HUNTER
The City University of New York

Department of Geography
695 Park Ave.
New York, NY 10021
Phone (212) 772-5322
Fax (212)772-5268

December 17, 2010

David E. Church, Executive Director
Orange County Water Authority
PO Box 118
99 Main Street, Suite 1
Goshen, New York, 10924
dchurch@co.orange.ny.us

Subject: Final Report on WRI Grant

Dear Mr. Church,

On behalf of myself, my co-PI Simon Gruber, and the other co-authors, I am happy to submit this final report on our WRI grant entitled *Potential Impacts of Climate Change on Sustainable Water Use in the Hudson River Valley*. This report reflects the changes to the preliminary report (submitted in May, 2009) that were discussed during our telephone conference of July 26, 2001. The telephone conference included the two of us as well as Kelly Dobbins and Simon Gruber.

I look forward to continued collaborations in the future.

Sincerely,

Allan Frei
Associate Professor, Department of Geography
Deputy Director CUNY Institute for Sustainable Cities
Tel: 212-772-5322 E-mail: afrei@hunter.cuny.edu

cc. Simon Gruber, Carina Molnar, Joseph Zurovhcak, ShihYan Lee

FINAL REPORT

Potential Impacts of Climate Change on Sustainable Water Use in the Hudson River Valley

December 17, 2010

A grant to:
The CUNY Institute for Sustainable Cities (CISC)

Funded by:
Water Resources Research Grant Program FY2008 New York State Water Resources Institute (WRI)
New York State Department of Environmental Conservation
and Hudson River Estuary Program
With Support from:
City University of New York (CUNY)
CUNY Institute for Sustainable Cities (CISC)
Orange County Water Authority (OCWA)

Authors:
Allan Frei (Co-PI, CISC)
Simon Gruber (Co-PI, Project Consultant, Orange County Water Authority)
Carina Molnar (Outreach Coordinator, CISC)
Joseph Zurovchak (Collaborator, SUNY Orange)
ShihYan Lee (Research Assistant, CUNY)

Contact Information:

Allan Frei (co-Primary Investigator)
Deputy Director, CUNY Institute for Sustainable Cities
Department of Geography, Hunter College
695 Park Ave.
New York, NY 10065
212-772-5322
afrei@hunter.cuny.edu

Simon Gruber (co-Primary Investigator)
Environmental Planner and Institute Fellow, CUNY Institute for Sustainable Cities,
845-534-5622
sgruber100@verizon.net

Carina Molnar
Outreach Coordinator, CUNY Institute for Sustainable Cities
212-650-3456
cmolnar@hunter.cuny.edu

Joseph Zurovchak
Associate Professor, Dept. of Biology
SUNY Orange
Chair, Sustainability Committee
845 341-4147
joseph.zurovchak@sunyorange.edu

ShihYan Lee
CUNY Graduate Center
shihyanlee@yahoo.com

Table of Contents

SECTION	Page
Summary and Conclusions	3
Recommendations	5
Introduction	6
Problem Statement and Research Objectives	6
Methodology	6
Principal Findings and Significance	8
Student Involvement and Support	14
Notable Achievements and Synergistic Activities	14
References	15
Appendix A: New York State DEC Key Concepts for Climate Change Literacy	16

Summary and Conclusions

The purpose of this project is to help the Orange County Water Authority (OCWA), as well as other Orange County government departments, to begin to include the potential impacts of climate change in their long-term water planning. We have generated a review of published information that is pertinent to OCWA's long range water planning activities, performed some additional technical analyses, begun outreach activities within Orange County, and articulated a number of preliminary recommendations for OCWA. The next step is to work with OCWA to determine how best to use this information, and how to continue outreach activities, to most effectively serve the interests of Orange County.

The conclusions of this report reflect the current understanding of how the human impact on climate may change in the future. In the coming years, the results used to derive these conclusions may change for two reasons. First, it is possible, although unlikely, that the uncertainty around climate change predictions will significantly decrease due to improved physical understanding of the climate system and more accurate models. The more likely reason that the conclusions might change is that, as time progresses, we will know with more certainty the magnitude of human greenhouse gas emissions, and will have more evidence as to the potential impacts of those changes. For example, the scenarios used to portray possible global greenhouse gas emissions were developed ten years ago. The actual global emissions that have occurred since then are, according to experts, actually greater than the "high emission" scenarios used in these analyses.

The following are our conclusions as to what may be expected *by the end of the 21st Century*, based on the best available scientific understanding. (The term "most likely scenario" is explained in the text of this report.)

- *Temperature and Precipitation Changes are expected in the Hudson River Valley*. There is complete agreement amongst models that temperatures in this region will increase, and reasonable agreement on the range of temperature changes that might be expected. However, there is less agreement on the magnitude, and even on the direction, of precipitation changes. It is likely that precipitation will increase, but it may also decrease significantly. It is likely that, regardless of any change in total precipitation, a greater proportion of precipitation will fall in larger events.

- *Surface Water, under "Most Likely" scenario, will not change significantly*. Under the most likely scenario, the mean annual surface water availability will not change significantly. This is because precipitation will most likely increase slightly. However, due to the uncertainty in precipitation changes, there is a smaller but still significant possibility that water supplies will change appreciably, either increasing or decreasing. Changes to the seasonal stream flow timing are likely to be minimal compared to more snow-dominated regions because in the Hudson River Valley snow does not dominate the annual water cycle. Lower groundwater levels, however, may reduce base flow to streams significantly.

- *Soil Moisture and Ground Water Supplies Appear to be More Vulnerable than Surface Water*. Soils will almost certainly be drier, possibly much drier. Groundwater levels, like soil moisture, are expected to be lower. At the upper bound of the "most likely" (67%) range of scenarios, mean soil moisture and mean ground water levels may not change significantly. At the lower bound of the "most likely" (67%) range of scenarios, mean soil moisture and mean ground water levels may be diminished by up to 25%.

- *Temperature Extremes will most likely increase; Drought frequency is uncertain.* It is extremely likely that the frequency of temperature extremes will change, with more hot days and fewer cold days. Under some scenarios, by the end of the century the summer climate of this region will resemble the southeastern US. The frequency of droughts in this region is unlikely to decrease, and may not change at all. However, if precipitation decreases, the frequency of droughts in this region may rise appreciably.

- *Outreach Conclusions*. The Orange County students who participated in the preparation of outreach materials showed great enthusiasm and interest in this subject. Although our wider outreach effort has not yet started, we expect that the interest on the part of a wider audience in Orange County will be similar. We presented a poster about this study at the 2009 annual Orange County Earth and Water Festival, a public education event sponsored by OCWA and the County on June 13 2009. We hope that findings of this study will also be used in development of educational presentations designed for elected officials, planning board members, and other municipal decision-makers, and for other adult audiences, as part of an OCWA project currently underway.

Recommendations for Orange County

- *Evaluate Water Demand Projections, Keeping in Mind that Groundwater Resources Appear to be More Vulnerable than Surface Water*. At the lower end of the most likely (67%) scenario, surface water resources available to OC will not change dramatically, but soil moisture and groundwater resources will be diminished. Development plans must consider the potential diminishment of these resources. Site design measures to maximize groundwater recharge, minimize surface runoff directly to streams, reduce the need for irrigation of lawns and other landscaping, and manage and restore water and soil resources will be important in new and existing development to respond to these trends. Complementary, non-structural measures including revised rates and pricing structures for potable water supplies to encourage water efficiency, and fee-based approaches for funding stormwater management programs (eg., fees based on the amount of impervious surface cover), will potentially be important tools.

- *Maintain Familiarity with Major Climate Change Studies*. Every five to seven years an updated Intergovernmental Panel on Climate Change assessment is produced – the IPCC is the internationally accepted organization for the global consensus of the current understanding of climate change. Periodically, other regional analyses might become publicly available. It would seem prudent of OCWA to keep abreast of the major results of these reports, which will allow OCWA to keep their plans flexible in the face of uncertainty.

- *Keep Plans Flexible*. While surface water availability may increase or decrease depending on how precipitation changes, soil moisture and groundwater resources are likely to be significantly diminished. Plans for development must remain flexible in terms of supply and demand in order to account for any uncertainties.

- *Maintain links to Regional Partners*. In the case of diminished water supplies, one strategy for flexibility is the possibility of shared water resources with other regional municipalities. This would involve shared risks as well as shared responsibilities.

- *Consider Effects of Extreme Events and Higher Temperatures on Water Quality*. Regardless of whether the total water supply changes, it is likely that OC surface water resources will experience a higher proportion of large precipitation events, and likely that water temperatures will increase. The potential implications for water quality, as well as ecological services, should be considered.

- *Continue Monitoring*. It seems prudent for OCWA to fund appropriate monitoring networks for water supply and stream flow. This will allow the county to accurately assess any changes that might occur during the coming decades. Monitoring water quality in streams is also important, because changes in precipitation patterns may cause increased runoff and erosion rates, thereby affecting water quality through increased sedimentation and other effects.

- *Conduct Historical Analyses*. The technical analysis performed for this report uses data from the Moodna Creek Watershed, which is available for only the last 10 years. In general, this is too short a time period for climatological analyses. The basic conclusions of this report would not change if we had a longer record. However, there are good reasons to reconstruct what happened during earlier decades. For example, in the absence of a continuous, ongoing, reliable stream gauge record in OC, it is impossible to estimate what the true historical seasonal cycle, or total annual stream flow, actually was because the last 10 years may not be representative of earlier decades. Also, we can not gauge how future changes might compare to historical precedents. How do the different dry scenarios for this century compare / contrast with the record drought of the 20th century that occurred in the early-mid 1960s? Professor Frei has begun to investigate the possible use of the water balance model to estimate historical conditions. It would be fruitful to continue this investigation. Details can be provided if OCWA is interested in pursuing this.

Introduction

This document is the final report to the Orange County Water Authority (OCWA), who is the main benefactor of this project. We have generated a review of information that is pertinent to OCWA's long range water planning activities, performed additional technical analyses specifically for this project, begun outreach activities within Orange County, and articulated a number of recommendations for OCWA (all of which are discussed in this report). The next step is to work with OCWA to determine how best to use this information, and how to continue outreach activities, to most effectively serve the interests of Orange County.

Problem Statement and Research Objectives

The problem that is addressed by this grant is that the municipality of Orange County, New York, is beginning to include the potential impacts of climate change in their long term water resource planning, but does not have the in-house technical expertise to review and interpret the current state of knowledge on climate change. They have hired outside consultants to partially address this issue, and this project is complementary to the consultants' work. To address this problem, we have identified three objectives. (1) The primary objective of this project is to provide to the Orange County (OC) Water Authority (OCWA) assistance *that they identify as necessary* to *begin* to include climate change in their planning process to meet their long-term water supply objectives. The goal is to ensure that plans include sufficient flexibility so that the community is prepared for, and can adapt to, climate change. (2) The second objective is to work with OC to perform outreach, which would help generate interest, disseminate information, and encourage input from OC residents in this process. (3) The third objective of this project is to use our experience with Orange County to develop materials that might be useful to other regional stakeholders, and to develop additional regional collaborations to continue this work, if appropriate, after the terms of this project have been completed.

Methodology

The methodologies used in this study relate to technical issues, as well as to non-technical outreach related activities. The main technical methods are to work with OC to identify what information about climate change is required by OCWA, to determine what format that information can most easily be used by OC, to determine whether or not that information is available, and finally to provide guidance for the use and interpretation of climate-related information. The first step is to identify publicly available information, including previous or on-going research reports that may be useful in that regard (Table 1).

PROJECT/REPORT NAME	DESCRIPTION
1. *NYSDEC* (NYSDEC 2009) New York State Department of Environmental Conservation (NYSDEC) Climate Literacy Points	A short document prepared by DEC which summarizes the main points that are understood about global climate change. Not specific to NY State.
2. *IPCC* [3] (Bates et al. 2008) Climate Change and Water, Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report Technical Paper VI, 2008	This report pulls together all the information that is relevant to water resources from the most recent (2007) IPCC analyses.
3. *NECIA* [2] (NECIA 2006) Report of the Northeast Climate Impacts Assessment (NECIA) Climate Change in the US Northeast, 2006	A report sponsored by the Union of Concerned Scientists which analyzes potential climate change for the Northeatern US
4. *NPCC* [1] (NPCC 2009) New York City Panel on Climate Change (NPCC) Climate Risk Information (CRI), 2009	Report by the NPCC to advise the Mayor of NY City, and the NYC Climate Change Adaptation Task Force on issues related to climate change and adaptation relating to NY City.
5. OCWA [4] Orange County, New York, Draft Water Master Plan: Task 2, Strategic Plan, March 2009	The OCWA Water Master Plan. Section 3.3.3 addresses water supply and climate change using results of the analysis by consultants hired by OCWA.
6. *NYSERDA* [5] New York State Energy Research & Development Authority (NYSERDA) Responding to Climate Change in New York State, (CLIMAID) ongoing, expected publication in 2011; draft synthesis report now available	Outline vulnerabilities of NY State to Climate Change, and suggested adaptation strategies. Orange County water may be included as a case study in the final report.
7. *NYCDEP* New York City Department of Environmental Protection (NYCDEP) Integrated Modeling Project, ongoing	Ongoing, state of the art modeling project to identify potential climate change impacts on NY City water supply, including water quality and availability

Table 1. Projects and reports about climate change that are useful for this project. All URLs are active as of April 15, 2009.

[1] http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf
[2] http://www.climatechoices.org/assets/documents/climatechoices/confronting-climate-change-in-the-u-s-northeast.pdf
[3] http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf
[4] http://waterauthority.orangecountygov.com/
[5] http://www.nyserda.org/programs/environment/emep/clim-aid-synthesis-draft.pd
f

The second step is to provide interpretation of the publicly available technical information so that it is useful to OC. The third step is to perform an additional technical analysis, as identified in the project proposal, that is required to help OCWA in this regard.

The first outreach methodology is to engage environmental study students at SUNY Orange, a community college in OC, in projects designed to disseminate information about this issue: that is, for the students to develop outreach materials. Professor Joseph Zurovchak, a co-author of this report, teaches this class. During the spring 2009 semester he had students prepare outreach materials that are to be presented at different forums. Materials include pamphlets, electronic presentations for oral delivery, podcasts, webpages, and local newspaper pieces. The figures and other materials included in student projects include either general information from

class or outside sources, or specific information supplied by this project. The information supplied by us comes from our own technical analysis as well as the sources outlined in Table 1 and discussed below. Students will make these materials available to the SUNY Orange community, public schools, and the county public in general. These materials were made public at the OC Earth and Water Festival on June 13, 2009. Our hope is that outreach efforts can continue.

Note that we use the terms "most likely" scenario in our technical findings. This terminology is based on the findings of the New York City Panel on Climate Change (NPCC) report, and is explained in the next section.

Principal Findings and Significance

Identification of Publicly Available Information. A number of previous or ongoing research projects and reports about climate change in this region (Table 1) provide a great deal of information that may be relevant to Hudson River Valley communities such as OC. These results should provide a comprehensive picture of what is known about climate change in this region. In this section we summarize the results that are most relevent to OC from each source listed on Table 1.

NYS DEC Climate Literacy Points (Table 1, #1) The New York State Department of Environmental Conservation (NYSDEC 2009) recently promulgated a document identifying the key concepts required for climate change literacy, as well as some resources for more information. This document has been thoroughly vetted by DEC, and the authors of this report agree with the DEC that it is a concise, accurate summary. It is not specific to NY State. The full content of this document is included in Appendix A of this report.

IPCC Table 1, #2) The Intergovernmental Panel on Climate Change (IPCC) is the internationally accepted organization for the global consensus of the current understanding of climate change. IPCC documents address the issue of climate change from the global perspective, but also show selected regional results. The document referred to in this report (Bates et al. 2008) summarizes the most recent IPCC findings that relate to water resources. An important take-home message from the perspective of OC is that, although there is good agreement amongst models on the range of temperature changes that might be expected, there is relatively poor agreement between models, and therefore significant uncertainty, on water cycle changes at local and regional scales, including in the Hudson River Valley. In the Hudson River Valley region, at least 80% of models indicate an increase in total annual precipitation, and in winter precipitation. In this region (and across most of the Northern Hemisphere) there seems to be good agreement that, regardless of whether total precipitation increases or decreases, the portion of precipitation coming from very large events will increase. However, there is less than 80% agreement in this region on whether we will see increased or decreased summer precipitation, mean annual soil moisture, or total annual runoff. This point bears repeating and emphasis: *for many aspects of the water cycle, there is less than 80% agreement amongst models on whether these values will increase or decrease*.

NECIA (Table 1, #3) The Northeast Climate Impacts Assessment (NECIA 2006) report has a regional focus on the northeastern U.S., and it provides some results that are relevant to OC water supplies. To demonstrate the dramatic potential for summer temperature changes, NECIA developed "climate migration" maps for various locations, including one for southeastern New York State (Figure 1).

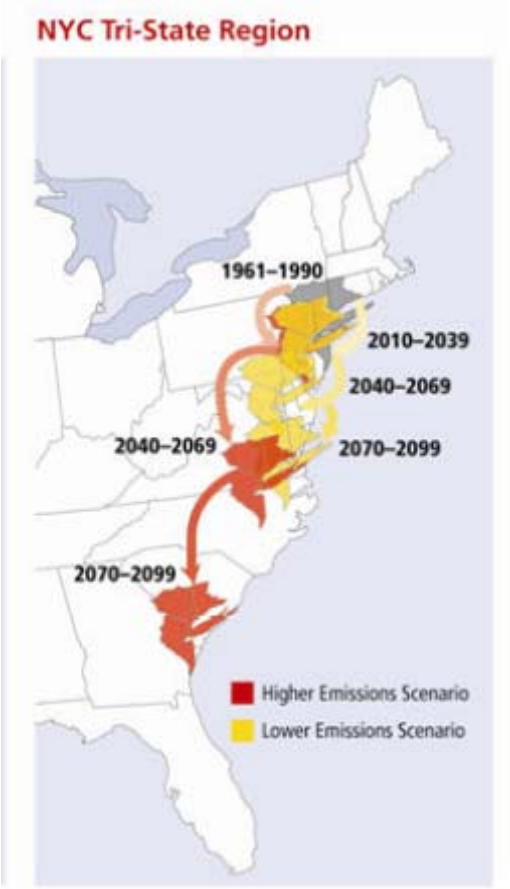

Figure 1. From NECIA (2006). Projected "migration" of summer climate in the Hudson River Valley region based on a heat index.

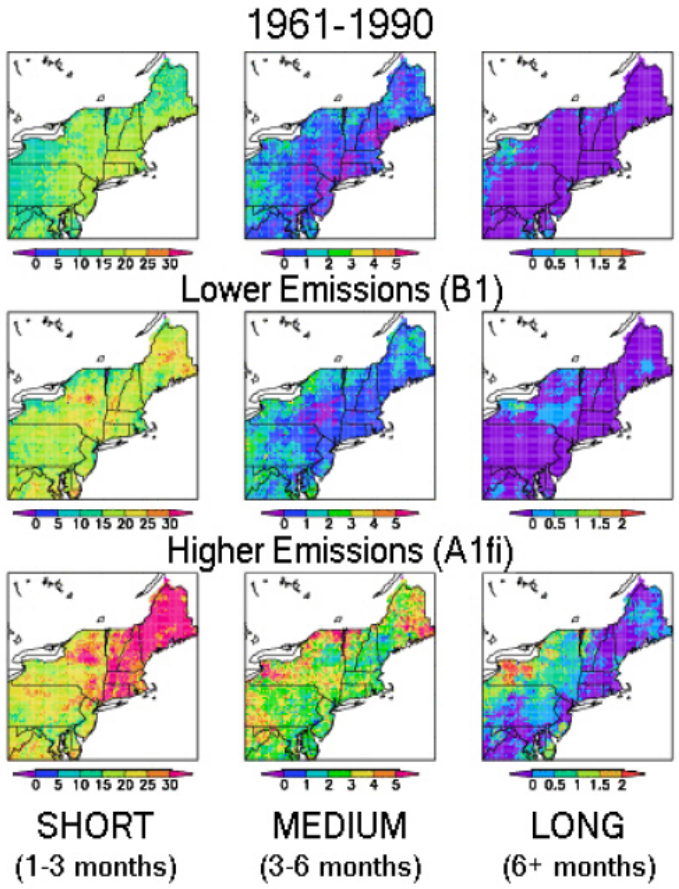

Figure 2. From NECIA (2006). Each map shows the total number of short-term (1-3 month), medium-term (3-6 month) and longterm (6+ month) droughts occurring during the historic 30-year reference period (1961–1990) and the 30-year period at the end of the century (2070–2099) under a higher- and lower-emissions scenario. Projected values are the average of the HadCM3 and PCM based VIC simulations.

NECIA indicates that by the end of the century the heat index of summers in southeastern NY State may be similar to the current climate of the South Carolina / Georgia region. The potential for droughts may be considerably increased under warmer conditions, depending on if / how precipitation changes. Figure 2 shows results from three models, with two specific greenhouse gas emission scenarios, of the number of droughts of different durations to be expected. Although these should be considered only sample scenarios, as they do not necessarily reflect the full range of possibilities, they are instructive. Under the low emission scenario there is no expected change in the frequency of either medium length droughts (duration of 3-6 months), which have been rare during the last 30 years, or longer droughts (duration greater than 6 months), which have not occurred in this region in the last 30 years. However, under the high emissions scenario, both medium length and longer droughts might be expected. The question of how these droughts might compare to the early-mid 1960s, when this region experienced the most significant long-term drought of the last century, was not discussed.

NPCC (Table 1, #4) The New York City Panel on Climate Change (NPCC 2009) report summarizes what is known about climate change and adaptation with a specific focus on New York City. Many of these results should in general be applicable to OC. Although the magnitude of the warming is expected to increase northward and inland from the city, the differences between New York City and OC should be within the uncertainty range. Figure 3 shows that all models predict a warming in this region, with 67% of the models falling between 4°F and 7°F, but some models indicating a warming of greater than

7°F. Figure 4 shows that the disparity in precipitation estimates is quite wide for this region. 67% of the models suggest a precipitation increase between 4% and 7%. Some models suggest an even greater increase in precipitation, while others suggest a decrease of up to 10%. Figure 5 contains a portion of a table from the NPCC report showing the expected change in the frequency of extreme temperature and precipitation events between now and the end of the century. It is clear that OC should expect a greater number of very hot days and fewer very cold days. However, changes in total precipitation and drought frequency are more uncertain. Note, however, that it is much more likely that the frequency of droughts will either increase or remain approximately the same, and not at all likely that the drought frequency will decrease.

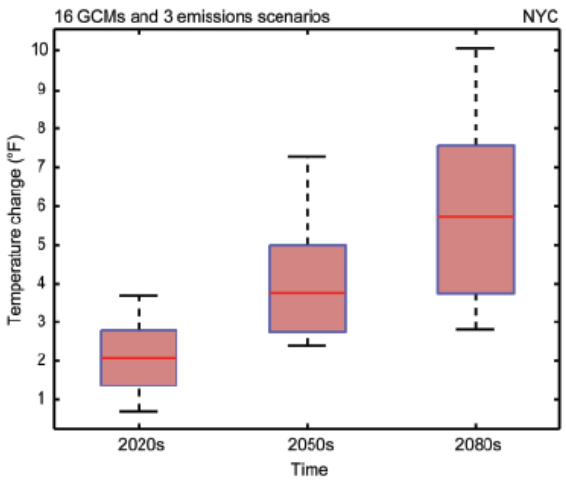

Figure 3. From NPCC (2009) Appendix B. Projected Temperature Changes by 30-Year Timeslice. The maximum and minimum values across the 16 GCMs and 3 emissions scenarios are shown as black horizontal lines; the central 67% of values are shown in the shaded areas; the median is the red line.

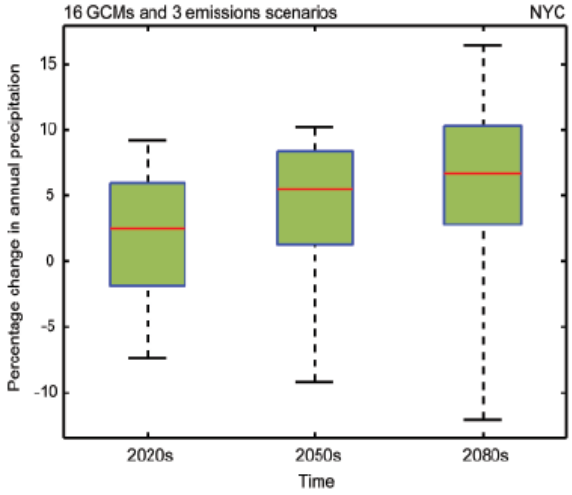

Figure 4. From NPCC (2009) Appendix B. Projected Precipitation Changes by 30-Year Timeslice. Projected precipitation changes (%) by 30-year time slice. The maximum and minimum values across the 16 GCMs and 3 emissions scenarios are shown as black horizontal lines; the central 67% of values are shown in the shaded areas; the median is the red line.

Baseline Climate and Mean Annual Changes (Relative to Baseline Years)

	Extreme Event	Baseline (1971-2000)	2020s	2050s	2080s
Heat Waves & Cold Events	# of days/year with maximum temperature exceeding:				
	90°F	14	19 (23 to 29) 38	23 (29 to 45) 58	29 (37 to 64) 79
	100°F	0.4[1]	0.5 (0.6 to 1) 3	0.6 (1 to 4) 8	1 (2 to 9) 19
	# of heat waves/year[2]	2	2 (3 to 4) 5	3 (4 to 6) 7	4 (5 to 8) 9
	Average duration (in days)	4	4 (4 to 5) 5	4 (5 to 5) 6	5 (5 to 7) 8
	# of days/year with minimum temperature below 32° F:	72	48 (53 to 61) 66	31 (45 to 54) 56	22 (36 to 49) 56
Intense Precipitation & Droughts	# of days per year with rainfall exceeding:				
	1 inch	13	11 (13 to 14) 15	11 (13 to 15) 16	11 (14 to 16) 17
	2 inches	3	2 (3 to 4) 4	2 (3 to 4) 5	2 (4 to 4) 5
	4 inches	0.3	0.1 (0.2 to 0.4) 0.5	0.2 (0.3 to 0.4) 0.6	0.1 (0.3 to 0.5) 0.7
	Drought occurs, on average[3]	~once every 100 yrs	~once every 33 (100 to 100) NA[4] yrs	~once every 8 (50 to 100) NA yrs	~once every 2 (8 to 100) 100 yrs

Figure 5. From NPCC (2009) Appendix B. For each parameter, the minimum, central range (including 67% of the projections), and maximum value are shown.

OCWA (Table 1, #5) The Orange County Water Authority (OCWA) Draft Water Master Plan, Task 2: Strategic Plan, dated March 2009, was available to us at the time of this writing. Section 3.3.3 contains a summary of a report prepared by consultants hired by OCWA which addresses the potential impacts of climate change on water supply. We found it to contain an excellent literature review and analysis. The information provided by this project should be complementary to consultants' analysis. The information from the sources outlined in Table 1, and the technical analysis described in the next section, may provide more details and specific ranges of uncertainty that may be useful to OCWA.

NYSERDA (Table, #6) The *New York State Energy Research & Development Authority (NYSERDA) Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State, also known as CLIMAID,* is a project, which is in progress at the time of this writing, that includes researchers from across NY State. The goal is to evaluate the state's prime vulnerabilities to climate change. The final NYSERDA findings have an expected publication date in 2010/2011. One of the main sectors examined by NYSERDA is "water resources." It is expected that OC will be mentioned in that report as a case study of a county that is taking appropriate action to include adaptation to climate change in the long term plans. The NYSERDA findings should be helpful to OC because the report may result in funding opportunities for resources to help municipalities across the state.

NYCDEP (Table 1, #7) The *New York City Department of Environmental Protection (NYCDEP) Integrated Modeling Project* is a major initiative to perform a comprehensive analysis of the vulnerabilities of the NY City water supply system to climate change. This includes the development of a suite of quantitative analyses and modeling capabilities to estimate the potential changes on water quantity and quality available to the city's reservoir system, which is located primarily in the Catskill

Mountains north of OC. This project began in late 2008 and is expected to last four to five years. DEP is working in conjunction with CUNY on this project, and Professor Frei is the CUNY Primary Investigator. DEP is eager to have their results and products be applicable to other municipalities in NY State. Thus, it is likely that some of their results, and perhaps computer simulation programs, may be useful to OC, and perhaps to other municipalities, in the future. It is currently too early in the project for any results.

Technical Analysis Performed for this Project The technical analysis performed for this study entails the application of a water balance model to estimate the current mean hydrological cycle and potential impacts of climate change in the Moodna Creek watershed, which is considered representative of OC surface water resources. This step is required for two reasons. First, here are currently no active stream gauges in OC, and therefor no reliable information on the annual cycle of streamflow, soil moisture, or other hydrological variables. Second, such a model is required to estimate the potential changes in the water balance associated with different scenarios of climate change. Meteorological data from Black Rock Forest (BRF, located in OC, in the Moodna Creek watershed) is available for the last decade or so, and is being used to drive the model, which produces estimates of monthly and annual mean values for streamflow, snow cover, and other hydrological parameters. The model has previously been used for studying climate change impacts on New York City water supplies from the Catskill Mountains (Frei et al. 2002). Note that this model is most appropriate for climatologically mean results, not extreme conditions such as droughts and floods. Figure 6 shows preliminary model results for mean monthly streamflow and snow cover during the period of overlap between the BRF meteorological station and ancillary data used to verify that model results are realistic. These results indicate that the model is providing a valid simulation of the mean hydrolocial cycle in the basin.

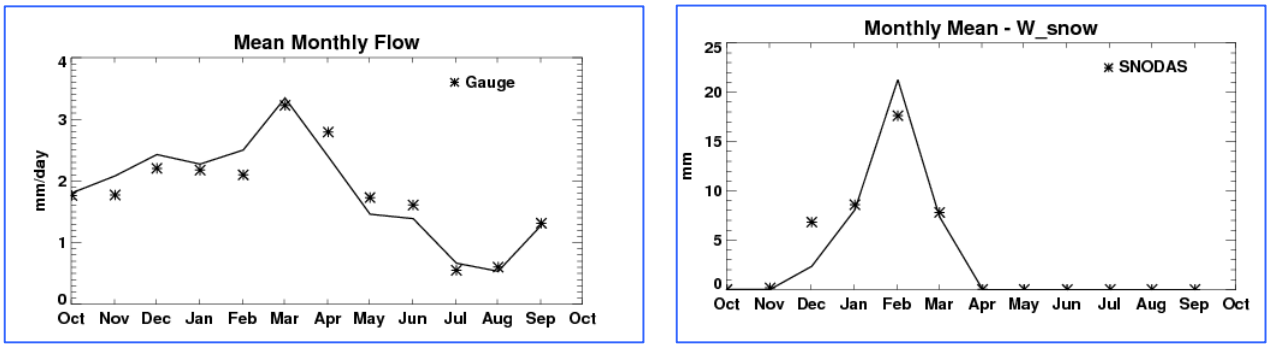

Figure 6. Water balance model validation. Modeled monthly mean streamflow (mm/day) anb monthly mean snow pack (mm of water) are shown with solid lines. Asterisks show ancillary data used to verify that model results are realistic. Ancillary gauge data is from the Ramapo River Gage near Mahwah, New Jersey. Ancillary snow pack estimates are from the National Operational Hydrologic Remote Sensing Center (NOHRSC) snow analysis (http://www.nohrsc.noaa.gov/archived_data/). All data is for the period 1999-2008.

Figure 7 shows the monthly mean streamflow (top panel), soil moisture (middle panel) and ground water (bottom panel). The solid black line shows the mean for the historical period (1997-2008). The red region shows most likely (67%) change, and the orange region shows the full range of potential change, according to the temperature and precipitation changes derived from model results in the NPCC analysis for NY City in the 2080s, and shown in Figures 3 and 4. This analysis indicates a number of points. (a) In the most likely scenario, Moodna Creek stream flow will not change much because increased precipitation will offset increased evaporation associated with warming. However, even a small percentage decline in available water (within the "most likely" range) can be important if population / demand increases. (b) It is less likely, but still possible, that a significant change in surface water availability will occur, which could entail either an increase or decrease, depending on how precipitation changes. (c) It is most likely that soil moisture, as well as groundwater, will decrease, possibly significantly. It is less likely that soil moisture as well as groundwater will increase, and if they do increase, it will only be incrementally.

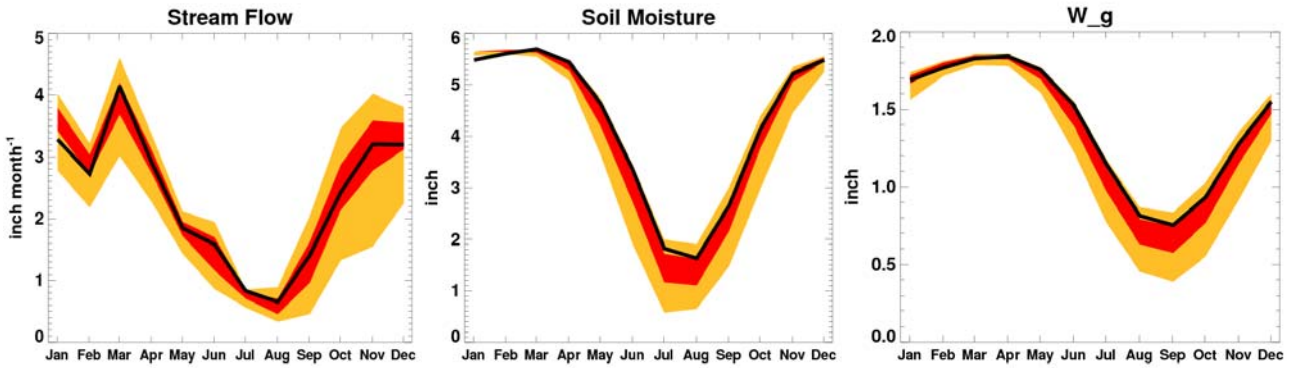

Figure 7. Technical Results obtained for this analysis: Moodna Creek water balance model results for climate change between now and the 2080s. Top panel shows monthly mean streamflow; middle panel shows monthly mean soil moisture; and bottom panel shows monthly mean ground water. Solid black line shows historical period (1997-2008). Red region shows most likely (67%) change, and orange region shows range of potential change, according to the temperature and precipitation changes derived from model results in the NPCC analysis for New York City in the 2080s, and shown in figures 3 and 4 of this report.

Figure 8 shows results for the Canonnsville Reservoir in the nearby Catskill Mountains. Annual mean changes in the Moodna are comparable to the Catskills. However, the potential impact of climate change on the seasonal streamflow cycle are much less dramatic in the Moodna because it is much less snow-dominated than the Catskill Mountains. This can be seen by comparing the projected spring and winter streamflow changes. In both the Catskills and the Moodna, spring stream flow is diminished and winter stream flow increases, but the magnitude of the potential shift is much greater in the Catskills.

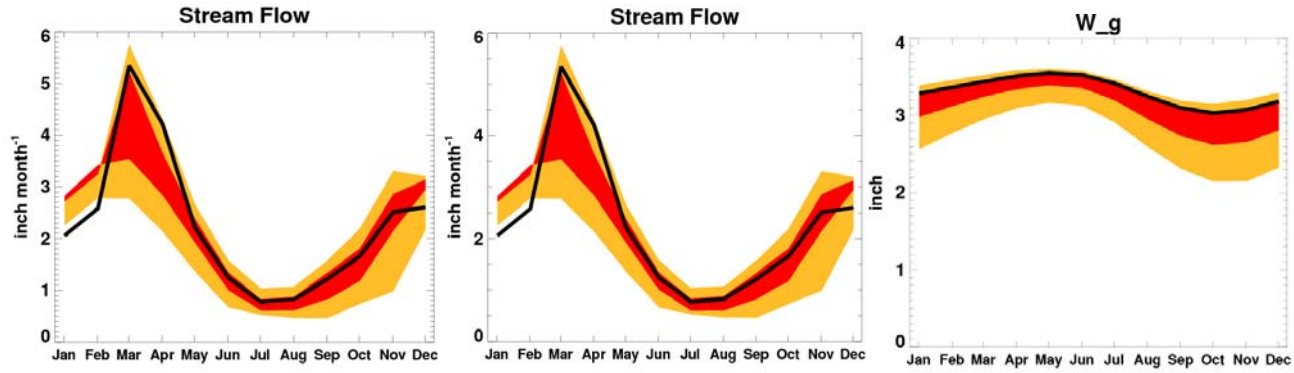

Figure 8. Same as figure 7 except this is for the Canonnsville Reservoir in the nearby Catskill Mountains. The time period used for this analysis is 1959-1988.

In contrast to the method employed here, the consultants for the *OCWA Draft Strategic Plan, Task 2* (Table 1) use a set of actual scenarios from several climate models, and use a monthly water balance program provided by the USGS. Their analysis is very useful and accurate. We chose to use the range of results from climate models because no specific scenarios can capture the full range of potential temperature and/or precipitation changes expected by all plausible scenarios. This sort of analysis is consistent with a great deal of current literature suggesting that, for adaptation purposes, such a technique is probably more appropriate (Dessai et al. 2009). Also, our water balance model is run on a daily time step (although the results are reported in monthly values). This is advantageous when calculating the snow melt, and when calculating the portion of water that is retained in the soil versus the portion that contributes to runoff, and thus may provide a more realistic simulation of the seasonal hydrologic cycle. Annual mean results should be similar between the two models.

Non-technical Objectives. The non-technical objective involves outreach, including OC residents as well connecting with other Hudson River Valley stakeholders for potential collaborations. Students from Dr. Zurovchak's Spring 2009 Environmental Conservation course at SUNY Orange produced draft outreach materials to deliver to various public sectors, including the campus community at SUNY Orange, local elementary and high schools, the general public within the region via a newspaper segment, and the public at large via the internet.

Mr. Gruber will be working with the Network members to disseminate technical findings and outreach materials to key stakeholders in the region, and to seek additional opportunities to present this information at meetings and conferences. The materials that we are producing are relevant to Hudson River Communities in general. We plan to evaluate potential outreach opportunities.

Student Involvement and Support

This project involves significant student involvement and support. As part of our outreach activities, the twenty students comprising Dr. Zurovchak's Spring 2009 Environmental Conservation course at SUNY Orange created otureach materials to deliver to various audiences (e.g., college campus, area public schools, web pages). In addition, three student employees are part of this project: one research assistant, and two outreach assistants. The research assistant, ShihYan Lee, a co-author of this report, supported the technical portion of this report, including data analysis, computer modeling, and preparation of figures.

Notable achievements and Synergistic Activities

Preliminary results of this project were presented at a meeting of Hudson River Valley Climate Network, on February 4, 2009. At this meeting, a number of NY State DEC employees, as well as representatives from OCWA, and from other regional stakeholders, were present. It is hoped that some of the connections made at that meeting will allow us to develop future regional collaborations. As a result of those connections, the CUNY Institute for Sustainable Cities hosted a meeting of the NY State Sea Level Rise Task Force on February 25, 2009 (http://www.dec.ny.gov/energy/51778.html).

Results of this project are intended to be included as part of a case study on Orange County in the final report of the *NYSERDA Responding to Climate Change in New York State* (expected publication in 2011) This document will serve as a guide for future activities for NY State in the area of climate change adaptation.

And, perhaps most importantly, it is hoped that the results of this project will be incorporated into Orange County's long term water planning process.

Finally, Professor Frei is working as the Primary Investigator on two contracts between the CUNY Institute for Sustainable Cities and the New York City DEP on their *Climate Change Integrated Modeling Project*. This project involves two 4-year contracts to hire a total of seven post-doctoral researchers to develop a suite of quantitative analyses and modeling tools to allow NY City to evaluate the potential impacts of climate change on the quantity and quality of the NY City water supply system. Professor Frei has discussed with the DEP project manager the possibility of using results of the DEP project to support the efforts of other NY State municipalities in their climate change adaptation activities. DEP has expressed an eagerness to make their work available in that regard. It is hoped that in the future funds can be obtained towards that end.

References

Bates, B. C., Z. W. Kundzewicz, S. Wu and J. P. Palutikof, Eds. (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. Geneva, Switzerland, IPCC Secretariat.

Dessai, S., M. Hulme, R. Lempert and R. J. Pielke (2009). Do we need better predictions to adapt to a changing climate? *EOS* 90(13): 111-112.

Frei, A., R. L. Armstrong, M. P. Clark and M. C. Serreze (2002). Catskill Mountain water resources: Vulnerability, hydroclimatology, and climate change sensitivity. *Annals of the Association of American Geographers* 92(2): 203-224.

NECIA (2006). Climate Change in the US Northeast, Northeast Climate Impacts Assessment, Union of Concerned Scientists**:** 52.

NPCC (2009). Climate Risk Information. C. Rosenszeig and W. Solecki. New York City, New York City Panel on Climate Change**:** 67.

NYSDEC (2009). New York State Department of Environmental Conservation (NYSDEC) Climate Literacy Points.

Appendix A:
New York State DEC Key Concepts for Climate Change Literacy
(Accepted 10/15/08)

1. The carbon cycle connects all life on Earth.
2. The greenhouse effect regulates the Earth's temperature.
3. Some human activities release greenhouse gases (GHG), which intensify the greenhouse effect that causes global warming.
4. Carbon dioxide generated by human activities is a major cause of global warming.
5. Global warming leads to climate change.
6. Many of the variables that constitute our global climate are currently changing more rapidly than at any other time in human history.
7. Changes consistent with climate change predictions are being observed in New York State.
8. Scientists predict more dramatic climate change impacts in the next several decades.
9. The amount of additional climate change we will experience in the future depends on how much we reduce GHG emissions now.
10. The impacts of climate change on our communities also depend on our ability to adapt.

1. The carbon cycle connects all life on Earth.
    a. Using energy from the sun, plants, animals and decomposers cycle materials (like carbon) through the environment.
    b. Plants and animals use carbon to build cells and grow.
    c. Burning fossil fuels (such as coal, oil and natural gas) releases carbon from the buried remains of plants and animals that lived millions of years ago, and returns it as CO_2 to the atmosphere.

2. The greenhouse effect is an important factor in regulating the Earth's temperature.
    a. Warmed by the sun, the Earth radiates heat. Certain gases trap some of this heat in the lower atmosphere.
    b. The heat-trapping process is called the "greenhouse effect", and the gases are "greenhouse gases" (GHG).
    c. Natural processes, as well as human actions, generate greenhouse gases.
    d. The primary natural greenhouse gases are carbon dioxide, methane, and water vapor.
    e. Without the greenhouse effect, earth would be too cold for humans and other organisms to survive.
    f. An increase in GHG concentrations causes the atmosphere to trap more heat, which raises global average temperatures.

3. Some human activities release greenhouse gases (GHG), intensifying the greenhouse effect and increasing global warming.

a. Human activities have increased concentrations of natural GHG like CO_2, nitrous oxide (N_2O) and methane, and added new GHG like halocarbons (compounds of carbon and halogens).
b. Human actions that release GHG include land use change and burning fossil fuels like coal, oil, and gas for manufacturing, transportation, space heating and cooling, and electricity generation.
c. Use of fossil fuels, atmospheric GHG concentrations, and temperature have all increased since the Industrial Revolution began 150 years ago.
d. Scientists first understood the greenhouse effect and predicted a human impact on the earth's average temperature from GHG 100 years ago.
e. Scientific measurements from around the world prove that the average temperature of earth is increasing.
f. Most scientists agree that the Earth is warming because of human activities and will continue to warm, but long term predictions vary regarding exactly how much warming will occur, and how fast.

4. Carbon dioxide generated by human activities is a major cause of global warming.

a. Natural and human processes release carbon dioxide (CO_2).
b. Since the Industrial Revolution humans have released more carbon dioxide than any other GHG.
c. Humans have more influence over the release of carbon dioxide than any other GHG.
d. Currently, the primary reasons for the increase in carbon dioxide in the atmosphere are human use of fossil fuels and land use changes such as deforestation.
e. Carbon dioxide can last for hundreds of years in the atmosphere, with levels building up over time.
f. Carbon dioxide levels currently are higher and are increasing more rapidly than at any time in human history.
g. Proposed state and federal laws aim to reduce the amount of carbon dioxide released into the atmosphere by human activities.

5. Global warming leads to climate change.

a. Many people use the terms "global warming" and "climate change" interchangeably, to refer to the warmer temperatures being experienced in many parts of the earth and to the changes in climate that these temperatures cause.
b. Weather refers to specific conditions at any given time. Climate refers to long term patterns of temperature, wind, precipitation, storms, and other variables.
c. Warmer atmospheric temperatures affect weather -- snow becomes rain; more water evaporates from warmer soil; warmer air can hold more water, making rainfall events more intense.
d. Warmer atmospheric temperatures cause some weather events to become more frequent and intense, others to become less frequent and intense.
e. Changes in average weather over a long time period indicate climate change.
f. As the Earth warms, it triggers the release of additional stored GHG from the Earth (feedback).

6. Many of the variables that constitute our global climate are currently changing more rapidly than at any other time in human history.

a. The Earth's climate changes over time.
b. Life on Earth is shaped by, depends on, and affects climate.
c. Historic and current emissions of GHG make some amount of additional climate change unavoidable.
d. Scientists agree that the earth's climate is changing, but long-term predictions vary regarding the rate and extent of change.
e. As of 2007, 11 of the last 12 years (1995-2006) ranked among the 12 warmest years in the record of global surface temperature since 1850.
f. The warming trend over the last 50 years (0.13 degrees C/decade) is nearly twice that for the last 100 years.

7. Changes consistent with climate change predictions are being observed in New York State.

a. Observations show that the effects of climate change are different in different regions on Earth.
b. New York State's average temperature has gone up 2ºF in 30 years.
c. Of New York's seasons, winters are warming fastest (5ºF in 30 years).
d. Scientists have documented that the ranges of several species are moving northward, suggesting a response to changing climate.
e. Bloom dates of many species are 4 to 8 days earlier on average, and the last frost date is two weeks earlier, affecting food webs and farming.
f. In many parts of the state, average rainfall is increasing, while snowfall is decreasing.
g. Sea level in New York Harbor is fifteen inches higher today than it was in 1850.

8. Scientists predict more dramatic climate change effects in New York in the next several decades.

a. Some extreme weather events are predicted to become more intense (no change in the intensity of snowstorms is predicted).
b. Shorter, warmer winters and longer, hotter summers will change conditions for recreation and tourism.
c. Changes in rainfall and average temperatures will affect both local and imported food supplies.
d. Rising sea levels and increased flooding from storms will threaten shorelines and waterfronts, affecting infrastructure, transportation, properties, businesses, and habitats.
e. Rising summer air temperatures will increase pollution-related asthma, heat exhaustion, and tropical diseases carried by insects moving northward.
f. Changes in regional climate and atmospheric CO_2 levels will favor invasive species and nuisance plants.
g. Climate-induced changes in habitats like wetlands and forests threaten wildlife, water quality and quantity, and forest products.

9. The amount of additional climate change we will experience in the future depends on how much we reduce GHG emissions now.

a. Reducing the amount of GHG we release into the atmosphere will decrease the risk of the most severe impacts of climate change.
b. The most effective way we can reduce GHG emissions is to improve energy efficiency and adopt low- or no-carbon sources of energy.
c. Personal decisions all help: change light bulbs, carpool, recycle, buy less, eat locally produced food, conserve water, insulate your home, and turn off lights and appliances.
d. Low carbon energy sources have added benefits, including reduced air pollution, lower fuel costs, energy independence, and new green technology jobs.
e. Choosing products with low life cycle CO_2 emissions will help reduce greenhouse gases. (Life cycle includes raw material extraction, production, distribution, use and disposal).
f. Thirty years ago, scientists, governments, and industries worked together and reduced the harmful chemicals destroying the ozone layer. We did it before and we can do it again.

10. The impacts of climate change on our communities also depend on our ability to adapt.

a. Humans will have to adapt to some amount of climate change.
b. Current social and economic systems assume a stable climate; Adapting to climate change requires building flexibility and resilience into planning for the future.
c. The sooner we reduce the amount of GHG we emit, the less risk we'll face in the future.

Climate Change "Key Concepts" Resources

Intergovernmental Panel on Climate Change

- Summary for Policymakers of the Fourth Assessment Report and the Frequently Asked Questions document. Both documents are accessible from the IPCC website (http://www.ipcc.ch/), with the Summary available from the IPCC home page and the FAQ found at http://ipcc-wg1.ucar.edu/

National Academy of Sciences

- Understanding and Responding to Climate Change, downloadable at http://dels.nas.edu/basc/climate-change/basics.shtml

Union of Concerned Scientists (UCC)

- Climate Change in the Northeast: A Report of the Northeast Climate Impacts Assessment, October 2006
- The Changing Northeast Climate: Our Choices, Our Legacy
- Reducing Heat-Trapping Emissions in the Northeast
- New York: Confronting Climate Change in the U.S. Northeast
- Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions (Executive Summary)
- Global Warming section on website (solutions, early warning, sound science initiative pages) http://www.ucsusa.org/global_warming

American Association for the Advancement of Science (AAAS)

- Communicating and Learning About Climate Change: An Abbreviated Guide for Teaching Climate Change, From Project 2061 at AAAS
- AAAS Board Statement on Climate Change

National Oceanic and Atmospheric Administration (NOAA)

- Climate Literacy: Essential Principles and Fundamental Concepts, Formal & Informal Education (Draft document)

United Nations Environment Program (UNEP) and United Nations Framework Convention on Climate Change (UNFCCC)

- Climate Change Information Kit (An Introduction to Climate Change)

Arctic Climate Impact Assessment

- Impacts of a Warming Arctic (Highlights Document)

The University Corporation for Atmospheric Research (UCAR) Website

- Understanding Climate Change: Global Warming FAQs http://www.ucar.edu/news/features/climatechange/faqs.jsp

Clean Air – Cool Planet Website

- What Does Global Warming Mean for the Northeast? http://www.cleanair-coolplanet.org/information/implications.php

Teachers' Guide to High Quality Educational Materials on Climate Change and Global Warming Website

- http://hdgc.epp.cmu.edu/teachersguide/teachersguide.htm

World Wildlife Fund (WWF)

- Your Climate, Your Future: An interdisciplinary approach to incorporating climate change in your classroom (lesson plans for grades 9-12)