Technical Challenges and Opportunities in Determining the Potential Effects of Climate Change on Water Quality in New England

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Why Do We Care About Climate Change and Water Quality?

What are the Challenges in Assessing the Effects of Climate Change?

What Have We Observed So Far?

What are the Opportunities for Better Assessments in the Future?
Climate Change and Water Quality

- Alter timing and amount of rain/snowfall, and streamflow
- Reduce the snowpack and spring runoff
- Extended low flow periods in summer
- More short term droughts
- More higher intensity storms
- Increased frequency of extreme heat days
Projected changes in temperature in New England

Source: USGCRP New England Regional Assessment
Projected changes in precipitation in New England

Source: USGCRP New England Regional Assessment
Impacts of Increased Temperatures on Aquatic Ecosystems

**Effects of warmer water temperatures**
- Reduced dissolved oxygen concentrations
- Decreased volume of water for dilution of chemical inputs
  - Increased concentration of nutrients and pollutants
- Changes in the rate of chemical reactions in the water column, sediment-water interface, and water-atmosphere interface
- Thresholds for certain species may be reached
  - Cold-water fish lose important habitat
- Increased algal blooms
- Decreased snow pack, changes in spring runoff, and reduced groundwater recharge
Projections of temperature changes in New England

Climate on the Move: Changing Summers in New Hampshire

Projected Days per Year over 90°F in Boston

Hayhoe et al. Fig. from Frumhoff et al.

U.S. Global Change Research Program: Global Climate Change Impacts in the United States
Impacts on Aquatic Ecosystems of Higher Intensity Precipitation Events and Resulting Higher Flows

- Increased delivery of sediments, sediment-enriched pollutants (e.g., phosphorous, pesticides) and soluble pollutants (e.g., nitrates) to rivers and streams
- Increased damage to aquatic systems through stream scour, displaced biota, and disrupted habitat
- Increased storm intensity makes it more difficult to capture runoff from the bigger storms
  - Likelihood is for fewer low intensity storms and more high intensity storms
- Simultaneously, increased drought and low flows in summer will stress aquatic systems
Importance of Understanding Typical Rainfall Patterns for Mgmt Efforts

New England rainfall is approximately 43 inches/year spread over 100 storms; note the large number of small storms contribute substantial flow volume.
Challenges in Assessing Climate Change Impacts

- Old precipitation patterns are invalid - can’t apply old data to project changes
  *Stationarity is dead.*

- Need climate models to reflect new patterns of precipitation intensity, duration, frequency

- Projecting precipitation has been a General Circulation Model (GCM) weakness; models much better, or more consistent, at projecting temperature changes
Comparison of 1990s GCM temperature projections, Central NH, deg. C difference from current

Comparison of 1990s GCM precipitation projections, Central NH, ratio of difference from current

**GCM Precipitation & Temperature**

CCCMI w/sulfates

CCCMI w/sulfates
Challenges II

- Which GCM models and emissions scenarios to use?
- If not GCMs, considering precip profiles: hi, med, low departure from historic patterns
- Selection of subbasins: size, topography, degree of flow regulation, presence of wetlands; path to water
- Just climate change, add land use, demographic data, some combination?
- Simple analysis (flow duration curves, P8 model) and/or complex models: HSPF or SWAT?
- Can we get higher resolution climatic results that are more meaningful to local users?
Climate Change Storylines

Emphasis on human wealth or sustainability; Globalization or regionalization
IPCC Emissions Scenarios

[Graph showing global cumulative carbon dioxide emissions (GtC) from 1990 to 2090, with different emission scenarios indicated by lines and symbols. The x-axis represents years from 1990 to 2090, and the y-axis represents emissions in GtC. The graph includes lines for High > 1800 GtC, Medium-High 1450-1800 GtC, Medium-Low 1100-1450 GtC, and Low < 1100 GtC.]
Challenges, III

- Scale: GCM grid cells are 22K sq. miles
- Any grid in NE/NY may contain variations of 1000s of feet of topography, several times, across that expanse
- Need downscaled GCM scenarios to account for local climate effects

1 grid cell = 22,500 square miles
(150 miles on a side)
US composed of ~160 cells
Downscaling

Obtain local-scale climate changes from regional-scale models

*Dynamical*: a higher resolution, limited-area numerical meteorological model (e.g. regional climate model)
- Requires a large amount of computational and data storage resources.
- Takes a long time to complete the simulations.

*Statistical*: empirical relationships between large- and small-scale observations are developed, then applied to global climate model output to provide regional detail. Computationally inexpensive and many representations can be generated quickly.
Challenges IV: Modeling a “Water”

- Models driven by tributary, outlet, and WWTF flows
- May/may not account for vertical mixing, layers, or stratification
- Chemical interactions in the water column
- Exchange rates across water segments may be wind or current dependant
- May factor in water levels and evaporation
- Contributions from ground water
- Atmospheric deposition of materials
- Climate data: precipitation and temperature
- BMP performance for control measures
Increases in the Number of Days with Very Heavy Precipitation (1958 to 2007)

U.S. Global Change Research Program: *Global Climate Change Impacts in the United States*, Updated from Grossman *et al.*
Frequency & Intensity

Estimated impact of climate change on intensity/return-period relationship
Keene, NH, *point process* model

<table>
<thead>
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<th>Return period (years)</th>
<th>Precipitation (cm)</th>
<th>Late-20th century</th>
<th>Mid-21st century</th>
<th>Δ%</th>
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<td>1,000</td>
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Projected Changes in Precipitation Intensity

Loss of Habitat for Brown Trout from a Doubling of CO$_2$ - 2050

Source: EPA, 1995

GFDL Climate Change Scenario
Hydrologic Change Scenarios:
EPA ORD **20 Watersheds Modeling Study**

- Watershed modeling in 20 U.S. watershed regions (~10 HUC 8 watersheds each)
- Focus on nutrients, sediment, streamflow
- Averaged daily data for 30-year historical and 30-year future periods (2040 – 2070)
- 2 water quality models, HSPF and SWAT
- 6 climate change scenarios based on REGIONAL downscaled models
  - Based on 4 GCMs
  - Also 4 Statistically downscaled models’ scenarios
- 2 Land-Use change scenarios
EPA ORD 20 Watersheds Study
Minnesota River case results

Location:
Minnesota River near Mankato, MN
- 16,200 sq. miles
- 76% crop, 1% forest, 1% impervious
### Temperature Change Between 1973-2002 and 2040-2070, Minnesota River

*** Preliminary Data ***

<table>
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<th>Month</th>
<th>Hadley-Stat</th>
<th>GFDL-Stat</th>
<th>Hadley-Reg</th>
<th>GFDL-Reg</th>
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Av Monthly Temps, 2040 - 2070, Mankato, MN

![Graph showing temperature changes](image-url)
Precipitation Change Between 1973-2002 and 2040-2070, Minnesota River

*** Preliminary Data ***

Av Monthly Precip, 2040 - 2070, Mankato, MN

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- **Baseline**
- **Hadley-Stat**
- **GFDL-Stat**
- **Hadley-Reg**
- **GFDL-Reg**
- **Hadley-GCM**
- **GFDL-GCM**

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Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Precipitation Model Comparisons

*** Preliminary Data ***

GCM comparison, Precipitation 2040-2070, Mankato

Statistical Downscale Comparison, Precip 2040-2070

Regional Downscale Comparison, Precip 2040-2070
Precipitation Model Comparisons, Minnesota River

*** Preliminary Data ***

Resolution comparison, Hadley model precip

Resolution comparison, GFDL model precip

![Graphs showing precipitation comparisons](image-url)
Flow Results, Minnesota River

*** Preliminary Data ***

Monthly average flows, Mankato

- Baseline
- Hadley reg
- GFDL reg
- Hadley GCM
- GFDL GCM
- Hadley Stat
- GFDL Stat

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Loading results, Minnesota River Study

*** Preliminary Data ***

**Annual Load, TSS, Tons/yr, at Mankato**

**Annual Load, TP, Tons/yr at Mankato**
Next Year

Results for the New England Coastal Basin
And Lake Champlain

Thank you

Questions??