New York City's Climate Change Integrated Modeling Project

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Acknowledgements

DEP Bureau of Water Supply

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Past Group Members: Don Pierson, Elliot Schneiderman, Mark Zion, Dave Lounsbury, Don Kent

City University of New York (CUNY)

Current CUNY Post-Docs: L. Huang, N. Acharya, Y. Li, K. Son

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Columbia University/NASA GISS

Cynthia Rosenzweig, David Major, Radley Horton

New York City Water Supply System

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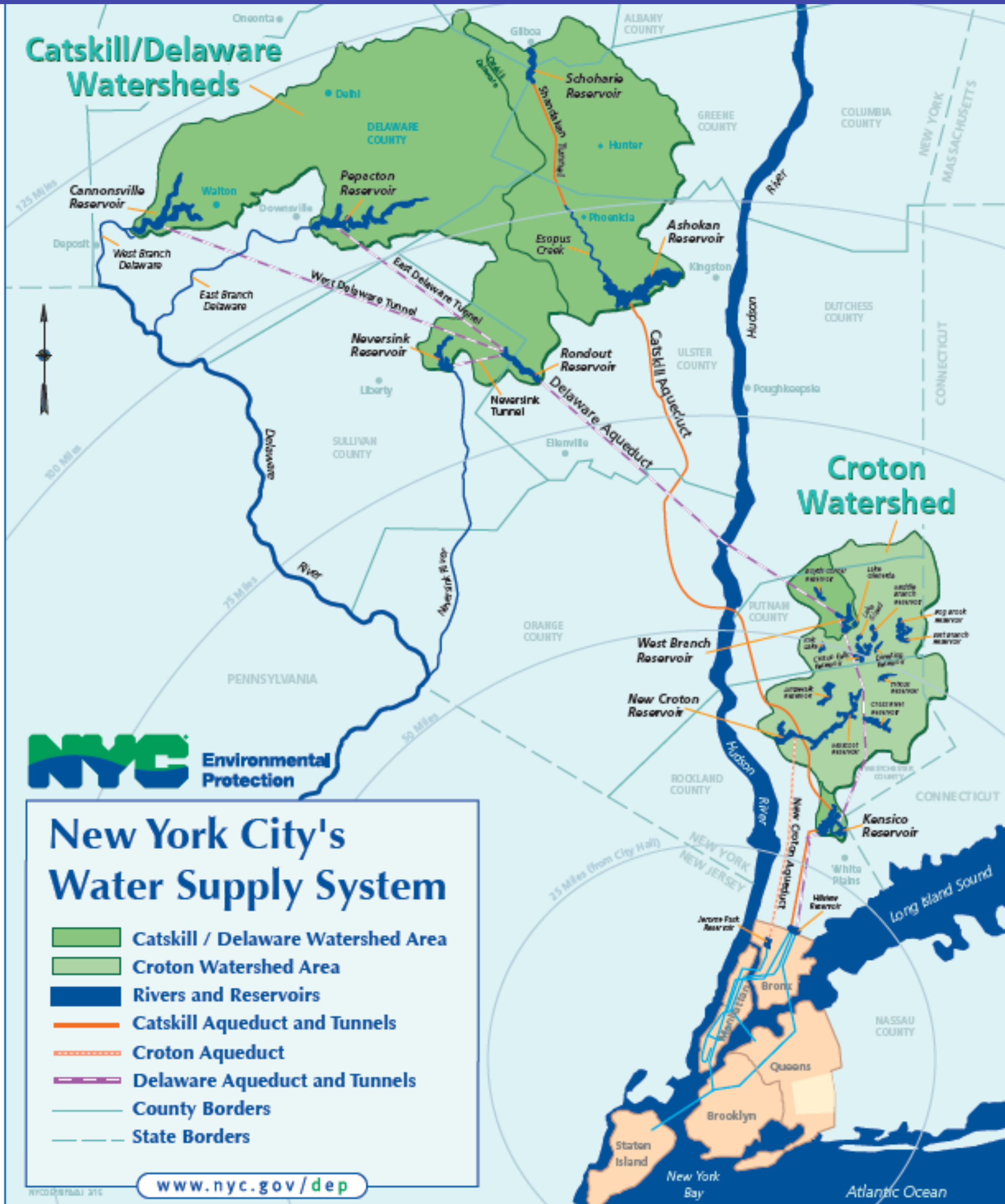

- **Primarily a surface water supply**
- **19 reservoirs & 3 controlled lakes**
- **Serves 9 million people (1/2 of population of NY State)**
- **System Capacity: 550 billion gallons**
- **Delivers ~1.1 billion gallons per day**
- **Source of water is a 2,000 square mile watershed in parts of 8 upstate counties**
- **Operated and maintained by NYC Dept. of Environmental Protection (DEP)**

New York City Water Supply System (cont'd)

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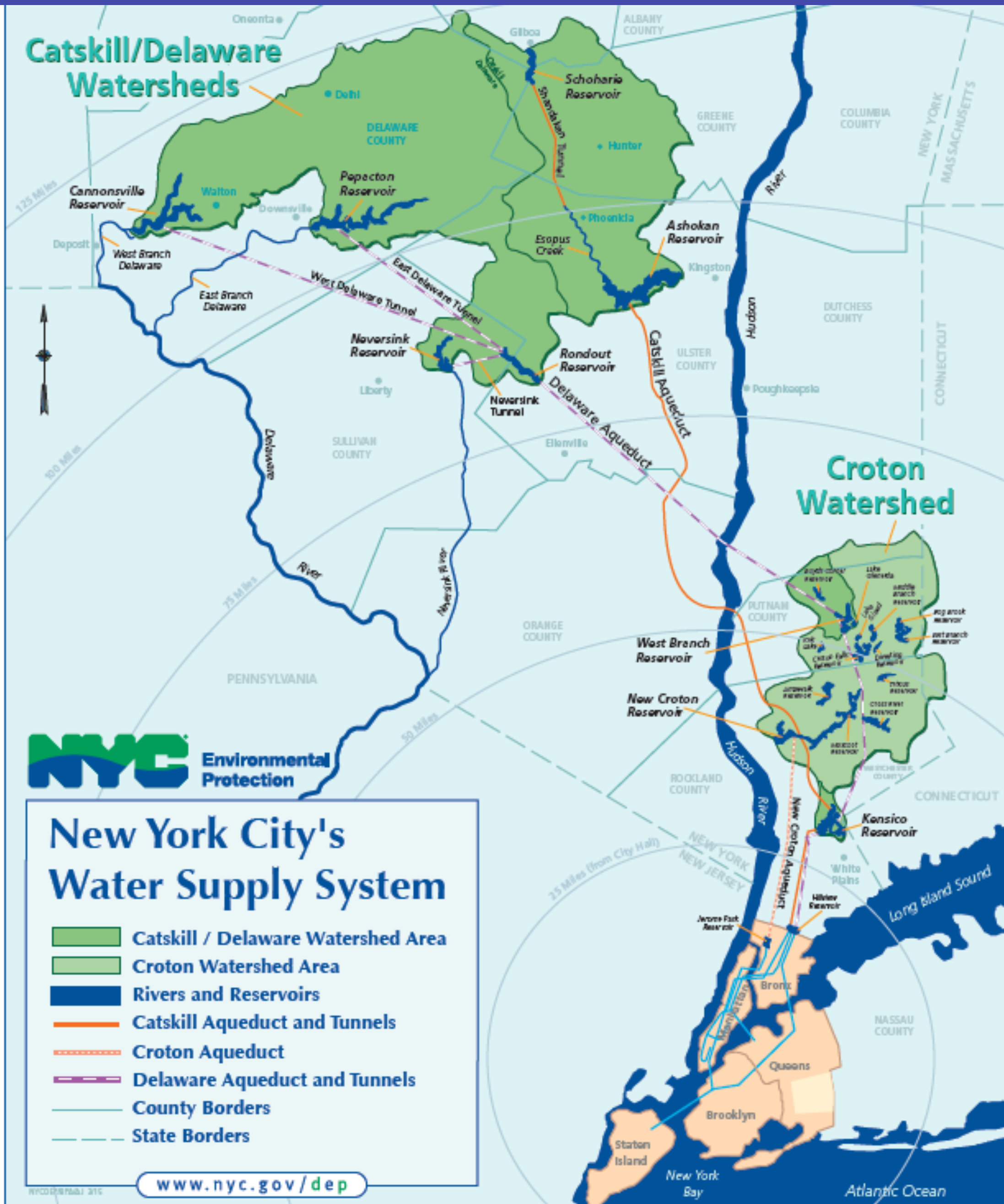

- Croton system (10% of supply) served by filtration plant; cost ~$2.3 billion
- Catskill and Delaware systems (90% of supply) are unfiltered (disinfection only)
- Disinfection provided by chlorination and UV (world's largest UV plant)
- NYC has been granted Filtration Avoidance by regulatory agencies (may operate without filtration); renewed every 5 years
- Climate change impacts:
- quantity (system-wide)
- in unfiltered supply:
  - turbidity
  - eutrophication
  - disinfection byproducts

History of Climate Change Evaluation

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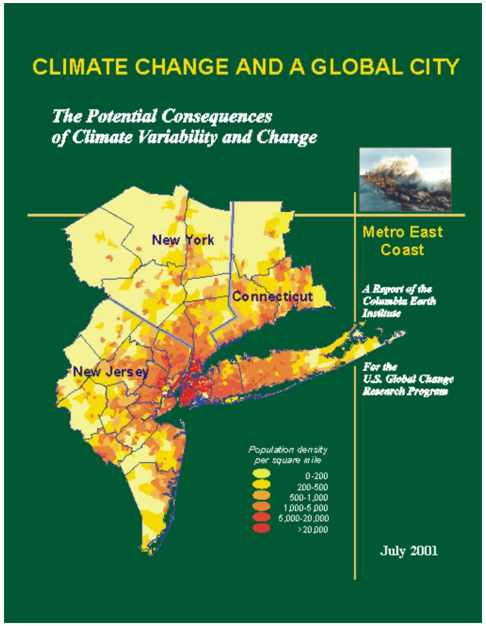
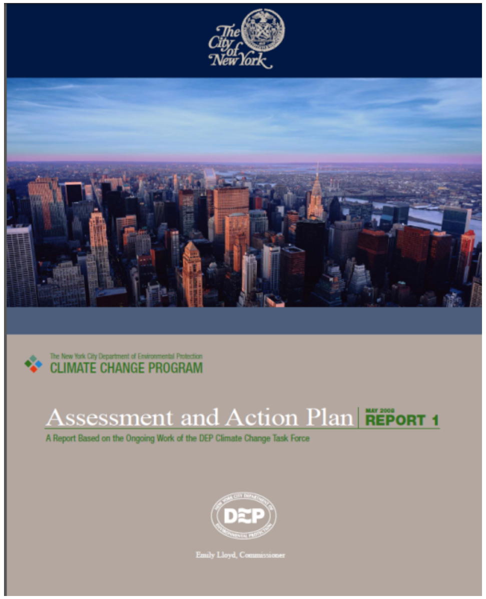
- 2001 – Metro East Coast Assessment, prepared by scientists at the Columbia Univ. Earth Institute
- 2003 – Joined European Union CLIME project (Climate Impacts on Lakes)
- 2004 – NYCDEP Climate Change Task Force formed
- 2006 – Draft Climate Change Guidelines and Climate Scenarios Reports issued

  – Planning for Climate Change Integrated Modeling Project (CCIMP) in Water Quality Modeling group begins
- 2007 – CCIMP Planning Workshop at Columbia Univ.

  – Water Utility Climate Alliance (WUCA) formed
- 2008 – Release of DEP Climate Change Program: Assessment and Action Plan





History of Climate Change Evaluation (cont'd)

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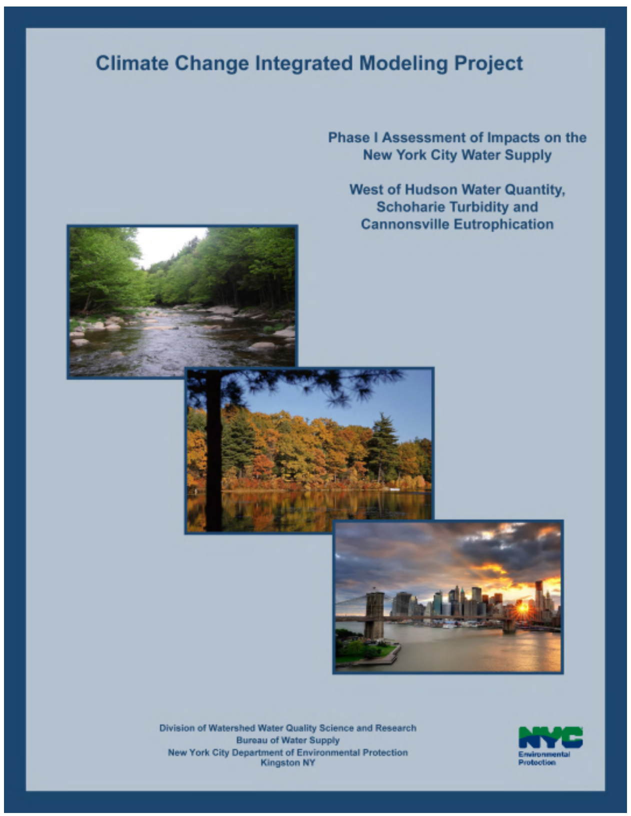
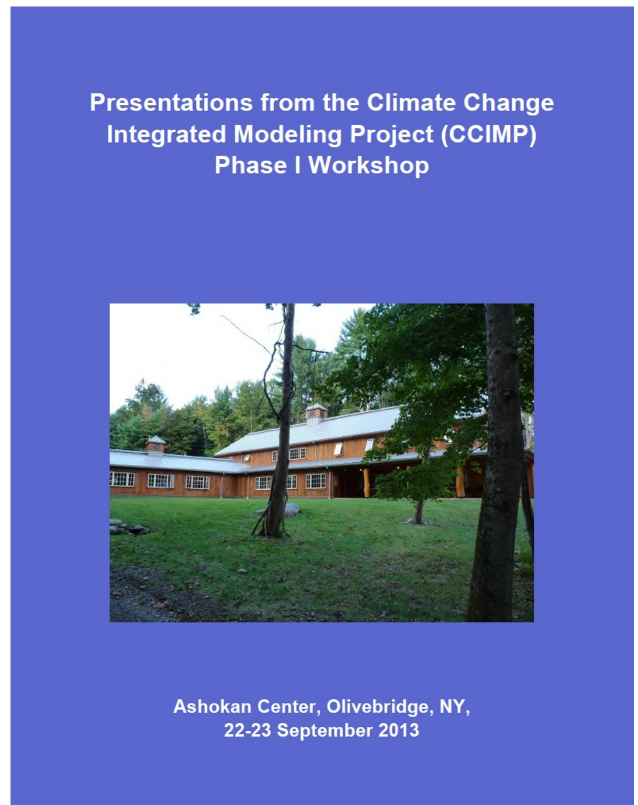
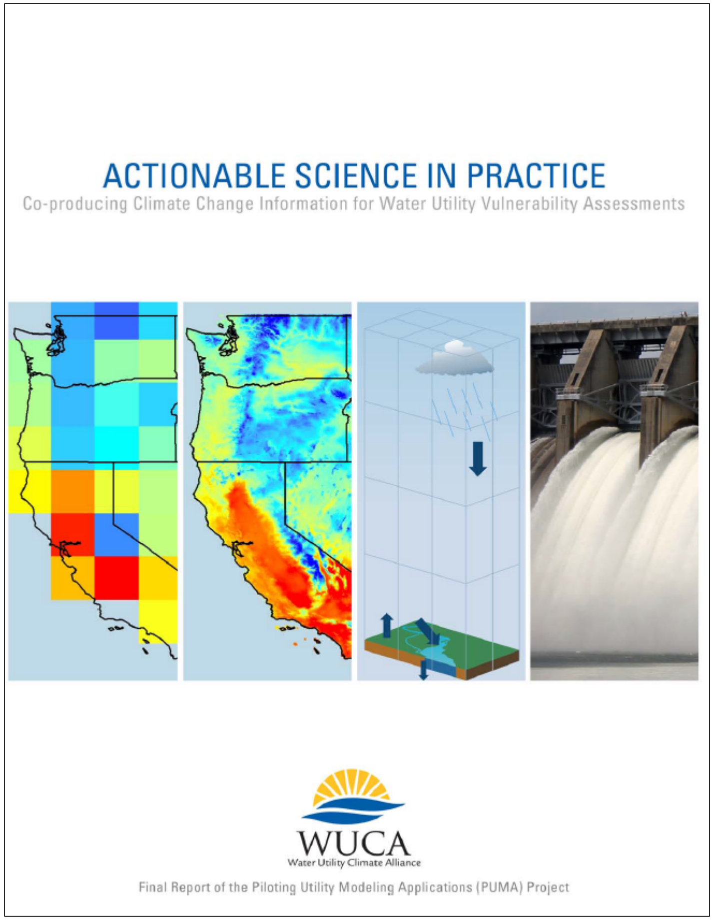
- 2009 – First contract with City University of New York (CUNY) to provide support for CCIMP
- 2010 – Piloting Utility Modeling Applications (PUMA) group formed
- 2013 – First CCIMP review workshop and review by expert panel
    - – Phase I concluded, report published





History of Climate Change Evaluation (cont'd)



- 2014 – Phase II of CCIMP begins
- 2014 – Second 4-year contract with CUNY to provide support for CCIMP
- 2015 – PUMA final report; DEP contribution describes Phase I of CCIMP
- 2015-2016 – New staff hired for 4 of 5 full-time positions in DEP's Water Quality Modeling Group
- 2015-2016 – New CUNY post-doctoral research staff hired (4 total)
- Ongoing – Phase II of CCIMP

CCIMP Phase I Goals and Study Areas

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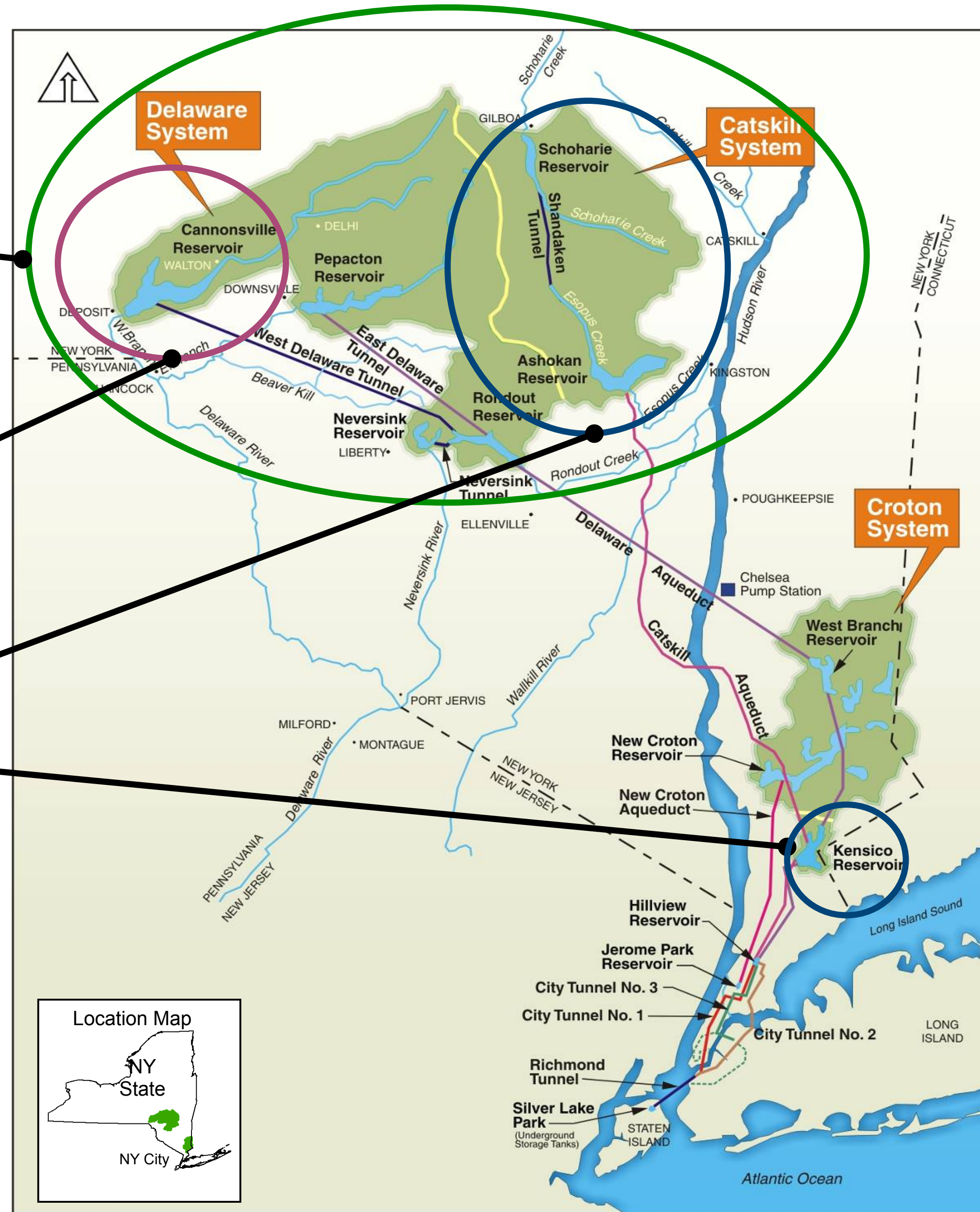
- Quantity – Focus on West-of-Hudson watersheds and reservoirs
- Eutrophication – Focus on Delaware System (particularly Cannonsville Reservoir)
- Turbidity – Focus on Catskill System



NYC DEP Contribution to PUMA

- Phase I of CCIMP began prior to PUMA
- DEP started with relatively simple modeling approaches and tools
  - downscaling of climate model data
  - watershed modeling: weather to runoff
  - reservoir models
- More complex approaches and tools, which require more data to operate and test, are now being investigated

NYC DEP Contribution to PUMA (cont'd)

- Identification of impacts:
  - reduction of winter snowpack
  - timing of winter runoff
  - changes in reservoir thermal stratification
  - increase in severity/frequency of extreme events
- After impacts are identified, investigate changes in operational policies to minimize negative impacts

1. Selecting Global Climate Models

- initial evaluation of 4 GCM's – probabilistic analysis of baseline GCM output compared with historical data
- no single model fit various weather variables well (air temperature, precipitation, solar radiation, wind)
- output from roughly 20 GCM's (CMIP3) used in subsequent modeling

2. Developing Future Climate Scenarios

- Future climate scenarios, downscaling developed using delta-change method
- ***advantage:*** direct scaling of local historical observations, using changes predicted by GCMs
- ***advantage:*** allowed staff to apply knowledge of past events when considering climate change
- ***disadvantage:*** time sequence of events in a scenario is unchanged from the historical record; changes in event frequency or antecedent conditions associated with climate change not captured

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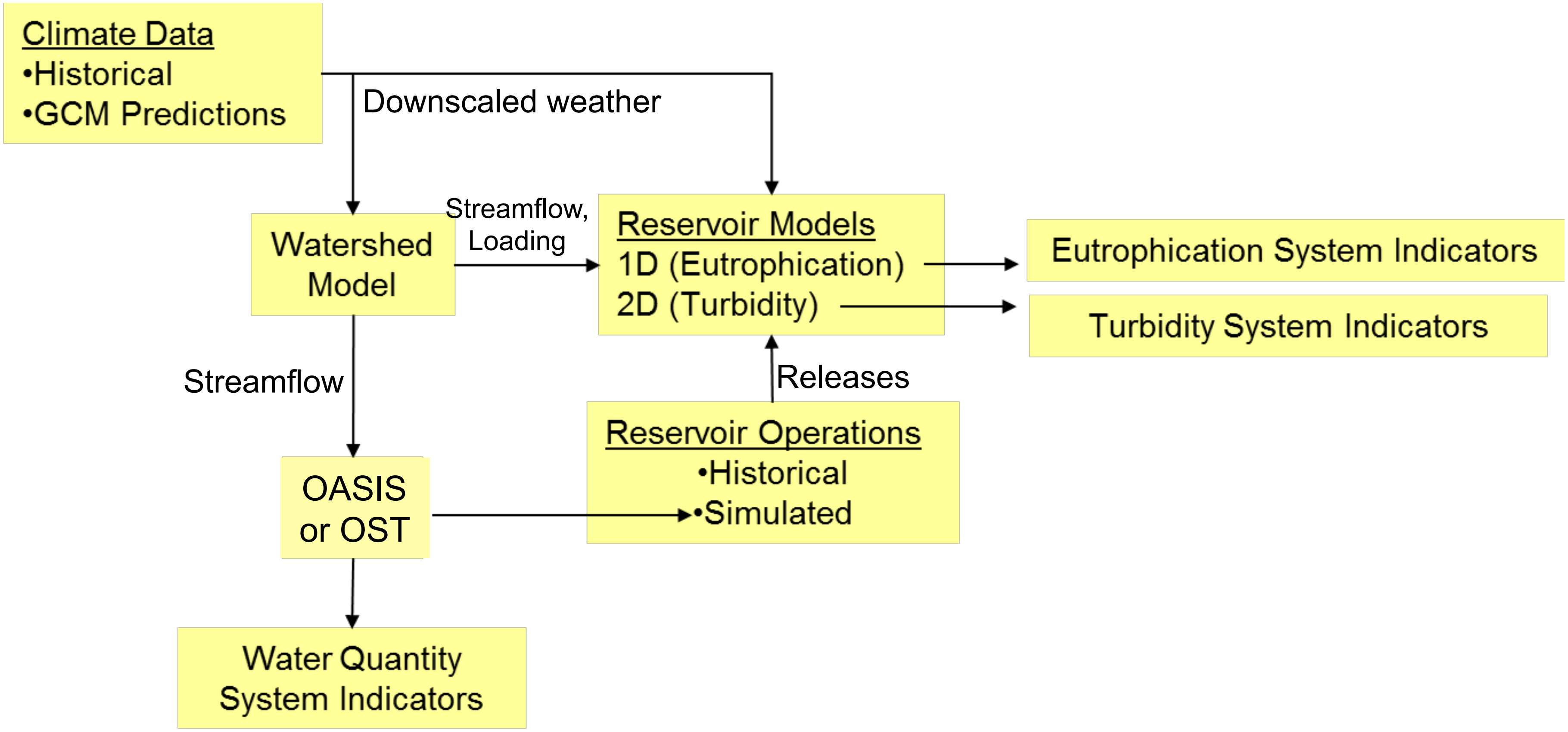
3. Water Quality Problems due to Extreme Events

- Impact of climate change on water quality of greatest interest to DEP
- Impacts driven by extreme events: increases in
  - turbidity
  - organic carbon/disinfection byproduct precursors
- Extreme events captured using "SD-delta method", a variant of the delta change method
- Change factors determined from infrequently-occurring (extreme) conditions used to generate scenarios

4. Bringing Scientific Expertise In-House: Partnership with CUNY Institute for Sustainable Cities

- 4 post-doctoral researchers working full-time with DEP staff at DEP office
- oversight by 4 faculty advisors (Alan Frei- CUNY, Larry Band- U. North Carolina, Tammo Steenhuis-Cornell, Paul Hanson– U. Wisconsin)
- mechanism for knowledge transfer, application of state-of-the-art models
- allows broad scope, including: climate science, forest hydrology, reservoir processes, watershed protection

NYCDEP Integrated Modeling System



Integrated Modeling Components – Phase I

- Global Climate Models (GCMs) – we use predictions developed by outside meteorologists & oceanographers
- Downscaling of climate predictions to watersheds
- Watershed (terrestrial) models (GWLF)
- Reservoir water quality models (UFI, Protbas, W2)
- System operations model - Operations Support Tool (OST)

GCM Emission Scenarios – Phase I

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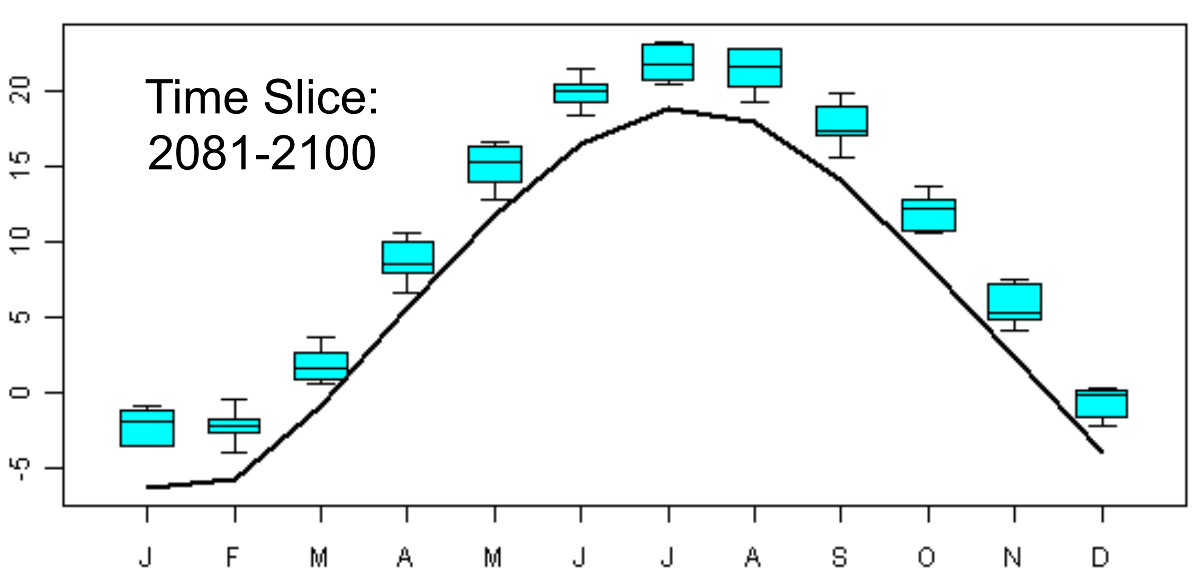
- We commonly select several GCMs, and several emission scenarios
- Common approach: all combinations of GCM/ emission are equally reliable/likely forecasts of future conditions
- For example, each of 4 GCMs (CCGCM, GISS, CCSM3, and ECHAM5/MPI-OM) generates prediction for 3 scenarios = 12 forecasts of conditions for:
  - Baseline (current conditions)
  - 2046-2065 (40 years out)
  - 2081-2100 (75 years out)

Some Selected Phase I Findings

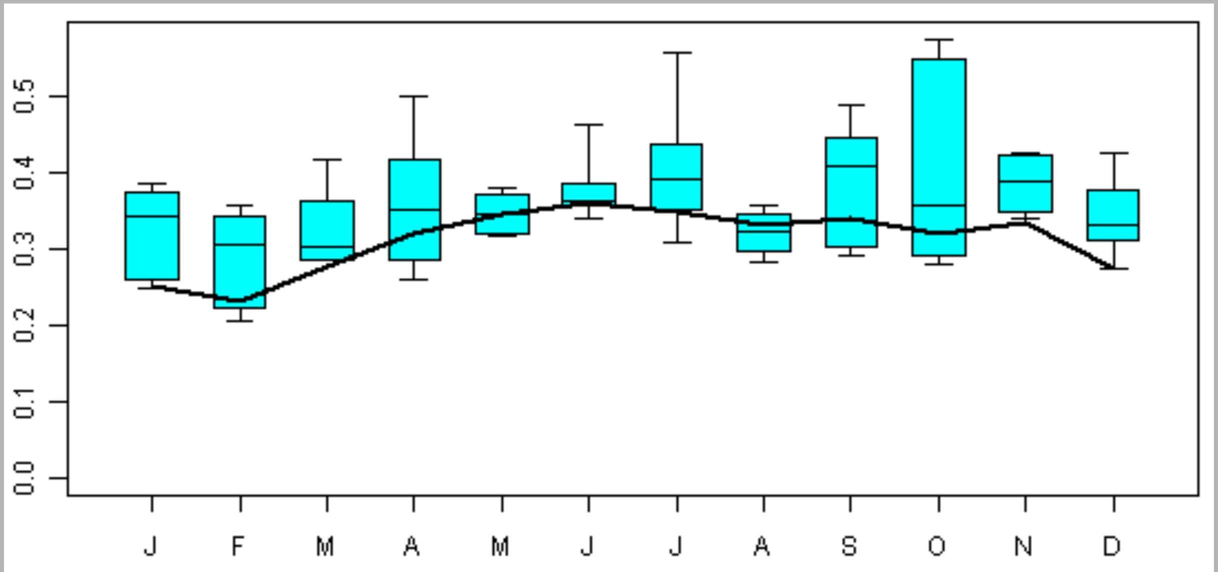
Climate Projections: Precipitation, Air Temperature

Mean Daily Air Temp. (^oC)



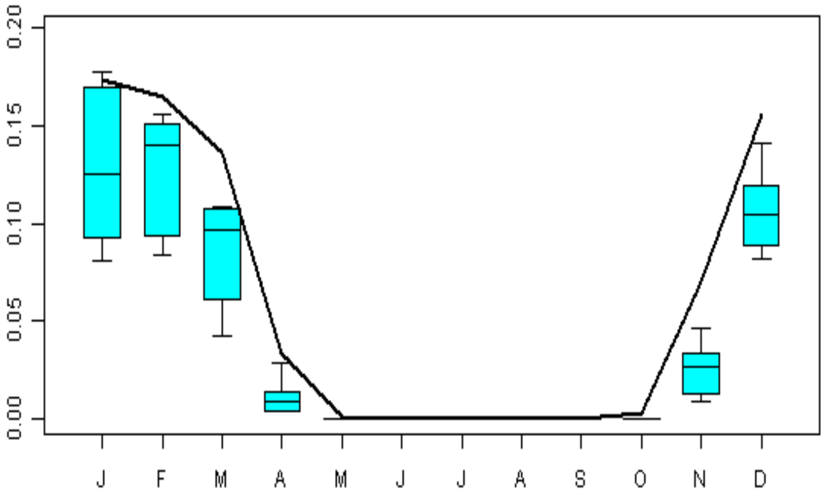
solid line is baseline (current) condition

Precipitation (cm/day)

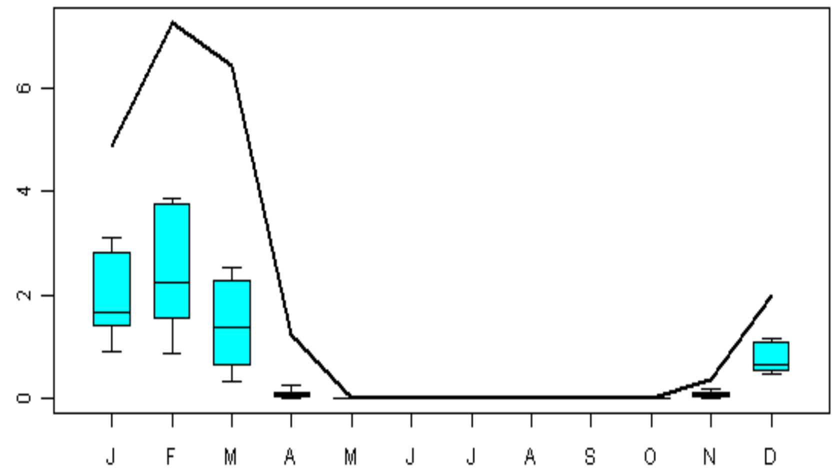


Changes in Snowfall, Snowpack

Snowfall (cm/day) 2081-2100

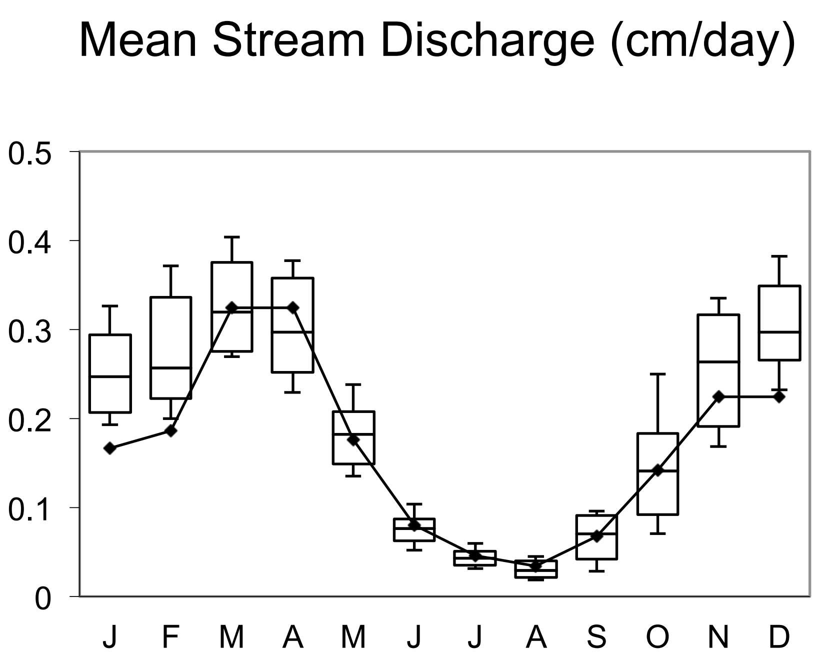


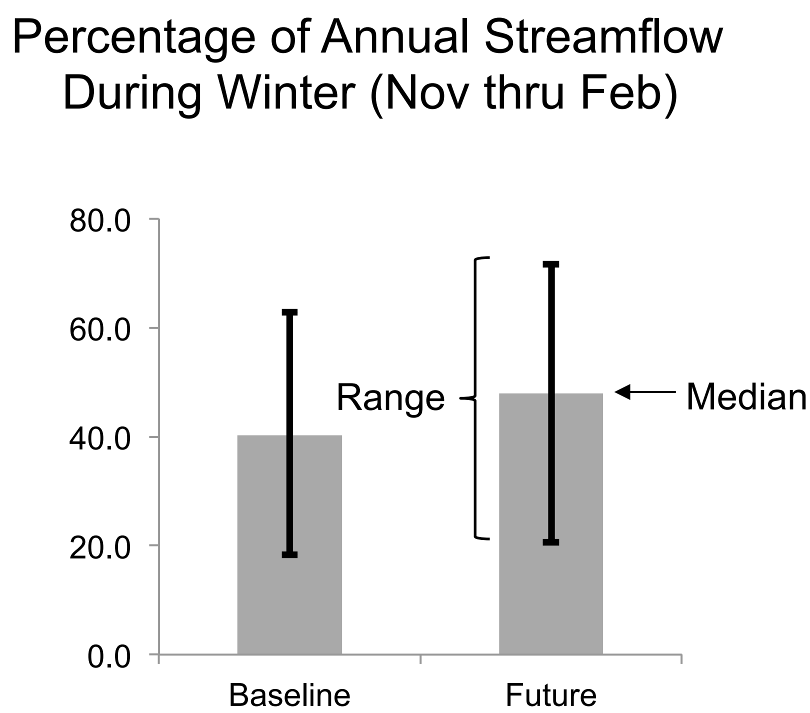
Snowpack (cm) 2081-2100



Solid line is baseline (current) condition
Areal average values for Catskill/Delaware watersheds

GCM scenarios indicate ample water supply



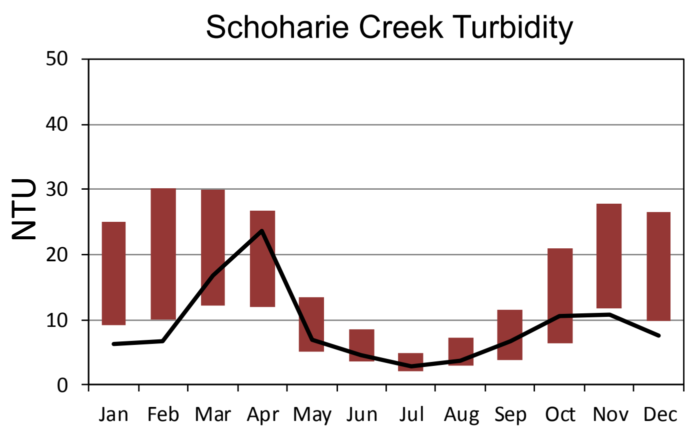


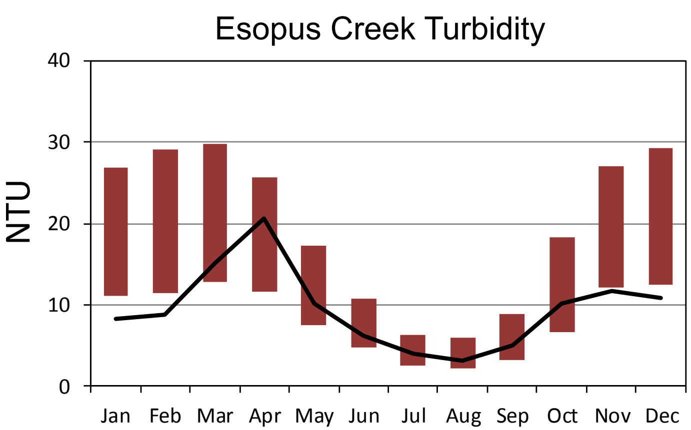
Solid line is baseline (current) condition
Average values for Catskill/Delaware watersheds

Effects of Climate Change on Catskill Turbidity

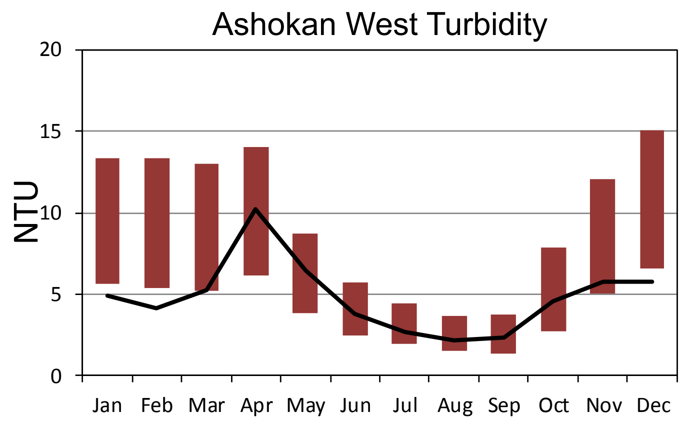
Average Monthly Predictions

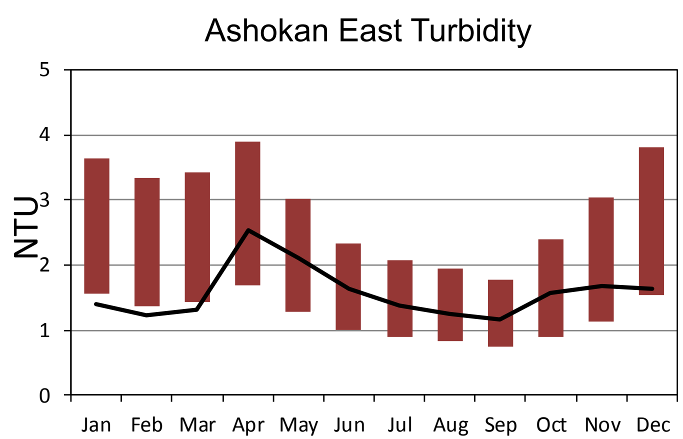
Streams





Reservoirs

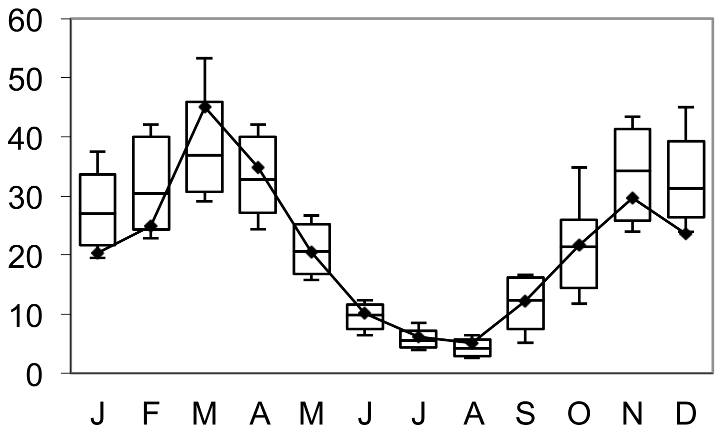


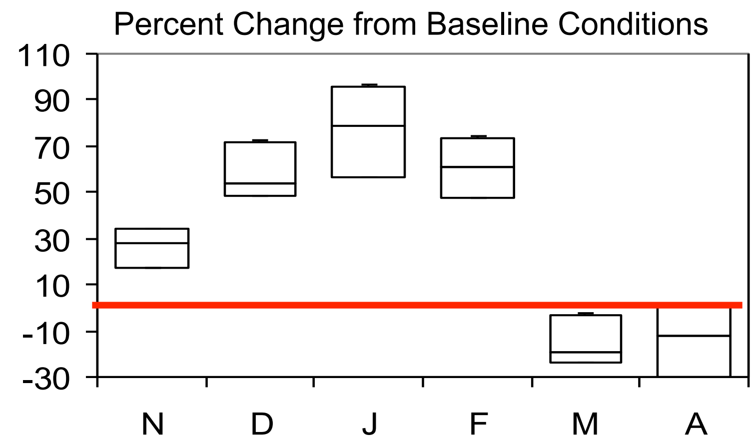


Bars show the range of climate change predictions
Line shows current (baseline) simulation

6% Increase in Mean Annual Load

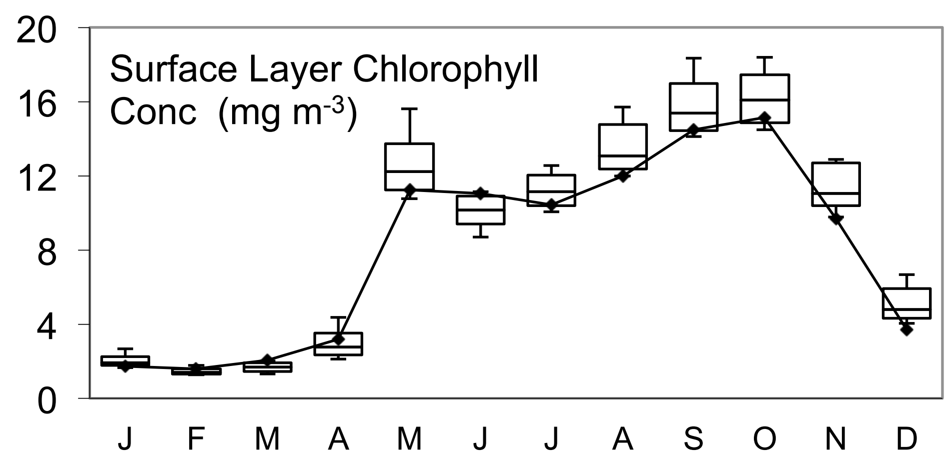
Watershed Dissolved Phosphorus Load ($kg\ km^{-2}\ month^{-1}$)





Growth (photosynthesis) increases:

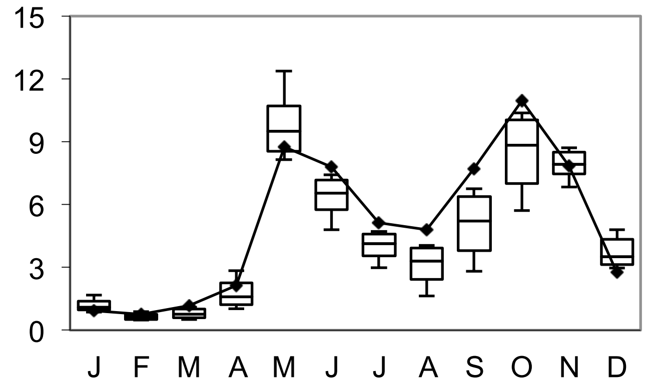
- Increasing water temperature (most important)
- Increasing nutrient load



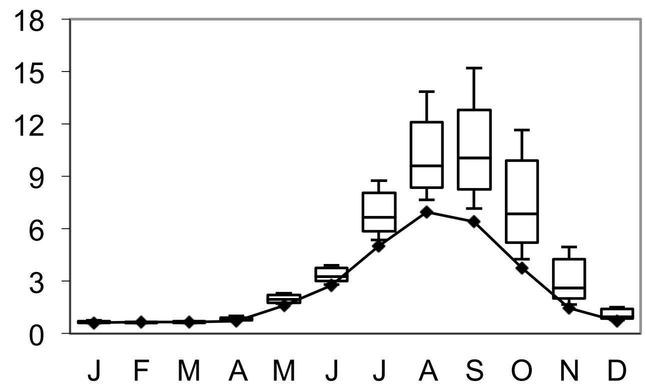
Source: Water Quality Modeling Status Report, March 2014. Areal average for WOH watersheds

Phase I Functional Group Biomass

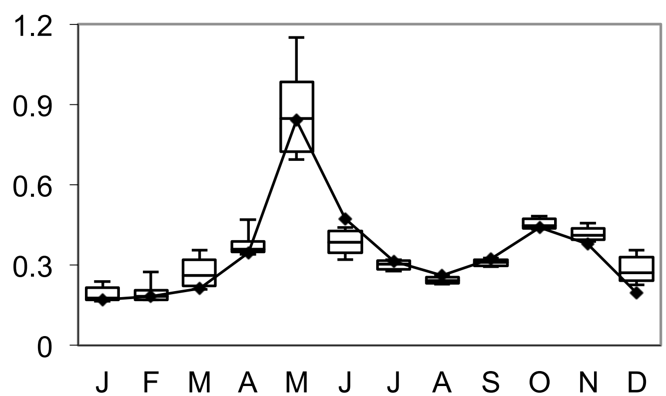
Diatoms



Cyanobacteria



Flagellates



Some Selected Phase II Preliminary Findings

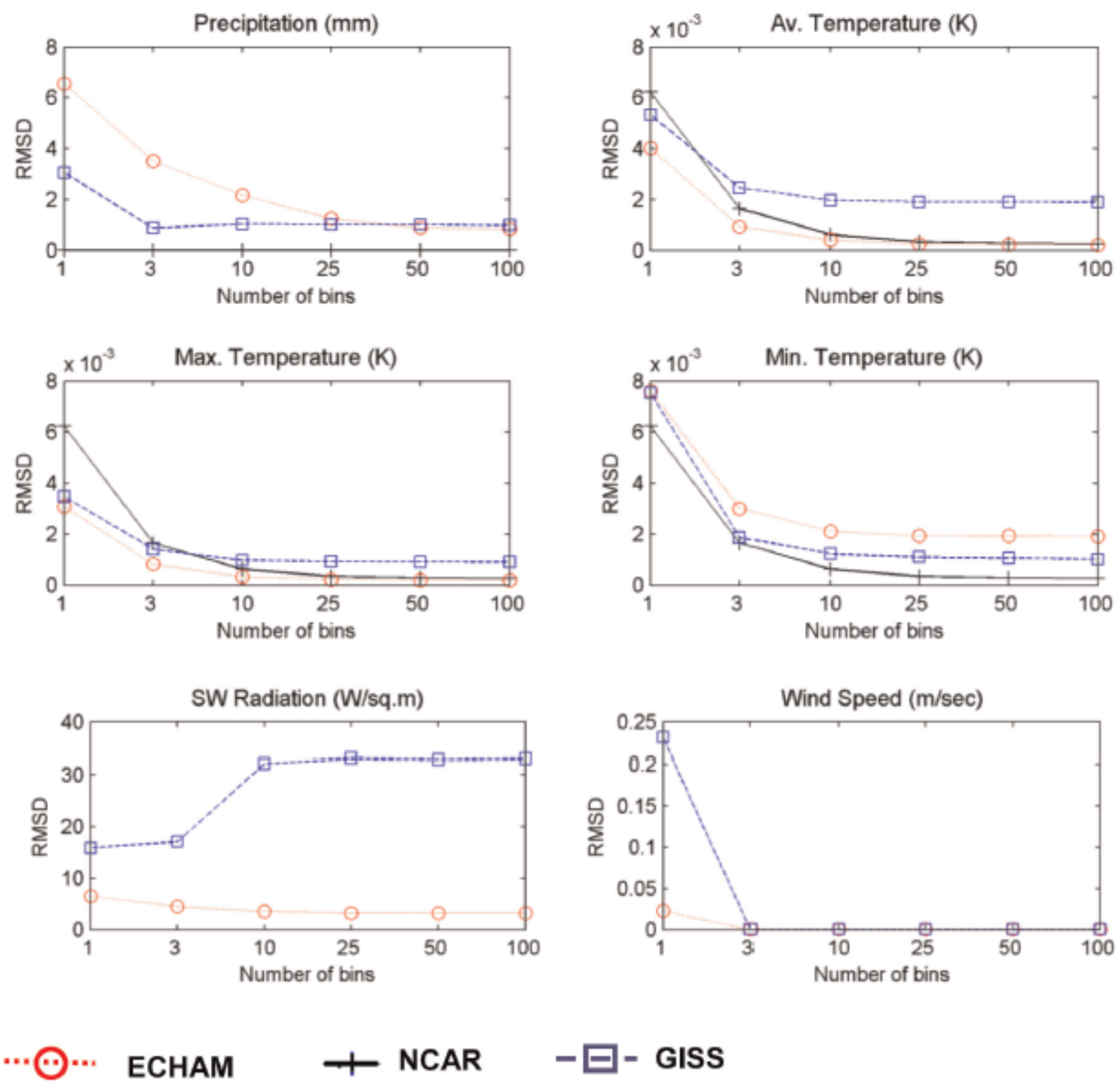
CCIMP Phase II

- Evaluate stochastic weather generators as alternative to change factor approach
- Application of SWAT watershed model (Soil Water Assessment Tool), begun at end of Phase I
- Application of forest ecosystem model (RHEESys) to Neversink watershed - a more detailed mechanistic approach to modeling of forested watersheds
- Development of disinfection by-product model (Cannonsville and Neversink)
- OST support and development

Goals of the CCIMP Phase II

- Update future climate scenarios used to drive watershed, reservoir models
  - CMIP5 (30+ models with daily PRCP already processed)
  - Test and evaluate downscaling multi-bin approach (quantile mapping)
- Stochastic weather generators
  - Synthetic time series of meteorological data
  - Better representation of extreme events
  - Application in “bottom-up” evaluations – identification of “plausible” climate conditions that challenge ability to successfully deliver water

Goals of the CCIMP Phase II



Goals of the CCIMP Phase II (cont'd)

- Apply and evaluate new watershed models
  - Simple model (GWLF) used previously
  - SWAT (Soil Water Assessment Tool)
  - RHEESys (Regional Ecohydrologic System)
  - NYC DEP has data to support these more complex, spatially-distributed models
  - More accurate prediction of climate impacts on runoff, sediment, nutrient, carbon loading

Goals of the CCIMP Phase II (cont'd)

- Develop DBP precursor reservoir model
  - Simulation of terrestrial sources of organic carbon (OC) and precursors – RHEESys and SWAT (above)
  - Reservoir model – internal processing and production of OC and precursors
  - Management: evaluate relative importance of terrestrial versus reservoir sources of DOC and precursors
  - Change factor ("top down") and weather generator ("bottom-up") evaluations of climate change

CCIMP Phase II – Logistics of Working Relationships

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CUNY / NYCDEP Contract

Climate Data, CMIP5

Data & CMIP5 results compilation, analysis, vulnerability assessment

Advisor:
A. Frei, CUNY
(also PI)

Postdoc:
N. Acharya

Watershed Hydrology Modeling

SWAT Model, watershed nutrient loads, effects of watershed management

Advisor:
T. Steenhuis,
Cornell U.

Postdoc:
Linh Hoang

Watershed Biogeochemical Modeling

RHESys Model, Forest Processes, contribution to nutrient, sediment, and hydrology

Advisor:
L. Band,
U. N. Carolina

Postdoc:
Kyongho Son

Reservoir Modeling

GLM Model, hydrothermal and biological processes, contribution of DOC and DBP

Advisor:
P. Hanson,
U. Wisconsin

Postdoc:
Yu Li

Vulnerability Assessment

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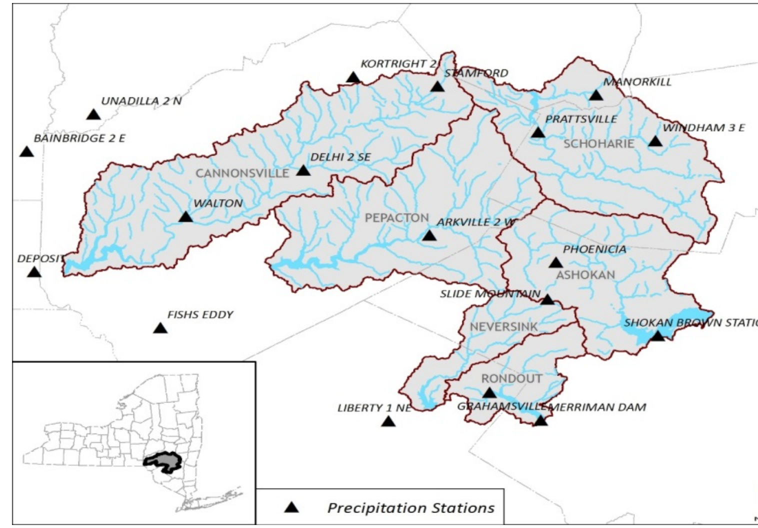
Selected Preliminary Results from the Evaluation of Stochastic Weather Generators



Basin-mean PRCP based on station obs

Weather Generator

Occurrence Process

Amount Process

Markov Chain Model
- 1st order (MC1)
- 2nd order (MC2)
- 3rd order (MC3)

Parametric distribution
- Exponential (EXP)
- Gamma (GAM)
- Skewed Normal (SN)
- Mixed Exponential (MEXP)
- Hybrid Exponential and Generalized Pareto (EXPP)

Resampling
- k-nearest neighbor

Curve Fitting
- Polynomial of order-2

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Selected 7 models for generating daily precipitation amounts

Type	Name	Abbrev.	Reference
Parametric	Exponential	EXP	Todorovic & Woolhiser (1975)
	Gamma	GAM	Ison et al. (1971), Richardson & Wright (1984)
	Skewed-normal	SN	Nicks & Gander (1994)
	Mixed exponential	MEXP	Woolhiser & Roldán (1982), Wilks (1999b)
	Hybrid exponential and generalized Pareto	EXPP	Li et al. (2012)
Resampling	k-nearest-neighbor conditional bootstrap	k-NN	Rajagopalan and Lall (1999)
Curve-fitting	2^{nd} order polynomial unconstrained by the prob max precip (PMP)	PN	Chen et al. (2015)

SWG Evaluation Criteria. Focus on Extremes.

MC models (prcp occurrence)

- # wet days/mo, spell length distributions

PRCP distributions (prcp amount)

- mean, median, std, IQR, skewness
- Q95, Q99
- Box-And-Whisker Plot
- Extreme Event Indices
  - RX1day: max daily ann prcp
  - RX5day: max 5-day ann prcp
  - R95p: ann total from all events >= 95 %tile
  - R99p: ann total from all events >= 99 %tile
- Extreme Value Theory (EVT-based) daily magnitudes
  - 50, 75, 100 year return periods

CCIMP Phase II – SWG Evaluation (cont’d)

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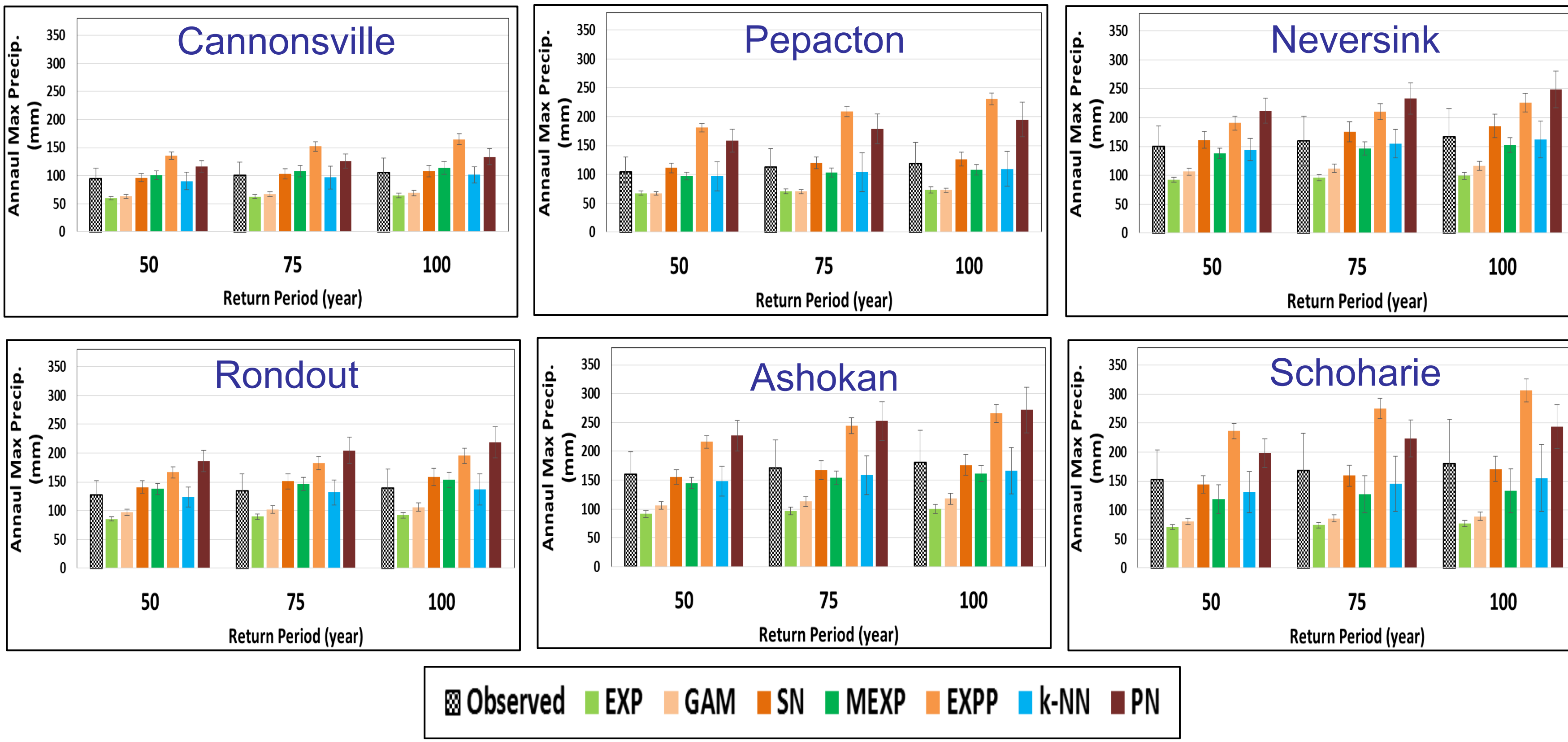
e.g. EVT-based Ann Max Daily PRCP Magnitude
50, 75, and 100-yr return periods



e.g. EVT-based Ann Max Daily PRCP Magnitude 50, 75, and 100-yr return periods

Mean Absolute Percentage Error (MAPE) (%)

for all watersheds

Return Level	EXP	GAM	**SN**	**MEXP**	EXPP	**k-NN**	PN
50 year	40.06	33.76	**5.45**	**9.93**	43.86	**6.71**	38.89
75 year	41.36	34.77	**6.23**	**11.17**	51.31	**6.5**	43.44
100 year	42.27	35.48	**6.78**	**12.07**	56.92	**6.37**	46.78

MAPE <10% "Highly Accurate"
10% <= MAPE < 20% "Good"
(Lewis, 1982)

CONCLUSIONS: MC1 as good as higher orders
3 distributions are good for extremes
k-NN less appropriate for climate change studies

Type	Name	Abbrev.	Reference
Parametric	Exponential	EXP	Todorovic & Woolhiser (1975)
	Gamma	GAM	Ison et al. (1971), Richardson & Wright (1984)
	Skewed-normal	SN	Nicks & Gander (1994)
	Mixed exponential	MEXP	Woolhiser & Roldán (1982), Wilks (1999b)
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“Bottom-Up”: Decision-Scaling (Brown et al)
Scenario-Neutral Response Surfaces (Prudhomme et al)

1. Motivation
   climate models do not provide the full range of uncertainty

2. This class of methods allows us to
   a. put our understanding potential impacts in context of our understanding of system-behavior
   b. identify “plausibility” (if not the actual probability) of desirable and undesirable system-states; and conditions under which different management options are optimal

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GCMs may not capture the full range of plausible scenarios: tree ring climate reconstructions for our region not captured by GCMs

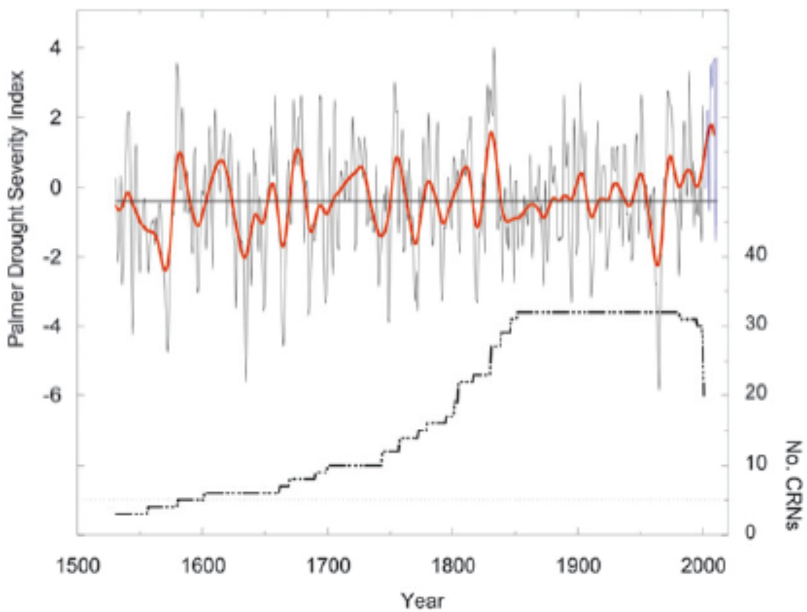
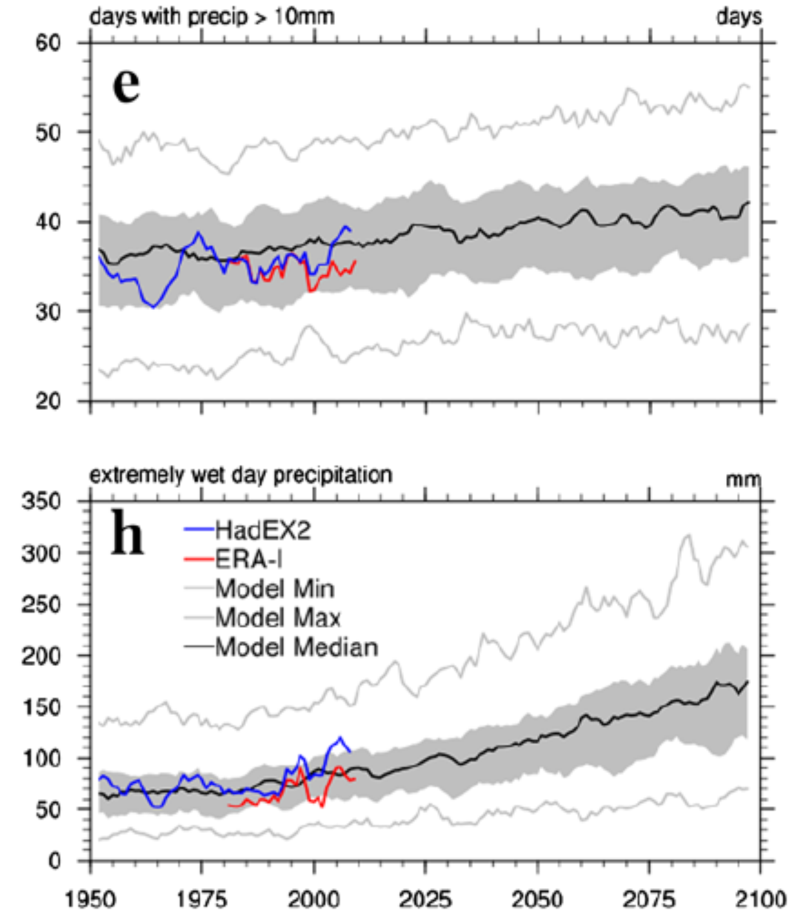


FIG. 3. Drought history of the NYC watershed region from 1531 to 2011. The orange, smoothed line is a 20-yr spline while the flat, black line represents the long-term median. Instrumental data during 2004–11 (in blue) is tacked onto the end of the tree-ring-based reconstruction (1531–2004). The thick, dot-dash line in the bottom of the figure represents the number of chronologies through time. The dashed-gray line highlights replication at five chronologies.



Is an Epic Pluvial Masking the Water Insecurity of the Greater New York City Region?* J. Clim, 2012

NEIL PEDERSON,# ANDREW R. BELL,# EDWARD R. COOK,# UPMANU LALL,@ NARESH DEVINENI,& RICHARD SEAGER,** KEITH EGGLESTON,++ AND KEVIN P. VRANES##

Changing climate extremes in the Northeast United States: observations and projections from CMIP5

Jeanne M. Thibeault · Anji Seth Climatic Change, 2014

CCIMP Phase II – “Bottom Up” Approach (cont’d)

Prudhomme et al. (2010): 2 basins in the UK

Response variable: annual flood peak magnitude

Forcing variables: mean annual change in PRCP and seasonal variation in PRCP

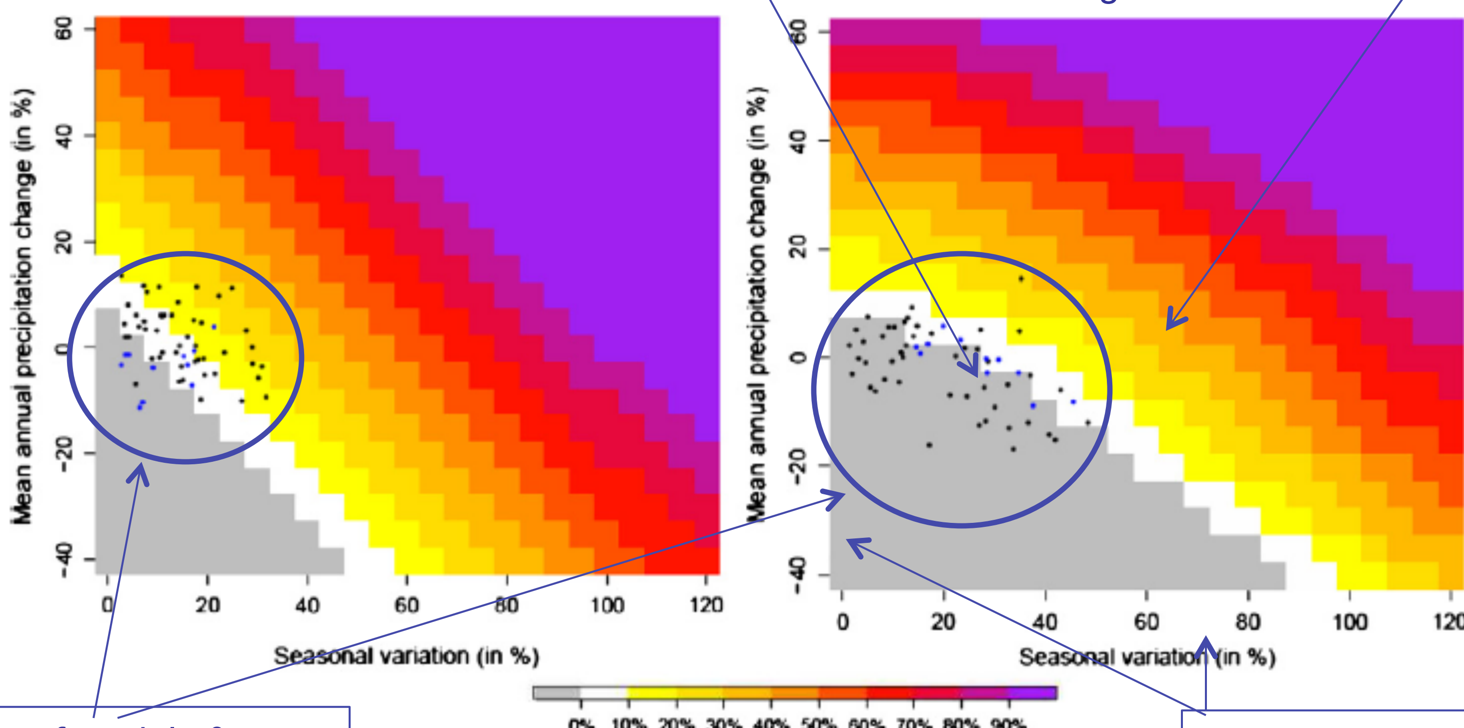
Assumes only one temperature scenario

Response surface (contours) produced by model

Reference (historical) period

NE Scotland

SE England



Ensemble of models & emission scenarios for 2080s

X, Y axes are forcing variables

Scenario-neutral approach to climate change impact studies: Application to flood risk J. Hydrology, 2010

C. Prudhomme [a,*], R.L. Wilby [b], S. Crooks [a], A.L. Kay [a], N.S. Reynard [a]

Thank You

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NYC.gov/DEP/ClimateChange

CUNYSustainableCities.org