New York City’s Climate Change Integrated Modeling Project

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Acknowledgements

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Wisconsin), Allan Frei (City Univ. of New York)

Columbia University/NASA GISS

Cynthia Rosenzweig, David Major, Radley Horton
New York City Water Supply System

- 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)
Ø Croton system (10% of supply) served by filtration plant; cost ~$2.3 billion

Ø Catskill and Delaware systems (90% of supply) are unfiltered (disinfection only)

Ø Disinfection provided by chlorination and UV (world’s largest UV plant)

Ø NYC has been granted Filtration Avoidance by regulatory agencies (may operate without filtration); renewed every 5 years

Ø Climate change impacts:
  Ø quantity (system-wide)
  Ø in unfiltered supply:
    Ø turbidity
    Ø eutrophication
    Ø disinfection byproducts
History of Climate Change Evaluation

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

- 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
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

Climate Data
- Historical
- GCM Predictions

Downscaled weather

Watershed Model

Streamflow

Reservoir Models
- 1D (Eutrophication)
- 2D (Turbidity)

Reservoir Operations
- Historical
- Simulated

OASIS or OST

Streamflow, Loading

Releases

Eutrophication System Indicators

Turbidity System Indicators

Water Quantity System Indicators
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)
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. (°C)

Time Slice: 2081-2100

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
Seasonality of Stream Discharge

GCM scenarios indicate ample water supply

Mean Stream Discharge (cm/day)

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

Percentage of Annual Streamflow
During Winter (Nov thru Feb)

Range
Median

Baseline
Future
Effects of Climate Change on Catskill Turbidity

Average Monthly Predictions

Streams

Schoharie Creek Turbidity

Esopus Creek Turbidity

Reservoirs

Ashokan West Turbidity

Ashokan East Turbidity

Bars show the range of climate change predictions
Line shows current (baseline) simulation
Effects of Climate Change on Streamflow, Nutrient Loading

6% Increase in Mean Annual Load

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

Percent Change from Baseline Conditions

Growth (photosynthesis) increases:
• Increasing water temperature (most important)
• Increasing nutrient load

Phase I Functional Group Biomass

Diatoms

Cyanobacteria

Flagellates
Some Selected Phase II Preliminary Findings
• 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

- Precipitation (mm)
  - RMSD vs. Number of bins

- Average Temperature (K)
  - RMSD vs. Number of bins

- Maximum Temperature (K)
  - RMSD vs. Number of bins

- Minimum Temperature (K)
  - RMSD vs. Number of bins

- Shortwave Radiation (W/sq.m)
  - RMSD vs. Number of bins

- Wind Speed (m/sec)
  - RMSD vs. Number of bins

ECHAM, NCAR, GISS
• 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

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
CCIMP Phase II – SWG Evaluation

Selected Preliminary Results from the Evaluation of Stochastic Weather Generators

Weather Generator

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

Amount Process
- 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

Basin-mean PRCP based on station obs
Selected 7 models for generating daily precipitation amounts

<table>
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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
e.g. EVT-based Ann Max Daily PRCP Magnitude
50, 75, and 100-yr return periods
Mean Absolute Percentage Error (MAPE) (%) for all watersheds

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<th>EXP</th>
<th>GAM</th>
<th>SN</th>
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<td>50 year</td>
<td>40.06</td>
<td>33.76</td>
<td>5.45</td>
<td>9.93</td>
<td>43.86</td>
<td>6.71</td>
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<tr>
<td>75 year</td>
<td>41.36</td>
<td>34.77</td>
<td>6.23</td>
<td>11.17</td>
<td>51.31</td>
<td>6.5</td>
<td>43.44</td>
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<tr>
<td>100 year</td>
<td>42.27</td>
<td>35.48</td>
<td>6.78</td>
<td>12.07</td>
<td>56.92</td>
<td>6.37</td>
<td>46.78</td>
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MAPE <10% “Highly Accurate”
10% <= MAPE < 20% “Good” (Lewis, 1982)

e.g. EVT-based Ann Max Daily PRCP Magnitude
50, 75, and 100-yr return periods
CONCLUSIONS: MC1 as good as higher orders  
3 distributions are good for extremes  
k-NN less appropriate for climate change studies

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

NE Scotland

SE England

Ensemble of models & emission scenarios for 2080s

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

X, Y axes are forcing variables

Response surface (contours) produced by model

Reference (historical) period
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