Global Climate Change and Transportation Infrastructure: Lessons from the New York Area

By **Rae Zimmerman**

Background and Introduction

Global climate change (GCC) is now well known, and its impacts are a stark reality. According to the Intergovernmental Panel on Climate Change (IPCC), changes in global climate in the 20th century, whether from human or natural causes, are already reflected in numerous indicators for atmospheric chemistry, weather, biological, physical and economic conditions,[1] and members of the Intergovernmental Panel on Climate Change (IPCC) working groups have rated the probability of those changes as either actually occurring or at least likely to occur.[2] The estimated impacts of these changes under varying scenarios are in many cases pronounced, and the ability to cope with these impacts varies considerably depending upon the capacity of individuals, groups and institutions to adapt.[3]

The implications of these changes and their impacts for the planning, design and operation of transportation infrastructure are profound because of the pervasiveness of this infrastructure, its centrality in our everyday lives and culture, its interdependencies with other infrastructure, and its historical location in areas vulnerable to global warming effects. Most importantly, transportation infrastructure plays a critical role in providing emergency response services should some of the potential climate change effects become realized. The manner in which transportation and climate change are interrelated is not only an engineering issue but involves the climate sciences and social and behavioral sciences as well. Thus, multidimensional, multi-sectoral and multi-disciplinary perspectives and actions are required to address the adverse effects of climate change. Geographical variations also should be taken into account, since global phenomena have local impacts, and spanning these two scales is often difficult. Incorporating a range of geographic scales is critical, however, since actions to prevent, mitigate, or reverse adverse global phenomena are implemented at many levels, especially through local actions, and the success of these attempts is the collective effect of actions at all scales.

This paper addresses two aspects of the relationship between climate change and transportation infrastructure, focusing on the results of studies conducted for the New York area (Rosenzweig and Solecki 2001a).[4] First, implications of climate change as a factor influencing the current relationships between urban development and transportation management are explored both nationally and regionally for the New York area as a basis for identifying mitigation and adaptation needs and measures. Second, details of flooding and heat-related effects on surface and subsurface transportation-related infrastructure are briefly presented as a basis for lessons these familiar phenomena generate for less obvious climate change and transportation relationships. The paper concludes with observations about the means to manage these outcomes within existing and expanded institutional frameworks and technologies.

The implications of global climate change for the New York metropolitan region have been addressed in at least two major studies. In 1996, attention to the impacts and prevention of climate change in the New York region were the focus of a 1996 conference and proceedings called *The Baked Apple? Metropolitan New York in the Greenhouse* (Hill 1996). That work included an inventory of the potential infrastructure that might be affected and how it could be affected (Zimmerman 1996: 57-83; New York Observer 1995: 19, 21). In 1999-2001, a consortium based at Columbia University led a stakeholder-based in-depth study of the impacts of climate change in the New York Metro East Coast (MEC) area, its consequences in light of other stressors, and the means available for adaptation. The study was directed by Dr. Cynthia Rosenzweig (NASA Goddard Institute of Space Studies) and Professor William Solecki (Montclair State University) and funded by the National Science Foundation, the U.S. EPA and others. The MEC Regional Assessment was one of 18 study areas of the U.S. Global Change Research Program's National Assessment of the Potential Consequences of Climate Variability and Change for the U.S. (Rosenzweig and Solecki 2001a and 2001b; National Assessment Synthesis Team 2000 at www.usgcrp.gov). One aspect of the MEC Assessment focused on institutional decision-making to manage climate change impacts on infrastructure and land use (Zimmerman and Cusker 2001: 9-1 to 9-25 and A11-A17; Martin 1999).

Development, Transportation and Global Climate Change

Development Patterns and Trends

The environmental impact of our lifestyles reaches far beyond the geographic boundaries of our cities and regions, extending from local to global scales. Concepts that are useful in portraying the role of development in global warming especially through the intermediary of transportation are "ecological footprints," land consumption ratios, and measures of coastal vulnerability, all of which point to the increasing per capita use of land and other resources to support our lifestyles.

Ecological Footprints. "Ecological Footprints" refer to the amount of land (and other resources) that urban areas use beyond their boundaries to produce food and other services.[5] Girardet (1995) points out, for example, that cities currently occupy 2% of the land area worldwide, yet consume 75% of the world's resources. In interpreting such observations, one should keep in mind that the flow is two ways - though cities may utilize regional resources, they give back to their regions employment, culture, recreation and other benefits.

Land Consumption Ratios. The amount of land consumed per capita (applicable to rural and suburban areas as well as urban areas) is a common "sprawl" indicator similar to the ecological footprint used to quantify the extent of land used in development. Studies by the U.S. EPA and others use the ratio of urbanized area growth (numerator) to population growth (denominator) (U.S. EPA 2000: 6). Over the past few decades, these ratios have been exceeding 1, indicative of increasing land consumption per capita. For example, according to the U.S. EPA report, the average ratio aggregated for 1950-1990 for the New York metropolitan urbanized area is 4.49 (based on an urban area growth rate of 136.8% and a population growth rate of 30.5%). The New York area ratio has consistently exceeded the national average.

Coastal Vulnerability. The National Oceanic and Atmospheric Administration (NOAA) has used large populations, high densities, and high growth rates in coastal areas as indicators of coastal vulnerability.[6] These indicators are significant because they reflect potential population exposures to the effects of sea level rise associated with climate change.

Implications for Transportation

Transportation, and in particular, emissions from vehicular transport, is considered a major contributor to greenhouse gases (GHGs). Indicators commonly used to substantiate this include (1) vehicular usage in terms of the extent of travel (e.g., vehicle miles of travel), (2) type and amount of energy used to provide such travel, and (3) environmental effects associated with both extent of travel and energy use (primarily in terms of emissions of greenhouse gases and other gases and particulates).

Vehicle Miles of Travel (VMT). According to the U.S. Department of Transportation (DOT), VMT is increasing on average nationally, having risen from 1.1 trillion miles in the year 1970 to 2.8 trillion miles during the year 2000, averaging a growth of 3.1% annually over that period, slightly slowing to 2.5% annually from 1990 to 2000.[7] This is consistent with data that show increasing numbers of licensed drivers and vehicles between 1969 and 1995 (Hu and Young 1999: 11), and in fact, the number of vehicles has increased during those years by 143% while population only increased 32% and the number of households increased 58% nationwide. New York State data indicate that VMT is also increasing within New York State (often in spite of a leveling off of population), and in the New York-New Jersey region. The increased levels of vehicular travel have potential consequences for global climate change since vehicle travel in total generates more emissions in spite of previous gains in fuel economies and engine and end-of-pipe technologies to reduce emissions.

Energy. Energy Information Administration data for the New York area and elsewhere indicate that transportation consumes a large amount of fossil fuel relative to other activities. Nationally, transportation accounted for 27.9% of total energy consumed in 2001, with the average annual percent change increasing from 1.4% in the period between 1973 and 2000 to 1.9% between 1990 and 2000 in spite of fuel economies (Davis and Diegel 2002: 2-3). In New York State, fossil fuel emissions from transportation continue to increase as numbers of motor vehicles are expected to rise. The New York State Energy Research and Development Administration (NYSERDA) 1999 Three Year Plan, citing the 1998 New York State Energy Plan, identified the following statewide energy use trends in transportation and associated energy use and air emissions: Although transportation accounts for 30% of energy use in New York State, it contributes 37% to carbon dioxide emissions; energy use for transportation is forecasted to grow 9% by 2015; and "in 20 years, if current trends continue, daily travel in metropolitan areas will increase by 50%" (NYSERDA 1999).

Emissions. Without a change in vehicular emissions, vehicular travel will continue to contribute to the buildup of greenhouse gases because of continued growth in VMT, in spite of fuel economies. By 2000, transportation accounted for about a third of the emissions of carbon dioxide (CO_2), a major greenhouse gas,[8] contributed by fossil fuels (Davis and Diegel 2002: 3-1). The percentage share of U.S. carbon dioxide emissions from all transportation sectors has increased in absolute terms only by about three percentage points since 1985. However, metric tons of carbon emitted by the transportation sector increased by 33% during that period.[9] Transportation is expected to be the largest growing CO_2 emitting sector, with growth projected at 47.5% between 1996 and 2020 (U.S. EPA 2000: 31).

National Ambient Air Quality Standard (NAAQS) pollutants are closely associated with global climate change. In 1999, transportation accounted for almost four-fifths of the U.S. emissions of carbon monoxide, over half of the NO_x emissions, and over two fifths of the VOC emissions (Davis and Diegel 2002: 4-3). All of these chemicals are NAAQS pollutants. Although highway vehicles initially dominated the carbon monoxide (CO) emission category (accounting for 88% in 1970), their share has gradually diminished to 50% since the share of CO emissions from off-highway vehicles (primarily used in construction and agriculture) has increased, (Davis and Diegel 2002: 4-3).

Patterns and Trends in Global Climate Change Phenomena in General and in the New York Region

Overall Global Climate Change Trends

Three indicators commonly used to describe global climate change trends are: concentrations of greenhouse gases in the atmosphere, global and regional temperatures, and sea level. Globally, all three of these factors are on the rise (with temporal and geographic variations). Although uncertainties exist in the way the data are interpreted, there is generally little disagreement about these patterns and trends and a growing consensus seems to be emerging that human activity is a significant cause (IPCC 2001a and National Research Council 2002). Moreover, public concern is consistent with these findings. A couple of decades ago, public perceptions had been marked by some skepticism about global climate change, but now the trend is toward growing awareness and concern both of general environmental effects and local vulnerabilities associated with climate change.[10]

Patterns and Trends in Potential Global Climate Change Consequences for the New York Area

Transportation not only contributes to climate change, but climate change also has several potential adverse effects on transportation infrastructure. The first effect is related to increased flood elevations or sea level rise and increased frequency and intensity of flooding episodes that can create hazards for transportation located in areas close to sea level. The second is more subtle, and is related to elevations in temperature that, if severe and persistent enough, can result in serious consequences for the materials used in transportation infrastructure.

Increased Flood Elevations. Global climate change-related sea level rise is associated with a number of interrelated factors, namely, increased precipitation, thermal expansion of water, and increased riverine flows from enhanced snowmelt. In the MEC study (Rosenzweig and Solecki, eds. 2001), estimated temperature and flood elevations over the next century differ according to the global climate models and greenhouse gas emission assumptions used, but all generally point to estimated increases in flood elevations and the return frequency of floods. For the year 2030, for example, across three scenarios (low, medium, high) the predictions for the New York region show that (Rosenzweig and Solecki 2001): increases in annual temperature range from 0.9 to 3.8 degrees F.; days exceeding 90 degrees range from 16 to 32 days; precipitation (annual in inches) ranges from a decline of 0.4 to 2.3 inches, potentially signifying drought conditions; sea level rise ranges from 3.7 to 7.6 inches; and the change in flood elevations ranges from 3.9 inches to 8.3 inches. A key factor is that the flood return frequency is projected to increase over the 21st century (Gornitz 2001). Gornitz, Couch and Hartig (2002: 73) estimate that as a consequence of the change in the flood return frequency, "the likelihood of a 100-year flood could become as frequent as once in 43 years by the 2020s, once in 19 years by the 2050s and once in 4 years by the 2080s, on average, in the most extreme case." Flooding has many different consequences, but several are particularly relevant to transportation and its infrastructure.

First, transportation systems are traditionally sited in low-lying areas already prone to flooding. Older facilities have not been planned to take into account increased flood frequencies and flood elevations or if they were, the advantages of the location in flat floodplains for ease of operation outweighed the disadvantages of flooding. Changes in these practices cannot easily be applied to the vast amount of infrastructure already in place in such locations (Zimmerman and Cusker 2001: Tables 9-6 and 9-7). New York City alone has over 500 miles of coastline, much of which is transgressed by transportation infrastructure – roadways, rail lines, and ventilation shafts, entrances and exits for tunnels and transit systems, many of which are at elevations at risk of being flooded even by traditional natural hazards (Jacob, Edelblum, and Arnold, J. 2001; U.S. Army Corps of Engineers, Federal Emergency Management Agency, National Weather Service, New York/New Jersey/Connecticut State Emergency Management 1995). Table 1 below summarizes the number of such facilities in both the New York and New Jersey portions of the region, many of which are among the most heavily used facilities in the region.[11]

Table 1. *Summary of the extent of transportation infrastructure potentially affected by sea level rise, New York region.*

Type of Transportation Infrastructure	**Facilities 10 ft. or less above sea level**	**Facilities 10-12 ft. above sea level**
TRANSIT (e.g., track, tunnels, stations, stairways, grates, and vent shafts)		
Amtrak, MetroNorth, Long Island Rail Road	10	4
Subways, PATH system	17	3
SURFACE TRANSPORTATION (roads, bridges, tunnels)	21	9
MARINE	6	-
AIRPORTS	2	2

Notes to Table 1:
(a) Figures are compiled from Zimmerman and Cusker (2001: Table 9-6, p. 163) from data in USACE (1995).
(b) Figures are compiled from Zimmerman and Cusker (2001: Table 9-7, p. 164) from data in USACE (1995).

Second, transportation systems provide support for hazardous waste management in the region (Zimmerman and Gerrard 1994), and as such, flooding of transportation infrastructure can become a major environmental and health issue as well as a safety issue if hazardous wastes are released during a flooding episode. This actually occurred during the Midwest floods in 1993, according to U.S. Geological Survey reports (Zimmerman 1994).

Temperature-Related Effects and Transportation Infrastructure. According to the MEC study, temperature increases in the MEC region between 1900 and 2000 are estimated at about 0.2 degrees Fahrenheit per decade, and this rate is expected to increase during the 21st century. Many daily and monthly annual and decade averages as well as temperature extremes and the timing of freezing and thawing cycles have been exceeded in the New York area. For example, a *New York Times* synopsis of temperature variations in 1999 alone in New York City indicates that 1999 had the seventh warmest February, tenth warmest May, hottest July (with a high of 101 degrees on July 5th and 6th), and the seventh warmest November. In addition, two days in December tied for the record high (Stevens 2000). That record tends to parallel U.S. trends.

According to engineers managing regional infrastructure (Zimmerman 1996: 64), materials used in roadways have a limited range of tolerance to heat, and the stress is exacerbated by the length of time temperatures are elevated and by stress factors, such as vehicle loadings on roadways and bridges during periods of congestion. Bridges can be particularly sensitive to exposure of the road surface to extreme heat. The extent of the risk is, in part, a function of the number of bridges. New York City alone has 2,200 bridges, potentially subject to extra stresses from elevated temperatures depending on the surface materials used. If these consequences are realized, they can, in turn, have economic and social effects, exacerbating already serious congestion problems in urban areas, as indicated by recent studies. According to the Texas Transportation Institute (2001: Appendices), for example, out of a total of sixty-eight areas studied, the New York-New Jersey area ranked 21st in its congestion index, 24th in the cost of congestion per person, and 2nd in the total cost of congestion. The Texas Transportation Institute 2002 (2002) study indicates that increasing congestion trends are widespread: annual transportation-related delay in 75 urban areas between 1982 and 2000 averaged 62 hours, and this increasing pattern of delay occurred in urban areas of all sizes (however, the extent of delay increases with urban size).

Conclusions

Given the patterns and trends in transportation and its infrastructure in the New York area (regardless of the degree of uncertainty in them), there is little doubt about the potential impact of global climate change effects on public services. As a society, we need to adopt both an adaptive mode, that aims to reduce exposures, as well as a preventive approach that targets sources of global climate change that are within our control, realizing that there is often a fine line between the two strategies.

Adaptation

In light of the more direct and immediate effects of flooding and temperature change and the more indirect, but fundamental effects associated with development patterns, a generic set of examples of adaptation strategies emerge applicable to planning, design, and management practices for both physical transportation facilities and the way transportation services are delivered. These strategies include (Zimmerman and Cusker 2001: 150):

- "Land use and environmental planning and capital programming to ensure the location of new structures and relocation of existing structures outside of impact areas associated with sea-level rise
- Acquiring property to prevent or guide development in hazard areas
- Redesigning structures to avoid impacts, including the removal of traditional flood retaining structures
- Retrofitting existing and redesigning new structures with barriers, higher elevations, and other forms of protection against water inundation and the extremes associated with heat and wind
- Using operational procedures and controls for infrastructure services and facilities to reduce or avoid population exposure during hazard events"

Other adaptations pertain to changes in the behavior and location of potentially affected populations so they are less vulnerable to the consequences of climate change with respect to transportation (Zimmerman and Cusker 2001: 150):

- "Educating the public about global climate change and adaptations and behaviors, including infrastructure and land usage patterns, that will reduce vulnerability
- Improving communication mechanisms such as warning systems
- Moving people and businesses away from vulnerable areas through incentives, relocations, and in extreme cases, evacuations
- Providing emergency response and disaster assistance for reconstruction"

Prevention

Prevention of the occurrence of some of the adverse climate change effects (as distinct from prevention of the adverse consequences of such effects) might involve, for example, the reduction of greenhouse gas emissions (which was not within the scope of the MEC study). This approach ultimately depends on what is known or believed about the sources of the build-up of greenhouse gases. Vehicular congestion and the development patterns that are often associated with it are likely to be key targets of a preventive approach.

An alteration in modes of transportation or vehicle choice could meet the needs of both adaptation and prevention. For vehicular-based sources of the emissions that influence global climate change, alternative engine, exhaust, and fuel designs that target energy intensive vehicles are well known that provide reductions in carbon dioxide emissions.[12] However, current cost estimates tend to point unfavorably to their use over currently used petroleum-based technologies, but these estimates do not typically internalize the cost of climate change. The good news is that the cost differentials tend to be narrowing as these technologies become more well-developed. The New York area can also take advantage of some immediate transportation alternatives that reduce automobile usage, such as increasing use of mass transit. The use of public transit has precipitously declined over the past decades, although there are signs of a comeback both nationally according to the American Public Transportation Association (New York Times 2001: A12) and particularly in the New York region (the New York area accounts for about fifteen percent of the trips nationwide by public transit).

A more dramatic approach would be to address the pattern of land development that accompanies population distribution and growth. Population distribution, i.e., the use of land, is a major factor affecting transportation, which in turn affects greenhouse gas emissions. Land is now being used at a faster rate than population is growing at the outskirts of the city, and people tend to be driving longer as a consequence of this. Much of the nation's transportation infrastructure is located along the coast by necessity, either because it is water-dependent, traverses waterbodies, or was historically located there, potentially increasing the consequences of sea level rise. New York City has 578 miles of waterfront, and the region's total is several times that. The population of Long Island, Connecticut and those parts of New York State that abuts Long Island Sound is concentrated along the coastal areas. That population, according to the Census of Population, was, in 1992, by far the densest in the Nation with the six counties of New York State on the Sound or adjacent to it ranking among the top 25 counties in the country with the highest population density (Zimmerman et al. 1999, based on U.S. census data).

Institutional Capacity Building for Adaptation and Prevention

The magnitude and complexity of the role of governmental and quasi-governmental jurisdictions within the 31-county MEC region involved in the global climate change issue is reflected in the very large investment in the built environment within the region and the number and variety of agencies and governments with direct and indirect authority over that investment. Both of these factors potentially provide opportunities for both adaptation and prevention.

First, the level of financial investment, income generated, and estimated assets in the MEC region are enormous. Prior to September 11th, a number of major capital investment projects in transportation were underway or under consideration in the region, such as the Route 9A reconstruction along Manhattan's west side. Since September 11th, estimates for the reconstruction of the transportation system in Lower Manhattan and connecting areas alone have exceeded $7 billion with over $4 billion committed by the federal government. Much of this area is either located in or connects to infrastructure at elevations considered vulnerable to sea level rise. Thus, given that considerable modifications of transportation infrastructure are already underway in the form of rehabilitation, accommodating climate change as a design and planning criterion may not produce marginally greater investment needs, depending on how it is accomplished.

Second, the total number and variety of organizations alone within the 31-county region is remarkable, and the number of entities within those organizations involved in infrastructure functions is even larger, estimated to be about 2000 (Zimmerman and Cusker 2001: 152). An extensive list of these entities for transportation is contained in Zimmerman and Cusker (2001: 203-204). Although these organizations have vast resources, coordination remains a key issue if these resources are to be useful to adapting to and preventing adverse climate change effects associated with transportation. A number of institutional mechanisms in the MEC region promote some level of integration and coordination among this very large number of entities. However, some forms of integration, for example, between transportation infrastructure and other infrastructure used to support it is often only addressed in an issue-specific or ad hoc manner (Zimmerman 2001). Most of the infrastructure-related entities tend to be highly specialized by function and by area of the region with little integration. For example, at the present time, region-wide planning in general is not the formal role of any governmental agency, though some organizations have undertaken this responsibility such as the Regional Plan Association. Development planning, coastal zone planning, and infrastructure planning, all of which affect transportation, occur within states and localities but by separate public agencies. When these activities are undertaken at a regional scale, they usually occur under the auspices of a state or federal program, and the boundaries of such efforts rarely encompass the entire region. An important aspect of capacity building at the institutional level is directly confronting and addressing public attitudes and behavior toward the uncertainties in global climate change.

In summary, building institutional capacity is the key to the management of both adaptation and prevention of the adverse climate change effects. The IPCC underscored the need for adaptive capacity, and much of the capacity in the transportation sector lies within the institutions responsible for transportation infrastructure from its planning and design through operation and maintenance. It is these organizations, together with public support, that will enable existing transportation investments to reinforce the goals of adapting to and preventing adverse effects of global climate change.

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[1] A summary of these indicators is presented in IPCC 2001c: 5-6. An example of a set of actual changes is the estimated increase over the 20th century in the atmospheric concentrations of a number of greenhouse gases by about 10 to 150 percent (the actual amount depends on which gas it is).

[2] The IPCC working group authors use the term "likely" where it appears next to an indicator to signify that a given condition has a 66-90% chance of occurring, very likely as a 90-99% chance, and virtually certain as a greater than 99% chance (IPCC 2001c: 5). Only the terms likely and very likely appear in the summary tables on pp. 5-6.

[3] The IPCC (2001b, 2001d) reports identify a wide range of impacts with varying degrees of certainty assigned to each.

[4] Though the emphasis is on the New York area, the results of New York area studies have broader applicability to other areas.

[5] Although the concept has been applied primarily to urban areas, it applies equally to suburbs and rural areas.

[6] This concept is usually quantified using county level data as well as in terms of shoreline miles.

[7] Davis and Diegel 2002 6-8, citing the U.S. DOT, FHWA 2001: Table VM-1, p. V-50 and annual figures.

[8] Although carbon dioxide's potential for global warming is far exceeded by other greenhouse gases (see Davis and Diegel 2002: 3-3 citing U.S. DOE, EIA 2001: Table 3 and IPCC), carbon dioxide is present is present in greater quantities and concentrations than these other gases.

[9] Calculated from Davis and Diegel 2002: 3-5.

[10] For example, McDaniels, Axelrod and Slovic (1995: 581) indicated that the public they surveyed ranked climate change ranked twelfth out of sixty five items, and the actual rank was 2.06 out of 3 on a scale from –3 ("poses no risk") to +3 ("poses great risk").

[11] Ten feet is usually used as the threshold for identifying the risk of sea level rise.

[12] See, for example, the comparative matrix provided by Davis and Diegel (2002: 3-9). Some of these alternatives were also explored in Kulash (2002).

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