The implications of SWAT parameter equifinality on climate change projections

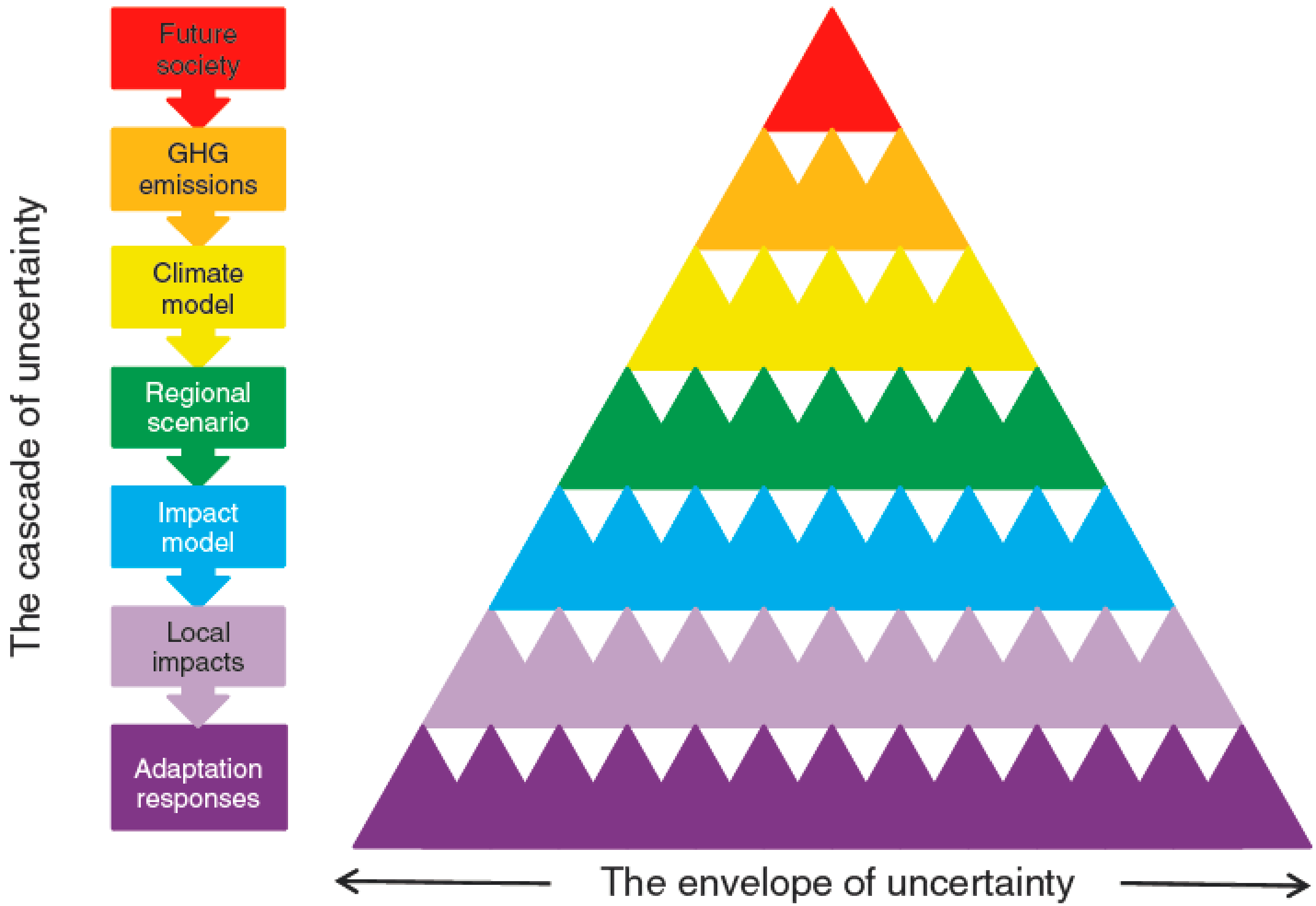
Darren L. Ficklin
Department of Geography, Indiana University, dficklin@indiana.edu
Bradley L. Barnhart
U.S. EPA, Corvallis, Oregon

Introduction

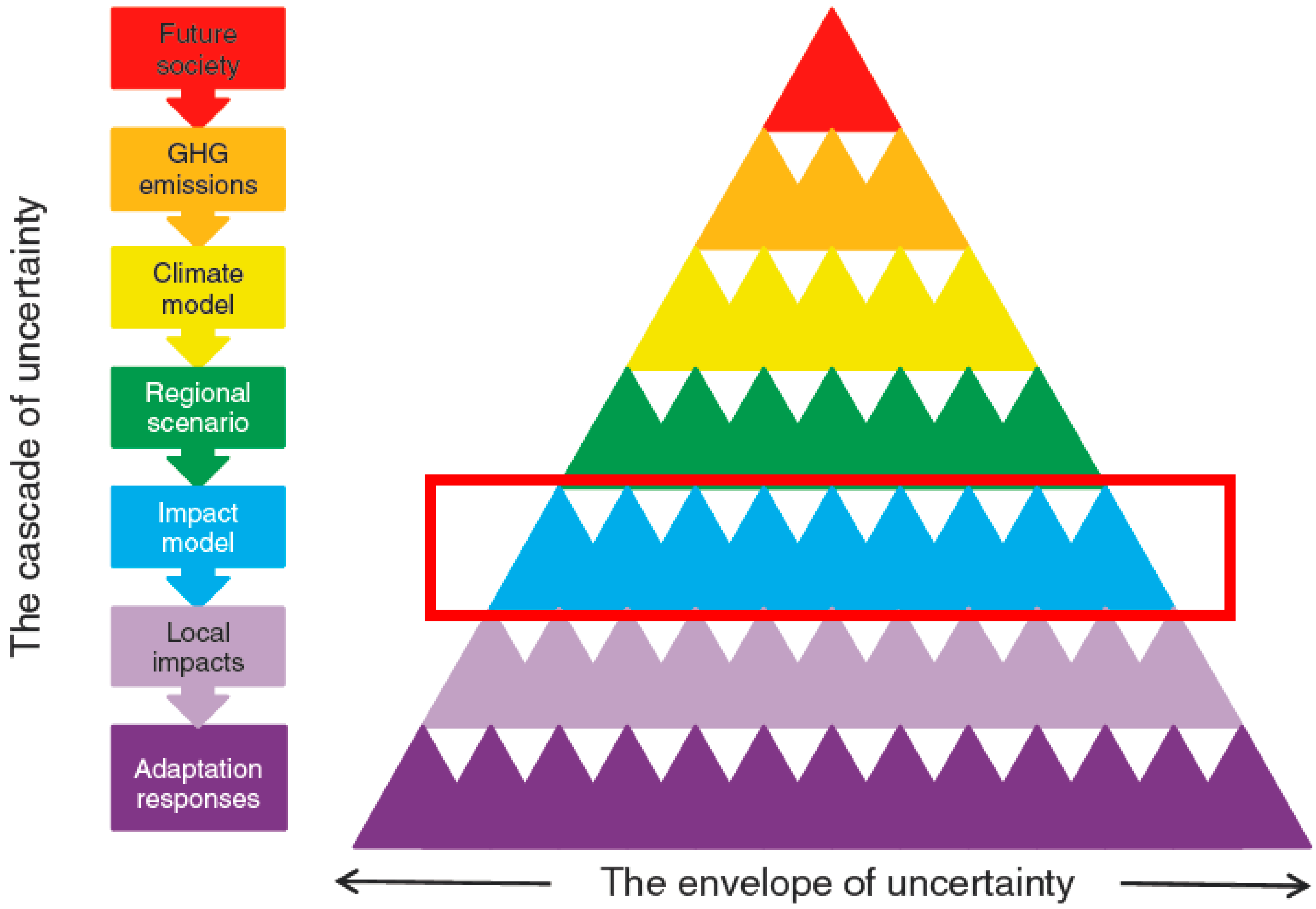
- The potential impact of climate change on water resources has been studied extensively throughout the world through the use of calibrated hydrologic models and General Circulation Model (GCM) output

- A Web of Science search of “SWAT” and “climate change” returns over 500 results

- This process is subject to uncertainties sometimes referred to as the “cascade of uncertainty”



Wilby & Dessai (2010, Weather)



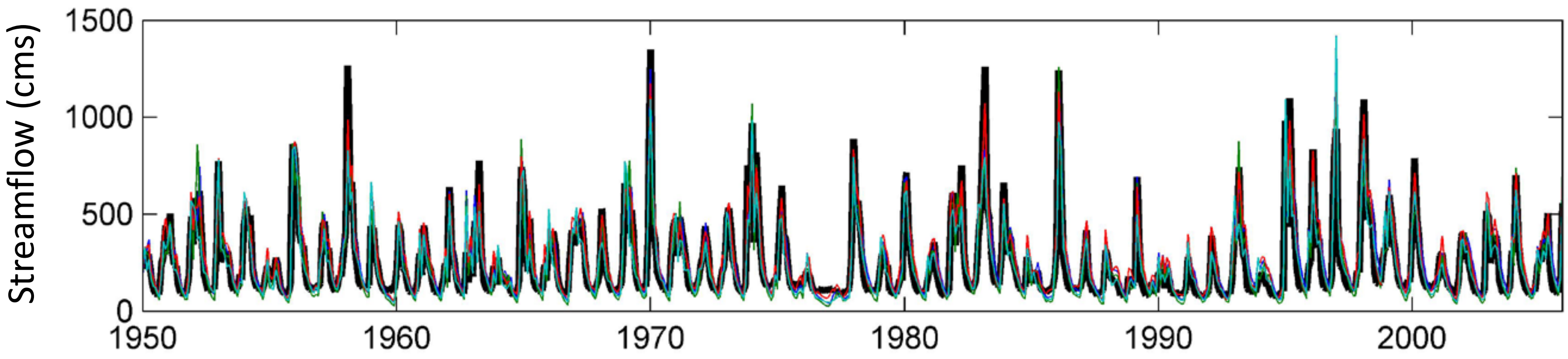
Wilby & Dessai (2010, Weather)

Hydrologic model uncertainty

- Models to be considered (including processes to be included, boundary conditions, etc.)
- Ranges (prior distributions) of parameter values to be considered for calibration
- Input data (and input data errors) that drive the model (including future scenarios for prediction)
- Error model, performance measure(s) or allowable error to be considered acceptable before accepting results
- Hydrological model equifinality

What is model equifinality?

- Multiple hydrological model parameter sets produce similar or acceptable model outputs

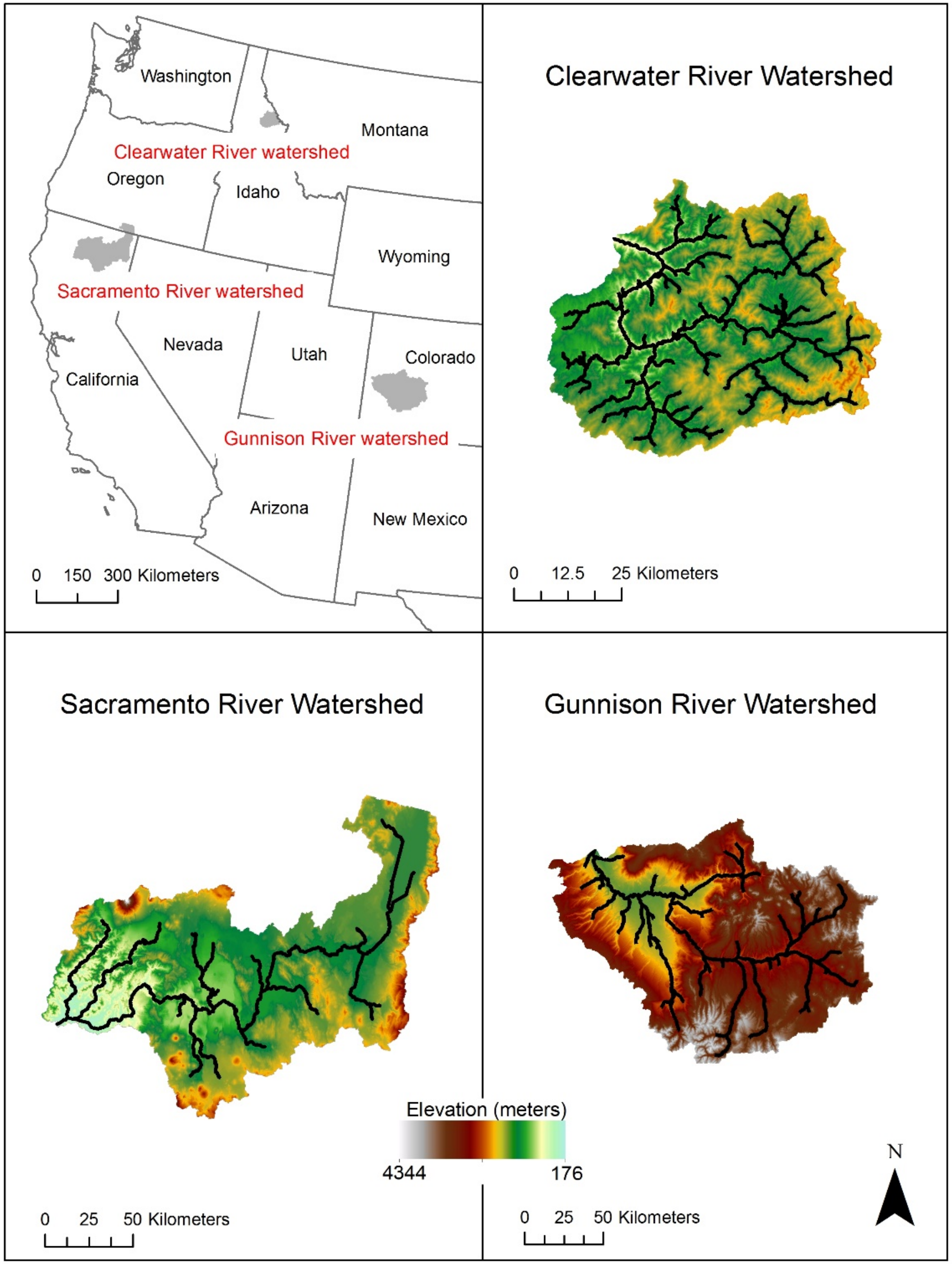


Objectives

- The goal of this work is to investigate SWAT model equifinality as a source of uncertainty for climate change projections
- How do acceptable parameter sets change hydrologic projections? Does it matter?
- Three distinct, important water resource regions in the western United States are analyzed
  - Upper Clearwater River watershed (a tributary of the Snake River basin)
  - Gunnison River watershed (a tributary of the Colorado River watershed)
  - Upper Sacramento River watershed

Study regions

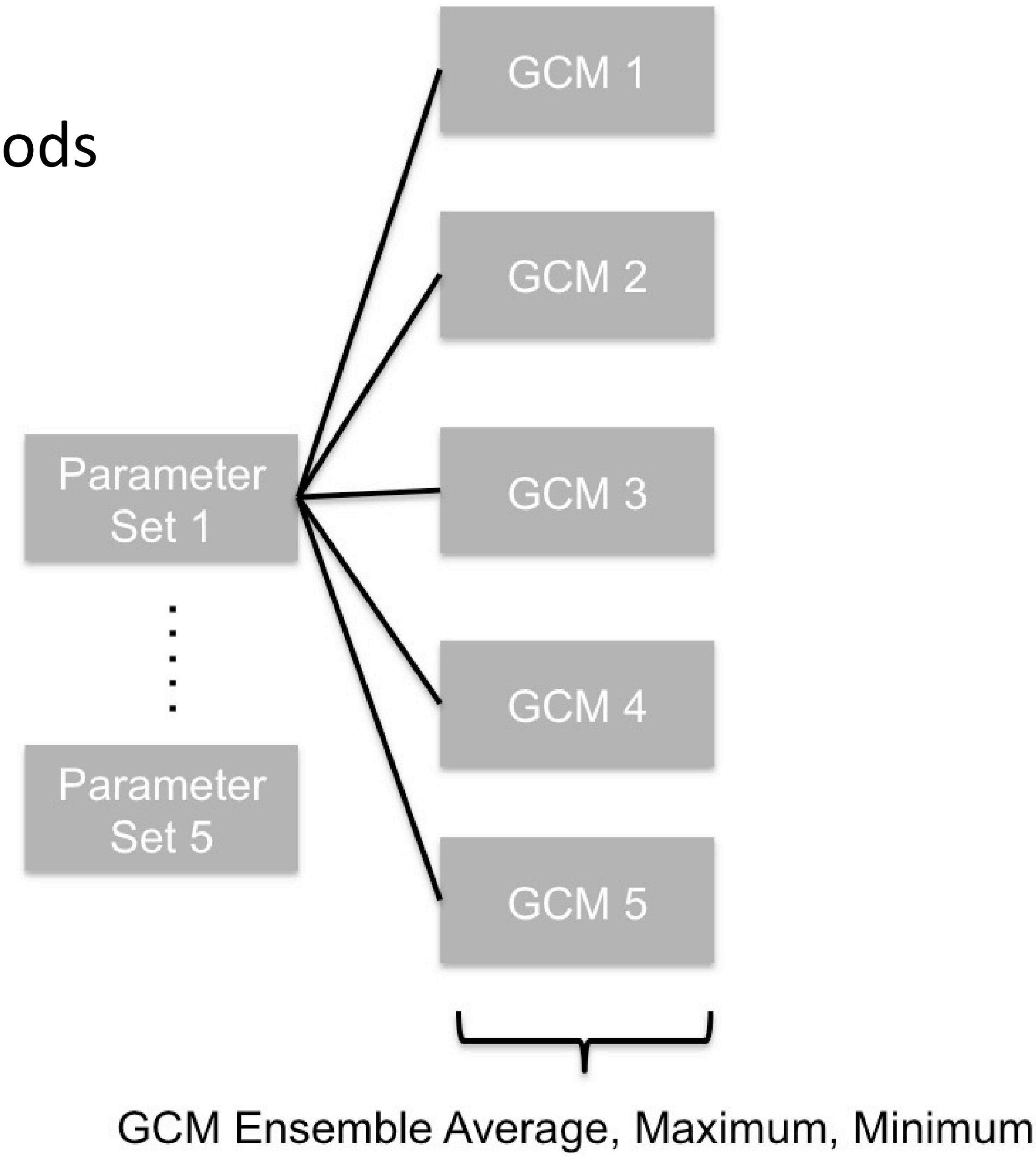
Watershed	Clearwater River	Gunnison River	Sacramento River
Watershed Outlet Coordinates	46°50'34.334"N 115°37'16.97"W	38°59'0.193"N 108°27'7.16"W	40°42'45.557"N 122°25'59.872"W
Area (km^2)	3,354	20,048	18,839
Max. elevation (m)	2,415	4,344	4,298
Min. elevation (m)	509	1,267	176
Ave. streamflow (m^3/s)	96.8	87.1	239.9
Ave. Annual Temp (°C)	5.6	1.3	9.4
Average annual precip. (mm)	1,410	520	890



Study Methods

<u>Historical time period</u>
Clearwater: 1970-1989
Gunnison: 1960-1979
Sacramento: 1950-1969

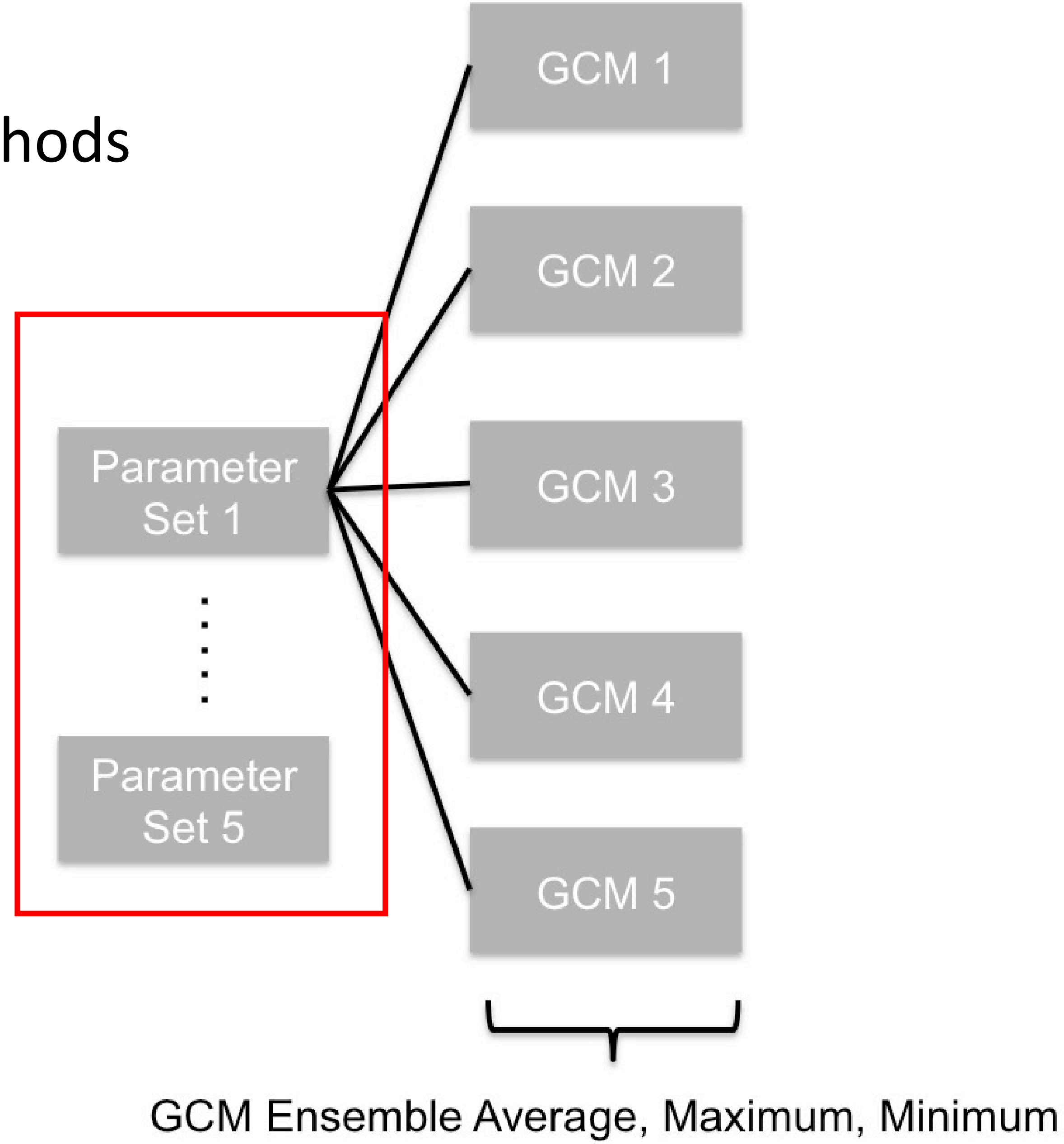
<u>Projected time period</u>
2081-2099



Study Methods

<u>Historical time period</u>
Clearwater: 1970-1989
Gunnison: 1960-1979
Sacramento: 1950-1969

<u>Projected time period</u>
2081-2099



Finding multiple calibration sets

SWAT model parameters were varied within a physically meaningful range for each watershed within SWAT-CUP

$$p_j : p_{j,abs\_min} \leq p_j \leq p_{j,abs\_max}$$

p is the parameter, *j* is the parameter index varying from 1 to 700, to produce 700 model sets

SWAT models were then run for each parameter set to allow 700 comparisons of observed and simulated streamflow at the outlet of each watershed

- 5 selected

Finding multiple calibration sets

- Parameters used:

ALPHA_BF.gw	ALPHA_BNK.rte	GW_DELAY.gw	GW_REVAP.gw	GWQMN.gw	LAT_TTIME.hru	REVAPMN.gw
CN2.mgt	SLSOIL.hru	SOL_AWC().sol	SOL_K().sol	SOL_BD().sol	CH_N2.rte	CH_K2.rte
EPCO.hru	ESCO.hru	SURLAG.bsn	PLAPS.sub	TLAPS.sub	RCHRG_DP.gw	SFTMP.bsn
SMFMN.bsn	SMFMX.bsn	SMTMP.bsn	SNO50COV.bsn	SNOCOVMX.bsn	TIMP.bsn	

700 combinations of the above parameters were used for each watershed

- Adequate calibrations and validations are based Moriasi et al. (2007)

NSE > 0.50 and RSR < 0.70, and if PBIAS +/- 25% for streamflow

Study Methods

<u>Historical time period</u>
Clearwater: 1970-1989
Gunnison: 1960-1979
Sacramento: 1950-1969

<u>Projected time period</u>
2081-2099

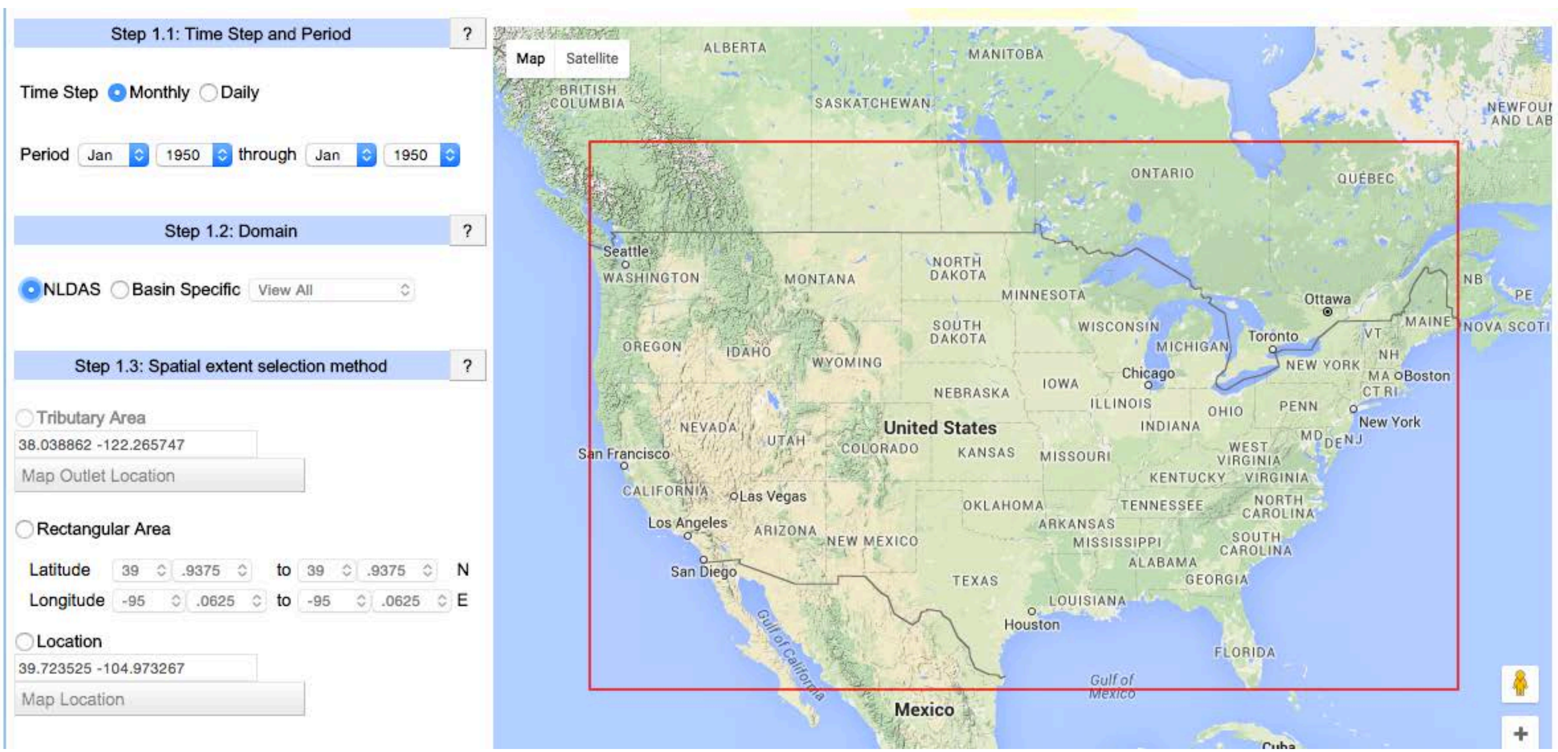
Downscaled GCMs

- Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections

  http://gdo-dcp.ucllnl.org/

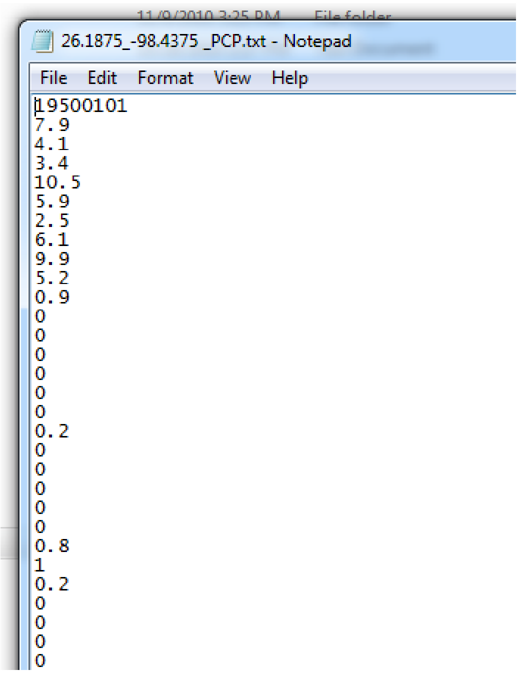
Over 20 downscaled GCMs for 4 emission scenarios available

RECLAMATION NCAR USGS
Santa Clara University
CLIMATE CENTRAL
SCRIPPS INSTITUTION OF OCEANOGRAPHY



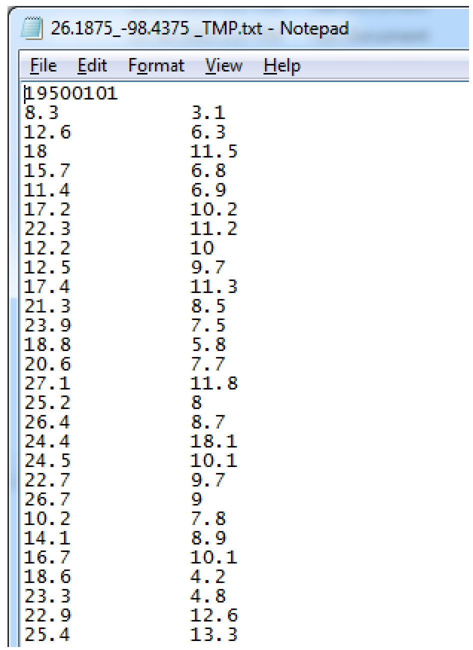
Downscaled GCMs

- Extract downloaded netCDF into SWAT format using a user-friendly MATLAB or R code found at my personal website: http://pages.iu.edu/~dficklin/


26.1875_-98.4375 _PCP.txt - Notepad

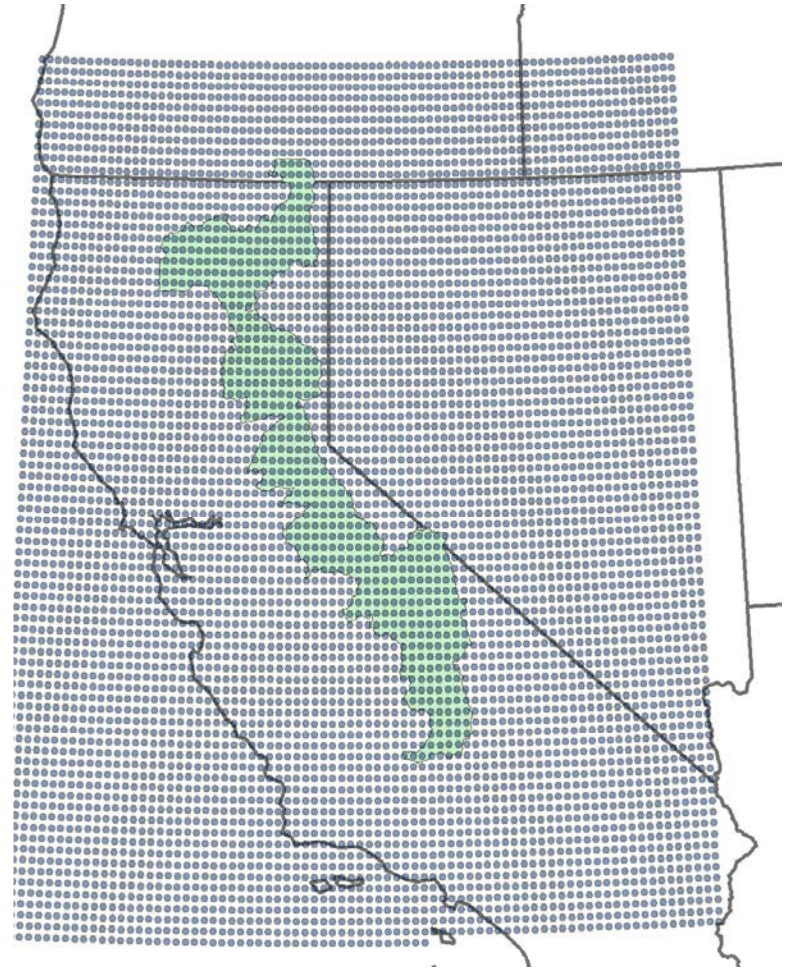
File Edit Format View Help

19500101
7.9
4.1
3.4
10.5
5.9
2.5
6.1
9.9
5.2
0.9
0
0
0
0
0
0
0.2
0
0
0
0
0
0.8
1
0.2
0
0
0
0


26.1875_-98.4375 _TMP.txt - Notepad

File Edit Format View Help

19500101	
8.3	3.1
12.6	6.3
18	11.5
15.7	6.8
11.4	6.9
17.2	10.2
22.3	11.2
12.2	10
12.5	9.7
17.4	11.3
21.3	8.5
23.9	7.5
18.8	5.8
20.6	7.7
27.1	11.8
25.2	8
26.4	8.7
24.4	18.1
24.5	10.1
22.7	9.7
26.7	9
10.2	7.8
14.1	8.9
16.7	10.1
18.6	4.2
23.3	4.8
22.9	12.6
25.4	13.3



Working on updated code to convert precip. and temp. files into SWAT input files

Results – Calibration and Validation

		Calibration					Validation				
		Years	NS	R2	RMSE	pbias (%)	Years	NS	R2	RMSE	pbias (%)
Clearwater	Parameter Set 1	1970-1989	0.70	0.80	57.8	19.9	1990-2005	0.66	0.79	55.5	15.0
	Parameter Set 2	1970-1989	0.79	0.84	48.5	20.4	1990-2005	0.83	0.85	34.3	10.4
	Parameter Set 3	1970-1989	0.81	0.86	45.5	21.2	1990-2005	0.82	0.87	35.8	13.7
	Parameter Set 4	1970-1989	0.76	0.79	52.1	18.7	1990-2005	0.71	0.74	50.7	11.2
	Parameter Set 5	1970-1989	0.72	0.76	56.7	21.3	1990-2005	0.77	0.79	45.8	13.8
Gunnison	Parameter Set 1	1960-1984	0.73	0.74	51.8	2.6	1985-2005	0.76	0.76	45.8	5.7
	Parameter Set 2	1960-1984	0.64	0.73	60.5	-17.8	1985-2005	0.62	0.70	57.1	-14.7
	Parameter Set 3	1960-1984	0.72	0.73	53.2	-12.0	1985-2005	0.75	0.76	46.0	-8.8
	Parameter Set 4	1960-1984	0.70	0.78	55.0	-15.9	1985-2005	0.68	0.77	52.7	-15.0
	Parameter Set 5	1960-1984	0.78	0.80	47.4	-14.9	1985-2005	0.77	0.79	44.2	-12.3
Sacramento	Parameter Set 1	1950-1984	0.85	0.87	74.7	-8.7	1985-2005	0.84	0.89	77.3	-16.1
	Parameter Set 2	1950-1984	0.84	0.84	77.3	-3.1	1985-2005	0.85	0.87	75.2	-11.0
	Parameter Set 3	1950-1984	0.91	0.93	60.3	-6.2	1985-2005	0.86	0.93	72.3	-19.6
	Parameter Set 4	1950-1984	0.86	0.86	73.5	18.1	1985-2005	0.87	0.87	71.9	19.1
	Parameter Set 5	1950-1984	0.93	0.92	54.8	-6.9	1985-2005	0.90	0.93	60.5	-7.1

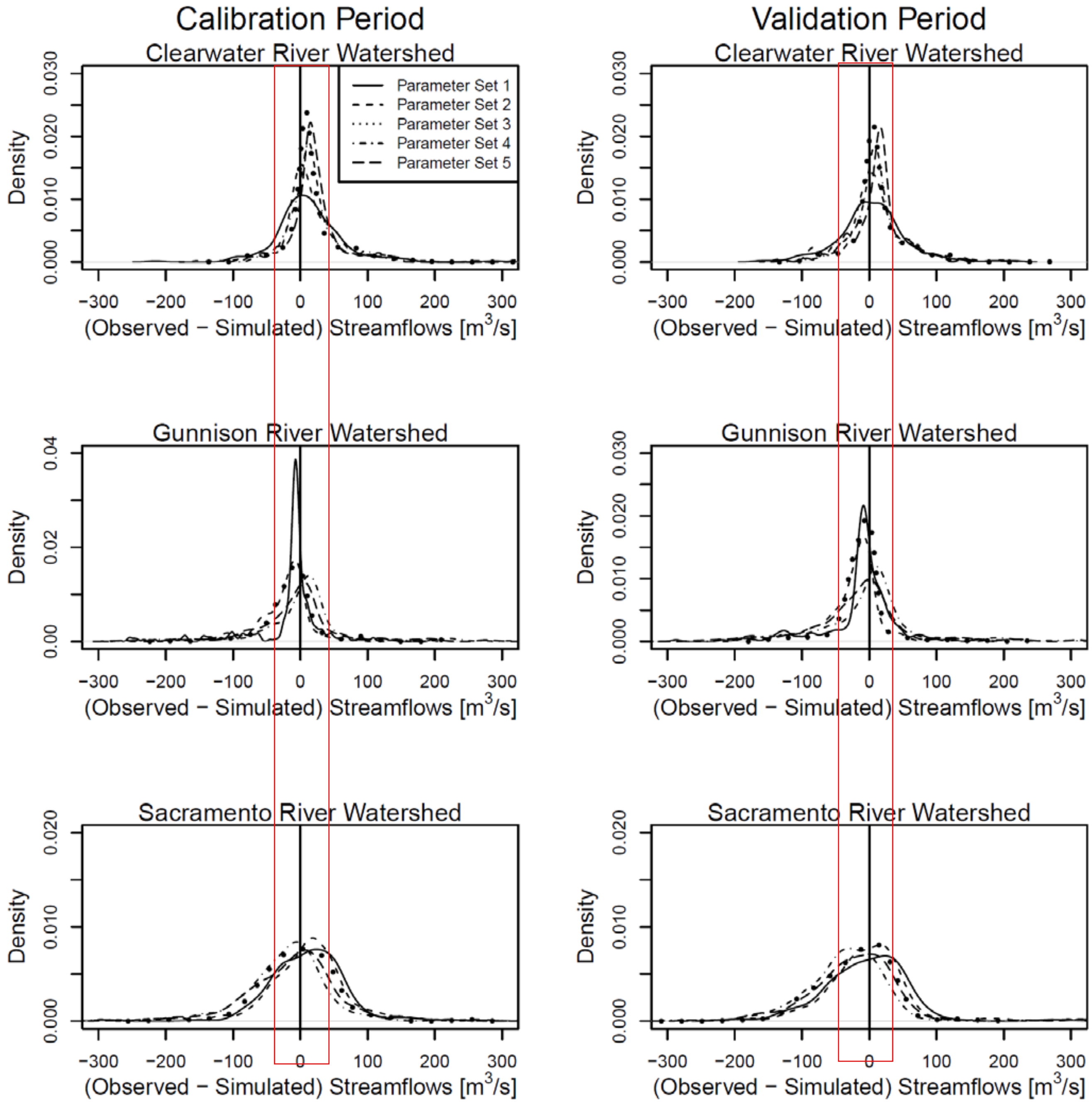
NSE > 0.50

Results – Calibration and Validation

		Calibration					Validation				
		Years	NS	R2	RMSE	pbias (%)	Years	NS	R2	RMSE	pbias (%)
Clearwater	Parameter Set 1	1970-1989	0.70	0.80	57.8	19.9	1990-2005	0.66	0.79	55.5	15.0
	Parameter Set 2	1970-1989	0.79	0.84	48.5	20.4	1990-2005	0.83	0.85	34.3	10.4
	Parameter Set 3	1970-1989	0.81	0.86	45.5	21.2	1990-2005	0.82	0.87	35.8	13.7
	Parameter Set 4	1970-1989	0.76	0.79	52.1	18.7	1990-2005	0.71	0.74	50.7	11.2
	Parameter Set 5	1970-1989	0.72	0.76	56.7	21.3	1990-2005	0.77	0.79	45.8	13.8
Gunnison	Parameter Set 1	1960-1984	0.73	0.74	51.8	2.6	1985-2005	0.76	0.76	45.8	5.7
	Parameter Set 2	1960-1984	0.64	0.73	60.5	-17.8	1985-2005	0.62	0.70	57.1	-14.7
	Parameter Set 3	1960-1984	0.72	0.73	53.2	-12.0	1985-2005	0.75	0.76	46.0	-8.8
	Parameter Set 4	1960-1984	0.70	0.78	55.0	-15.9	1985-2005	0.68	0.77	52.7	-15.0
	Parameter Set 5	1960-1984	0.78	0.80	47.4	-14.9	1985-2005	0.77	0.79	44.2	-12.3
Sacramento	Parameter Set 1	1950-1984	0.85	0.87	74.7	-8.7	1985-2005	0.84	0.89	77.3	-16.1
	Parameter Set 2	1950-1984	0.84	0.84	77.3	-3.1	1985-2005	0.85	0.87	75.2	-11.0
	Parameter Set 3	1950-1984	0.91	0.93	60.3	-6.2	1985-2005	0.86	0.93	72.3	-19.6
	Parameter Set 4	1950-1984	0.86	0.86	73.5	18.1	1985-2005	0.87	0.87	71.9	19.1
	Parameter Set 5	1950-1984	0.93	0.92	54.8	-6.9	1985-2005	0.90	0.93	60.5	-7.1

PBIAS +/- 25%

Results – Calibration and Validation



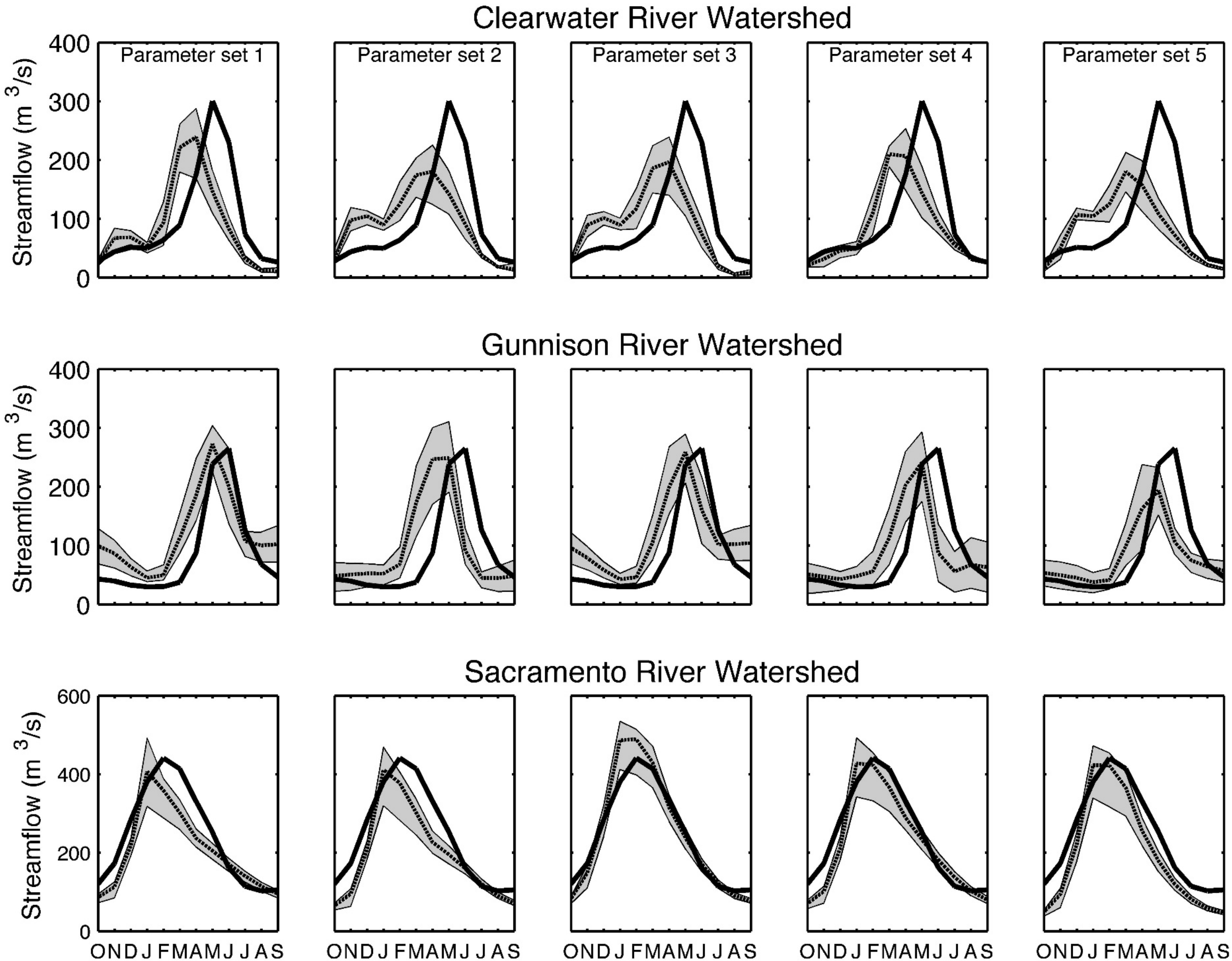
Results – Hydrologic Projections

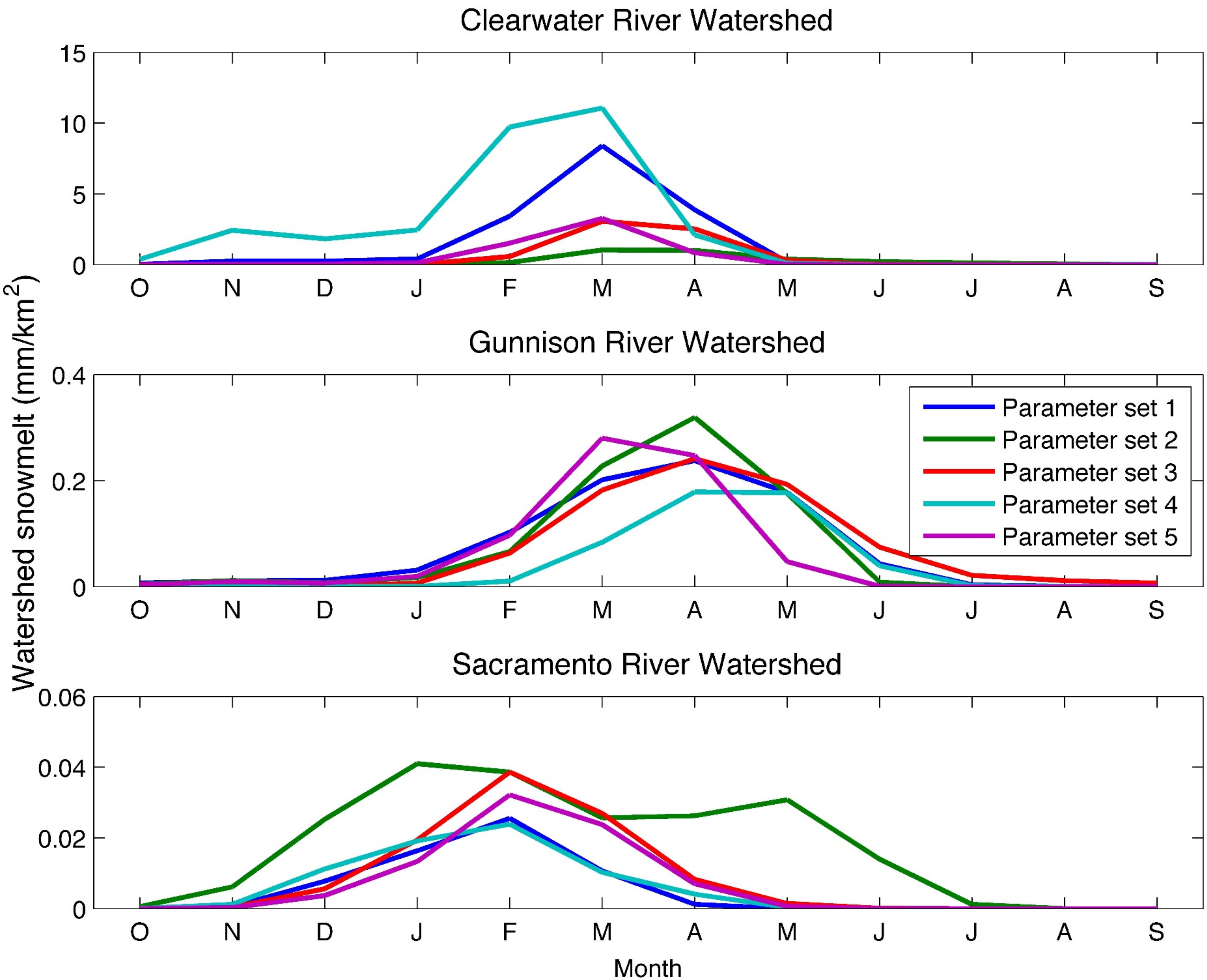
Average annual streamflow for the 2080s compared to the historical time period

	Parameter set	Ensemble average annual streamflow (%)	Ensemble maximum ave. annual streamflow (%)	Ensemble minimum ave. annual streamflow (%)
Clearwater River	1	−8.8	1.0	−21.5
	2	−4.0	5.2	−17.1
	3	−8.9	1.1	−21.9
	4	−11.0	−1.9	−21.8
	5	−13.8	−4.6	−24.2
Gunnison River	1	36.7	65.3	3.4
	2	12.1	39.0	−26.2
	3	29.8	59	−3.4
	4	3.2	36.9	−40.8
	5	−5.5	21.1	−37.0
Sacramento River	1	−14.7	−6.9	−24.7
	2	−19.0	−12.2	−29.7
	3	−23.2	−16.4	−33.3
	4	2.2*	9.5	−7.7
	5	−8.5	−0.7	−20.0

* Represents no significant difference from the historical streamflows at $p = 0.05$.

The average annual streamflows for the Clearwater River, Gunnison River, and Sacramento River watersheds are 96, 87, and 239 m3/s.


Clearwater River Watershed
Gunnison River Watershed
Sacramento River Watershed
Parameter set 1
Parameter set 2
Parameter set 3
Parameter set 4
Parameter set 5
Streamflow (m 3/s)
0
100
200
300
400
600
O N D J F M A M J J A S



Clearwater River Watershed
15
10
5
0
O
N
D
J
F
M
A
M
J
J
A
S
Gunnison River Watershed
0.4
0.2
0
Parameter set 1
Parameter set 2
Parameter set 3
Parameter set 4
Parameter set 5
Sacramento River Watershed
0.06
0.04
0.02
0
Watershed snowmelt (mm/km2)
Month

Conclusions

- Most hydroclimatic studies are based on a model chain where GCM outputs are input into a calibrated hydrologic model with the assumption that realistic hydrologic projections are produced
- Even though historical calibrations are adequate from all parameter sets, future streamflow projections from downscaled GCMs can vary widely
    - Some projections resulted in lower streamflows and some in higher streamflows compared to historical amounts
- The annual streamflow analysis shows that different parameter sets can lead to differences in ensemble average, maximum, and minimum annual streamflows.
- For the monthly streamflow analysis, nearly all parameter sets agree on a forward shift in streamflow for all watersheds.
    - However, they do not agree on the exact timing of this shift or the streamflow peak magnitude
- All parameter sets should be explored during calibration and validation, and projections from all valid parameter sets should be used to increase the robustness of the results and confidence in the directions and trends of the projections