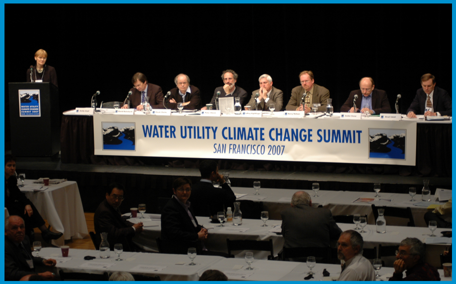

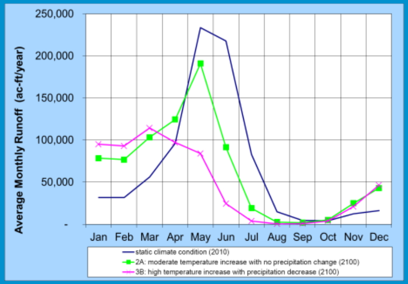

The State of Assessment and Adaptation Planning in the Water Sector:

A Selective Overview

David Behar

Climate Program Director

San Francisco Public Utilities Commission

Science for Climate Change Adaptation: Enhancing Decision Support Capability

Aspen Global Change Institute

August 5-10, 2012

San Francisco
Water Power Sewer
Services of the San Francisco Public Utilities Commission

San Francisco Water Power Sewer

The Stakes on Climate Change:
Water and Clean Water Sector Only

2011-2031: Without Adaptation

Drinking Water
Infrastructure Investment

$335 Billion [1]

OR $1 Trillion through 2035 [4]

Clean Water
Infrastructure Investment

$298 Billion [2]

By 2050: Potential Adaptation Costs

Drinking Water + Clean Water Sector:

$448 - 944 Billion [3]

[1] "2009 Drinking Water Infrastructure Needs Survey and Assessment: Third Report to Congress." USEPA Office of Water, 2005.
[2] "Clean Watersheds Needs Survey 2008: Report to Congress." USEPA, May 2010.
[3] "Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs," Association of Metropolitan Water Agencies, National Association of Clean Water Agencies, 2009.
[4] "Buried No Longer: Confronting America's Water Infrastructure Challenge, American Water Works Association, 2012.

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Water Utility Climate Alliance

43 million drinking water customers

WUCA
Water Utility Climate Alliance

Mission Statement

The Water Utility Climate Alliances provides leadership in assessing and adapting to the potential effects of climate change through collaborative action. We seek to enhance the usefulness of climate science for the adaptation community and improve water management decision-making in the face of climate uncertainty.

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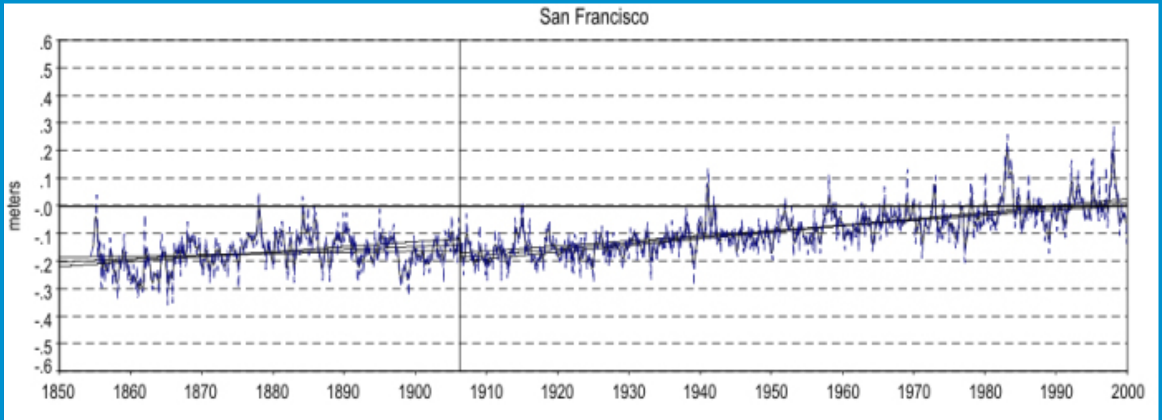
A core objective…

WUCA Water Utility Climate Alliance

“Actionable Science”

A Working Definition:

Data, analysis, and forecasts that are sufficiently predictive, accepted and understandable to support decision-making, including capital investment decision-making.



The Wild Wild West …

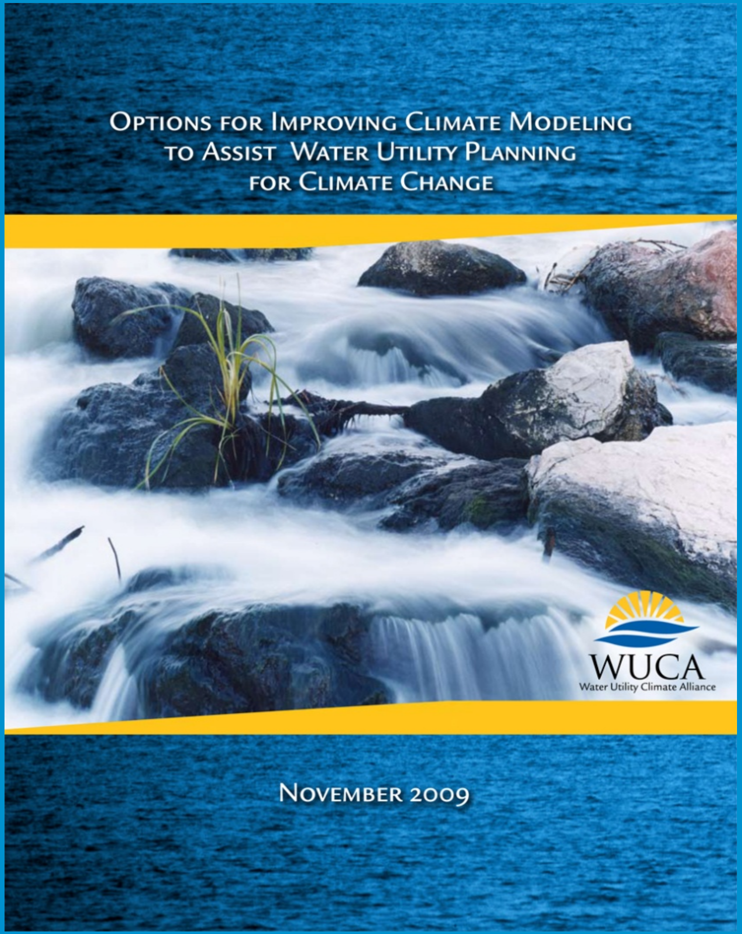
San Francisco Water Power Sewer

Climate Modeling White Paper

"Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change"

Authors:
Joe Barsugli, Chris Anderson, Joel Smith, Jason Vogel

Available at ***www.wucaonline.org***



Symbiosis

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Piloting Utility Modeling Applications (PUMA): Assessment, Services, Co-Production

Five Utilities

San Francisco PUC
Portland Water Bureau
Seattle Public Utilities
Tampa Bay Water
New York City DEP

Four Climate Science Consortiums

NCAR/Climate Central/CNAP (CA-NV RISA)
Climate Decision Support Consortium (Northwest RISA)
Southeast Climate Consortium
CUNY/Kansas State Univ./Columbia Univ.

Modeling Advisory Committee (MAC)

Phil Duffy (Climate Central); Ed Maurer (Santa Clara); Tom Johnson (EPA); Levi Brekke (BoR); Linda Mearns (NCAR); John Abatzaglou (U. Idaho); Mike Dettinger (Scripps); Claudia Tebaldi (Climate Central); Joe Barsugli (Western Water Assessment)

Project Mgr, WUCA: David Behar

WUCA Water Utility Climate Alliance

Project Mgr, RISAs: Phil Mote

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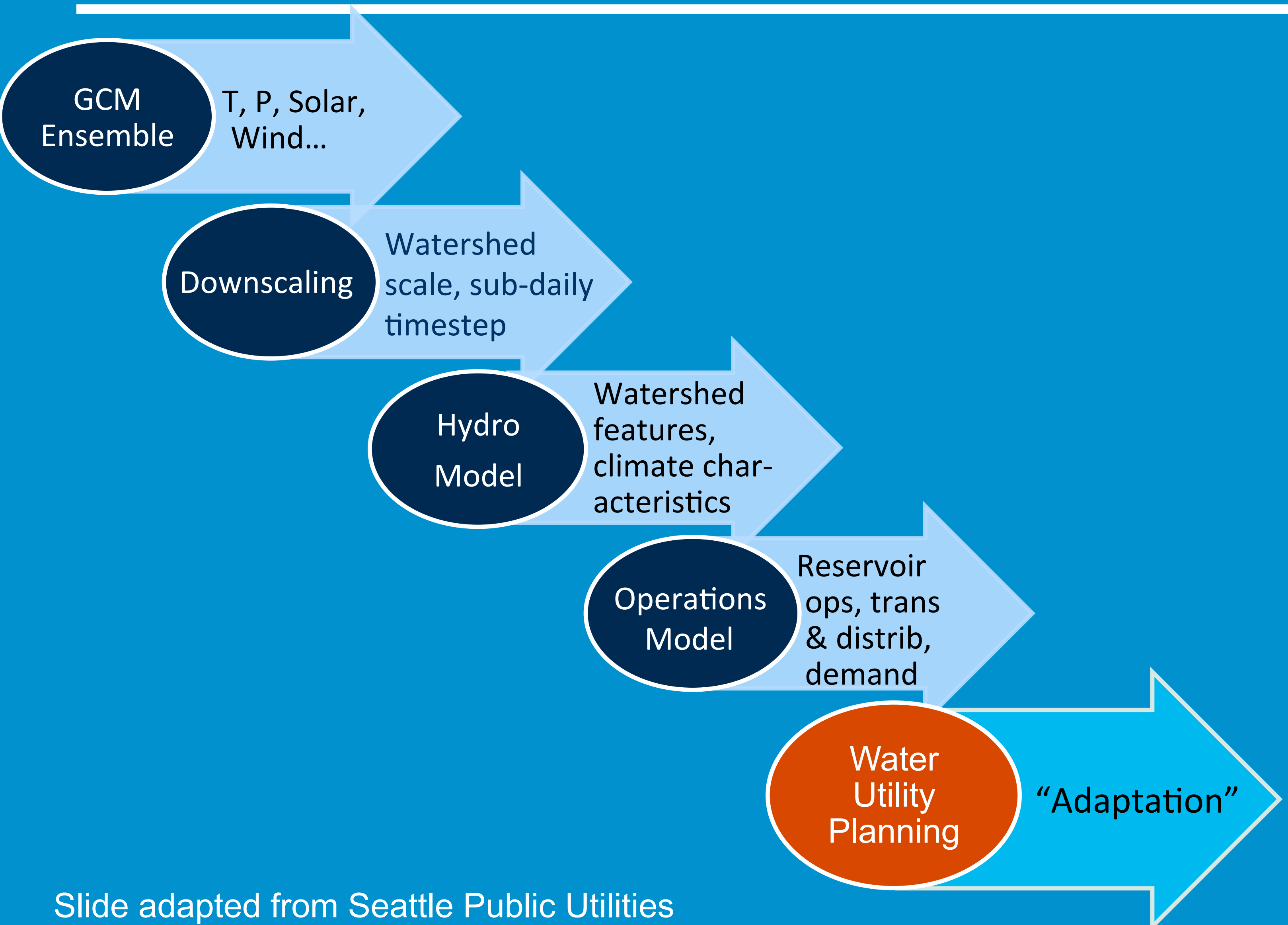
Chain of Models



Slide adapted from Seattle Public Utilities

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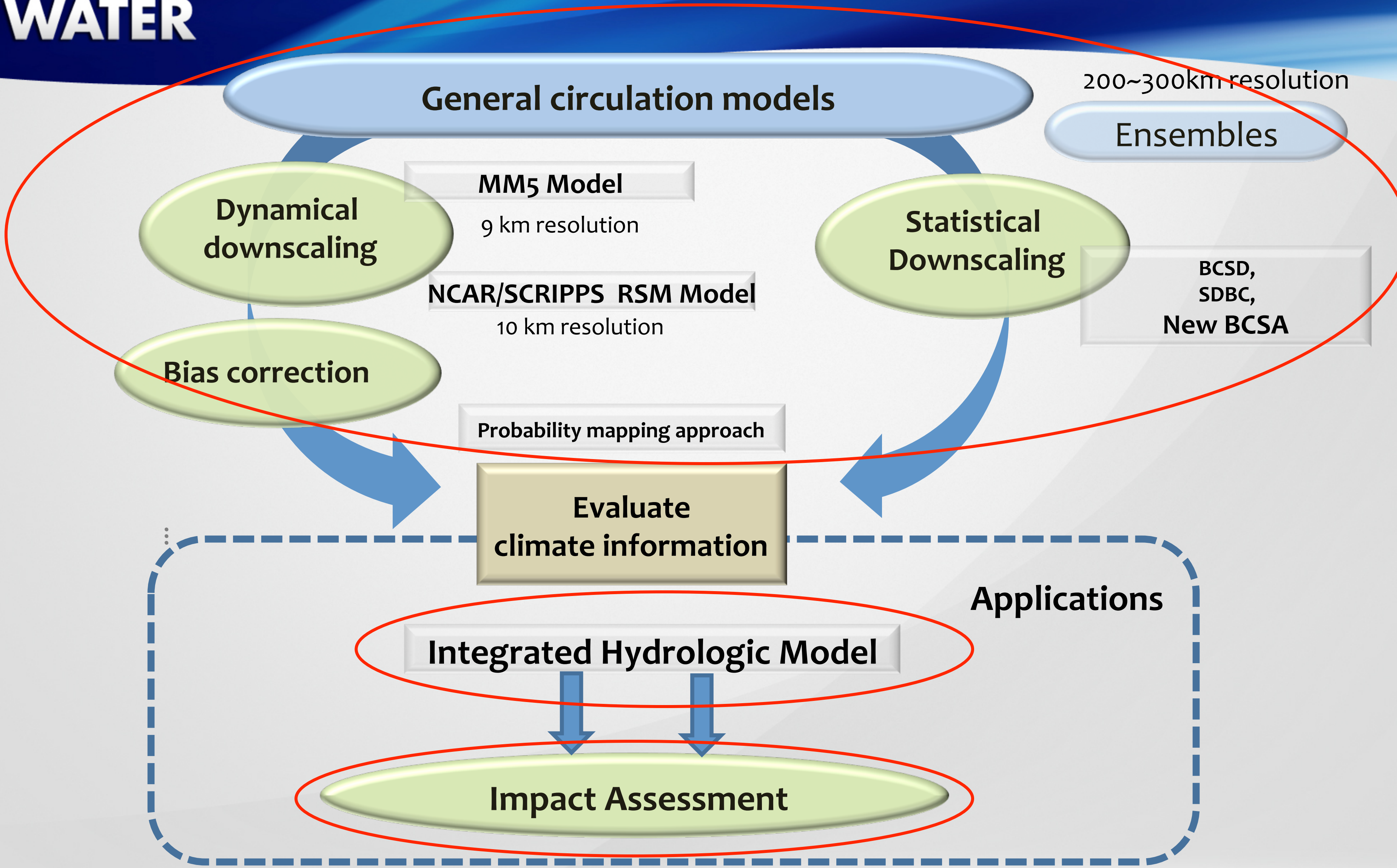
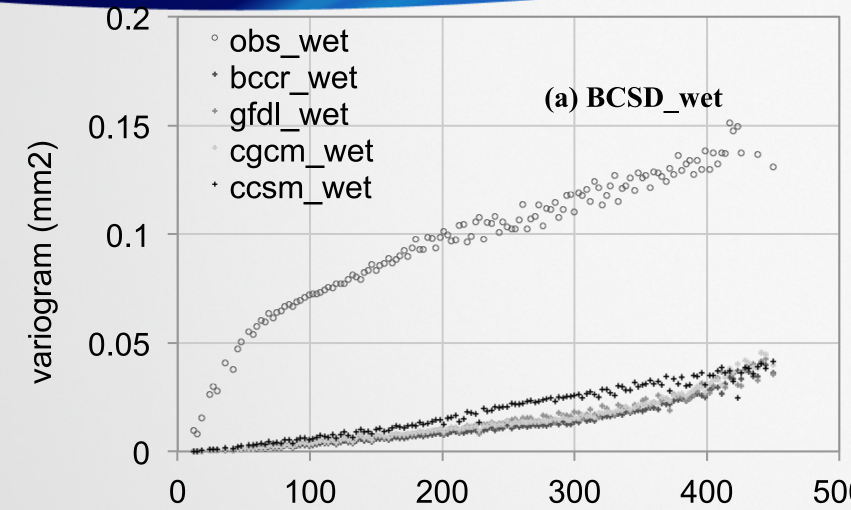
Assessment in the Water Business

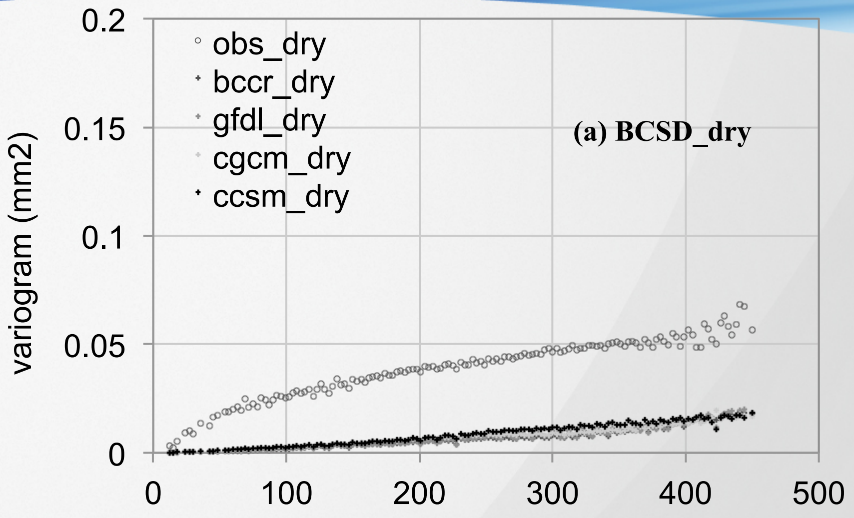
- Tampa Bay Water
- Denver Water
- New York City Department of Environmental Protection
- San Francisco Public Utilities Commission

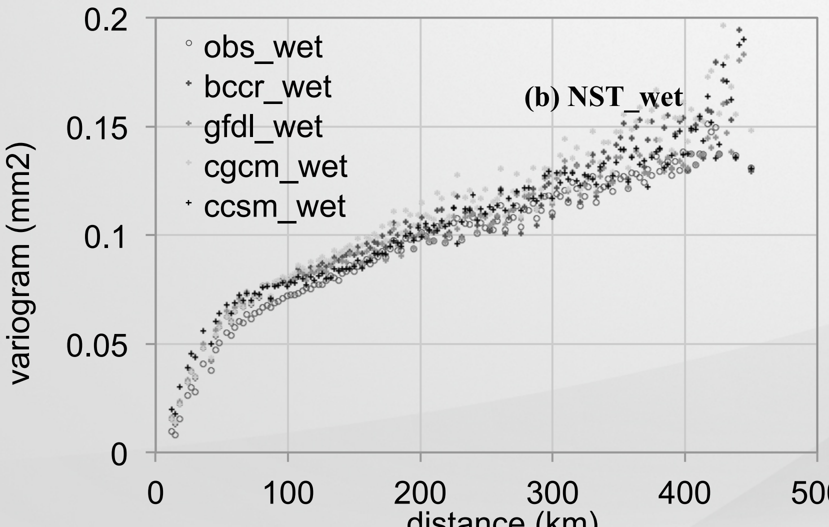
Climate Change Assessment Framework

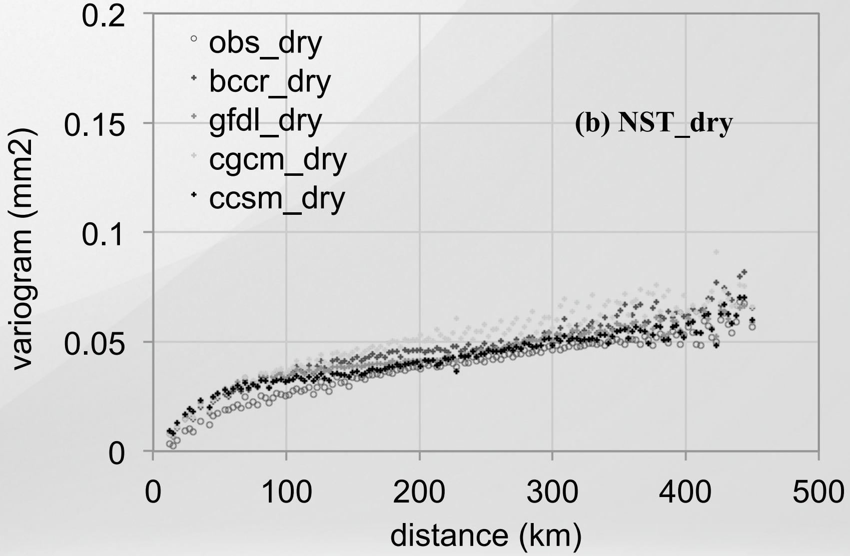


BCSD GCMs and NST GCMs Variogram Comparisons

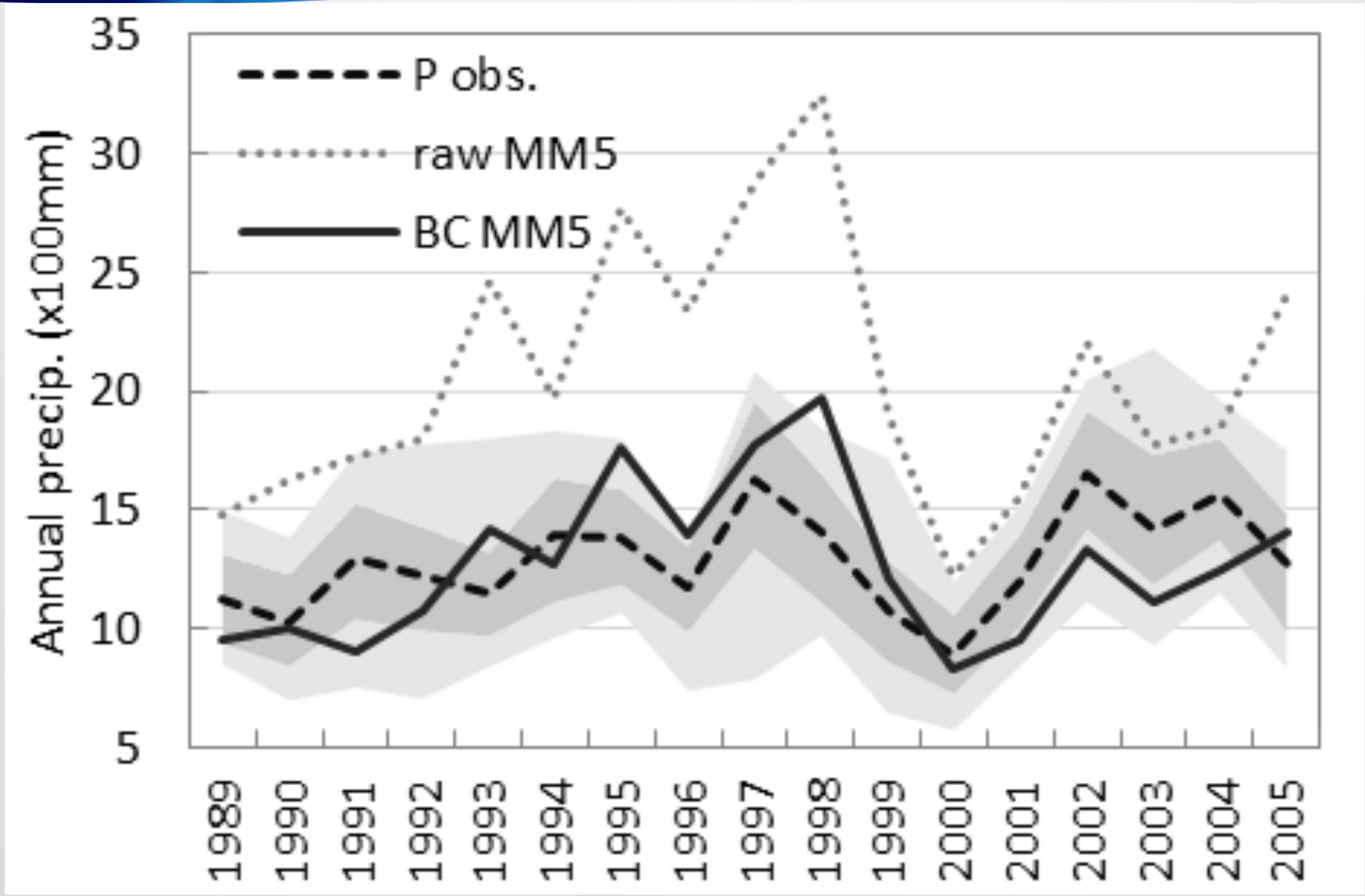




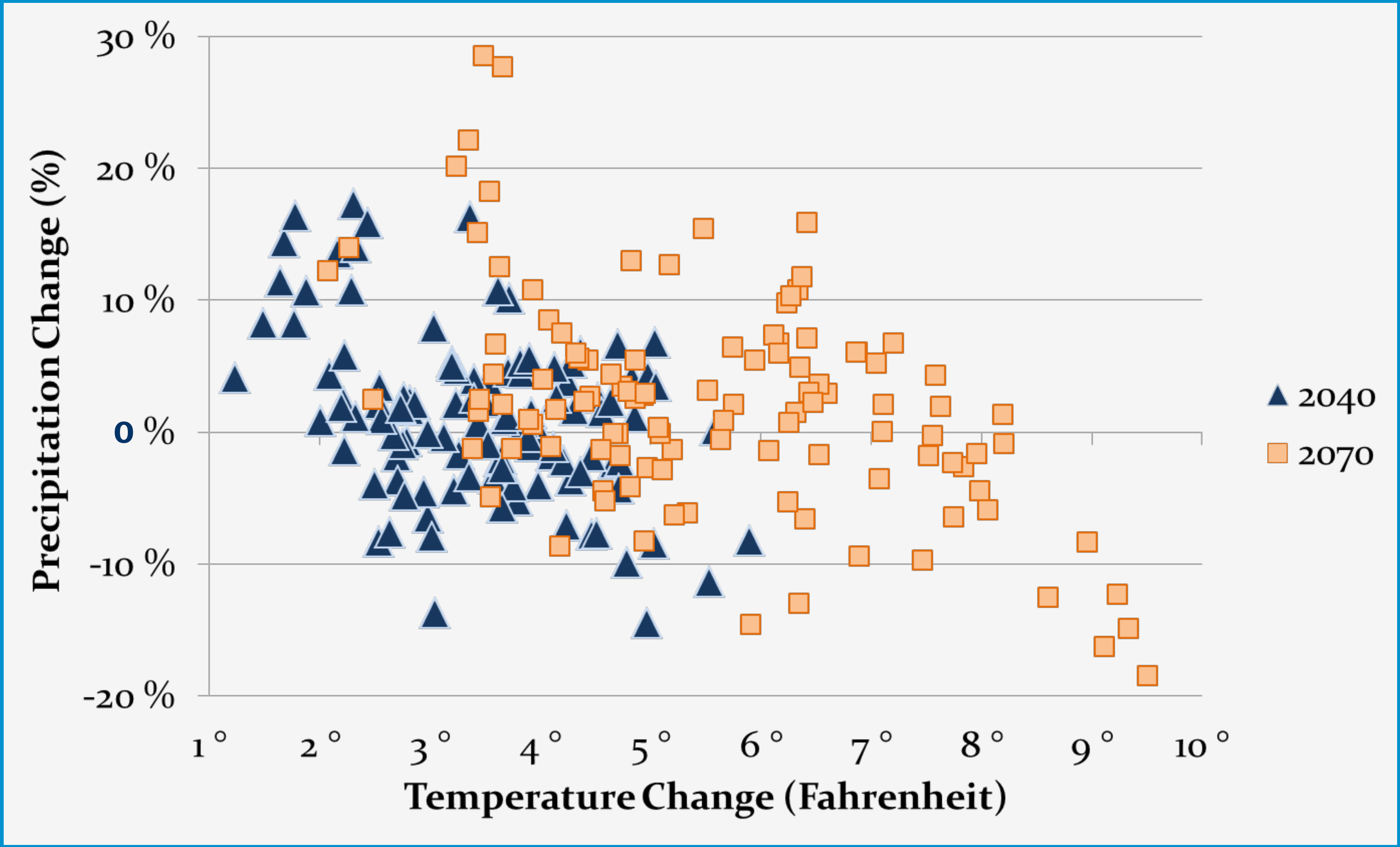




Comparison of annual observed, modeled and bias-corrected rainfall timeseries



Projected Changes for Denver's Watershed (Front Range Study, 2012)



Slide courtesy Denver Water

San Francisco Water Power Sewer

Denver Water: Information Selection

- ***Simple Assessment***
  - Constant Temperature or Precipitation offsets
    - Increase of 1ºC
    - **Increase of 5ºF**
    - Increase of 7.5%
    - Decrease of 3%
- ***Sophisticated Approach***
  - Scenarios for 2040 and 2070
    - warm and wet
    - warm and dry
    - median
    - very warm and wet
    - very warm and dry

30 Sets of NEW Streamflow for 18 sites

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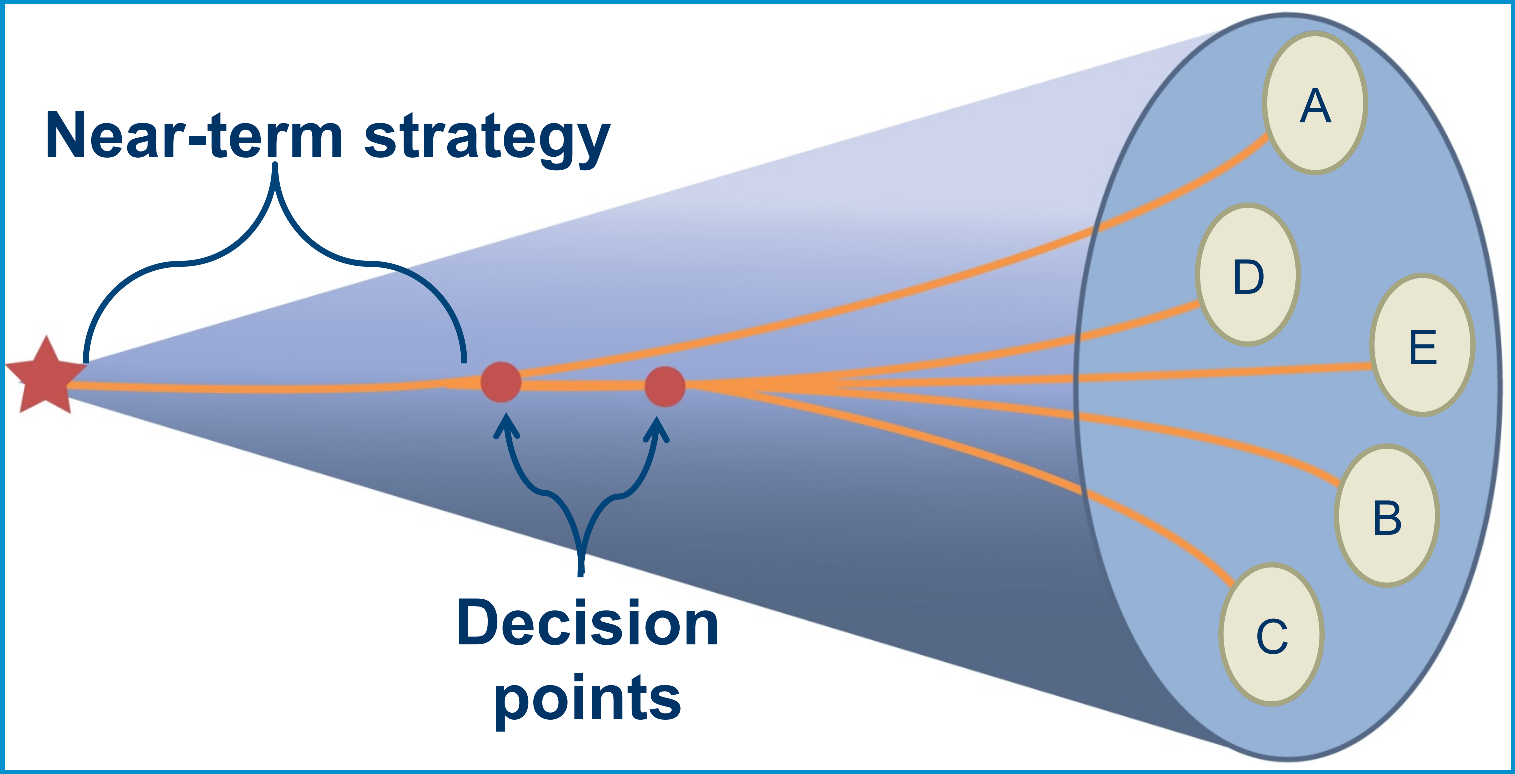
Denver Water: Scenario Planning

The Cone of Uncertainty

Present



Future

NYCDEP: Climate Change Scenarios

Change Factor Method Applied for 8 GCM/Emission Scenarios

GCM - Emission Scenario	Current Conditions Scenario	65 Year into Future Scenario	100 Year into Future Scenario
ECHAM-A1B	1981-2000	2046-2065	2081-2100
ECHAM-A2	"	"	"
ECHAM-B1	"	"	"
GISS-A1B	1981-2000	2046-2065	2081-2100
GISS-A2	"	"	"
GISS-B1	"	"	"
NCAR-A1B	1980-1999	2046-2065	2080-2099
NCAR-A2	"	"	"

- GCM/Emission Scenario data obtained from IPCC AR4 (2007)
- For each GCM/Emission Scenario, precipitation and air temperature are compared in control vs. future periods to derive monthly change factors.

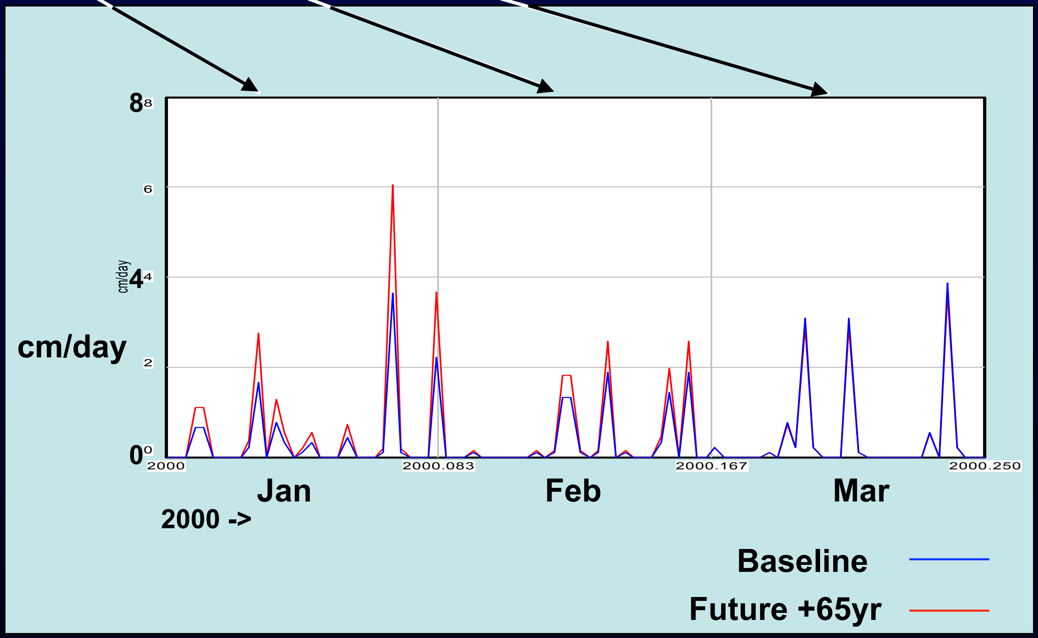
NYCDEP:
Application of Change Factor Method - Precipitation

Average GCM-Projected Precipitation by Month for Control and Future Periods

	J	F	M	A	M	J	J	A	S	O	N	D
Control Period (1981-2000)	2.9	3.3	4.8	4.8	4.7	4.6	3.5	3.5	3.2	3.5	3.1	3.3
Future Period (2046-2065)	4.8	4.6	4.6	4.9	4.2	4.6	4.1	3.1	3.5	3.8	4.1	4.9
Delta Precip Factor = Future/Control	1.7	1.4	0.9	1.0	0.9	1.0	1.2	0.9	1.1	1.1	1.3	1.5

Daily Precipitation Input Data for Model Simulations

*(Future = Baseline * Factor)*



NYCDEP Datasets Used: Phase 1 (highlighted) and Phase 2 (all)

	GCM Acronym	Daily Precipitation			Daily Mean Air Temperature		
		A1B	A2	B1	A1B	A2	B1
1	BCCR BCM2	1	1	1	1	1	1
2	NCAR CCSM3	3,5,6,7,8	1,3,5	6,7,8	3,5,6	1,3,5	6,7,8
3	CGCM3.1(T47)	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
4	CGCM3.1(T63)	1		1	1		1
5	CNRM-CM3	1	1	1	1	1	1
6	CSIRO-Mk3.0	1	1	1	1	1	1
7	CSIRO-Mk3.5	1			1		
8	ECHAM5/MPI-OM	4	1	1	4	1	1
9	MIUB ECHO-G	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
10	IAP FGOALS-g1.0	1,2,3		1,2,3	1		1,3
11	GFDL-CM2.0	1	1	1	1	1	1
12	GFDL-CM2.1						
13	GISS-AOM	1		1**	1		1
14	GISS-ER	1	1	1	1	1	1
15	INGV-SXG	1	1		1	1	
16	INM-CM3.0	1	1	1			
17	IPSL-CM4	1	1	1	1	1	1
18	MIROC3.2-hires	1		1	1		1
19	MIROC3.- medres	1,2	1,2	1,2	1,2,3	1,2,3	1,2,3
20	MRI-CGCM2.3.2	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5	1,2,3,4,5

What We Need from the Climate Modeling Community

- Access to updated repository of downscaled GCM output for our region for variables of interest (daily precipitation, max/min/ average air temperature, wind speed, solar radiation, relative humidity).
- Guidance for GCM/RCM selection. Which GCMs and/or downscaling methods are most appropriate for our region/ application/parameters; and why?
- Better tools for downscaling data.
- Capturing effects of climate change on local convective storms is very important (These storms have a large effect on turbidity).

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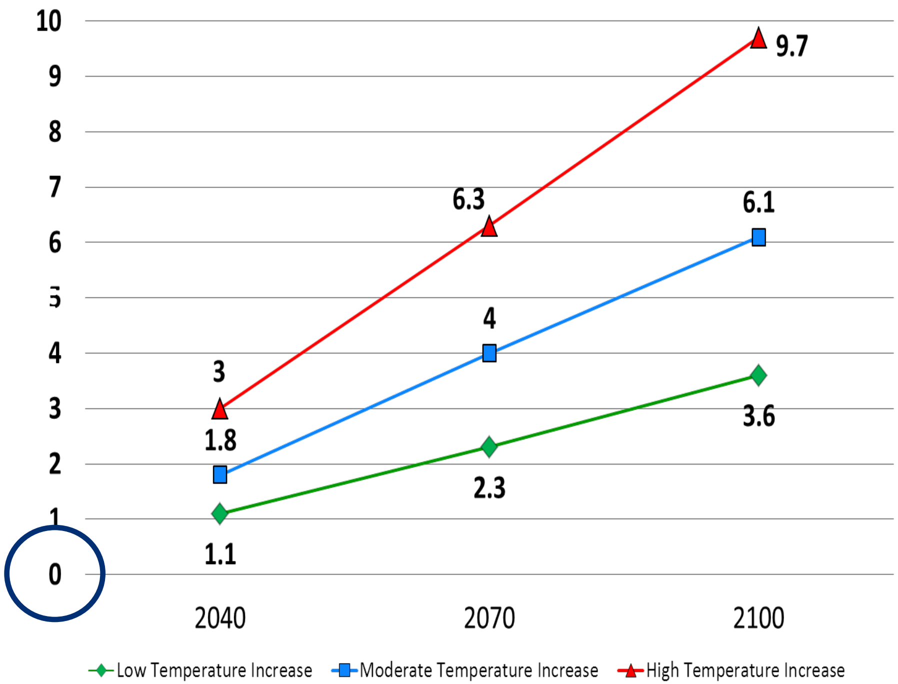
Projections Inventory – Work in Progress

Compiled by David Rupp, OCCRI and David Behar, SFPUC)

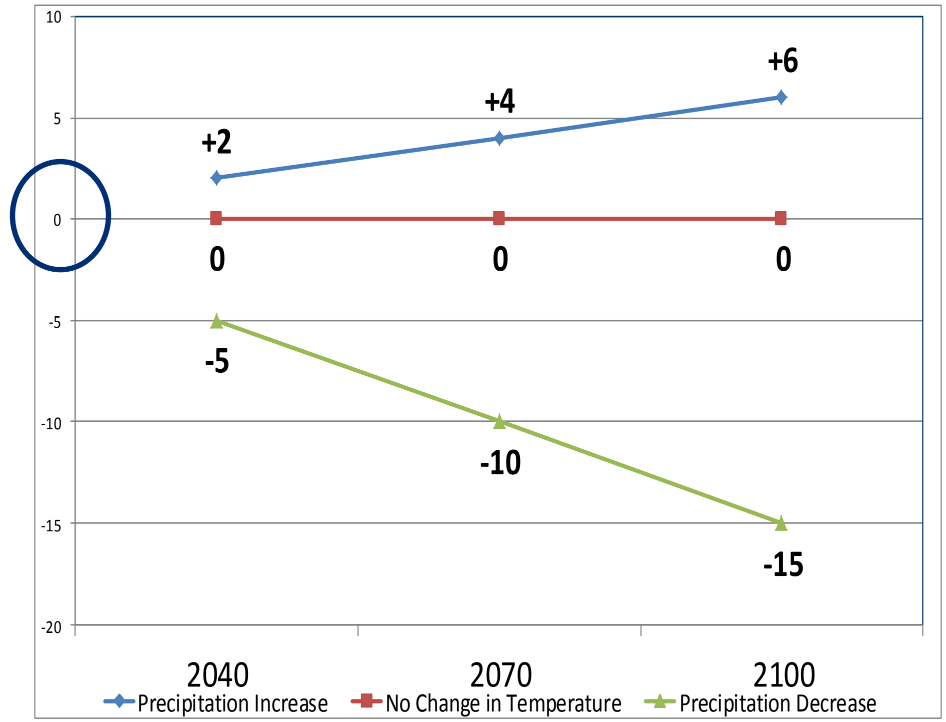
Emissions/ Concentration Scenario	Spatial Domain	Temporal Domain	Spatial Resolution*	Finest Temporal Resolution Available*	GCM	RCM
Contact: Chris Castro, U of Arizona (Dominguez et al, 2011, PNAS)						
SRES A2	US and N. Mexico	1967-2081	35 km	6 hr	HADCM3	WRF
SRES A2	US and Mexico	1950-2100	35 km	6 hr	ECHAM5	WRF
SRES A2	US and Mexico	1950-2100	35 km	6 hr	CESM (CMIP5)	WRF
Contact: L. Ruby Leung, PNNL						
RCP4.5	North America	1975 - 2005, 2005 - 2100	20 km	hourly	CCSM4	WRF-CLM
Contact: Xin-Zhong Liang, Univ Maryland						
SRES A2	US+PartialMex/Can	2090-2099	30 km	3 hr	HadCM3P	CMM5
SRES B2	US+PartialMex/Can	2090-2099	30 km	3 hr	HadCM3P	CMM5
SRES B1	US+PartialMex/Can	2045-2055, 2090-2099	30 km	3 hr	PCM	CMM5
SRES A1Fi	US+PartialMex/Can	2090-2099	30km	3 hr	PCM	CMM5
SRES A1b	US+PartialMex/Can	2045-2055, 2090-2099	30 km	3 hr	CCSM	CMM5
SRES B1	US+PartialMex/Can	2045-2055, 2090-2099	30 km	3 hr	CCSM	CMM5
SRES A1Fi	US+PartialMex/Can	2045-2055, 2090-2099	30 km	3 hr	CCSM	CMM5
Contact: Steve Hostetler, USGS						
SRES A2	US & S. CANADA	2010-2099	50 km	Monthly stats	MPI ECHAM5	RegCM3
SRES A2	US & S. CANADA	2038-2069	50 km	Monthly stats	GFDL CM2.0	RegCM3
SRES A2	US & S. CANADA	2010-2099	50 km	Monthly stats	PSU/SGS GENMOM	RegCM3
SRES A2	W. US (with Canada)	2010-2099	15 km	Monthly stats	MPI ECHAM5	RegCM3
SRES A2	W. US (with Canada)	2038-2069	15 km	Monthly stats	GFDL CM2.0	RegCM3
SRES A2	W. US (with Canada)	2010-2099	15 km	Monthly stats	PSU/USGS GENMOM	RegCM3
SRES A2	E. US (with Canada)	2020-2099	15 km	Monthly stats	MPI ECHAM5	RegCM3
SRES A2	E. US (with Canada)	2038-2069	15 km	Monthly stats	GFDL CM2.0	RegCM3
SRES A2	E. US (with Canada)	2020-2080	15 km	Monthly stats	PSU/USGS GENMOM	RegCM3
Total						
Contact: John Mejia, Desert Research Institute, Nevada						
SRES A2	Western N. America	1980-2000, 2041-2070	36 and 12 km	3 hr	CCSM	WRF
SRES A2	Western N. America	1980-2000	36 and 12 km	3 hr	CCSM-SST biases	WRF
Contact: Norm Miller, Lawrence Berkeley Laboratory						
SRES or RCP x	Western US and CA/NV	1985-1994, 2060-2069	32 km (10 km CA/ NV)	?	CCSM3	WRF-CLM
SRES or RCP y	Western US and CA/NV	1985-1994, 2060-2070	32 km (10 km CA/ NV)	?	CCSM3	WRF-CLM
SRES or RCP x	Western US and CA/NV	1985-1994, 2060-2071	32 km (10 km CA/ NV)	?	CCSM3	RegCM

SFPUC Sensitivity Analysis: Temperature and Precipitation Scenarios Only

Temperature



Precipitation



Sources: Expert Elicitation (Dan Cayan, Joel Smith),
IPCC Fourth Assessment Report (2007), Literature Survey

Sensitivity Analysis – Streamflow to Temperature and Precipitation Change

	2040	2070	2100
Temperature Precipitation	+ 0.6 deg C + 0%	+ 1.3 deg C + 0%	+ 2 deg C + 0%
Temperature Precipitation	+ 1 deg C + 0%	+ 2.2 deg C + 0%	+ 3.4 deg C + 0%
Temperature Precipitation	+ 1 deg C - 5%	+ 2.2 deg C - 10%	+ 3.4 deg C - 15%
Temperature Precipitation	+ 1 deg C + 2%	+ 2.2 deg C + 4%	+ 3.4 deg C + 6%
Temperature Precipitation	+ 1.65 deg C + 0%	+ 3.5 deg C + 0%	+ 5.4 deg C + 0%
Temperature Precipitation	+ 1.65 deg C -5%	+ 3.5 deg C -10%	+ 5.4 deg C -15%

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Median Runoff into Hetch Hetchy
(results based on 1975-2008, median year is 2003)

Change in Median Runoff volume for future climate conditions

Climate Change Scenario		Hetch Hetchy Runoff (% change from 2010) 2040	2070	2100
1A	Low temperature increase No precipitation change	-1%	-2%	-3%
2A	Moderate temperature increase No precipitation change	-1%	-3%	-5%
2B	Moderate temperature increase Precipitation decrease	-8%	-16%	-25%
2C	Moderate temperature increase Precipitation increase	-1%	+2%	+2%
3A	High temperature increase No precipitation change	-2%	-6%	-10%
3B	High temperature increase Precipitation decrease	-9%	-19%	-29%

SFPUC Next Stage: Full Assessment

San Francisco Water Power Sewer

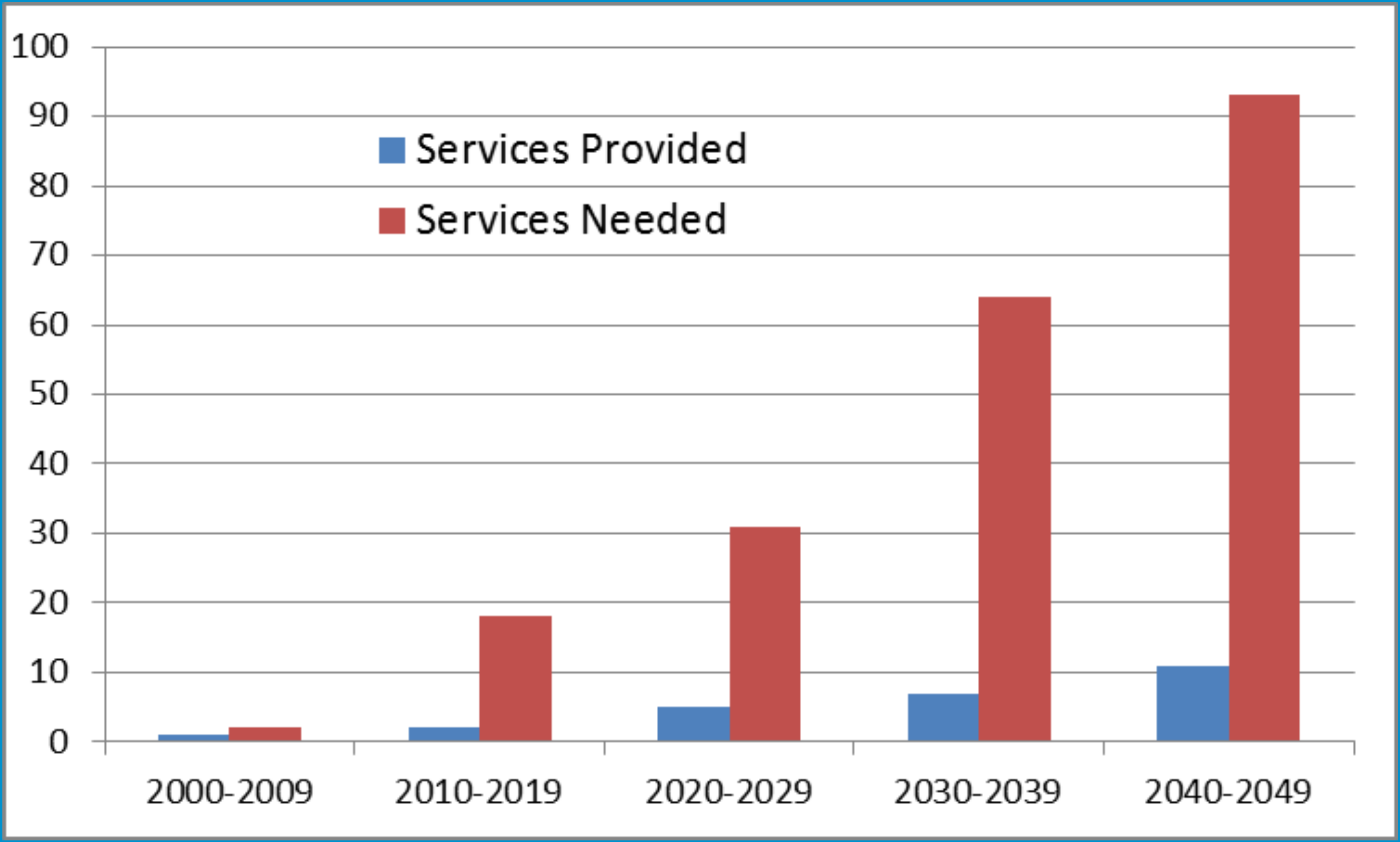
- Task 1: D… ds in obs data, ac… o data
- Task 2… ssemble c… s
  - Surv… st… ctions (Rupp/B…
  - Approaches,
    - A. Broad Ense…
    - B. Bayesian A…
    - C. Hybri…
- Task 3: … g
- Task 4… ogic anal…
- Task 5: F… cision support con… M, RDM)
- Task 6: Pro… ce report, stakeholder work… p

Team: **David Yates** (Project Manager) and **Caspar Amman**, NCAR; **Bridget Thrasher**, Climate Central; **David Behar** and **Alexis Dufour**, SFPUC.

Synthesis

- Commonalities
  - Partnerships between water managers and climate scientists
    - CO-PRODUCTION OF ASSESSMENT
  - Iterative use of climate information
  - Downscaling (NYCDEP’s a little different)
  - Downstream modeling tools process climate information
- Differences
  - Partnerships: Each one a new invention of different nature
  - Different GCM and downscaling tools selected
  - Method of selection: availability, cost, opportunity, evaluation, experimentation
  - Complexity, difficulty
  - Reproducability? “Best Practice?”

A Climate Services Scenario



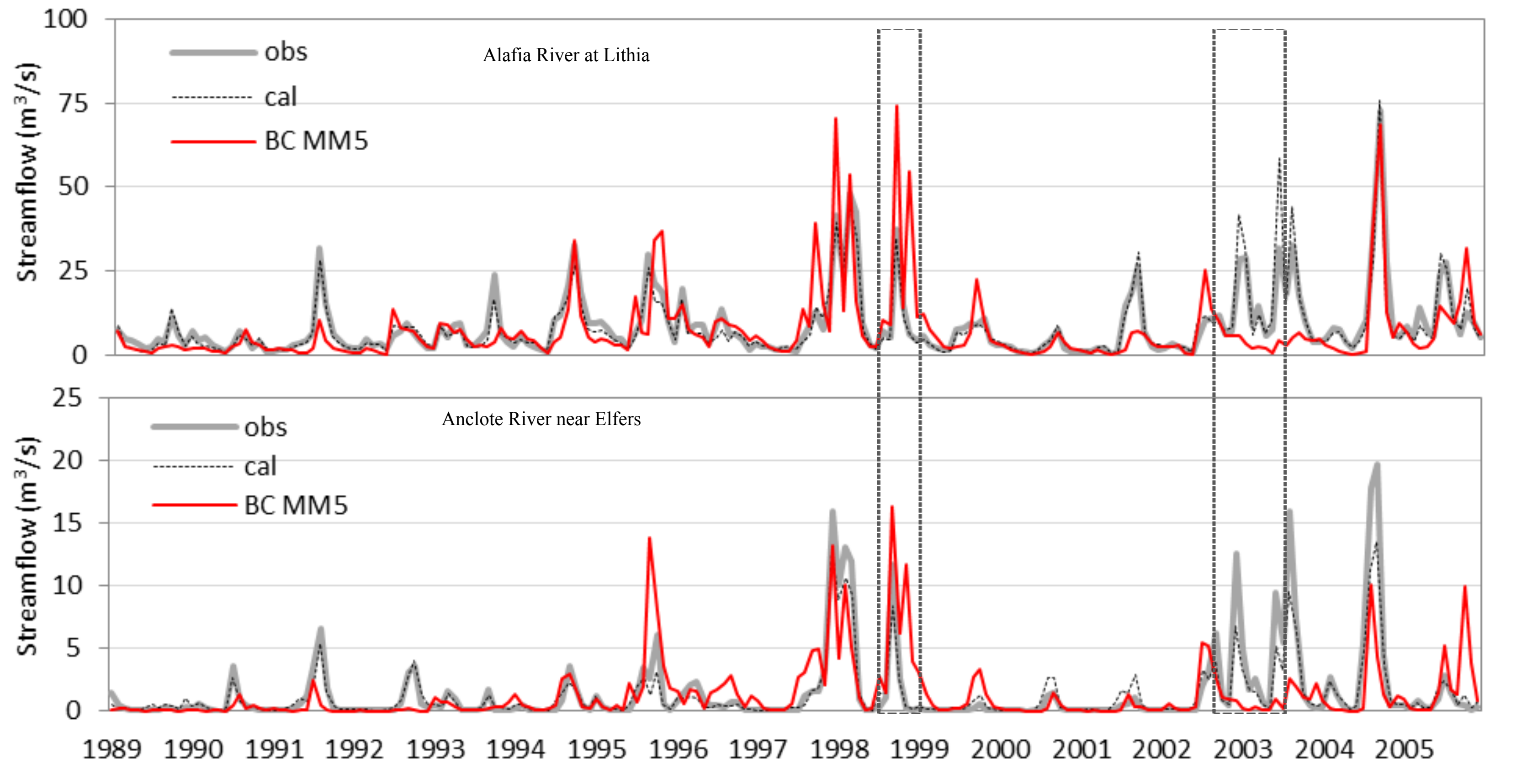
Note: fake data – for illustration purposes only

Thank you

David Behar, Climate Program Director
San Francisco Public Utilities Commission
525 Golden Gate Avenue, 10th Floor
San Francisco, CA 94102
dbehar@sfwater.org 415-554-3221

San Francisco
Water Power Sewer
Services of the San Francisco Public Utilities Commission

Monthly Streamflow Hydrographs

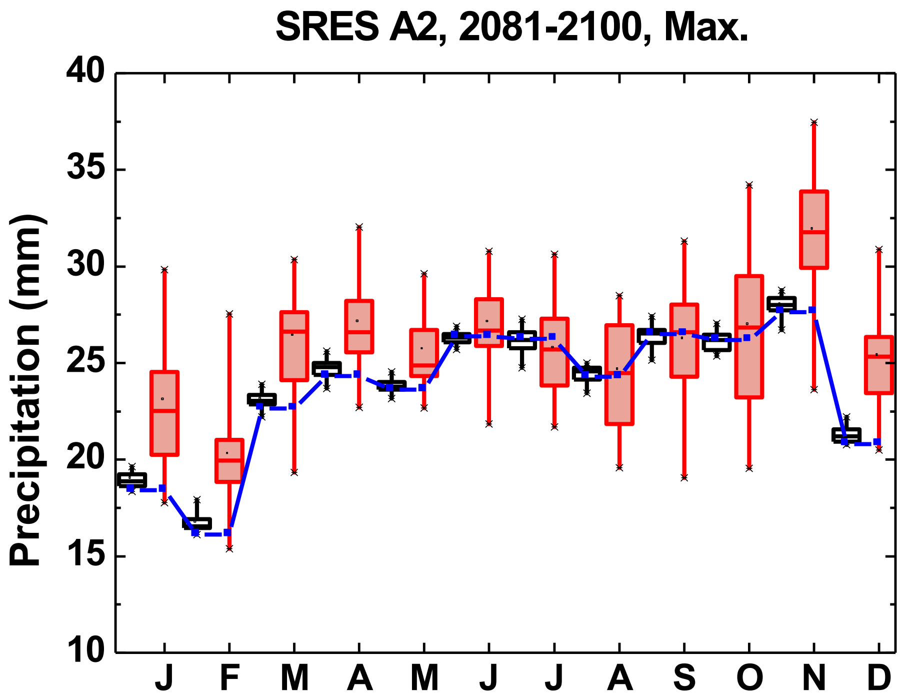


NYCDEP: Results of Different CF Methods

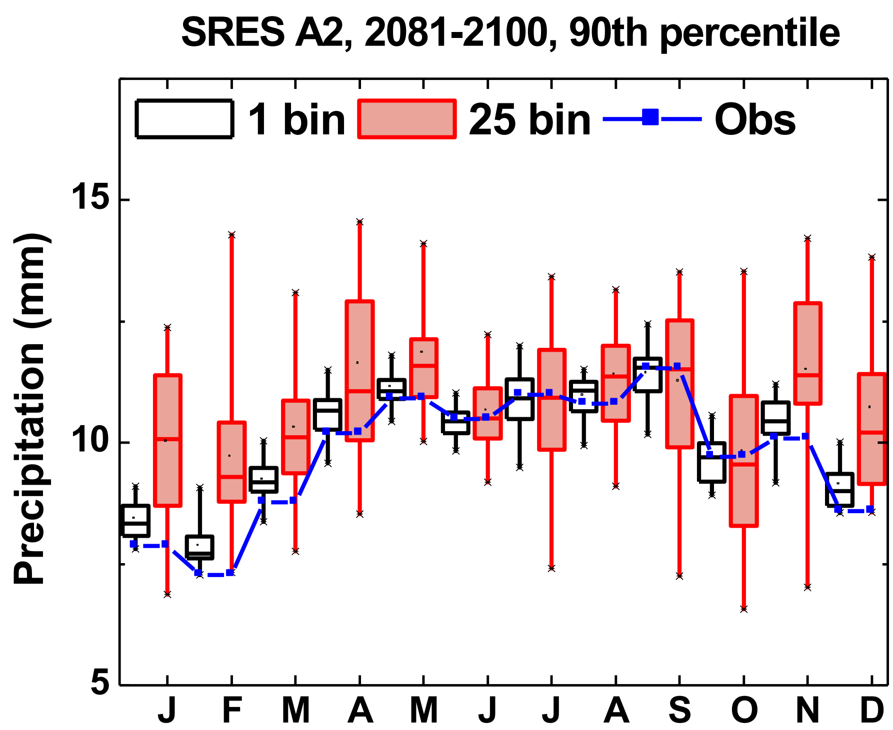
NYC Environmental Protection

Cannonsville Watershed Precipitation for 20 year Scenarios

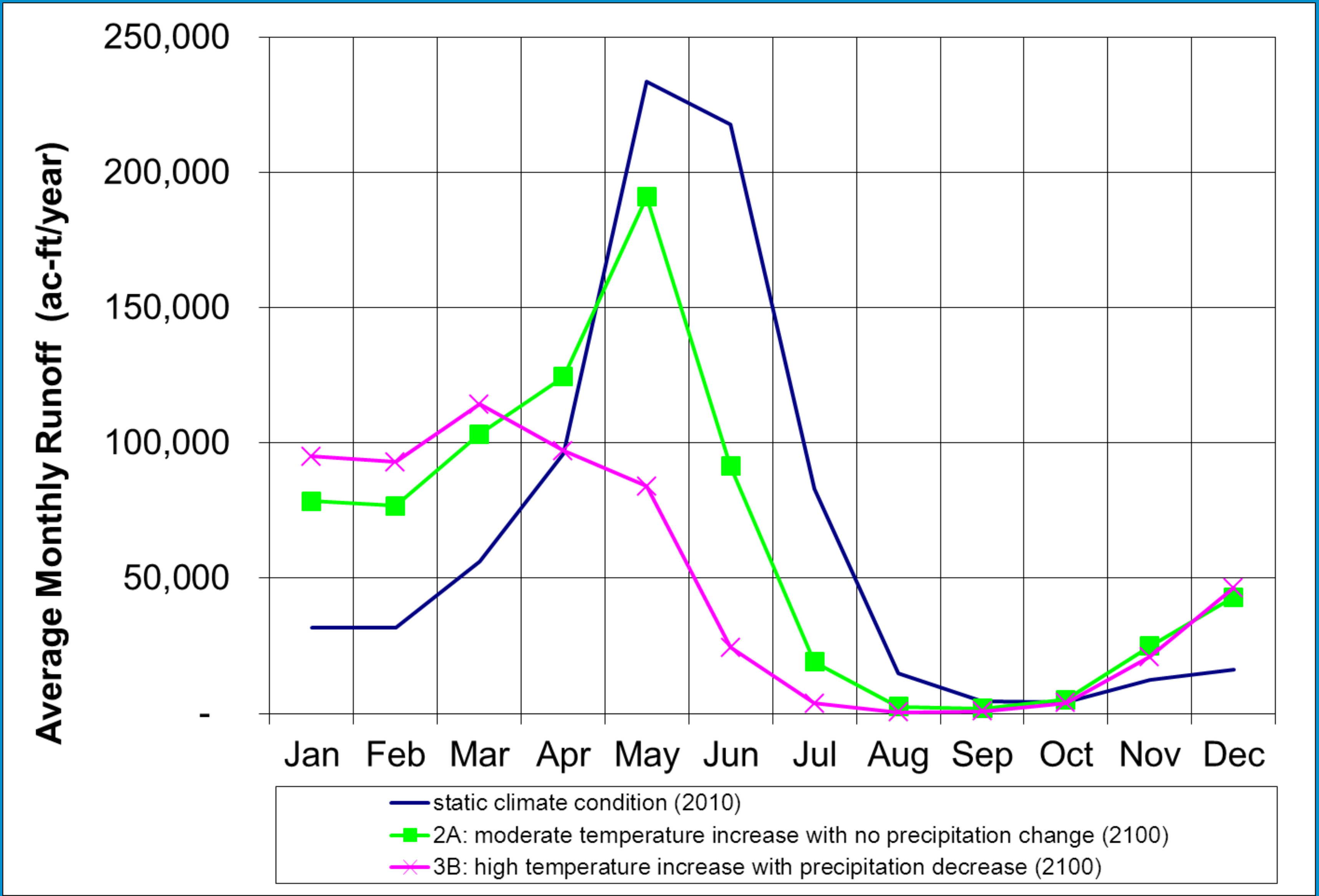
Monthly Max



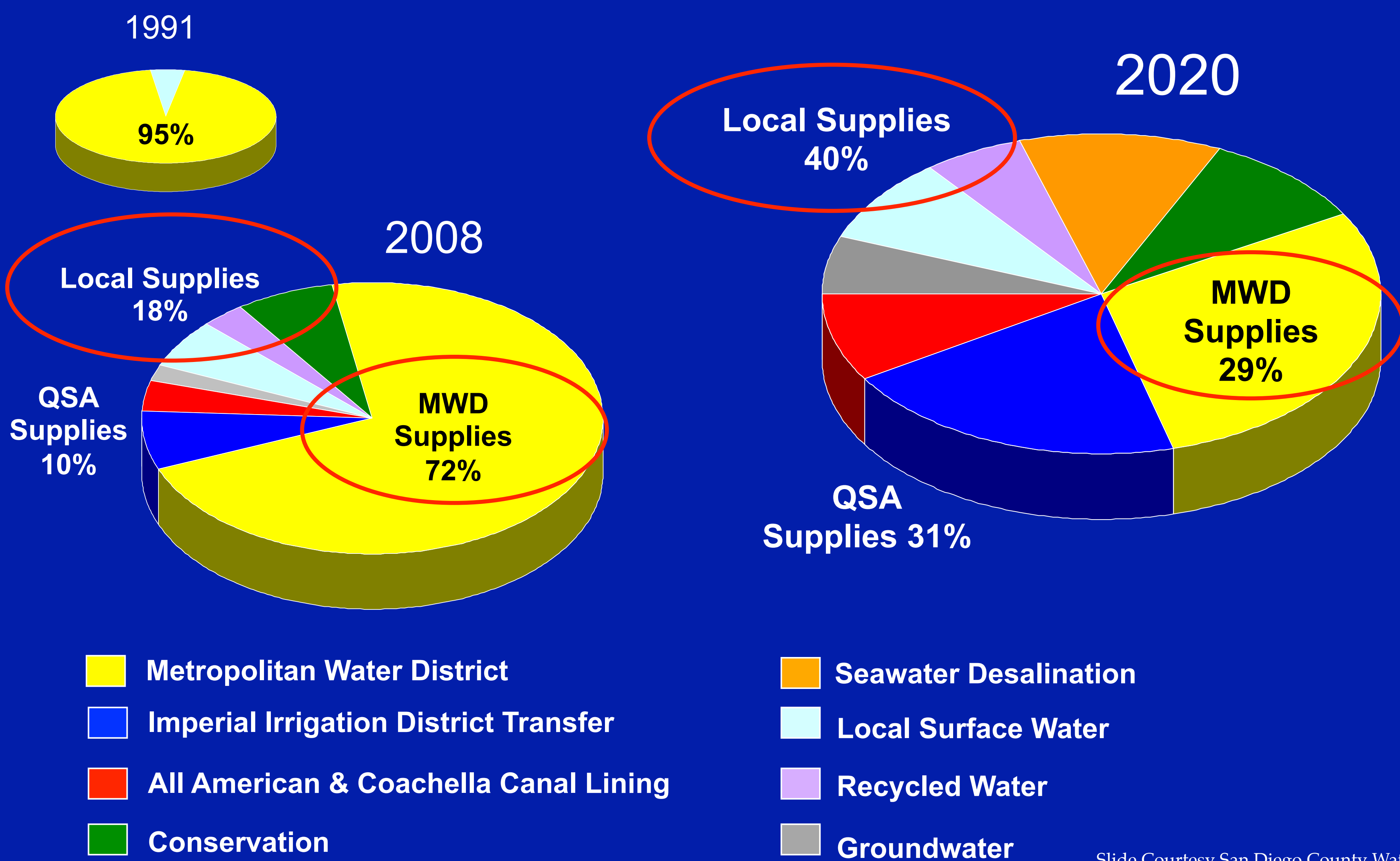
Monthly 90th Percentile



Monthly Runoff into Hetch Hetchy: Two Climate Scenarios for Yr 2100

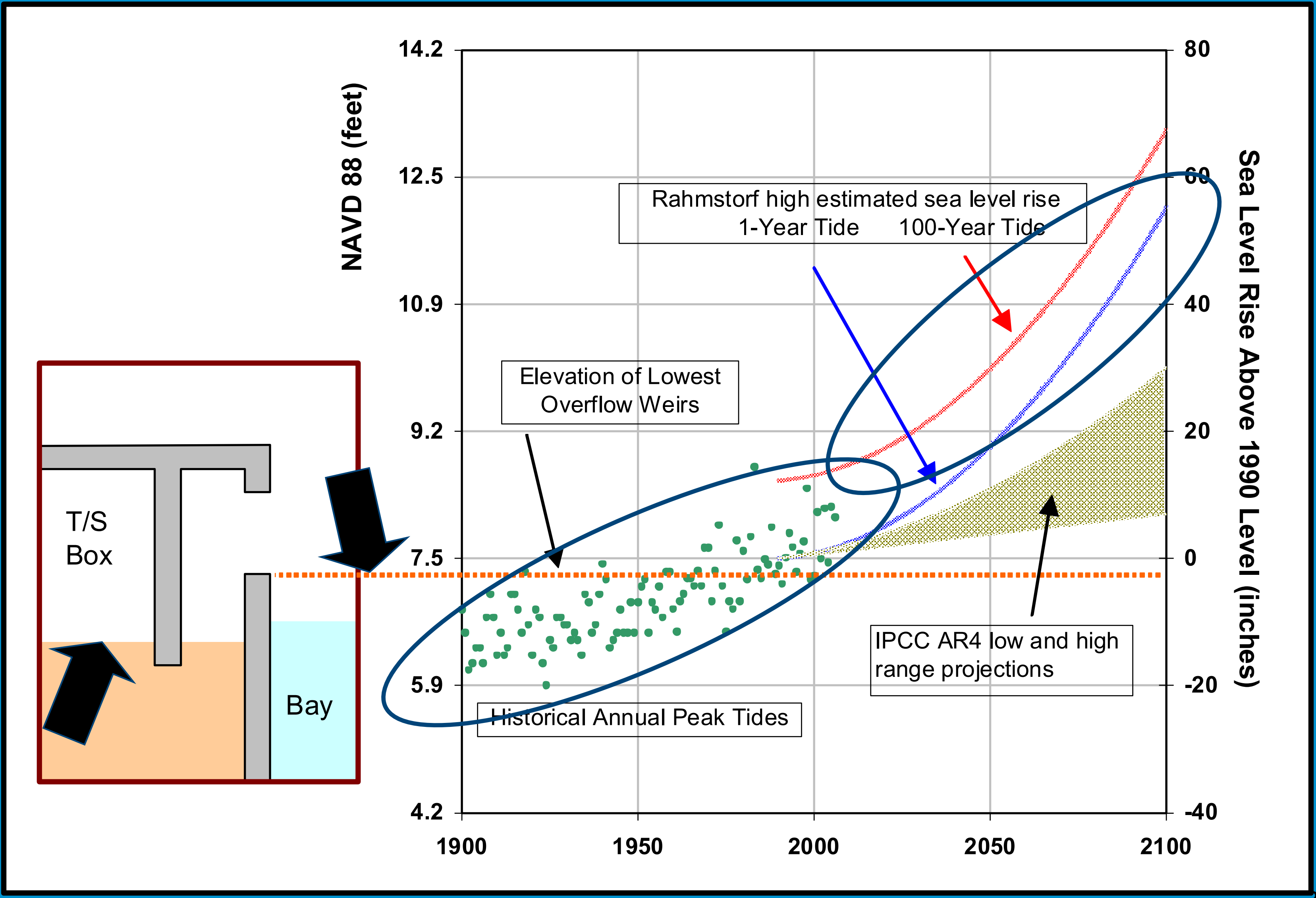


Diversifying San Diego County's Water Supply Portfolio



Slide Courtesy San Diego County Water Authority

Sea Level Rise: Today's Adaptation Challenge

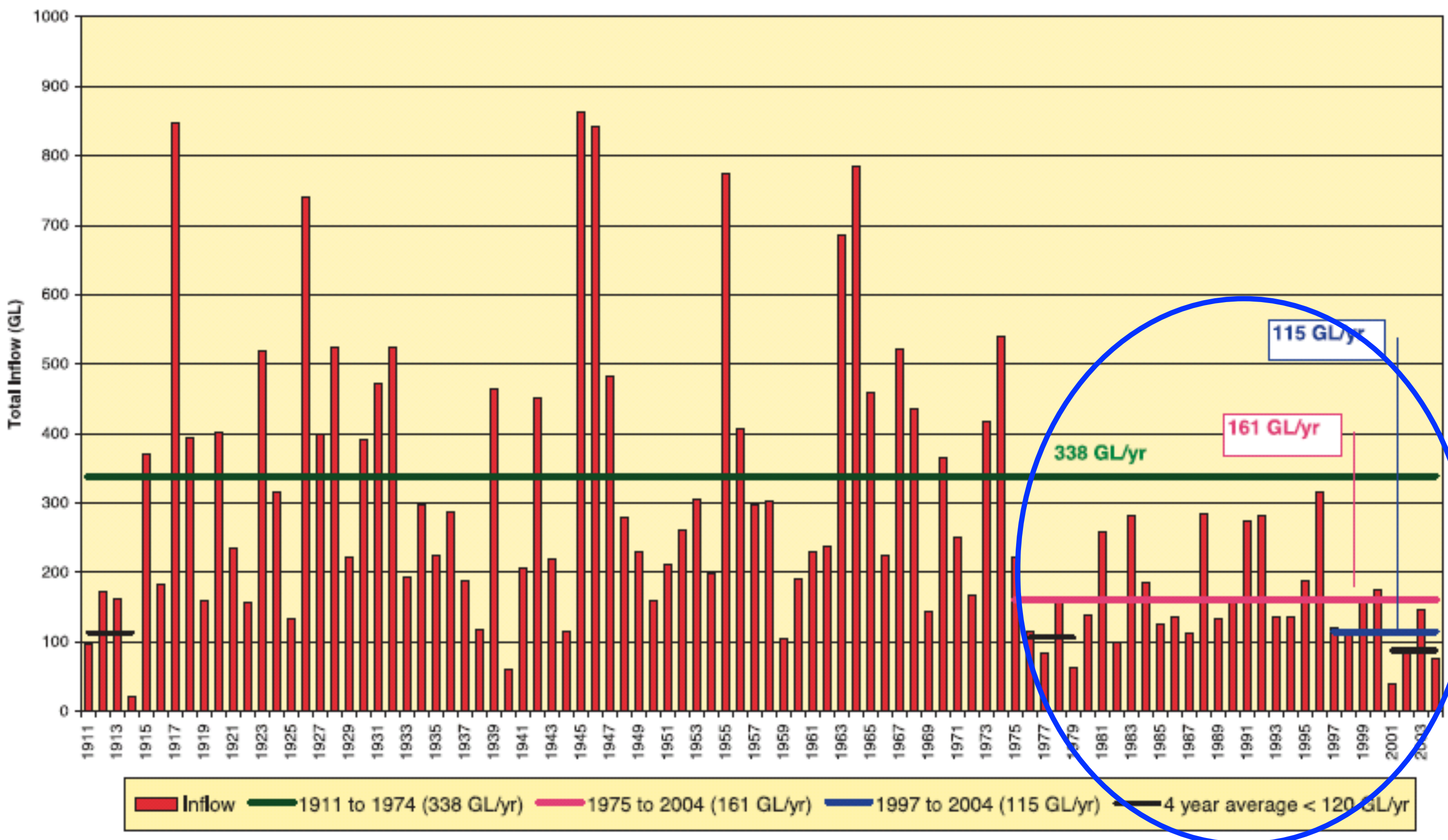


Backflow Prevention for twenty-nine bayside discharges/collection points

Current status:

- Today: 16 of 29 overflow weirs have backflow during the seasonal high tides.
- Total Project Costs: $20-40 million over 5 years.

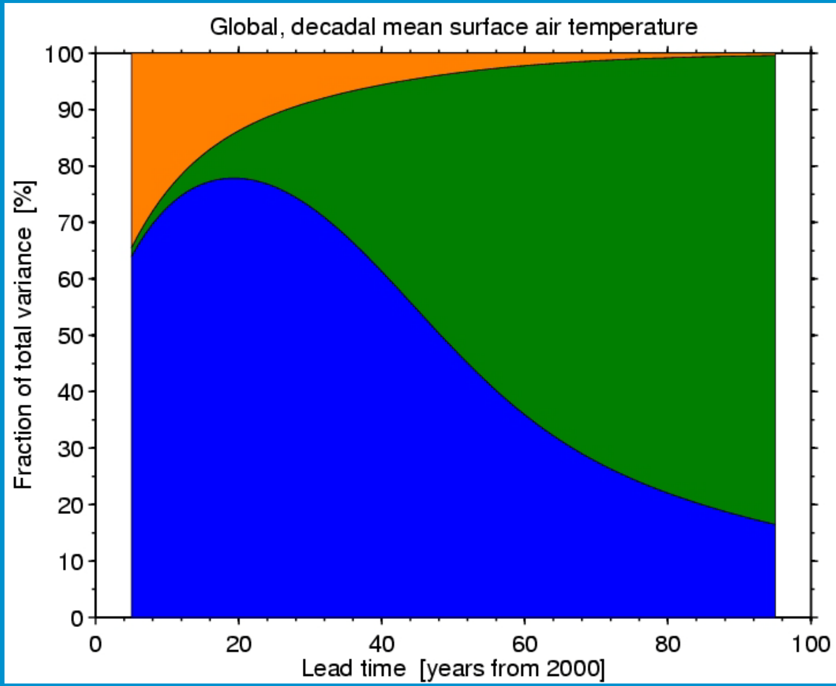
Perth: Storage inflows (1911-2003)

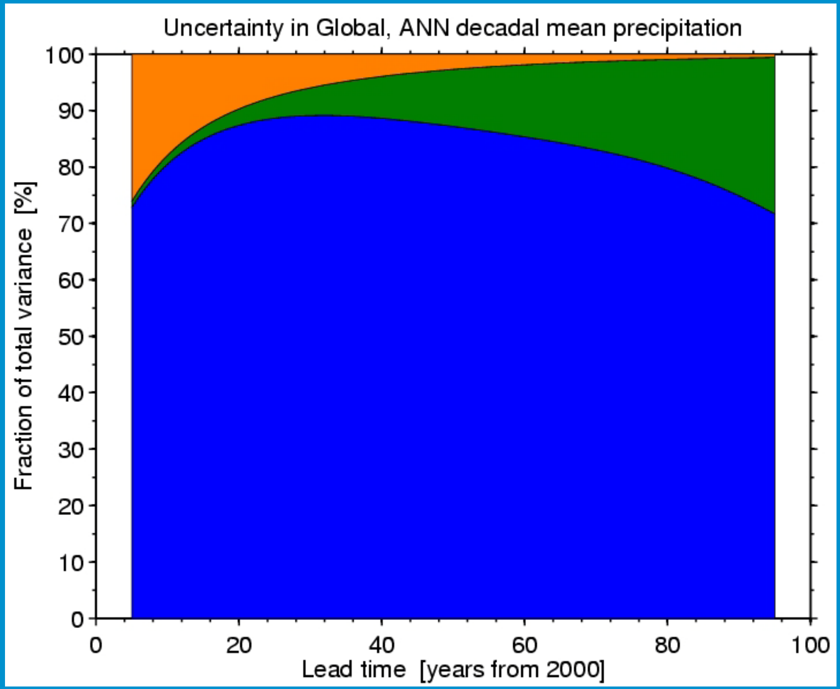


Note: A year is taken as May to April ("2004": May 2004 to Apr 2005 is an estimate only)

Uncertainty: Natural variability/ Emissions scenario/Model uncertainty

Emissions uncertainty
Internal variability
Model uncertainty





From Hawkins & Sutton 2009 (BAMS) and 2010 (Climate Dynamics)

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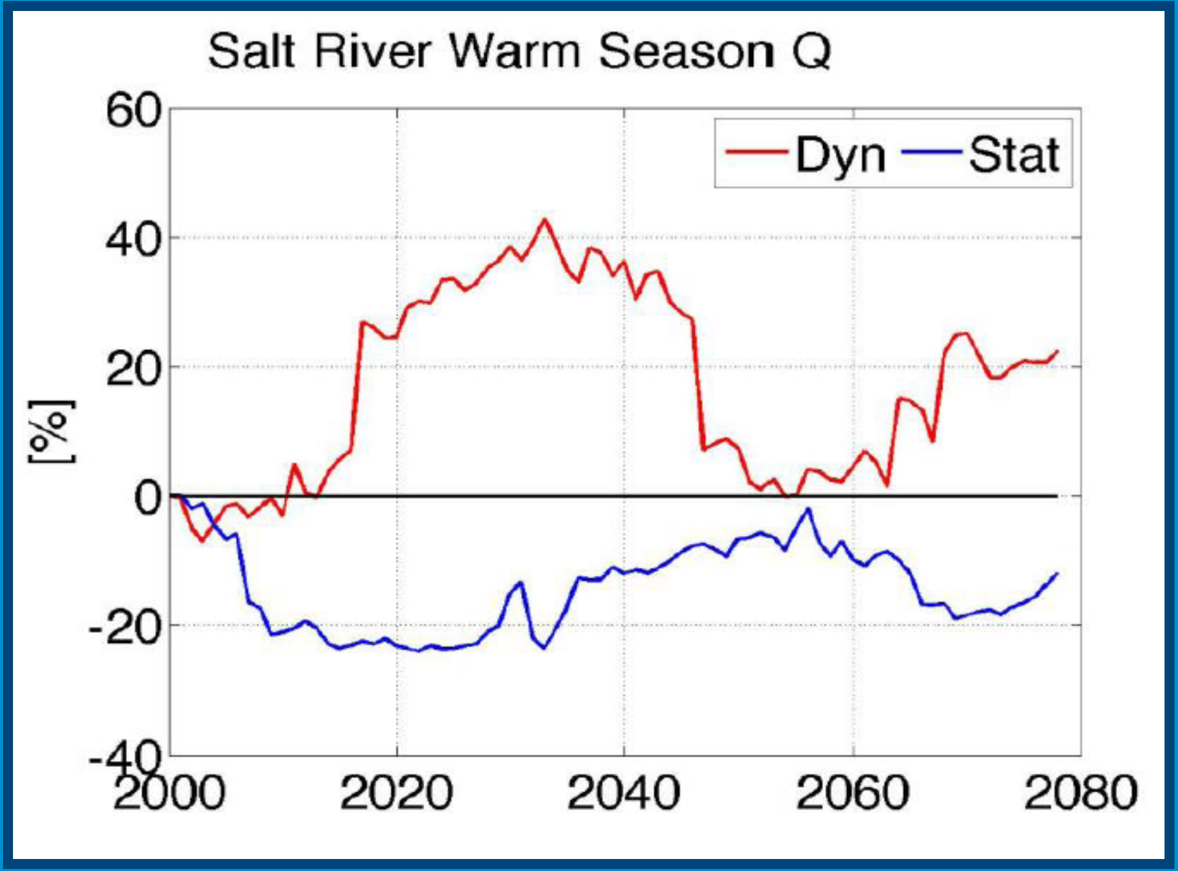
Priorities

- T, P, Wind, Solar: What we care about most
- Subdaily saved data: Can we make it available?
- Higher resolution GCM runs: Next best thing?
- Focus on central latitude precipitation: Continued improvement to Tropical Pacific, etc.
- Improved characterization of uncertainty
- "Community" archived datasets: Accessible multi-model ensembles
- Dynamical, other downscaling experiments that respond to our scale needs
- CORDEX-inspired experiments

Provided to National Academies Committee on Future of Climate Modeling in the US next 20 years

Southwestern United States: Salt River



Boundary conditions from HadleyCM3.
Statistically DS data from Maurer et al; dynamically DS data generated using nested WRF

Dominguez, Rajagopal, Castro, Troch, Demaria, Gupta, Durcik, Chang, University of Arizona.
Slide courtesy Gregg Garfin, Institute of the Environment, University of Arizona

San Francisco Water Power Sewer

Extremely Wet, Median and Critically Dry Year Runoff

Change in runoff volume for two future climate conditions for Extremely Wet, Median, and Critically Dry Years (results based on 1975-2008)

Climate Change Scenario		**Year Type**	**Hetch Hetchy Runoff (% change from 2010)**		
			2040	**2070**	**2100**
2A	moderate temperature increase/ no precipitation change	EXTREMELY WET	-1%	-1%	-2%
		MEDIAN	-1%	-3%	-5%
		CRITICALLY DRY	-3%	-9%	-15%
3B	high temperature increase/ precipitation decrease	EXTREMELY WET	-7%	-14%	-22%
		MEDIAN	-9%	-19%	-29%
		CRITICALLY DRY	-15%	-31%	-47%

Climate Scenarios

Scenario	*Description*	*Mean Annual Temperature (˚F)*			*Mean Annual Precipitation (inches)*		
Base (2010 conditions)		55.1˚F			36.9 inches		
Change from Base		***Change from Base (˚F)***			***Change from Base (%)***		
		2040	*2070*	*2100*	*2040*	*2070*	*2100*
1A	Low temperature increase no precipitation change	+1.1	+2.3	+3.6	0	0	0
2A	Moderate temperature increase no precipitation change	+1.8	+4.0	+6.1	0	0	0
2B	Moderate temperature increase precipitation decrease	+1.8	+4.0	+6.1	-5	-10	-15
2C	Moderate temperature increase Precipitation increase	+1.8	+4.0	+6.1	+2	+4	+6
3A	High temperature increase no precipitation change	+3.0	+6.3	+9.7	0	0	0
3B	High temperature increase Precipitation decrease	+3.0	+6.	+9.7	-5	-10	-15

Median Runoff into Hetch Hetchy
(results based on 1975-2008, median year is 2003)

San Francisco Water Power Sewer

Change in Median Runoff volume for future climate conditions

Climate Change Scenario		Hetch Hetchy Runoff (% change from 2010) 2040	2070	2100
1A	Low temperature increase No precipitation change	-1%	-2%	-3%
2A	Moderate temperature increase No precipitation change	-1%	-3%	-5%
2B	Moderate temperature increase Precipitation decrease	-8%	-16%	-25%
2C	Moderate temperature increase Precipitation increase	-1%	+2%	+2%
3A	High temperature increase No precipitation change	-2%	-6%	-10%
3B	High temperature increase Precipitation decrease	-9%	-19%	-29%

2012 WUCA Work Plan

- 12 Projects, including:
  - Piloting Utility Modeling Applications (PUMA): Assessment and climate services experiments in five water utilities
  - Decision Support Planning Methods White Paper: Case Studies of DSPMs in action
  - Engage in National Climate Assessment
  - Participate in CESM Societal Dimensions Work Group focus area on water resources
  - Discern federal agency adaptation activities (stagnant – the WUCA work plan, not the activities)
  - Write short white papers on urgent subjects: First paper on Climate Services (Behar, Fleming, et al)

San Francisco Water Power Sewer

Approaches

1. Improving understanding of how climate system works and how it is represented in models

2. Improving archiving of data from models that currently exist to enhance accessibility and downstream experiments

Objectives for improved science

1. Improve model agreement on change in key parameters.
2. Narrow range of model output
3. Match model resolution with scales of water utility hydrologic and systems models (and other users' tools)
4. Improved projections within planning horizons of decisionmakers, i.e. several decades

Options for Improving Modeling - 1

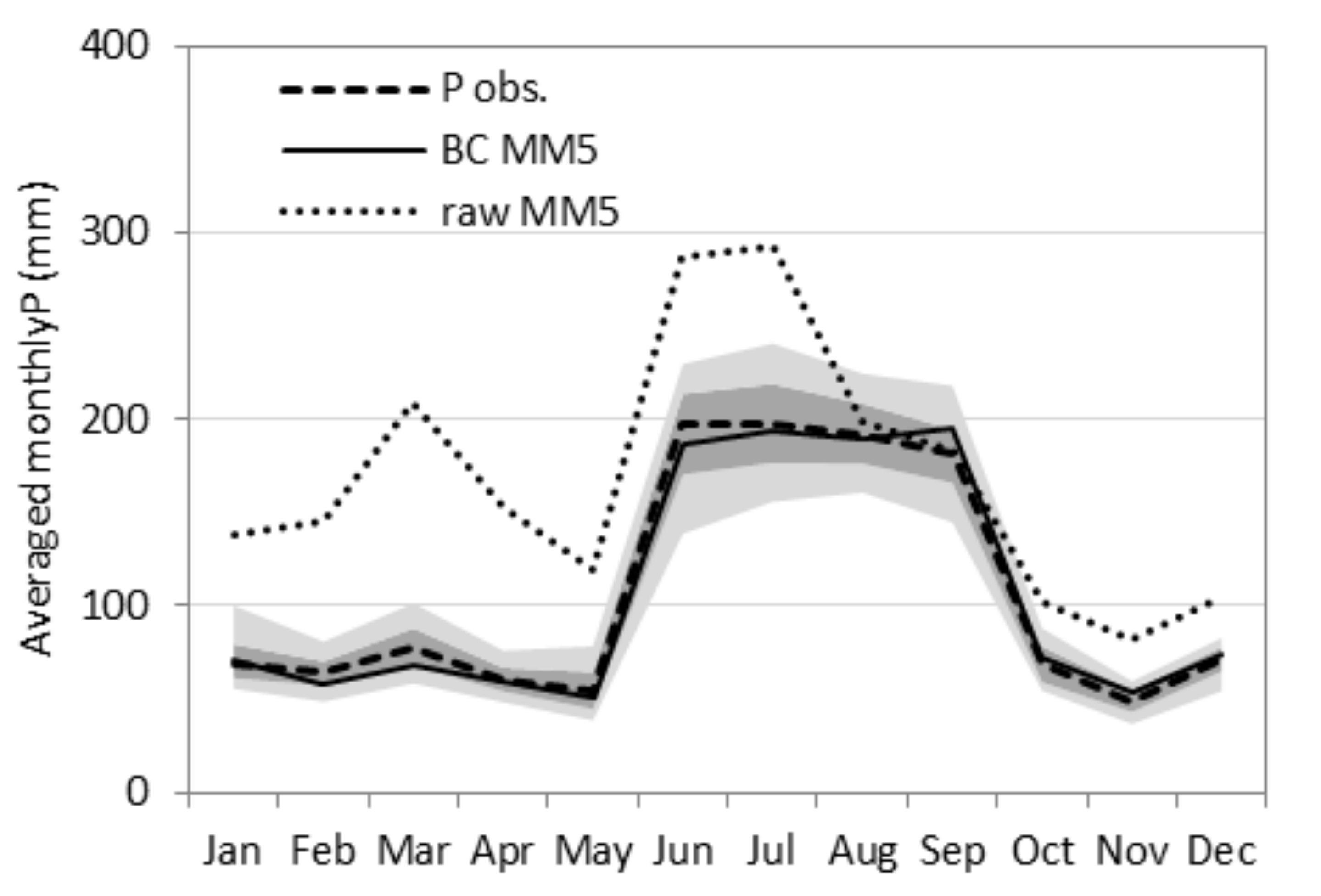
- **GCM Options**
  1. Development and enhancement of global climate model ensembles
  2. Improved use of observations to constrain climate model projections
  3. Improved modeling of the Tropical Pacific
  4. Improved decadal prediction

Options for Improving Modeling - 2

- **Downscaling Options**

1. Development of regional ensembles
2. Development of regional climate model components
3. Development of statistical downscaling techniques for probabilistic downscaling, extremes, and daily data

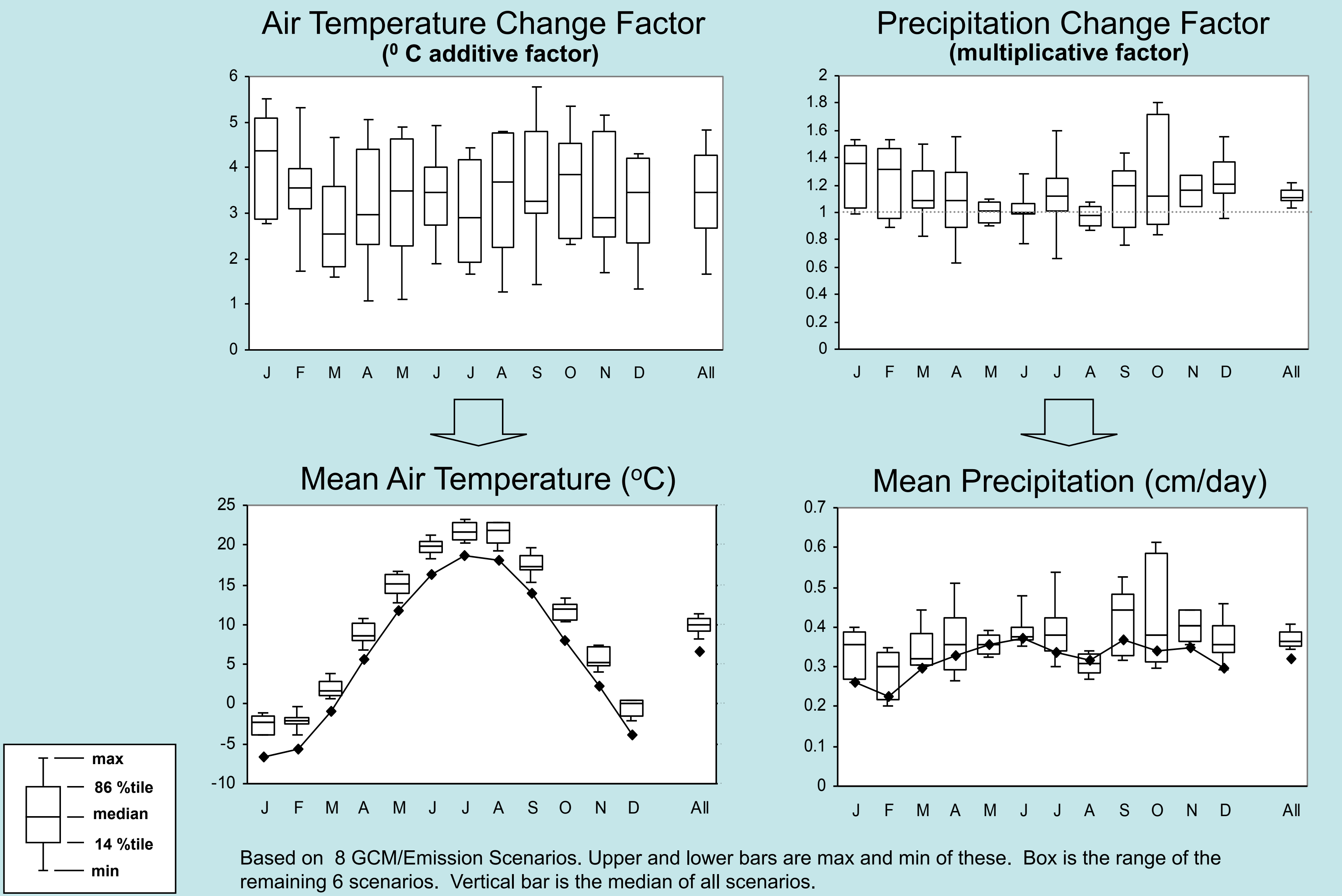
Monthly Mean Precipitation



Summary of Assessment Work to Date

- Focused on re-analysis data sets
- Temporal & spatial variability are important for hydrologic modeling
  - Downscaling method matters
- High resolution climate models needed to reproduce spatial & temporal distribution of rainfall
- Rain-driven hydrologic systems, climate model physics need improvements

Monthly Precipitation and Air Temperature for 8 GCM/ Emission Scenarios – 100 years forward



Based on 8 GCM/Emission Scenarios. Upper and lower bars are max and min of these. Box is the range of the remaining 6 scenarios. Vertical bar is the median of all scenarios.

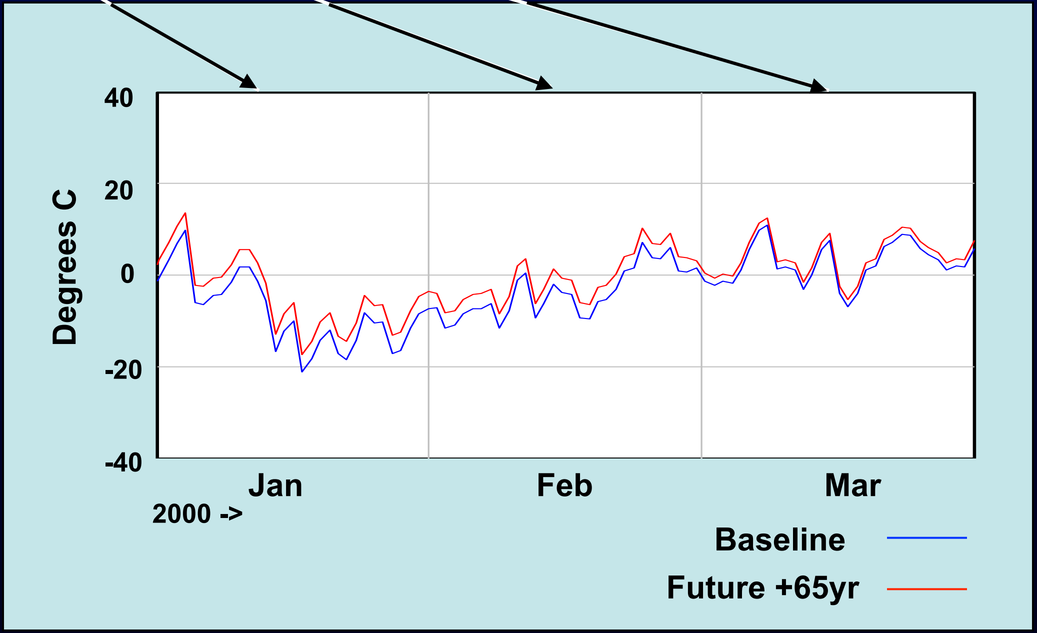
Application of Climate Change Factor Method
Air Temperature

Average GCM-Projected Air Temperature by Month for Control and Future Periods

	J	F	M	A	M	J	J	A	S	O	N	D
Control Period (1981-2000)	-5.4	-3.3	2.4	7.5	12.2	17.7	20.3	19.2	15.0	9.6	2.2	-2.5
Future Period (2046-2065)	-1.6	-0.2	4.0	9.3	15.4	20.0	22.8	21.9	18.6	11.4	4.9	0.2
Delta Temperature Factor = Future - Control	3.8	3.1	1.6	1.8	3.3	2.3	2.5	2.8	3.6	1.8	2.8	2.6

Daily Air Temperature Input Data for Model Simulations

(Future = Baseline + Factor)



"No Regrets" Strategies

* Planning for Drought

* Planning for Regulation

* Planning for Climate Change

Is there a difference?