Runoff projections and impacts on water resources

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UNIVERSITY OF WASHINGTON

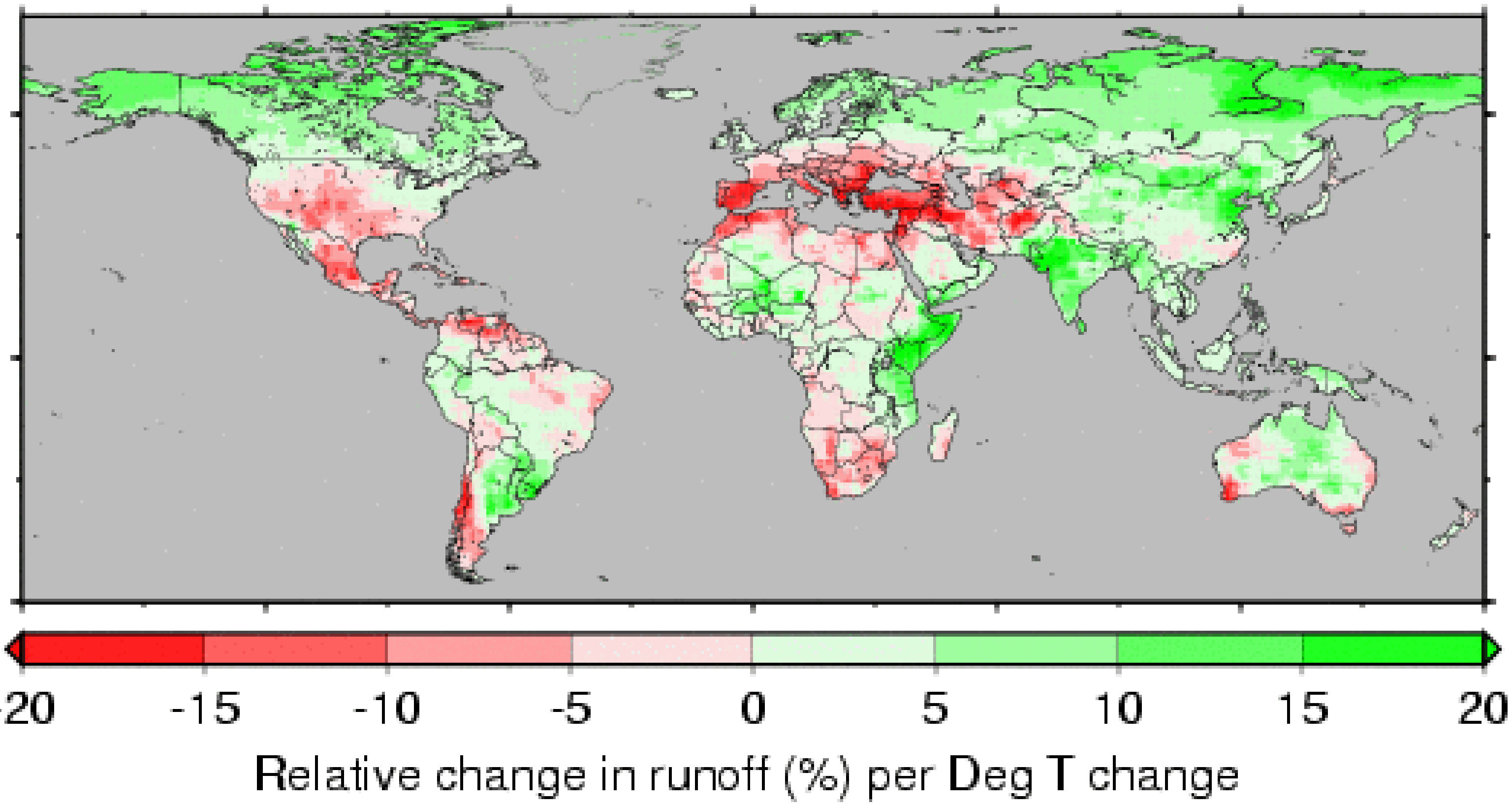
Department of Civil and Environmental Engineering

Outline of this talk

1) Projected runoff changes over the next century – the global and continental picture
2) Downscaling to the regional and watershed scale
   - Statistical downscaling
   - Dynamical downscaling
3) Hydrological and water resources implications -- examples
4) Weak links and the path forward

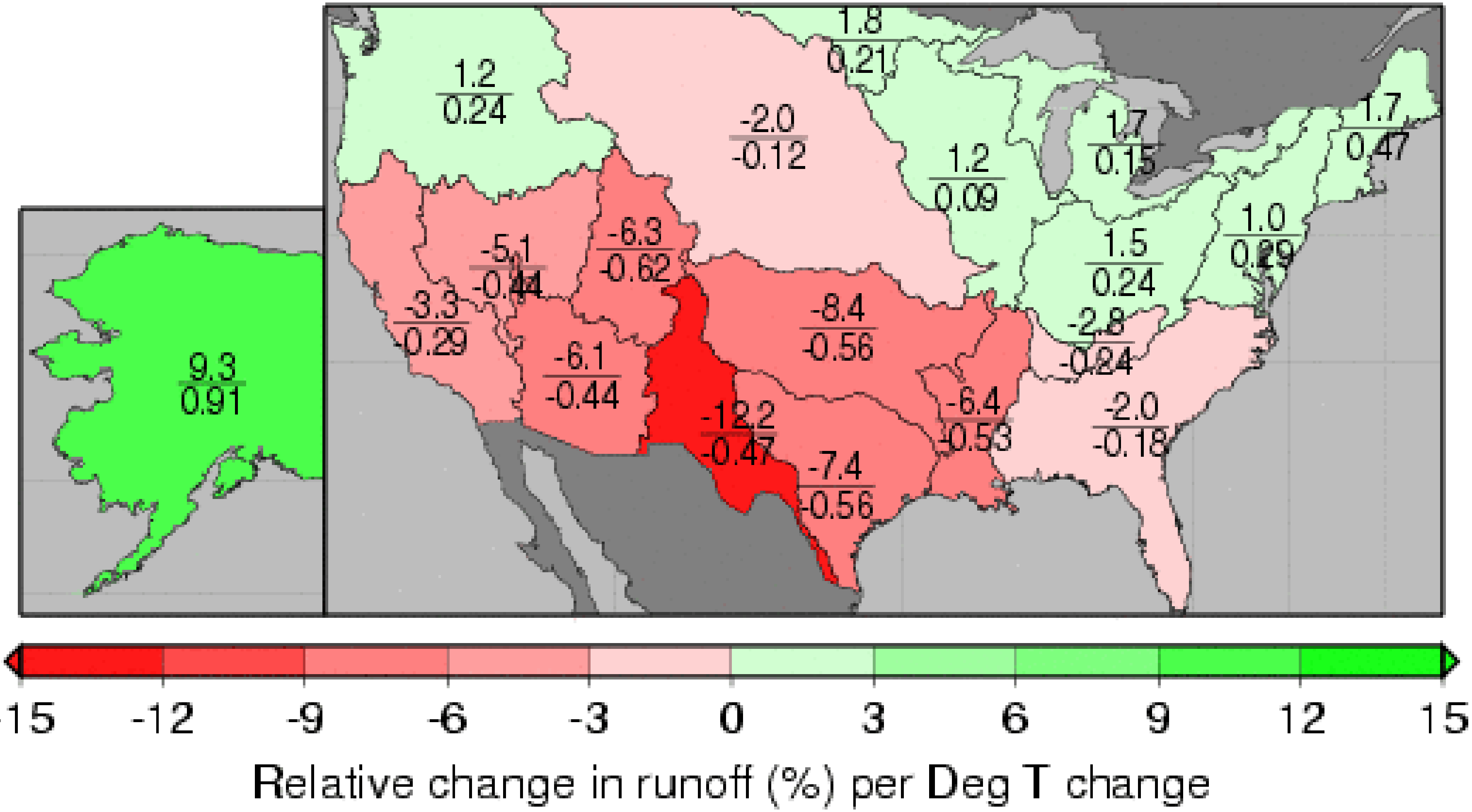
1) Projected global and regional runoff changes

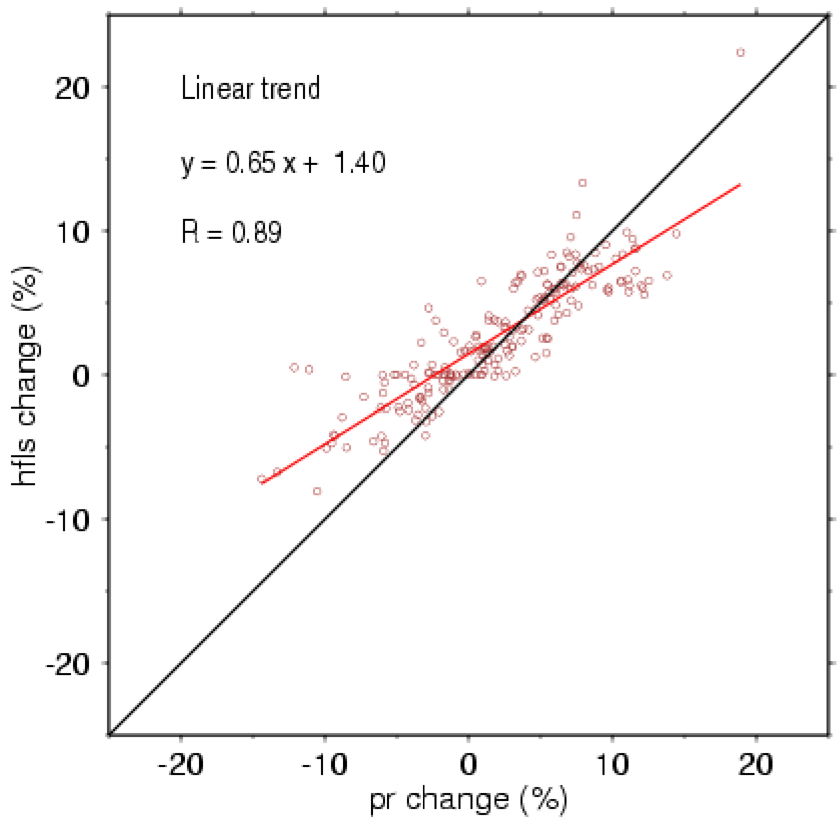
Median runoff sensitivities per degree of global warming, from 68 model pairs – 30-year model average runoff minus 1971-2000 model average (23 models, 3 global emissions scenarios)



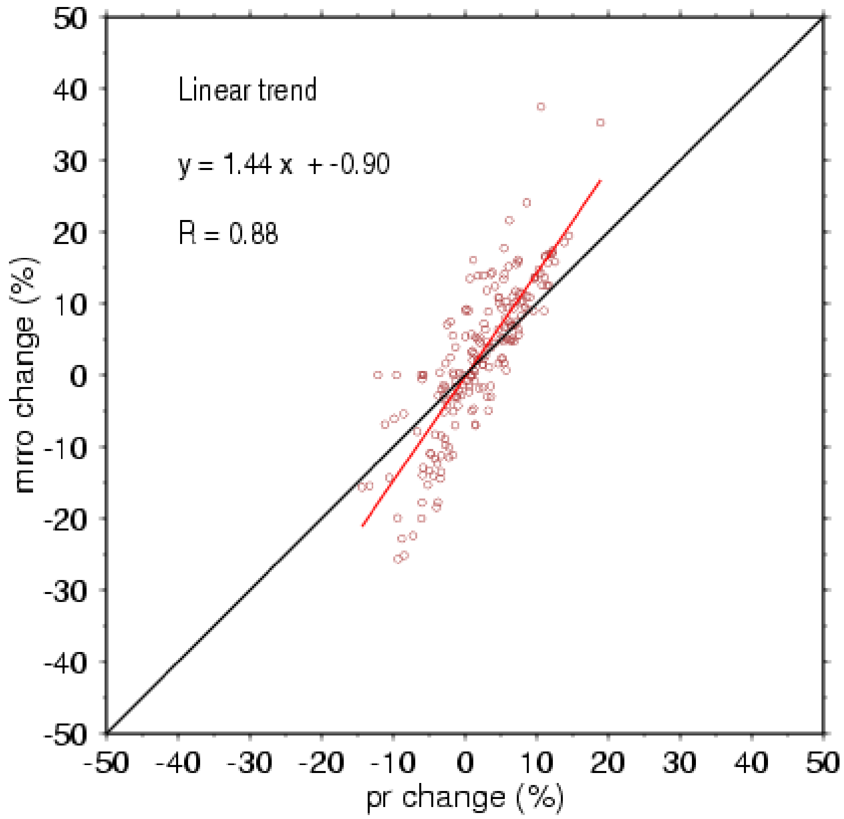
Runoff decreases by	0%	5%	10%	15%
% of world's population	33	26	22	21
% of world's GDP	46	55	55	51

Continental U.S. and Alaska



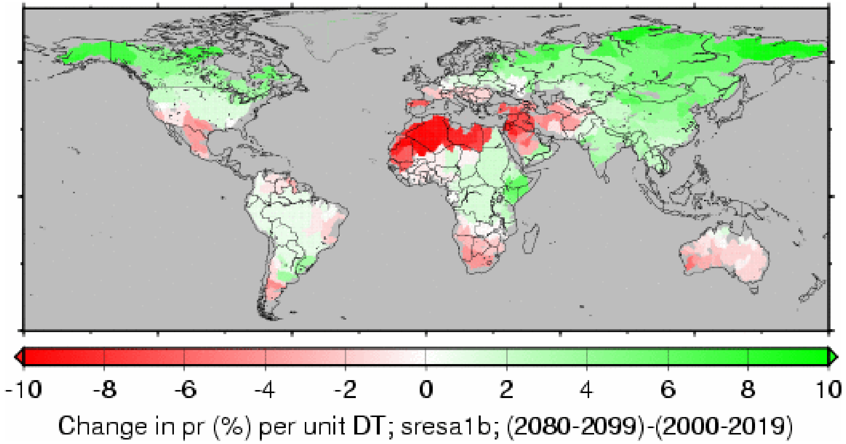


All scenarios Top 200 basins
Precipitation change per degree T change vs evaporation change per degree T

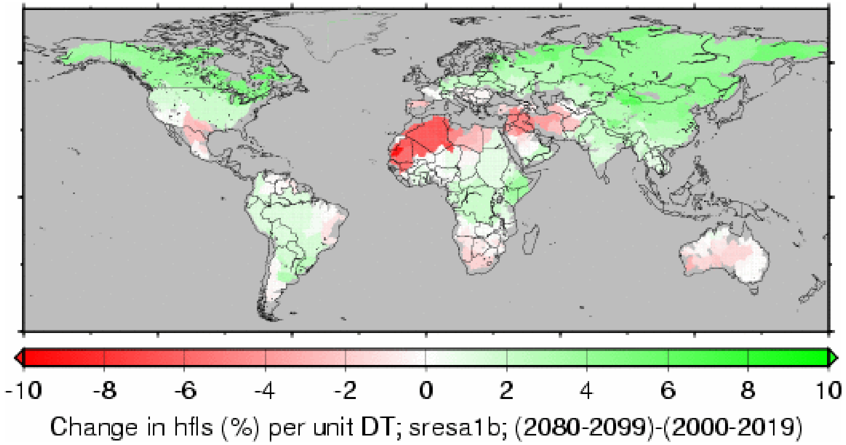


All scenarios Top 200 basins
Precipitation change per degree T change vs runoff change per degree T

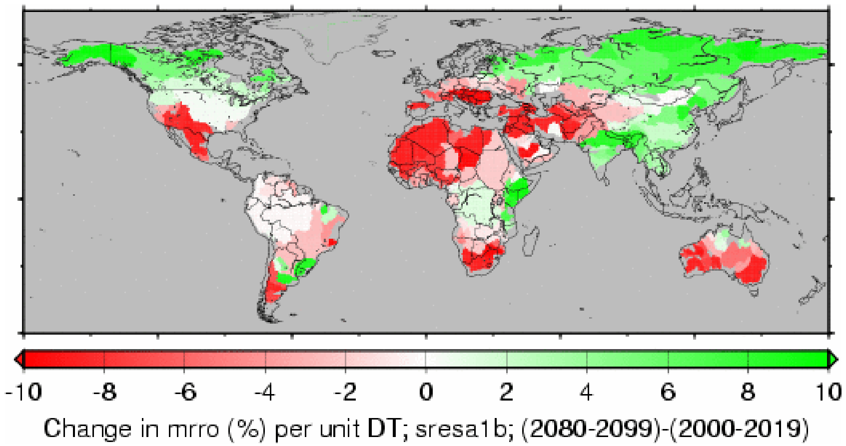
A1B scenario Top 200 basins



Precipitation change per Degree T change in the 21st Century



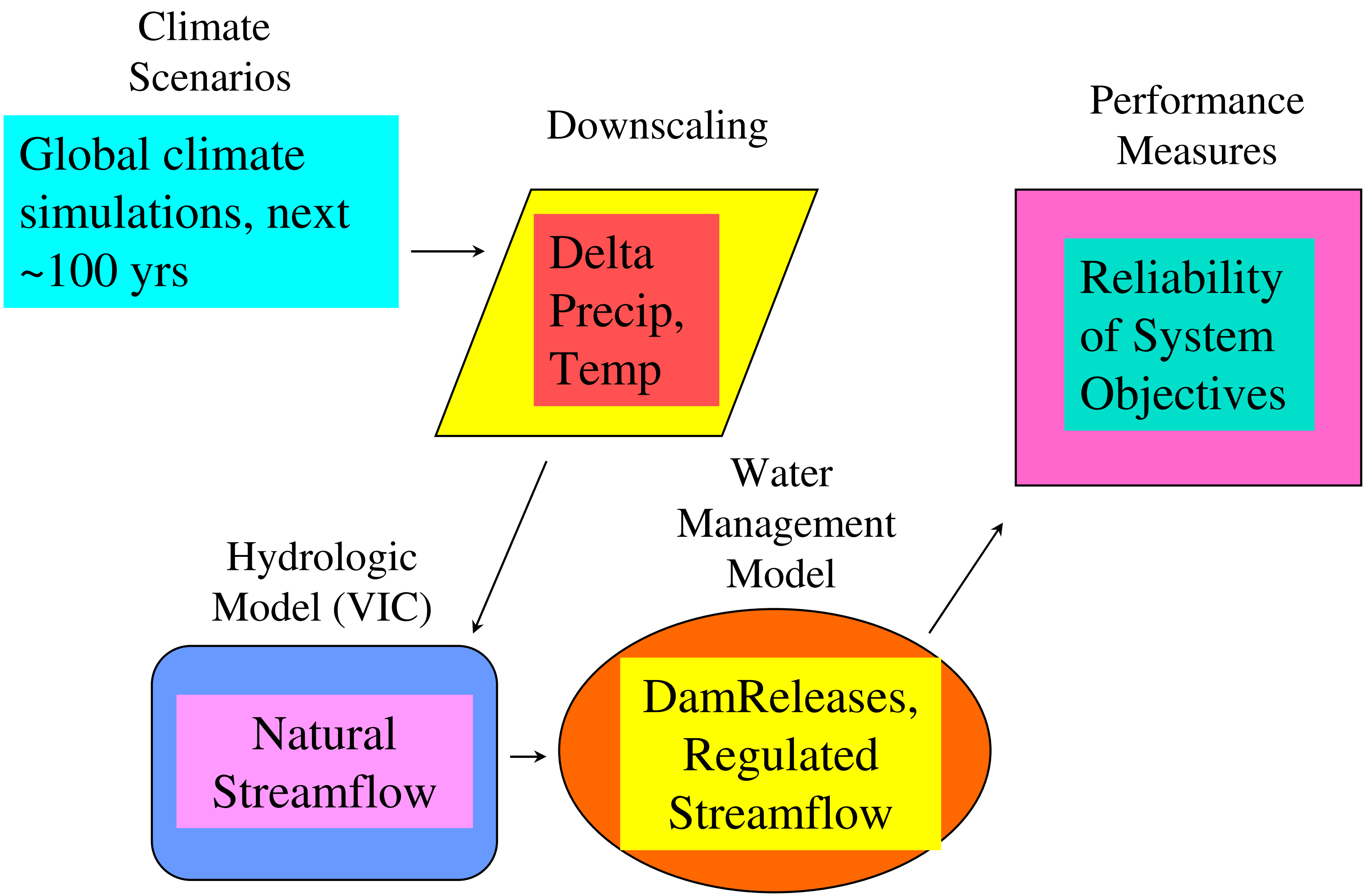
Evaporation change per Degree T change in the 21st Century



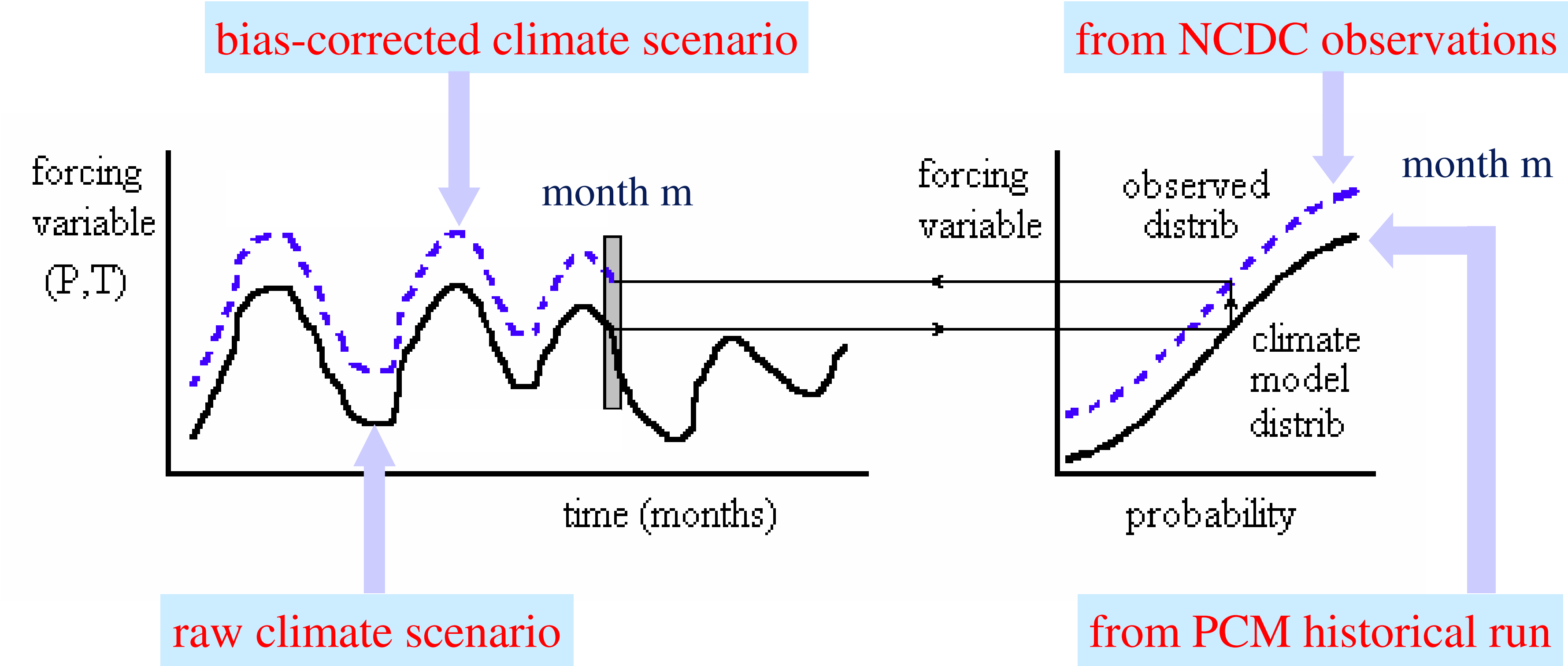
Runoff change per Degree T change in the 21st Century

2) Downscaling

a) **Statistical**
b) **Dynamical**


Climate
Scenarios
Global climate simulations, next ~100 yrs
Downscaling
Delta Precip, Temp
Performance
Measures
Reliability of System Objectives
Hydrologic
Model (VIC)
Natural Streamflow
Water
Management
Model
DamReleases, Regulated Streamflow

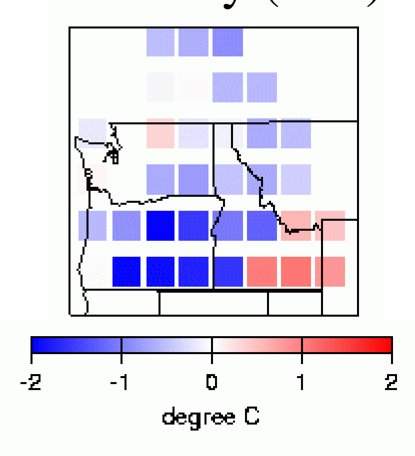
Bias Correction



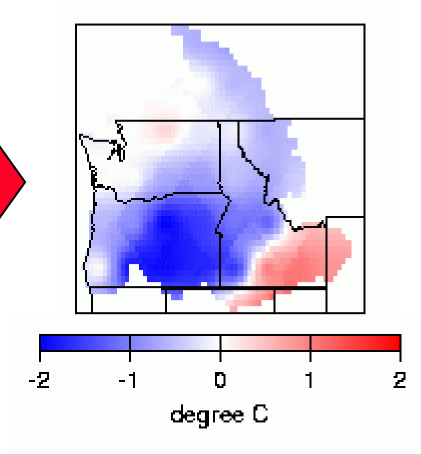
Note: future scenario temperature **trend** (relative to control run) removed before, and replaced after, bias-correction step.

Spatial Downscaling

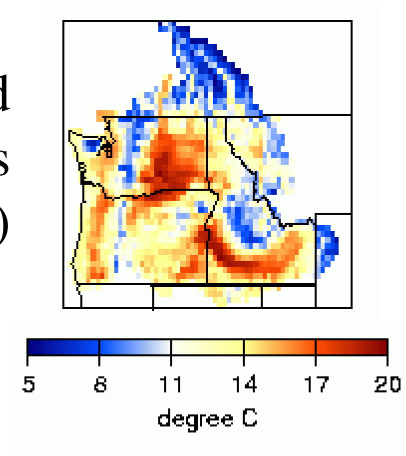
monthly PCM
anomaly (T42)



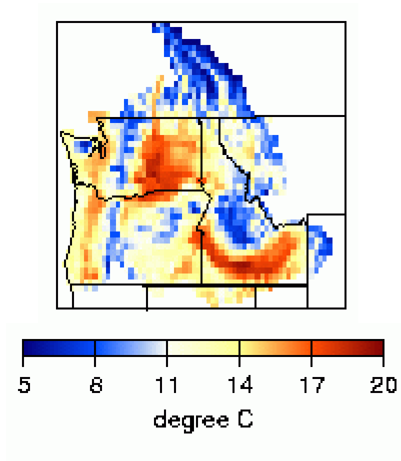
interpolated to
VIC scale



observed
mean fields
(1/8-1/4 degree)



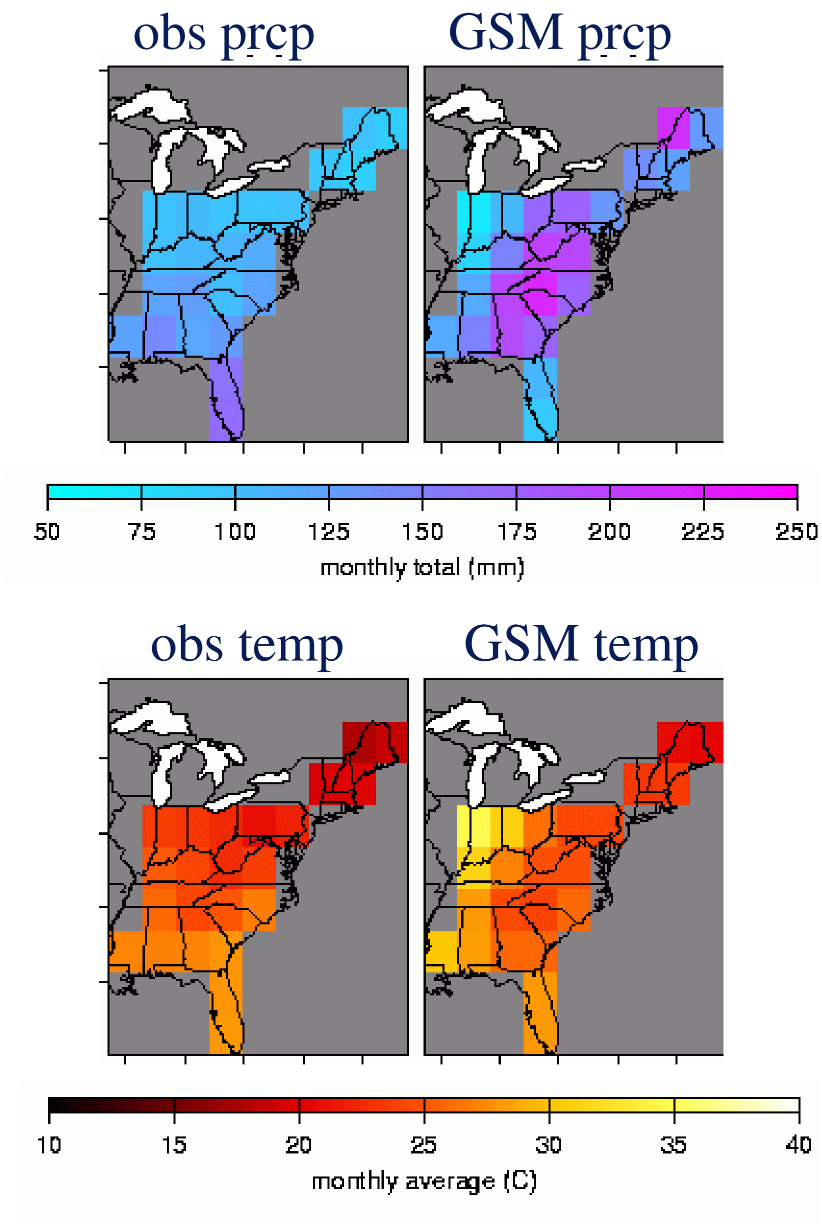
VIC-scale
monthly simulation



Regional Bias: spatial example

GSM: NCEP Global Spectral Model

JULY



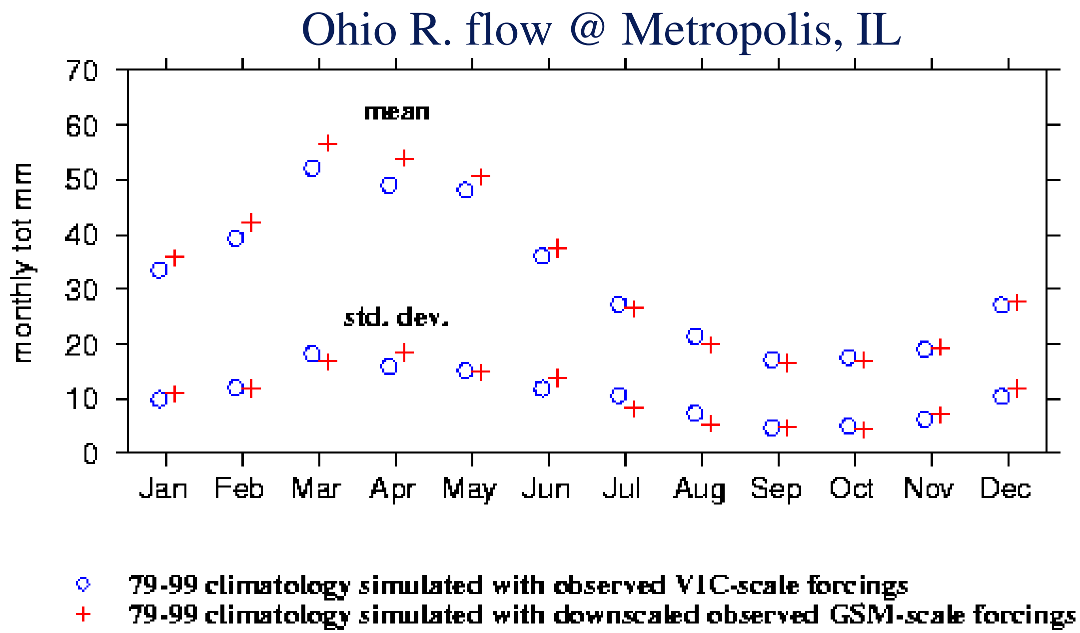
Verification using NCEP Global Spectral Model (GSM) output

Start with GSM-scale monthly **observed** T & P ("unbiased") time series

Process into the daily VIC-scale input time series

Force hydrology model to produce streamflow

Is simulated streamflow unbiased against observed streamflow?



Dynamical Downscaling (Regional Climate Model)

Motivation: Statistical approaches are dynamically inconsistent (postprocess climate model output, then force a land (hydrology) model with characteristics different from those in the GCM – notably evapotranspiration

Regional Climate Modeling at CIG

WRF Model (NOAH LSM)

Resolution: 12 to 36 km

(~7- 32 mi)

- ECHAM5 forcing
- CCSM3 forcing

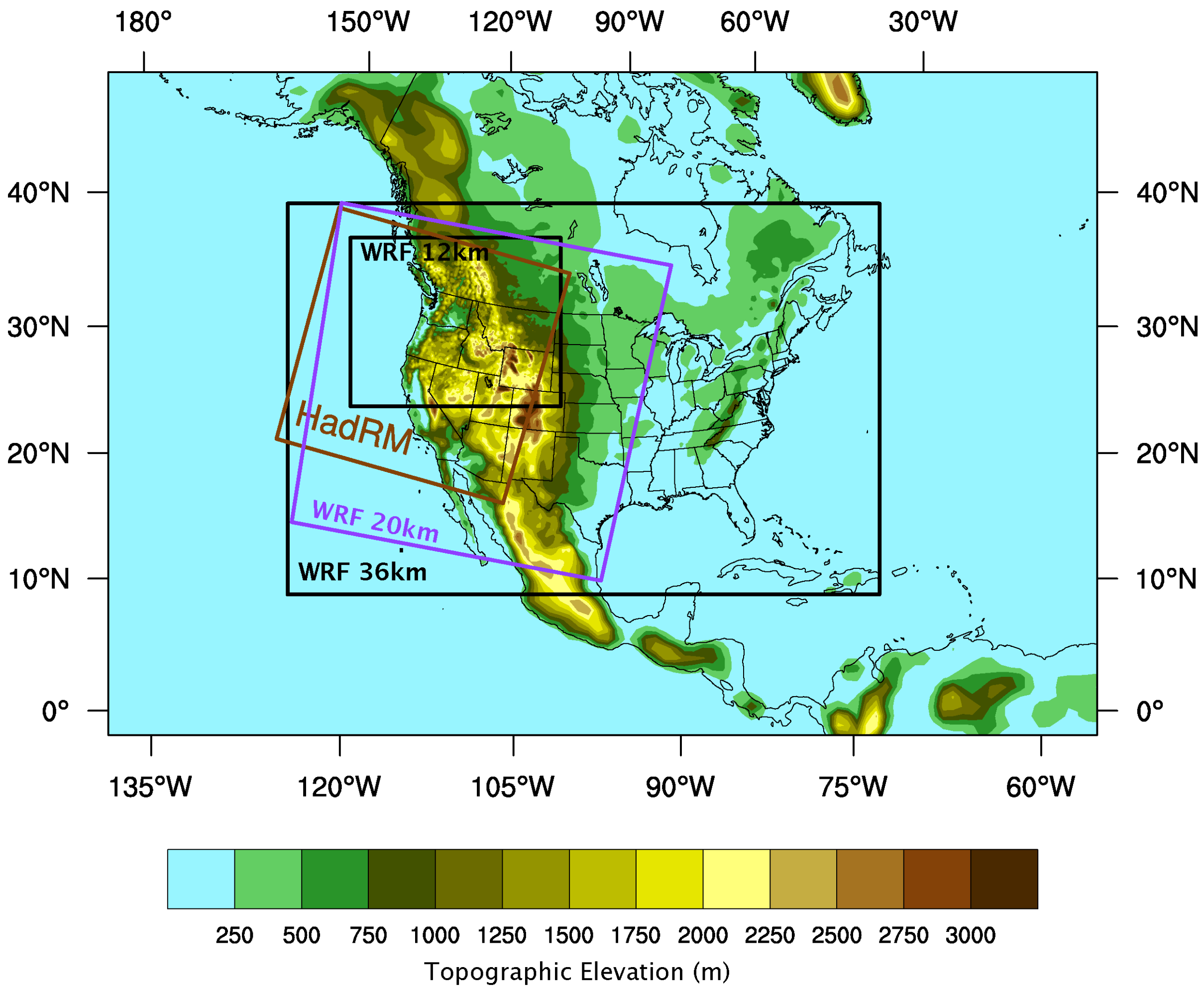
  (A1B and A2 scenarios)

HadRM

Resolution: 25 km

(~15 mi)

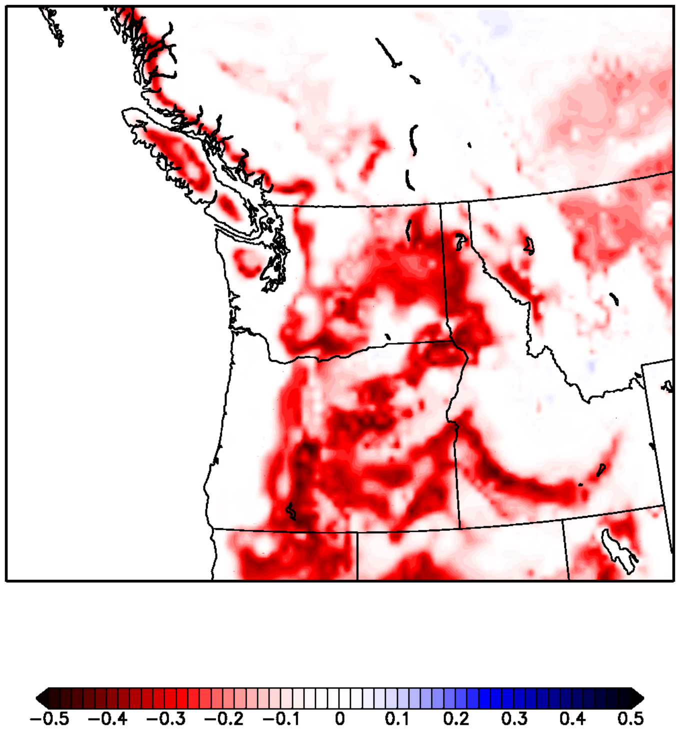
- HadCM3 forcing



Land-Atmosphere Interactions

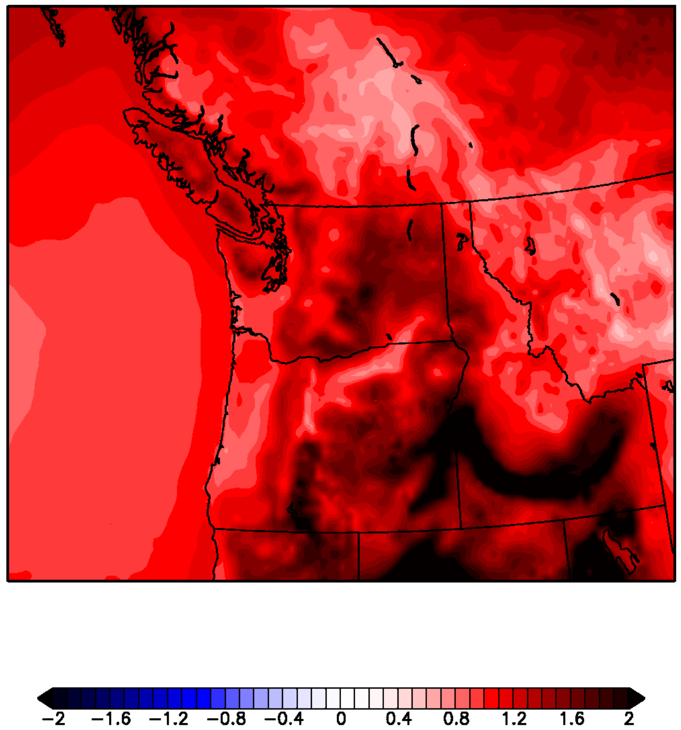
Wintertime Change from 1990s to 2050s

Snow Cover Change



Change in fraction of days with snow cover

Temperature Change

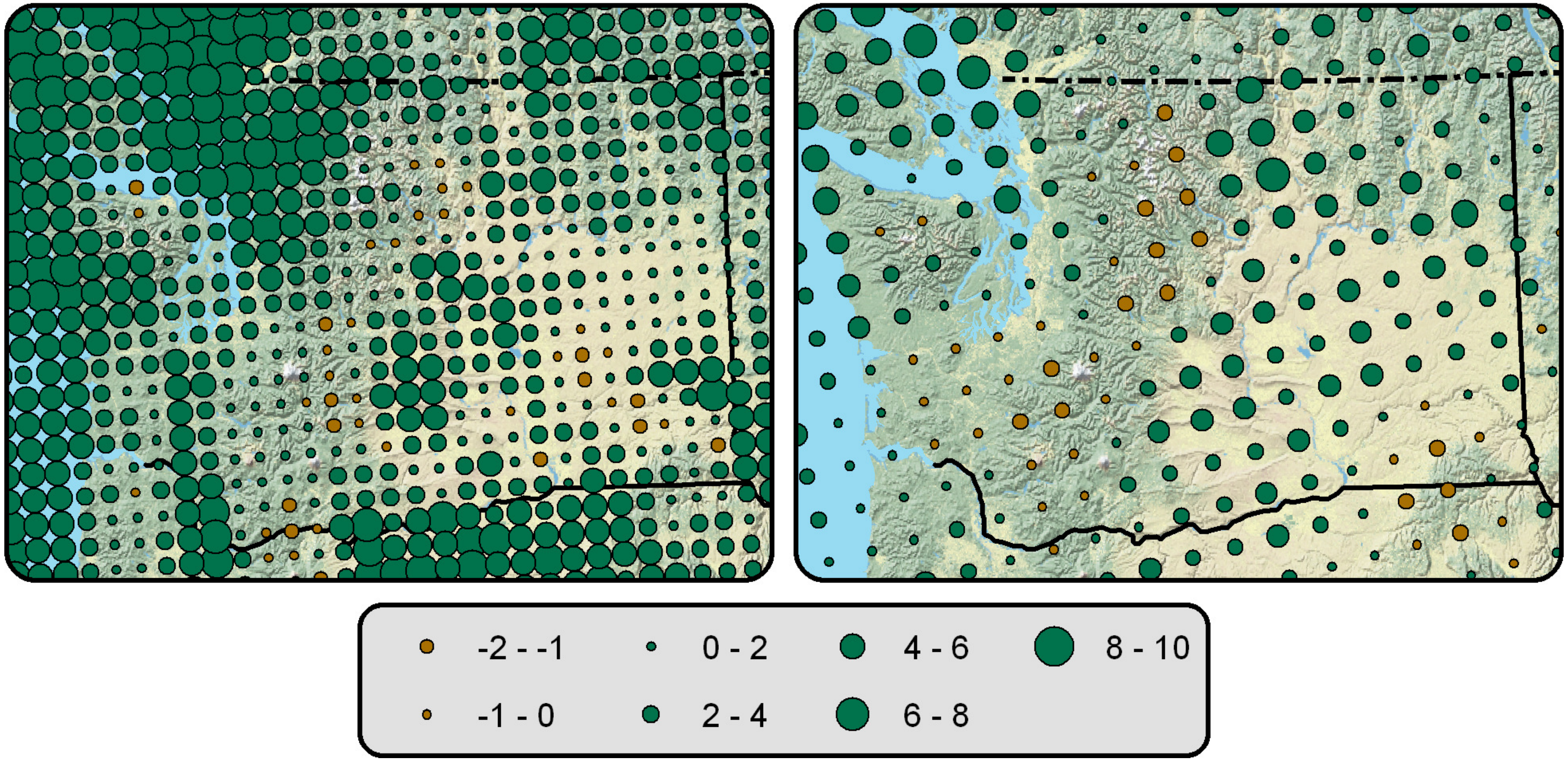


Change in winter temperature (degrees C)

Salathé et al. 2008

Extreme Precipitation

CCSM3-WRF ECHAM5-WRF



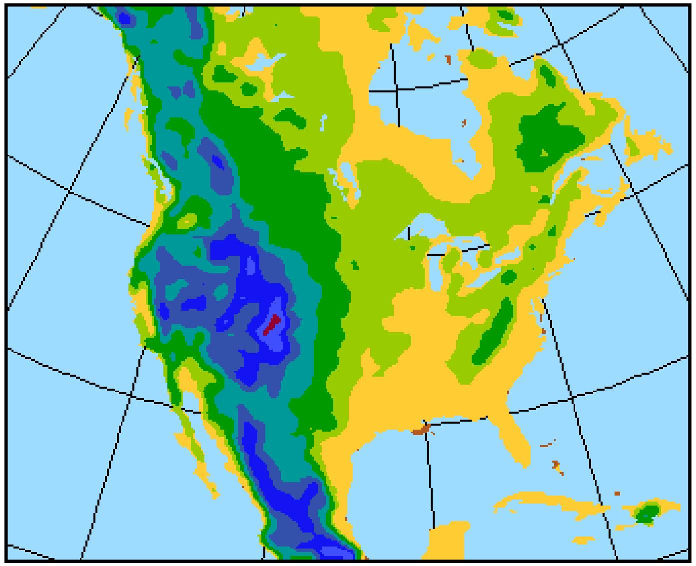
Change from 1970-2000 to 2030-2060 in the percentage of total precipitation occurring when daily precipitation exceeds the 20th century 95th percentile

- ***Larger*** increase on windward slopes of Cascades, Columbia basin
- ***Smaller*** increase or ***decrease*** along Cascade crest

The North American Regional Climate Change Assessment Program (NARCCAP)

- Exploration of multiple uncertainties in regional model and global climate model regional projections.
- Development of multiple 50-km regional climate scenarios for use in impacts assessments.
- Evaluation of regional model performance over North America.

50-km Grid



	GFDL	CGCM3	HADCM3	CCSM
MM5			X	X1
RegCM	X1**	X		
CRCM		X1**		X
HADRM	X		X1	
RSM	X1		X	
WRF		X		X1

Red = run completed

www.narccap.ucar.edu

Drawbacks of dynamical downscaling

- Requires postprocessing for bias correction and (often) spatial downscaling, just like GCM output
- Adds a layer of uncertainty as to implementation (e.g. to nudge or not to nudge)?
- Highly computationally intensive, hence usually sacrifice representation of GCM-level model uncertainty
- Is the eventual solution higher GCM resolution?

3) Hydrological and water resources implications – examples

A) Columbia River basin

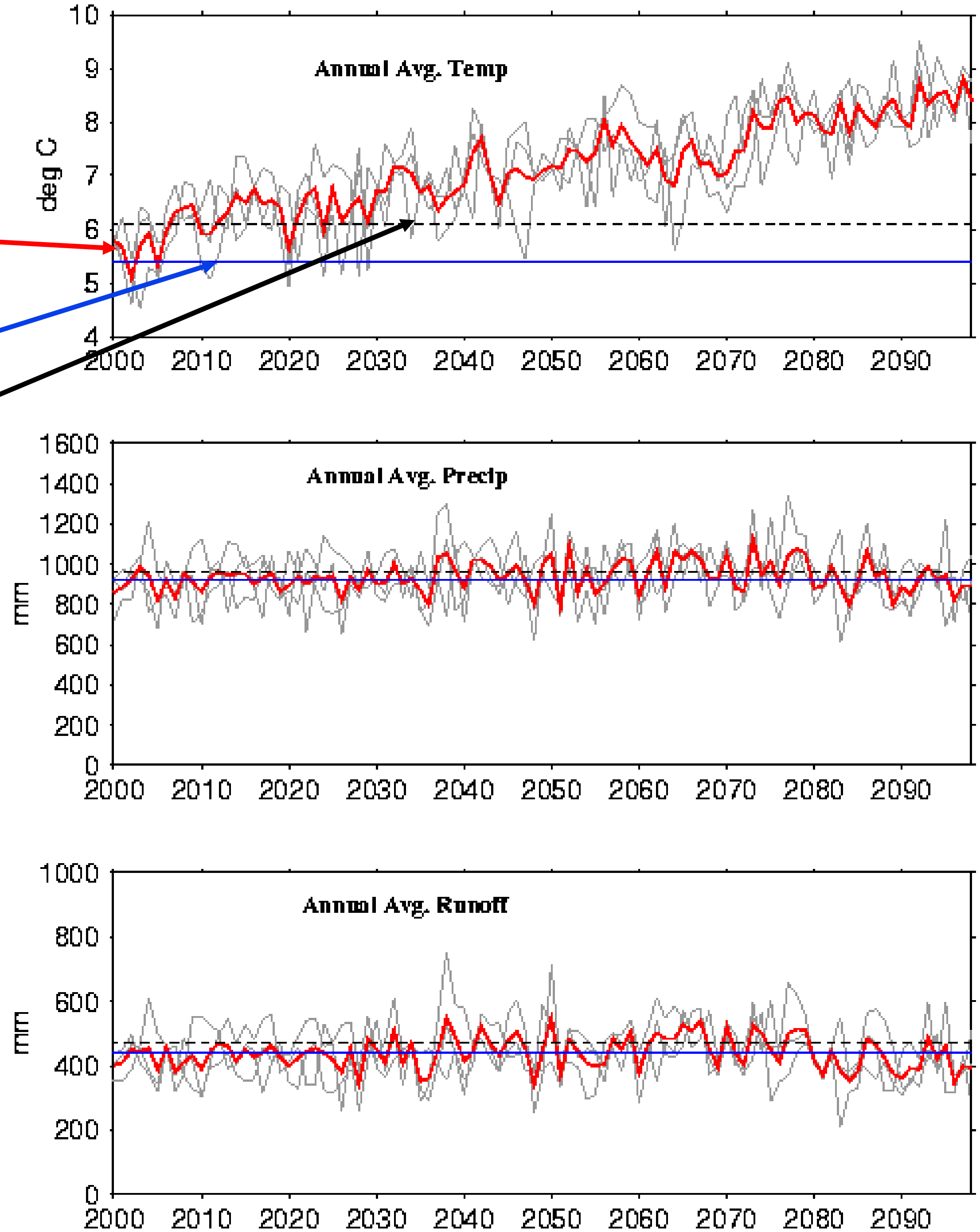
B) Colorado River basin

C) Washington climate change impacts assessment – Yakima River basin

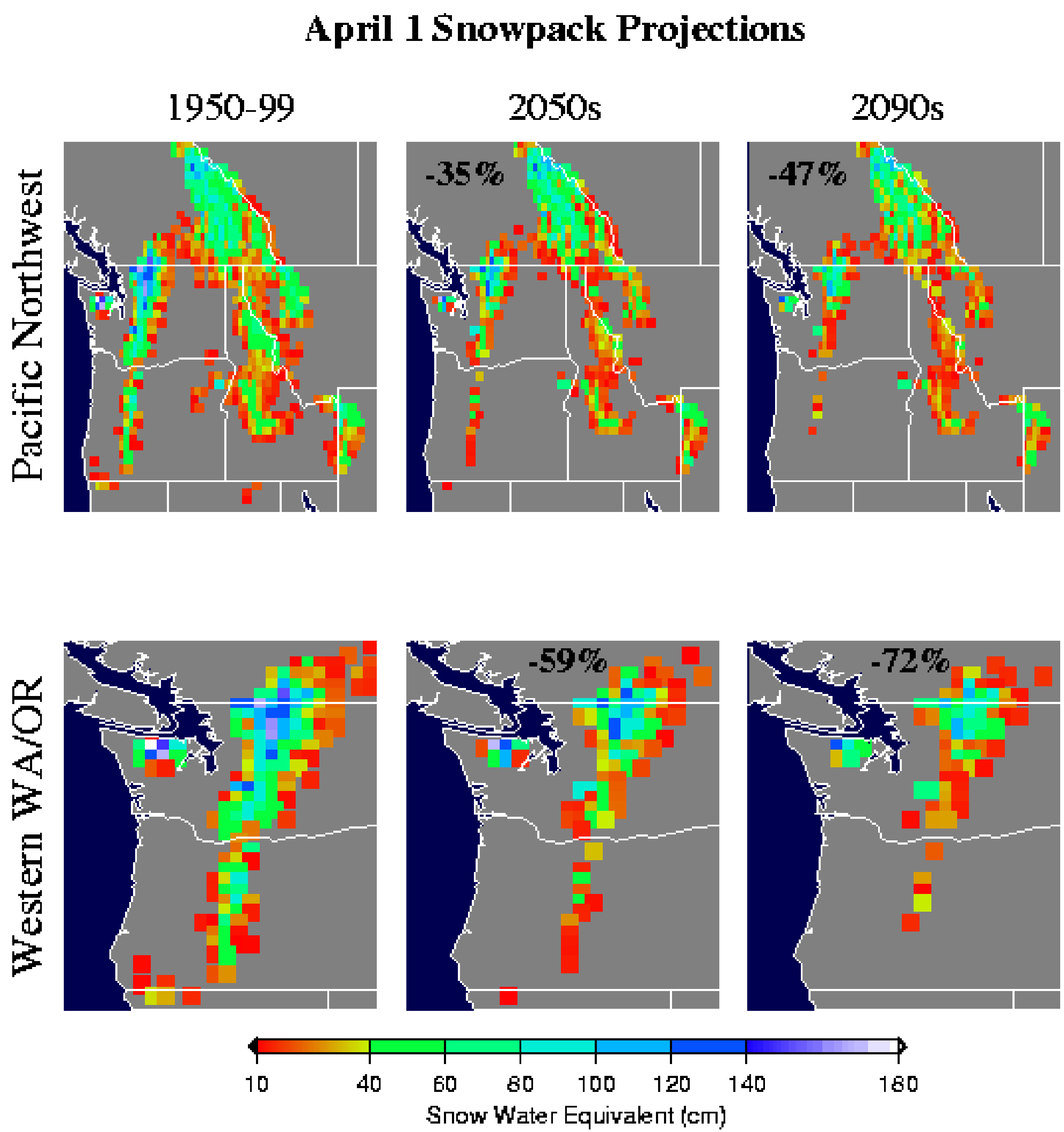
3a) Hydrology and water management implications: Columbia River Basin

PCM

Business-as-Usual scenarios



Columbia River Basin (Basin Averages)

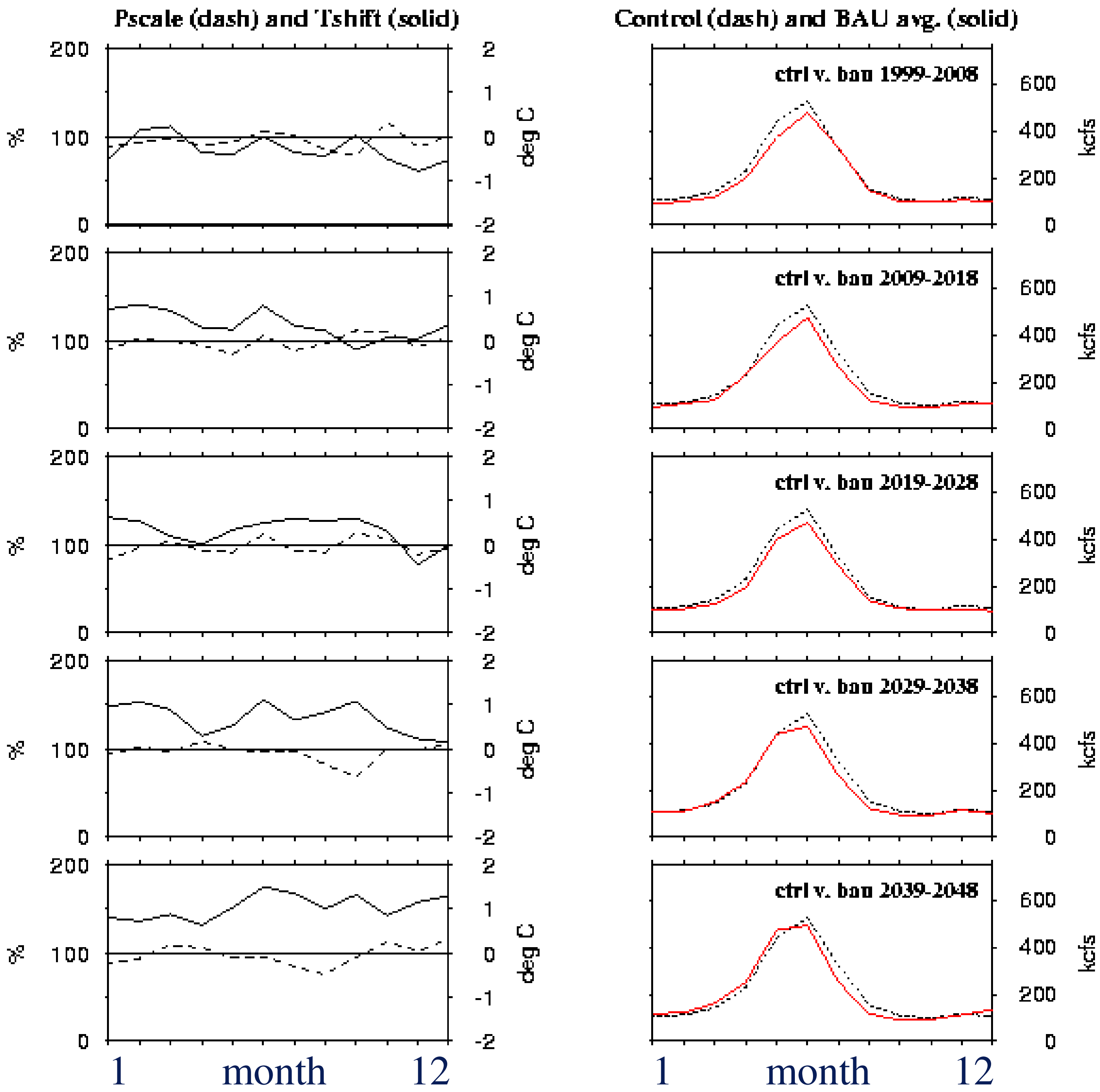

April 1 Snowpack Projections
1950-99
2050s
2090s
Pacific Northwest
Western WA/OR
-35%
-47%
-59%
-72%
10
40
60
80
100
120
140
160
Snow Water Equivalent (cm)

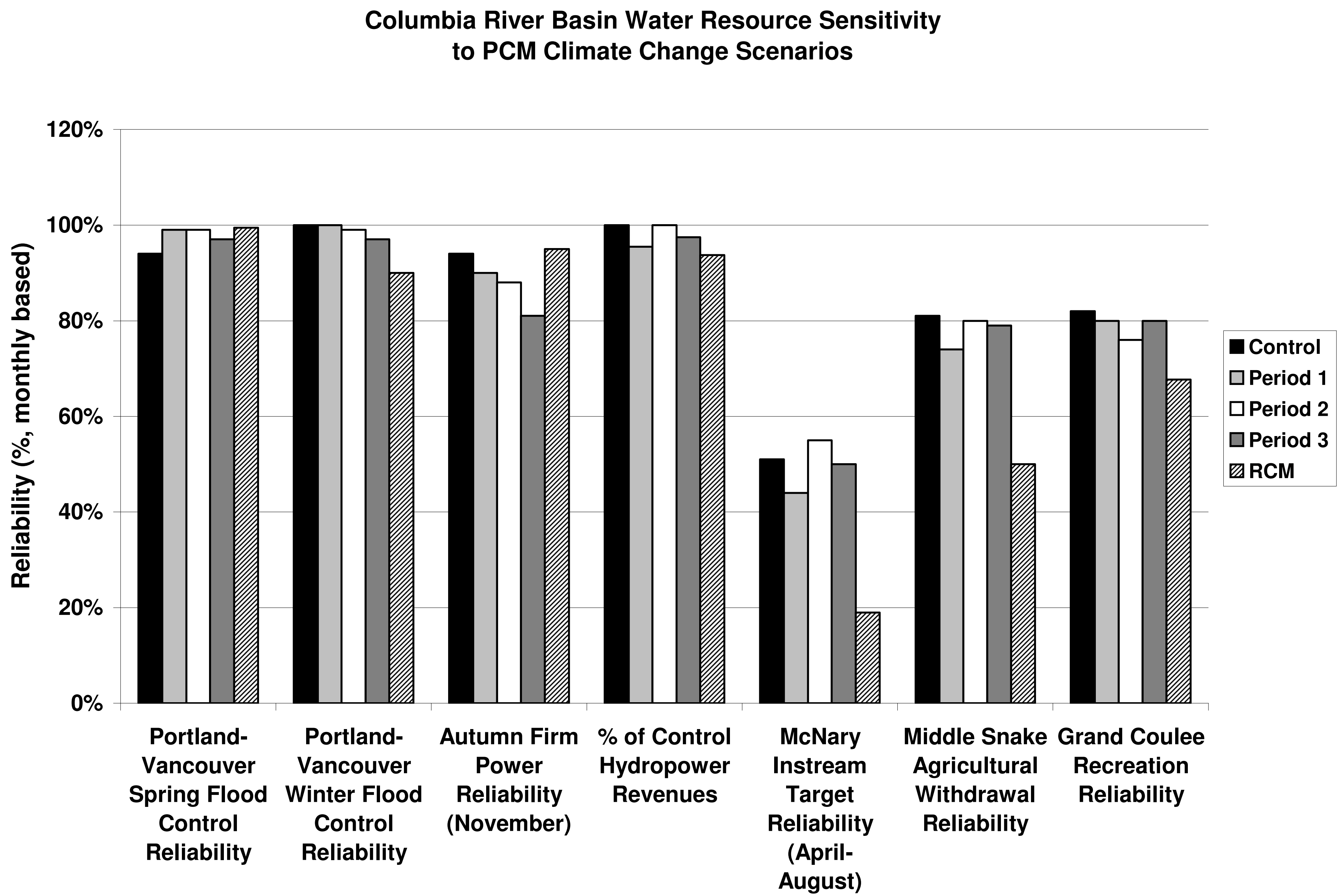
PCM

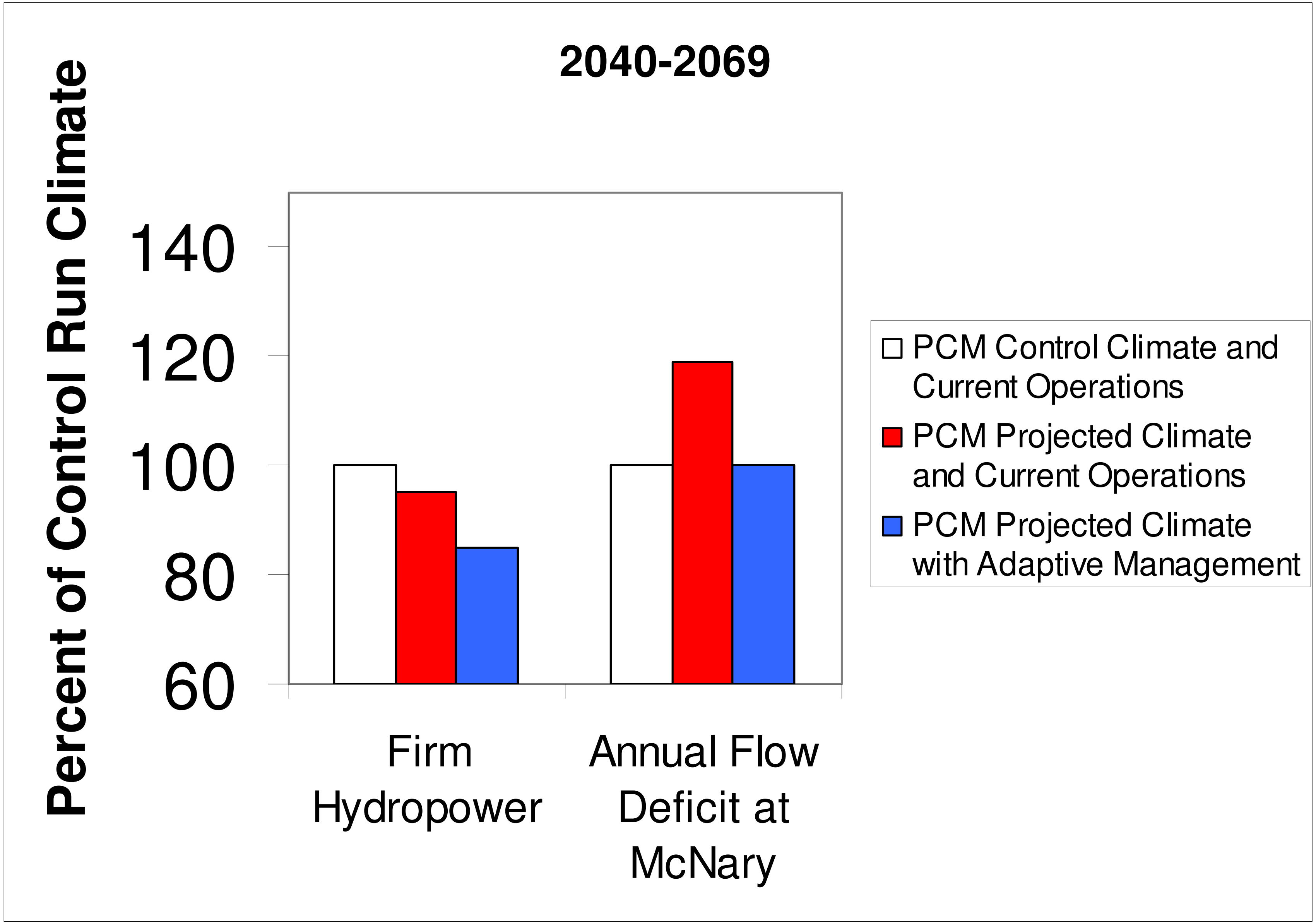
Business-As-Usual

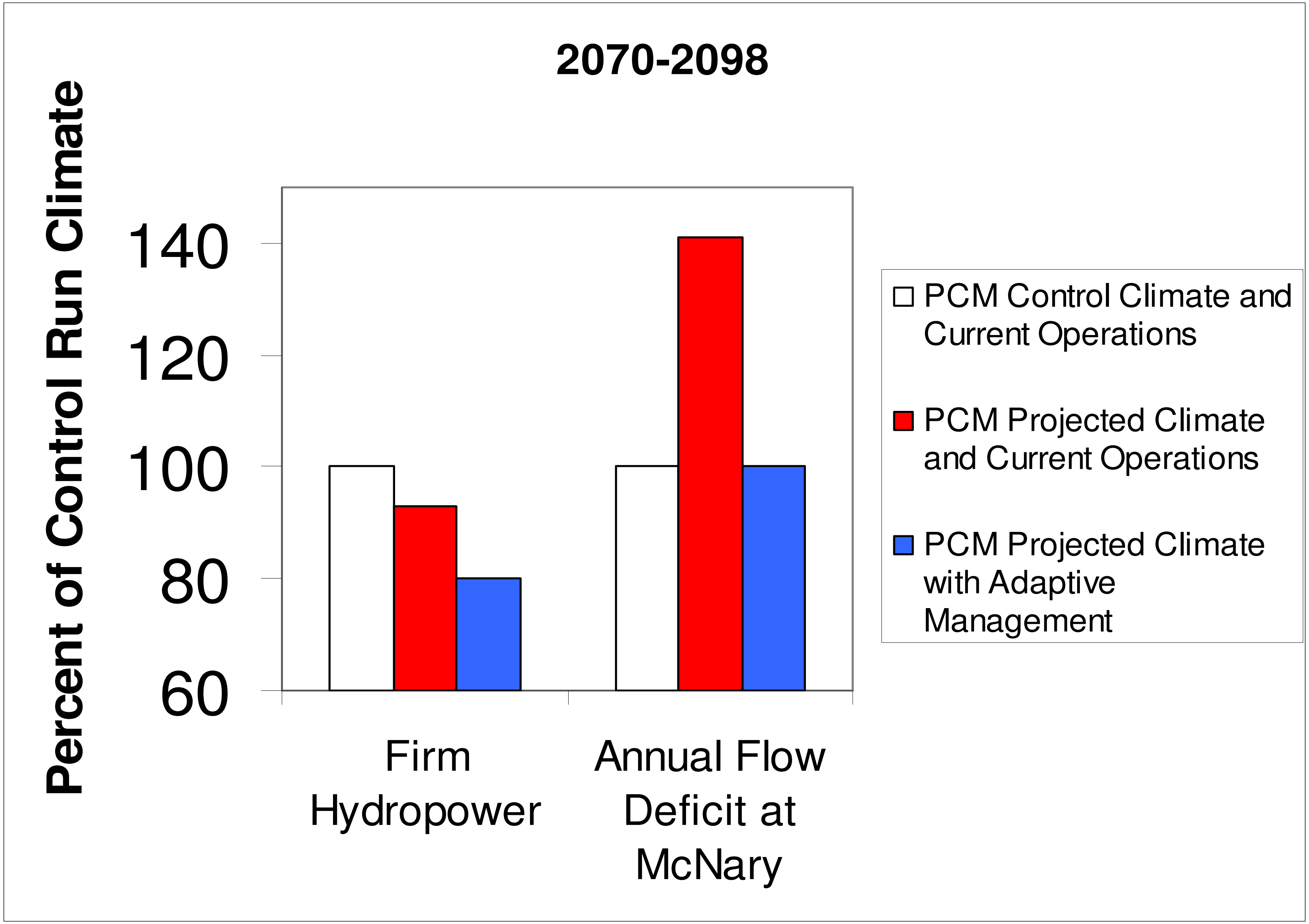
Mean Monthly Hydrographs

Columbia River Basin @ The Dalles, OR




Columbia River Basin Water Resource Sensitivity
to PCM Climate Change Scenarios
Reliability (%, monthly based)
120%
100%
80%
60%
40%
20%
0%
Portland-Vancouver Spring Flood Control Reliability
Portland-Vancouver Winter Flood Control Reliability
Autumn Firm Power Reliability (November)
% of Control Hydropower Revenues
McNary Instream Target Reliability (April-August)
Middle Snake Agricultural Withdrawal Reliability
Grand Coulee Recreation Reliability
Control
Period 1
Period 2
Period 3
RCM


2040-2069
Percent of Control Run Climate
140
120
100
80
60
Firm Hydropower
Annual Flow Deficit at McNary
PCM Control Climate and Current Operations
PCM Projected Climate and Current Operations
PCM Projected Climate with Adaptive Management

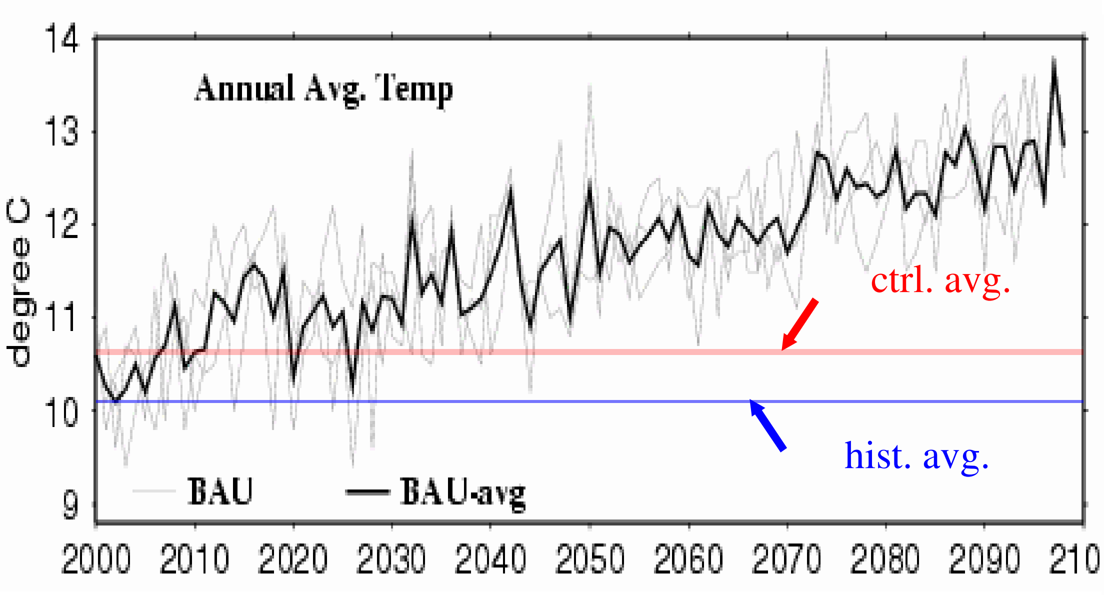


2070-2098
Percent of Control Run Climate
140
120
100
80
60
Firm Hydropower
Annual Flow Deficit at McNary
PCM Control Climate and Current Operations
PCM Projected Climate and Current Operations
PCM Projected Climate with Adaptive Management

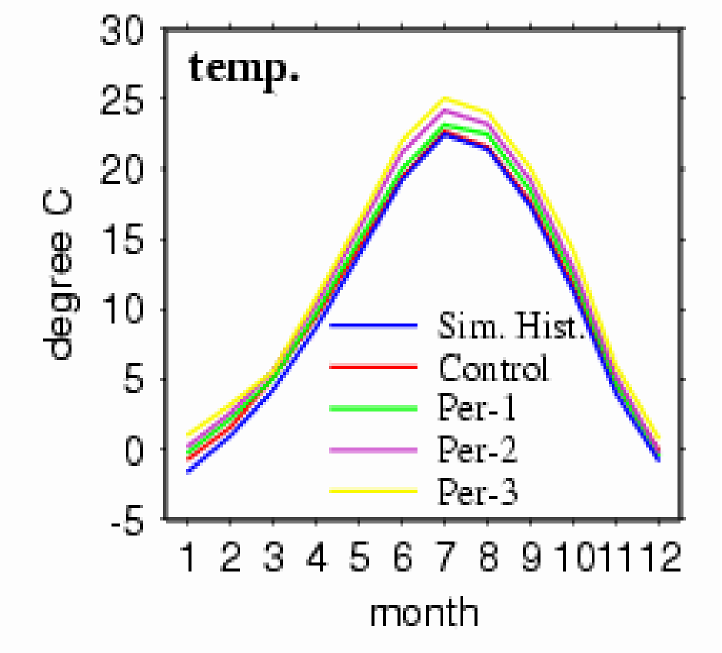
3b) Hydrology and water management implications: Colorado River basin

PCM Projected Colorado R. Temperature

Timeseries



Annual Average

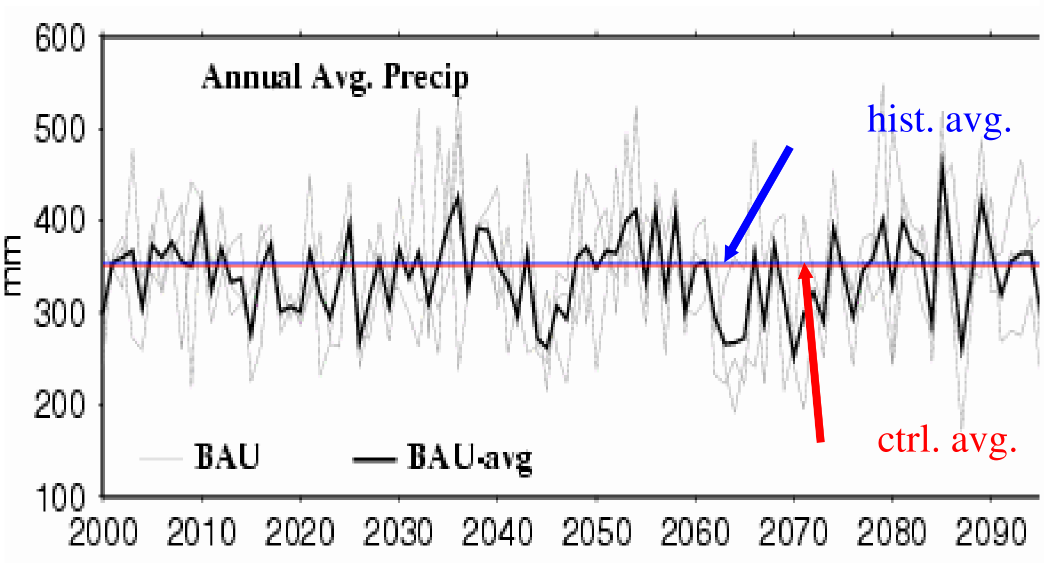


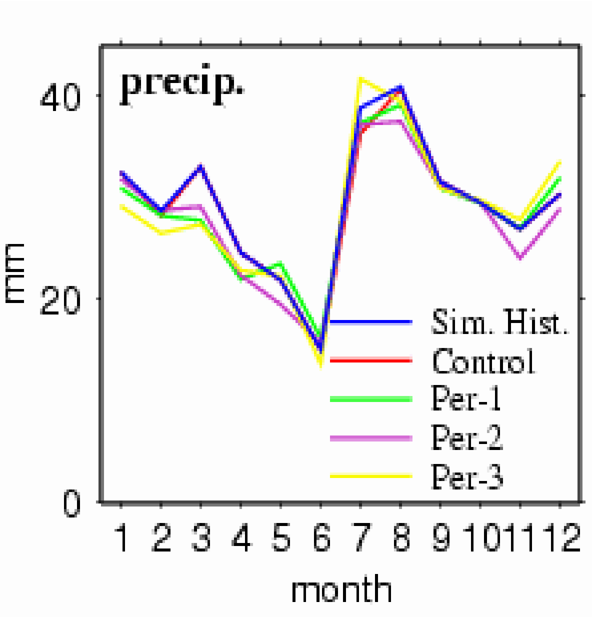
Period 1 2010-2039 Period 2 2040-2069 Period 3 2070-2098

PCM Projected Colorado R. Precipitation

Timeseries

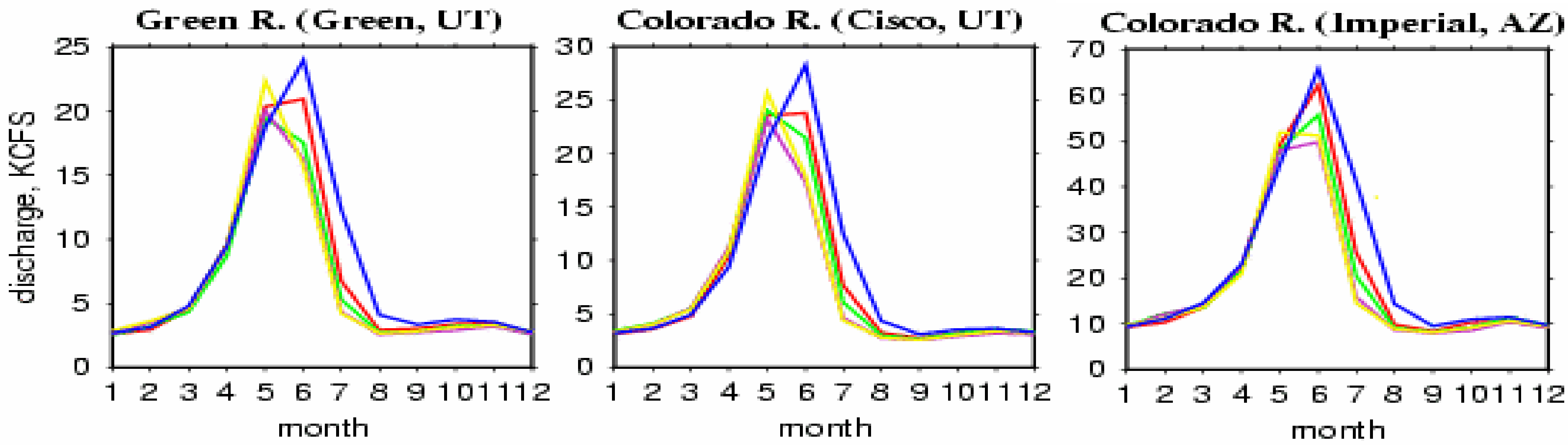
Annual Average





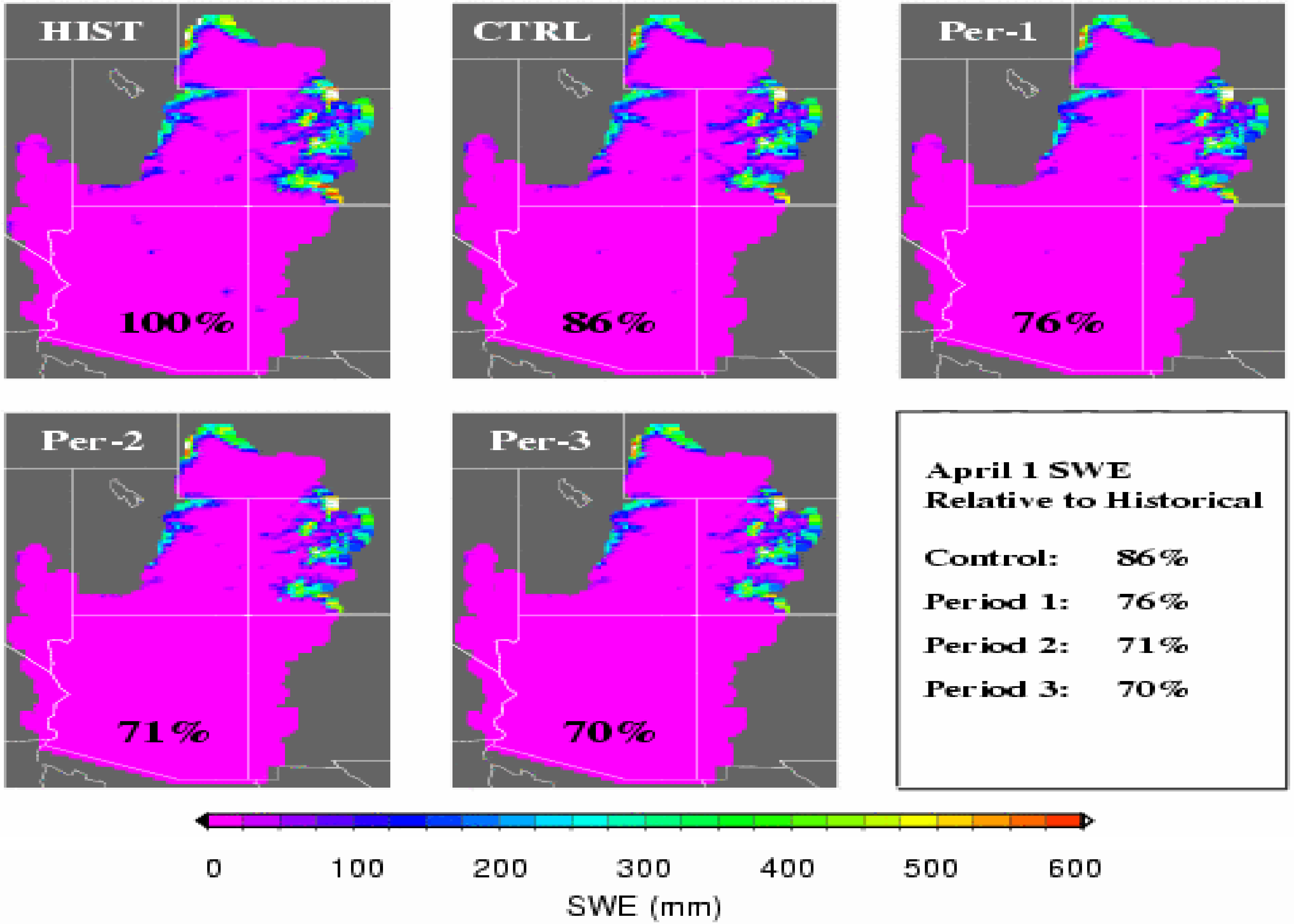
Period 1 2010-2039 Period 2 2040-2069 Period 3 2070-2098

Annual Average Hydrograph

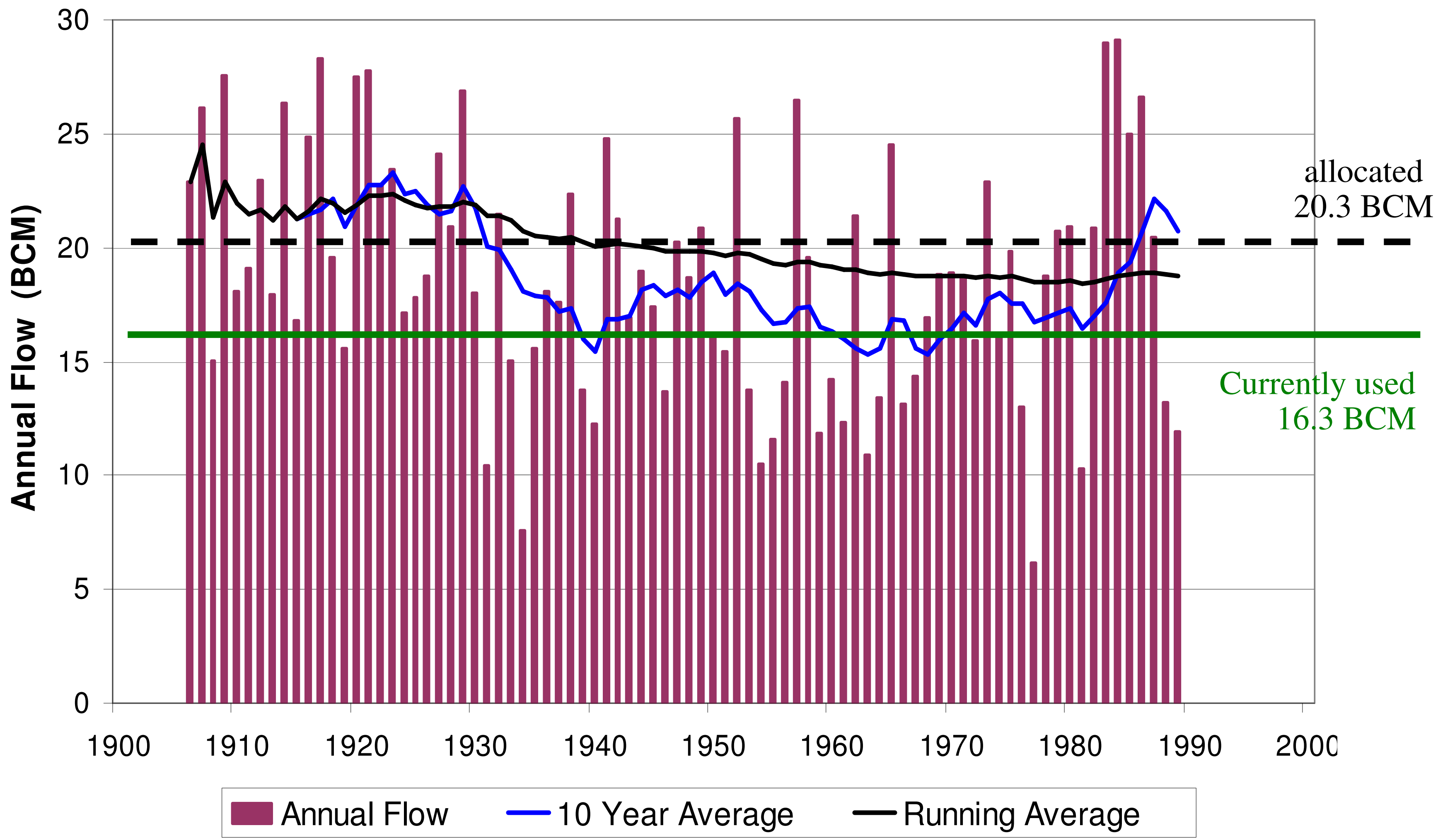


Simulated Historic (1950-1999)
Control (static 1995 climate)
Period 1 (2010-2039)
Period 2 (2040-2069)
Period 3 (2070-2098)

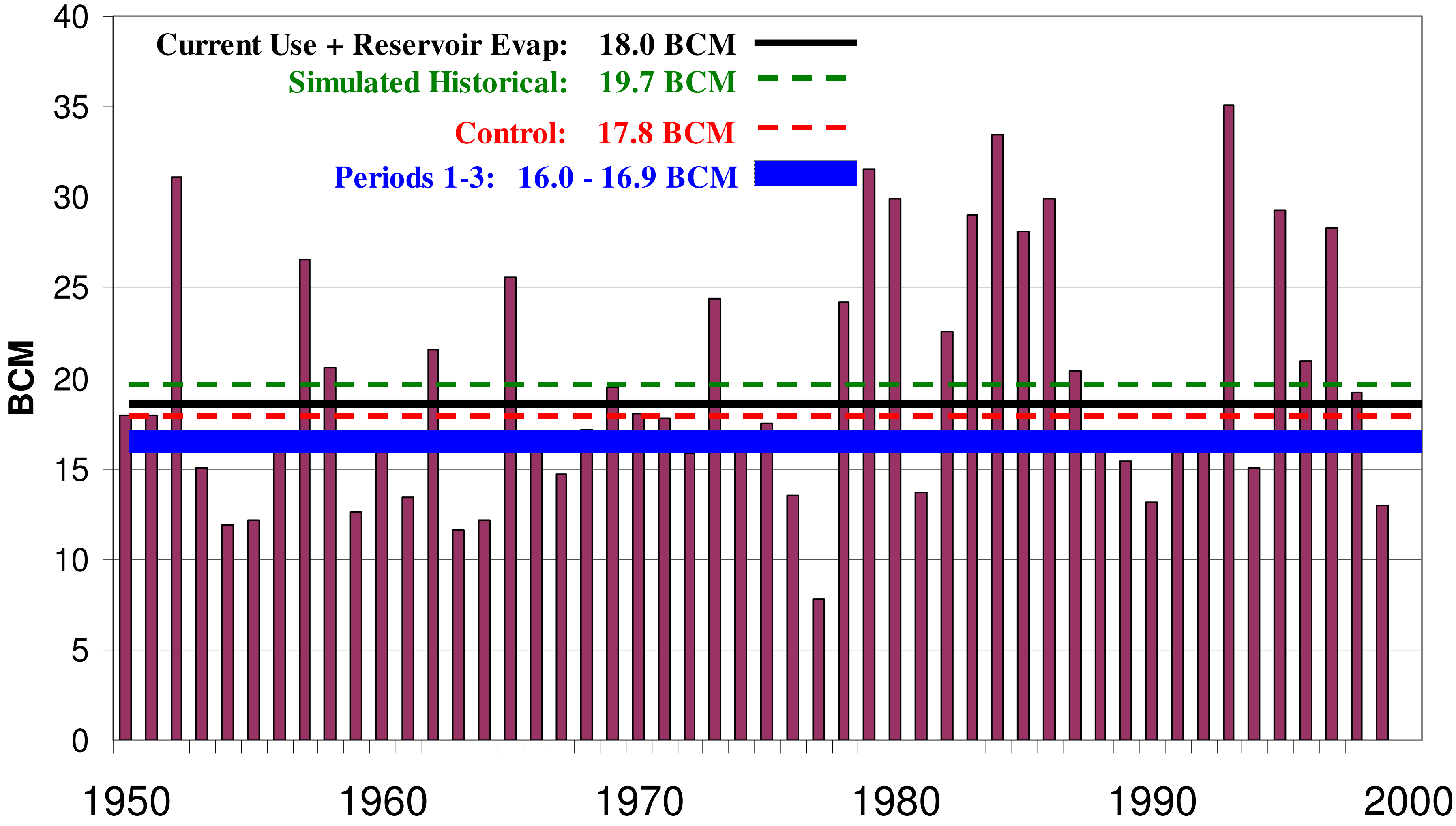
April 1 Snow Water Equivalent



Natural Flow at Lee Ferry, AZ

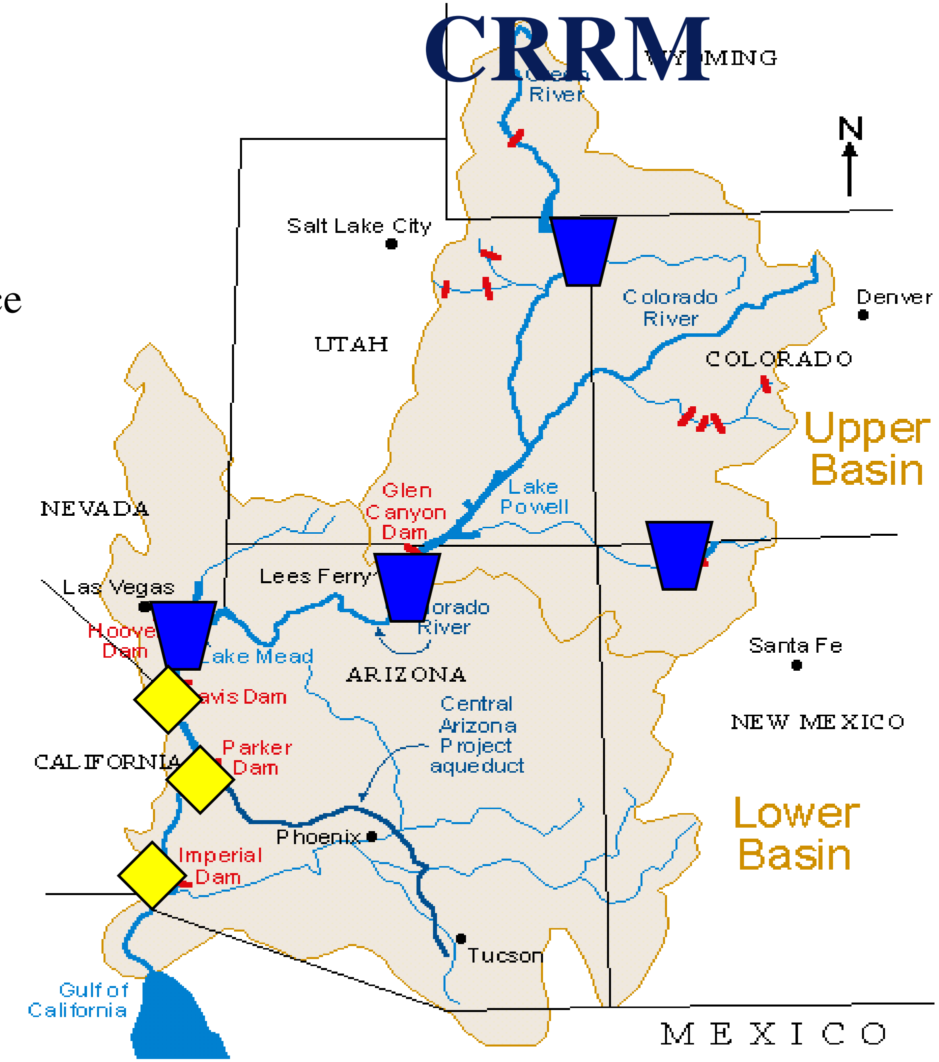


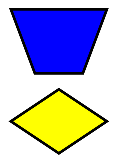
Natural Flow at Imperial Dam, AZ



CRRM

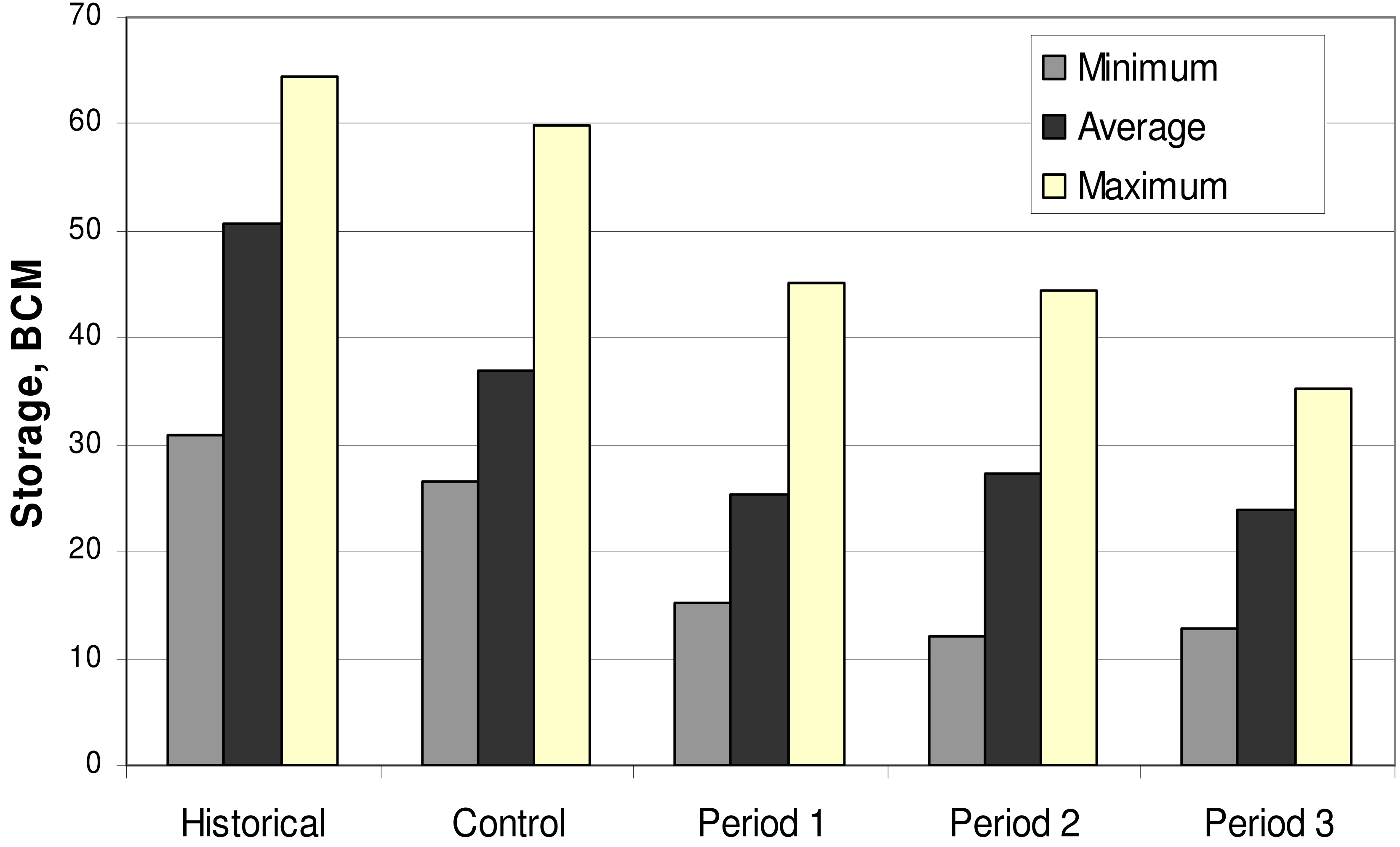
- Historic Streamflows to Validate
- Projected Inflows to assess future performance of system
- Monthly timestep
- Basin storage aggregated into 4 storage reservoirs
  - **Lake Powell and Lake Mead have 85% of basin storage**
- Reservoir evaporation = **f(reservoir surface area, mean monthly temperature)**
- Hydropower = **f(release, reservoir elevation)**



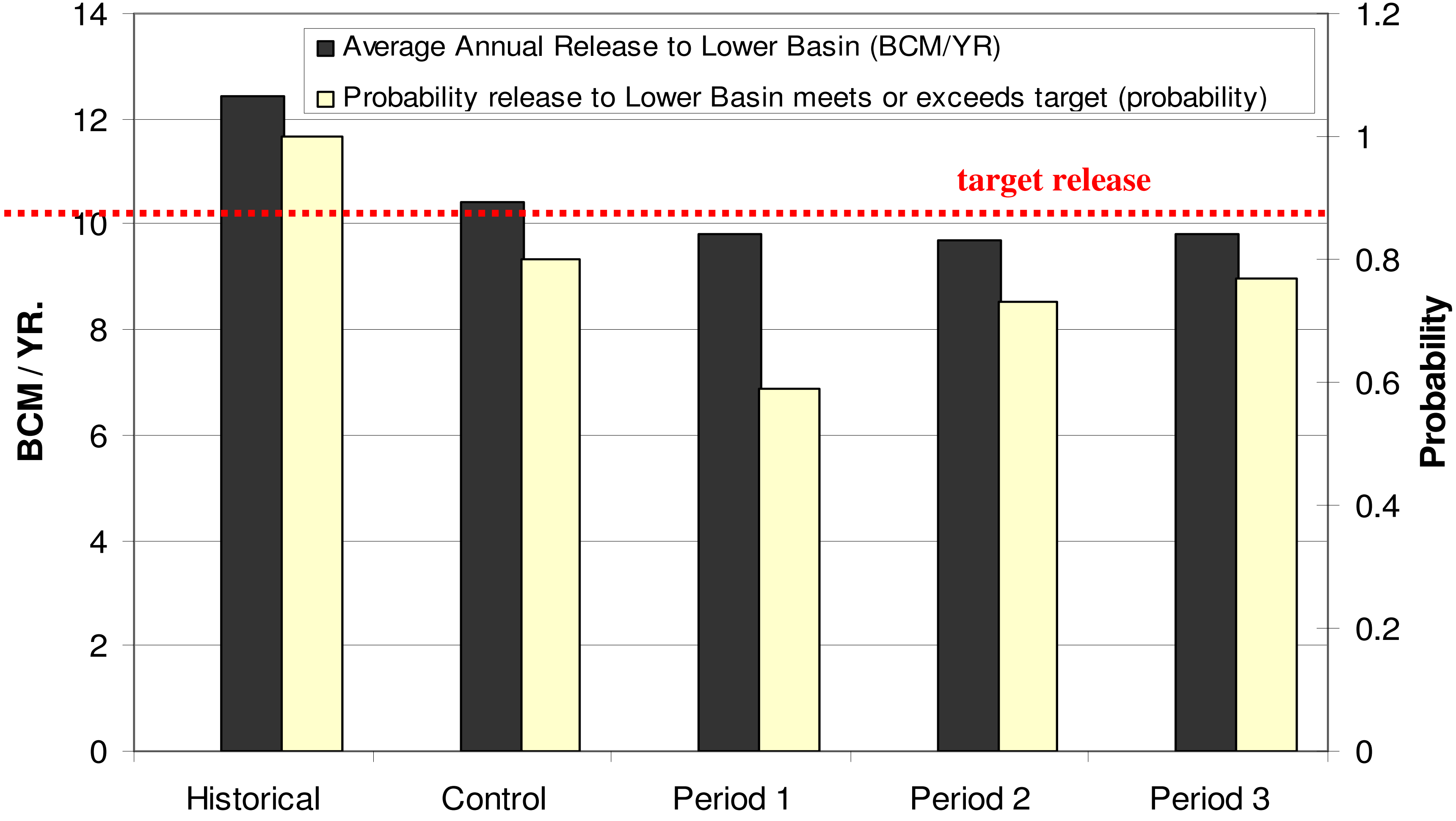


Storage Reservoirs
Run of River Reservoirs

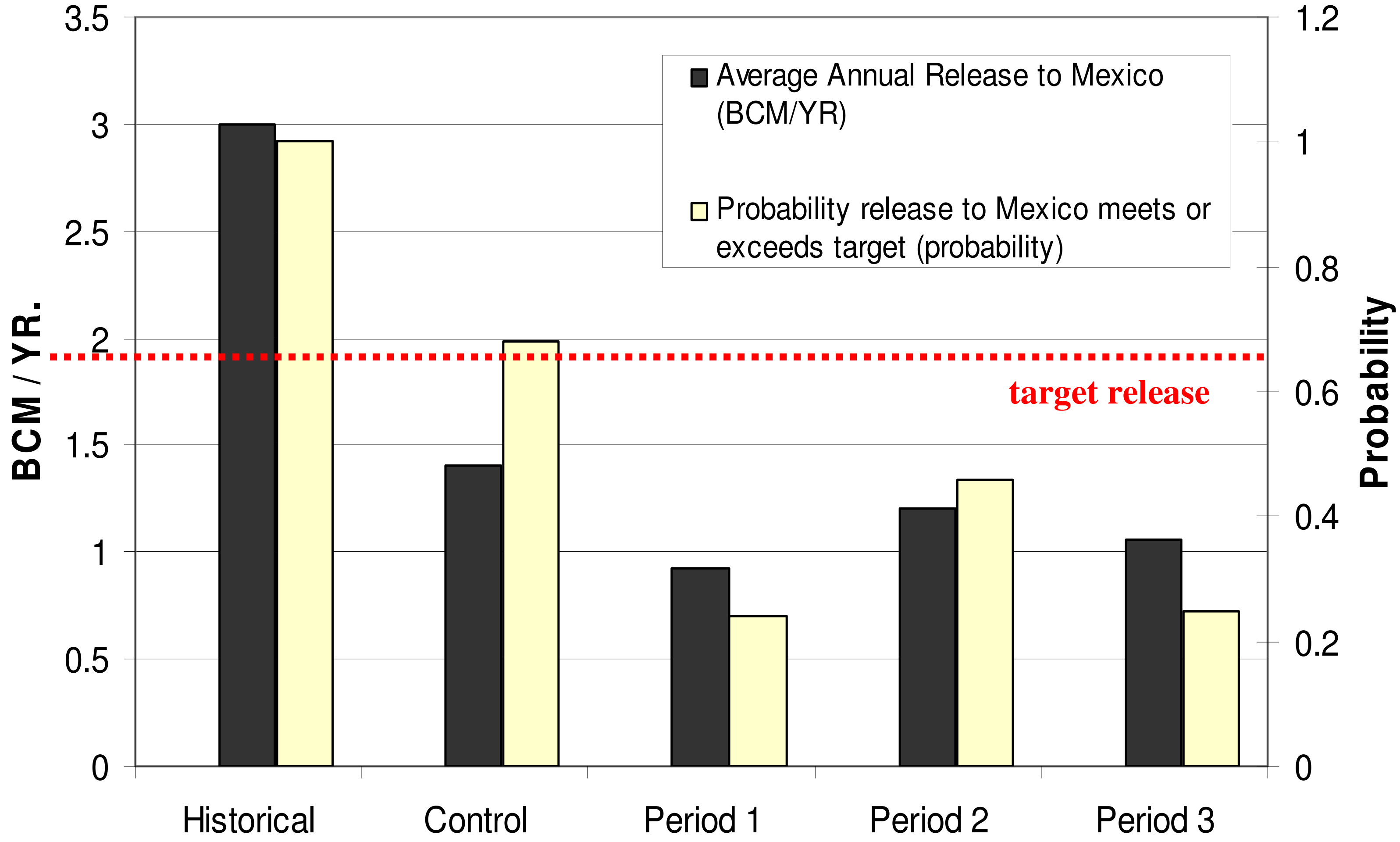
Total Basin Storage



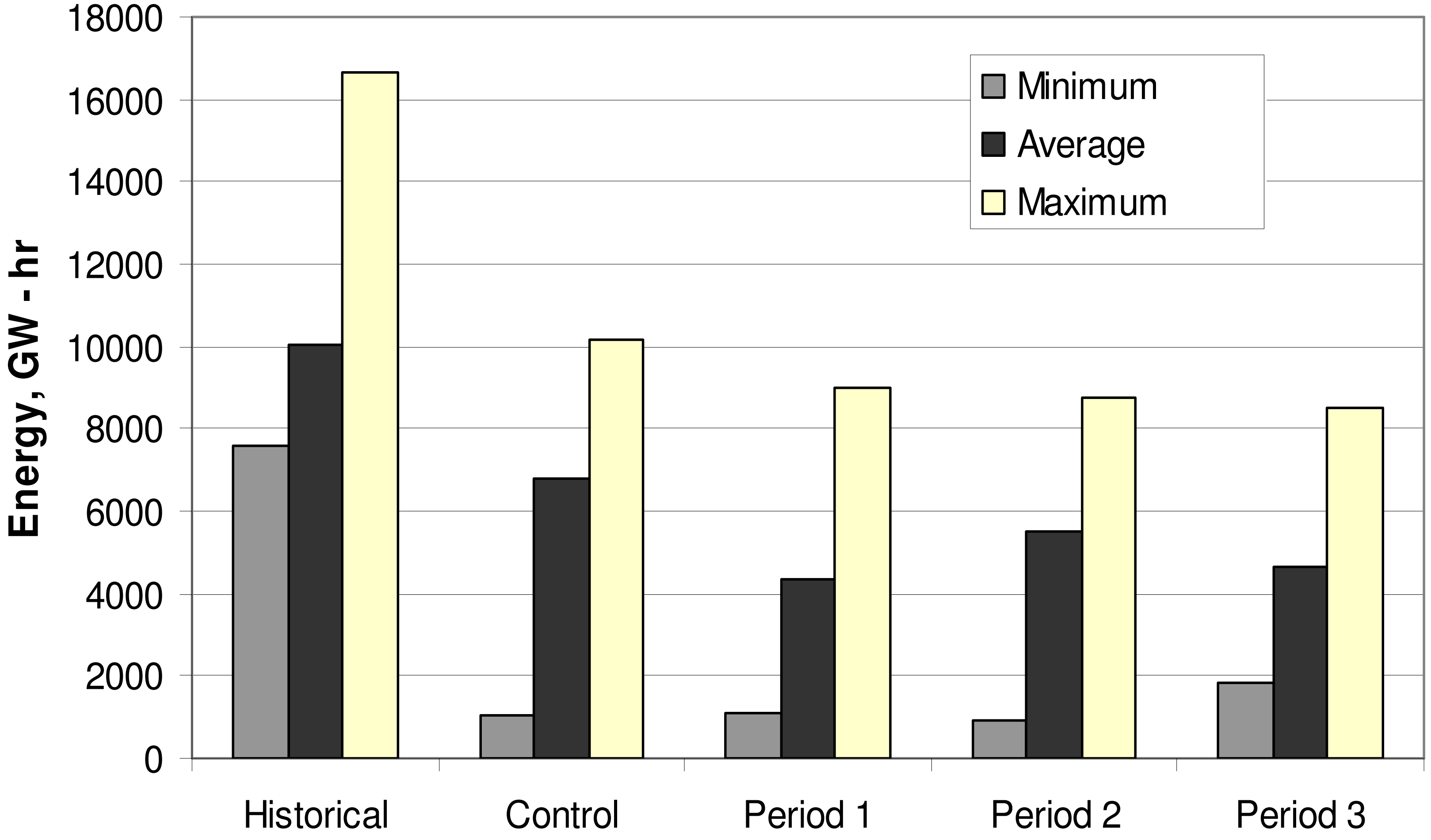
Annual Releases to the Lower Basin



Annual Releases to Mexico



Annual Hydropower Production



3c) Washington Climate Change Impacts Assessment

2007 State Legislature of Washington passed HB 1303 which mandated *the preparation of a comprehensive assessment of the impacts of climate change on the State of Washington* to be performed by the UW Climate Impacts Group

The assessment was to be focused on the impacts of global warming generally, and specifically in relation to:

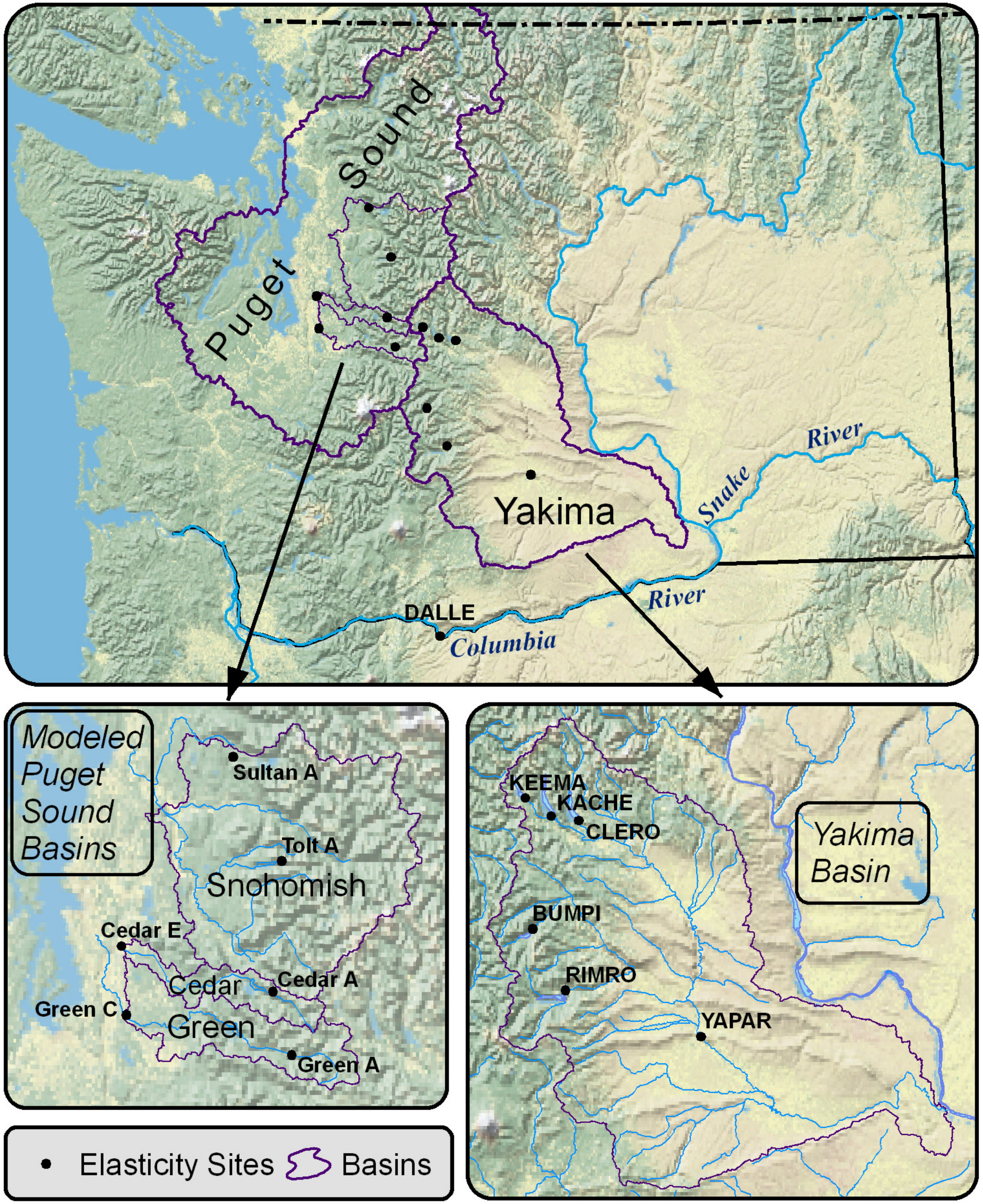
public health,
agriculture
coastal zone
forestry
Infrastructure (specifically stormwater)
water supply and management
salmon and ecosystems
energy

For summary see Climatic Change special issue, later this year

Assessment Overview: Study Region

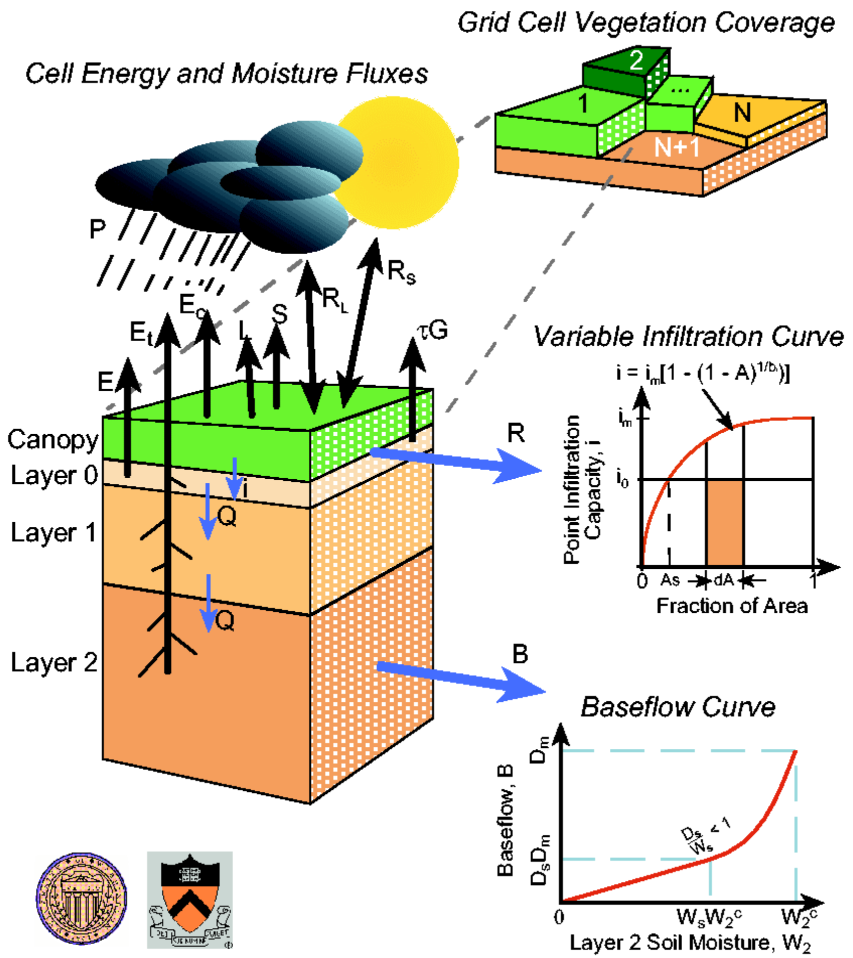
Focus Watersheds

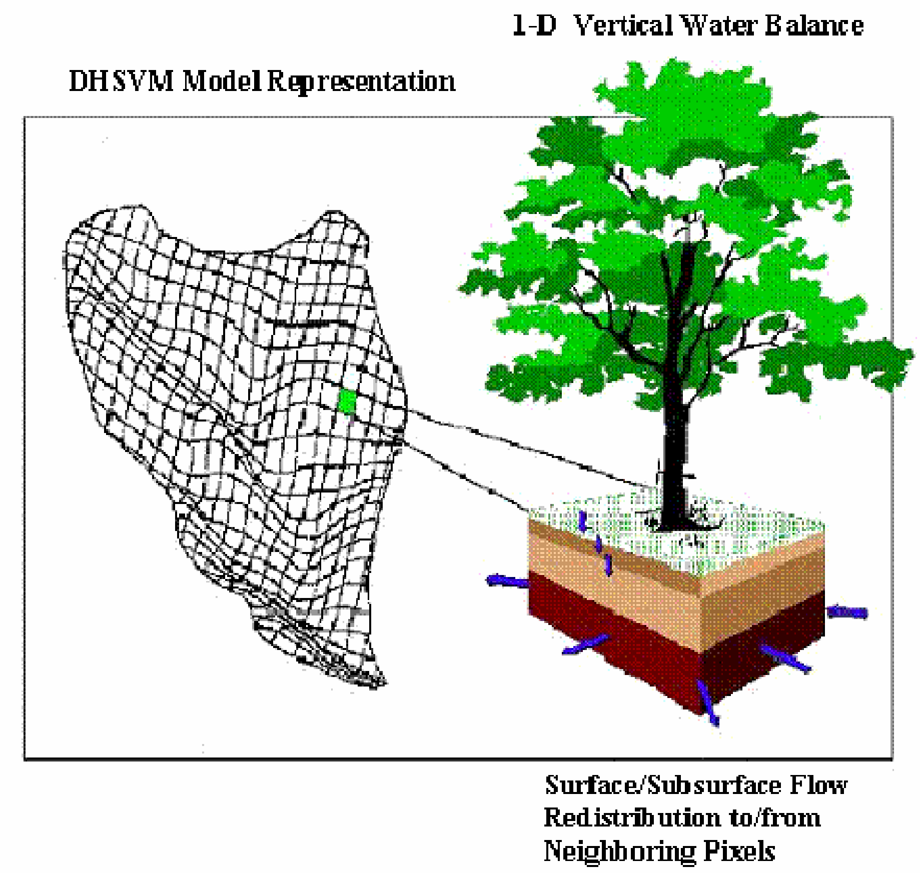
- Columbia River
  - Washington portion
- Puget Sound
  - Green River
  - Snohomish River
  - Cedar River
  - Tolt River
- Yakima River



Hydrologic Simulations

Variable Infiltration Capacity (VIC)
Macroscale Hydrologic Model

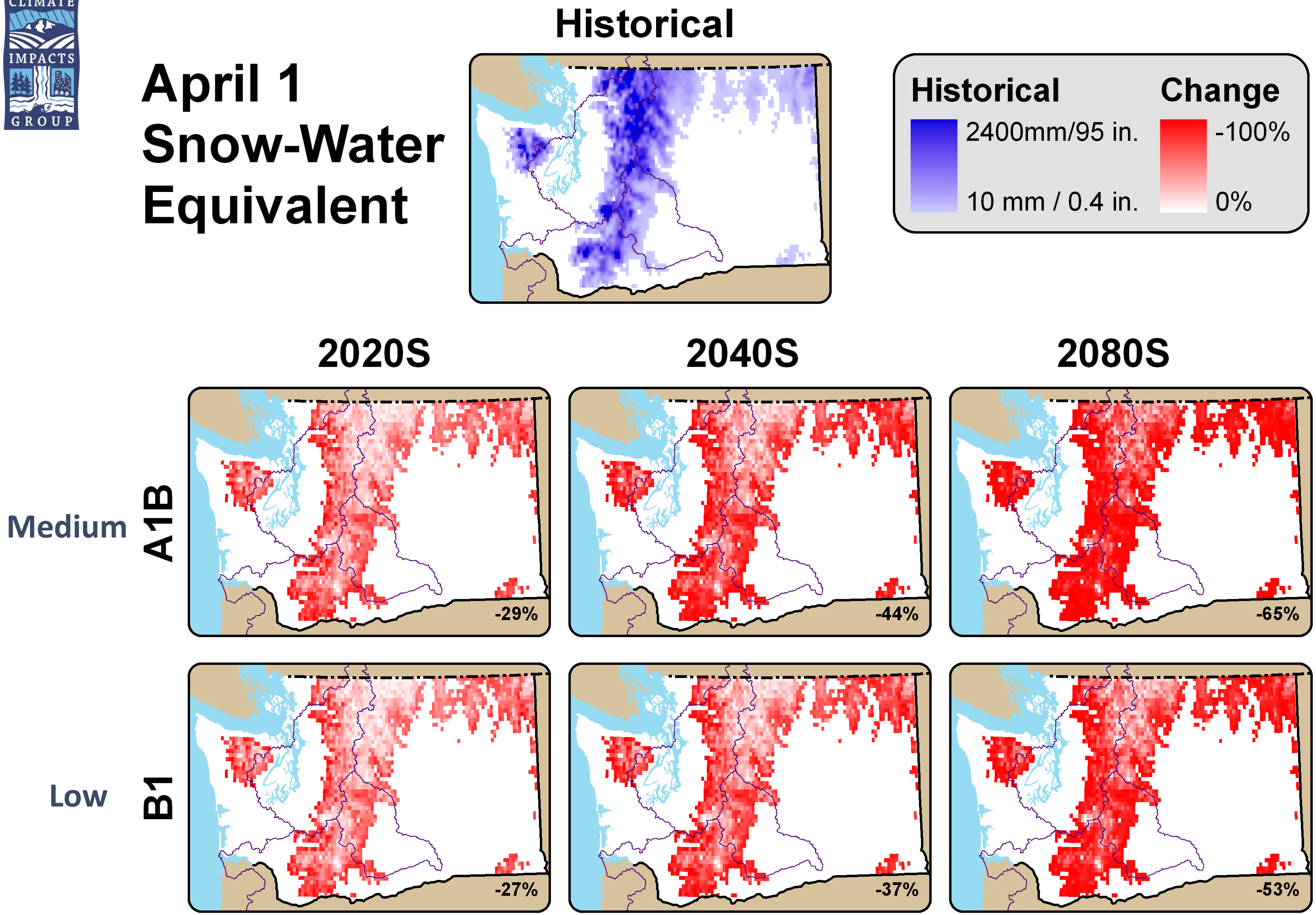




Large Scale Model (VIC)
~12mi² per cell

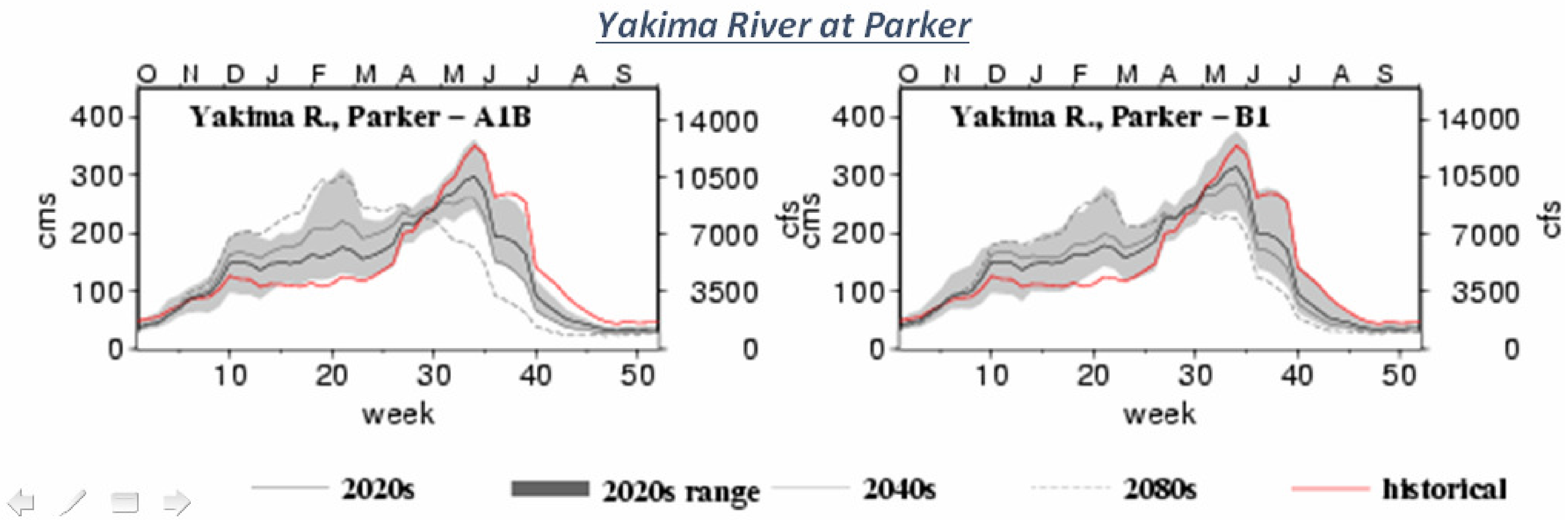
Fine Scale Model (DHSVM)
~6 acres per cell

April 1 Snow-Water Equivalent

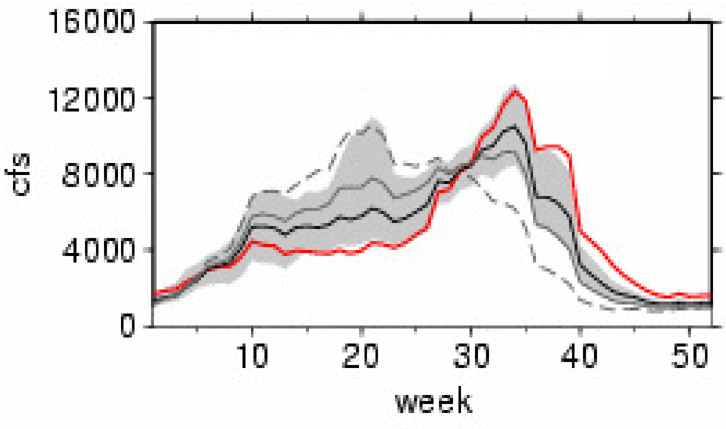


Elsner, M.M. et al. 2009: Implications of 21st Century climate change for the hydrology of Washington State (in review)

Weekly Streamflow Projections

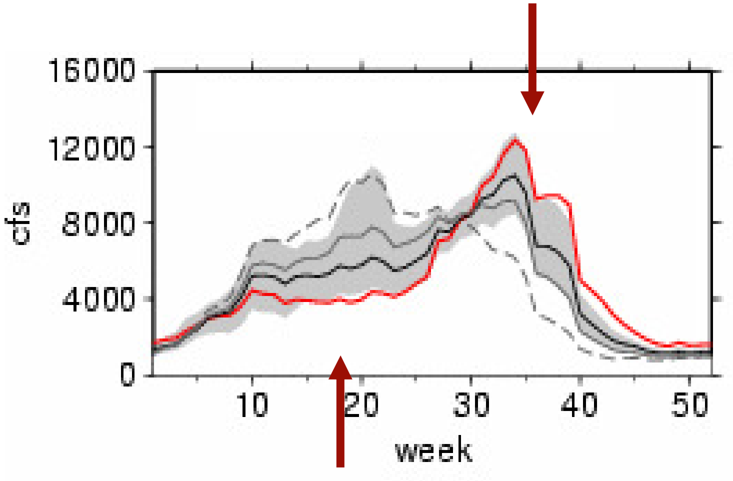


Yakima River Basin



Unregulated

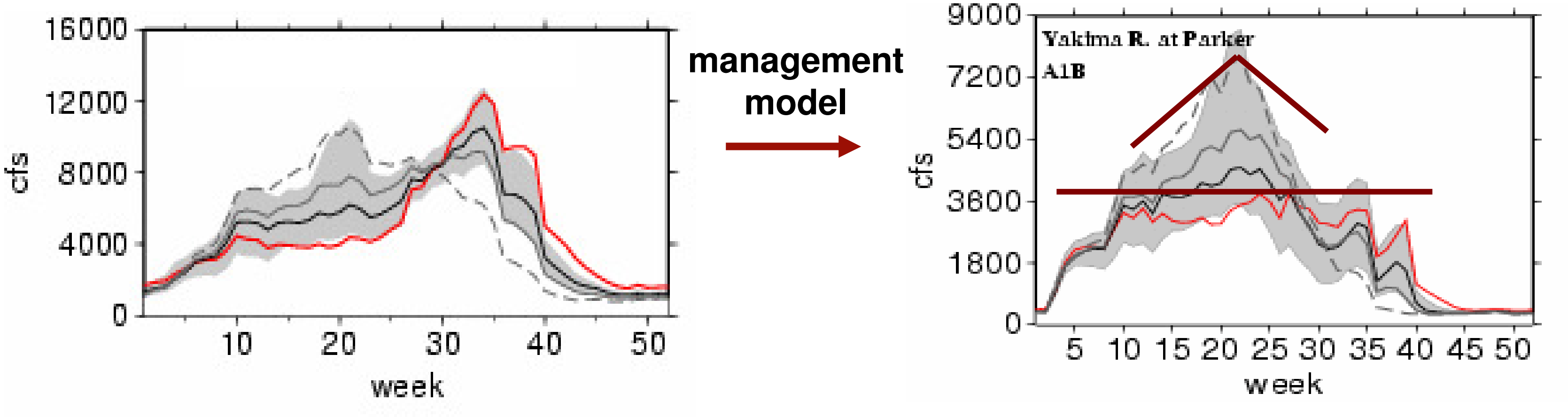
Yakima River Basin



Unregulated

- **Basin shifts from snow to more rain dominant**

Yakima River Basin

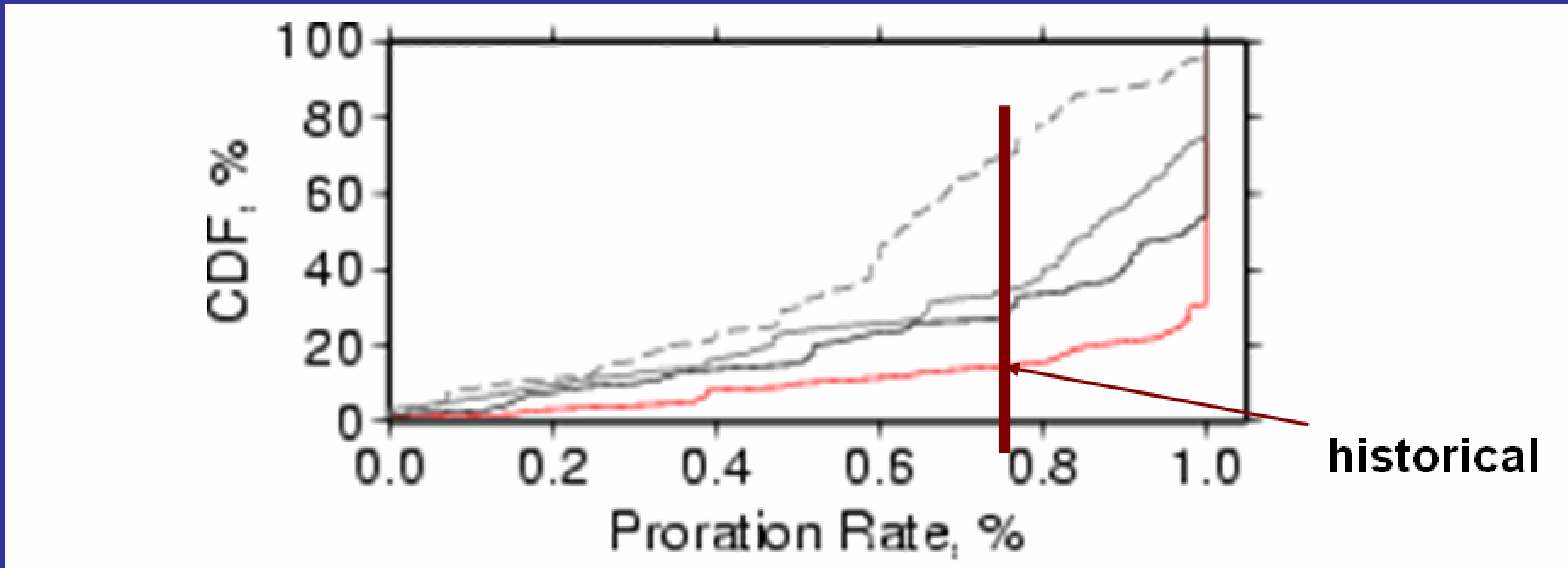


Unregulated

Regulated

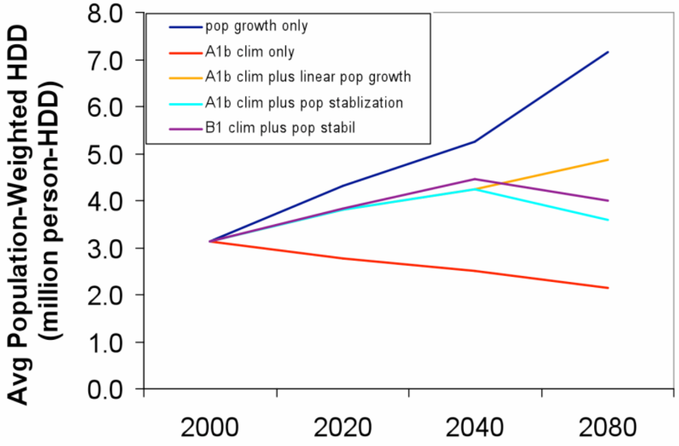
- Basin shifts from snow to more rain dominant

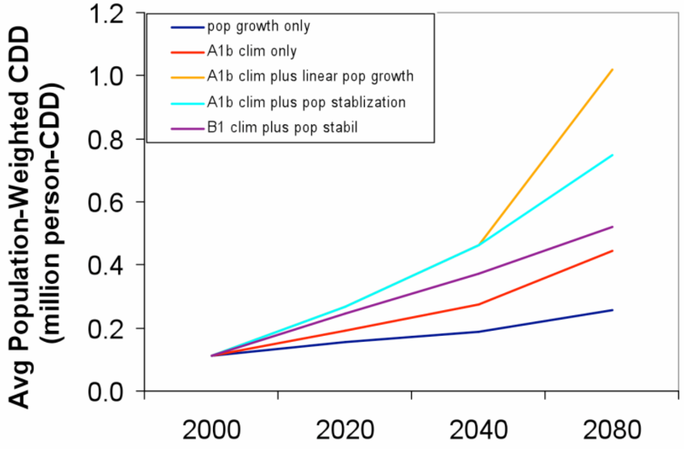
Yakima River Basin water management effects

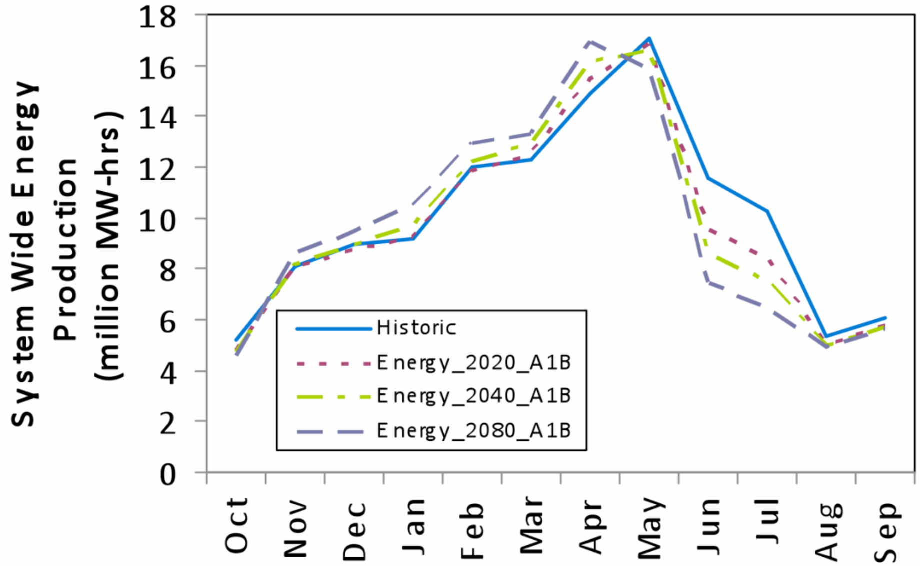


- Basin shifts from snow to more rain dominant
- Water prorating, junior water users receive 75% of allocation
- Junior irrigators less than 75% prorating (current operations):
  - 14% historically
  - 32% in 2020s A1B (15% to 54% range of ensemble members)
  - 36% in 2040s A1B
  - 77% in 2080s A1B

Shifts in energy production and demand – Columbia River basin







Weak links and the path forward

1) Stationarity is dead (how do we represent nonstationarity in the planning process

2) Understanding the hydrologic sensitivities

3) Representing hydrologic and water management uncertainty

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

- **Contention is virtually unassailable given observed trends globally and regionally (although certainly not everywhere for all variables!)**

- **Replacement for established risk, uncertainty, and reliability protocols is less obvious**

- **Distinguishing low frequency variability from trends is very difficult**

Understanding the hydrologic sensitivities

Temperature Sensitivity

percent change in flow per °C temp increase

	VIC		Noah 2.7		SAC		SAC NWS[A]
	tmin & tmax	tmax	tmin & tmax	tmax	tmin & tmax	tmax	temp
historic	-5.3	-9.8	-7.9	-15.8	-5.1	-8.9	-3.9
1 deg	-4.9	-9.4	-7.4	-15.4	-5.1	-8.9	-3.9
2 deg	-4.6	-9.0	-7.1	-15.2	-5.1	-9.1	-3.8
3 deg	-4.3	-8.6	-6.5	-14.7	-5.0	-9.2	-3.6

Precip Elasticities

percent change in flow per percent increase in precip

	VIC	Noah 2.7	SAC	SAC NWS
-30%	2.7	6.0	4.4	5.0[B]
-20%	2.5	4.9	3.7	3.8[B]
-10%	2.3	4.2	3.2	3.0
historic	2.2	3.6	2.7	2.4
+10%	2.1	3.1	2.4	2.2

[A] Lake Powell inflow, lowest location on Colorado SAC NWS simulates
[B] Reference=historic, therefore deltas larger (30 and 20% instead of 1% as used in other calculations)

3) Representing hydrologic and water management uncertainty