Vulnerability and Resilience of Human Populations to Climate Change

Session 8, Changing Planet Workshop, June 27 – 30, 2011, Dickinson College, Carlisle, PA

Neil Leary, Center for Sustainability Education, Dickinson College.

Summary of the Session: In this session we will share ideas and resources for teaching about who is vulnerable to climate change and why. We will demonstrate use of a 'Jigsaw' exercise for engaging students in small group work to examine selected case studies and discuss the ways in which different populations are vulnerable and/or resilient to climate stresses, the underlying factors that create these conditions, and strategies for decreasing vulnerability and enhancing resilience. There is a powerpoint presentation that accompanies the session.

Background: This 90-minute session is part of a four-day workshop that brought together faculty from multiple colleges and diverse disciplines to work collaboratively on developing new and revised courses, explore engaged learning pedagogies, and add to their knowledge for interdisciplinary teaching about climate change within a liberal arts curriculum. The workshop was held twice on the campus of Dickinson College, first in summer 2010 and again in summer 2011. Participants came from more than 20 colleges and universities and with expertise in disciplines that span the sciences, social sciences and humanities. The workshops are part of a NASA supported project Cooling the Liberal Arts Curriculum, A Campaign for Climate Change Education (http://communities.earthportal.org/changingclimate/).

Objectives of the Session:

- Become familiar with the wide range of potential impacts of climate change on human wellbeing and learn about sources of information about impacts.
- Understand human vulnerability to climate change as a function of exposures to climate hazards and social, economic, technological and other factors that influence the sensitivity of societies and individuals to climate stresses and their resiliencies and capacities for coping with and adapting to stresses.
- Develop ideas for exercises and projects that engage students in exploring the vulnerability and resilience of human populations to climate variability, extremes and change.

Agenda for the Session:

- Presentation: Vulnerability and resilience of human populations to climate change – 20 minutes.
- Exercise: Jigsaw, Case Studies of Human Vulnerability to Climate Change – 50 minutes
- Full Group Discussion – 20 minutes
  - Debrief on case studies
  - Ideas for student projects

Essential Principles of Vulnerability (or what we would like our students to learn):

- Climate change will affect almost everything
  - Positive & negative effects
  - Direct & indirect
- Impacts will differ for different people and places
- Who is vulnerable has biophysical & social determinants

- Vulnerability is a function of exposure, sensitivity, resilience/adaptive capacity
- Vulnerability is high where there are significant exposures, high sensitivity & low capacity
- Vulnerability is greatest where
  - there are exposures to multiple stresses
  - natural systems are severely degraded, and
  - human systems are failing
- Highly vulnerable groups include
  - The poor, the marginalized
  - Elderly, young, infirm
  - Natural resource based livelihood groups
  - People in arid & semi-arid interiors
  - People in low lying coasts, small islands, flood plains
  - Cities with weak institutions, weak governance
  - Cities with large informal settlements
- Climate change is a danger now, not just in distant future
- The danger can be reduced by
  - Reducing exposure
  - Reducing sensitivity (diversify livelihoods, hedge risk, share risk)
  - Increasing resilience, capacity

Topic Overview:

The literature on vulnerability to climate change and other environmental stresses offers numerous definitions of vulnerability. While they differ in their emphases and details, common to most definitions of vulnerability is the susceptibility to suffer harm (Leary and Beresford, 2009). Vulnerability has been looked at as the propensity of a group, place or system to be harmed by a particular perturbation or stress, such as climate change, or a suite of multiple perturbations and stresses that might include, for example, natural hazards, demographic change, urbanization, exposures to pollutants, technological change and/or economic globalization. Vulnerability has also been looked at from the perspective of the potential to suffer a particular outcome or harm, for example mortality, hunger or dislocation, that is determined by multiple and interacting forces.

Liverman (2001) and Cutter (1996) distinguish two general strands in studies of vulnerability, one biophysical and the other social. The biophysical approach has its roots in the natural hazards field. Primary attention is given to characterizing exposure to a hazard in biophysical terms. The spatial distribution of some hazardous condition is identified; human occupancy of the hazardous zone (e.g., floodplain, coastal area, seismic zone) is estimated; the magnitude, duration and frequency of the hazard (e.g., flood, hurricane, earthquake) is determined; and the potential loss of life and property associated with particular events are estimated.

The second strand gives primary attention to the social determinants of vulnerability. The causes of vulnerability are sought in the social processes and conditions that place people in harm's way and shape their capacities to absorb stresses, cope with and adapt to change, and recover from harm. Similar to the 'wounded soldier' from the Roman use of *vulnerabilis*, whose risk is primarily determined by his wounded state, Kelly and Adger (2000) make the analogy that it is primarily the existent state of an exposed group that determines its vulnerability.

These two strands have been integrated during the past decade or more by researchers trying to achieve a more holistic and complete theory of the causes of vulnerability. Kasperson et al. (2006) characterize vulnerability as having three dimensions: *exposure* to stresses, perturbations and shocks; *sensitivity* of people, places and ecosystems to stress or perturbation, including their capacity to anticipate and cope with the stress; and *resilience* of exposed people, places and ecosystems in terms of their capacity to absorb shocks and perturbations while maintaining function. Other authors decompose vulnerability into the components *exposure, sensitivity* and *adaptive capacity* (e.g. Adger, 2006). While different authors have applied slightly different decompositions, the basic concepts of exposure, sensitivity, and resilience or adaptive capacity have provided structure for organizing the many different causes of vulnerability and to draw together the biophysical and social strands of vulnerability research.

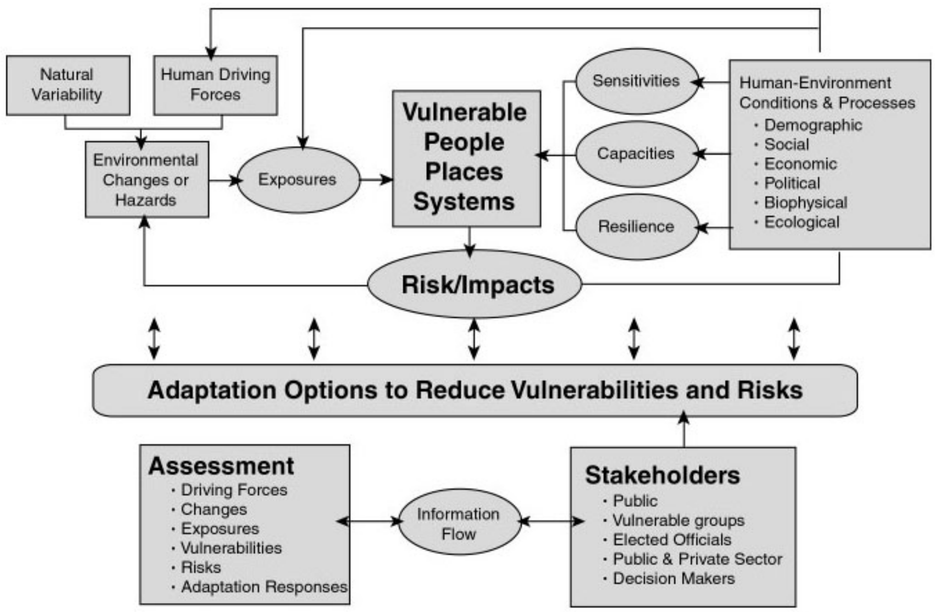
There is a growing body of case studies of vulnerability to natural hazards, climate change and other forms of environmental change (e.g. Birkmann, 2006; Leary et al., 2008; and Kasperson et al., 1995). An overarching and robust result from case studies of vulnerability to environmental hazards is that the harm suffered is not a simple function of exposure but also depends to an important degree on social, economic, governance and other forces that determine who and what are exposed to hazards, their sensitivities and their capacities. The state and dynamics of these processes vary from place to place and from person to person, generating conditions of vulnerability that differ in both character and degree. Consequently, populations exposed to similar environmental stresses are not impacted to the same extent or in the same ways. Differences in vulnerability are also apparent for different sub-populations or groups inhabiting a region, and even from household to household within a group. Factors such as sources and diversity of a household's livelihood, experience and skills, level of wealth, ownership and access to land, water and other resources, support from social networks, and access to technical assistance and knowledge give rise to differences in vulnerability between households.

The most severe outcomes are not expected to arise where a single stress acts alone but where multiple stresses, environmental and other, are at work to create conditions of high vulnerability. The specific interacting stresses and their relative importance vary across contexts but often include population growth, growing numbers of people living in poverty, urbanization that concentrates people and infrastructure in harm's way, economic globalization, conflict, human transformations of the environment, unsustainable intensification of land uses, and climate variability and change.

Vulnerability is often associated with poverty and can be particularly high where cumulative stresses have widened gaps between rich and poor, degraded the natural resource base of livelihoods, eroded the capacity of local institutions to respond effectively, and pushed economic and governance systems to states of or near failure. Unfortunately, such conditions exist in many parts of the world. Places where this is true are consequently vulnerable to severe harm from exposure to climate stresses, both from current climate variations and extremes, and increasingly in the future as the climate changes.

More optimistically, the potential severity and risk of severe outcomes are less where social, economic and governance systems function in ways that enable effective responses to prevent, cope with, recover from and adapt to adverse impacts. For example, a healthcare system that is effective in delivering services to a population, combined with public health programs that promote preventive behaviors, disease monitoring and vector control, can substantially limit the risk that climate change would cause widespread and persistent epidemics. Disaster prevention,

Vulnerability dimensions, processes, assessment and responses. Source: Leary and Beresford, 2009.



preparedness, early warning and response systems can similarly help to limit the extent of harm from changes in the frequency or severity of extreme climate events. Poverty reduction can provide households with access to all manner of resources that can help them to cope with and overcome climate-related impacts.

These and other examples indicate that improving the performance of human systems can reduce vulnerability. Doing so can yield near-term payoffs, as we improve our management of existing climate risks, as well as the longer term benefits associated with building resilience to a changing climate. But optimism should be tempered by the reality of how challenging it has been to achieve even minimal progress where key human systems have been dysfunctional.

Jigsaw: Case Studies of Human Vulnerability to Climate Change

The following exercise uses a technique called a Jigsaw to have students work in teams to explore and teach each other reasons for human vulnerability to climate change. A description of the Jigsaw technique can be found on the SERC-Carleton website: http://serc.carleton.edu/NAGTWorkshops/coursedesign/tutorial/jigsaw.html.

We will do the first step of the Jigsaw and then discuss how we might adapt and use this technique in teaching about vulnerability and other aspects of climate change.

Step 1: Divide the class into case study teams and assign a different case study to each team. Ask the teams to read and discuss their assigned cases, with the goal of developing a small number of key ideas or lessons to share with the other teams.

Short readings for five case studies are provided in the appendix of this document:

- Pennsylvania
- New York Metropolitan Area
- Kivalina, Alaska
- Heihe River Basin, China
- Bara Province, Sudan

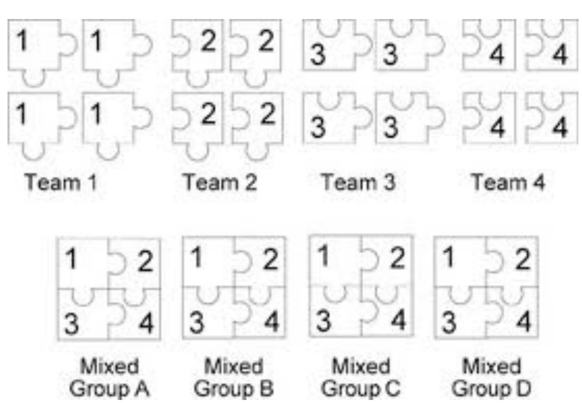
Provide the teams the following questions to guide their discussions:

- What climatic stresses will people in the study area face in coming decades and which are likely to be most challenging?
- What potential consequences might result from exposure to these stresses?
- Are some groups more vulnerable than others to adverse consequences? Why?
- What resources and capabilities are available to people in the study area for reducing vulnerability or increasing resilience?
- What local challenges or problems might impede people from taking effective actions?

Step 2: Regroup the class into new groups, mixing one student from each case study team into each new group. The new groups have discussions in which each member teaches the others in the group the key ideas or lessons from her/his case study. The group works together to identify commonalities and differences across the case studies.

Step 3: Each member of the class writes a synthesis of the nature and causes of vulnerability to climate change, drawing on the case studies for examples of how biophysical, social, economic and governance factors shape vulnerability.

Step 4 (optional): Reconvene the original case study teams in the following class to brainstorm adaptive strategies for reducing vulnerability, develop recommendations, and present the recommendations to the class.



References:

Birkmann, J. 2006. *Measuring Vulnerability to Natural Hazards, Towards Disaster Reslient Societies*. United Nations University Press, New York.

Cutter, S. L. 1996. "Vulnerability to environmental hazards." *Progress in Human Geography* 20, 4: 529-539.

Kasperson, J. X., R. E. Kasperson, and B. L. Turner II, eds. 1995. *Regions at Risk, Comparisons of Threatened Environments*. United Nations University Press, Tokyo, Japan and New York, NY, USA.

Kasperson, J. X., R. E. Kasperson, B. L. Turner, II, W. Hsieh, and A. Schiller. 2006. "Vulnerability to Global Environmental Change." In E. Rosa, A. Diekmann, T. Dietz and C. Jaeger, eds., *The human dimensions of global environmental change*, Cambridge, MA: MIT Press.

Kelly, P. M. and W. N. Adger. 2000. "Theory and practice in assessing vulnerability to climate change and facilitating adaptation." *Climatic Change* 47:325-352.

Leary, N., C. Conde, J. Kulkarni, A. Nyong and J. Pulhin, eds. 2008. *Climate Change and Vulnerability*. Earthscan, London.

Leary, N., and S. Beresford. 2009. Vulnerabililty of people, places and systems to environmental change. In C.G. Knight and J. Jaeger, eds., *Integrated Regional Assessment of Global Climate Change*. Cambridge University Press, Cambridge, UK. Pp. 117-149.

Liverman, D. M. 2001. "Vulnerability to global environmental change." In J.X. Kasperson and R.E. Kasperson, eds., *Global Environmental Risk*, United Nations University Press (London: Earthscan). pp 201-216.

Useful Resources:

Intergovernmental Panel on Climate Change (IPCC): http://www.ipcc.ch/.

This website provides access to the reports of the IPCC going back to 1990. The reports of Working Group II cover climate change impacts, adaptation and vulnerability. If you need graphics for a slide presentation, figures from reports can be downloaded from: http://www.ipcc.ch/publications_and_data/publications_and_data_figures_and_tables.htm.

US Global Change Research Program: http://www.usgcrp.gov/usgcrp/default.php

The USGCRP is a multi-agency program of the federal government on climate change science and impacts. Reports that synthesize information from a wide range of research activities are available from their website, including the 2009 report Global Climate Change Impacts in the United States.

Pennsylvania Climate Change Advisory Committee.

http://www.depweb.state.pa.us/portal/server.pt/community/climate_change_advisory_committee/10412.

The State of Pennsylvania has established a Climate Change Advisory Committee and four working groups to plan for adaptation to climate change (infrastructure, public health and safety, natural resources, and tourism & outdoor recreation). The working groups have public meetings about once every 3 months. The website provides information about the Advisory Committee and the adaptation working groups, access to Pennsylvania's Climate Change Action Plan, and Pennsylvania's Climate Change Impact Assessment, as well as information about climate change related legislation and regulation.

Pennsylvania Climate Change Impact Assessment Report (2009):
http://www.depweb.state.pa.us/portal/server.pt/community/climate_change_advisory_committee/10412.
This report from the Environment and Natural Resources Institute of The Pennsylvania State University was prepared for the Pennsylvania Department of Environmental Protection. It presents an overview of climate change projections and potential impacts for Pennsylvania.

Climate Change in Pennsylvania, Impacts and Solutions for the Keystone State (2008):
http://www.ucsusa.org/global_warming/science_and_impacts/impacts/climate-change-pa.html.
Another report on climate change impacts in Pennsylvania, this one from the Union of Concerned Scientists.

Climate Change and a Global City, Metropolitan East Coast (MEC) Assessment, 2000.
http://metroeast_climate.ciesin.columbia.edu/.
Report of the 2000 assessment of climate change vulnerability and impacts in New York City, along with maps of climate and socioeconomic data for the city. Probably the first comprehensive study of climate change threats to a major urban area. The site includes an education module that uses GIS to explore climate change issues for the NY metro area.

APPENDIX: Case Studies of Vulnerability

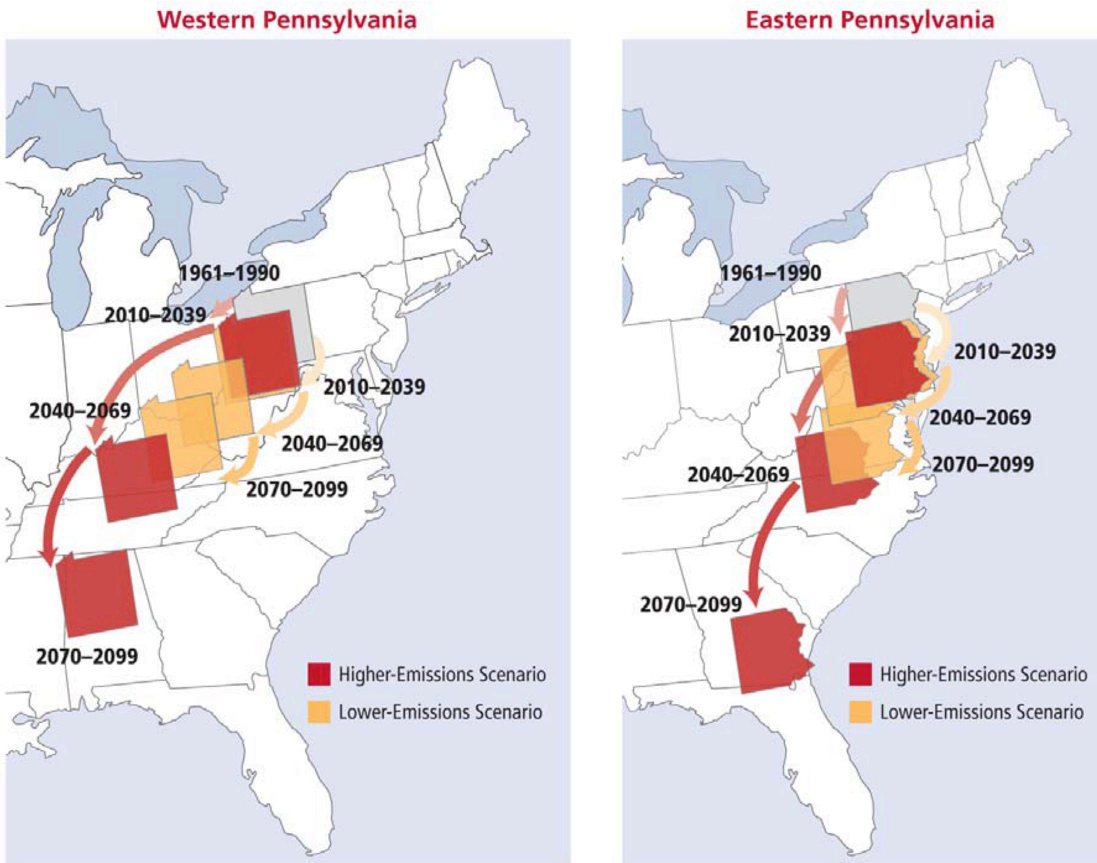
Case Study: Pennsylvania

"Endowed with lush forests, fertile soils, extensive coal seams, and navigable rivers, the state created a thriving industrial economy that helped spur the prosperity of a young nation. For much of the past century, Pennsylvania has worked successfully to diversify its economy as the Rust Belt industries of coal, steel, and manufacturing waned. Today the state owes at least as much to its service industries (such as health care, trade, and tourism) and modern manufacturing sectors (food processing and pharmaceuticals, for example) as to its aging mines, mills, and factories. Despite Pennsylvania's efforts to revitalize, however, many of its cities, towns, and rural regions have not fully recovered from the decline of traditional industries. Climate change will only add to the state's economic challenges while also dramatically altering many aspects of its landscape, character, and quality of life." (UCS, 2008).

Climate: Projections of global climate models for the IPCC A2 (high emission) and B1 (lower emission) scenarios indicate that average annual temperatures at the end of the 21st century in Pennsylvania will be about 2 to 4 ^{o}C warmer than at present and annual precipitation would increase by 6 to 10 percent (Shortle et al, 2009). But most of the additional precipitation will fall in the winter. With warmer summer temperatures and little change in summer precipitation, soil moisture droughts are expected to become more frequent from late spring through early fall. Heavy precipitation events are also likely to become more common, resulting in flashier runoff and more frequent flooding. Days of extreme heat will increase in frequency (e.g. the number of days over 90 ^{o}F per year is projected to increase from 15 per year to 40-75 per year in Harrisburg; UCS, 2008).

Ecosystems: The climate in much of the state will become unsuitable for many of the tree species that are now present; some important species such as black cherry are projected to disappear entirely from the state. Stresses on forests from insects and pathogens and from a more variable hydrologic cycle combined with a warmer climate could result in greater tree mortality. Aquatic ecosystems and fisheries are expected to face greater stresses from more variable flows, lower summer flows, and higher water temperatures. (Shortle et al, 2009)

Agriculture: Projected effects of climate change on crop yields are mixed; results vary depending on the climate scenario, the time horizon (mid-century or end of century), region, and crop. In general, for climate change scenarios with projected warming in range of 1 to 3 ^{o}C, yields of crops such as hay, corn and soybeans would rise, but decrease for scenarios with greater warming. Dairy cows will be subject to greater heat stress and changes in forage production. Impacts of climate change on Pennsylvania farmers will be strongly shaped by changes in prices, which are influenced by the effects of climate change on supplies of agricultural commodities nationally and globally. (Shortle et al, 2009)



Projections of changes in average summer heat index for high and low emission scenarios. Source: UCS, 2008.

Information for this case study was compiled from:

Shortle, J., D. Abler, S. Blumsack and 7 other authors (2009). *Pennsylvania Climate Impact Assessment, Report to the Department of Environmental Protection*. Environment and Natural Resources Institute, The Pennsylvania State University. http://www.depweb.state.pa.us/portal/server.pt/community/climate_change_advisory_committee/10412.

Union of Concerned Scientists (2008). *Climate Change inn Pennsylvania, Impacts and Solutions for the Keystone State*. UCS Publications, Cambridge, MA. http://www.ucsusa.org/global_warming/science_and_impacts/impacts/climate-change-pa.html.

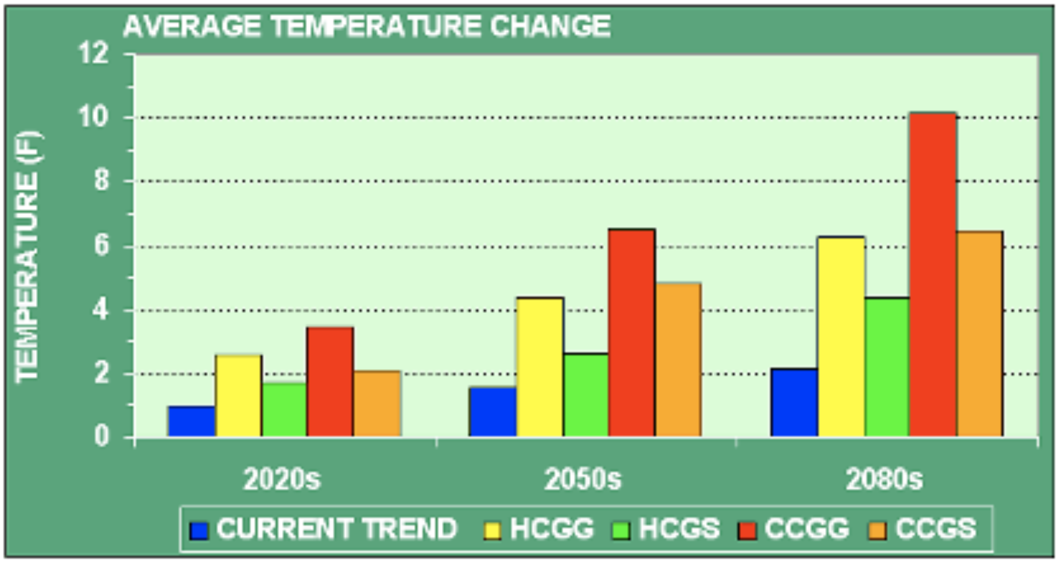
Case Study: New York Metropolitan Region

People: As of the 1990 U.S. Census, the New York metropolitan region had a total population of roughly 20 million, of which 7.3 million lived in New York City. The population of the metro area is highly diverse, with significant ethnic, black and Hispanic populations and large elderly population. The MEC region is one of the most important financial and business centers in the world. Yet almost 24% of the population of New York City lived below the poverty line in 1995; statewide, 16% lived below the poverty line. Population and employment has declined in the urban counties and increased in the suburban counties of the metro area. Hundreds of thousands of manufacturing jobs have been lost in recent decades, while lower paying service jobs have increased. There is growing inequity between residents with low wage and low skill jobs and residents with high wage and high skill jobs.

Place: The New York metropolitan region is 13,000 square miles. It is a water dominated landscape with 1500 miles of coastline, 4 of the 5 boroughs of NYC are islands, and there are important waterways and harbors. Jamaica Bay is one of the largest coastal ecosystems of New York State and an important habitat for migratory waterfowl. Competition for land has pushed development and infrastructure into flood prone areas. Much of the coastline is subsiding. The city's infrastructure is in poor shape - the US Army Corps of Engineers gave the city a failing grade in 1996 for its infrastructure, particularly its aging water mains and solid waste treatment system, which dumps raw sewage into city harbors during storms. Disruption of transportation systems – highways, subway, airports - due to flooding is a recurrent problem. Water pumping and water quality treatment facilities are also vulnerable to coastal flooding from storm surge. Marshlands in Jamaica Bay have been disappearing at an alarming rate, partly due to sea level rise. The electric grid has had problems with blackouts and brownouts during heat waves. Air quality is a problem and NYC neighborhoods have asthma rates that are among the highest in the nation. The metro area is dependent for food, water and energy that are imported from other regions. Political jurisdictions include 1,600 cities, towns, and villages in the three states of New York, New Jersey, and Connecticut, with populations of often conflicting social and political agendas, which impedes coordination of regional planning and policies.

Climate: A nor'easter storm hit NYC in December 1992 with wind gusts of up to 90 miles per hour and water surges 8 ½ feet above mean sea level. Four million subway riders were stranded, FDR Drive was flooded, LaGuardia Airport grounded flights for the day and federal disaster assistance totaled $233.6 million. In 1999 a heat wave pushed water demand to a record level, caused a blackout that left 200,000 people in Manhattan without power for 19 hours, and 33 people died of heat related causes in the city. That same year Hurricane Floyd just bypassed the city but caused large scale flooding in northern New Jersey and southern New York and property damages of $1 billion.

Projections of warming in the MEC region from human caused climate change range from about 4 to 10 ^{o}F by the 2080s, and projections of precipitation range from -15 to +30 percent. The average number of days above 90 degrees, currently 13, will increase by 2 to 3 times by mid-century. Sea level rise, caused by thermal expansion of warming oceans and melting of glaciers and ice sheets, will increase the reach of storm surges and associated damages from future hurricanes and nor-easters. Mid-case projections indicate that floods of a magnitude with a current return period of once per 100 years will become 50-year floods. In worst case scenarios, 100-year floods could happen as often as ever four to five years.



Projections of future temperature changes in New York metropolitan area (°F), compared to average (1961-1990) temperatures in the MEC region. HCGG=Hadley Centre Greenhouse Gas; HCGS=Hadley Centre Greenhouse gas and Sulfate aerosols; CCGG=Canadian Centre Greenhouse Gas; CCGS= Canadian Centre Greenhouse gas and Sulfate aerosols. Source: Metropolitan East Coast Assessment; http://metroeast_climate.ciesin.columbia.edu/climate.html.

Information for this case study was compiled from:

Motavalli, J., and S. Barnes (2004). Greater New York: Urban Anxiety. In J. Motavalli, ed., *Feeling the Heat, Dispatches from the Frontlines of Climate Change*. Routledge, New York, pp. 39-59.

Rosenzweig, C., and W. Solecki (2001). "Climate Change and a Global City, Learning from New York." *Environment* 43 (3):8-18.

Rosenzweig, C., and W. Solecki, eds. (2001). *Synthesis of Climate Change and a Global City: The Metropolitan East Coast Assessment*. Metro East Coast Report of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change. New York, Columbia Earth Institute.

Case Study: Village of Kivalina, Alaska

People and Place: Kivalina is a traditional Inupiat village located about 625 miles northwest of Anchorage on the tip of an 8-mile long barrier island between the Chukchi Sea and a lagoon at the mouth of the Kivalina River. The population in 2007 was 389, of which 97% are Native Alaskan and 3% are white; 44% of the population is under the age of 18 and 6% are 65 years of age or older.

Kivalina's economy depends on subsistence activities, including fishing and hunting of whale, seal, walrus and caribou. Only two residents have commercial fishing licenses. Employers include a school, community service organizations, city government, tribal council, airlines, local stores and a zinc mine 50 miles from town. 65% of adults are not in the workforce; among those who are, the unemployment rate is 25%. Median household income is $30,833; 26% of the population lives below the poverty line.

Kivalina, Alaska

Transportation into the community is by plane and barge. The airfield, built in 1960, has daily flights to Kotzebue, AK. Barge service to move goods operates in July and August. Access to emergency services is via air and boat. Water is drawn from the Wulik River via a 3 mile pipe and stored in water tanks. The water lasts the community only 6-months; water is rationed when the water is down to 12 feet in the last tank. Homes are not fully plumbed – residents haul water from the water tank to their homes and 'honeybuckets' to an open landfill site.

Coastal erosion and sea ice: Coastal erosion is a serious threat to the village of Kavalina. The island has been reduced from 54 acres to only 27 acres by the effects of wave action and storm surges. Sea ice along the coast used to provide a natural buffer that protected coastal land from waves and storm surges for roughly half the year. But warmer temperatures in the arctic have reduced the thickness, extent and duration of sea ice along the western and northern coasts of Alaska, exposing the coasts to erosive forces powerful fall and winter storms. Changes in climate and sea ice are also impacting hunting. The season for hunting bearded seals, which used to last for the month of June, is now only about 3 days because the ice breaks up so quickly. Whale hunters used to set up whaling campus for several weeks, but now the ice seldom extends far enough to reach the whales' migration routes.

Climate: Kivalina lies in the transitional climate zone, characterized by long, cold winters and cool summers. Average low temperature in January is -15 ^{o}F, the average high in July is 57 ^{o}F. Average annual snowfall is 57 inches and average rainfall is 8.6 inches. Chukchi Sea is ice free and open to boat traffic from mid-June to the first of November. Average arctic temperatures have increased at almost twice the rate of the global average in the past 100 years. Annual mean arctic sea ice extent has declined at a rate of nearly 3% per decade since 1978 and ice thickness has decreased.

Climate model projections of annual mean warming in the arctic exceed the global average by roughly a factor of two. The range of temperature changes by end of the 21st century across models is 2.8 to 7.8 °C. The warming will be accompanied by significant reductions in sea ice and thawing and decrease in areal extent of areas underlain by permafrost.

The Law Suit: The village of Kavilina filed a federal lawsuit in 2008 against Exxon Mobil, British Petroleum and others to " . . . recover damages from global warming caused by the defendents actions . . . defendants contribute to global warming through their emissions of large quantities of greenhouse gases." The US Army Corps of Engineers (USACOE) estimates that in 10-15 years erosion will have critical impacts on infrastructure of the village and has concluded that the village must be moved. The cost of moving the village is estimated to be $95 million to $400 million. The village residents want to relocate to a new site located 2 miles to the southeast of their current location. In order to continue their subsistence hunting and fishing lifestyle, which is dependent on access to the coast, the new site is also low-lying and vulnerable to coastal storms and sea level rise. The lawsuit was dismissed in October 2009 but the village is appealing the decision.

Information for this case study was compiled from:

Anisimov, O., D. Vaughan and others (2008). Polar regions (arctic and Antarctic). In S. Solomon et al, eds., *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.

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Case Study: Heihe River Basin of China

People and place: The Heihe River, the second longest inland river in China, originates from Qilian Mountain, flows south through Qinhai and Gansu provinces, and ends in Juyanhai Lake in Inner Mongolia Autonomous Region. The basin has an area of 128,000 square kilometers and a population of 1.8 million people living in 11 counties, 3 small cities, and five prefectures. The region has an arid and semi-arid continental climate characterized by low and irregular rainfall, high evaporation and recurrent drought. Average annual rainfall declines as you travel downstream through the basin, averaging 300-500mm per year in the uppermost reach of Qilan Mountain, 100-200mm in the middle reach, and less than 60mm in the lower reach, making it one of the driest areas at the same latitude on Earth. Water supply is highly dependent on spring melt of the Qilian Mountain glacier, which has been retreating at a rapid rate of 1-meter annually.

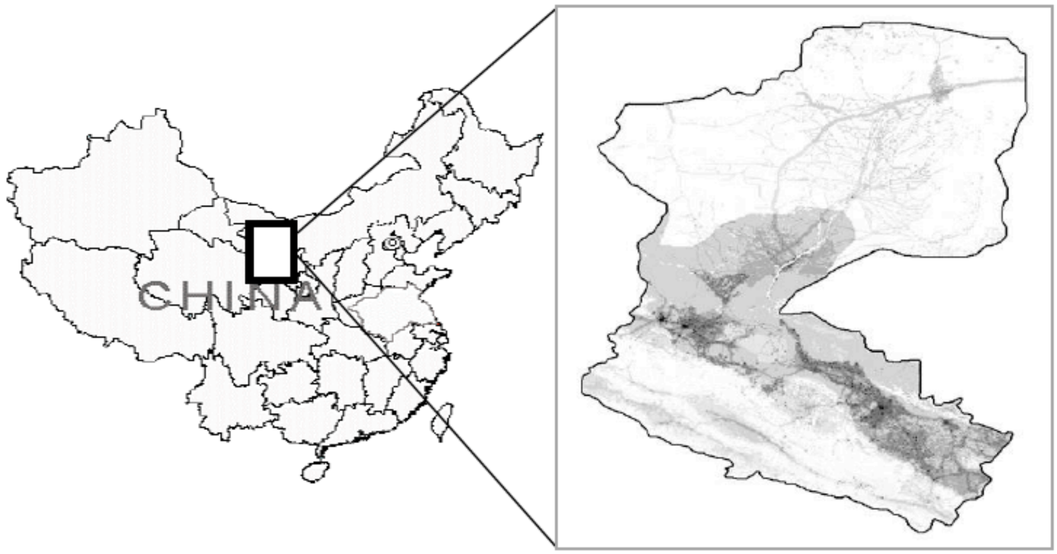
The Heihe River basn is a poor region with a harsh environment and fragile ecological systems that include mountain systems, forest, grassland, oasis and desert. The region is critically short of water and arable land. It has few financial resources, poor infrastructure, low levels of education, and little access to technology and markets. The economy is natural resource based and agriculture is the major economic activity. Oasis agriculture is practiced in the middle reach, drawing water for irrigation from the Heihe river and its tributaries to grow wheat, potatoes and corn. Rangeland farming dominates in the upper reach and herding in the lower reach.

Early in 2000 the Chinese government launched a major new initiative to develop China's poor, underdeveloped western regions, including the Heihe basin, and help close income disparities between coastal and western China. This new policy has brought new industrial and housing developments to the region, but often these have been sited on productive farmland, which is short supply.

Multiple stresses act on the people and environmental systems of the basin: rapidly growing population and demands for food and water; high poverty rate; land degradation; and water pollution. Land degradation and limited water supplies restrict present agricultural production and threaten food security of the region. Drought is a major hazard in the basin. Droughts occurred in about 50% of the years since 1951 in the middle reach.

Current water withdrawals relative to average annual water availability are extremely high, ranging from 80 to 120 percent. The World Meteorological Organization uses 40% water withdrawal ratio as a threshold indicating a high level of water stress. In the Heihe basin, withdrawal ratios are 2 to 3 times greater. Policies to manage water resources, such as water supply controls, transferable water rights, water pricing, and use of farmers' associations to manage water, have been controversial and resulted in conflicts among water users, including violent clashes.

Climate change: The region has experienced warming temperatures, rising about 1 ^{o}C over the past 50 years. Projections of climate change indicate further temperature increases of 1.0 to 2.5 ^{o}C by 2050; projections of precipitation changes range from increases to decreases. More frequent and severe drought is expected because of higher evaporation in the warmer climate and changes in hydrologic cycle. Higher temperatures, and growing population, will drive the demand for irrigation water up and most municipalities in the basin will face worse water shortages than at present. Some studies suggest food and fibre production will decrease.



Map of the Heihe River Basin with approximate population distribution shown in shades of grey (black is higher population density)

Information for case study compiled from:

Yin, Y., N. Clinton, B. Luo, and L. Song (2008). Resource system vulnerability to climate stresses in the Heihe river basin of western China. In N. Leary, C. Conde, J. Kulkarni, A. Nyong and J. Pulhin, eds., *Climate Change and Vulnerability*. Earthscan, London.

Yin, Y., Z. Xu, and A. Long (2008). Evaluation of adaptation options for the Heihe river basin of China. In N. Leary, J. Adejuwon, V. Barros, I. Burton, J. Kulkarni and R. Lasco, eds., *Climate Change and Adaptation*. Earthscan, London.

Case Study: Bara Province, North Kordofan, Sudan

__Place and Climate__: The Gireigikh Rural Council of Bara Province in the state of North Kordofan is comprised of 17 rural villages with a combined population of roughly 6000. The region, located in the Sahel, has a semi-arid climate, is dominated by sandy soils of poor fertility, and has desert scrub or Acacia-steppe vegetation. Average rainfall in the area is quite low, roughly 250-300 mm per year, and the region experiences significant seasonal and inter-annual rainfall variability. Drought has been a recurrent feature in the Sahel. The magnitude and intensity of droughts have increased over the last 100 years and there has been a general drying trend since the mid-20^{th} century. Droughts that were widespread in Sudan in 1967-1973 and 1980-1984 caused significant human and livestock mortality, huge displacements of people, and adverse impacts on tribal structures that continue to impede local resource management and governance.

Climate change scenarios constructed for a national study project that average temperatures will rise in Sudan from between 1.5^{o}C and 3.1 ^{o}C from baseline in August and 1.1 to 2.1 ^{o}C in January. Average rainfall is projected to decrease by 6mm per month during the rainy season. The higher temperatures and reduced rainfall will exacerbate the water deficit and tendency toward drought that characterizes North Kordofan.

__People__: Two tribes inhabit the area of Gireigikh, the Gawama'a and the Kawahla. The Gawama'a are agropastoralists who farm crops and raise livestock for food and cash. The Kwahla are a semi-nomadic tribe who raise livestock, moving them seasonally to different grazing lands. Forests are used by both settled and semi-nomadic communities for fuelwood, building materials, edible fruits, and aromatic resin. Trees that produce gum arabic have traditionally been an important cash crop that replenishes soils in a rotation of 4-5 years for crop cultivation and 15-20 year fallow period with Acacia trees, which are also a source of nutritious foliage for camels.

Rangelands in the region are often over stocked with animals and the practice of shifting cultivation to allow fallow land to replenish has declined. Excessive cutting of trees, and the failure to replant, has caused deforestation. These human pressures, combined with recurring droughts, is causing soil erosion, land degradation, and desertification. The degradation of the local resource base has undermined livelihoods and left communities more vulnerable to adverse effects of future drought.

Average incomes are lower in North Kordofan State than in Sudan as a whole, and the percentage living in poverty is higher. An estimated 25 percent of households are described as destitute because of lack of assets and labor power.

__Sustainable Development__: The people living in the 17 villages of Gireighkh Rural Council have benefitted from a development project implemented in 1992. The project sought to protect and rehabilitate rangelands and reduce household vulnerability to drought and other shocks by diversifying livelihoods. The project provided water wells for more diversified vegetable production, women's irrigated gardens, an experimental nursery station, support for dairy production, planting of windbreaks, and local credit systems. Goats were replaced with sheep, a less aggressive grazer. Training was provided for rangeland management and para-veterinarian skills. Village committees were set up to manage these activities locally and a committee within the rural council was created to coordinate efforts across the villages. These institutions are still operating and the project has had a positive impact on rangelands and community resilience and prompted nearby villages to replicate some of their practices.

Information for the case study compiled from:

Osman-Elasha, B., and E. Sajak (2008). Livelihoods and drought in Sudan. In N. Leary, C. Conde, J. Kulkarni, A. Nyong and J. Pulhin, eds., *Climate Change and Vulnerability*. Earthscan, London.

Osman-Elasha, B., N. Goutbi, E. Spanger-Siegfried, and others (2008). Community development and coping with drought in rural Sudan. In N. Leary, J. Adejuwon, V. Barros, I. Burton, J. Kulkarni and R. Lasco, eds., *Climate Change and Adaptation*. Earthscan, London.