POTENTIAL IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES: Accelerated Climate Prediction Initiative (ACPI) Results for the Columbia River Basin

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Presentation to

Northwest Power Planning Council

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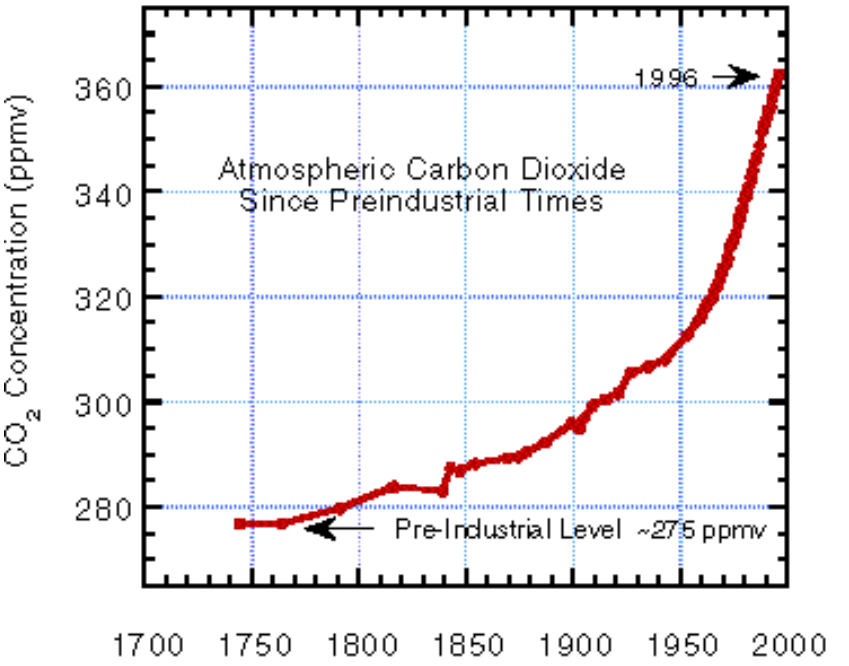
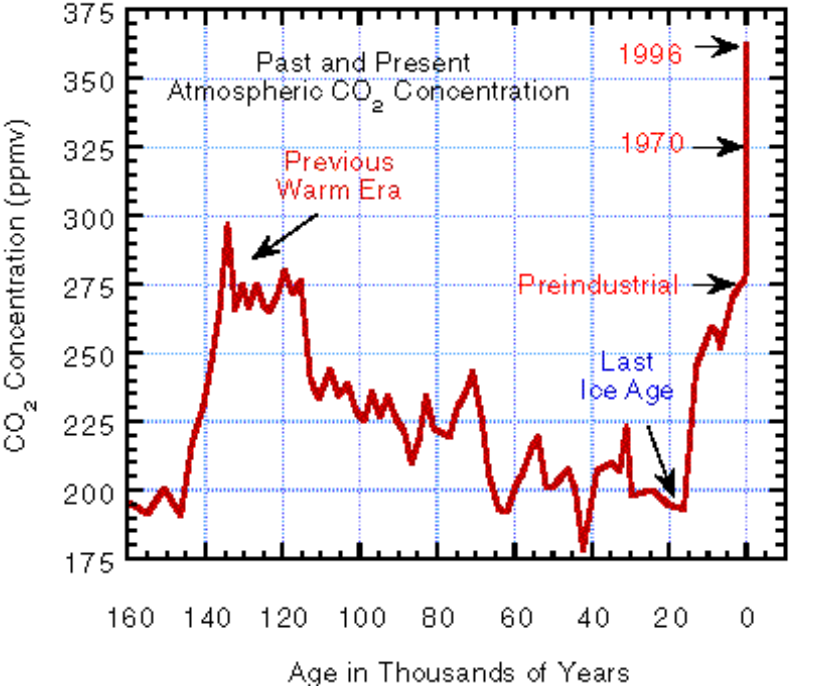
Outline of this talk

1) Climate variability and change context
2) Prediction and assessment approach
3) Accelerated Climate Prediction Initiative (ACPI)
4) Hydrology and water management implications for Columbia River Basin
5) Conclusions and comparative analysis

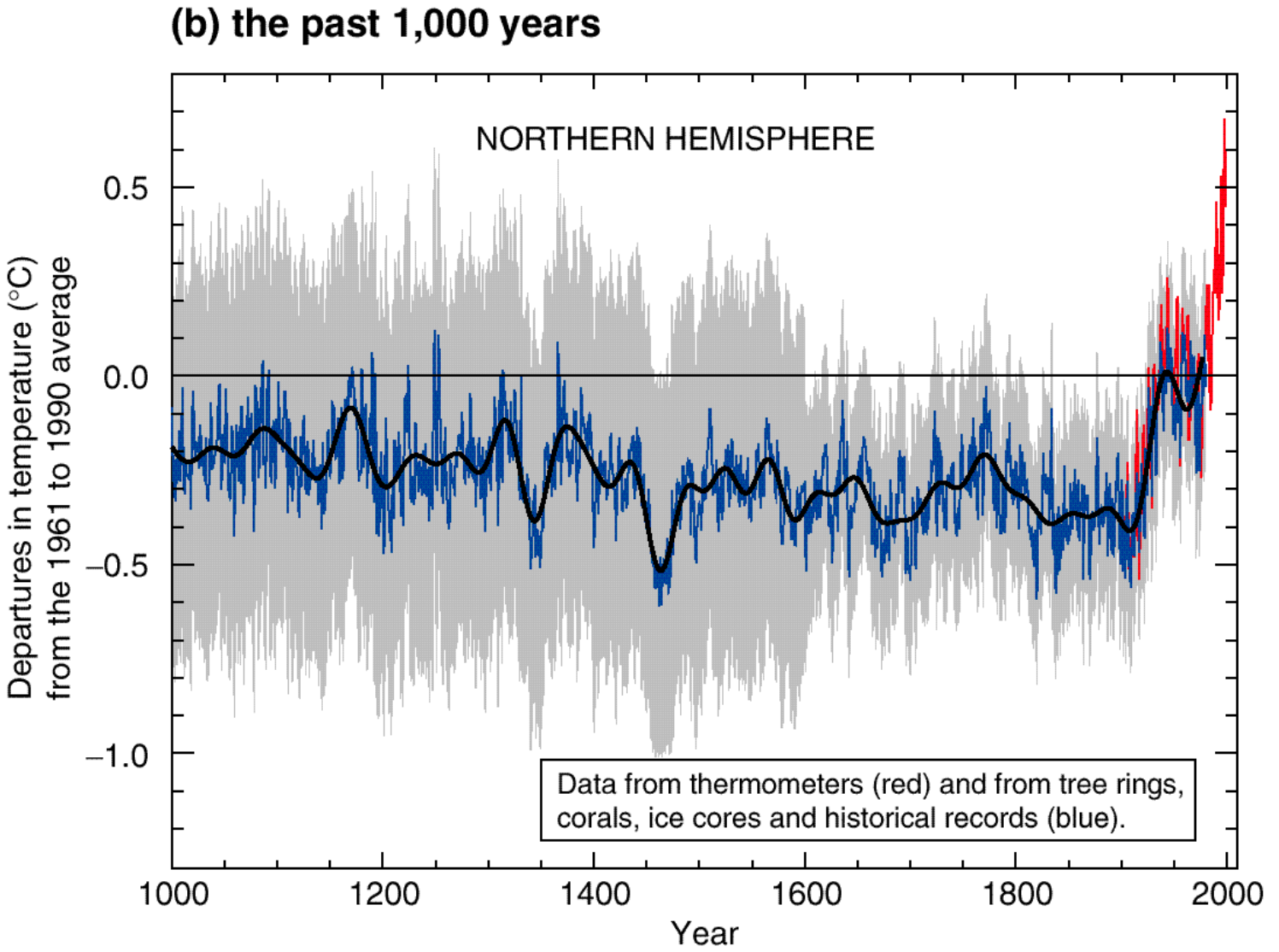
1) Climate variability and change context

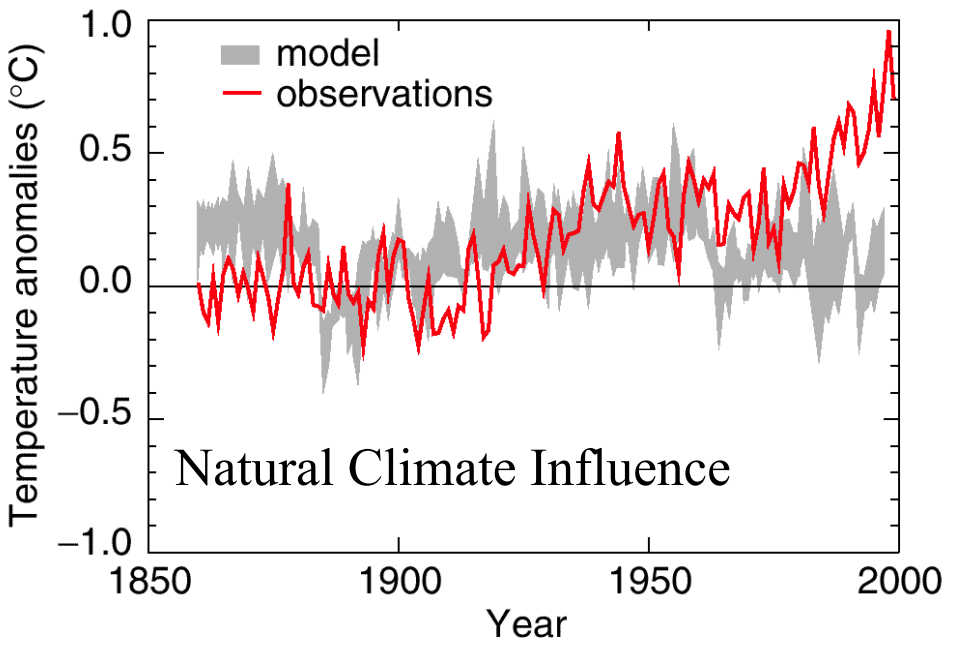
Humans are altering atmospheric composition

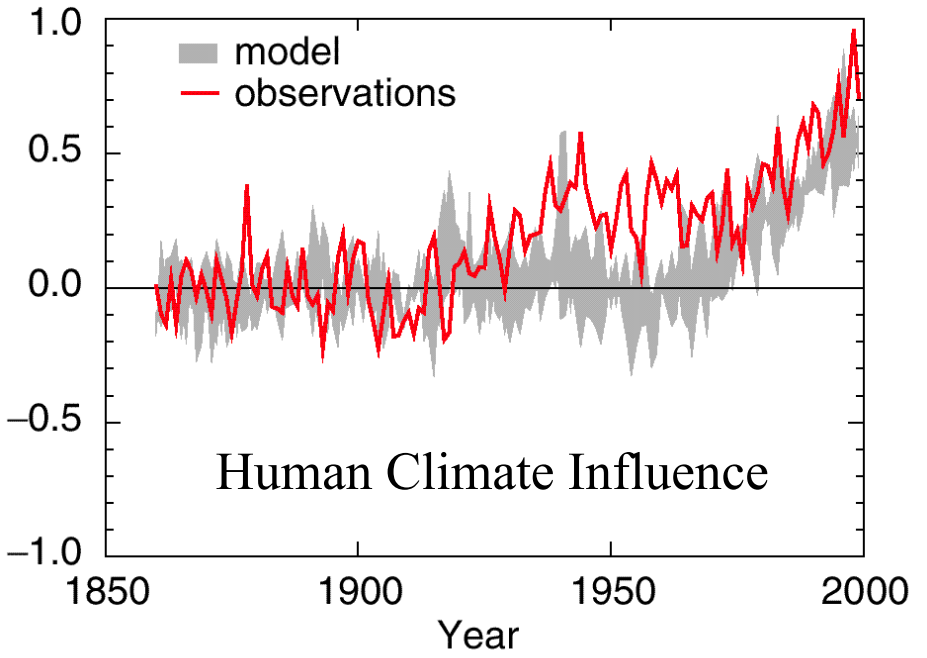


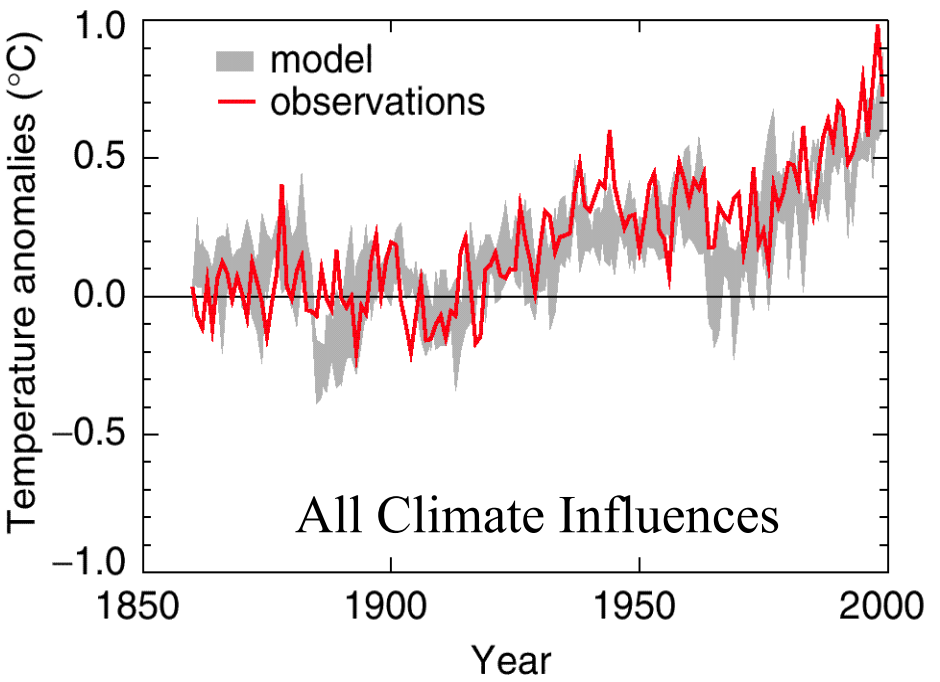


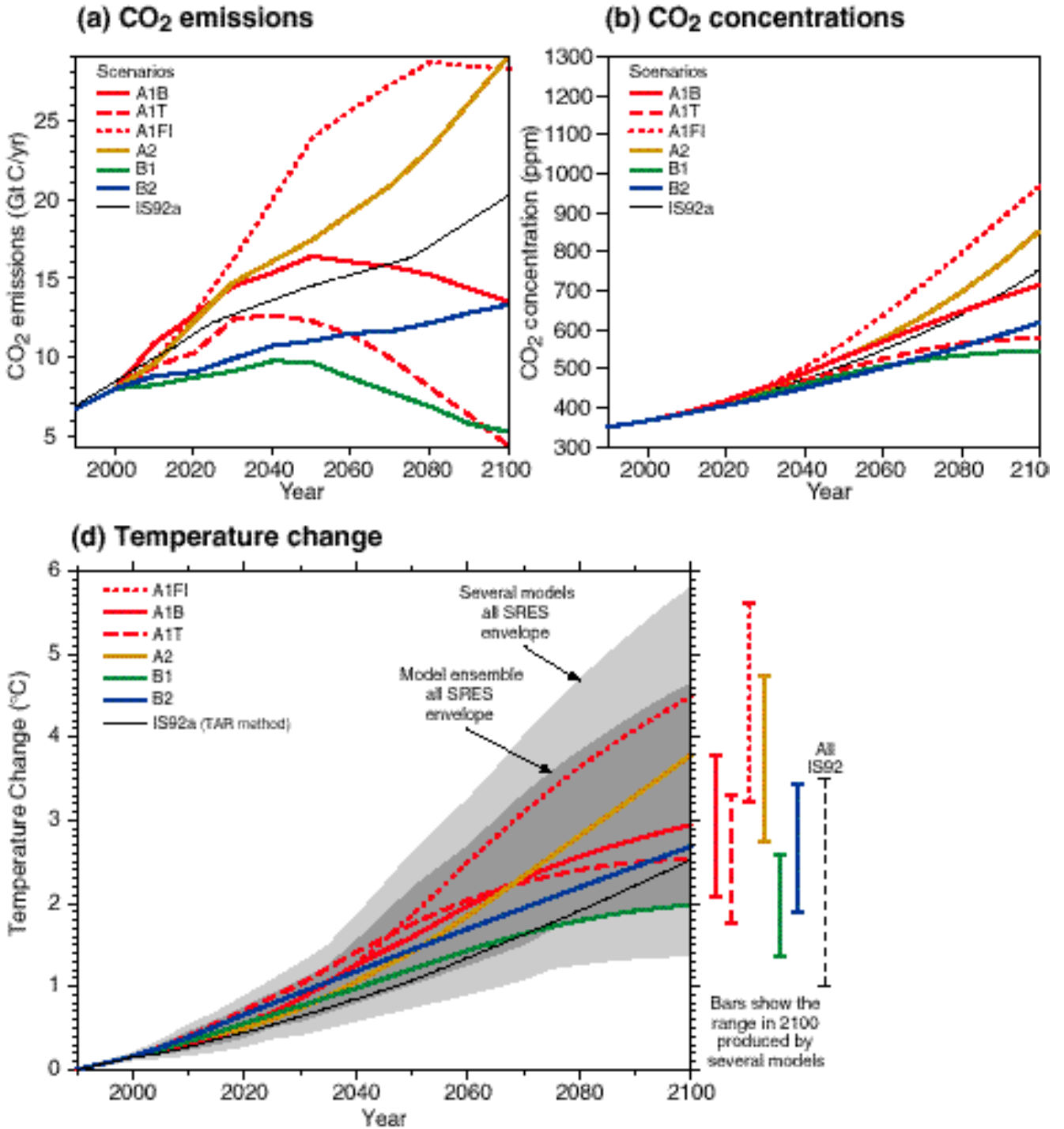
The earth is warming -- abruptly




model
observations
Natural Climate Influence
Temperature anomalies (°C)
1.0
0.5
0.0
−0.5
−1.0
1850
1900
1950
2000
Year

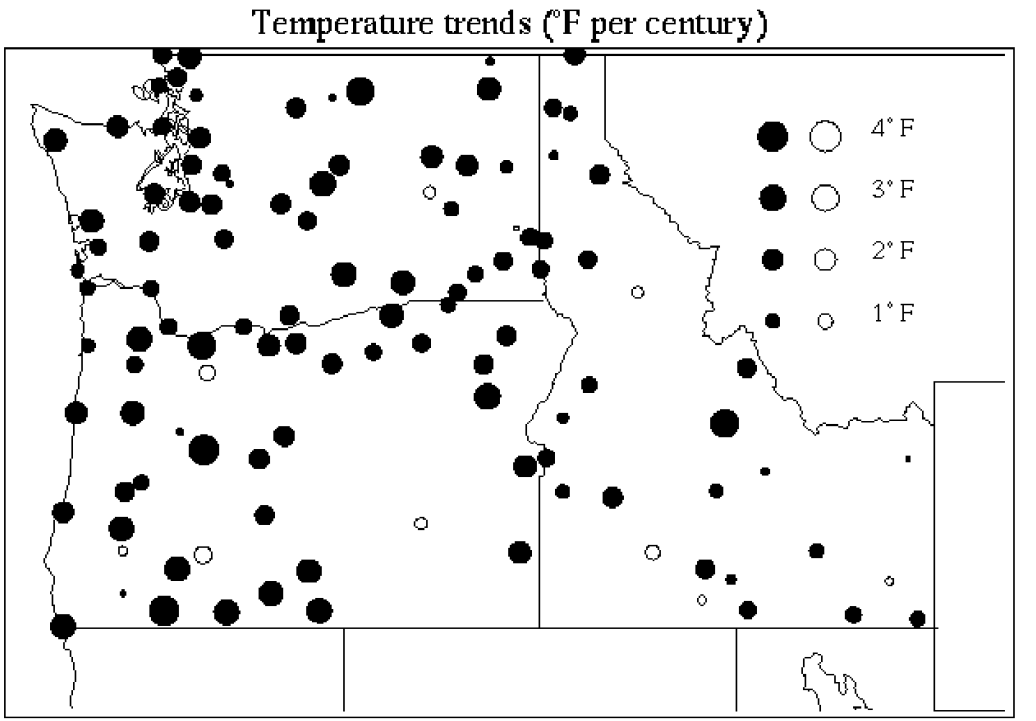

model
observations
Human Climate Influence
1.0
0.5
0.0
−0.5
−1.0
1850
1900
1950
2000
Year


model
observations
All Climate Influences
Temperature anomalies (°C)
1.0
0.5
0.0
−0.5
−1.0
1850
1900
1950
2000
Year

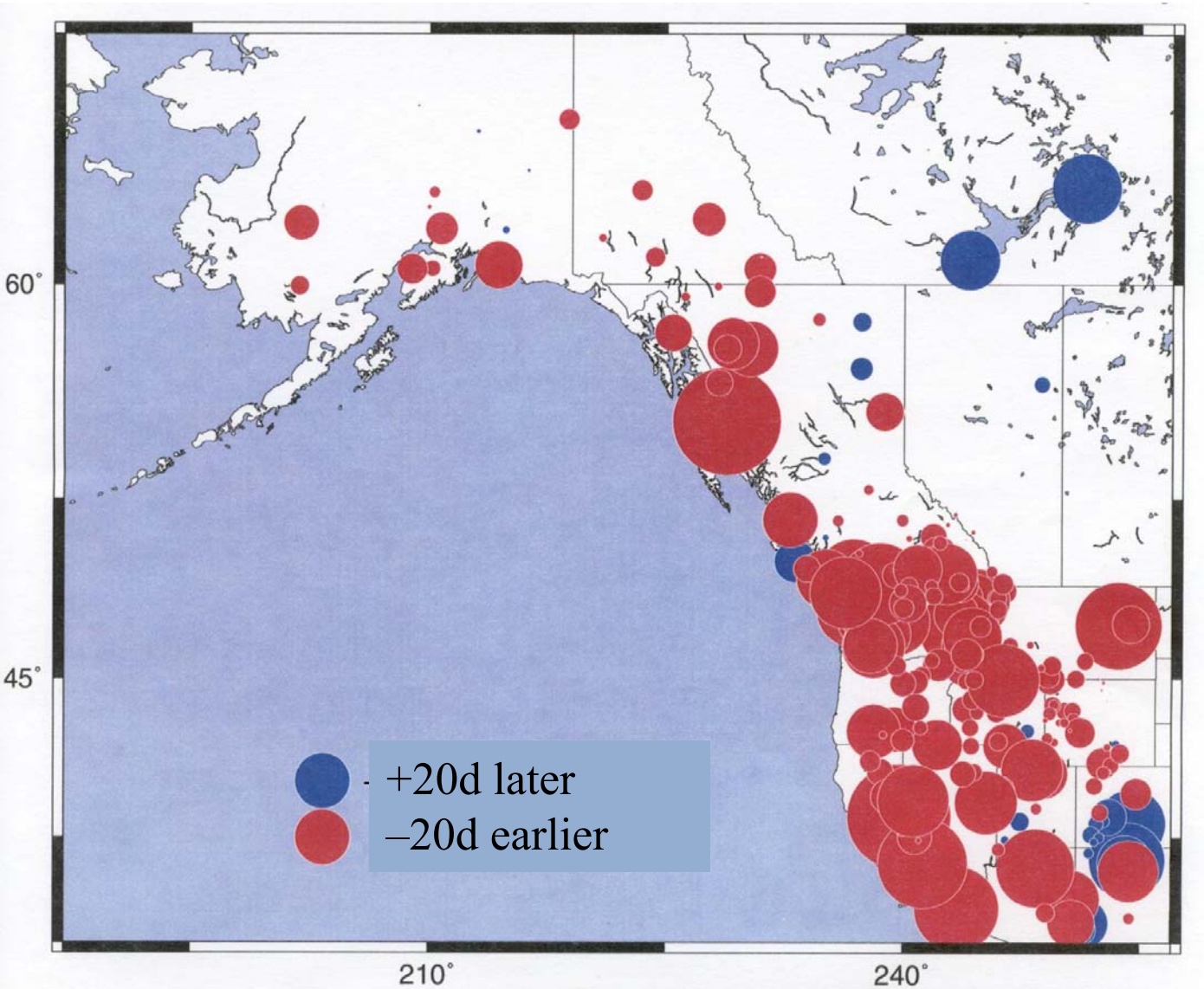

(a) CO2 emissions
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a
CO2 emissions (Gt C/yr)
Year
(b) CO2 concentrations
CO2 concentration (ppm)
(d) Temperature change
A1FI
A1B
A1T
A2
B1
B2
IS92a (TAR method)
Several models all SRES envelope
Model ensemble all SRES envelope
All IS92
Bars show the range in 2100 produced by several models
Temperature Change (°C)

Temperature trends in the PNW over the instrumental record

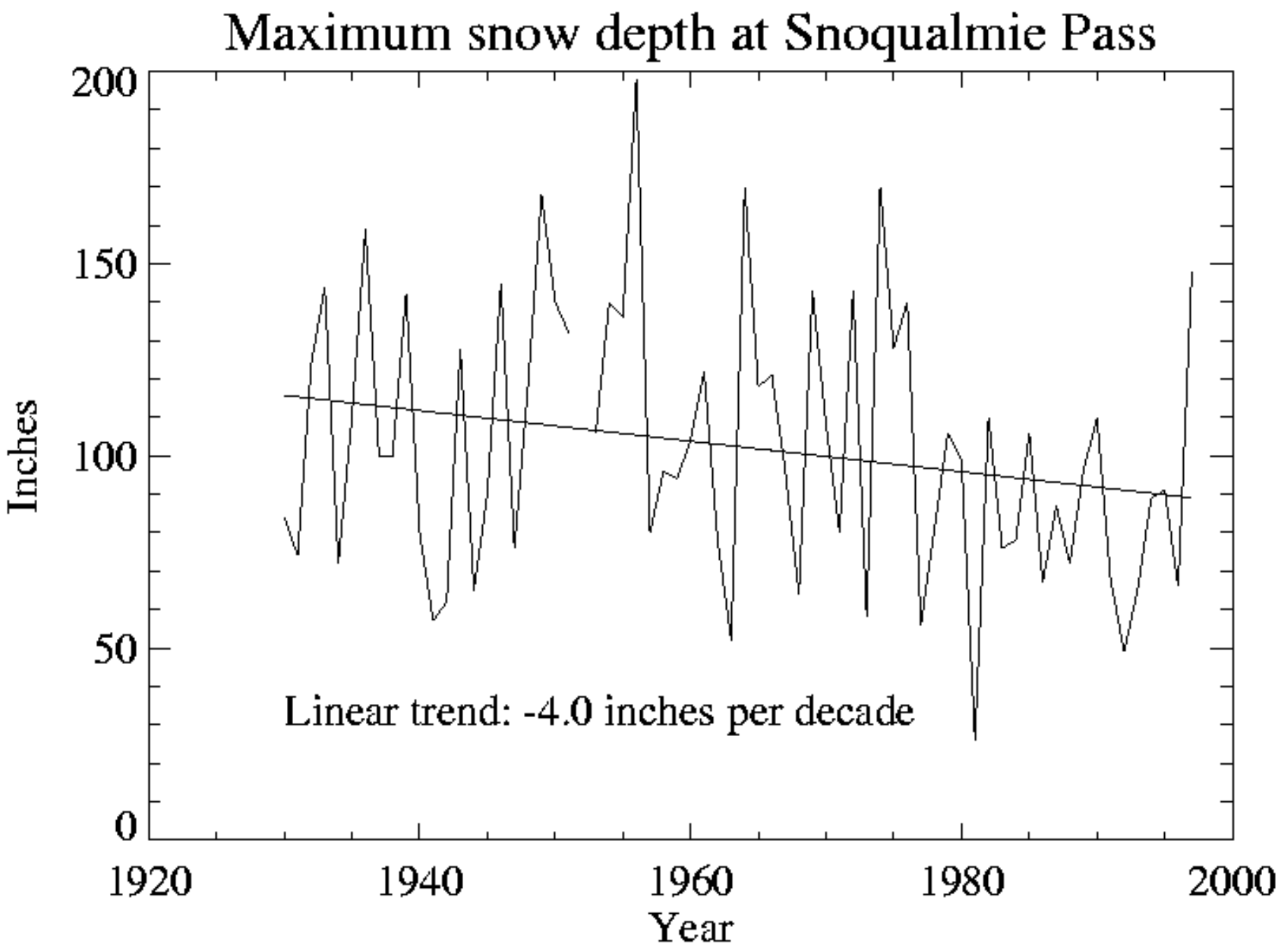
- **Almost every station shows warming (filled circles)**
- **Urbanization not a major source of warming**



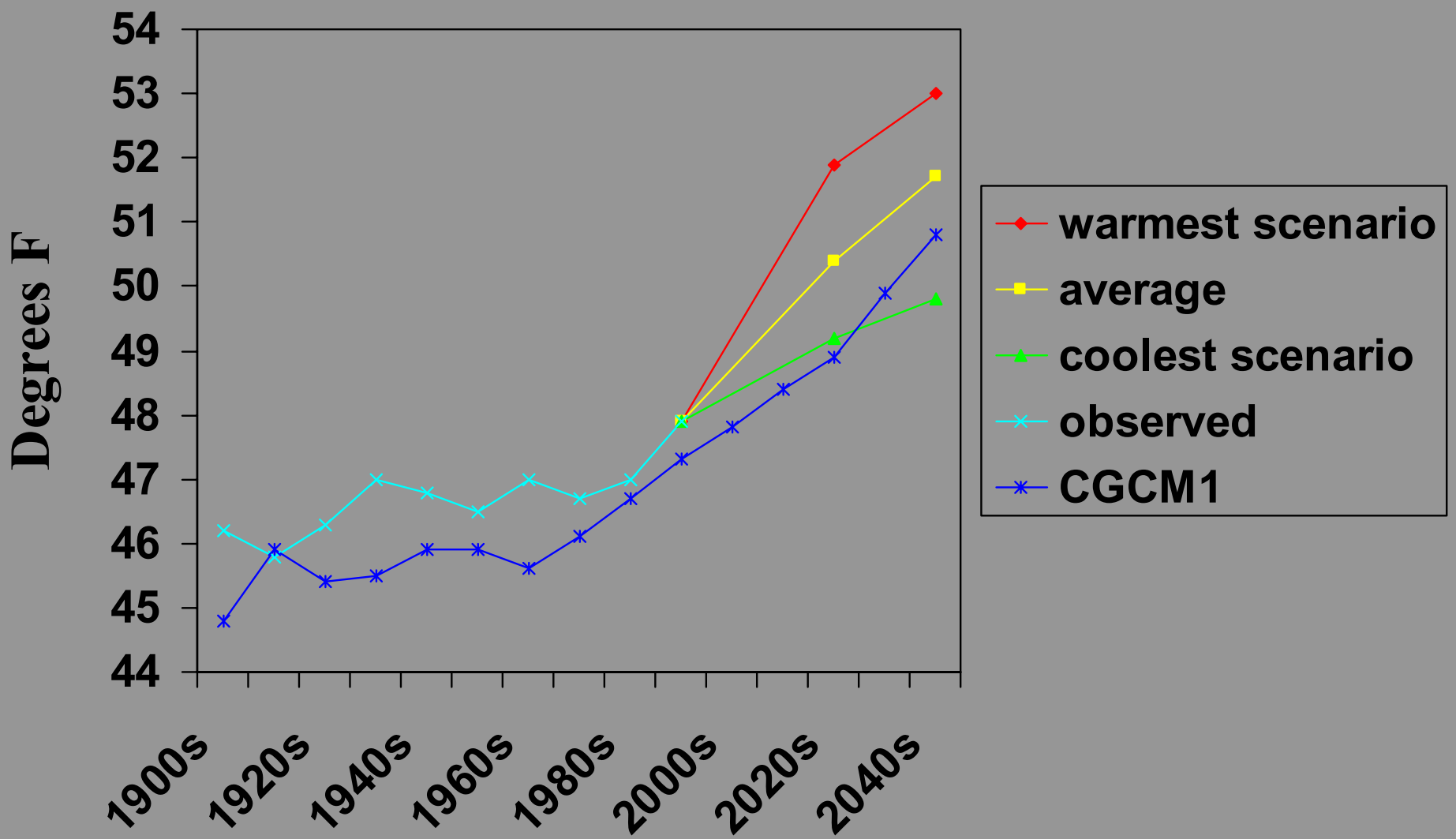
Trends in timing of spring snowmelt (1948-2000)



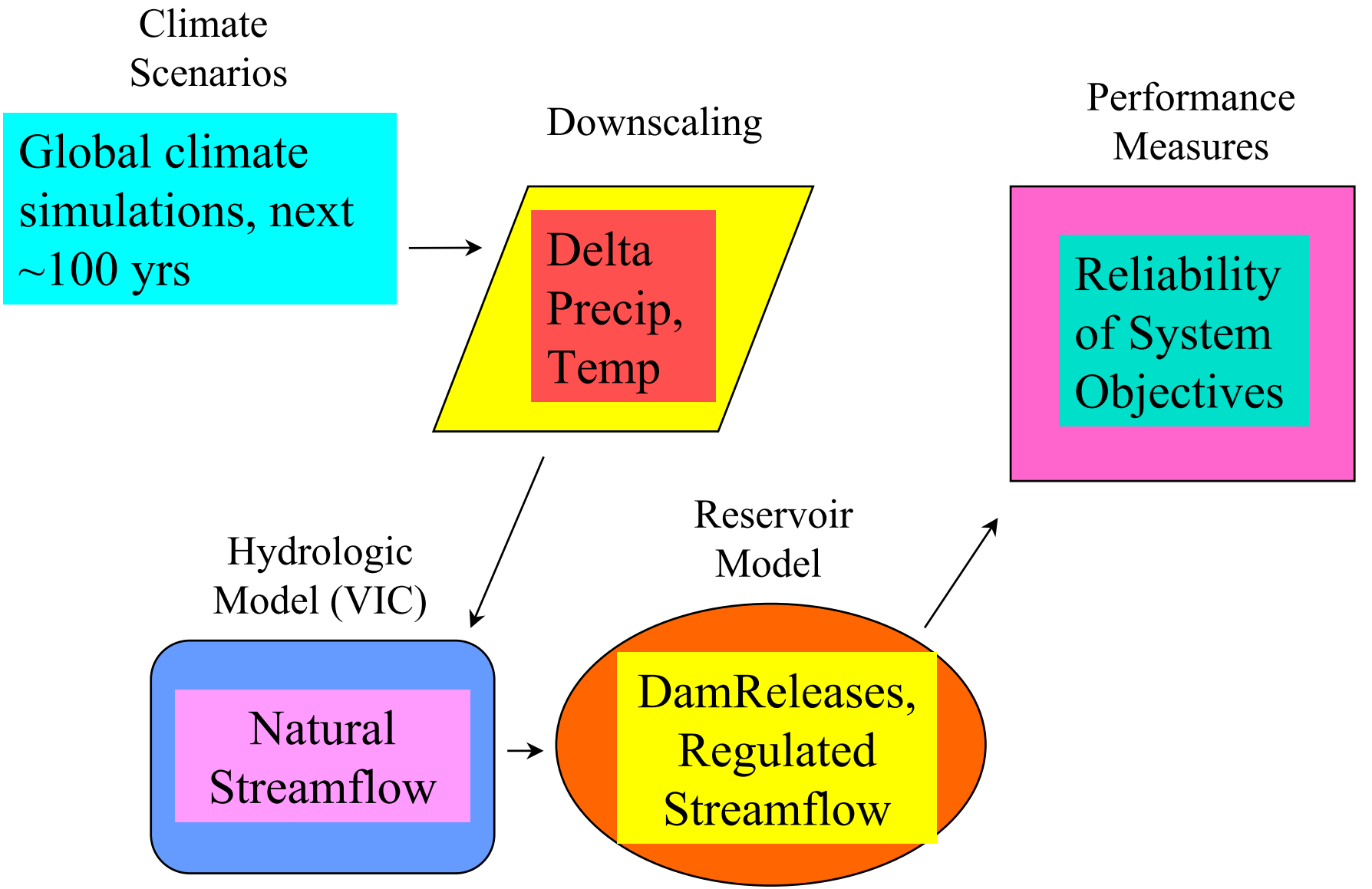
Courtesy of Mike Dettinger, Iris Stewart, Dan Cayan


Maximum snow depth at Snoqualmie Pass
200
150
100
50
0
Inches
Linear trend: -4.0 inches per decade
1920
1940
1960
1980
2000
Year

Northwest warming

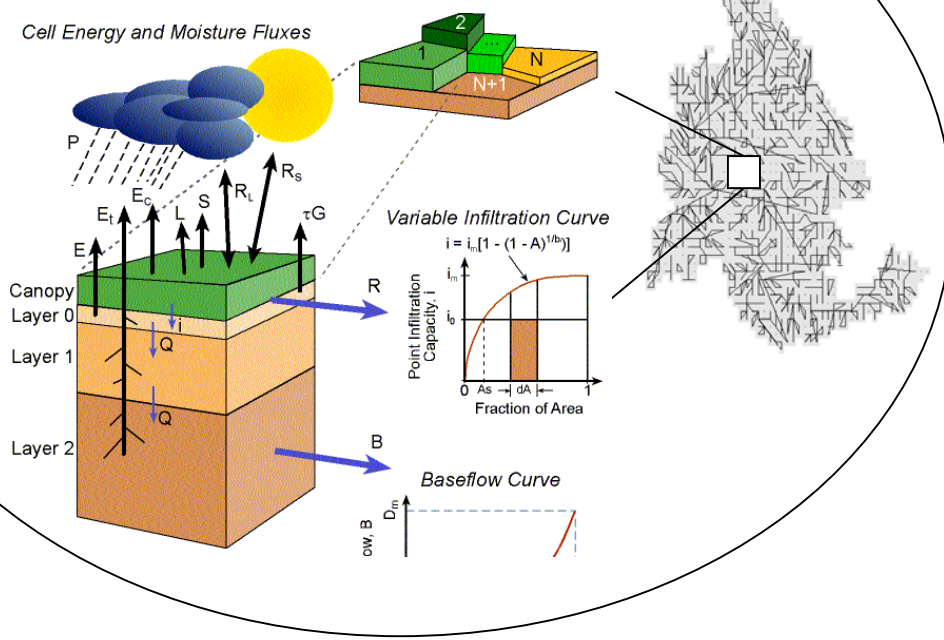


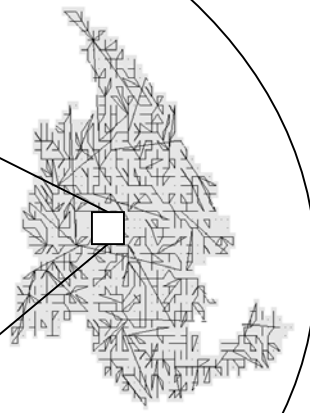
2) Prediction and assessment approach


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

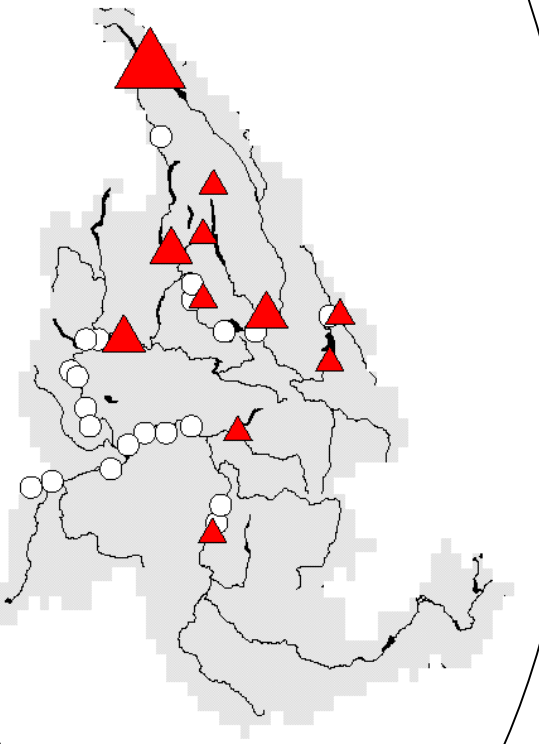
Coupled Land-Atmosphere-Ocean General Circulation Model

Hydrology Model





Reservoir Model



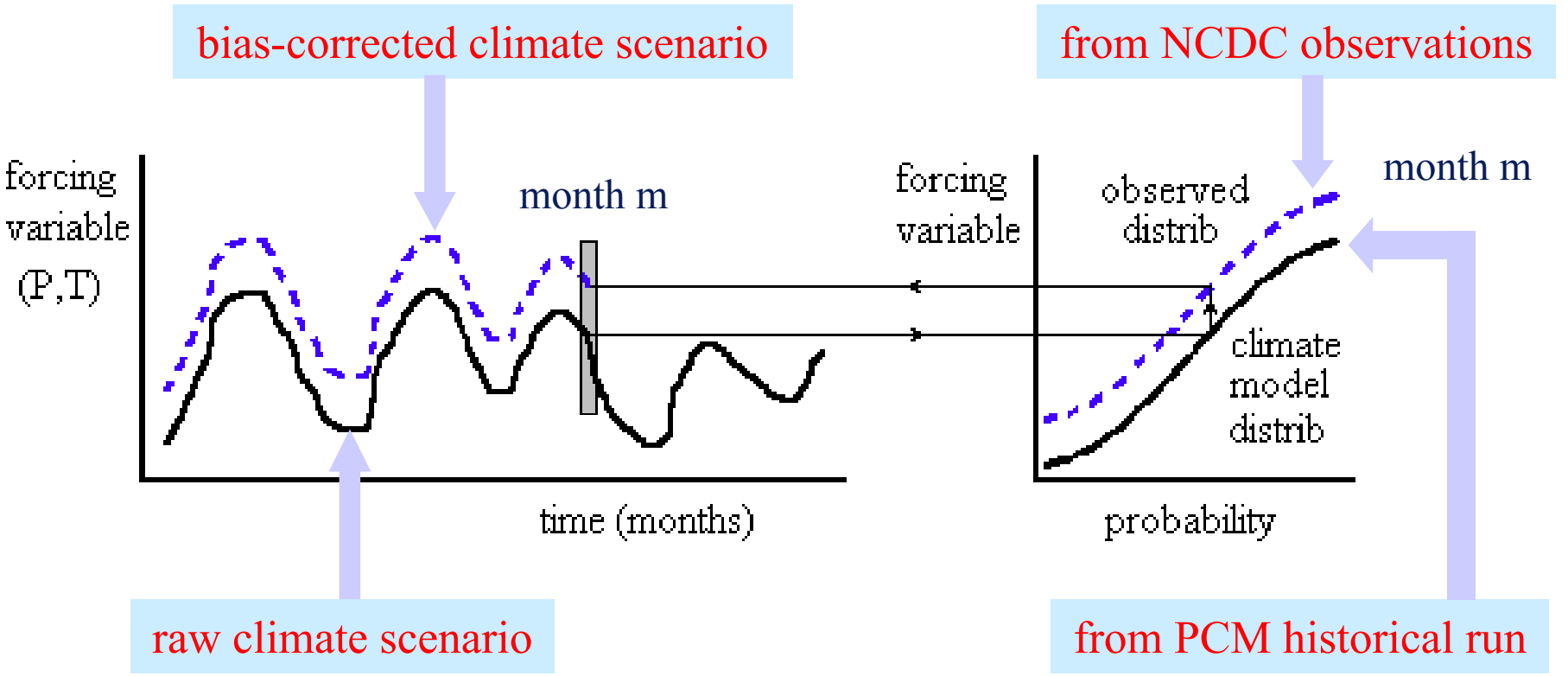
Bias Correction and Downscaling Approach

climate model scenario meteorological outputs → **hydrologic model inputs** → **snowpack runoff streamflow**

- 2.8 (T42)/0.5 degree resolution
- monthly total P, avg. T

- 1/8-1/4 degree resolution
- daily P, Tmin, Tmax

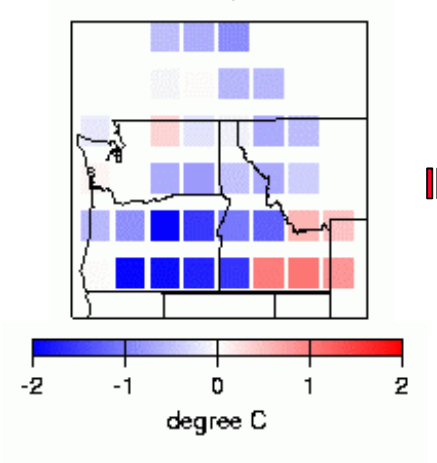
Bias Correction



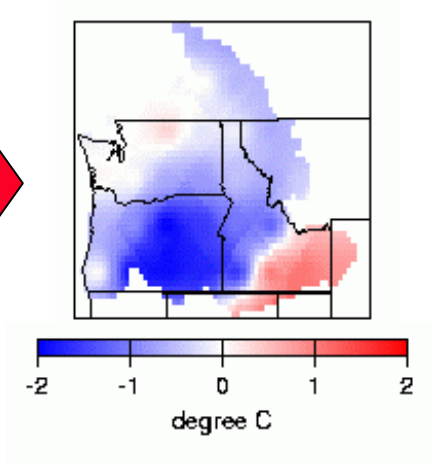
Note: future scenario temperature **trend** (relative to control run) removed before, and replaced after, bias-correction step.

Downscaling

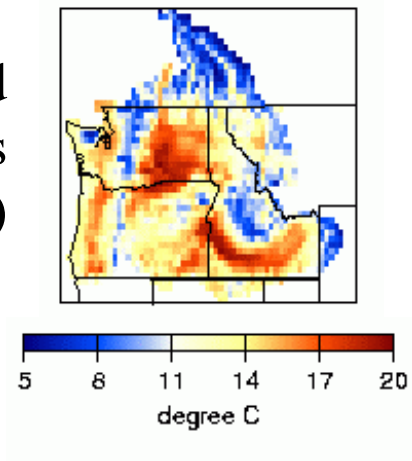
monthly PCM anomaly (T42)



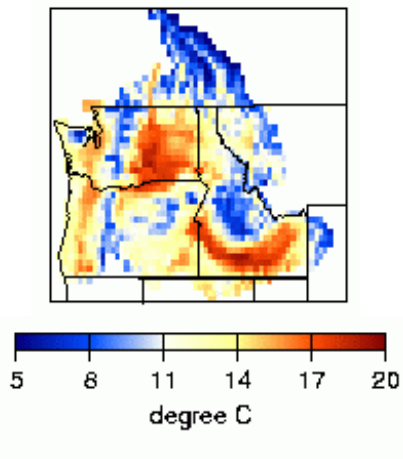
interpolated to VIC scale



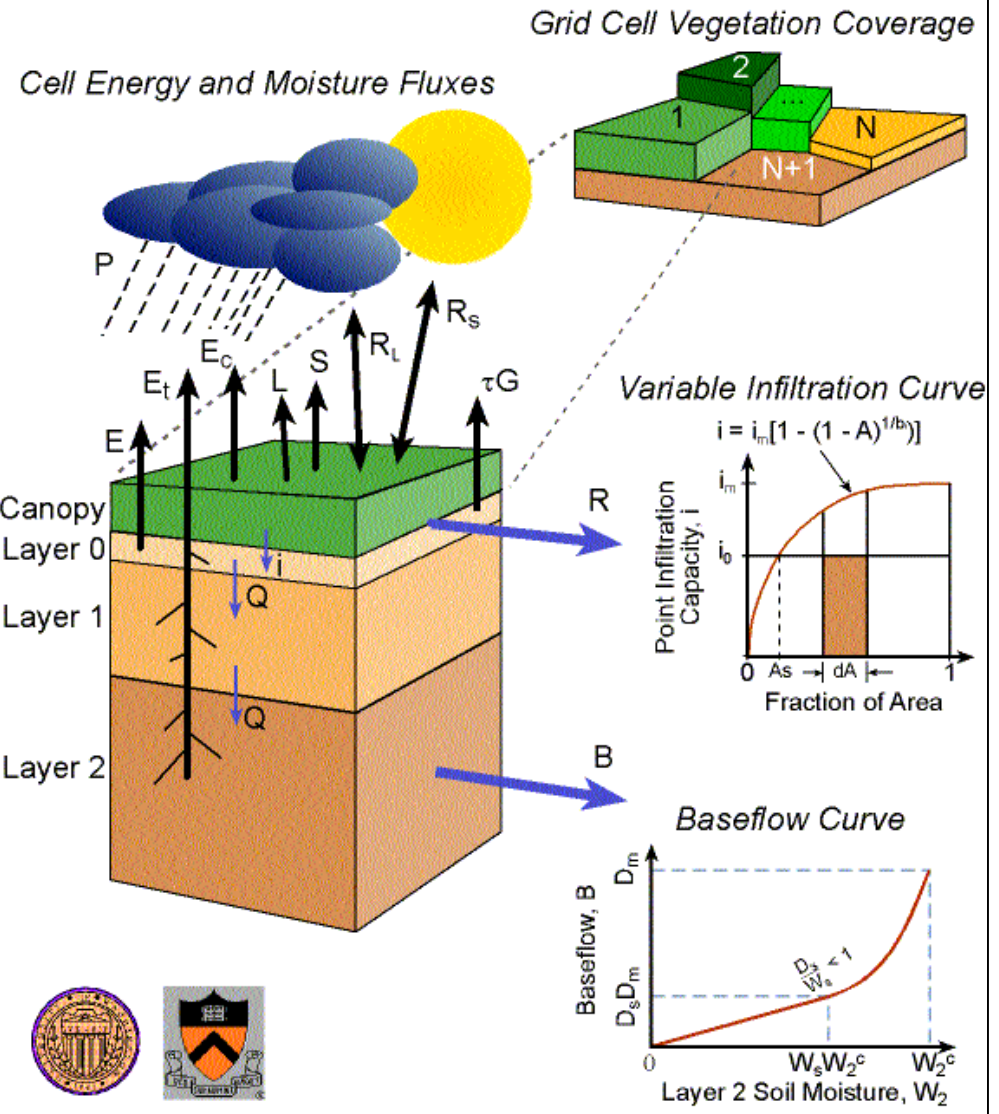
observed mean fields (1/8-1/4 degree)



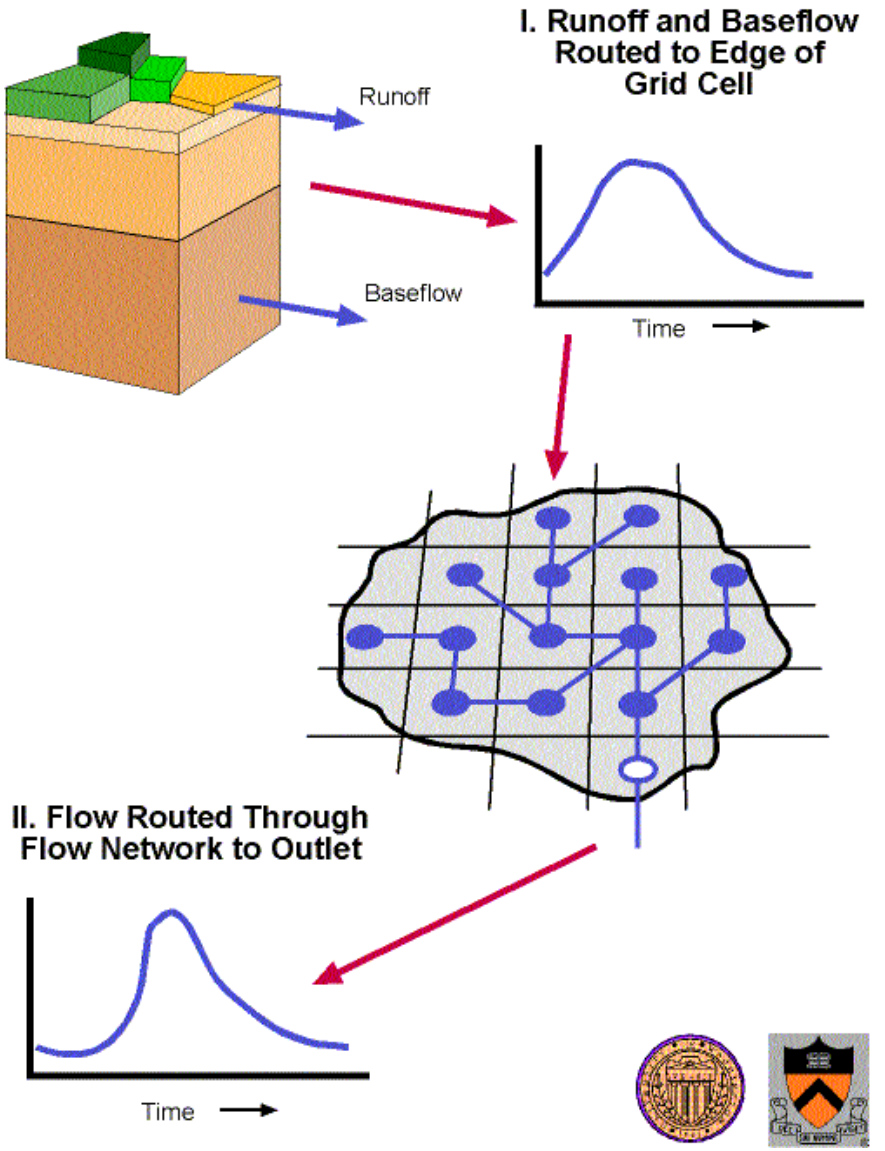
VIC-scale monthly simulation



Variable Infiltration Capacity - n Layer (VIC-nL) Macroscale Hydrologic Model



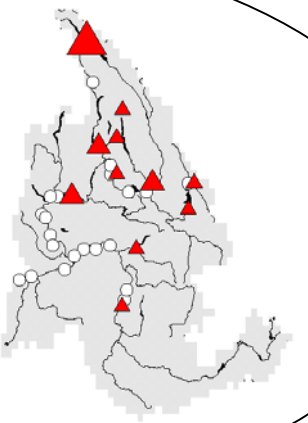
River Network Routing Scheme for VIC-nL



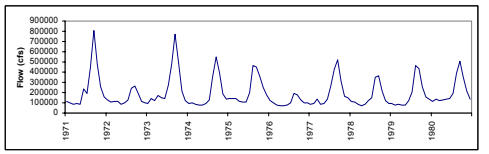
Overview of ColSim Reservoir Model

Reservoir Operating Policies

Physical System
of Dams
and Reservoirs



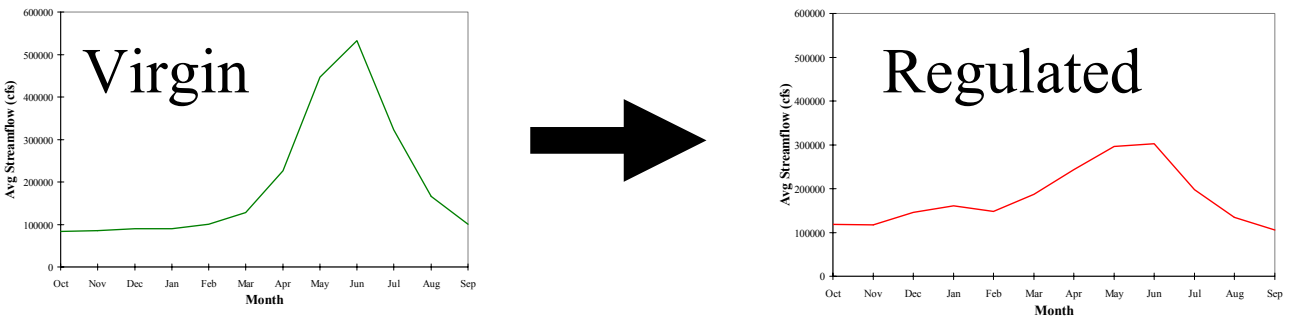
Streamflow Time Series



Reservoir Storage
Regulated Streamflow
Flood Control
Energy Production
Irrigation Consumption
Streamflow Augmentation

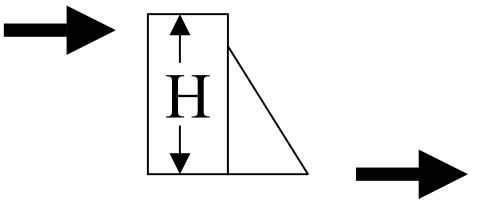
Dam Operations in ColSim

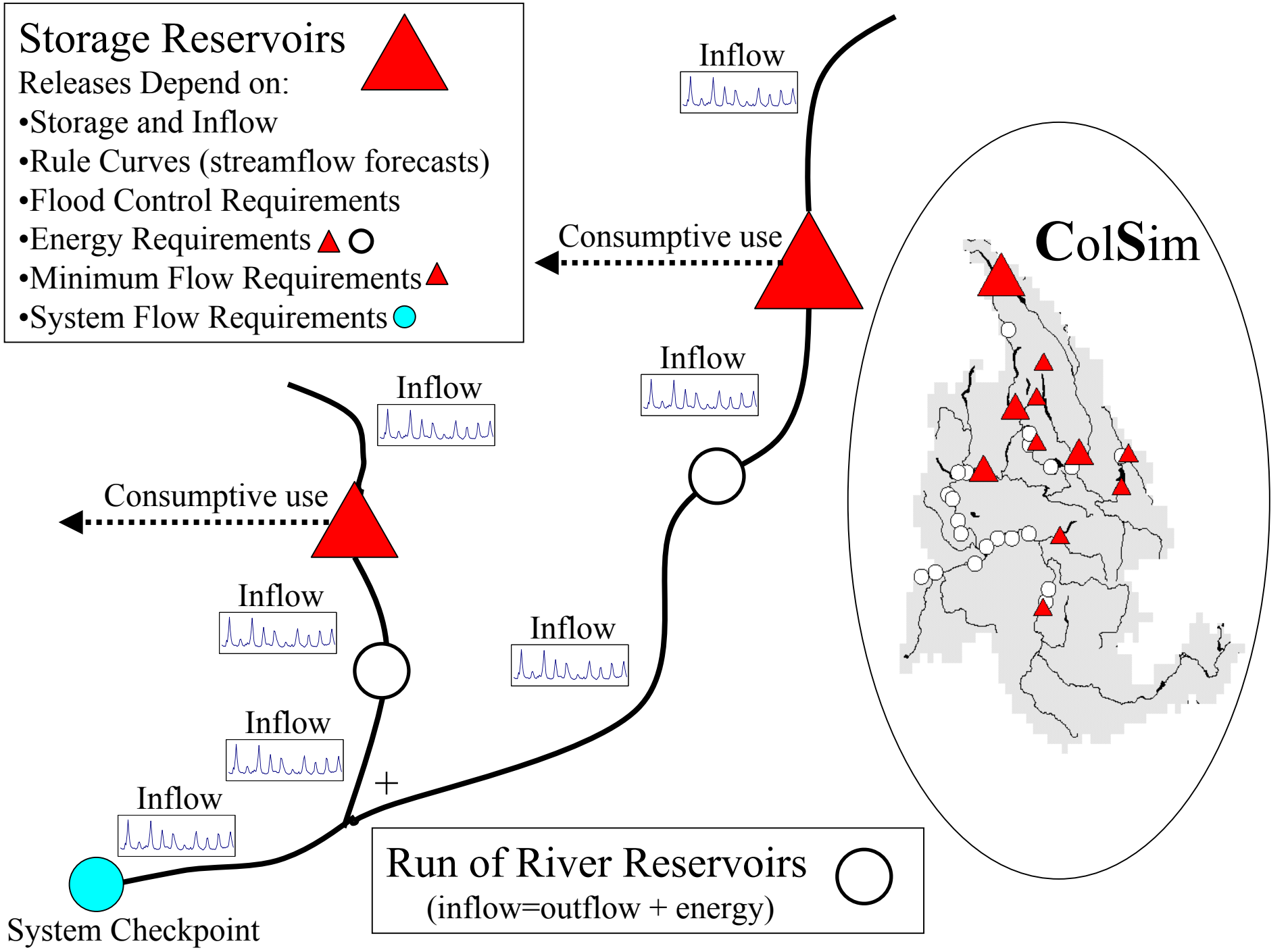
Storage Dams



Run-of-River Dams

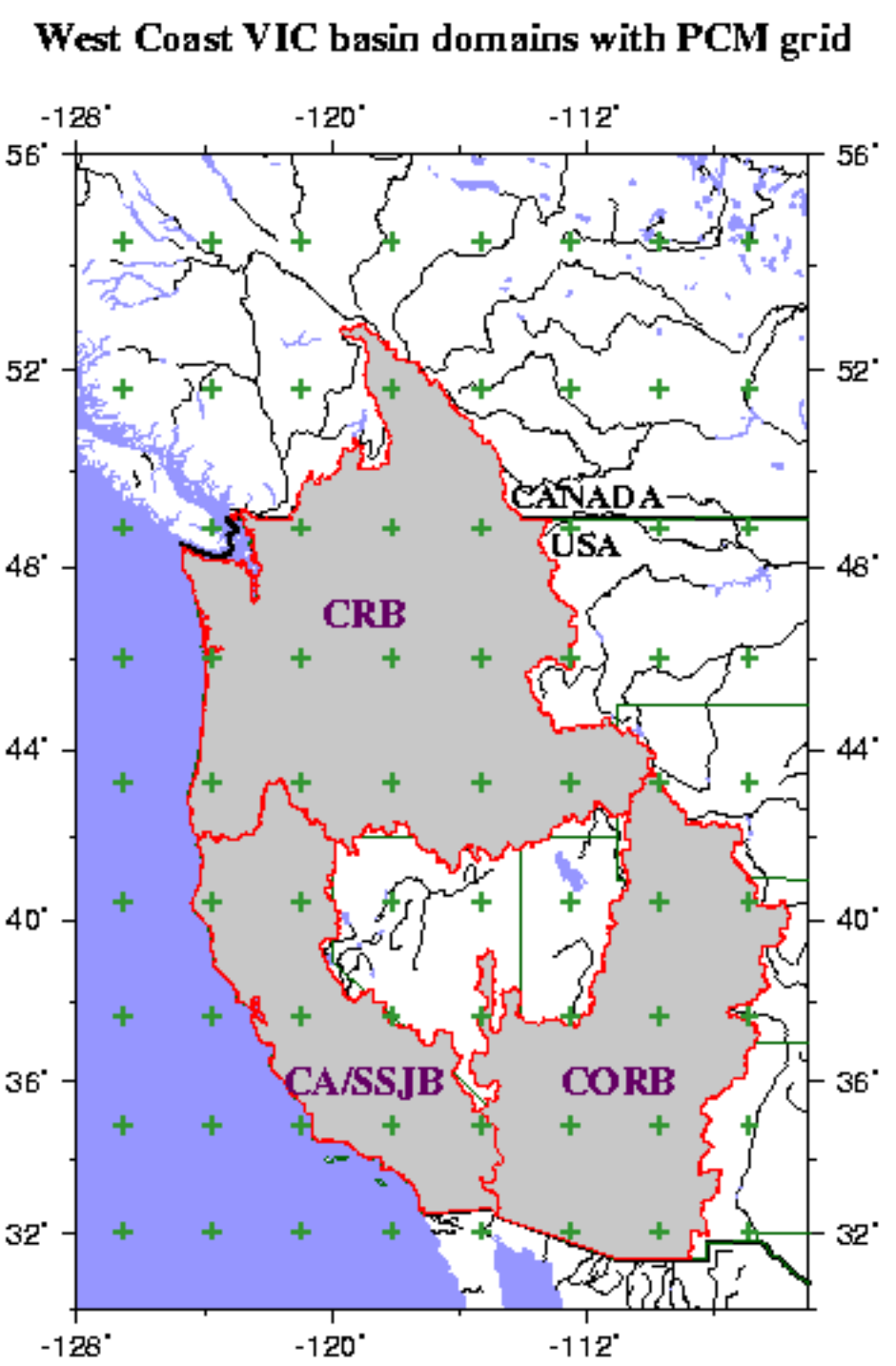
Flow In=Flow out + Energy




Storage Reservoirs
Releases Depend on:
•Storage and Inflow
•Rule Curves (streamflow forecasts)
•Flood Control Requirements
•Energy Requirements
•Minimum Flow Requirements
•System Flow Requirements
Inflow
Consumptive use
Inflow
Inflow
Consumptive use
Inflow
Inflow
Inflow
Inflow
+
System Checkpoint
ColSim
Run of River Reservoirs
(inflow=outflow + energy)

3) Accelerated Climate Prediction Initiative (ACPI)

Accelerated Climate Prediction Initiative (ACPI) – NCAR/DOE Parallel Climate Model (PCM) grid over western U.S.



Climate Change Scenarios

PCM Simulations (~ 3 degrees lat-long)

Historical	B06.22 (greenhouse CO_2+aerosols forcing)	1870-2000
Climate Control	B06.45 (CO_2+aerosols at 1995 levels)	1995-2048
Climate Change	B06.44 (BAU6, future scenario forcing)	1995-2099
Climate Change	B06.46 (BAU6, future scenario forcing)	1995-2099
Climate Change	B06.47 (BAU6, future scenario forcing)	1995-2099

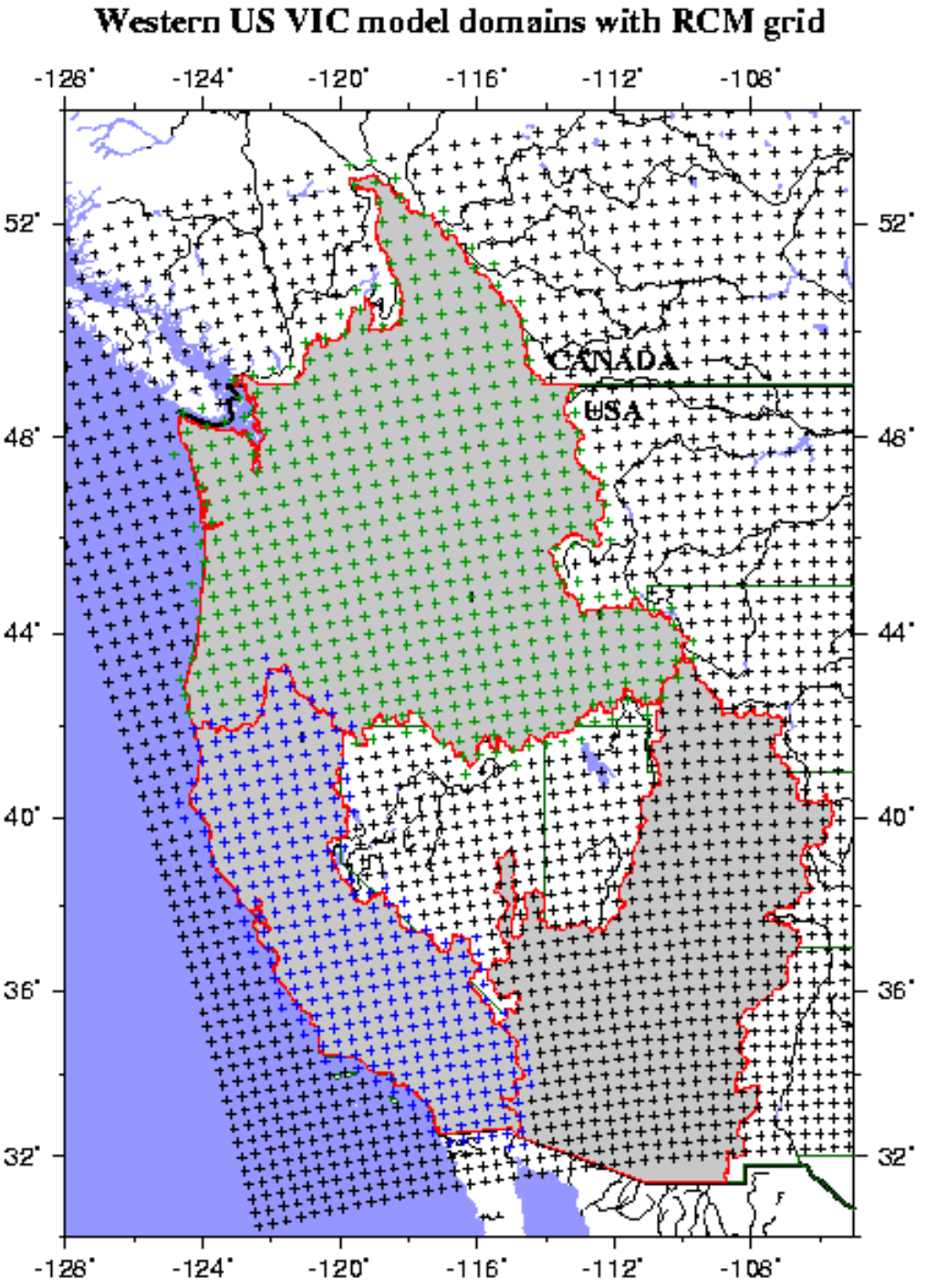
PNNL Regional Climate Model (RCM) Simulations (~ ¾ degree lat-long)

Climate Control	B06.45 derived-subset	1995-2015
Climate Change	B06.44 derived-subset	2040-2060

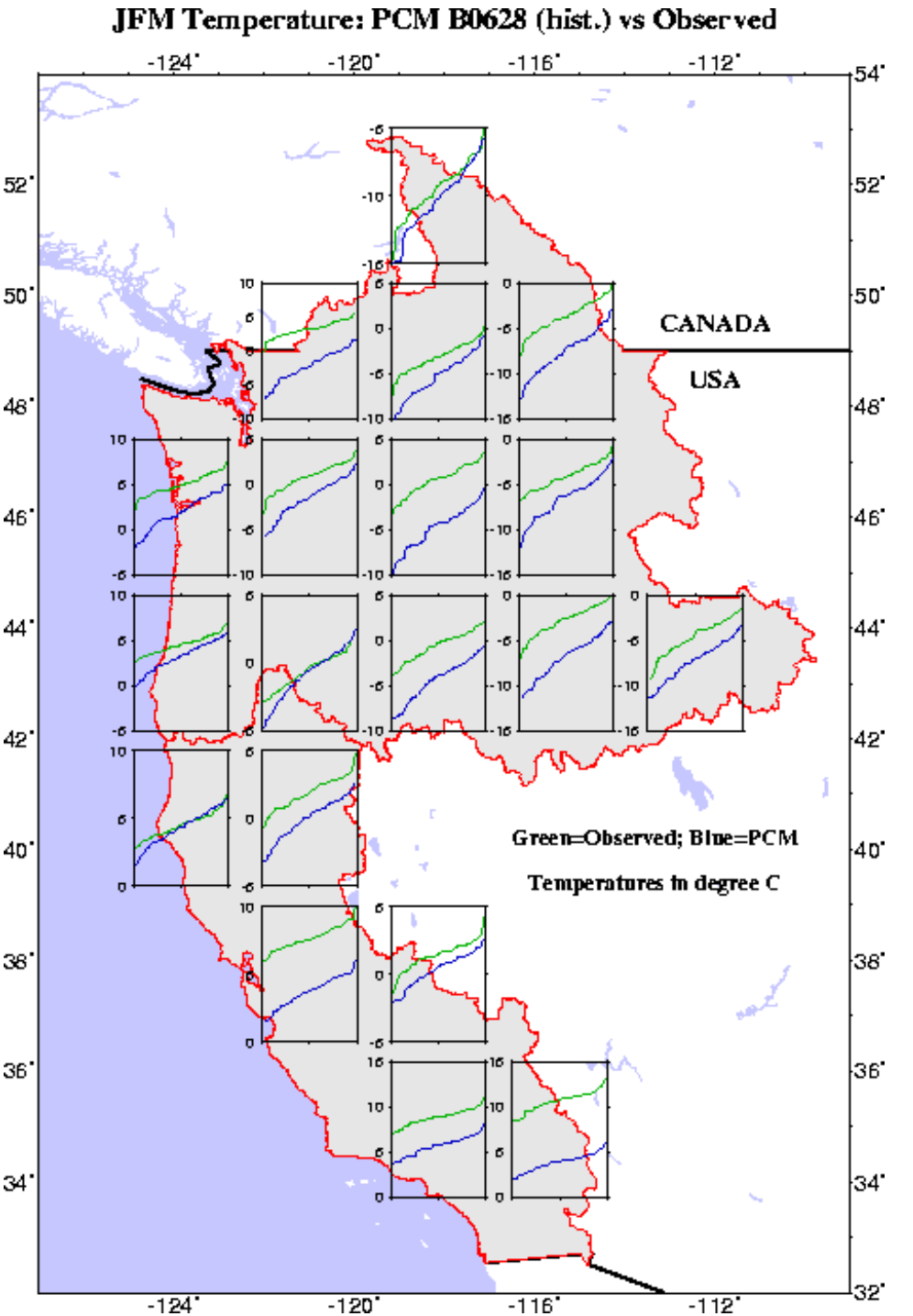
Future streamflows

- **3 ensembles averaged**
- **summarized into 3 periods;**
  - » **Period 1 2010 - 2039**
  - » **Period 2 2040 - 2070**
  - » **Period 3 2070 - 2098**

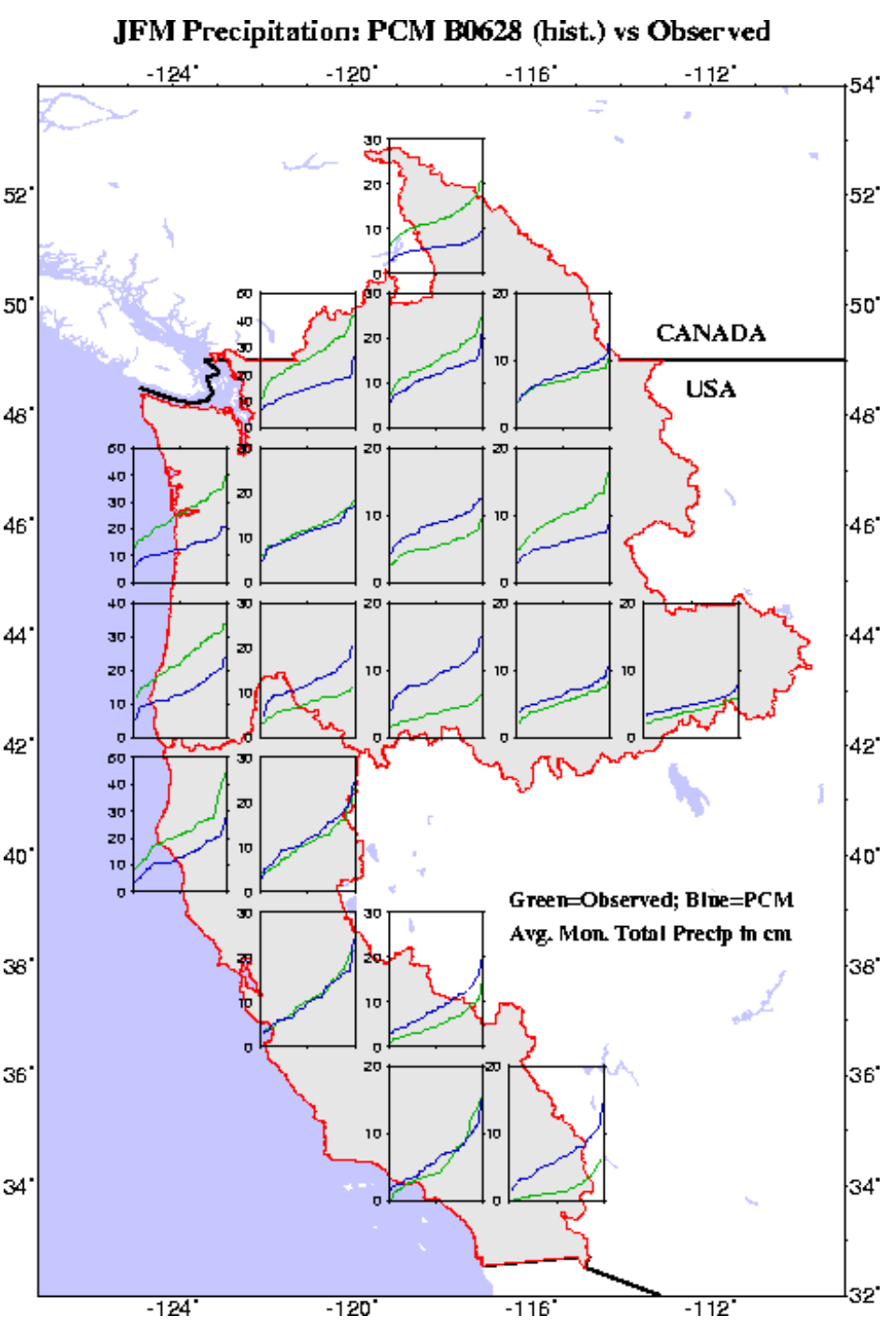
Regional Climate Model (RCM) grid and hydrologic model domains



ACPI: PCM-climate change scenarios, historic simulation v air temperature observations



ACPI: PCM-climate change scenarios, historic simulation v precipitation observations

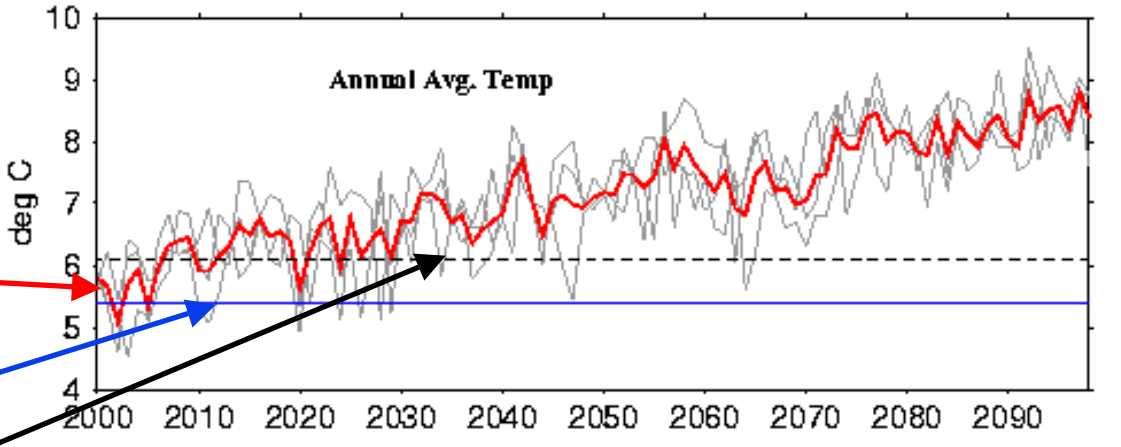


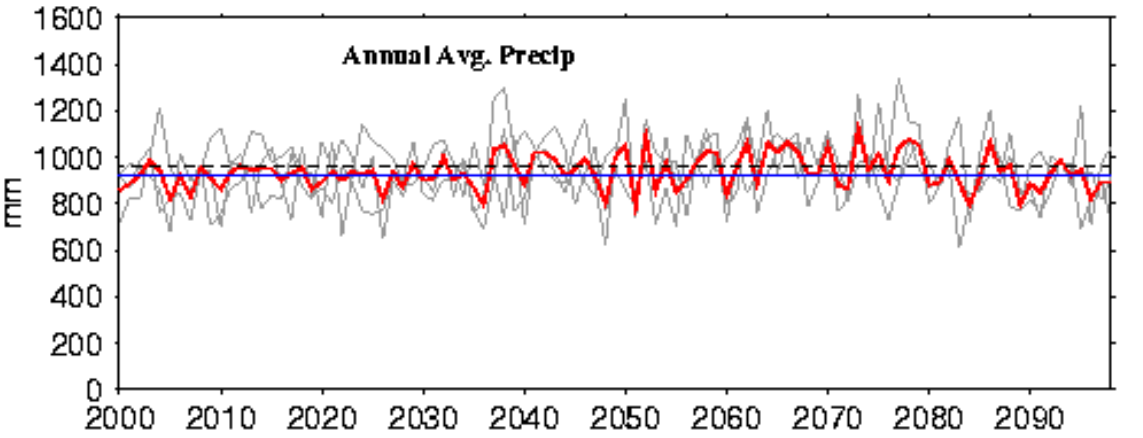
4) Hydrology and water management implications: Columbia River Basin

BAU 3-run average

historical (1950-99)

control (2000-2048)

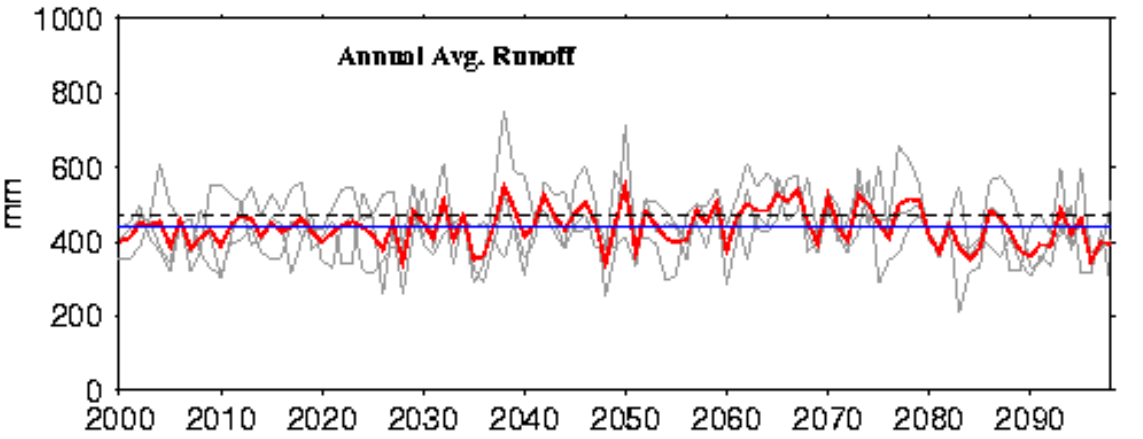




PCM

Business-as-Usual scenarios

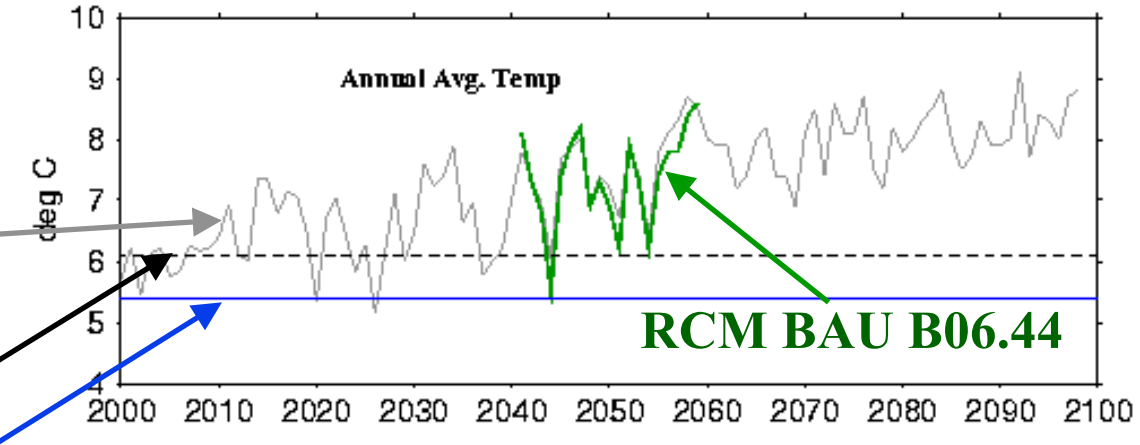
Columbia River Basin (Basin Averages)

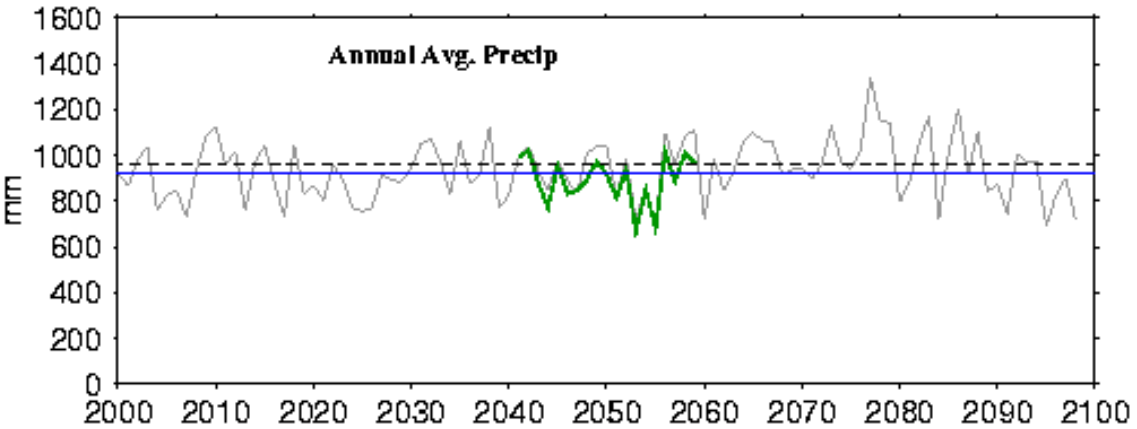


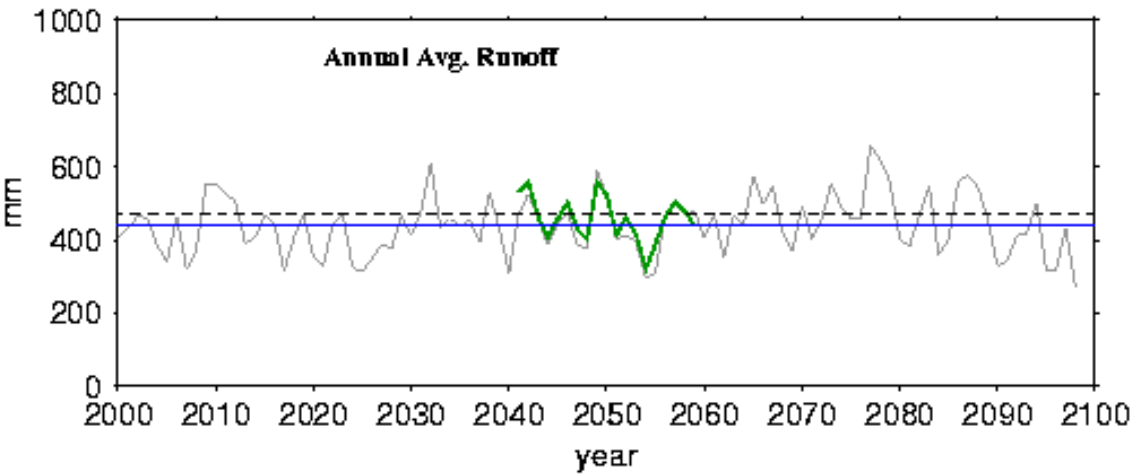
PCM BAU B06.44

control (2000-2048)

historical (1950-99)





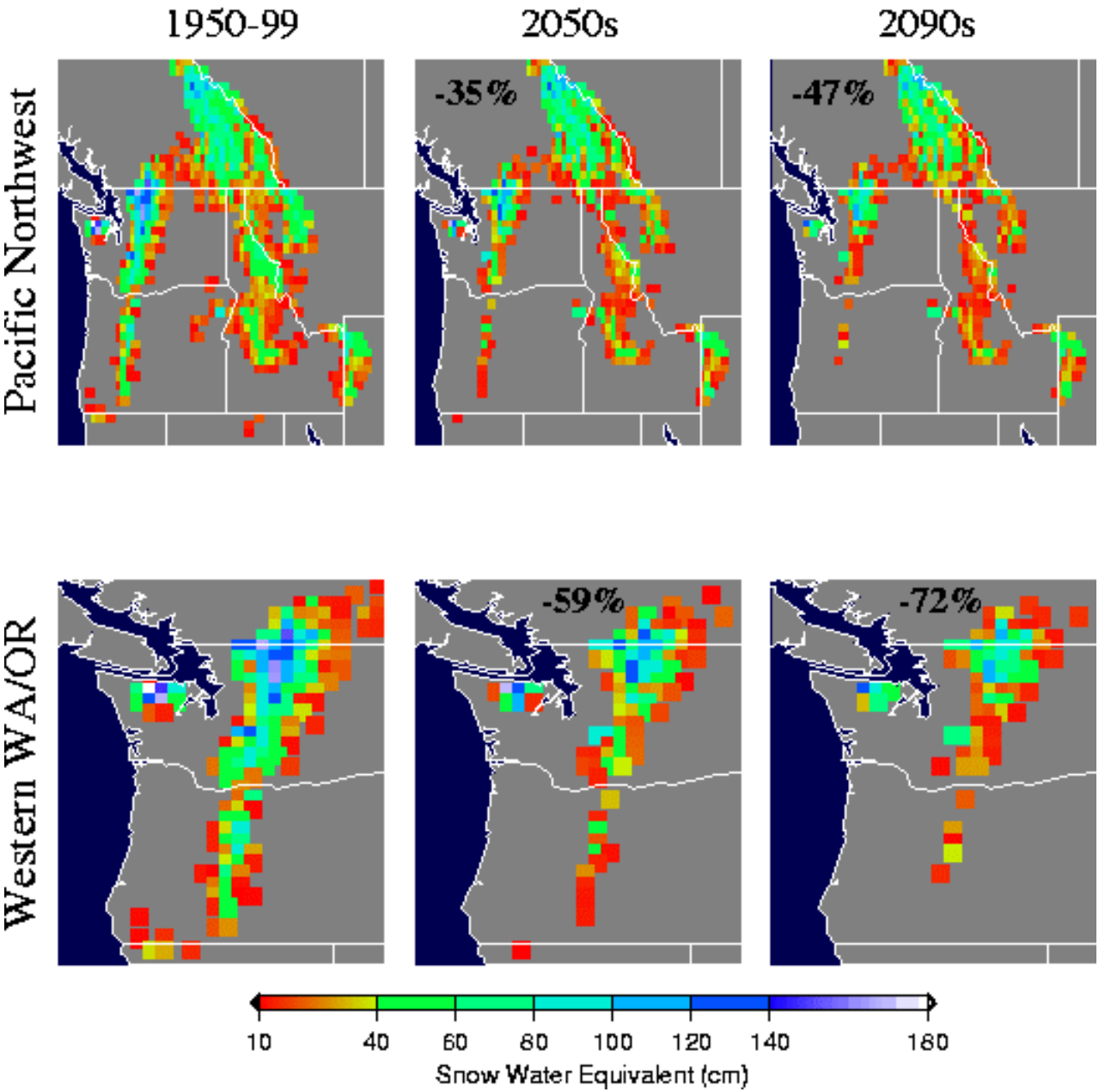


RCM

Business-as-Usual scenarios

Columbia River Basin (Basin Averages)

April 1 Snowpack Projections

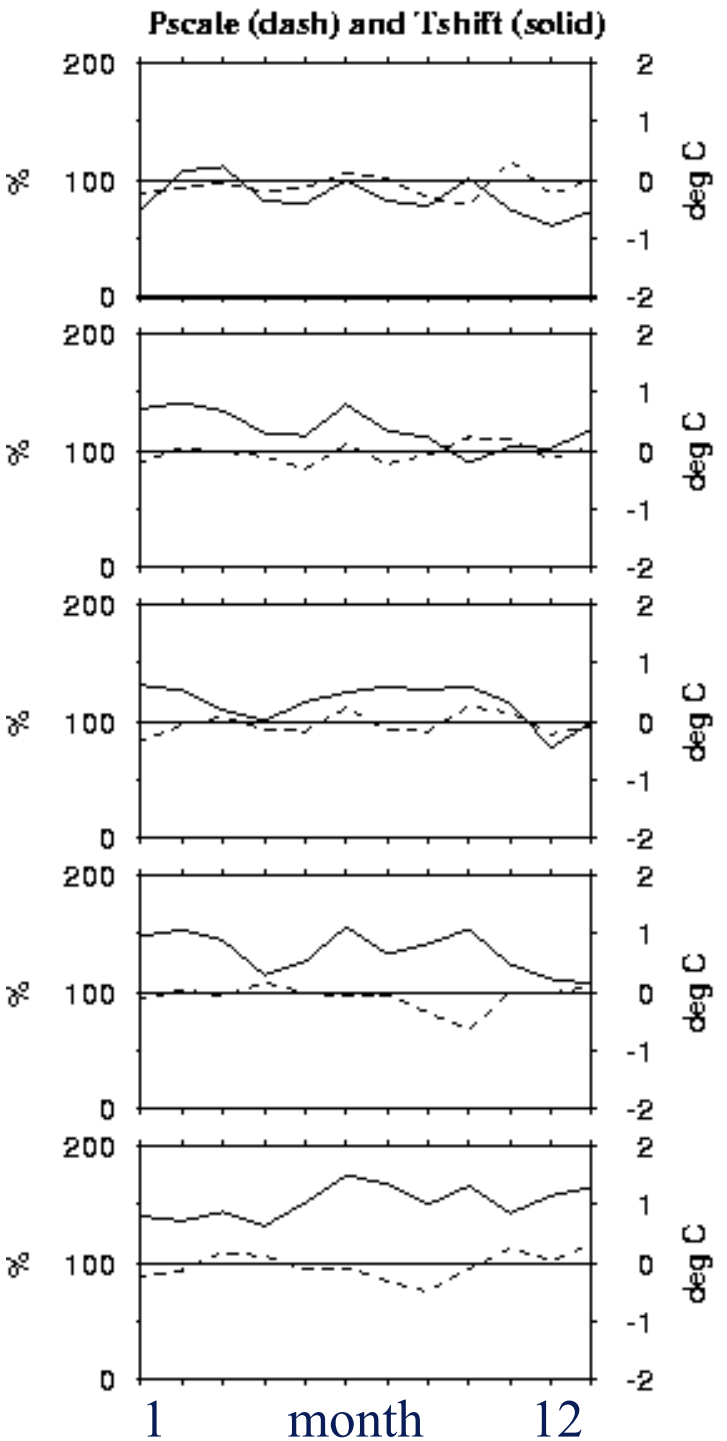


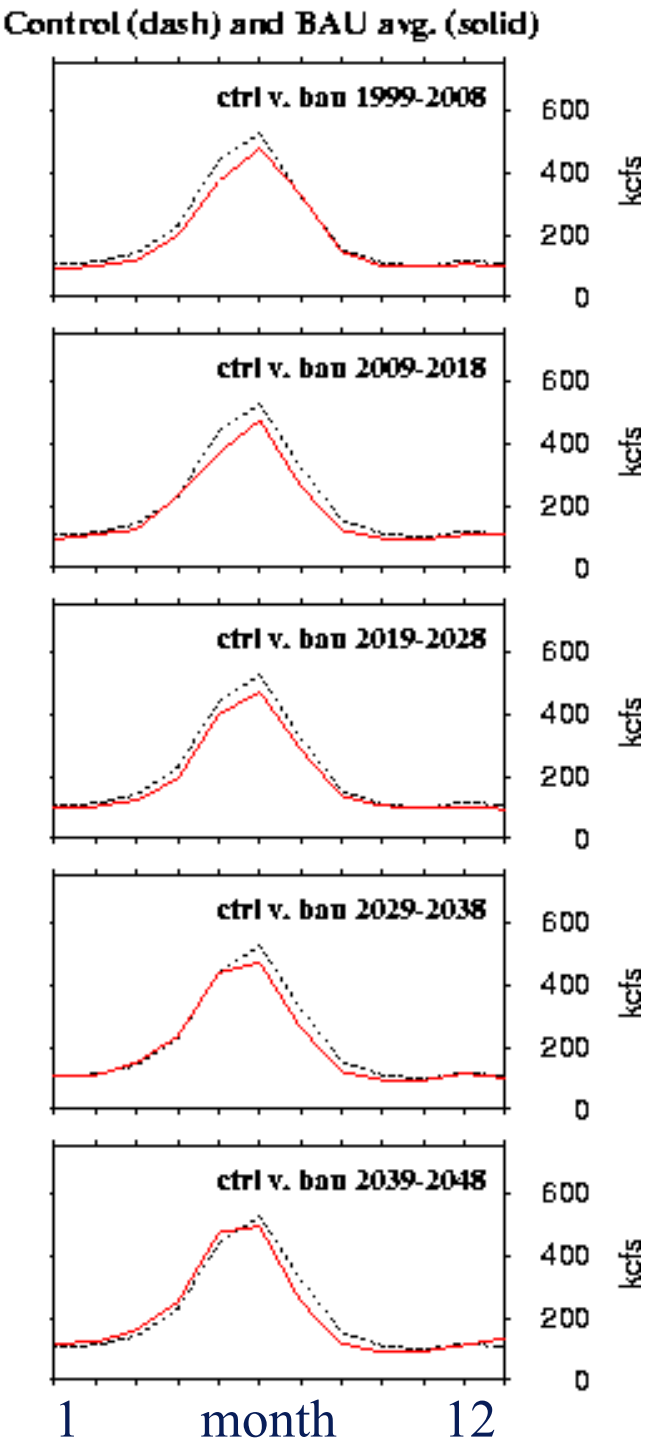
PCM

Business-As-Usual

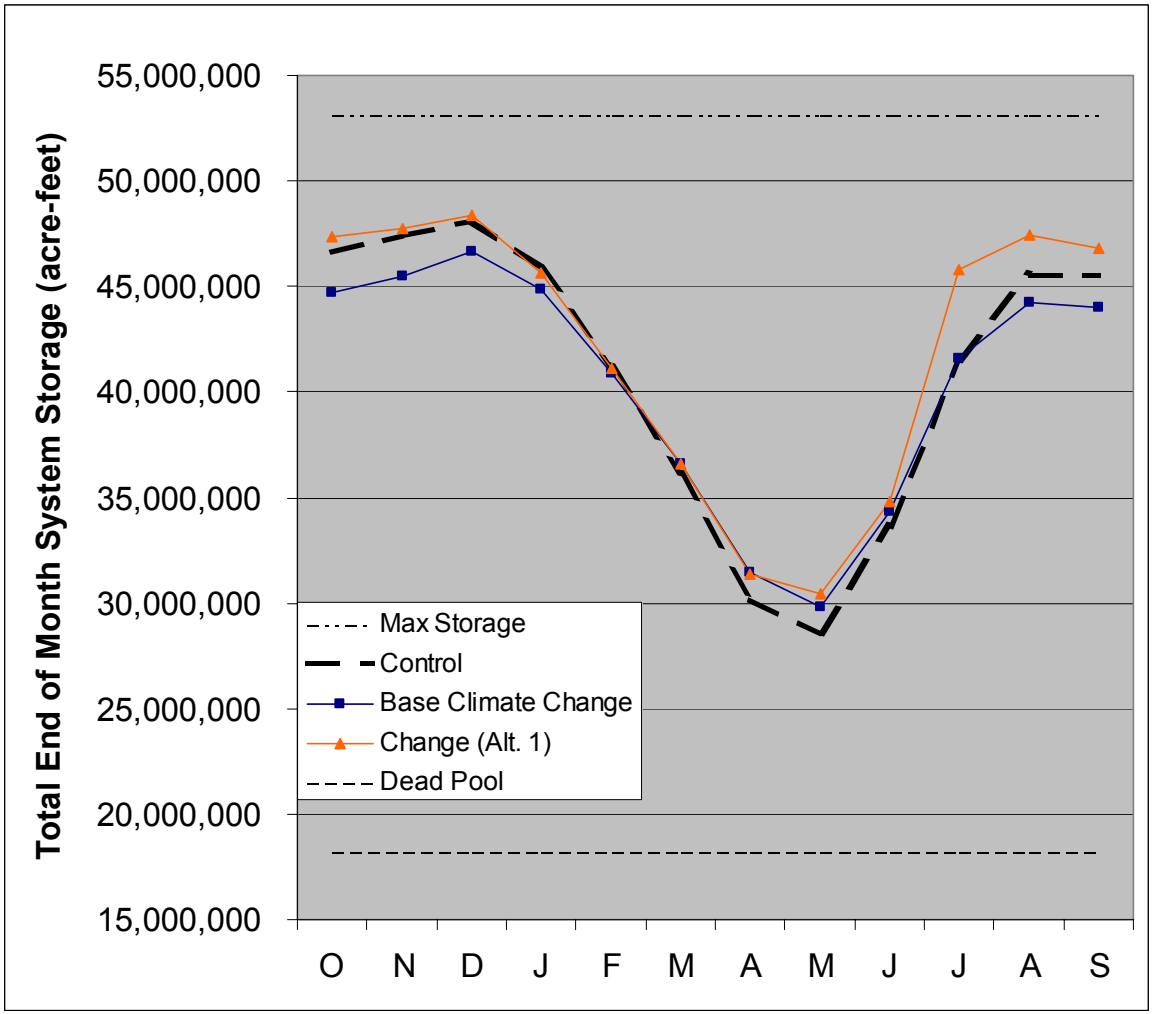
Mean Monthly Hydrographs

Columbia River Basin @ The Dalles, OR

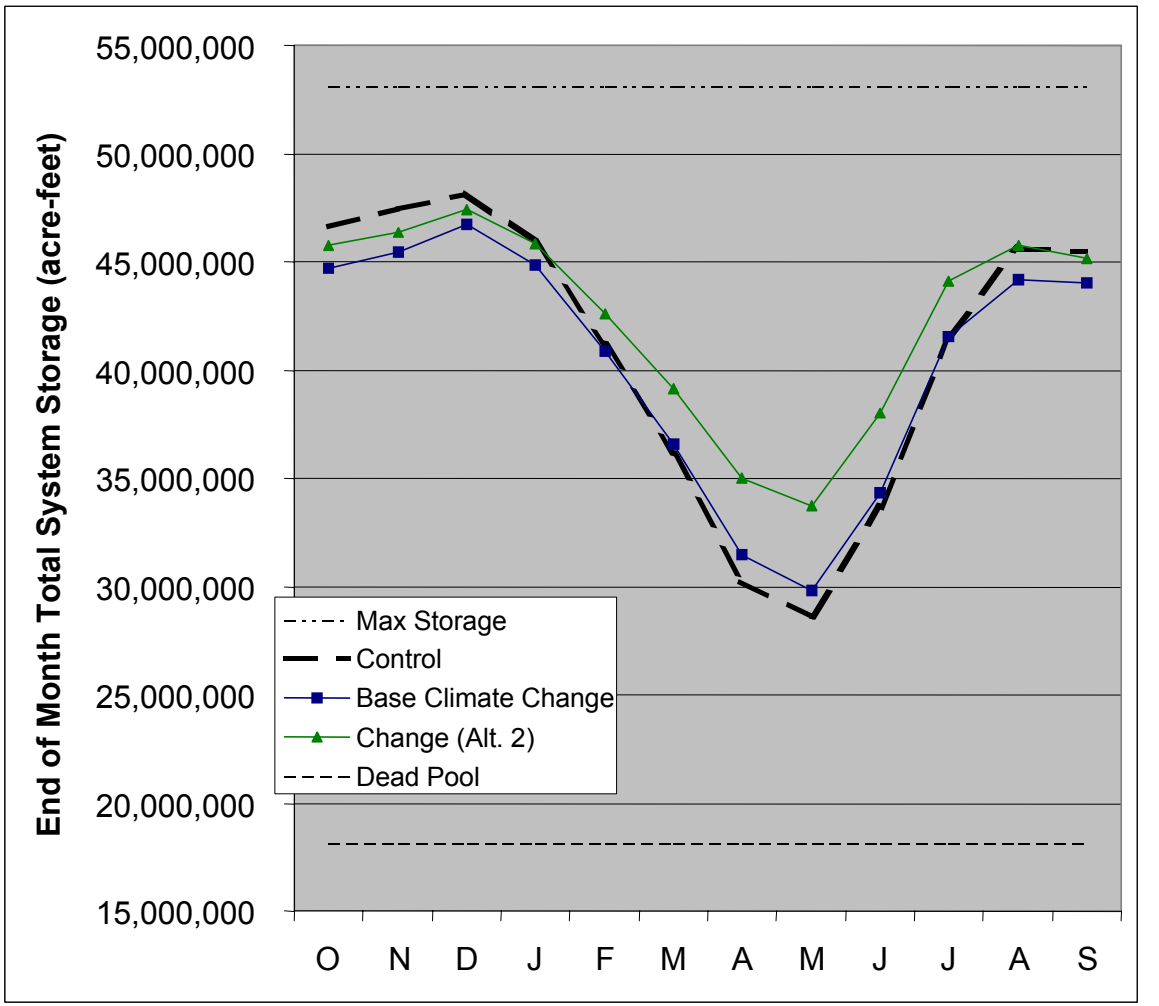


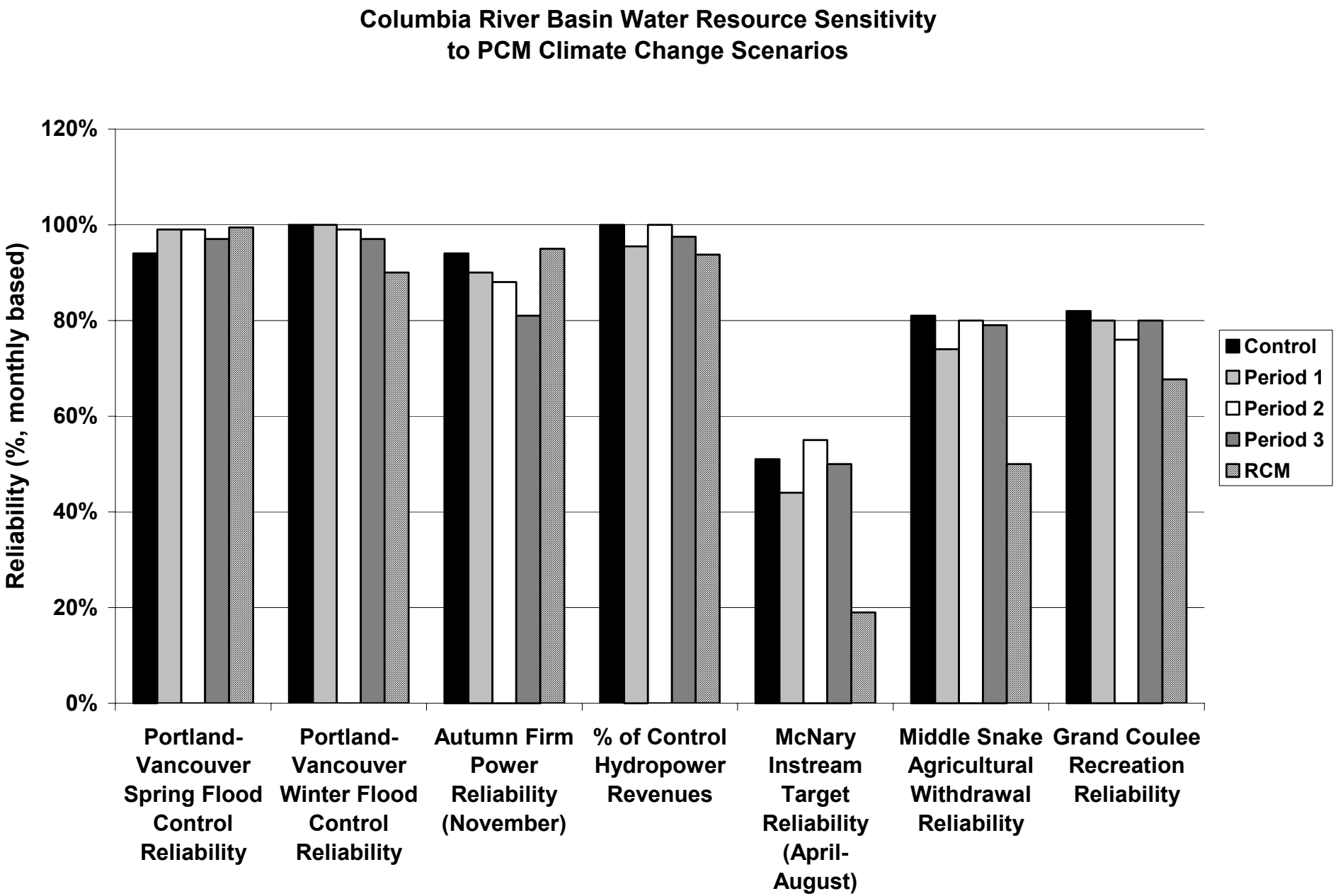


CRB Operation Alternative 1 (early refill)



CRB Operation Alternative 2 (reduce flood storage by 20%)

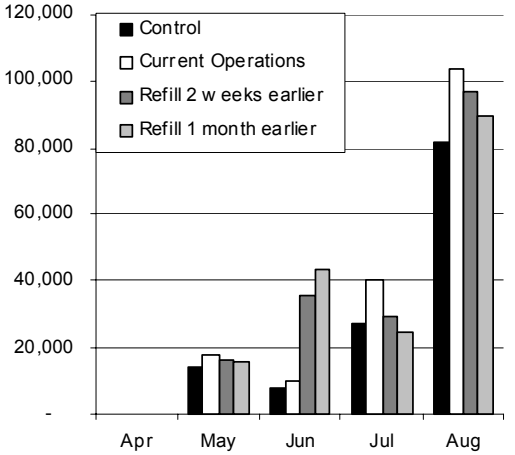


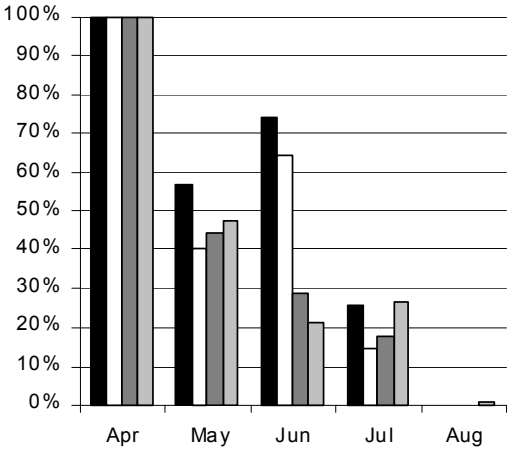

Columbia River Basin Water Resource Sensitivity
to PCM Climate Change Scenarios
Reliability (%, monthly based)
120%
100%
80%
60%
40%
20%
0%
Control
Period 1
Period 2
Period 3
RCM
Portland-Vancouver Spring Flood Control Reliability
Portland-Vancouver Winter Flood Control Reliability
Autumn Firm Power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

Average Monthly Deficit at the McNary Dam Target (cfs)

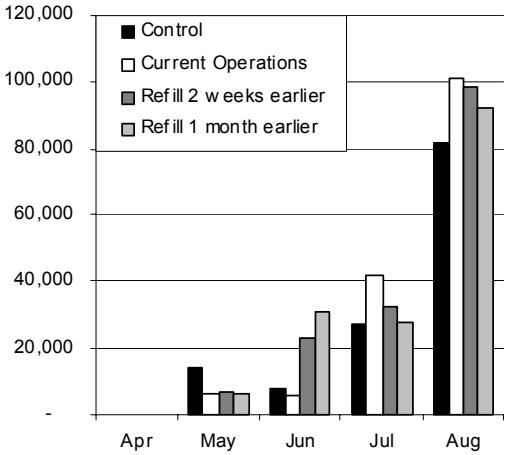
Monthly Reliability at the McNary Dam Target

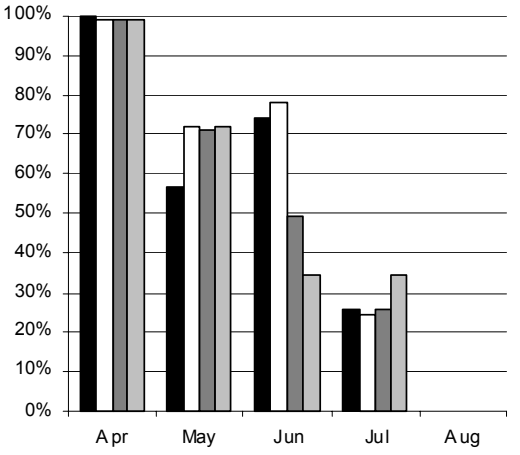
Period 1



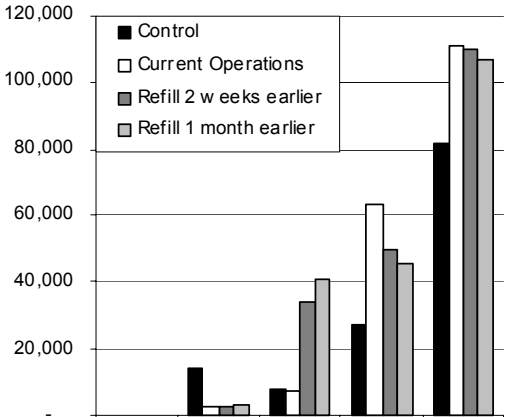


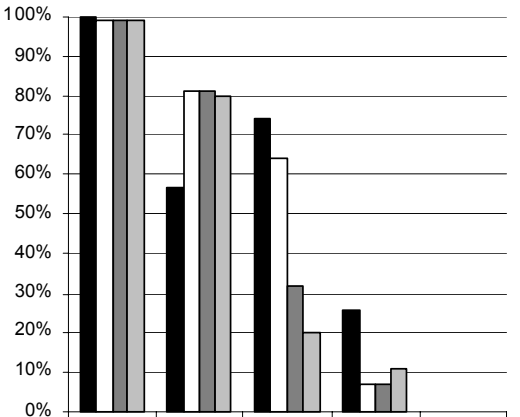
Period 2

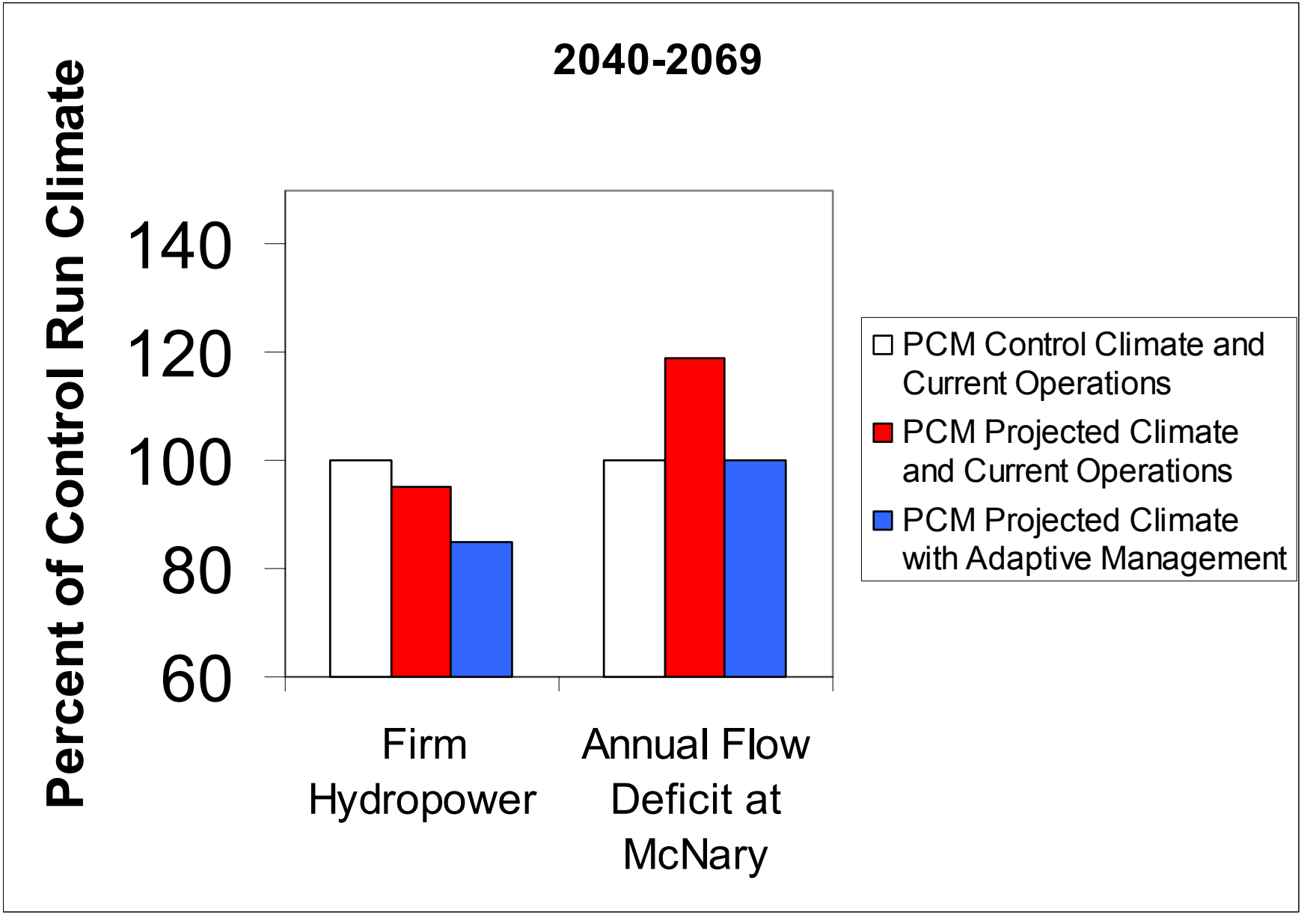


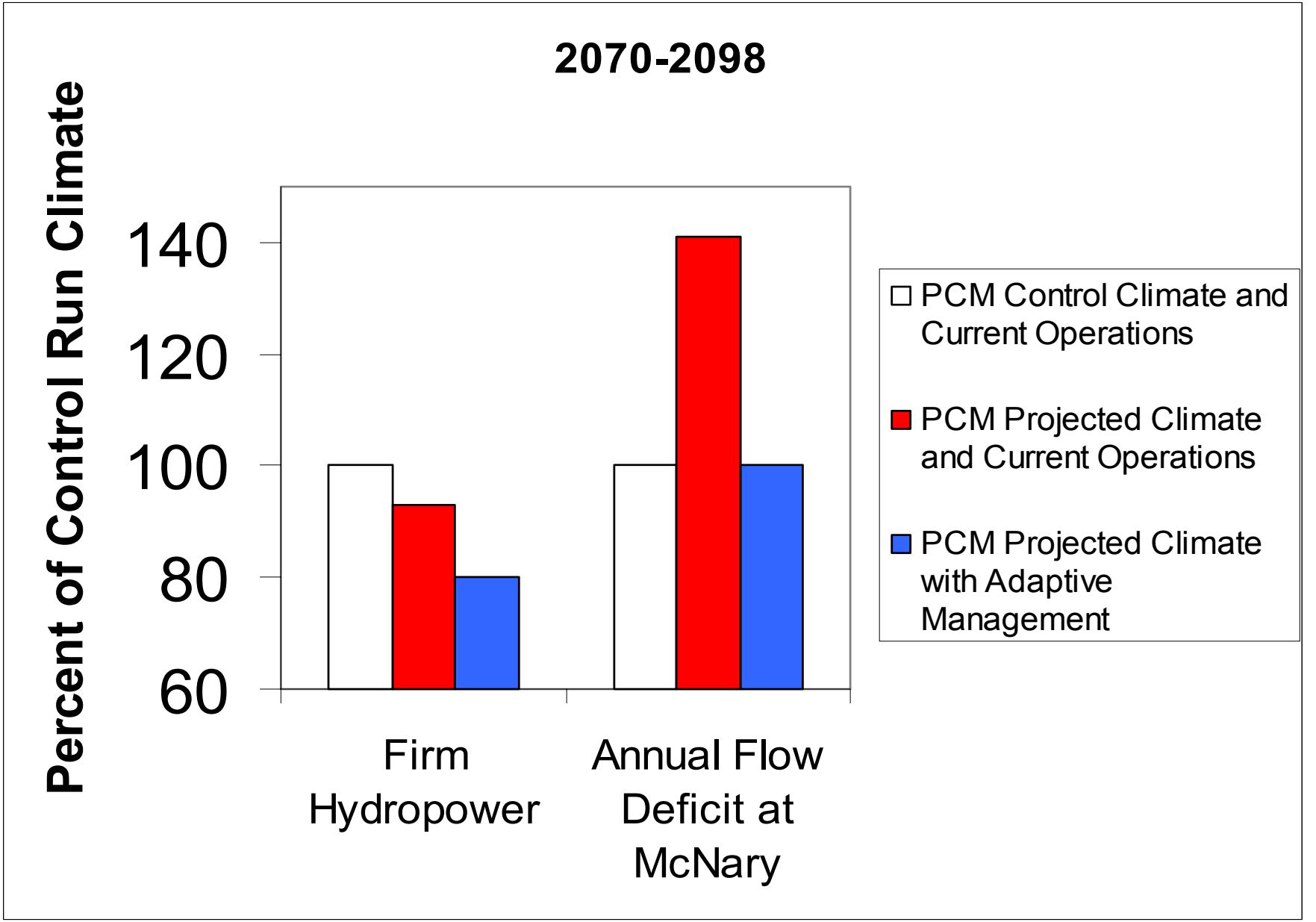


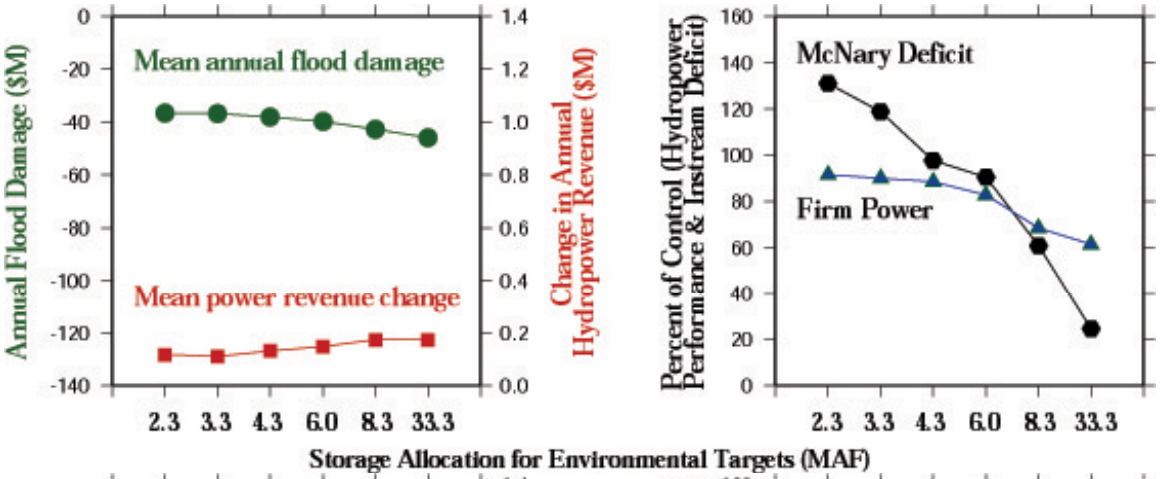
Period 3

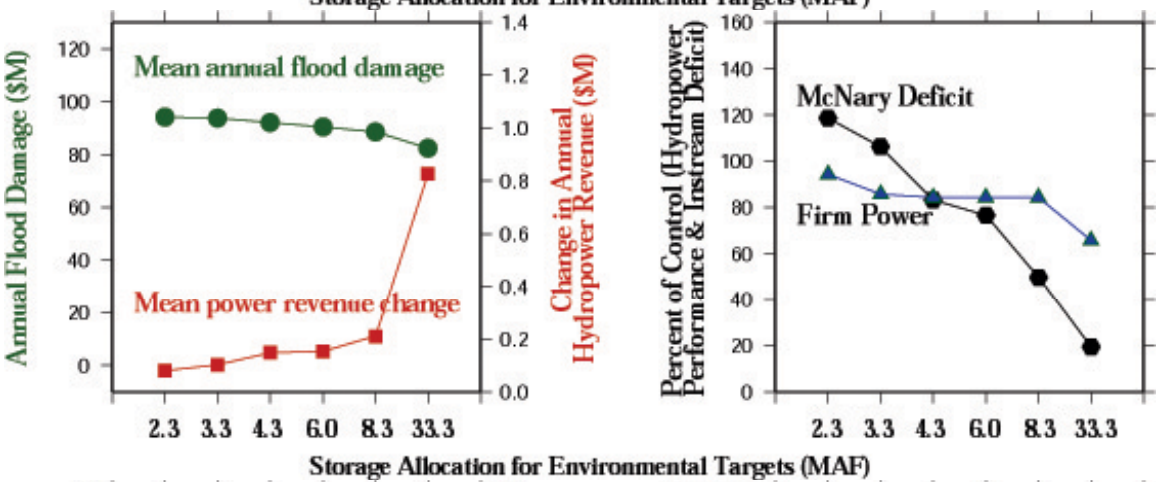





2040-2069
Percent of Control Run Climate
140
120
100
80
60
Firm Hydropower
Annual Flow Deficit at McNary
PCM Control Climate and Current Operations
PCM Projected Climate and Current Operations
PCM Projected Climate with Adaptive Management


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


Annual Flood Damage ($M)
Change in Annual Hydropower Revenue ($M)
Mean annual flood damage
Mean power revenue change
0
-20
-40
-60
-80
-100
-120
-140
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2.3
3.3
4.3
6.0
8.3
33.3
Storage Allocation for Environmental Targets (MAF)
Percent of Control (Hydropower Performance & Instream Deficit)
McNary Deficit
Firm Power
160
140
120
100
80
60
40
20
0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1.4
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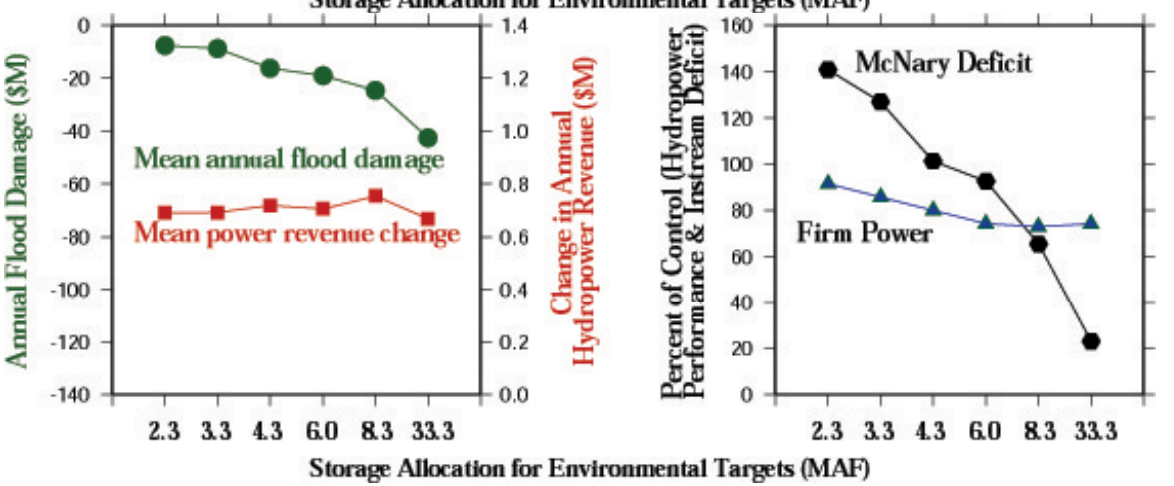
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Percent of Control (Hydropower Performance & Instream Deficit)
McNary Deficit
Firm Power
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120
100
80
60
40
20
0

5) Summary evaluation and conclusions

1) **Firm power is reduced by the system's inability to meet current hydropower demands without compromising other operating goals (especially instream flows).**

2) **Total hydropower production is relatively unaffected (occasionally increasing) under the projected climate changes.**

3) **However, fish flow targets would be difficult to meet under altered climate, and mitigation by altered operation is essentially impossible.**

4) **Although the monthly time step used in this study complicates evaluation of changes in flood risk, the current flood rules appear to be overly conservative, and flood control begins to compete with other water management considerations as hydrographs shift from spring towards winter.**