Exceptional service in the national interest

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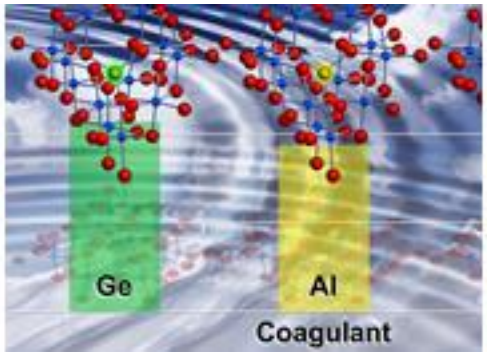

Upper Rio Grande Impacts Assessment
Update to URGWOM EC 12.05.2013

Jesse Roach PhD — Sandia National Laboratories

Dagmar Llewellyn — U.S. Bureau of Reclamation

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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SAND# 2013-10776W

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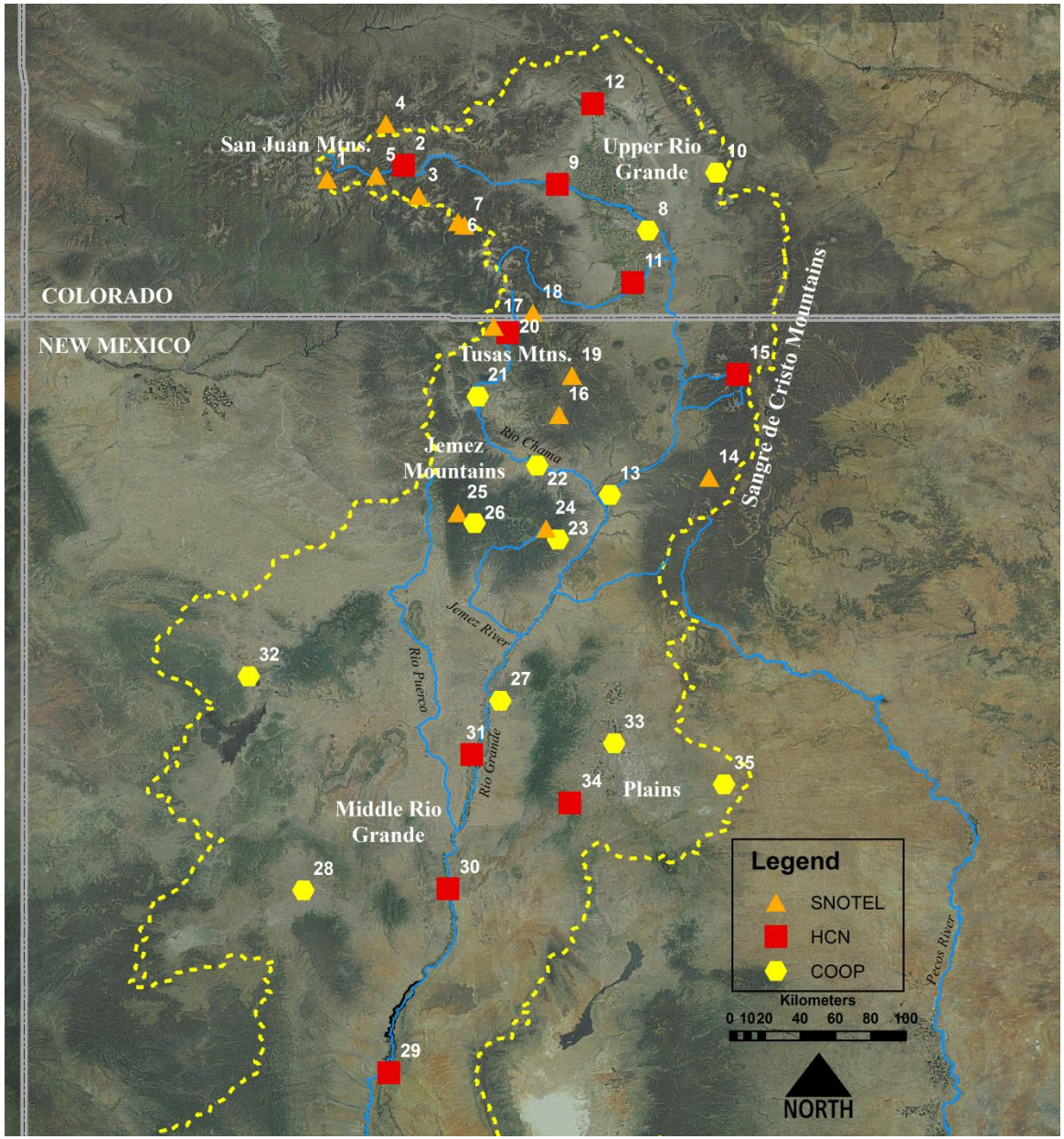
- **Upper Rio Grande (Climate Change) Impacts Assessment (URGIA)**
  - **Report on transient simulations is due out imminently**
  - **The "period analysis" piece where URGWOM and URGSiM were meant to overlap is being used for the Santa Fe Basin study, and will likely be used for the Albuquerque Basin study.**
  - **The URGWOM runs that were done utilized input data that had problems with it, and so are not useable.**

SAND# 2013-10776W

Observed Trends Analysis 1971-2011 Ariane Pinson USACE



Observed Trends Tmax 1971-2011 Ariane Pinson USACE

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Table 1 Rate of change in monthly maximum temperature (Tmax) in °C/year for 1971-2011.

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual °C/yr	°C/ 10 yr.
San Juan Mountains	0.04	-0.06	-0.01	-0.04	-0.03	-0.02	0.02	-0.04	0.00	-0.07	0.08	0.03	-0.01	-0.10
Sangre de Cristo Mtns.	0.04	-0.02	0.02	0.00	0.04	0.01	0.00	0.01	0.01	0.00	0.05	0.01	0.01	0.10
Tusas Mountains	0.08	-0.04	-0.03	-0.04	0.00	0.03	0.04	0.03	-0.02	-0.05	0.18	0.05	0.02	0.17
Jemez Mountains	-0.02	-0.06	0.03	0.00	0.01	-0.01	0.00	0.01	0.00	-0.04	0.02	-0.05	0.00	-0.02
Pajarito Plateau*	0.01	-0.01	0.05	0.03	0.05	0.04	0.03	0.03	0.04	0.01	0.04	-0.04	0.03	0.33
All Mountain Sites	***0.03***	***-0.04***	***0.01***	***-0.01***	***0.01***	***0.00***	***0.02***	***0.00***	***0.00***	***-0.03***	***0.06***	***0.00***	***0.00***	***0.02***
Northern Valleys	0.03	-0.03	0.03	0.00	0.02	0.00	0.01	0.01	0.00	-0.02	0.02	-0.02	0.00	0.03
Rio Chama Valley	0.08	0.02	0.08	0.03	0.06	0.03	0.04	0.04	0.04	0.01	0.05	0.01	0.04	0.38
Middle Rio Grande	0.05	0.00	0.03	0.03	0.07	0.04	0.04	0.06	0.06	0.03	0.05	0.01	0.04	0.39
Plains	0.07	0.01	0.05	0.03	0.06	0.05	0.03	0.03	0.06	0.02	0.07	0.01	0.04	0.40
All Valley Sites	***0.06***	***0.00***	***0.04***	***0.02***	***0.05***	***0.03***	***0.03***	***0.03***	***0.03***	***0.01***	***0.04***	***0.00***	***0.03***	***0.30***
Region (All Sites)	***0.05***	***-0.01***	***0.03***	***0.01***	***0.04***	***0.02***	***0.02***	***0.02***	***0.03***	***0.00***	***0.05***	***0.00***	***0.02***	***0.24***

Red: Increase significant at 90% (0.1) confidence level; Purple: Decrease significant at 90% (0.1) confidence level.

**Significance not calculated (sample size too small).*

Decadal trend (°C/10 yr.) calculated as Annual Trend x 10.

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Observed Trends Tmin 1971-2011 Ariane Pinson USACE

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Table 1 Rate of change in Tmin (°C/year) by region for 1971-2011.

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual °C/yr	°C/ 10 yr.
San Juan Mountains	0.10	0.04	0.11	0.09	0.06	0.06	0.07	0.05	0.07	0.07	0.11	0.07	0.07	0.69
Sangre de Cristo Mtns.	0.16	0.10	0.06	0.08	0.05	0.06	0.05	0.06	0.04	0.06	0.09	0.12	0.06	0.60
Tusas Mountains	0.18	0.06	0.11	0.09	0.09	0.13	0.16	0.12	0.11	0.14	0.23	0.17	0.12	1.23
Jemez Mountains	0.05	0.02	0.02	0.02	0.03	0.03	0.06	0.04	0.04	0.05	0.05	0.03	0.04	0.36
Pajarito Plateau*	0.05	0.03	0.04	0.02	0.04	0.03	0.02	0.03	0.03	0.01	0.03	0.00	0.03	0.25
All Mountain Sites	***0.10***	***0.04***	***0.06***	***0.06***	***0.05***	***0.05***	***0.07***	***0.05***	***0.05***	***0.06***	***0.09***	***0.07***	***0.06***	***0.59***
Northern Valleys	0.07	0.02	0.01	0.03	0.04	0.01	0.03	0.04	0.02	0.01	0.03	0.01	0.02	0.24
Rio Chama Valley	0.09	0.05	0.03	0.04	0.04	0.03	0.04	0.05	0.03	0.02	0.02	0.02	0.03	0.32
Middle Rio Grande	0.03	0.03	0.03	0.07	0.08	0.07	0.05	0.05	0.04	0.04	0.03	0.03	0.04	0.39
Plains	0.00	-0.03	-0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.00	-0.02	-0.02	0.00	0.04
All Valley Sites	***0.04***	***0.02***	***0.01***	***0.04***	***0.05***	***0.03***	***0.04***	***0.04***	***0.03***	***0.02***	***0.02***	***0.01***	***0.03***	***0.29***
Region (All Sites)	***0.06***	***0.03***	***0.03***	***0.05***	***0.05***	***0.04***	***0.04***	***0.05***	***0.03***	***0.03***	***0.04***	***0.03***	***0.04***	***0.38***

Red: Increase significant at 90% (0.1) confidence level; Purple: Decrease significant at 90% (0.1) confidence level.

**Significance not calculated (sample size too small).*

Decadal trend (°C/10 yr.) calculated as Annual Trend x 10.

Observed Trends Precip 1971-2011 Ariane Pinson USACE

Table 1 Net change in precipitation (cm) by region for 1971-2011.

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Net Annual Change
San Juan Mountains	0.01	-0.03	-0.06	0.01	-0.05	-0.05	-0.03	-0.01	0.00	0.01	-0.09	0.07	-0.20
Sangre de Cristo Mtns.	0.01	0.04	-0.07	0.01	-0.04	-0.04	0.00	0.02	0.04	0.02	-0.07	0.00	-0.07
Tusas Mountains	-0.05	-0.12	-0.30	0.09	-0.03	-0.06	-0.06	-0.19	0.08	0.00	-0.25	0.13	-0.76
Jemez Mountains	-0.04	0.00	-0.09	0.04	-0.04	0.00	0.01	-0.07	-0.01	0.03	-0.07	0.10	-0.14
Pajarito Plateau*	-0.01	0.00	-0.02	0.01	-0.01	0.01	-0.07	0.06	-0.02	0.03	-0.02	0.03	-0.02
All Mountain Sites	***0.00***	***-0.01***	***-0.07***	***0.02***	***-0.04***	***-0.03***	***-0.03***	***-0.03***	***0.01***	***0.02***	***-0.08***	***0.06***	***-0.18***
Northern Valleys	0.00	0.00	0.01	0.02	-0.01	-0.01	-0.01	0.02	0.01	0.01	-0.02	0.00	0.01
Rio Chama Valley	0.00	0.01	-0.04	0.04	-0.02	-0.01	0.01	0.01	0.01	0.01	-0.02	0.02	0.03
Middle Rio Grande	-0.01	-0.01	0.00	0.00	-0.01	0.01	0.02	-0.05	-0.03	0.00	-0.01	0.00	-0.08
Plains	0.00	0.00	0.01	0.00	0.00	0.02	0.03	0.01	-0.03	0.03	-0.01	0.01	0.06
All Valley Sites	***0.00***	***0.00***	***0.00***	***0.01***	***-0.01***	***0.00***	***0.01***	***0.00***	***-0.01***	***0.01***	***-0.02***	***0.00***	***-0.01***
Region (All Sites)	***0.00***	***0.00***	***-0.01***	***0.01***	***-0.01***	***0.00***	***0.00***	***-0.01***	***0.00***	***0.01***	***-0.02***	***0.01***	***-0.03***

Red: Increase significant at 90% (0.1) confidence level; Purple: Decrease significant at 90% (0.1) confidence level.

**Significance not calculated (sample size too small).*

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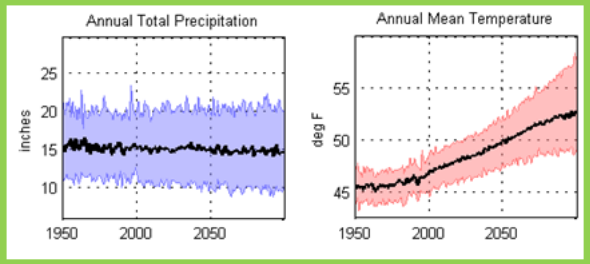
Transient Simulation Methodology

112 runs
1950-2099

General Circulation Model (GCM)

112 Statistically Downscaled Regional Projections of ΔP and ΔT



Variable Infiltration Capacity (VIC) Model

112 Runoff Projections Using Rainfall Runoff Model

Post processing bias correction of flows (224 hydrographs)

Operations model (URGSiM)

Impacts to water deliveries, flows, and reservoir levels.

Climate Change Analysis: CMIP3 -> VIC -> URGSiM

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1. Coupled Model Intercomparison Project 3 (CMIP3)
   - 16 different GCMs run for 3 different greenhouse gas emission scenarios with a variety of boundary conditions
   - 112 model runs from 1950-2099 that generate global Temperature and Precipitation time series.

	Emissions Scenarios																		
Climate Models:	A1b							A2					B1						
bccr_bcm2_0	1							40					76						
cccma_cgcm3_1	2	3	4	5	6			41	42	43	44	45	77	78	79	80	81		
cnrm_cm3	7							46					82						
csiro_mk3_0	8							47					83						
gfdl_cm2_0	9							48					84						
gfdl_cm2_1	10							49					85						
giss_model_e_r		11		12				50					86						
inmcm3_0	13							51					87						
ipsl_cm4	14							52					88						
miroc3_2_medres	15	16	17					53	54	55			89	90	91				
miub_echo_g	18	19	20					56	57	58			92	93	94				
mpi_echam5	21	22	23					59	60	61			95	96	97				
mri_cgcm2_3_2a	24	25	26	27	28			62	63	64	65	66	98	99	100	101	102		
ncar_ccsm3_0	29	30	31		32	33	34	67	68	69	70		103	104	105	106	107	108	109
ncar_pcm1	35	36	37	38				71	72	73	74			110	111				
ukmo_hadcm3	39							75					112						

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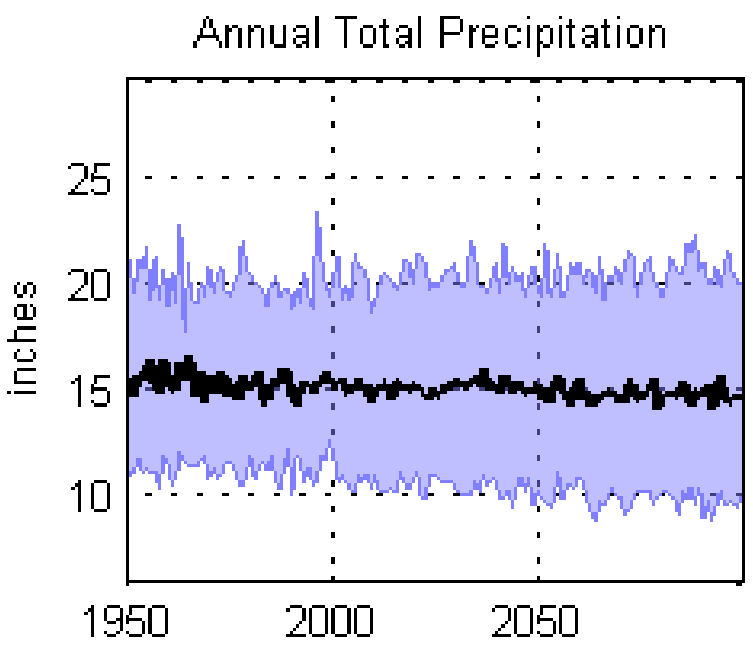
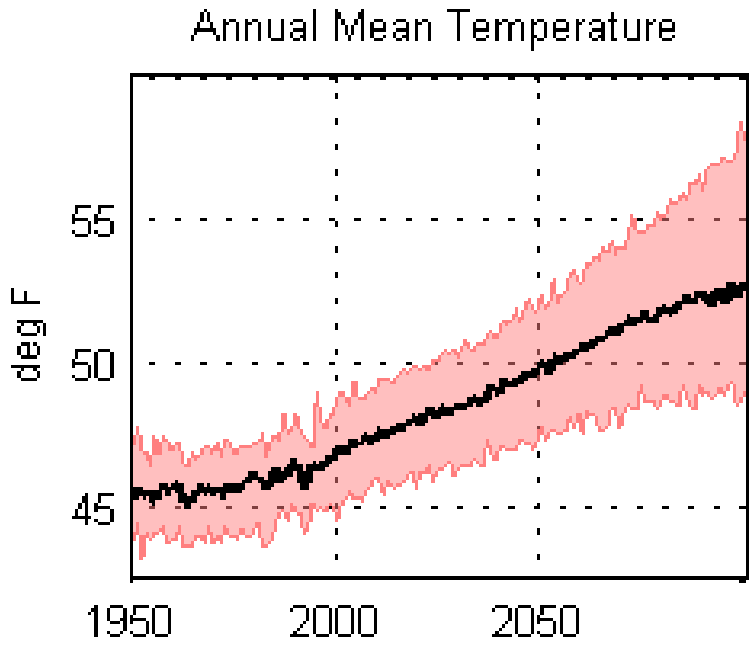
Climate Change Analysis: CMIP3 -> VIC -> URGSiM

1. Coupled Model Intercomparison Project Phase 3 (CMIP3)
2. Spatial downscaling of CMIP3 results to a 1/8th degree grid

Ensemble projections for Rio Grande Basin:





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Climate Change Analysis: CMIP3 -> VIC -> URGSiM

3. Temperature and Precipitation at 1/8th degree drive Variable Infiltration Capacity (VIC) model.
4. "Bias corrected" VIC hydrographs used to drive the Upper Rio Grande Simulation Model (URGSiM)

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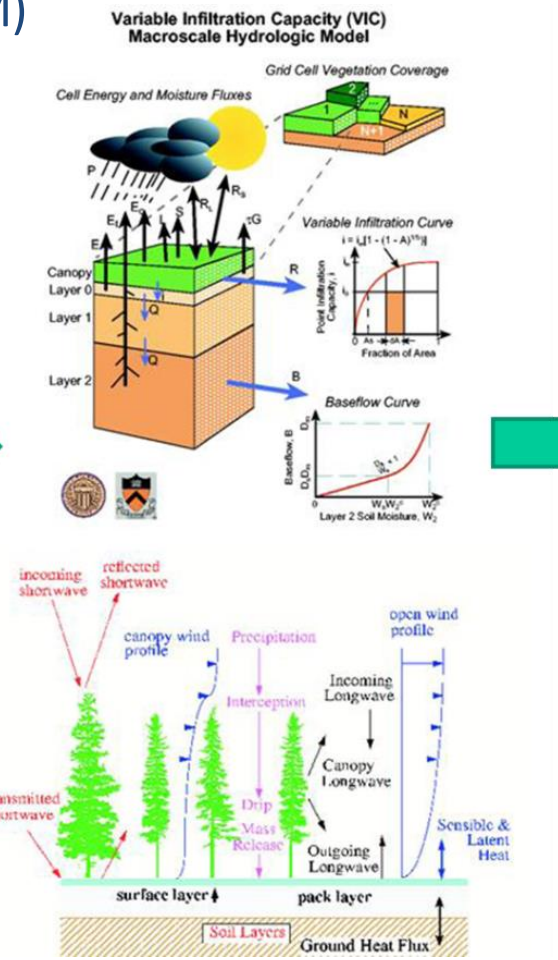
Downscaled GCM Output (T and P)



Hydrographs

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URGSiM

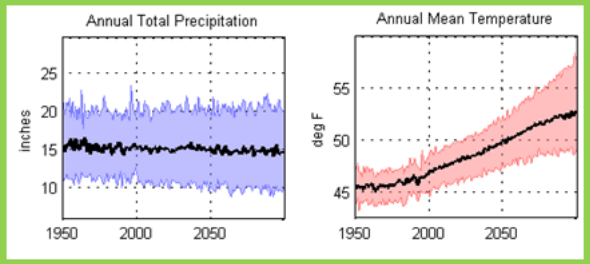
- Monthly timestep operations model of the Upper Rio Grande hydrologic system developed at Sandia National Laboratories with support from Reclamation and USACE
- Gaged flow inputs at 21 locations
- Includes regional groundwater models dynamically connected to river system.
- Includes agricultural and municipal/industrial demand, consumption, and return flows.
- Models storage and operations at 9 reservoirs

Transient Simulation Methodology

112 runs
1950-2099

General Circulation Model (GCM)

112 Statistically Downscaled Regional Projections of ΔP and ΔT



Variable Infiltration Capacity (VIC) Model

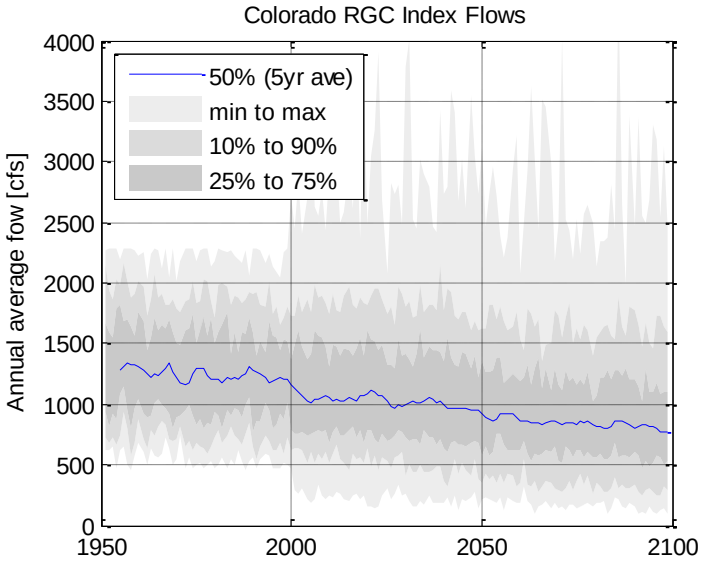
112 Runoff Projections Using Rainfall Runoff Model

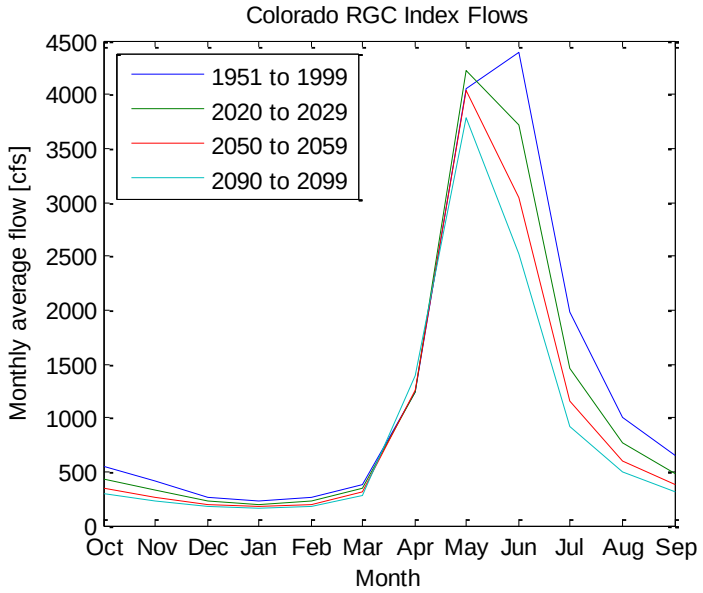
Post processing bias correction of flows (224 hydrographs)

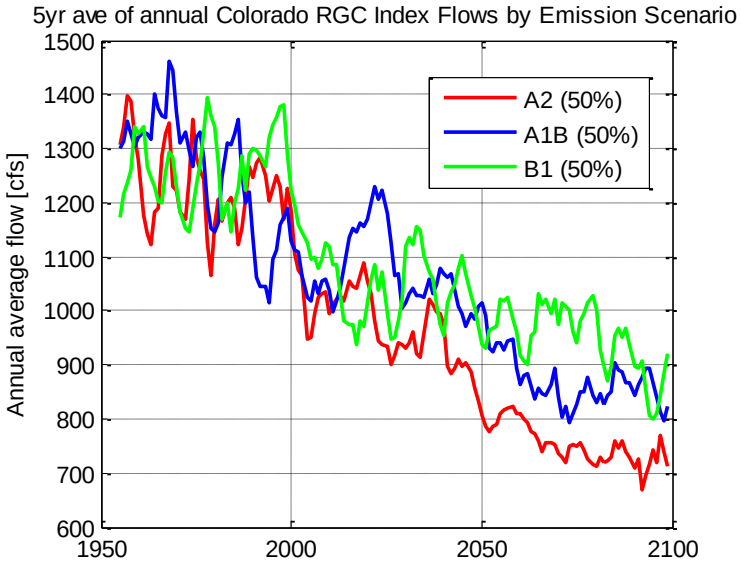
Operations model (URGSiM)

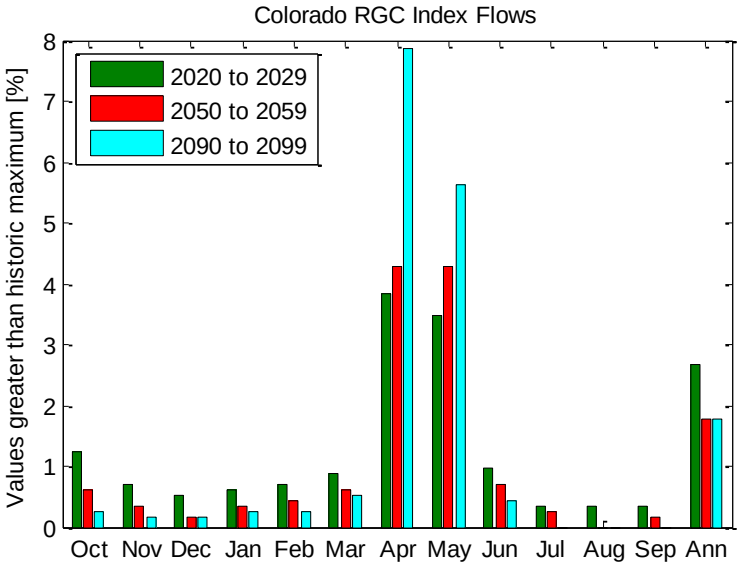
Impacts to water deliveries, flows, and reservoir levels.

Transient results: Reduced Supply at Colorado Index Gages



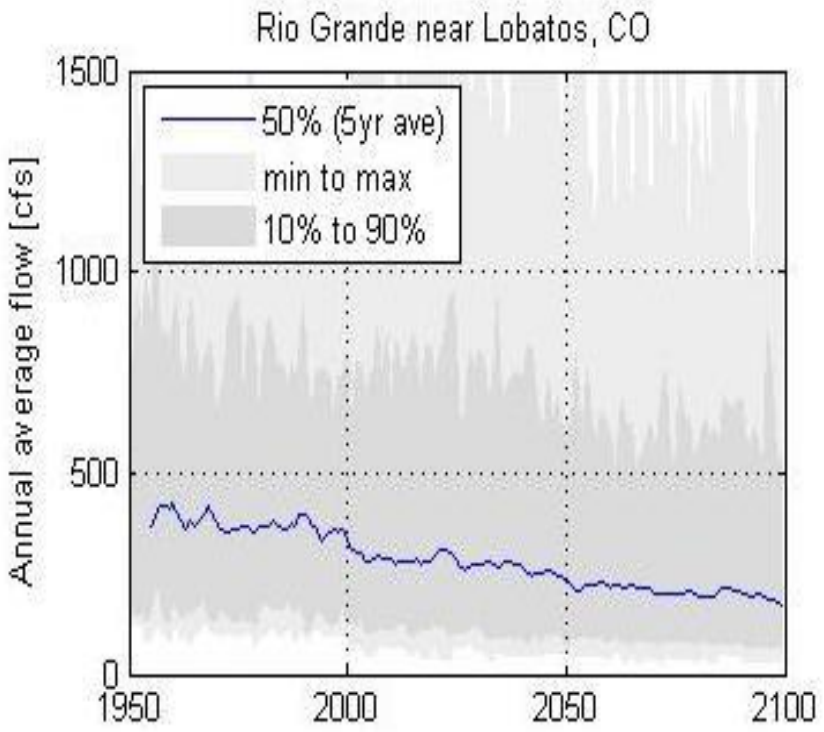


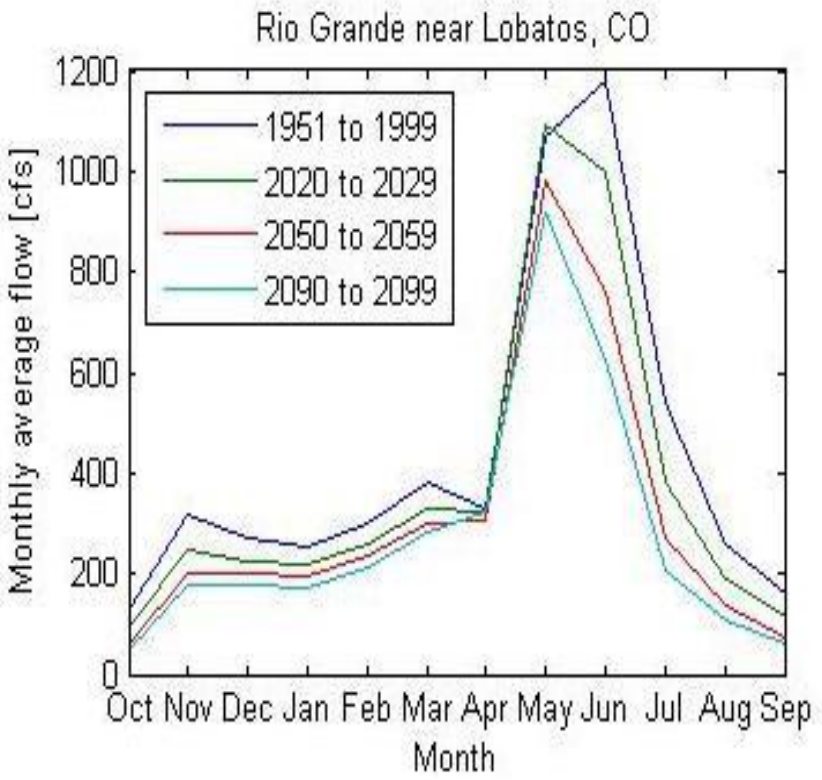




Which is magnified at Lobatos

- Colorado State-Line Deliveries to New Mexico: ~ 50% median decrease, most of which occurs in June through August





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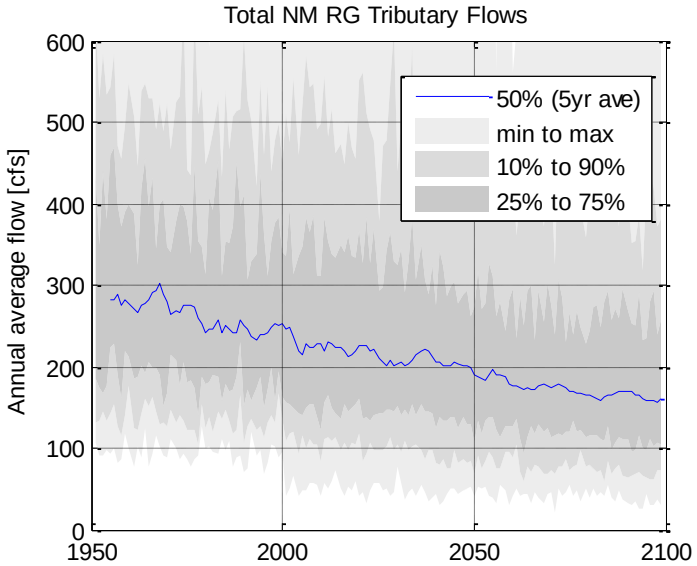
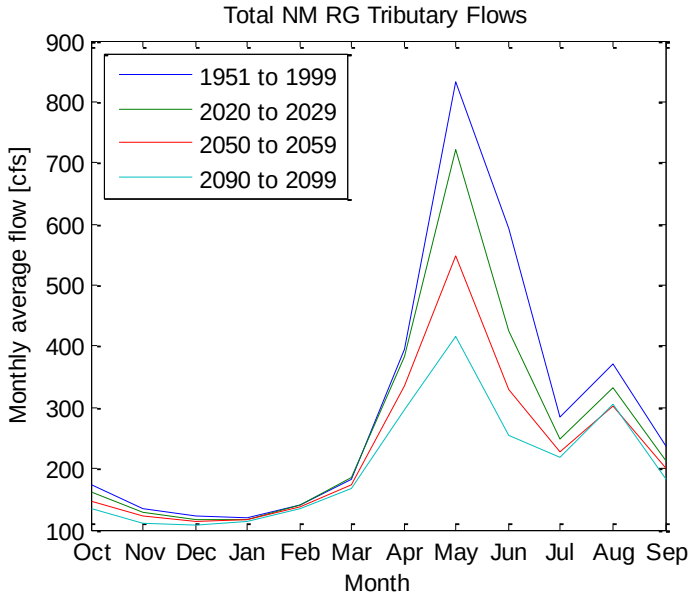
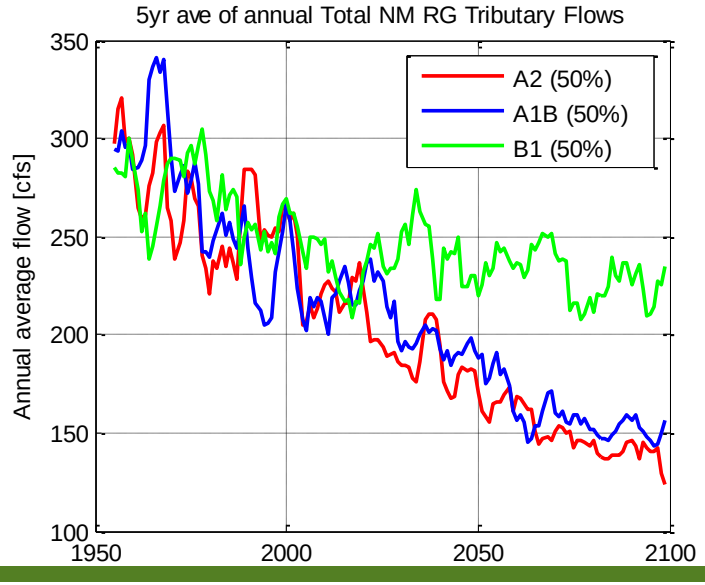
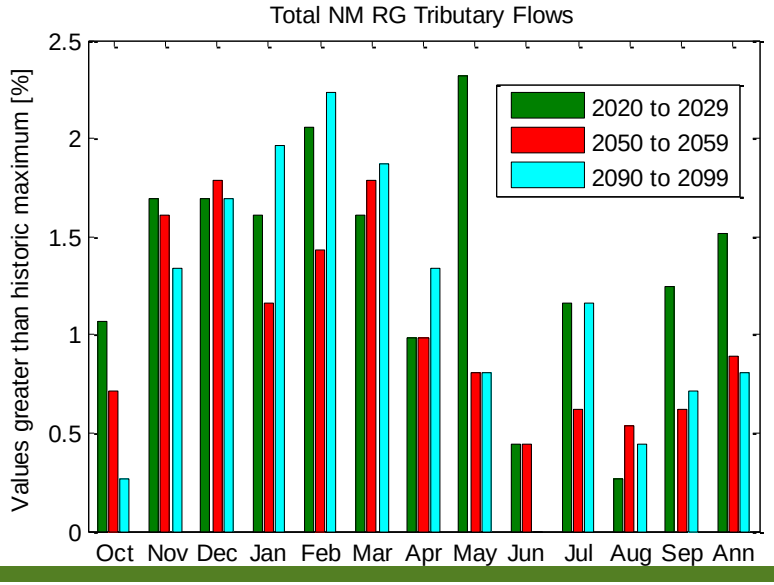
and RG tributaries (not including Chama and Jemez)









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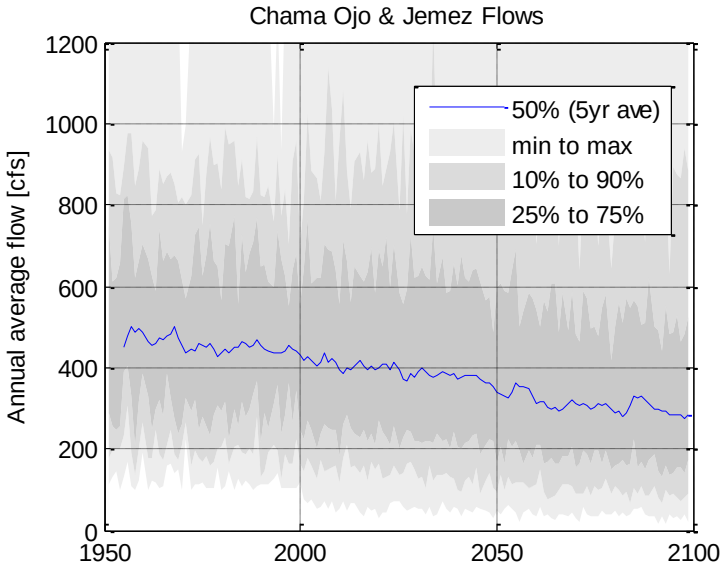
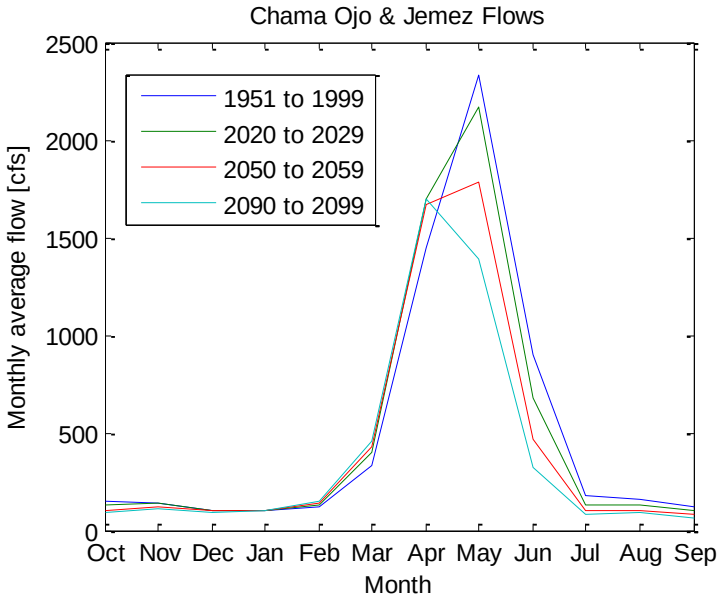
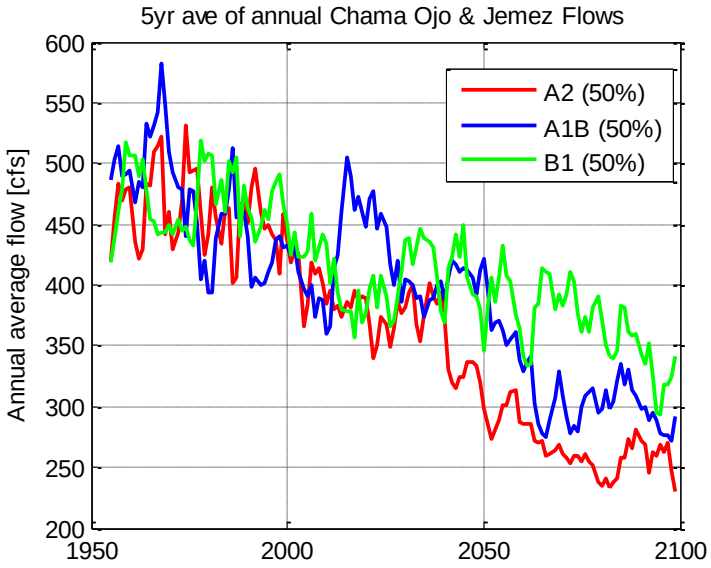
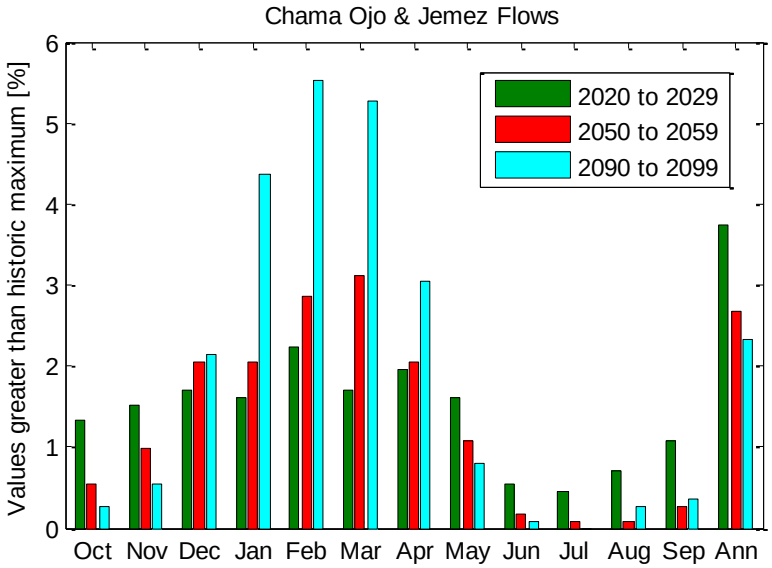
and Chama and Jemez

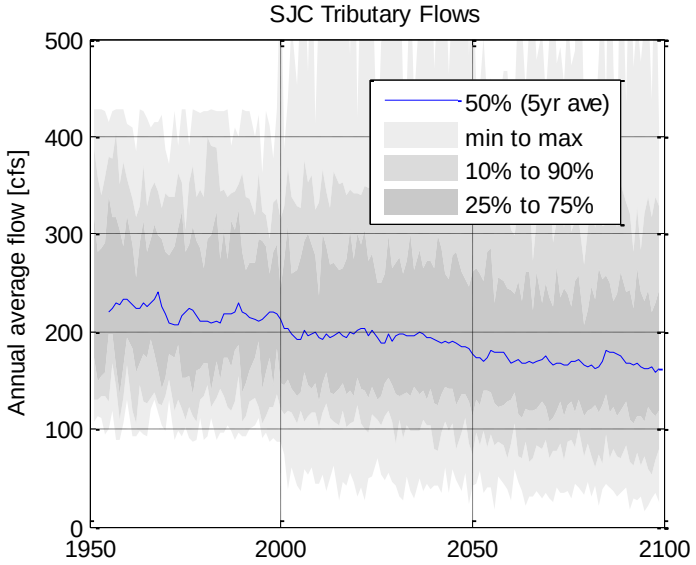


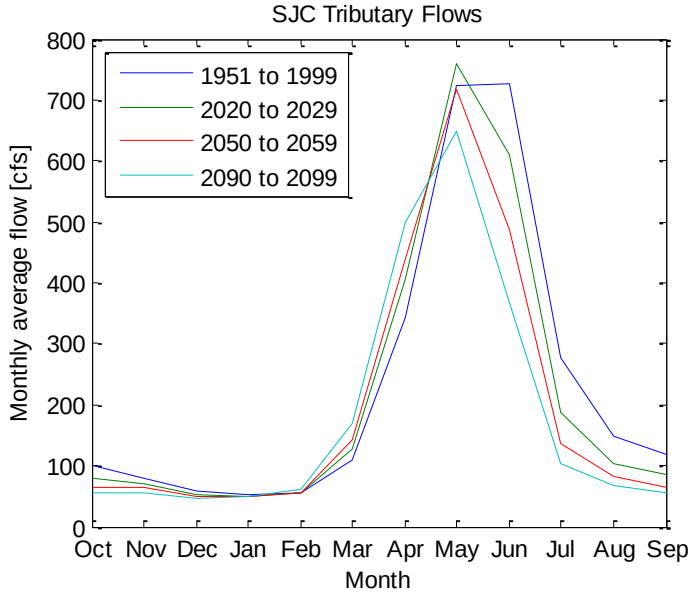


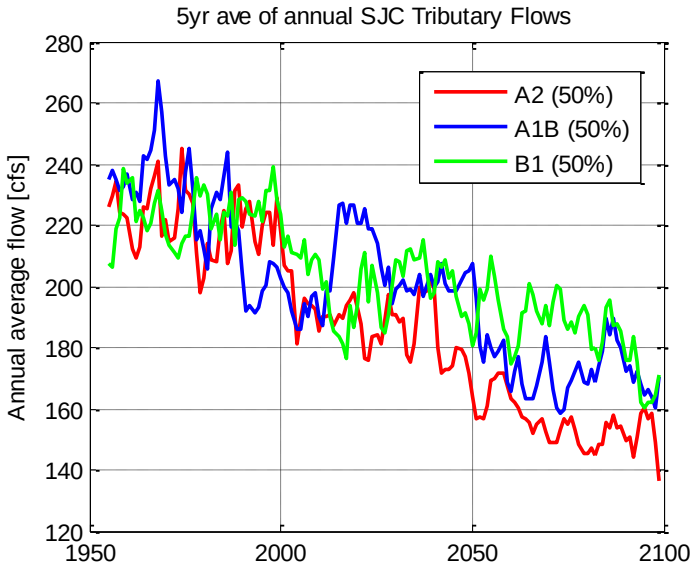


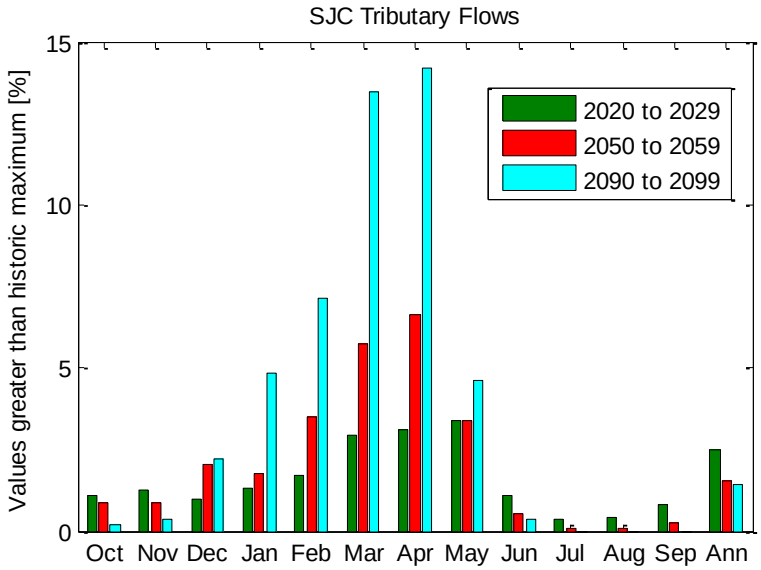


and SJC on SJ side of the divide



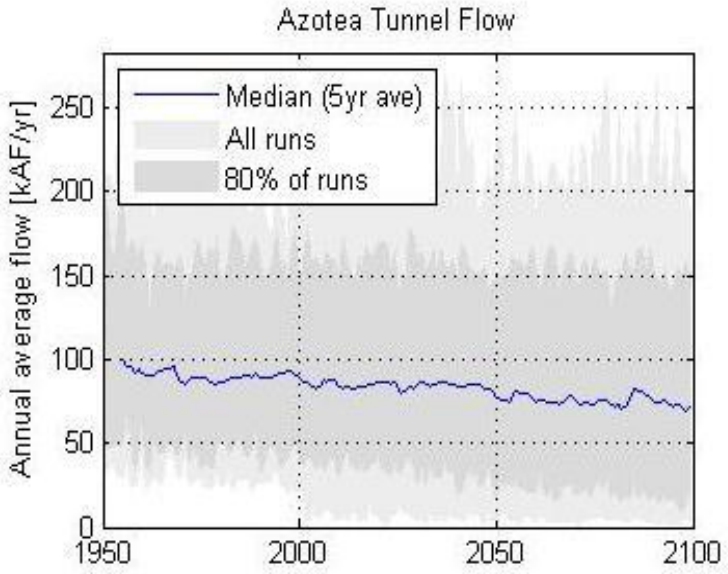


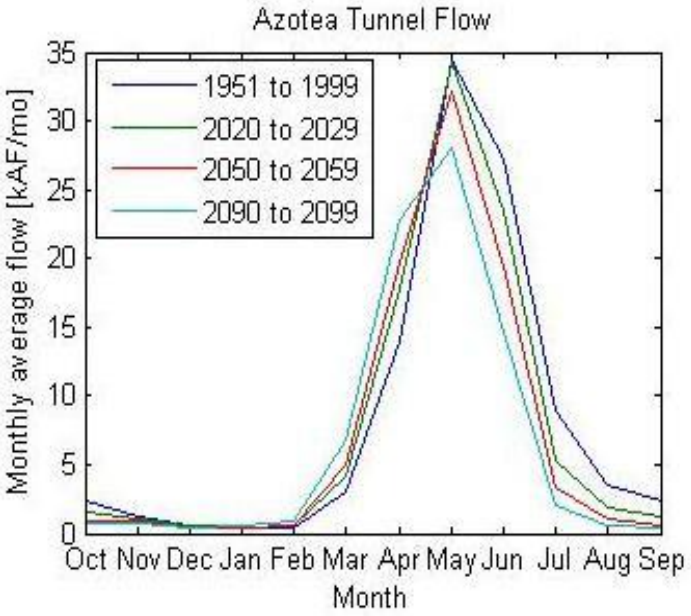


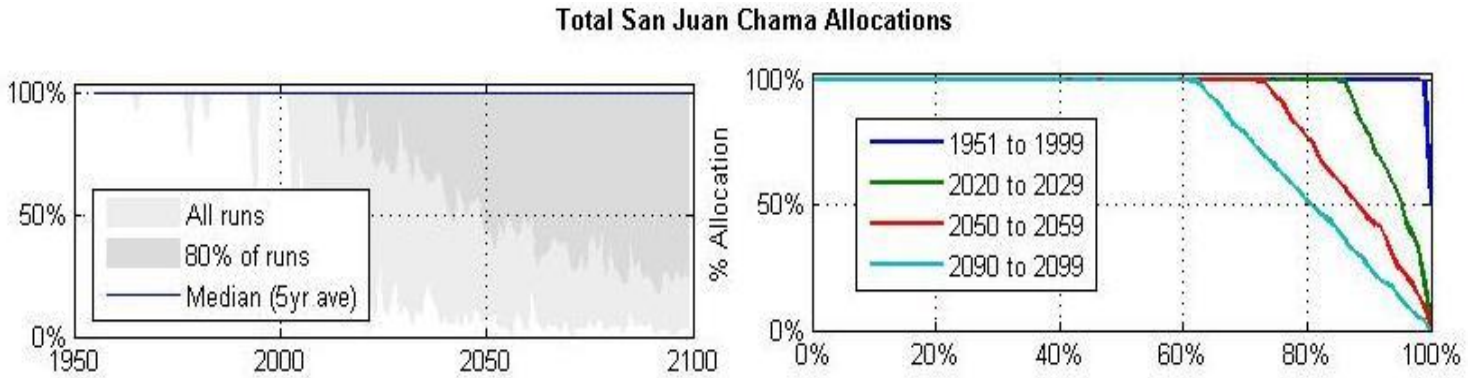


But reduction not as severe on Chama side of divide

- Imported water (San Juan – Chama Project). ~15% reduction







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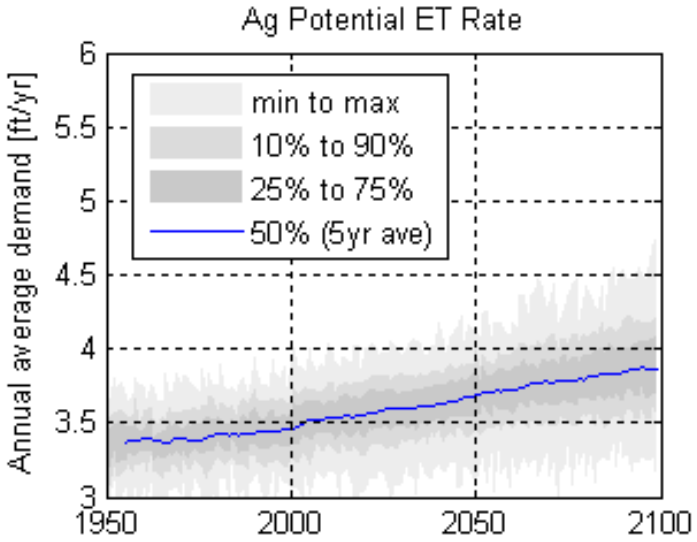
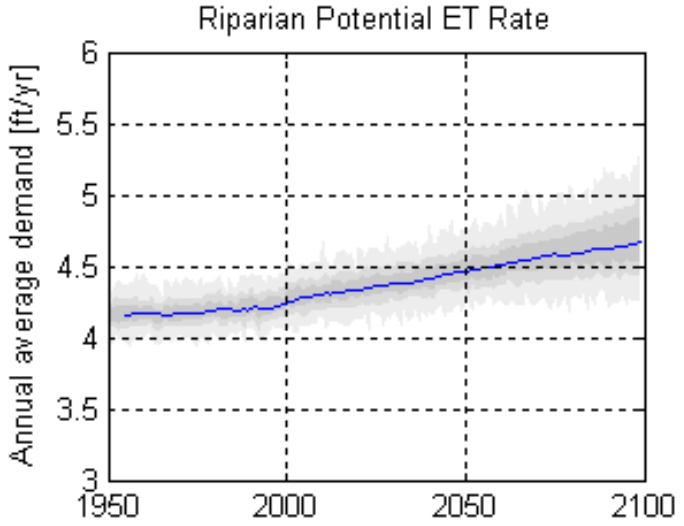
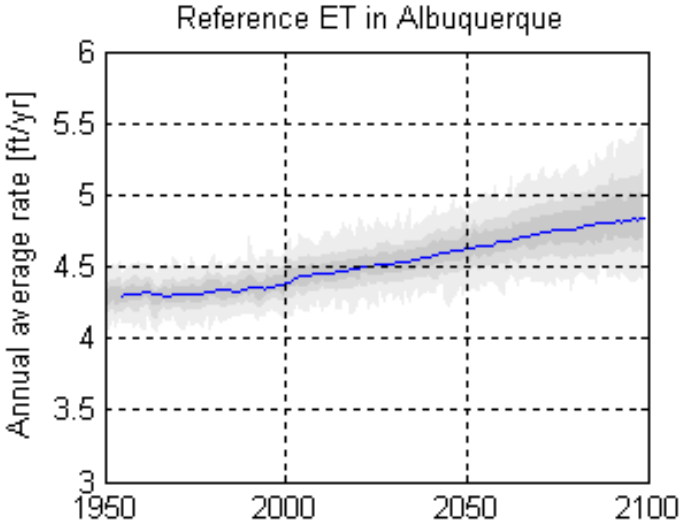
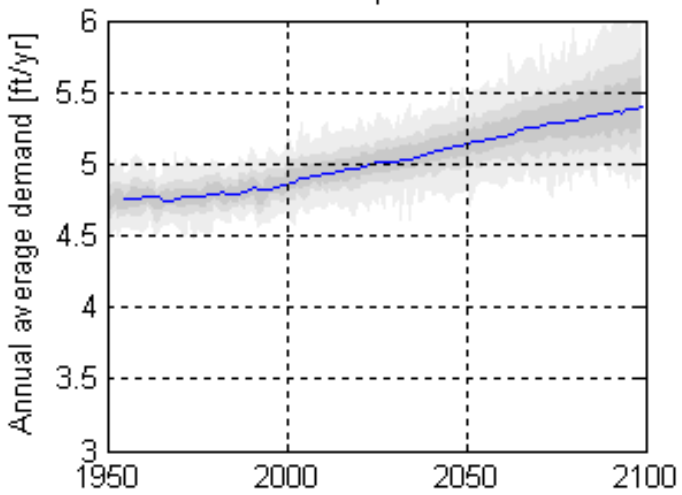
Results: Increased temperature leads to increased demand









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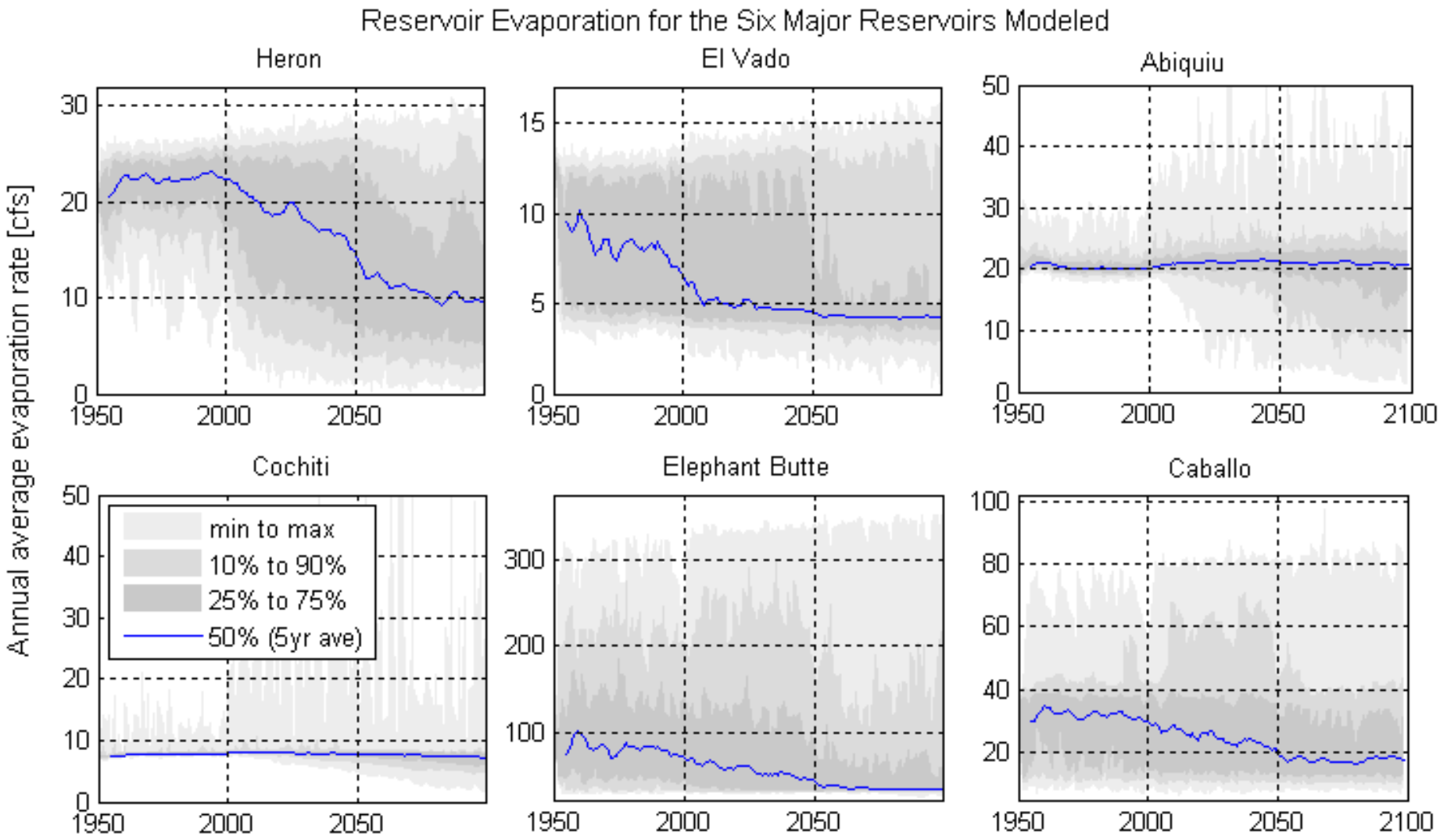
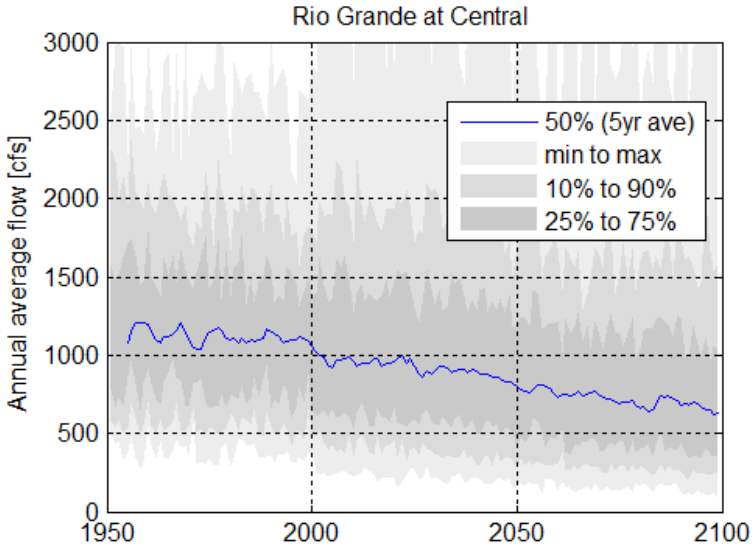
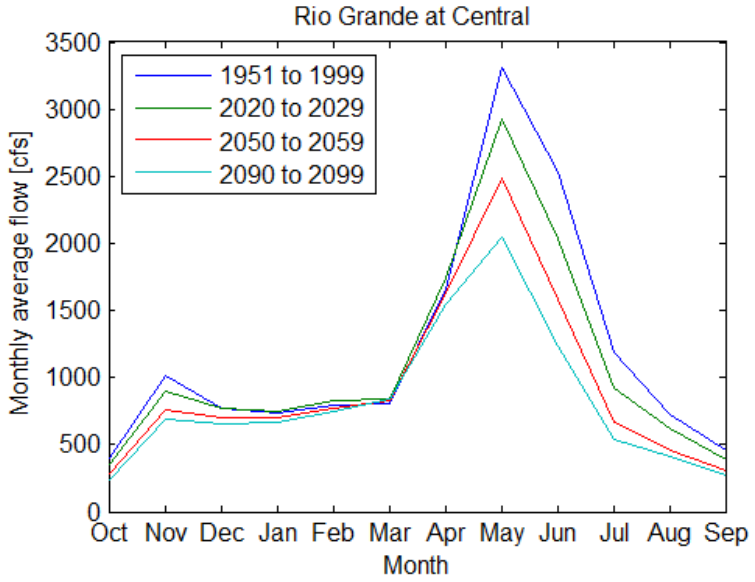
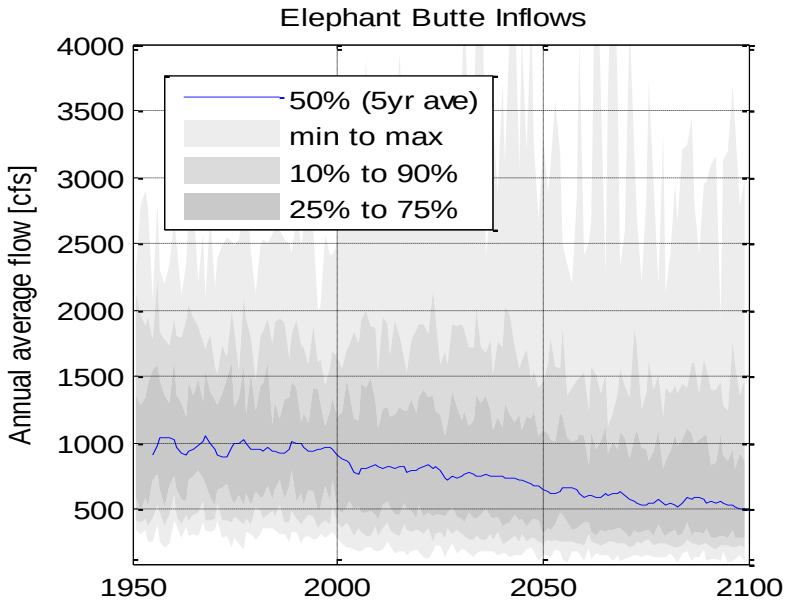
does not rise due to reduced availability and especially

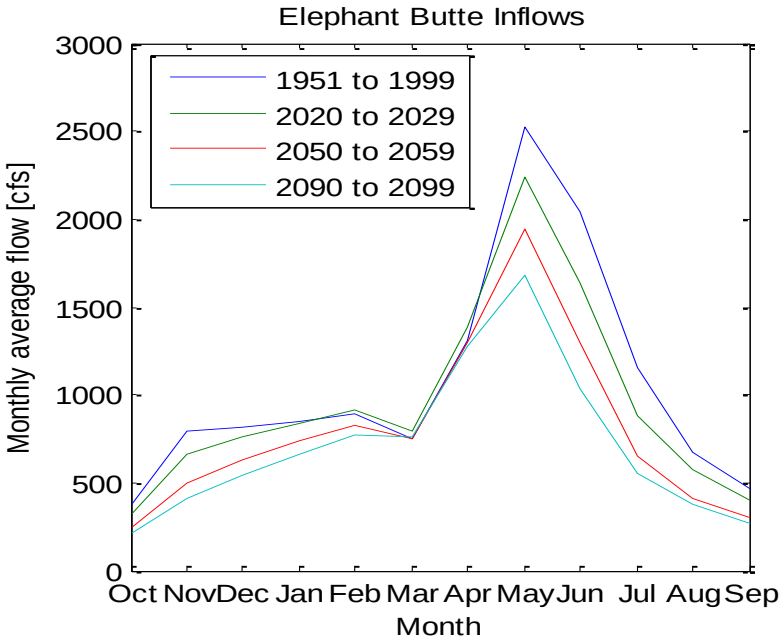


But reduced supply & increased ag demand squeezes the system:









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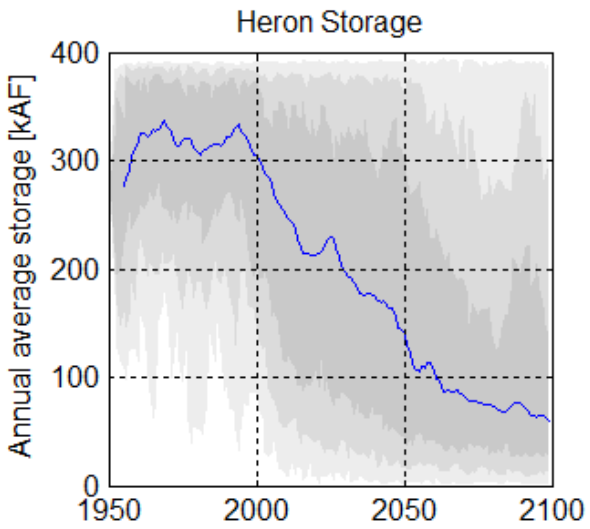
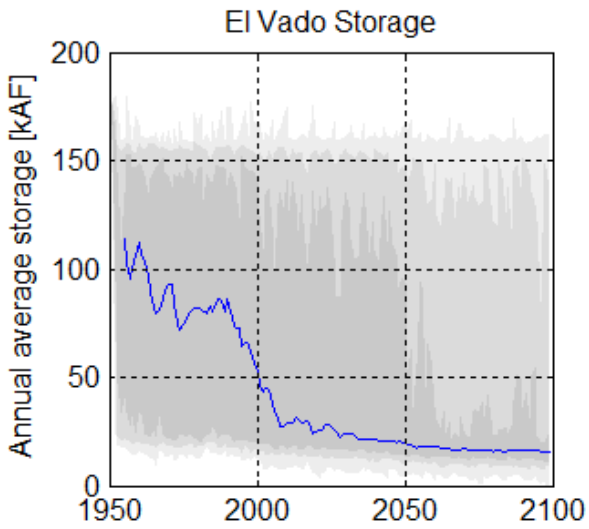
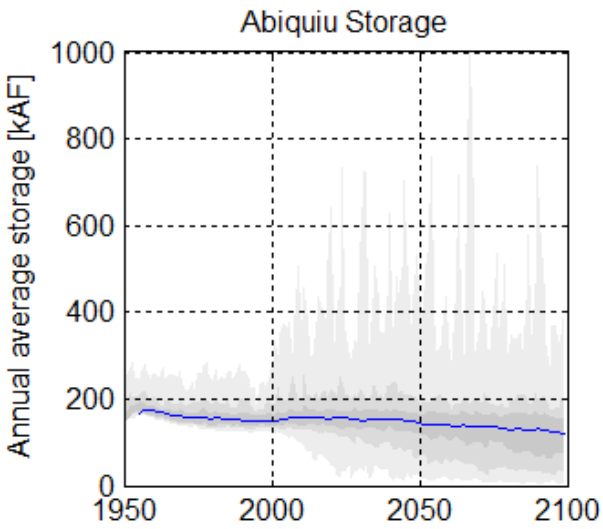
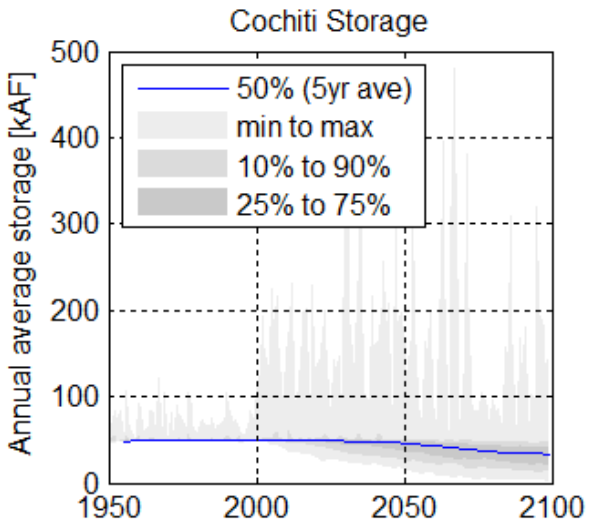
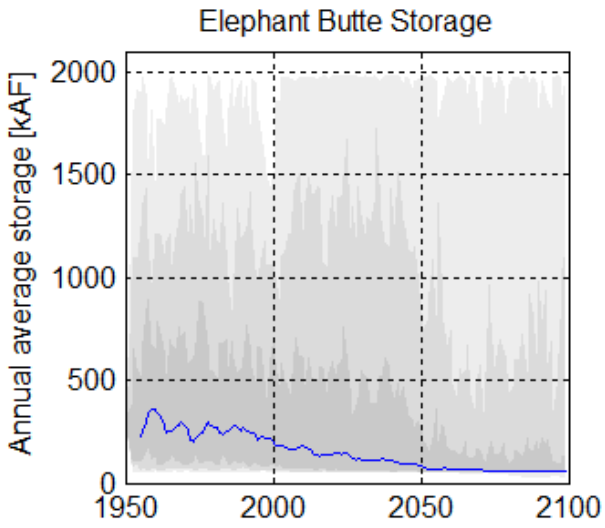
Reservoirs:

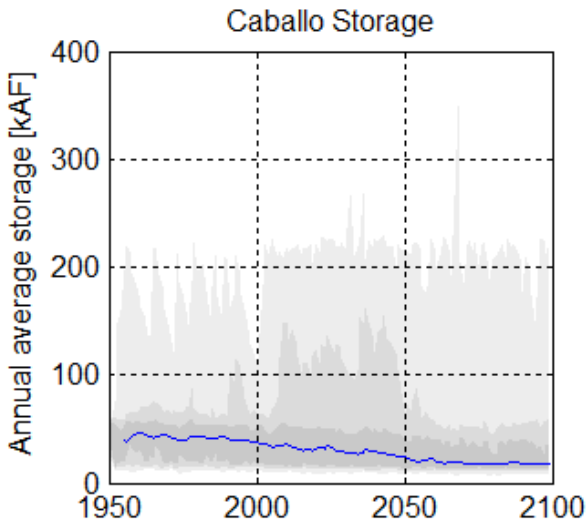

Heron Storage
Annual average storage [kAF]
400
300
200
100
0
1950
2000
2050
2100


El Vado Storage
Annual average storage [kAF]
200
150
100
50
0
1950
2000
2050
2100


Abiquiu Storage
Annual average storage [kAF]
1000
800
600
400
200
0
1950
2000
2050
2100


Cochiti Storage
Annual average storage [kAF]
500
400
300
200
100
0
1950
2000
2050
2100
50% (5yr ave)
min to max
10% to 90%
25% to 75%


Elephant Butte Storage
Annual average storage [kAF]
2000
1500
1000
500
0
1950
2000
2050
2100


Caballo Storage
Annual average storage [kAF]
400
300
200
100
0
1950
2000
2050
2100

Transient vs “Period Analysis”

Spatial Average of change in average temp and average precip predicted by GCMs for 1950-1999 vs 2010-2039, 2040-2069, 2070-2099

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Step 2.4: Area or Location ?

Latitude	31	.6875	N through	38	.5625	N	**Area Limits**	Min	Max
Longitude	-107	.9375	E through	-105	.0625	E	Latitude	25.1875	52.8125
							Longitude	-124.6875	-67.0625

Use the above lat/long menus or mouse (click map for draggable marker) to define the red box position.

Lat: 40.9135 Lon: -95.1416

Period Analysis

Spatial Average of change in average temp and average precip predicted by GCMs for 1950-1999 vs 2010-2039, 2040-2069, 2070-2099

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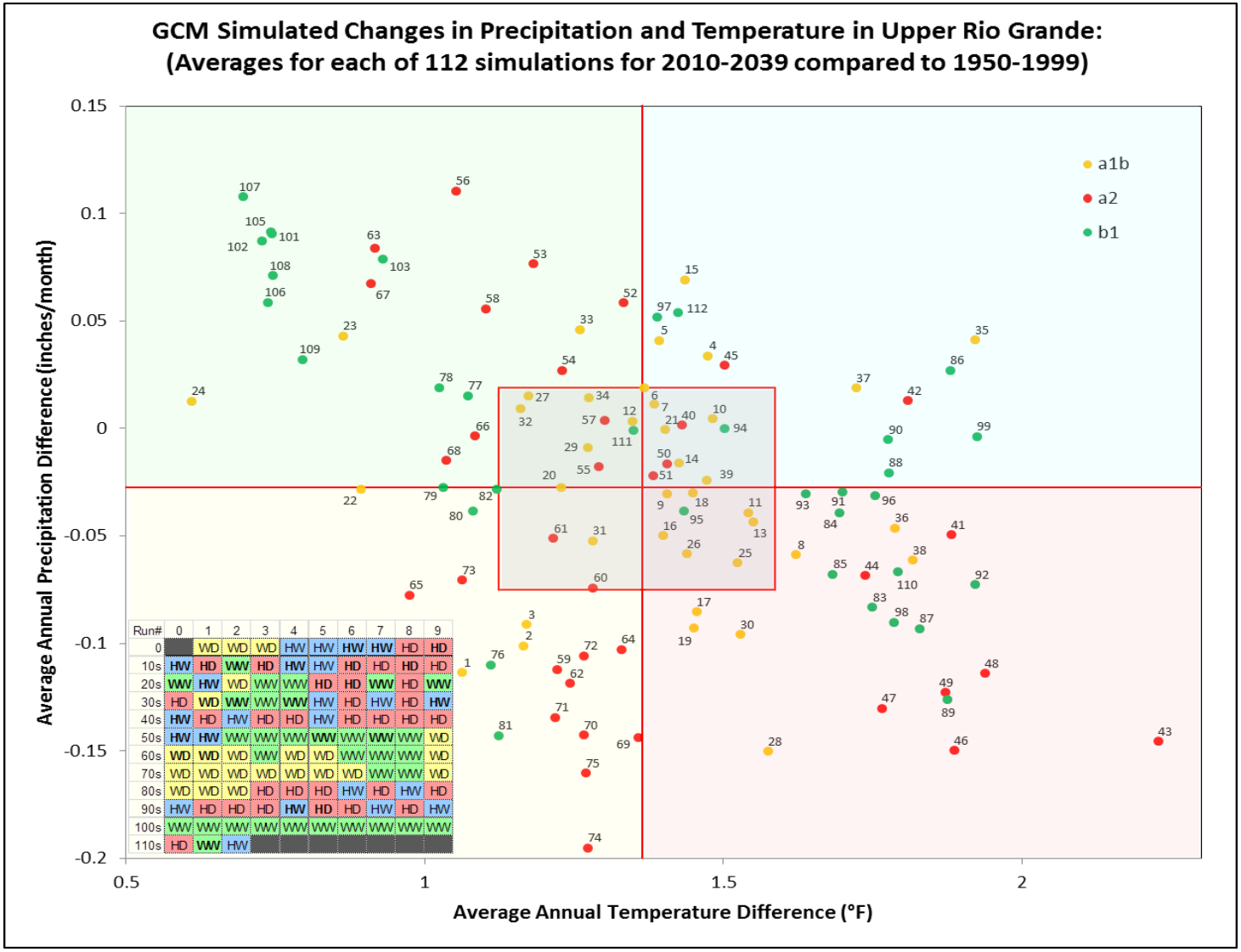
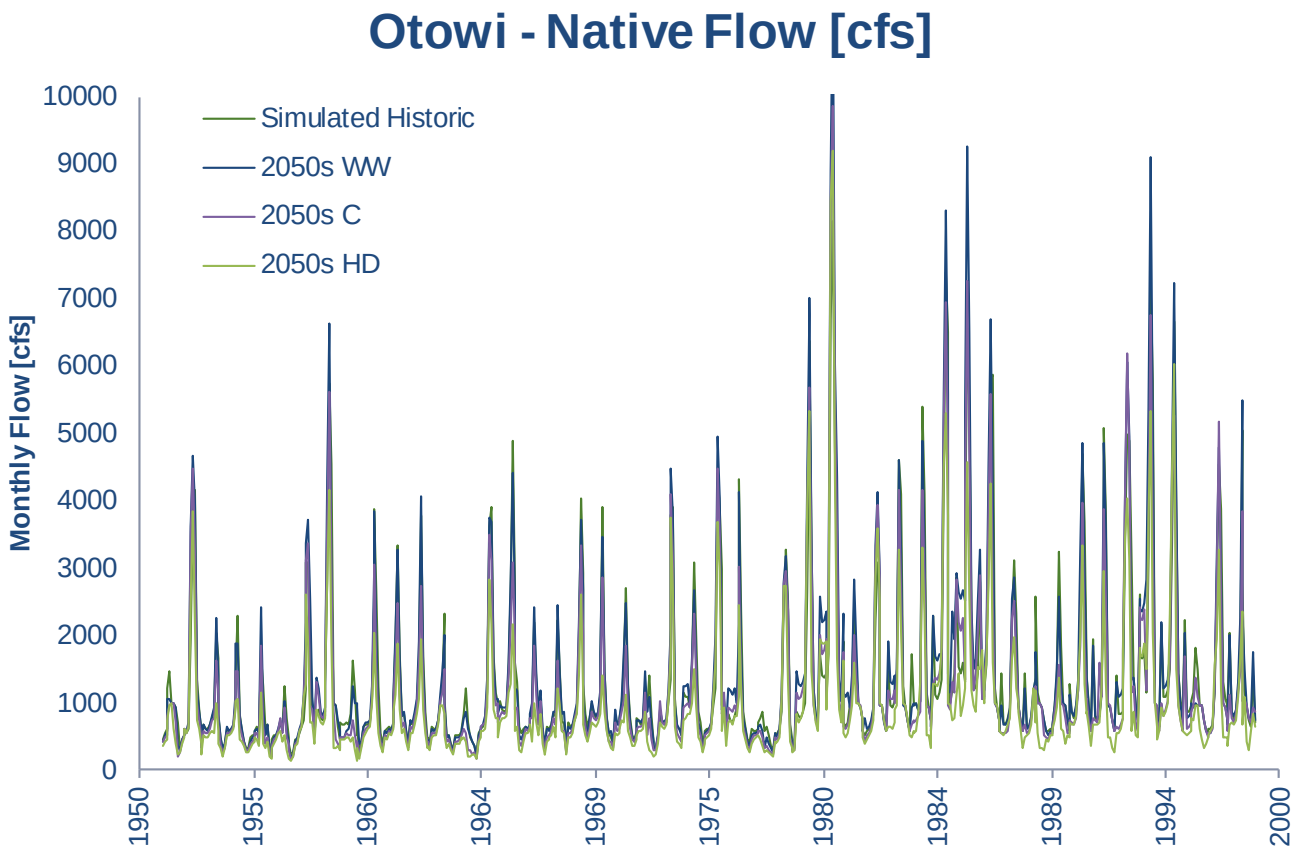


Period Analysis

Ensemble "delta" then added to historic* temperature and precip fields, and VIC model run with the modified historic data and changes evaluated.



***Spatially distributed precipitation and temperature fields based on historic point data. (Maurer et al 2002)**

Period Analysis

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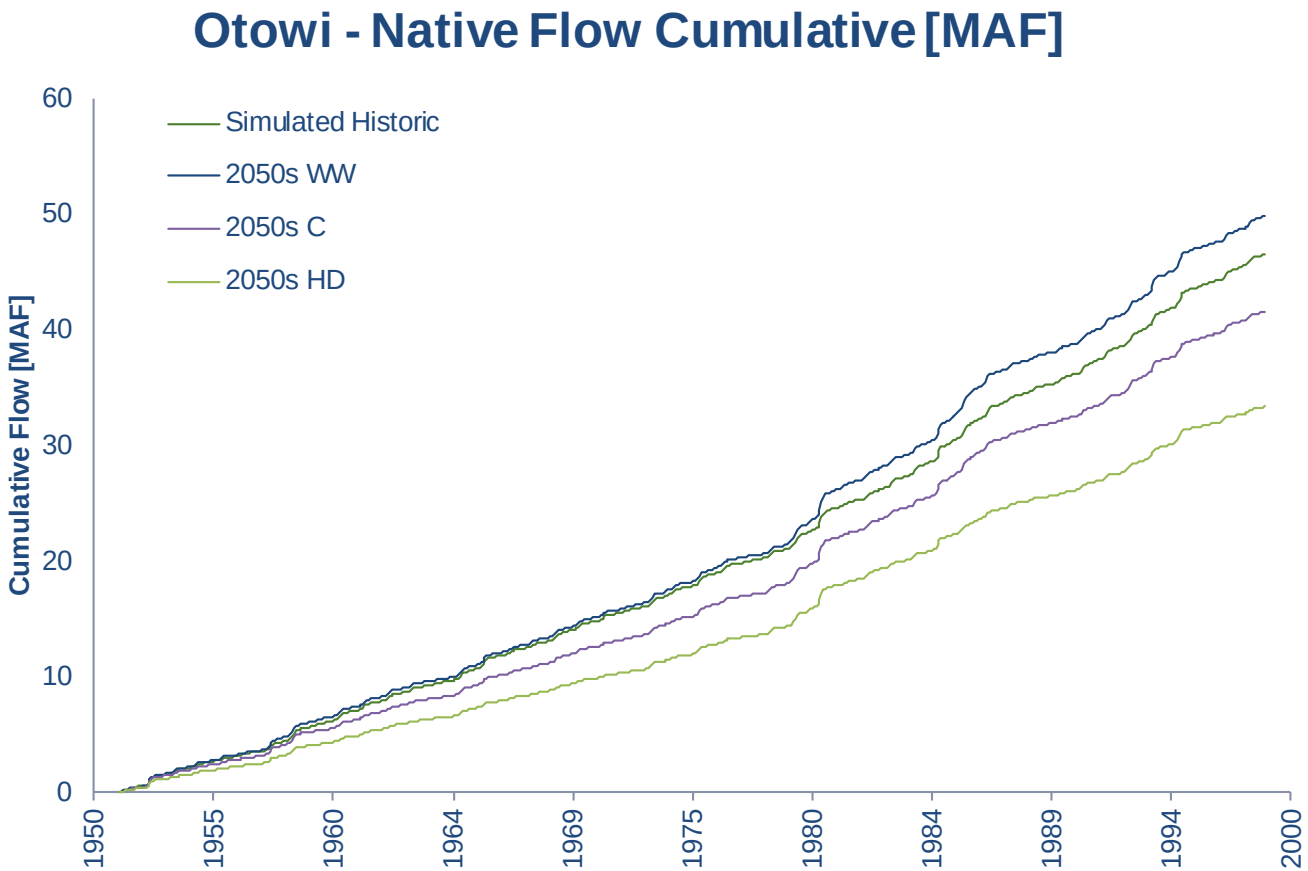

***Spatially distributed precipitation and temperature fields based on historic point data. (Maurer et al 2002)**