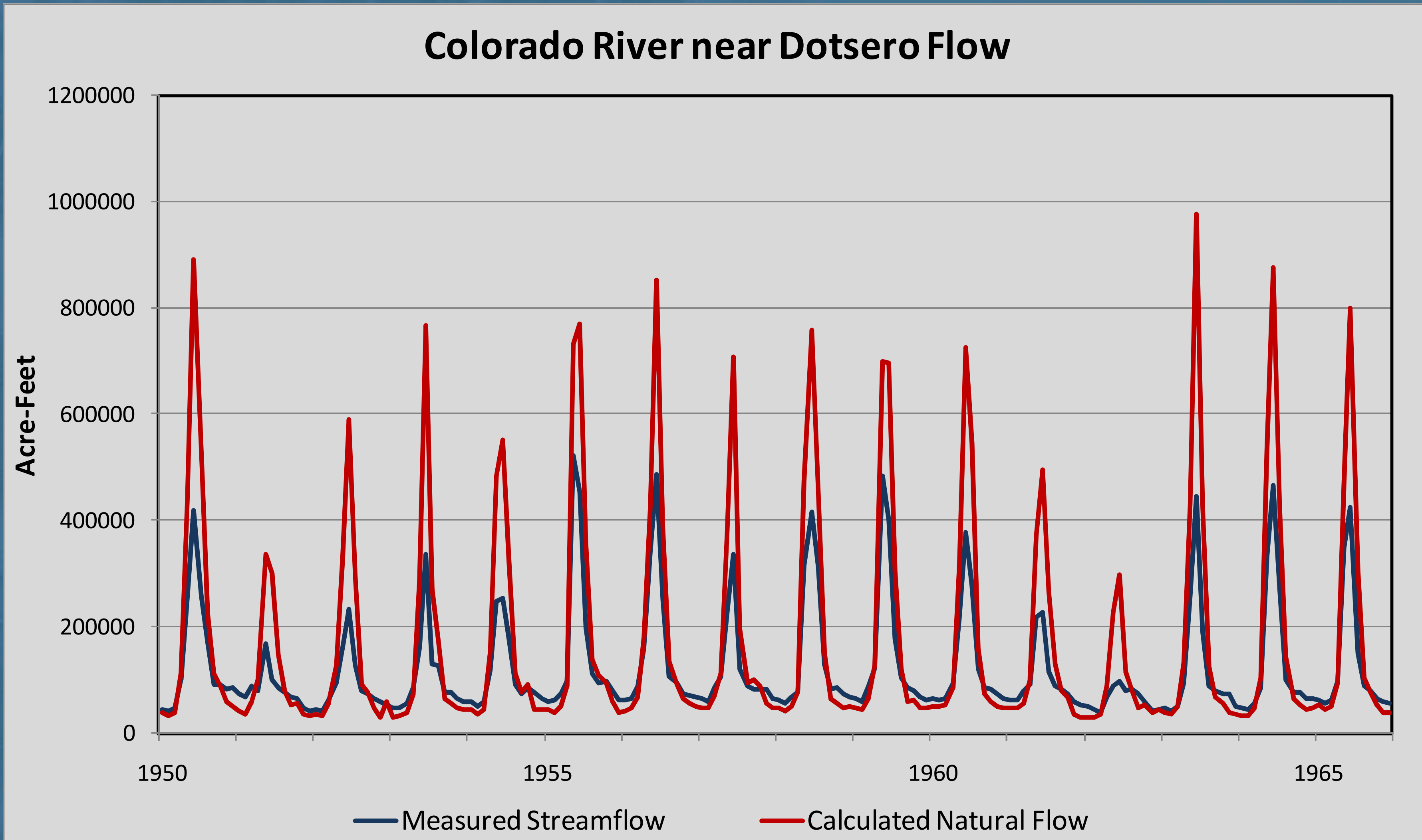
Inflow Hydrology



Physical Systems

- Diversion Structures
  - Location on the River
  - Headgate and Canal Capacities
  - Return Flow Locations
- Reservoirs
  - Location on River or Off-Channel
  - Location of Carrier Ditches
  - Storage Volume, Outlet Capacities, Account Size, Area/Capacity Tables
- Instream Flow Reaches
  - Beginning/Ending of Reach

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Physical Systems

- The Five Basin Models Represent Over 13,400 Diversion Structures Explicitly
  - 699,000 Irrigated Acres
  - Larger Structures; Structures that are Important in Administration (Per Water Commissioner); Structures Receiving Reservoir Water
  - 24 Transbasin Diversions (out of the Colorado Basin)
  - 15 Trans-tributary diversions
  - 47 Municipal and Industrial Diversions

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Physical Systems

- Remaining Structures are Represented in Aggregates
  - 223,000 acres or 24 percent of total acreage
  - Grouped by Location
  - Structures on Smaller Tributaries not Represented in the Model; Structures without Diversion Records

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Physical Systems

- 54 Key Reservoirs in Colorado
  - 3.49 Million Acre-feet Combined Storage
- 193 CWCB Instream Flow Segments
- 20 Minimum Bypass Agreements

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Physical Systems

Meadow Creek	Shadow Mtn/ Grand Lake	Granby	Cottonwood Creek Res
Willow Creek	Williams Fork	Wolford Mountain	Leon Creek Reservoirs
Con-Hoosier Blue	Clinton Gulch	Dillon	Bonham Reservoirs
Green Mountain	Homestake	Reudi	Vega
Grass Valley	Rifle Gap	Grass Valley	

Taylor Park	Blue Mesa	Morrow Point	Fruit Growers
Silver Jack	Crystal	Fruitland	Ridgway
Crawford	Overland	Paonia	

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Physical Systems

Vallecito	Lemon	Cascade	Lake Hope
Jackson Gulch	Summit	Narraguinnep	Trout
Groundhog	McPhee	Gurley	Miramonte

Beaver Creek	Pot Hook	Lester Creek	Steamboat
Taylor Draw	Allen Basin	Stillwater	Stagecoach
Elkhead	Fish Creek	Catamount	Yamcolo

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Water Demands

- Irrigation Demands
  - Full Irrigation Water Requirements from StateCU
- Municipal Demands
  - 1998 to 2005 Average Monthly Diversions
- Transbasin Demands
  - 1998 to 2005 Average Monthly Diversions or provided by Owners

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Water Demands – Sources

- Reservoir "Demands"
  - Reservoir Capacities or Operational Targets
  - Operational Targets for Ruedi, Green Mountain, Willow Creek, Paonia, Taylor Park, and Blue Mesa Provided by USBR
  - Operational Targets for Williams Fork Provided by DWB
  - Operational Targets for Lemon, Vallecito, and Catamount Reservoirs Provided by Operators

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Administrative Conditions

- Water Rights (Direct, Storage, Instream Flow)
- Reservoir and Carrier Operations
- Policies and Agreements (Such as Minimum Bypasses, Fish Flows, etc)

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Administrative Conditions

- Model "Operating Rules" for the Five Colorado Models Define:
  - How Water is "Carried" to Off-Channel Reservoirs
  - How Demands are Satisfied From Reservoirs and in What "Priority"
  - How Water is "Carried" to Collection Systems and Common Demands and in What "Priority"

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Model Operations

1. Considers Natural Inflow and Return Flows from Previous Time Steps
2. Identifies Most Senior Water Right
3. Estimates Diversion =min (Demand, Water Right, Headgate Capacity, Available Flow)
4. Adjusts Downstream Flows to Reflect Senior Diversions and Immediate Return Flows
5. Future Returns are Calculated
6. Repeated for Next Junior Water Right

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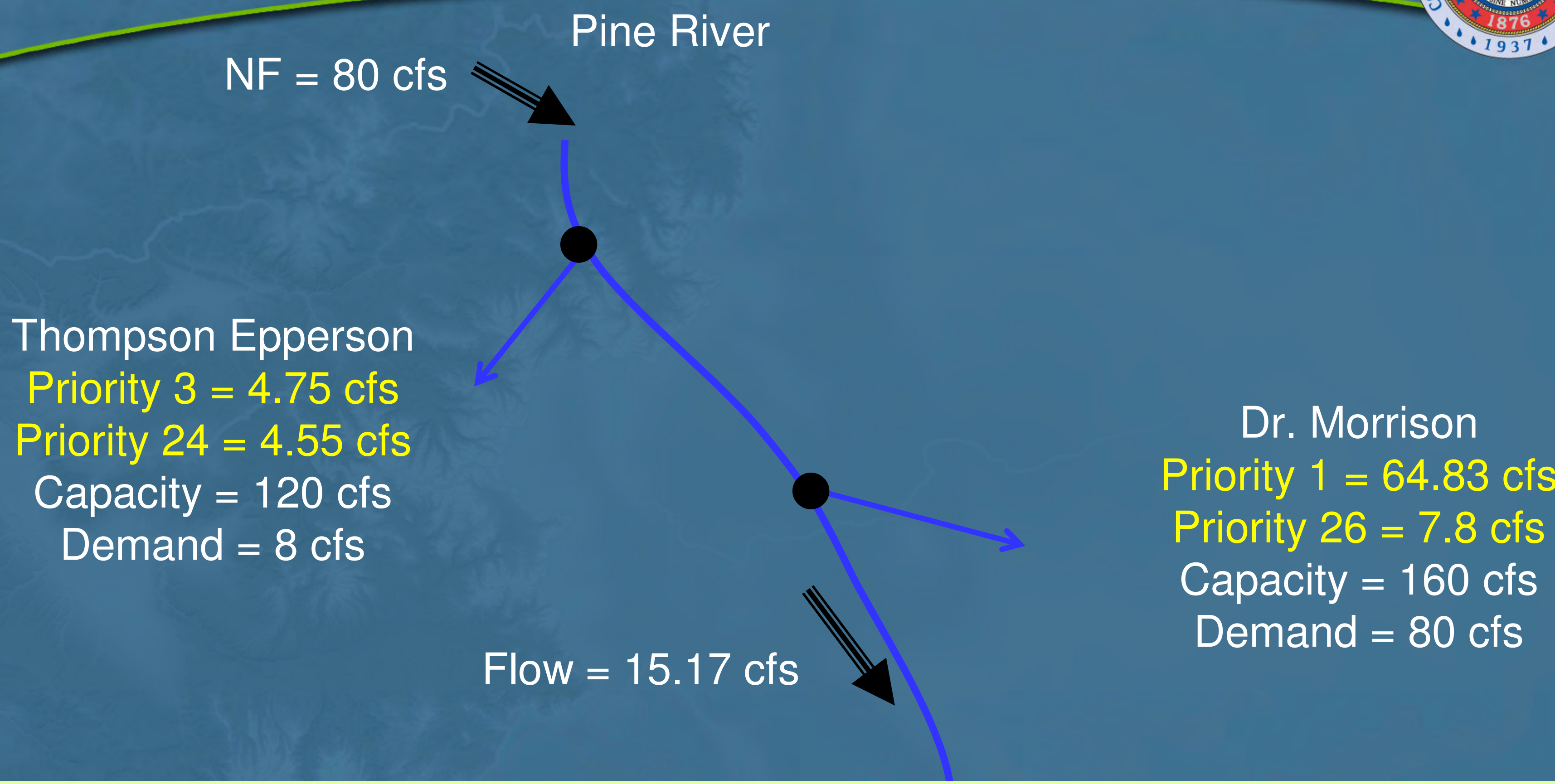
Model Operations

1) Priority 1: Direct Diversion = min (demand, water right, capacity, physical flow) = min(80, 64.83, 160, 80) = 64.83
2) Demand is decreased to 80 – 64.83 = 15.17
3) Diversion structure capacity is decreased to 160 – 64.83= 95.17
4) Flow Downstream is Decreased to 80 – 64.83 = 15.17

Model Operations



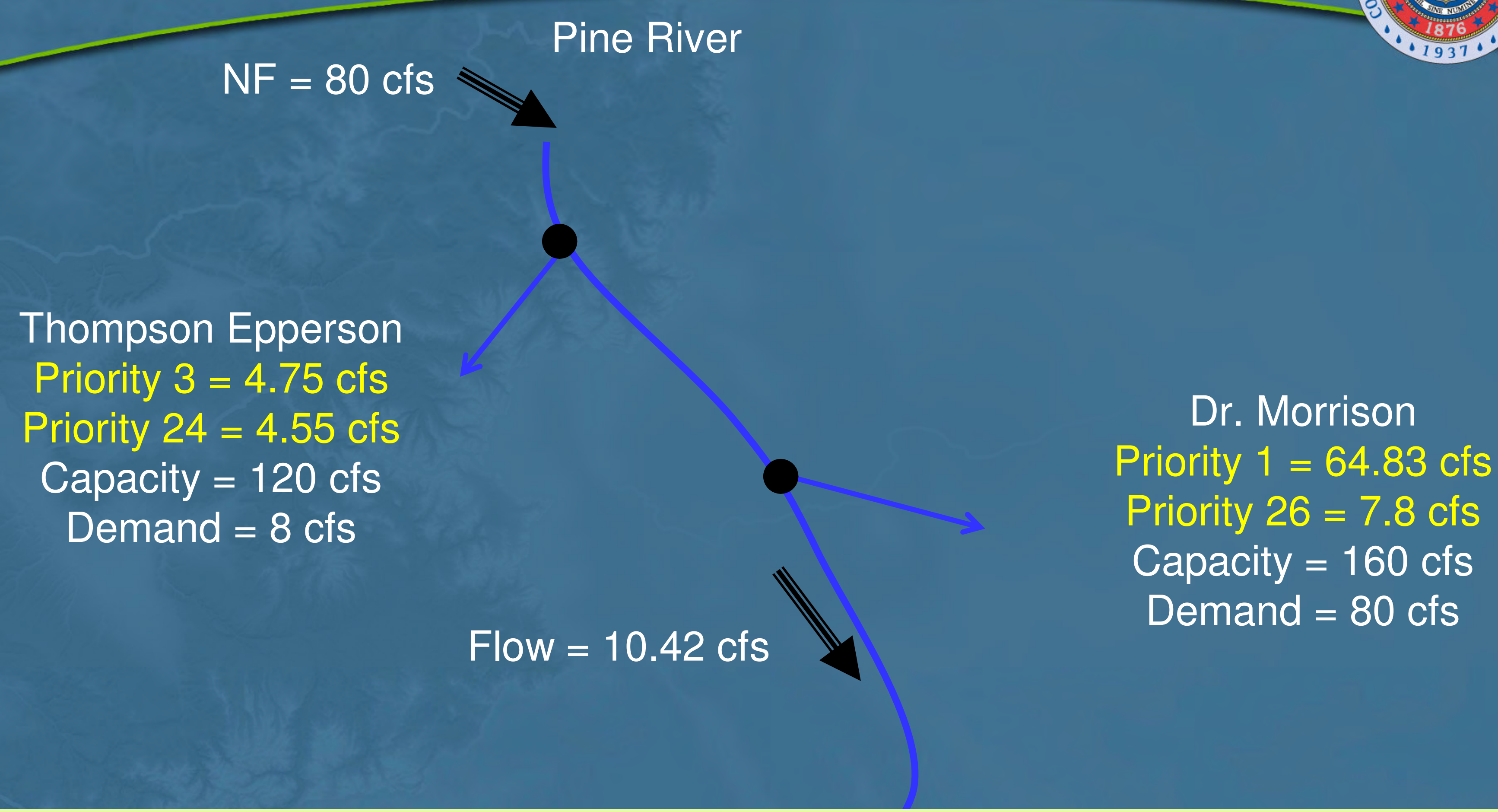
5) Priority 3: Direct Diversion = min (demand, water right, capacity, physical flow) = min(8, 4.75, 120, 15.17) = 4.75

6) Demand is decreased to 8 – 4.75 = 3.25

7) Diversion structure capacity is decreased to 120 – 4.75 = 115.25

8) Flow Downstream is Decreased to 15.17 – 4.75 = 10.42

Model Operations

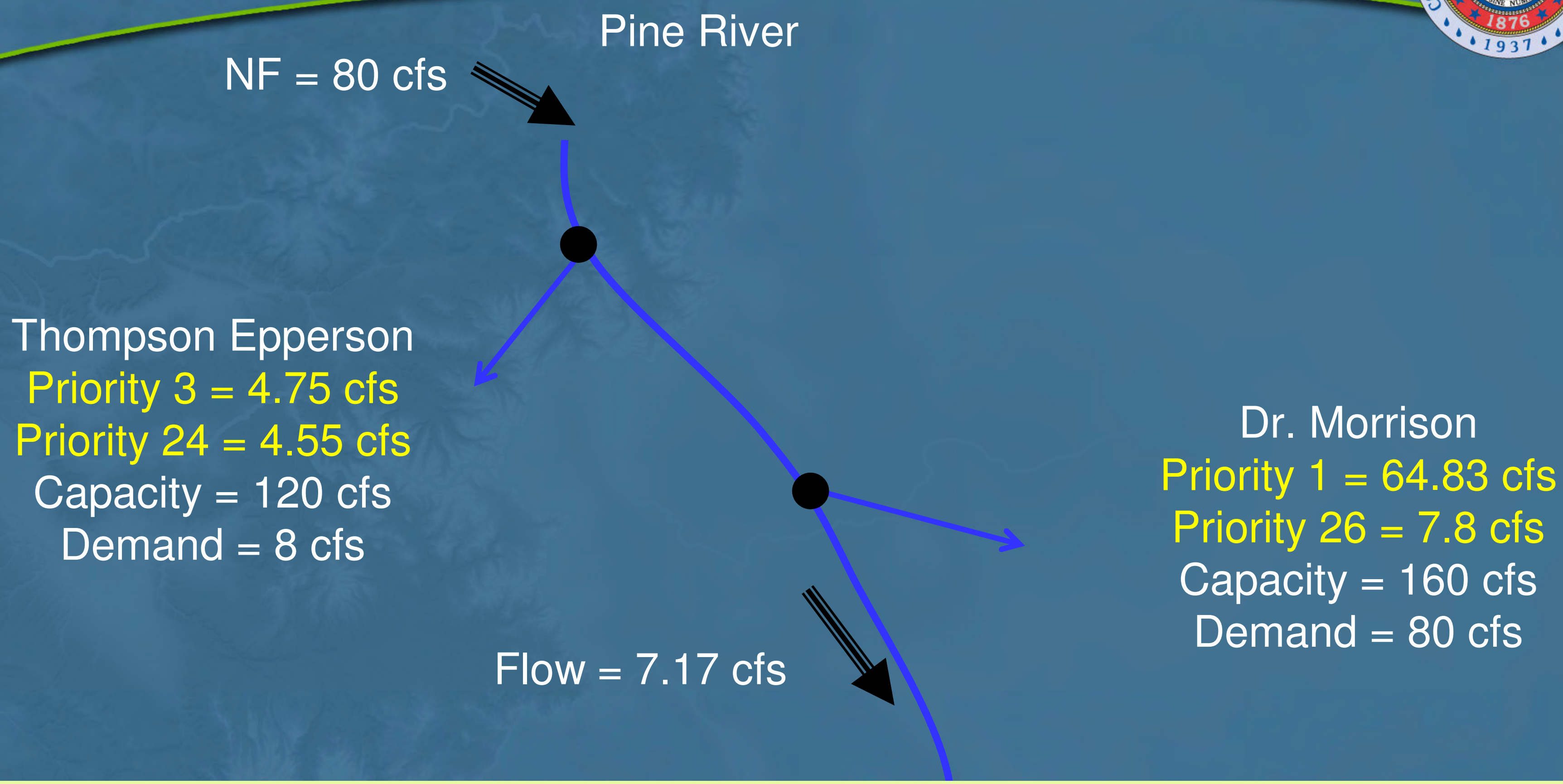


9) Priority 24: Direct Diversion = min (demand, water right, capacity, physical flow) = min(3.25, 4.55, 115.25, 10.42) = 3.25

10) Demand is decreased to 3.25 – 3.25 = 0 Demand is Satisfied

11) Flow Downstream is Decreased to 10.42 – 3.25 = 7.17

Model Operations



12) Priority 26: Direct Diversion = min (demand, water right, capacity, physical flow) = min(15.17, 7.8, 95.17, 7.17) = 7.17

13) Demand is decreased to 15.17 – 7.17 = 8.0 Demand is Shorted

14) Diversion structure capacity is decreased to 95.17 – 7.17 = 88

15) Flow Downstream is Decreased to 7.17 – 7.17 = 0

Model Calibration

- Do Simulated Results = Historical Measurements? Compare:
  - Diversions
  - Streamflows
  - Reservoir Contents

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Model Calibration

- Calibration “Knobs”
  - Return Flow Locations (Ex. More Return Flows above Shorted Diversions, Around Gage)
  - Natural Flow Distribution to Ungaged Tributaries; Need Enough Physical Flow to Meet Historical Diversions
  - Revise “Priorities” Assigned to Operating Rules
  - Change Operating Rule Types
  - “Explain” Unresolved Issues with Calibration
    - Ex. Model Simulates Full Reservoir, However Historical Contents were Low due to Maintenance

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Model Calibration

- Streamflow Average Annual Calibration (with a few exceptions)
  - Within 3% for Upper Colorado Basin Gages
  - Within 1% for Gunnison Basin Gages
  - Within 1% for San Juan Basin Gages
  - Within 1% for Yampa Basin Gages
  - Within 1% for White Basin Gages

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Model Calibration

- Streamflow Calibration Exceptions below Projects with "General Operating Criteria"
  - 6 % for Surface Creek at Cedaredge
  - 4 % for Uncompaghre River at Delta
  - 2 % for Dolores River at Bedrock
  - 6 % Ranch Creek near Fraser
  - 32% Plateau Creek near Collbran (1% Plateau Creek near Cameo)

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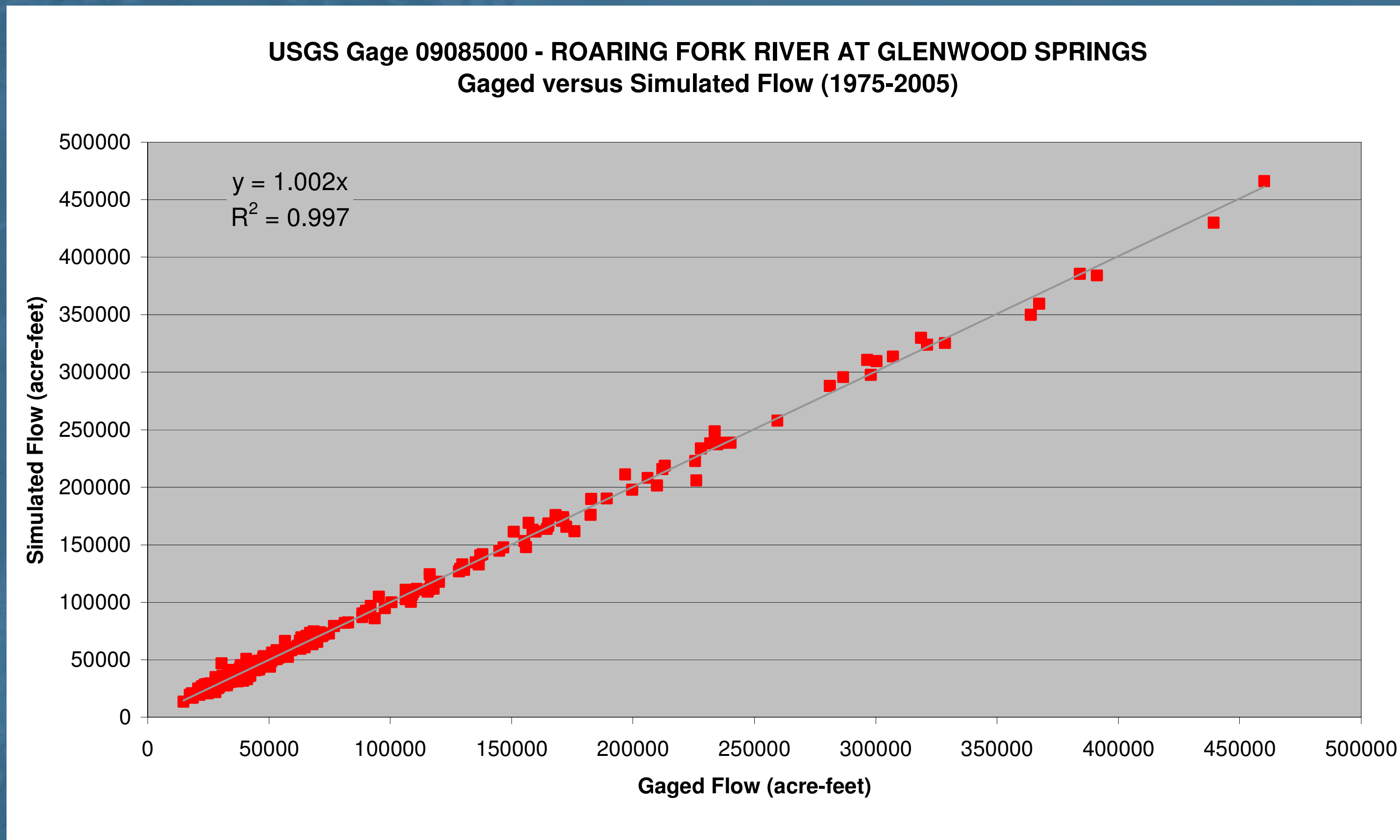
Model Calibration

- Calibration on Larger Tributaries Generally Very Good



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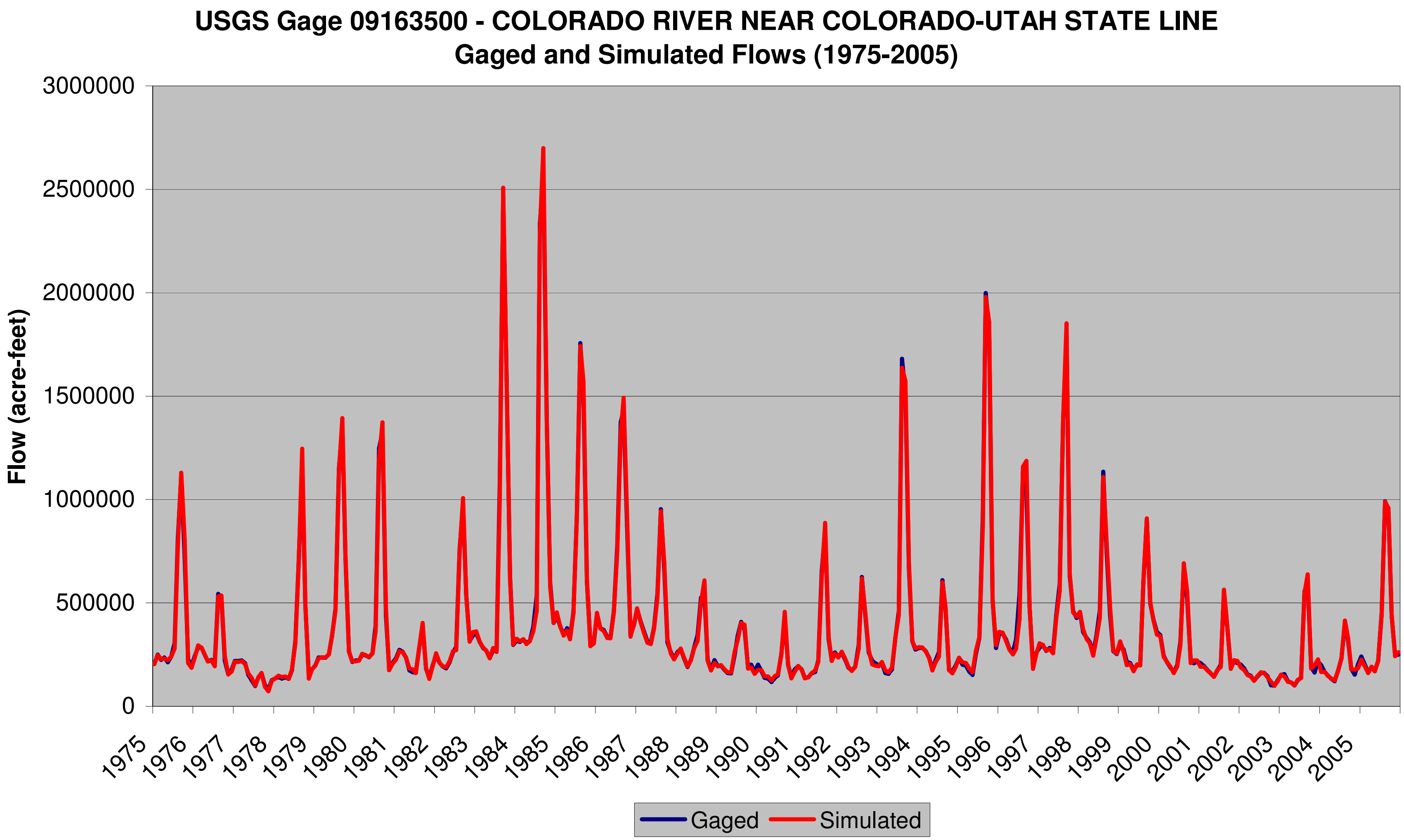
Model Calibration



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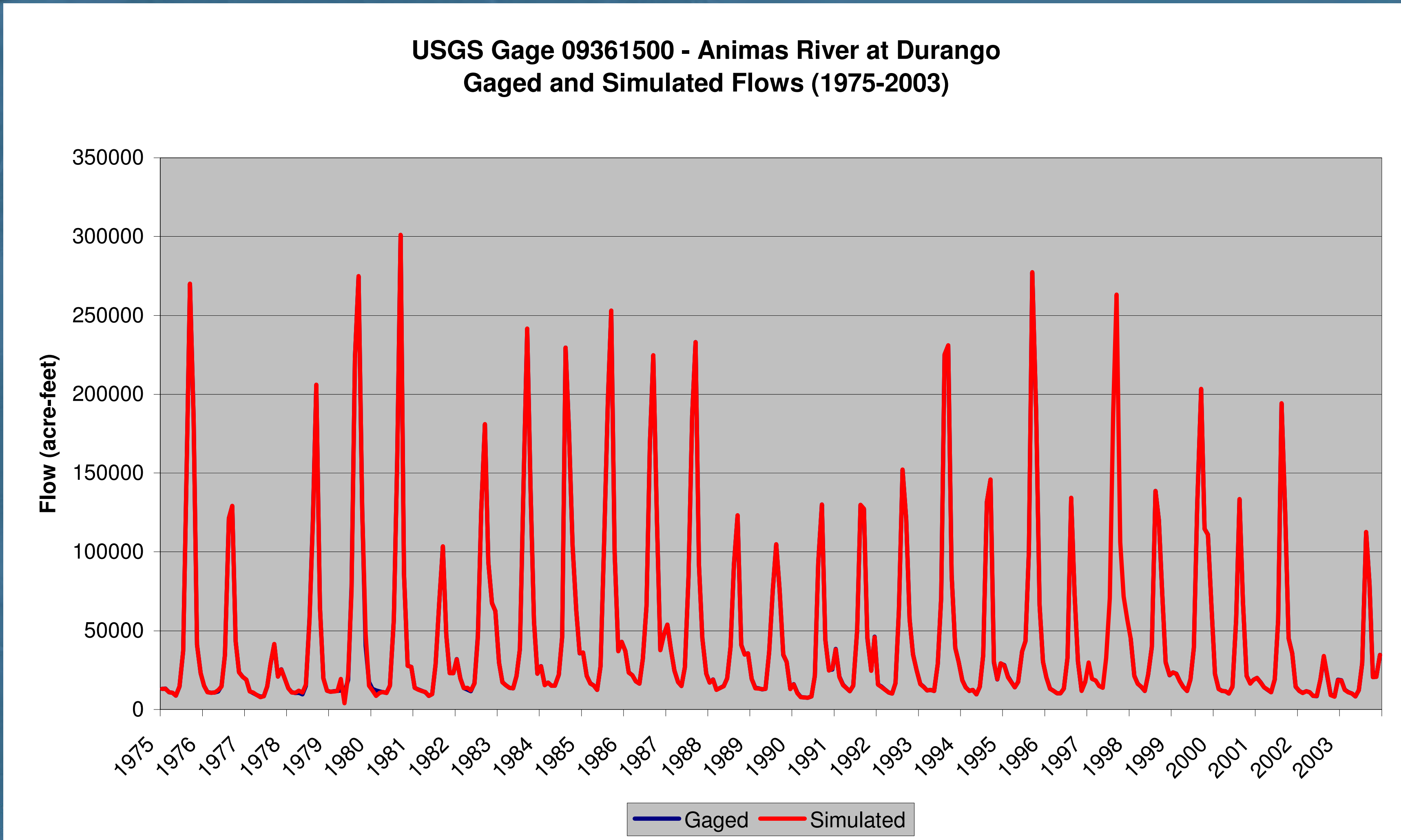

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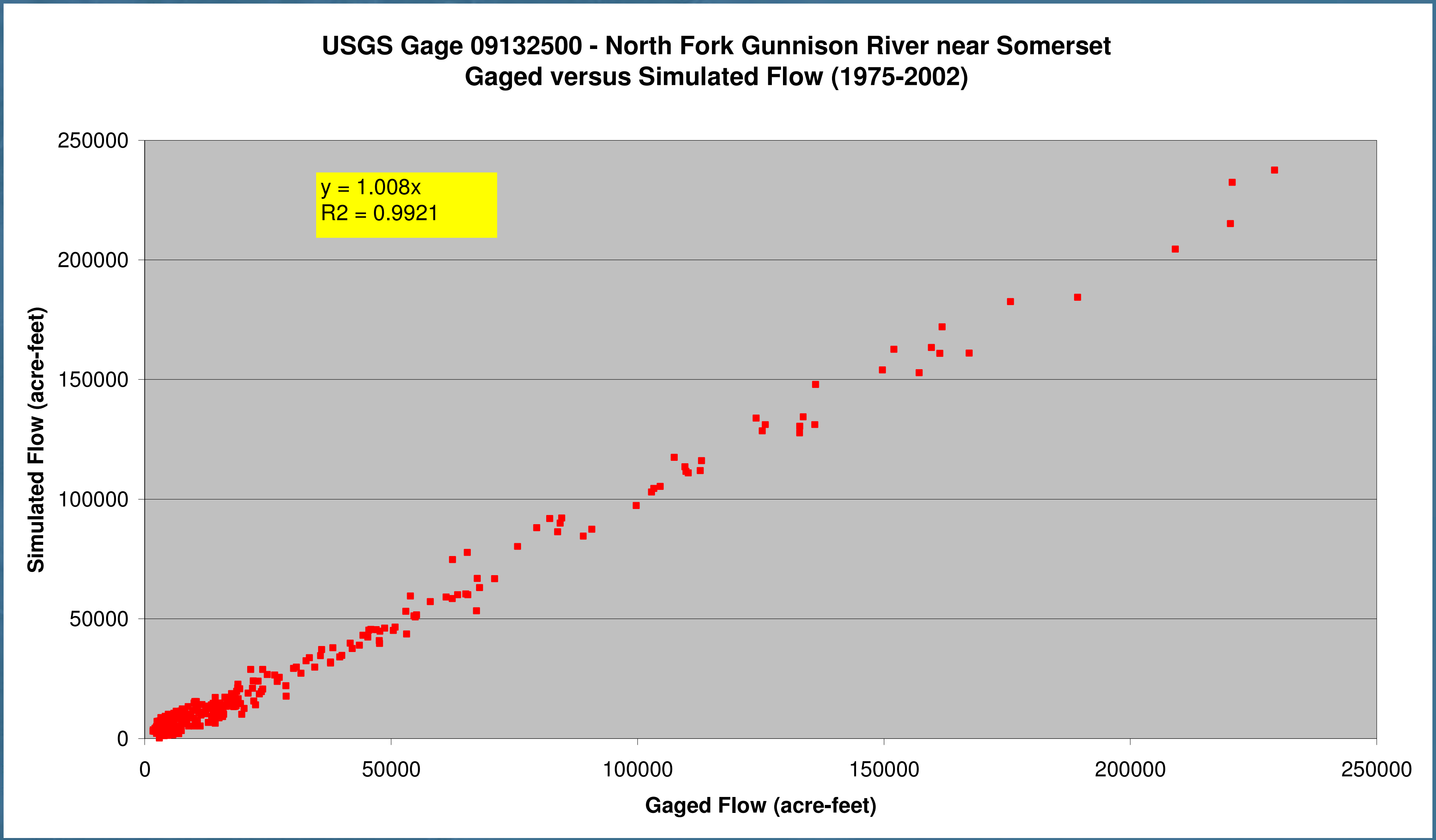

Model Calibration

- Simulated Diversions Calibration
  - 1% of Historical Upper Colorado Diversions
  - 2% of Historical of Gunnison Diversions
  - 1% of Historical San Juan Diversions
  - 2% of Historical Yampa Diversions
  - 1% of Historical White Diversions

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Model Calibration

- Diversion Calibration Exceptions
  - Bonham Branch , Coon Creek, and Cottonwood Branch Pipelines in Plateau Basin (Upper Colorado)
  - Transbasin Diversions Calibrate well, but in some cases the individual diversions under collection systems over or under divert (Upper Colorado)
  - Fortification Creek and Williams Fork due to lack of Hydrology (Yampa)
  - Some Aggregated Diversions are Shorted Likely Because they Historically Re-Divert each other's Return Flows

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Model Calibration

- Diversion Calibration Exceptions :
  - Fruitland Canal - diversions are simulated using operating rules, order of use under project may not be understood (Gunnison)
  - Shortages on Currant and Surface Creeks indicate interactions between the two tribs, irrigated lands in Alfalfa Run, and Filling of Fruitgrowers not completely understood (Gunnison)
  - Dolores River main stem irrigation demands are generally met, shortages occur on West Fork and Fish Creek tribs where gage data and historical diversion records are limited (San Juan)

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Model Calibration

- Reservoir Calibration Results
  - Reservoir Calibration Good with Some Exceptions
  - Grass Valley and Rifle Gap Simulation Do not Match Historical Due to Limited Project Demand Information
  - Vega Reservoir Affected by Lack of Information and Understanding of Southside Canal Diversions
  - North Fork of the Gunnison Off-Channel Reservoirs Affected by Inconsistent Diversion Coding and Lack of Full Understanding of Project Operations
  - Reservoirs with "Operational Storage Targets" for Flood Control – Appear to be a General Guidelines

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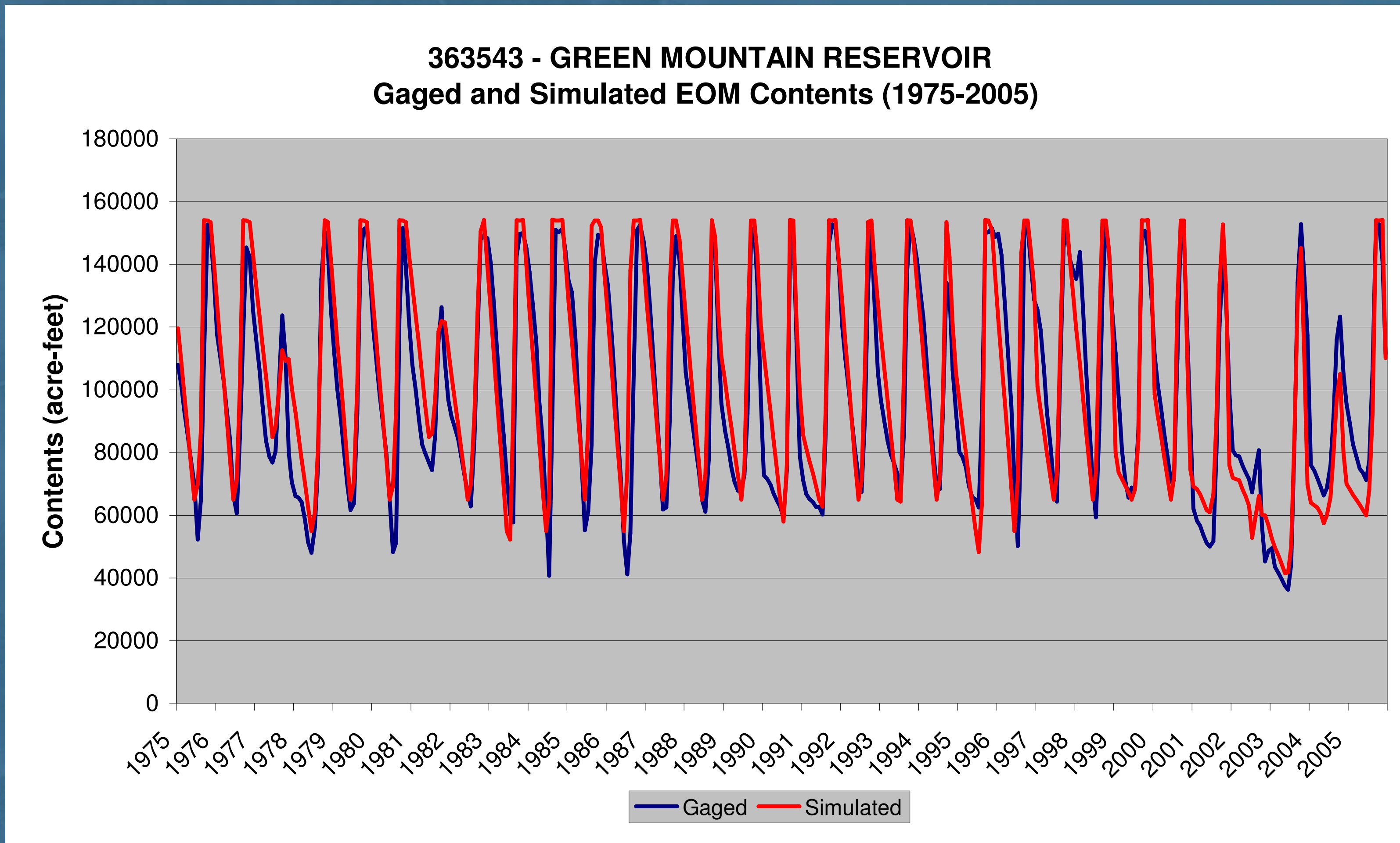
Model Calibration



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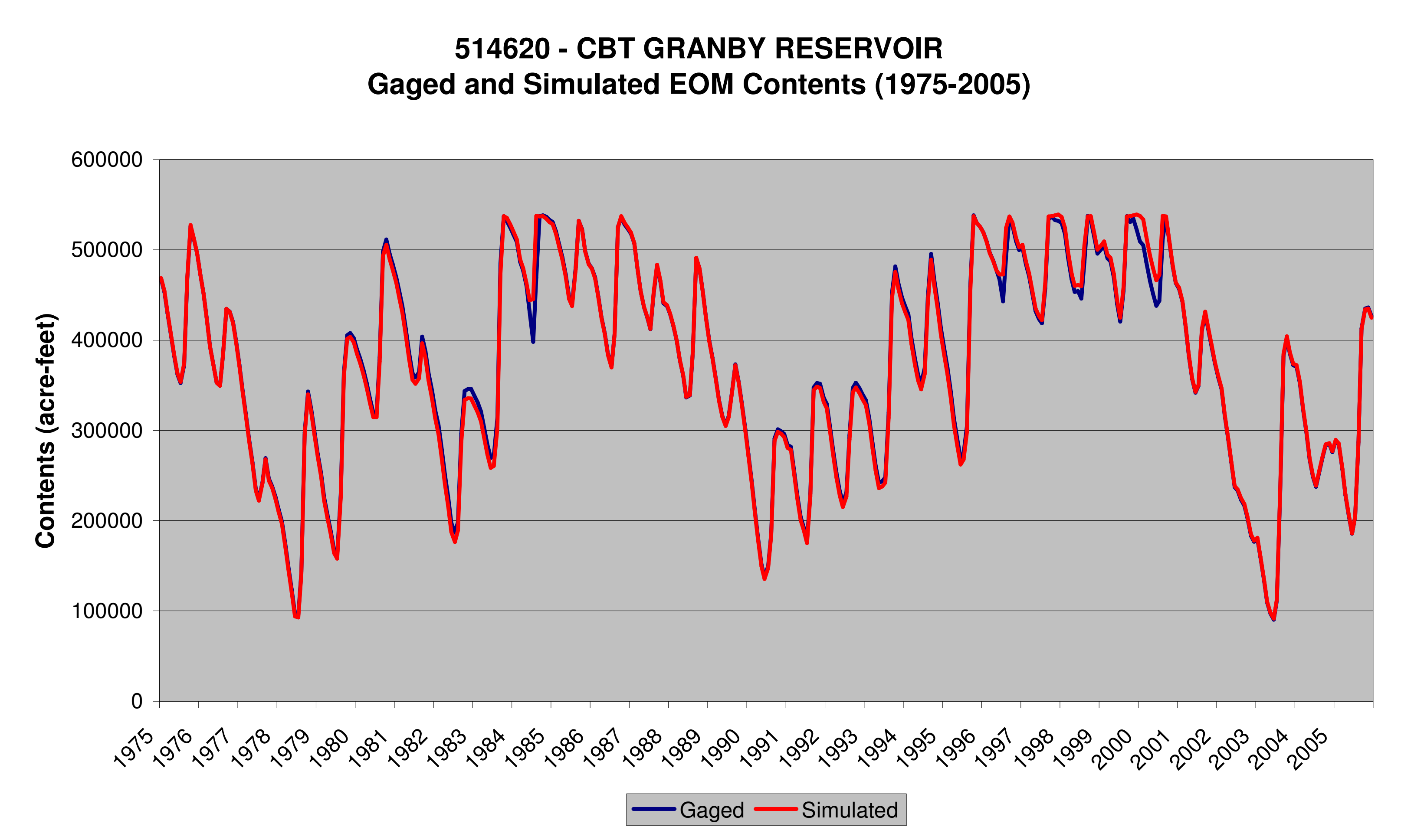

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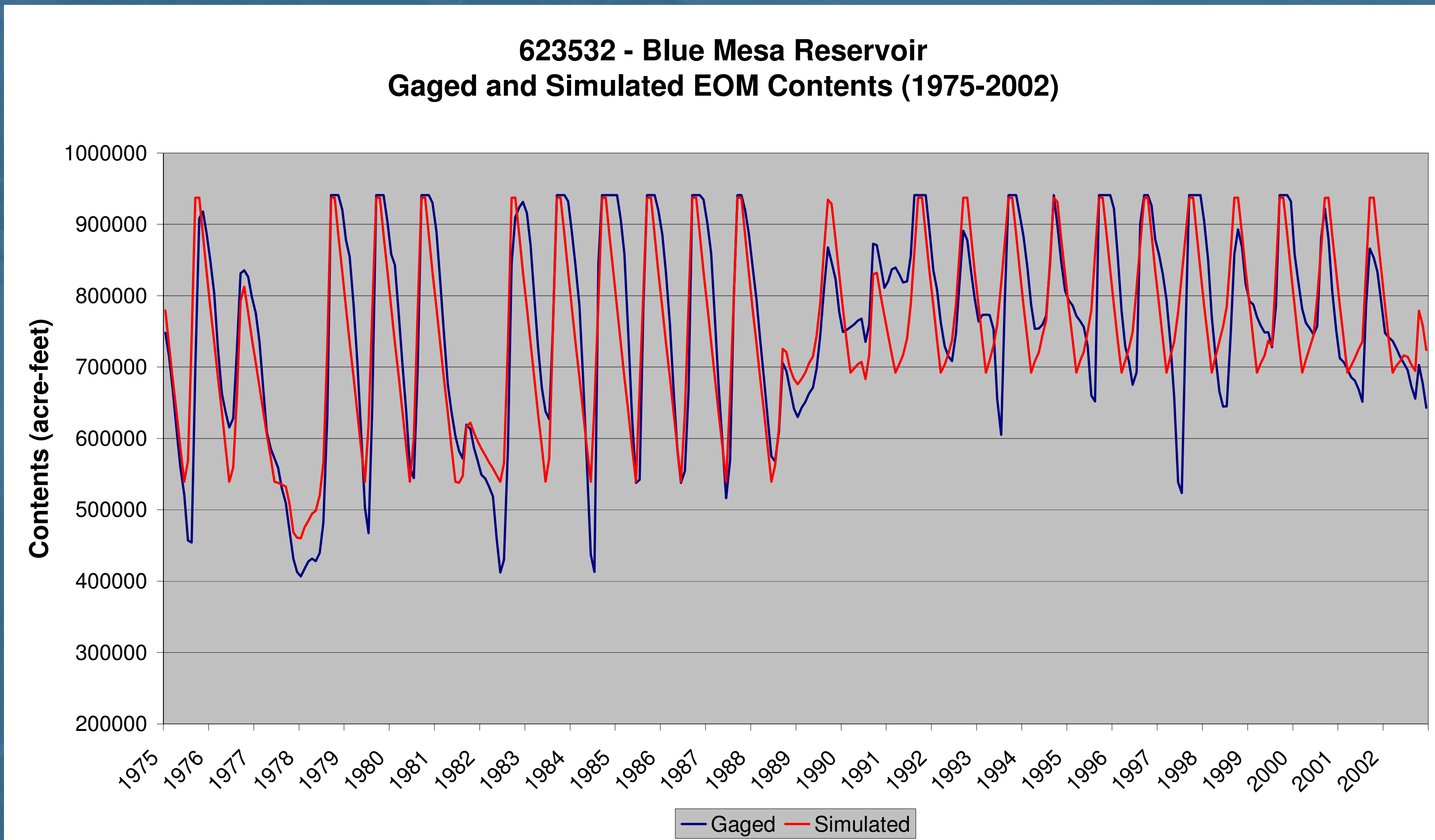

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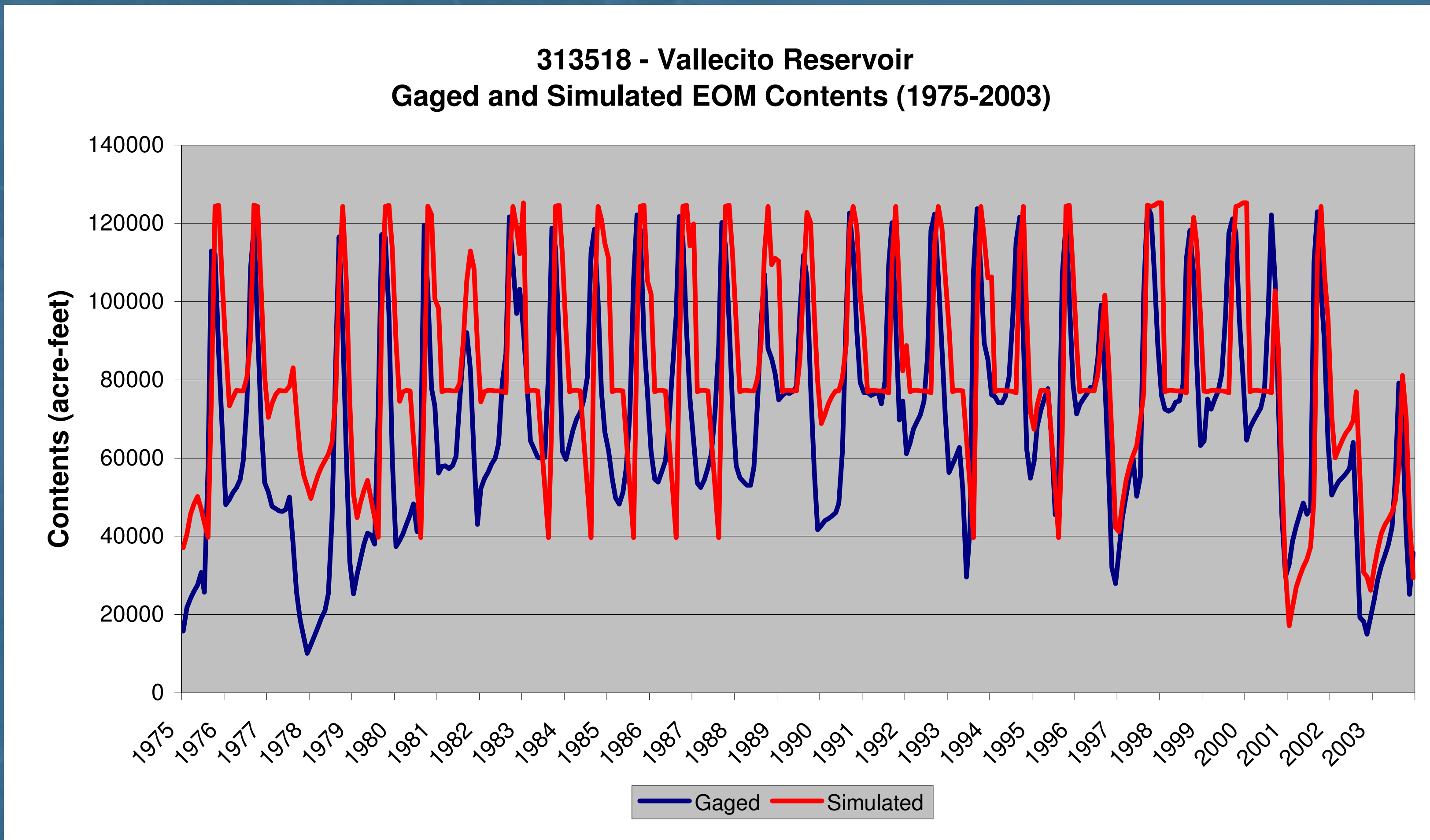
Model Calibration



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Model Calibration

- Basin-wide Calibration Results are Good for all Five Models
- Understanding and Representation of Colorado Project Operations are Good
- Colorado StateMod Models are Appropriate Prediction Tools to Consider Effects of Basin Climate Variability

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StateMod Enhancements

- CRWAS StateMod Model Enhancements
  - Some Funding Under CRWAS for Enhancements
  - Suggestions were Provided through BRT
  - Some Suggestions Provided Better Project Operation Understanding, Calibration was Already Good
  - Some Suggestions Improved Calibration

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StateMod Enhancements

- Incorporated Elkhead Reservoir enlargement and new operations
  - Did not affect Calibration, provided better representation of current operations
- Worked with Division 6 Engineer to better understand futile call in the Piceance basin
  - Provided better understanding of calibration limitations, added to documentation

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StateMod Enhancements

- Added High Savery Reservoir in Wyoming Portion of Yampa Model (completed 2005)
  - Did not affect Calibration, provided better representation of current operations
- Added the Finalized Black Canyon of the Gunnison Federal Instream Flow Right
  - Did not affect Calibration, provided better representation of current operations

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StateMod Enhancements

- Met with Water Commissioners and Operators of North Fork Gunnison Projects
- Revised Historical Data and Operations for Paonio, Overland, Fruitland, Fruitgrowers, and Crawford Reservoirs
  - Revised Historical Data Improved Natural Flow Estimates
  - Reservoir Calibration Improved

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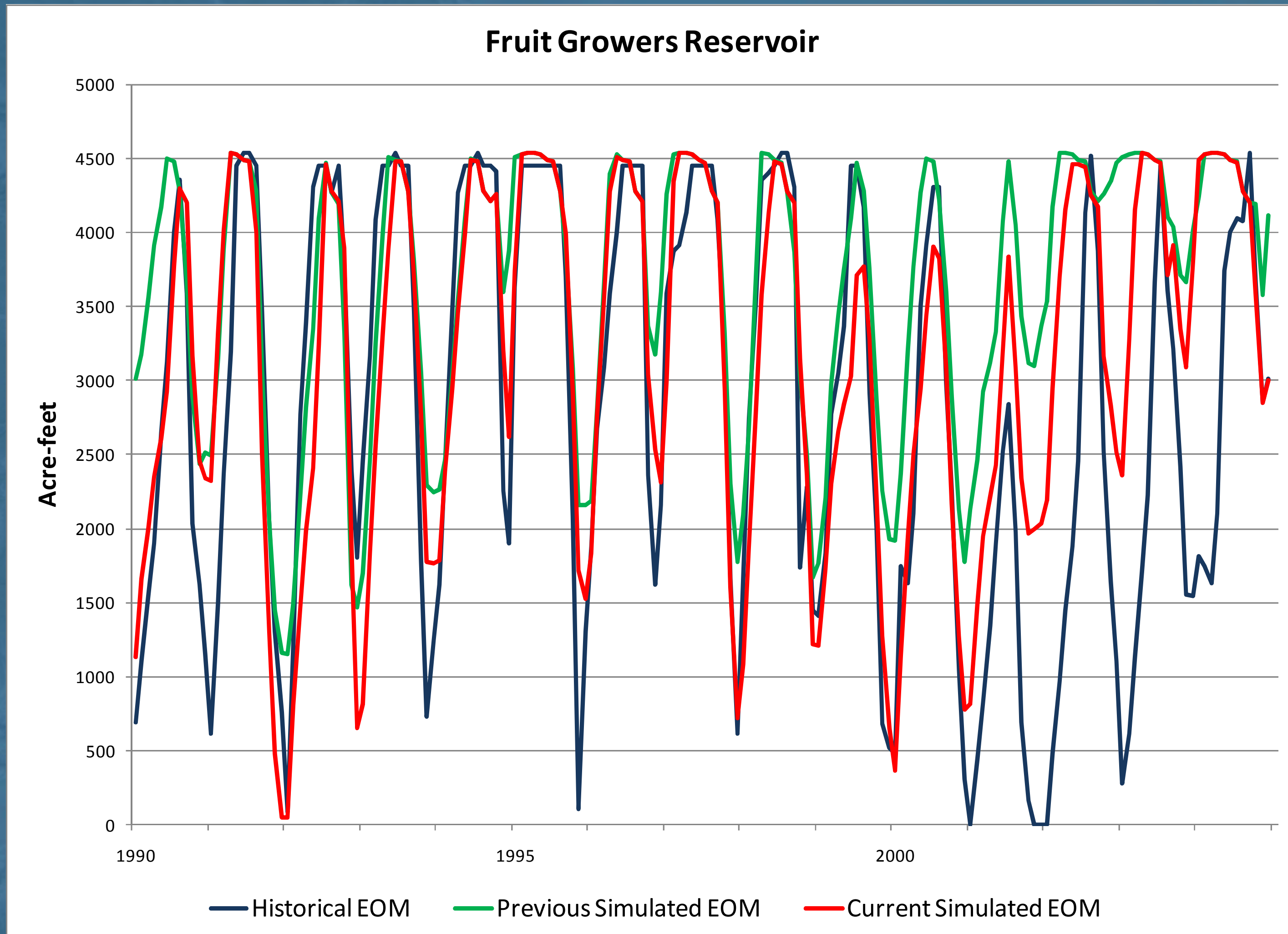
North Fork Gunnison Enhancements



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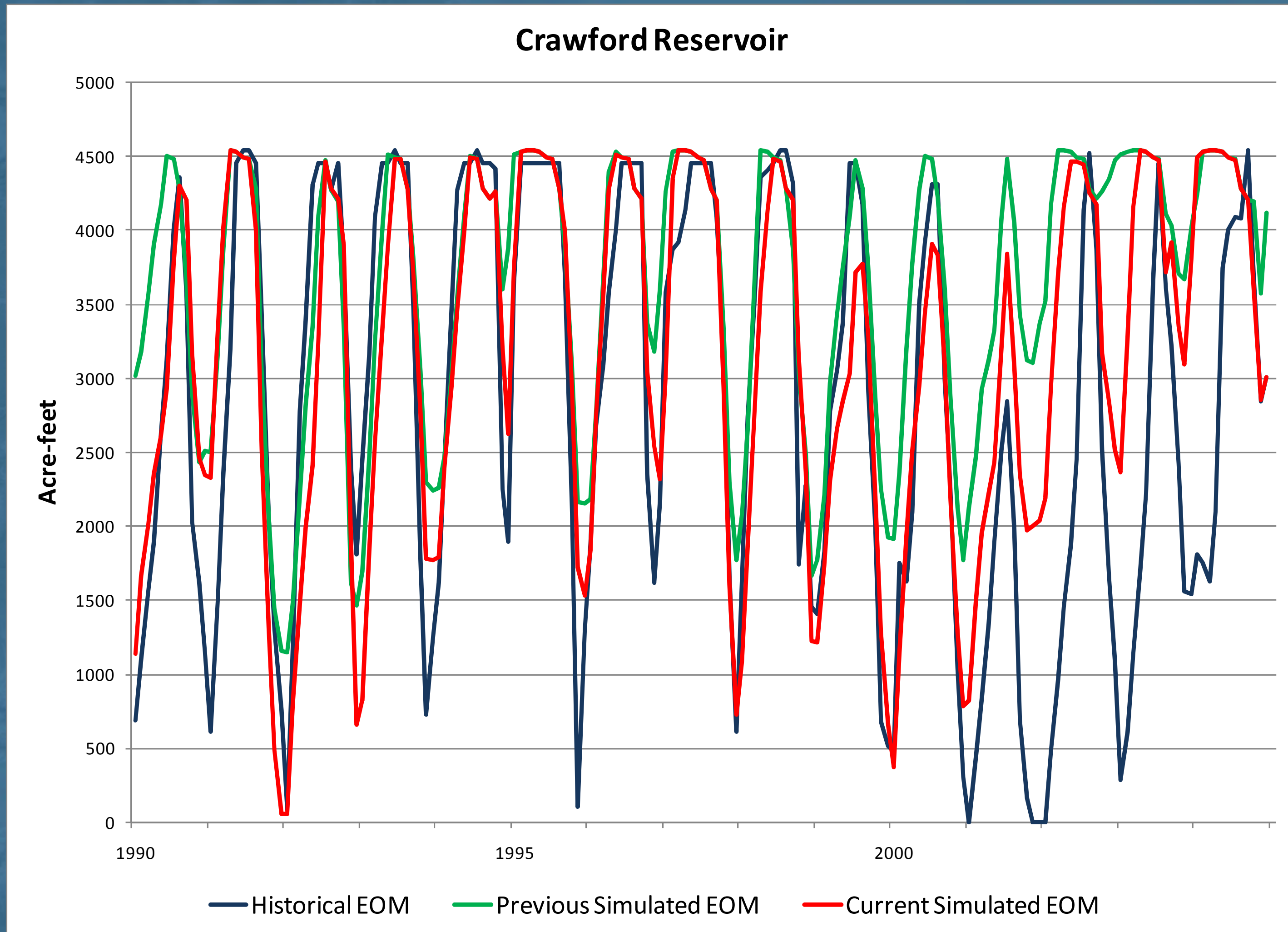
North Fork Gunnison Enhancements



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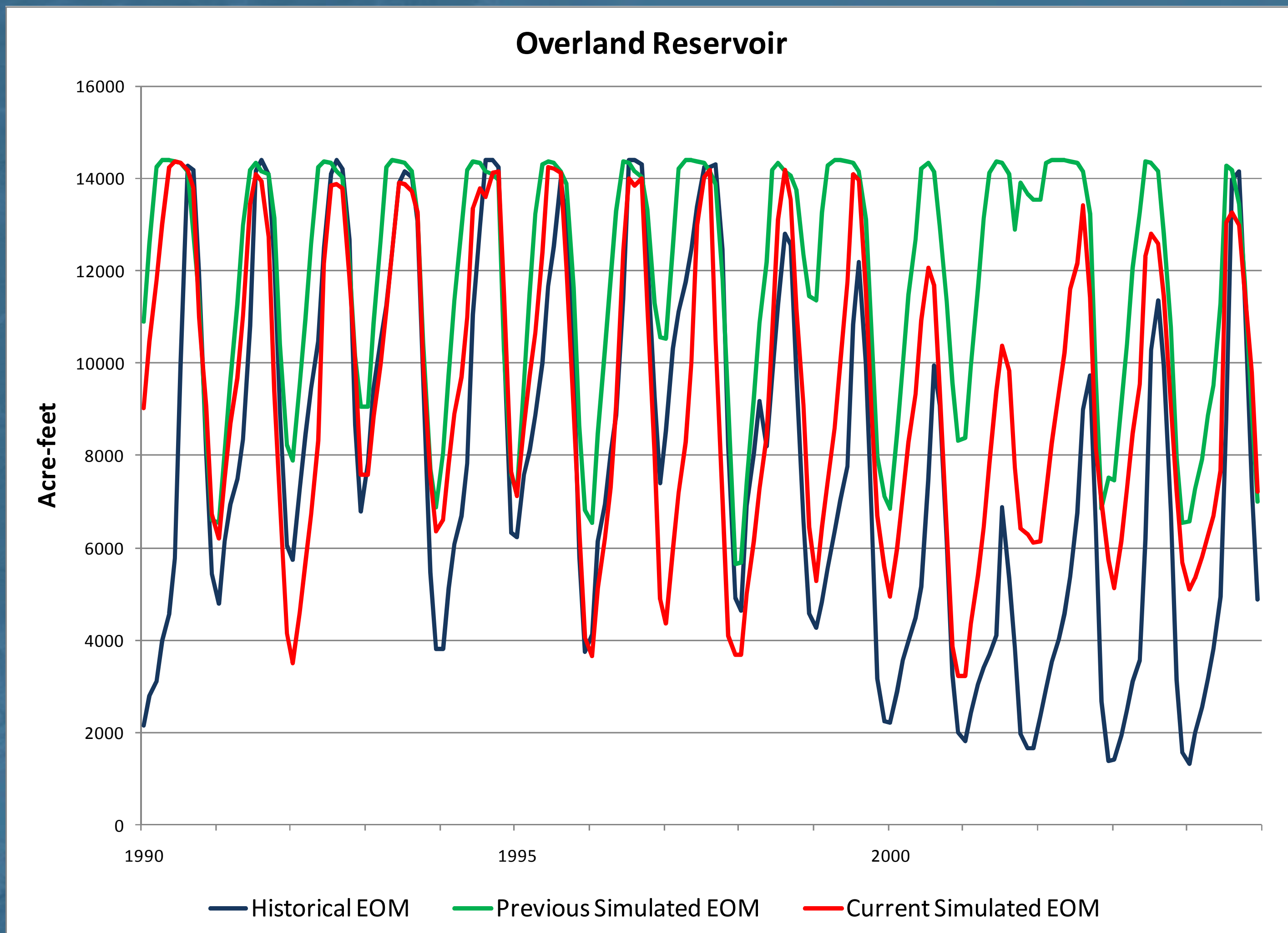
North Fork Gunnison Enhancements



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StateMod Enhancements

- Reviewed Denver Water Questions and Suggestions on Grand Valley Project Operations
  - Helped Denver Water understand model demands
  - Revised water rights for Power demands
  - Revised historical "split" of Grand Valley Project Demands
  - Did not affect Calibration, provided better representation of current operations

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StateMod Enhancements

- Reviewed Colorado Springs Suggestions on Con-Hoosier and Homestake Representation
  - Revised order in which Colorado Springs meets Blue River Decree requirements in Substitution Year
  - Incorporated new historical diversions and reservoir contents for Homestake Project
  - Improved Natural Flows - did not significantly affect Calibration, provided better representation of current operations

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StateMod Enhancements

- Met with Water Commissioners to Understand Historical Records Associated with Collbran and Molina Projects
  - Received new information regarding diversion records
  - Water commissioners are preparing mapping and providing information on Southside Canal turnouts (not included in Diversion Records)
  - Expect data will help with Natural Flow concerns on Plateau Creek for Phase II

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StateMod Enhancements

- Met with Ute Water Conservancy District Staff and Consultants
  - Incorporated new operational criteria
  - Added James Creek Reservoir
  - Did not affect Calibration – again upcoming Southside Canal revisions should improve Calibration

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StateMod Enhancements

- Had Discussions with Yamcolo and Stagecoach Reservoir Operators and Water Commissioners
  - Included new account and user ownership
  - Revised reservoir operations
  - Did not affect Calibration, provided better representation of current operations

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StateMod Enhancements

- Reviewed Upper Gunnison River Accounting Sheet and Discussed Taylor Park Reservoir and Blue Mesa Reservoir Operations with Water Commissioners
  - No changes required, represented operations are current

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StateMod Enhancements

- Added 25 new Instream Flow segments
  - 7 in the Yampa
  - 3 in the Gunnison
  - 12 in the Upper Colorado
  - 3 in the San Juan
- Removed Moffat System Bypass Requirement on Jim Creek

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StateMod Enhancements

- Contacted Transbasin Diverters for better Current Use Demands
  - Received some data, but mostly represented "full-build out" or future demands
  - Still reviewing assumptions to assure transbasin diversion representation is consistent
  - Likely continue to use "recent" demands for Phase I for some structures

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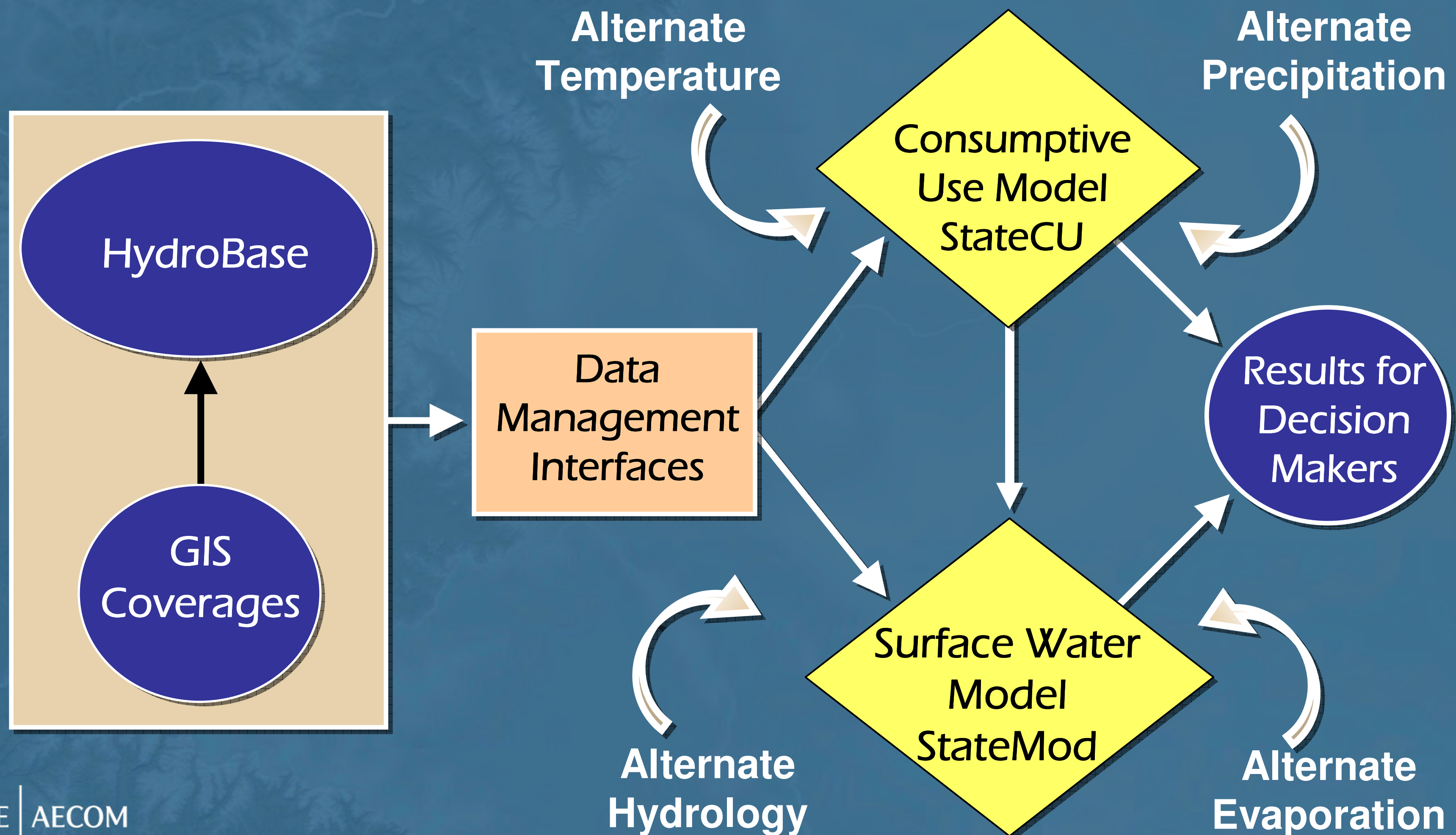
Next (Last) Step for Phase I - Water Availability



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StateMod and Water Availability

StateMod Water Resources Planning Models

- Replace Current Demands with CIR-Based Demands from CGMs
- Replace Natural Flow Hydrology with CGM based Hydrology
- Model Determines *Physical* and *Legal* Water Availability at every Modeled Node

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Comments and Questions?

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