Vulnerability of Infrastructure to Climate Variability: How Does This Affect Infrastructure Lending Policies?

Paul Freeman and Koko Warner

Report Commissioned by the Disaster Management Facility of The World Bank and the ProVention Consortium

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Preface

The Disaster Management Facility (DMF) and the ProVention Consortium commissioned this study in response to growing concerns for the potential impact of climate variability and adaptation issues on international strategies and lending programs for infrastructure projects.

The Disaster Management Facility provides proactive leadership in introducing disaster prevention and mitigation practices in development activities at the World Bank. The ProVention Consortium is an international coalition of public, private, non-governmental and academic organizations dedicated to increasing the safety of vulnerable communities and to reducing the impact of disasters in developing countries.

Economic development is frequently disrupted by weather-related natural disasters. These extreme events can cause sharp increases in poverty and slow the pace of human development.
This paper explores issues related to the vulnerability of infrastructure to weather-related natural events. It explores whether different types of critical infrastructure face different risks from changes in climate variability, and the impact of disasters on the poor.

The paper emphasizes coping strategies to deal with increased vulnerability as it relates to infrastructure. Two main themes are developed here. First, how to incorporate increased vulnerability as a component of the planning process for infrastructure projects and second, how to increase the coping skills to deal with increasing risk.

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Vulnerability of infrastructure to climate variability: How does this affect Infrastructure lending policies?

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Executive Summary

This report examines the impact of climate change on the international organizations' infrastructure lending policies. Climate change concerns the impact of increasing surface temperature on weather events. Two general impacts can be expected from climate change: increased intensity of extreme weather events and changes to regional weather patterns. Both of these changes impact infrastructure development in poorer countries.

Extreme weather events damage infrastructure. As surface temperature has increased over the past decades, so have the damages caused by extreme weather events. Since the decades of the 1950's, the annual direct losses from natural catastrophes have increased from $3.9 billion to $40 billion a year by the 1990's (IPCC 2001a). Of the annual total of $40 billion, approximately $9.6 billion of direct damage occurs to infrastructure. If surface temperature increase as estimated by the Intergovernmental Panel on Climate Change (IPCC), the direct losses from extreme weather events are anticipated to dramatically increase as well. By some estimates, direct losses from extreme weather events could reach as high as $100 billion annually during the next century (MunichRe 1999a). Infrastructure's share of that total could reach in excess of $25 billion a year.

The impact of these direct losses from catastrophes will significantly impact the poor. All major studies that examine the impact of natural catastrophes on economic development describe the heavy burden that these disasters place on the poor. In fact, in some of the most hazard prone regions of the world, the increased losses from natural catastrophes could negate the capacity of economic development to reduce the number of people living in poverty.

The current knowledge about climate change and forecasted impacts upon infrastructure are based on broad regional analysis. Research in the future must fill the gap between regional knowledge of climate change impacts and country and infrastructure specific knowledge. More specific information will clarify which countries and types of infrastructure are likely to experience infrastructure loss in the future.

Based on better research at a country specific level, planning for the impact of climate change is essential for future infrastructure lending policy. There is considerable scope for reducing risk through appropriate planning efforts. Despite the ability to plan for catastrophes, policy makers do not currently incorporate this activity into country-level or infrastructure project planning.

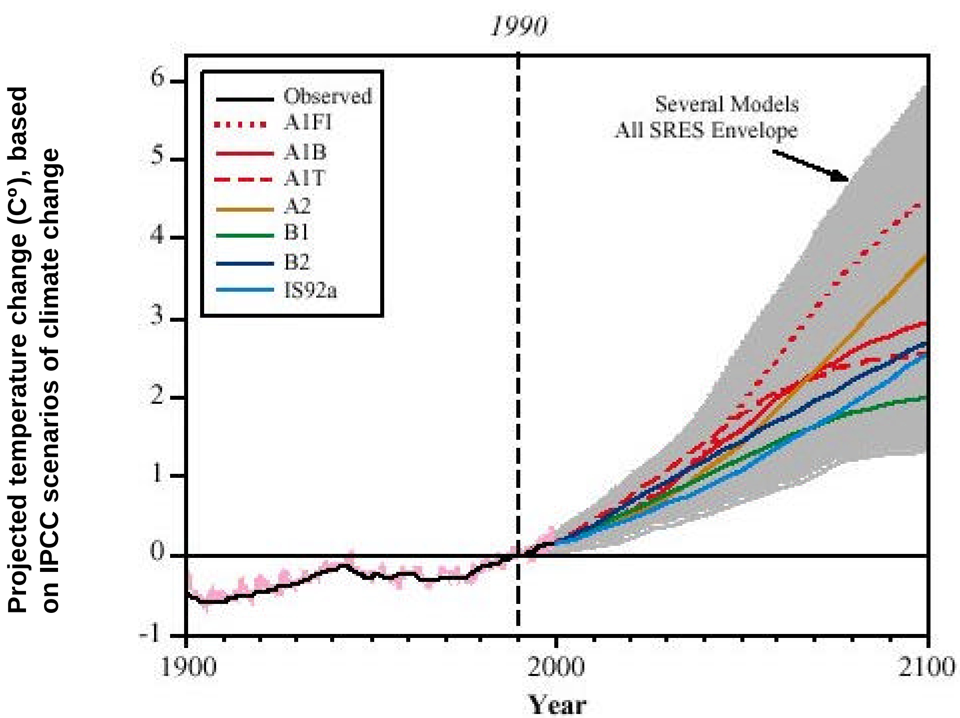
An inevitable result of the increased damages to infrastructure from climate change will be a dramatic increase in resources needed to restore infrastructure and assist the poor. International organizations, and among them, the World Bank play a unique role in providing post disaster infrastructure lending. As damages rise in the future, the international community will increasingly rely on the Bank to provide leadership and funding for post disaster reconstruction. Among the roles the Bank may need to play is as a change agent to promote the use of market mechanisms to assist the poorest countries to arrange ex ante reconstruction funding through insurance and other financial mechanisms. Finally, the poor will require more resources to absorb the impact of catastrophes. Just as the poor are more dependant on public infrastructure to maintain their livelihood, they will require more assistance once the damages to the infrastructure increase.

1. Introduction

The World Bank's Disaster Management Facility commissioned this paper to investigate the impacts of climate change on Bank infrastructure lending policy. Climate change refers to the increase in average mean surface temperature that has occurred in the past 100 years, and the expectation that the next century will experience even greater surface temperature increases. The United Nation's Intergovernmental Panel on Climate Change IPCC was created to understand the causes and impacts of the observed changes in mean surface temperature.

Figure 1 displays the observed temperature increase relative to 1900 and the range of projected temperature increase after 1990 as estimated by the IPCC (IPCC 2001d).

Figure 1: Projected rise in global mean temperature



The figure shows both the historical increases in average surface temperature over the past century as well as ranges of projected temperature shifts, depending on different long-term scenarios. All scenarios indicate an upward trend in average surface temperature.

Increases in average (or mean) surface temperature will influence the normal range of weather patterns for major areas of the globe (IPCC 2001a). The normal range of weather patterns will be influenced in two ways. First, there will be gradual changes in weather patterns. Incremental changes in precipitation patterns will result in either increase in water availability or more droughts. While most studies conclude that the developed world can adapt to gradual changes in weather patterns, the same cannot be said for the poorest regions of the world. The infrastructure and economic capacity to effect timely response actions may be beyond the means of some African countries (Downing et al. 1997).

The second concern is the increased variability of extreme weather events associated with increases in surface temperature. In fact, climate variability and extremes is the most threatening part of global climate change. Chapter 18 of the IPCC's Third Assessment Report notes that

> The key features of climate change for vulnerability and adaptability are those related to variability and extremes, not simply changed average conditions. Most sectors and regions are reasonably adaptable to changes in average conditions, particularly if they are gradual. However, these communities are more vulnerable and less adaptable to changes in the frequency and/or magnitude of conditions other than average, especially extremes (IPCC 2001b).[1]

Increases in surface temperature increase the frequency and severity of extreme weather events. With this increase in the frequency and severity of events, the damages caused by weather related natural extreme events like floods and windstorms (i.e. hurricanes and typhoons) also increase.

International concern about extreme weather events has grown as the economic damage associated with those events has skyrocketed. Since the 1950s, the total direct damages from floods, storms, and other weather-related

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[1]Chapter 18, page 879.Throughout this paper, the terms "vulnerability" and "adaptability" will use IPCC definitions as appear in the TAR. "Adaptive capacity" is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. "Vulnerability" is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2001b).

events have increased 14 times. The losses from weather related events were $3.9 billion per year in the 1950's and had spiraled to $40 billion annually by the 1990's (IPCC 2001c). Approximately one quarter of yearly losses are in the developing world (IPCC 2001c)—$10 billion annually in the 1990's. When non-weather events, primarily earthquakes, are added to these totals, the annual losses from all natural hazards climb to approximately $63 billion a year (MunichRe 1999a). Analysis shows that while non-weather events such as earthquakes occur at about the same frequency over time, weather-related events such as floods and storms have risen in frequency and intensity, especially since the 1950s. A recent report estimates that losses from predicted increases in surface temperature from climate change could exceed $100 billion a year over the next century (Munich Re 2000).

Affected regions are vulnerable both because of climate-related extremes and their status as developing regions (Burton et al. 1993). Socio-economic factors increase the vulnerability to loss in these regions. Africa is particularly vulnerable to the gradual impacts of changing climate patterns because of poverty, recurrent droughts, inequitable land distribution and over-dependence on rain-fed agriculture. For sudden-onset weather events, Asia and Latin America have the highest worldwide exposure to extreme weather events (MunichRe 1998). Rapid population growth and concentration of people and infrastructure in coastal areas—particularly in some of the largest cities in the world—increases the potential losses from extreme weather events (IPCC 2001b).

This paper discusses how climate change may impact Bank infrastructure policies, focusing on the impacts of gradual changes in climate patterns, and direct damages to infrastructure from sudden climate-related extremes. Section 2 identifies the direct losses from climate-related natural catastrophes over the past decade. Direct losses are a result of the interaction between an extreme weather event and assets in the hazard-affected area. Total direct damages from extreme events have risen in recent decades, and trends reveal that climate variability partially drives this historical increase. Section 3 isolates the losses to infrastructure from the aggregate direct damages identified in section 2. Section 3 also reviews the existing literature on the linkages between the natural hazard and specific infrastructure loss. Finally, the section considers who pays for existing damages. Section 4 outlines how climate change will increase direct losses in the future, and the distribution of the expected increased losses for individual countries. The section also provides an overview of regional impacts on infrastructure from gradual changes in weather patterns. Section 5 examines how losses to infrastructure affect the poor. While all major studies conclude that the poor bear an unequal portion of catastrophe impacts, measuring this has been problematic. This section will discuss how impacts on the poor may be more accurately determined. Section 6 makes three recommendations for future work and concludes.

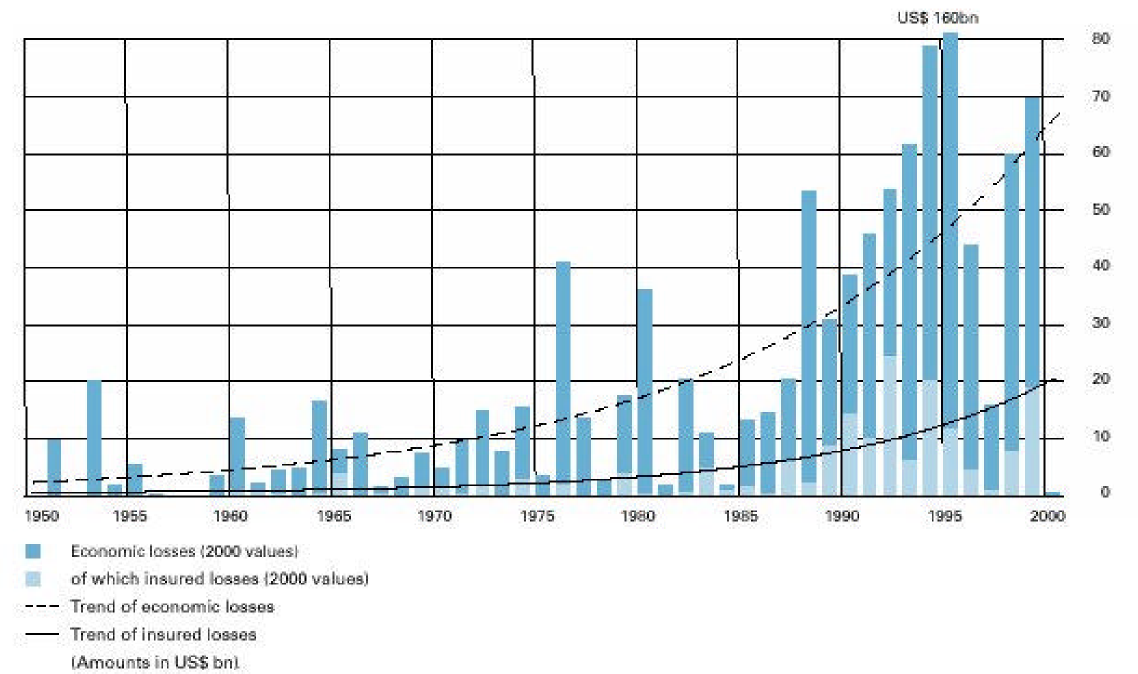
2. Direct losses from extreme weather events over the last century

This section identifies direct losses from extreme weather events over the past 100 years. Direct losses to extreme events depend on two factors: the characteristics of the weather event and the assets exposed to the event. This section first explores trends in climate-related extreme events. It then examines the contribution of climate variability to these trends. Finally, it looks at assets exposed to extreme weather events.

2.1 Rising total direct damages from extreme events

Munich Re notes, “worldwide losses from natural catastrophes increased in the second half of the 20th century in a dramatic and disturbing way. This trend appears to have become even more firmly entrenched since the mid-1980s” (MunichRe 1999a). Direct losses represent the financial value of damage to and loss of capital assets. In economic terms, direct losses like these can be equated to stock losses (MunichRe 1999a). Figure 2 illustrates the rising costs associated with these events. As described in the introduction, annual losses to weather-related events were $3.9 billion in the 1950’s, and had spiraled to $40 billion annually by the 1990’s (IPCC 2001a). A key issue surrounding these direct losses is the range over which these losses vary. Although average expected losses have already reached $40 billion annually, losses can be substantially higher in some years. Direct losses in 1995 were US$160 billion.

Figure 2: Economic losses from natural catastrophes in the 20th century



Source: (MunichRe 1999b)

A wealth of information exists about the direct losses caused by natural disasters. Swiss Re publishes a series of articles on important insurance issues in its *sigma* series. Each year, an issue of *sigma* is devoted to describing the insured losses from all large natural disaster events from the prior year. In much the same way, Munich Re publishes an annual report on natural catastrophes for the prior year. Munich Re tracks both insured and economic losses on a worldwide basis. From time to time, Munich Re and Swiss Re publish special reports that discuss specific issues related to natural disasters and often compare disasters to key economic indicators for hazard prone countries. The publications from both of these organizations are valuable primary information sources.

Since 1988, the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters (CRED) has maintained an Emergency Events Database (EMDAT). EMDAT contains essential core data on the occurrence and effect of over 12,000 disasters in the world from 1900 to present.[2]

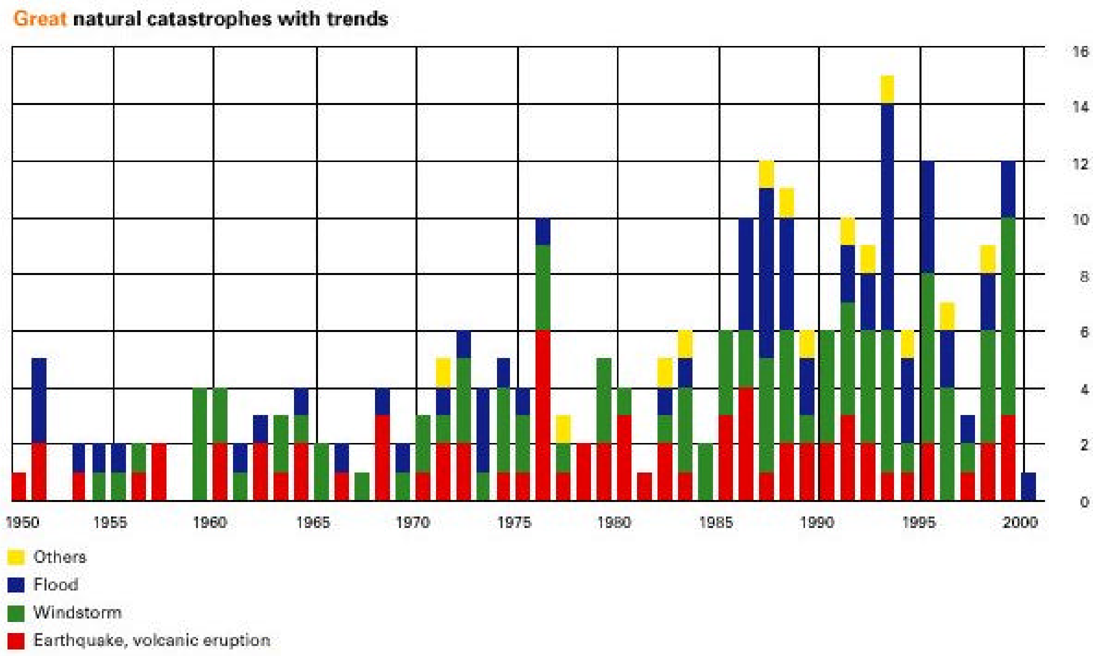
Each year, the International Federation of Red Cross and Red Crescent Societies (IFRC) prepares a survey of natural hazard events, the World Disasters Reports. The annual surveys are based on information from the CRED database and other data sources as well as the IFRC experience in providing support to countries and regions severely hurt by natural disasters.

2.2 Variability in climate extremes and historical increase in direct damages

Variability in climate extremes has contributed to the rising trend in total direct damage. Variability in climate extremes is defined as the frequency and intensity of weather events. Climate variability goes along with, and is an integral part of, climate change (Hulme et al. 1999). Time series data show the relationship between climate variability and dramatic upward trends for total direct damages. Three main categories of natural disasters account for 90% of the world's direct losses: floods, earthquakes, and tropical cyclones (primarily hurricanes and typhoons). Figure 3, which divides losses to specific types of events, shows that while earthquake occurrence remains relatively stable over time, the incidence of weather-related events has accelerated.

[2] The Universite Catholique de Louvain in Brussels, Belgium now maintains the database. The database contains links to other data sourcesThe database can be accessed at http://www.cred.be/emdat.

Figure 3: Natural catastrophe trends in the 20th century



Source: (MunichRe 1999b)

During the past decades, the economic costs of rainstorms, river floods, droughts, and other extreme weather events have increased 14 times from the decade of the 1950's to the decade of the 1990's (MunichRe 1999a)

2.3 Asset concentrations in hazardous areas contribute to higher losses

Larger concentrations of assets and populations in hazard prone regions contribute substantially to higher direct losses from climate-related events. Floods, earthquakes, and tropical cyclones periodically revisit the same geographic zones.[3] Some of the highest risk areas are also some of the most populous: India, China, and Southeast Asia face both a high risk for seismic activity, as well as for floods, hurricanes, and cyclones. The increased

[3] Earthquake risk lies along well-defined seismic zones that incorporate a large number of developing countries. High-risk areas include the West Coast of North, Central and South America, Turkey, Pakistan, Afghanistan, India, China, and Indonesia. The pattern of hurricanes in the Caribbean and typhoons in South Asia, Southeast Asia, and the South Pacific is well established. Floods occur in 1% of the worldwide landmass. (Swiss Re, 1997)

concentration of populations and assets in hazard prone regions will lead to more damage caused by natural hazards. Poor and non-poor alike are moving their assets to hazard-prone areas. A growing number of extremely large cities are located in hazardous areas, which means that large amounts of infrastructure may be affected (UnitedNations 1997). Currently, every year an estimated 46 million people and their assets are at risk of flooding from storm surges.

3. Current infrastructure losses as a component of world-wide direct losses

This section isolates the losses to infrastructure from the direct loss totals in the previous section. Section 3 reviews the existing literature on what type of natural hazard event affects what type of infrastructure. Finally, the section considers who pays for existing damages.

3.1 Infrastructure damage is a key component of total direct losses

As the previous section describes, total direct damage has increased dramatically over the past decades. As total direct damages increase globally, it is reasonable to expect that infrastructure damage as a portion of those overall losses would increase as well. Using data from the World Development Indicators (WorldBank 1999), 24 percent of invested capital stock is public infrastructure. Even if infrastructure is no more vulnerable to loss than other types of capital stock, annual direct damage to infrastructure could reach into the billions. If annual total direct total losses for weather-related events now are $40 billion, then total direct losses for infrastructure already reach $9.6 billion. This annual loss figure can vary significantly, depending on the frequency and severity of weather-related events in any given year. Based on historical data, in 1995 infrastructure losses alone were $32.6 billion (MunichRe 1999a).

3.2 Linking infrastructure damage to different weather events

Is there a relationship between some types of weather-related disasters and the infrastructure damaged? Research suggests this is the case. The IPCC has outlined representative examples of projected infrastructure impacts of extreme climate phenomena (IPCC 2001a). Figure 4 illustrates examples of infrastructure impacts resulting from projected changes in extreme events.

Some simple extremes like more rain are very likely to impact infrastructure by increasing flooding and landslide damage. Complex extremes include increased summer drying, cyclones and storms, drought and flood cycles, and monsoons. Each of these events will impact infrastructure. Increased tropical cylone peak wind activity and peak precipitation intensity damage coastal infrastructure. Flooding associated with El Niño weather patterns will affect infrastructure in hazard zones. Drought and flood cycles are likely to intensify in many regions, impacting hydro-power potential and infrastructure. Increased intensity and frequency of monsoons is likely to cause greater damage to infrastructure in temperate and tropical Asia.

Figure 4: Examples of infrastructure impacts resulting from projected changes in extreme climate events	
Projected changes during the 21st century in extreme climate phenomena and their likelihood[a]	**Representative examples of projected infrastructure impacts**[b] **(all high confidence of occurrence in some areas**[c]**)**
Simple extremes	
More intense precipitation events (*very likely*[a] over many areas)	• Increased flood, landslide, avalanche, and mudslide damage • Increased pressure on government and private flood insurance systems and disaster relief
Complex extremes	
Increased summer drying over most mid-latitude continental interiors and associated risk of drought (*likely*[a])	• Increased damage to building foundations caused by ground shrinkage • Decreased water resource quantity and quality, impacts on hydro-power • Increased risk of forest fires
Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities (*likely*[a] over some areas)[e]	• Increased coastal erosion and damage to coastal buildings and infrastructure
Intensified droughts and floods associated with El Niño events in many regions (*likely*[a])	• Decreased hydro-power potential in drought-prone regions • Flood damage to infrastructure in hazard zones
Increased Asian monsoon precipitation variability (*likely*[a])	• Increased flood and drought magnitude and damages in temperate and tropical Asia
Increased intensity of mid-latitude storms (little agreement between current models)[d]	• Increased property and infrastructure losses

[a]Likelihood refers to judgmental estimates of confidence used by TAR WGI: very likely (90-99% chance), likely (66-90% chance). Unless otherwise stated, information on climate phenomena is taken from the Summary for Policymakers TAR WGI.
[b]These impacts can be lessened by appropriate response measures.
[c]High confidence refers to probabilities between 67 and 95% as described in the Summary for Policy Makers, TAR WGI, footnote 6.
[d]Information from TAR WGI, Technical Summary, Section F.5.
[e]Changes in regional distribution of tropical cyclones are possible but have not been established.

Source: (IPCC 2001a)

Figure 4 shows that flooding poses one of the greatest threats to infrastructure, particularly for those structures that provide water for cities, agriculture, hydropower, and other purposes. In addition to the IPCC's work, three other studies link specific types of infrastructure damage to types of climate-related extreme events.

First, Benson finds that different types of hazards cause varying levels of physical damage to infrastructure and economically productive sectors. For example, droughts may have minor impacts on infrastructure and productive capacity, but can result in heavy crop and livestock losses. Floods can cause extensive damage to both infrastructure and other productive capacity, and can wipe out agricultural yields, depending on the agricultural cycle (Benson and Clay 2000).

Second, the work by ECLAC, the United Nations Economic Council for Latin American Countries, outlines possible damage by event type (Otero and Marti 1995). ECLAC's work also outlines the effects of extreme climate events on particular sectors. Figure 5 highlights the linkages between event type, infrastructure impacts, and impacts on the agricultural sector, a key sector in most developing countries. Figure 5 complements the previous figure by highlighting the impact of infrastructure loss on economically productive sectors.

In a manual for estimating the socio-economic effects of natural disasters, ECLAC provides broad outlines for the most probable types of infrastructure damage by type of disaster. For example, the manual explains how floods can impact clean water supply, damage buried pipes and semi-buried tanks, dam structures, and harm pump equipment. Floods were considered to cause damage in all infrastructure categories, deteriorating or destroying integral structural components, deforming the land on which they rest, or rendering them useless because wind or water have deposited extraneous material in them (mud, ash, debris, etc.). Droughts tend to impact infrastructure more mildly, and can damage highway infrastructure and railway damage through foundation shrinkage and distortion of soldered rails. Windstorms bring additional loads to bear on buildings, affecting both structural and non-structural elements, but only minimally affecting foundations and underground elements (ECLAC 1999).

Figure 5: Selected effects of natural disasters on infrastructure and agriculture			
Type of event	***Surface effect***	***Infrastructure impact***	***Agricultural impact***
Hurricane, typhoon, and cyclone	• Strong, gusty winds • Flooding (through rainfall) • Flooding (through storms)	• Damage to buildings, distribution, & high-tension lines • Damage to bridges and buildings; landslides • Damage to bridges, roads, and buildings	• Loss of trees, damage to plants, esp. grains • Loss of plants, esp. roots and tubers, soil erosion • Extensive damage to plants and irrigation systems; saline deposits; soil contamination and erosion
Drought	• Dryness of earth • Wind gusts • Desertification	• Shrinkage damages building foundations & under-ground infrastructure • Wind damage to roof tops • No major damages, type of infrastructure needed may change	• Destruction of crops and forests • Soil erosion & damage to forests • Land covered with sand; type and time of crops altered; trees ruined; increased weed growth
Flood	• Soil erosion • Water-saturation and landslides • Sedimentation	• Softening of building foundations • Buried buildings; damage to other structures • Damages functions of hyro-power dams, water management systems	• Destruction of crops; alteration of type and time of harvest • Localized damage to fields of crops & forests • Soil contamination OR improvement of soil conditions possible
Tsunami	• Floods	• Destruction or damage to buildings; bridges, irrigation systems; water pollution	• Localized destruction of crops; salt deposits; damage to coastal forest, vegetation, wells

Source: Adapted from (Cuny 1983) and (Otero and Marti 1995)

Third, in a study examining the long-term macroeconomic impacts of catastrophes, Albala-Bertrand finds that although earthquake damage is targeted primarily at housing, flooding poses a conspicuous problem for productive infrastructure damage, particularly for transportation networks. For climate-related events such as floods and hurricanes, infrastructure is the dominant loss category (Albala-Bertrand 1993). At least one other report shows that infrastructure losses to extreme climate events were concentrated in regions subject to hurricanes and floods, and almost half of all losses were associated with flood-related damage to roads (Burby 1998).

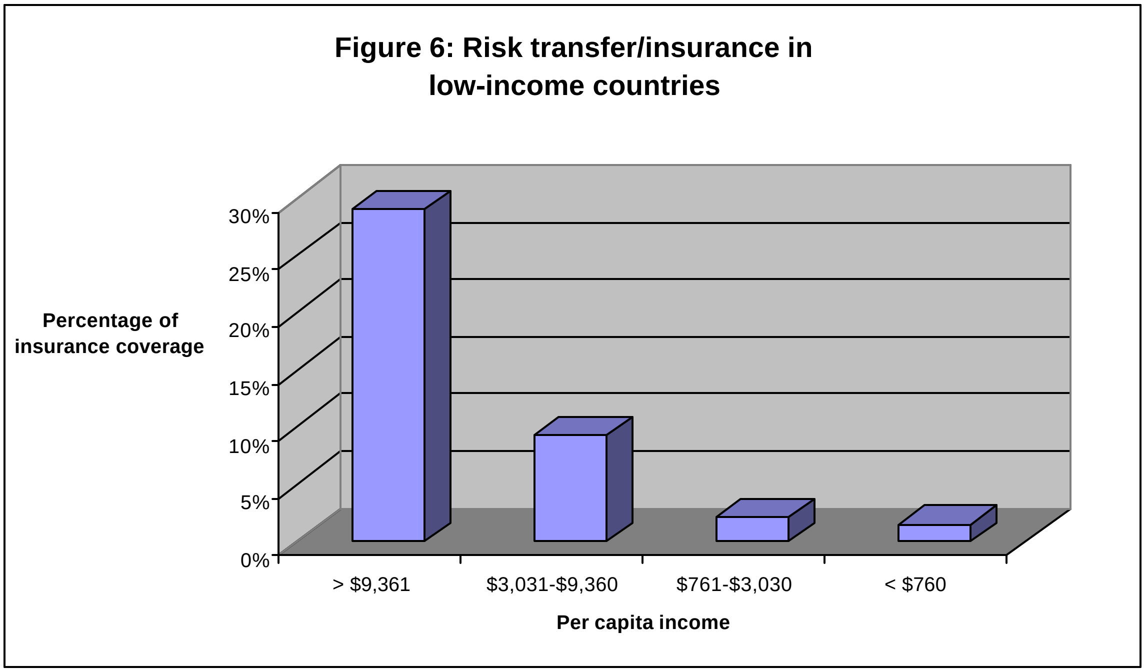
This work demonstrates that different types of critical infrastructure face notably different risk from changes in climate variability. It suggests that flooding and windstorms have the most widespread impacts on infrastructure such as buildings, bridges, roads, and water systems. Droughts appear to impact infrastructure to a milder degree, but have a heavy impact on agricultural sectors.

3.3 Who pays for infrastructure damage following a catastrophe?

For poorer countries, governments and victims tend to pay for the damage to infrastructure. Currently, 95% of infrastructure in the developing world is government-owned, and governments bear the responsibility to repair damaged infrastructure following an extreme event.

Governments also assume some risk for privately owned infrastructure. Although private parties have become more involved in infrastructure ownership and management, privatization contract law categorizes catastrophe events under *force majeure* provisions. The concept of *force majeure* in privatization agreements, unless otherwise specified, relieves the private party from liability associated with an unforeseen and unavoidable event such as a catastrophe (Fucci 1999). The *force majeure* provisions largely allocate financial responsibility for catastrophe risk to governments, even for privatized infrastructure (Gibbon 1996).

Insurance is not widely available or used in developing areas. Figure 6 illustrates that up to 29% of total losses are covered by some risk transfer/insurance mechanism in countries with a per capita income at or above US$9,361.



Source: (MunichRe 1999a)

For countries with per capita income of less than US$760, only about 1% of total losses are insured (MunichRe 1999a). Currently, insurance is not widely used as a resource to help recover from the impacts of natural catastrophes.

What resources are available for governments to pay for infrastructure damages? Traditionally, the governments of poorer countries have turned to the international financial community to provide financing for infrastructure reconstruction following extreme events. The resources available to the international development community are limited and have remained stagnant for nearly 10 years [WorldBank, 1999 #3]. As the cost of disasters increase, the demand on the international financial community to provide needed resources has also increased. For example, the Inter American Development Bank (IDB) has increased its average annual disaster related spending by a factor of 10 in the past five years in comparison to the previous 15 years. In consuming the limited funding available, natural disasters divert resources needed to support longer term economic and social development objectives. The OAS notes “funds intended for development are diverted into costly relief efforts. These indirect but profound economic effects and their drain on the limited funds now available for new investment compound the tragedy of a disaster in a developing country” (Bender 1991). To pay for infrastructure repair following a natural catastrophe, the poorest countries must seek grants or loans from the international finance community. Since 1980, the World Bank has funded $7.5 billion in post-disaster losses (Gilbert and Kreimer 1999). Governments increasingly need help to locate resources to pay for infrastructure damage.

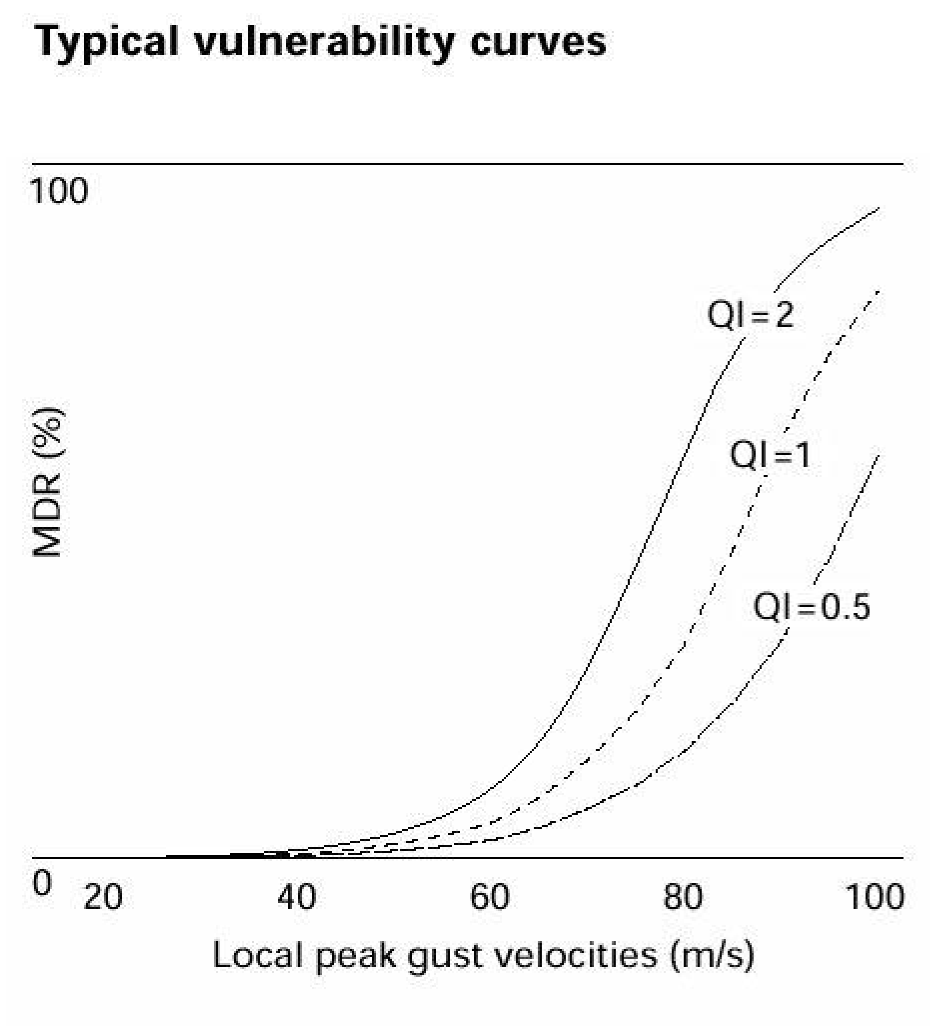
4. Future infrastructure vulnerability and climate variability

If infrastructure vulnerability to climate-related events is currently a cause for concern, it will become even more so in the future. The section first examines the relationship between changes in the magnitude of extreme events and losses to infrastructure. Next, the section outlines projected weather patterns with climate change. Finally, it shows how gradual changes in weather patterns and changes in the variability of extreme events will affect regions in the developing world.

4.1 Small changes in climate variability will bring large infrastructure loss

Small changes in climate variability correlate with large increases in infrastructure damage. Models that forecast future potential damage to assets highlight this interesting phenomenon. Swiss Re and Munich Re show that damage from windstorms is exponentially related to peak gust velocity. Figure 7 shows typical vulnerability curves that illustrate the relationship between local peak gust velocities and mean damage. Note from the curve, that moving from a wind speed of 40 to 60 meters per second increases marginal damage from about 2 to 10 percent. Moving from a wind speed of 60 to 80 meters per second increases losses to 75 percent (SwissRe 1997) for buildings of substandard quality (quality index 2). As wind speed increases, minor changes in velocity can drive up damage significantly. The curves reflect a quality index (QI) for building construction, with the middle curve representing a standard quality level. Lower quality building worsens marginal damage.

Figure 7: A 20 meter per second increase in wind speed can increase damage by 65%



Source: (SwissRe 1997)

Similar damage curves exist for flooding events (MunichRe 1997; SwissRe 1998). A small increase in flood levels may vastly increase flood damage, as incremental flood levels overwhelm existing flood protection systems. In the U.S., many coastal structures were designed with the 100-year flood as their basis. This flooding level determines the elevations at which federal infrastructure projects are built (it is also the level to which coastal structures must be built to qualify for flood insurance through FEMA's Flood Insurance Program). If sea level rises, a 50-year flood may become as severe as (or even more severe than) a 100-year flood before sea-level rise (Reynolds et al. 1998).

4.2 Climate variability and projected weather patterns

As the introduction discussed, climate change will impact infrastructure through gradual changes in weather patterns, and increasing variability of extreme events. Climate change will gradually affect weather patterns over broad regions. Figure 8 depicts an IPCC assessment of observed changes in weather extremes during the last half of the 20th century (left column), and in projected changes during the 21st century (right column).[4] As discussed in sections 2 and 3, weather-related extreme events have increased. The figure reinforces the message that climate variability will increase, and that small changes in the frequency or intensity of these events will drive up damage to infrastructure. In the future, the IPCC estimates that more intense precipitation events are very likely over many areas. Drought and increased tropical peak wind intensities are likely. The mean and peak precipitation intensities for tropical cyclones are also likely increase to in many areas.

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[4] More details can be found in the Third Assessment Report, Chapters 2 (observation), 9, and 10 (projections). The information from figure 4 comes from Table 1 of Working Group I's "Summary for Policymakers." In it the authors explain, "This assessment relies on observational and modeling studies, as well as the physical plausibility of future projections across all commonly-used scenarios and is based on expert judgement."

Figure 8: Observed and projected changes in climate variability		
Changes in Weather-related phenomenon	**Confidence in observed changes (latter half of the 20th century)**	**Confidence in projected changes (during the 21st century)**
More intense precipitation events[a]	Likely, over many Northern Hemisphere mid- to high latitude land areas	Very likely, over many areas
Increased summer continental drying and associated risk of drought	Likely, in a few areas	Likely, over most mid-latitude continental interiors. Lack of consistent projections in other areas.
Increase in tropical cyclone peak wind intensities[b]	Not observed in the few analyses available	Likely, over some areas
Increase in tropical cyclone mean and peak precipitation intensities[b]	Insufficient data for assessment	Likely, over some areas
[a] For other areas, there are either insufficient data or conflicting analyses [b] Past and future changes in tropical cyclones location and frequency are uncertain.		

Source: Adapted from (IPCC 2001c)

The IPCC projects that weather patterns will become more extreme for many regions. These changes will be accompanied by exponential increases in damage, especially for events like flooding and windstorms.

4.3 Climate variability and extreme events in broad geographic regions

Climate change is forecasted to bring gradual changes in weather patterns, and changes in the variability of extreme events to broad geographic regions. Weather pattern changes and weather-related extreme events will impact specific areas differently. Figure 9 summarizes some forecasted regional impacts of gradual weather changes and extreme climate events in developing regions. Forecasts predict an increase in climate-related extremes for all regions, but negative impacts of these events appear particularly for areas like Africa, Latin America, and Asia (IPCC 2001b).

For Africa in general, increased floods, droughts, and other extreme events will stress water resources, food security, and infrastructure. Desertification may affect larger regions. Flooding and drought on major rivers in Africa will affect agriculture and hydropower systems.

Figure 9: Selected impacts of climate-related extreme events in developing regions	
Region	**Expected regional impact of extreme events**
Africa	• Increases in droughts, floods, and other extreme events will add to stress on water resources, food security, human health, and infrastructure, and would constrain development in Africa (*high confidence*) • Sea level rise would affect coastal settlements, flooding and coastal erosion especially along the East-Southern African coast (*high confidence*) • Desertification exacerbated by reductions in average annual rainfall, runoff, and soil moisture (*medium confidence*) • Major rivers highly sensitive to climate variation: average runoff and water availability would decrease in Mediterranean and southern countries in Africa, affecting agriculture and hydro-power systems (*medium confidence*)
Asia	• Extreme events have increased in temperate Asia, including floods, droughts, forest fires, and tropical cyclones (*high confidence*) • Thermal and water stress, flood and drought, sea-level rise, and tropical cyclones would diminish food security in countries of arid, tropical, and temperate Asia; agriculture would expand and increase in productivity in northern areas (*medium confidence*) • Sea-level rise and increase in intensity of tropical cyclones would displace tens of millions of people in low-lying coastal areas of temperate and tropical Asia; increased intensity of rainfall would increase flood risks in temperate and tropical Asia (*high confidence*) • Climate change would increase energy demand, decrease tourism attraction, and influence transportation in some regions of Asia (*medium confidence*)
Latin America	• Loss and retreat of glaciers would adversely affect runoff and water supply in areas where glacier melt is an important water source (*high confidence*) • Floods and droughts would increase in frequency, higher sediment loads would degrade water quality in some areas (*high confidence*) • Increases in the intensity of tropical cyclones would alter the risks to life, property, and ecosystems from heavy rain, flooding, storm surges, and wind damages (*high confidence*) • Coastal human settlements, productive activities, infrastructure, and mangrove ecosystems would be negatively affected by sea-level rise (*medium confidence*).
Small Island States	• Projected sea-level rise of 5 mm yr-1 for the next 100 years would cause enhanced coastal erosion, loss of land and property, dislocation of people, increased risk from storm surges, reduced resilience of coastal ecosystems, saltwater intrusion into freshwater resources, and high resource costs for adaptation (*high confidence*) • Islands are highly vulnerable to impacts of climate change on water supplies, agricultural productivity including exports of cash crops, coastal ecosystems, and tourism as an important source of foreign exchange for many islands (*high confidence*)
Note: Footnote 6 of the IPCC's TAR "Summary for Policymakers" uses the following words to indicate judgmental estimates of confidence: *very high* (95% or greater), *high* (67 – 95%), medium (33 – 67%), *low* (5 – 33%), and *very low* (5% or less). (IPCC 2001a).	

Source: (IPCC 2001c)

For Asia, flooding, drought, and tropical cyclones will increase. These extreme events will add to food security problems and displace millions of people. Infrastructure such as transportation, and the tourism sector will also be more vulnerable in Asia. In Latin America floods and droughts will increase, disturbing water resources and infrastructure. Tropical cyclones are expected to increase in intensity and frequency, which will alter current risk to infrastructure.

IPCC findings about general negative impacts of climate change on the frequency and magnitude of climate-related extreme events range from medium to high confidence at the regional level. Increased climate variability will bring with it rising costs of infrastructure protection or repair. Emerging patterns of infrastructure damage and climate variability point to surging future losses in developing countries. The next section discusses how these heavy losses may affect the poor, typically a large part of developing country populations.

5. Disproportional impacts of climate variability on the poor

The poor bear a disproportional burden of direct damage from catastrophes, and climate change will exacerbate this effect. One author notes

> For both developed and developing countries, the lower the economic, political, and social status of the people…affected by disasters, the larger the loss burden… Consequently, the people and activities most affected by natural disasters are bound to be those belonging to the poorest and most powerless social sectors of less developed countries, especially in those countries undergoing rapid transition with little or no regard for social consequences at the margin (Albala-Bertrand 1993).

Every major study of the impacts of natural catastrophes in developing countries reaches this conclusion (Benson 1997; IPCC 2001a; Otero and Marti 1995; Sen 1999; WorldBank 2000a). The poor generally are more vulnerable, suffer greater costs, and have less capacity to take compensating action, than richer societies/households. Even if the macroeconomic costs are small, the costs for the most vulnerable within society may be large. Climate-related extreme events thus pose a more serious threat than would appear from the macroeconomic data (Albala-Bertrand 1993).

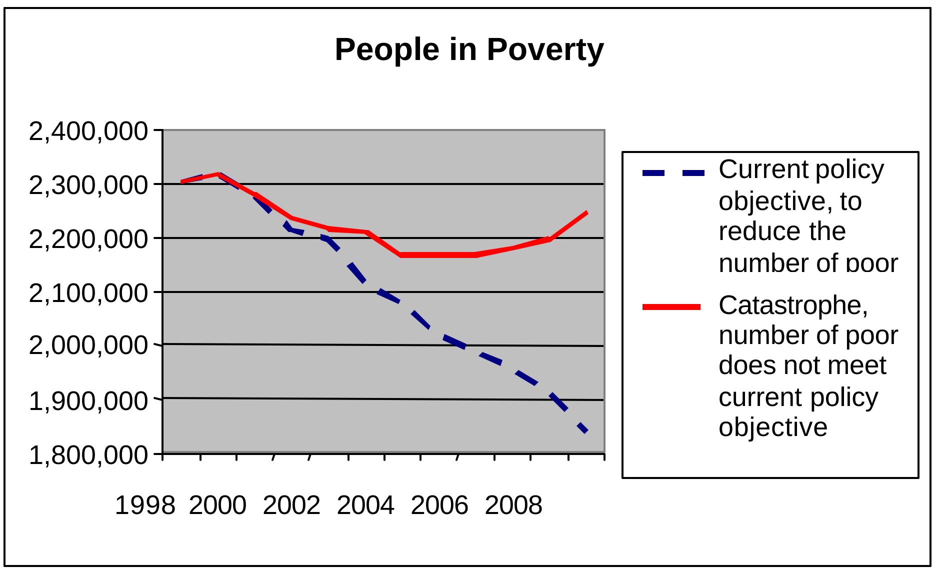
One factor in this heightened vulnerability to the devastating consequences of disasters is reliance of the very poor on critical infrastructure (WorldBank 1994). The poor may have no alternative path to access the services provided by public infrastructure. Reliable access to critical infrastructure services such as clean water, energy, shelter, transportation, and medical care play a vital role in maintaining minimum living standards for the very poor. Rural transport, electrification, and irrigation projects, which have a proven track record in poverty reduction, are damaged by catastrophes. Replacement is often delayed, and resources for reconstruction are diverted from other poverty-reducing development projects. Research shows that long-term disability and destruction of infrastructure can trap families in chronic poverty (WorldBank 2000b). Furthermore, although the poor have relatively fewer assets to lose, assets they do have may be of lower-quality construction and lie predominantly in higher-risk areas (Parker et al. 1995). The poor often live in crowded, inadequately maintained or makeshift homes. In some regions the poor cannot afford to live in more desirable, less hazard-prone areas.

Beyond widely accepted conclusions that the poor bear the heavier load from direct damages to infrastructure from extreme events, quantifying this burden has proved difficult. Because the poor are not well reflected in macroeconomic data, analysis of that data alone disguises the consequences of disasters on the poorest segments of society.

Work is progressing on measuring the impact on the poor, by supplementing macroeconomic modeling with a household level model. An initial assessment of the impacts of Hurricane Mitch on the poor of Nicaragua is one example of this type of effort. The household model used in this example is based on the *Nicaragua Living Standards Measurement Study Survey 1998* conducted by the World Bank, the United Nations Development Program (UNDP) and the Government of Nicaragua.

The first step in modeling the effect of catastrophes on poverty is to measure the impacts that catastrophes would have if each person's share in both growth and catastrophe losses were directly proportional to their consumption[5]. Each person therefore loses an equal part of his or her income. The results shown in figures 10 and 11 are obtained by first estimating the macroeconomic impact of a natural catastrophe, using a probabilistic method. Then, changes to real per capita income are calculated based on this estimate and incorporated into a poverty module. The module assumes that losses are proportional to consumption for each segment of the population. Figure 10 illustrates that catastrophes can slow or stall the reduction of poverty.

Figure 10: Catastrophes can slow or stall the reduction of poverty



The dotted line in figure 10 shows the current policy objective for Nicaragua: to reduce the number of people in poverty. The dotted line indicates that, in the absence of a catastrophe, GDP growth alone reduces the number of people in poverty by 500,000 people by 2008. In the case of a catastrophe (shown by the solid line), the impact on poverty is substantial. For the decade following a 1998 catastrophe, the number of people living in poverty decreases

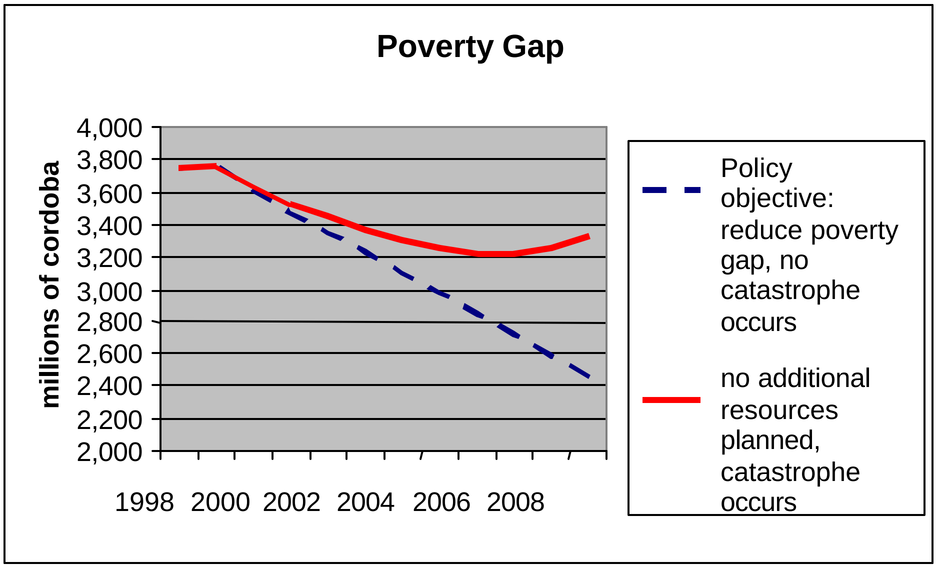
[5] Consumption being a proxy for income used to determine poverty quintiles.

only slightly. Towards the end of the projected period, the number of people in poverty begins to rise slightly.

A major issue in this analysis is the incorporation of natural catastrophes into broad planning. To avoid the outcome described by the solid line in figure 10, the impacts of natural catastrophes on the poor would need to be considered. To meet poverty reduction objectives even when catastrophes occur, more assistance than is currently planned will be required. Considering catastrophe impacts and poverty in broad planning activities could help Nicaragua achieve its poverty reduction measures, even when a catastrophe occurs. If the impacts of natural catastrophes are not considered, when a catastrophe occurs, Nicaragua will not achieve its poverty reducing objectives.

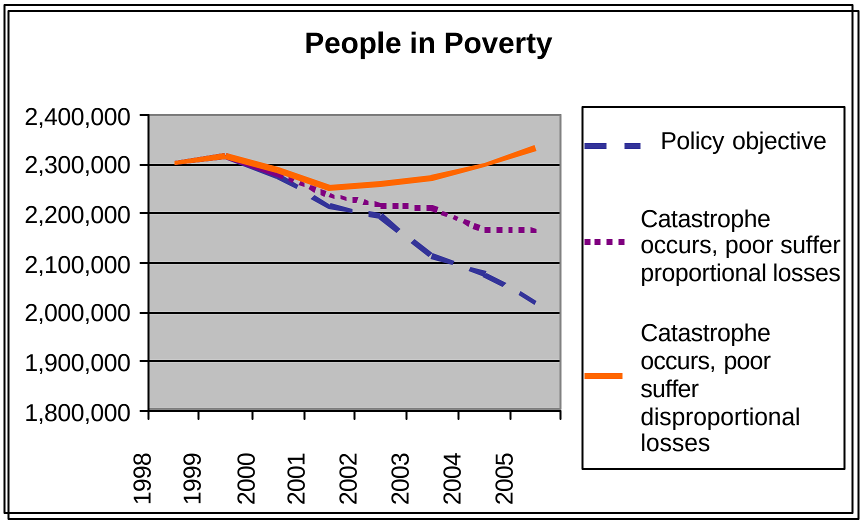
Beyond the sheer numbers of those living in poverty, the poverty gap and is also accentuated by catastrophes. The poverty gap is the amount of money needed to raise expenditures of the poor to the poverty line. Again, using an estimate of the macroeconomic impact of a natural catastrophe, figure 11 shows that catastrophes can accentuate the poverty gap. In the case where no catastrophe occurs, and the current policy objective is met (represented by the dotted line), the amount of cordobas needed to reduce the poverty gap declines from almost 3,800 million cordobas to just over 2,400 cordobas over a decade. This situation changes when catastrophe exposure is incorporated into macroeconomic projections. When the amount of aid for poverty reduction remains fixed and a catastrophe occurs (represented by the solid line), figure 11 shows that the amount of money needed to raise expenditures of the poor to the poverty line remains at approximately the same real level over a decade. Instead of reducing poverty and reducing the amount of money needed for poverty relief, in the case of a catastrophe the poverty gap does not close significantly.

Figure 11: Catastrophes can accentuate the poverty gap



These results are based on the assumption that people proportionally shared the boon of economic growth, as well as the brunt of catastrophe losses. If the poor suffer from catastrophes in direct proportional to their consumption, catastrophes can slow poverty reduction measures. To the extent that the poor are disproportionately affected by catastrophes, the poverty impacts demonstrated above will be magnified. Doubling the fractional burden of natural catastrophes on the poor, the relative number of people in poverty increases, with an additional 150,000 people in poverty by 2005 (figure 12). The poverty gap also increases every year, with an additional gap of 300 million cordoba by 2005. The deterioration will occur with probabilistic certainty unless additional resources are included in planning.

Figure 12: The number of people in poverty increases if the poor suffer disproportionally from catastrophic events



This paper has reviewed current direct losses and infrastructure exposure to climate-related events. It has mapped out future exposure to climate-related disasters and pointed out that developed countries and the poor will bear a disproportional burden of infrastructure damage. What do these findings imply for future infrastructure lending policy?

6. Future infrastructure policy and climate variability

Climate change threatens to increase the direct loss of infrastructure exponentially, with three major implications for the amount and terms of future infrastructure lending policy. First, research must move knowledge of climate change impacts to the country level. Second, planning for sudden- and gradual-onset disaster events is essential. Third, demand will rise for resources to pay for infrastructure replacement and sustain the poor following catastrophes.

6.1 Country-level studies needed

Current knowledge about climate change and forecasted impacts upon infrastructure are based on broad regional analysis. Research in the future must fill the gap between regional knowledge of climate change impacts and country- and infrastructure-specific knowledge. Country-level analysis must be done in the future to aid policy makers in deciding the appropriate infrastructure mix in hazard prone areas. More specific information will clarify which countries and which types of infrastructure are likely to experience infrastructure loss in the future. Figure 13 indicates that research must focus on country- and infrastructure-specific vulnerability to weather related extremes.

Figure 13: Research in these areas will aid future infrastructure policy

Type of event	**Country vulnerability**	**Project vulnerability**
Sudden-onset	• Move from regional to country-specific vulnerability to losses • Overlay socio-economic factors of a country with loss potential • Understand which countries face the highest infrastructure loss risk • Understand relationship between most vulnerable countries and the financial resources needed to respond to sudden-onset events. • Identify availability of resources for most vulnerable countries	• Link different types of disaster to types of infrastructure planned and already existing in affected countries • Identify specific climate variability impacts on infrastructure projects in most vulnerable countries • Locate necessary financial resources to protect current infrastructure in areas prone to extreme climate variability
Gradual-onset	• Account for longer-term patterns in climate change in infrastructure planning. • Understand links between resources needed for resilient infrastructure and appropriate country-assistance strategies (includes appropriate institutional measures that encourage prudent hazard-proofing)	• Develop reliable forecasting to assess how future climate change may affect prospective infrastructure projects • Develop models to better understand how climate change may affect infrastructure and sectors that rely on specific types of infrastructure

Research must also improve knowledge of specific infrastructure exposure to different types of events. Research should identify specific climate variability impacts on infrastructure projects in the most vulnerable countries. It should link different types of disaster to types of infrastructure planned and already existing in affected countries.

Catastrophe modeling provides one tool to identify infrastructure vulnerability on a disaggregate basis. Modeling provides a prospective look at future damage from changes in climate variability. Catastrophe models integrate projections about the severity of future natural hazard events, accounting for the influence of global change, with the increased concentration of assets in hazard prone regions. Reliable modeling is needed to assess how future climate change may affect prospective infrastructure projects. Models are needed to better understand how climate change may affect infrastructure and sectors that rely on specific types of infrastructure. Modeling will improve understanding of shifting sectoral patterns, such as agriculture and energy production that is dependent on reliable water supply. This type of analysis is not widely used in developing countries. Modeling efforts in the developing world should be accelerated.

6.2 Planning for sudden- and gradual-onset events needed

Planning for sudden- and gradual-onset events for countries and specific projects is essential for future infrastructure lending policy. There is considerable scope for reducing risk through appropriate planning efforts. Recommendations that catastrophe planning be incorporated into development activities have been made for years. Methods exist to plan for expected infrastructure losses. Despite the ability to plan for catastrophes, policy makers do not incorporate this activity into current country-level or infrastructure project planning. Figure 14 presents a planning matrix for sudden- and gradual-onset events.

Figure 14: Planning Matrix for Sudden- and Gradual-onset catastrophes		
	Country planning	**Project planning**
Sudden-onset event	• Funding of post-disaster infrastructure reconstruction • Income-support for the poor	• Siting infrastructure projects in non-hazard zones • Resistance/resilience: infrastructure building standards
Gradual-onset event	• Appropriate mix of infrastructure over the long-run • Drought & famine, food security	• Long-term life span of infrastructure projects must consider climate changes, especially climate-dependent structures like irrigation & energy systems

Sudden-onset events require both country-level and project-level planning. Events such as floods and tropical cyclones are associated with high levels of infrastructure damage, and in the future these losses are estimated to rise 2.5 times (MunichRe 1999a). For such events a primary issue will be incorporating the potential infrastructure exposure into normal economic planning. Planning for infrastructure loss and replacement should be a vital part of annual budget setting.

For project planning, sudden-onset events require planners to more carefully consider the trends in climate variability and climate change in infrastructure siting and building standards. Project planning must account for greater frequency and intensity of catastrophes. Siting and building standards must account for more extreme events. Other factors that affect the resilience of infrastructure to sudden-onset events must also be considered, such as institutional factors that affect how infrastructure is used.

Gradual-onset events that come with longer-term shifts in regional patterns of climate variability require planning at the country and project level. Gradual-onset events include drought, and evidence suggests drought will be a particular problem in Africa, and for Latin America where intensified cycles of drought and flood are predicted. At the country level, changes in weather patterns will affect the type of infrastructure projects needed in the future.

Linkages between future climate variability and the longer-term nature of these projects must be understood.

Countries should consider the appropriateness of long-term infrastructure as climate patterns may change the reliability of rain, and frequency and intensity of flooding and drought. Countries must plan for the impact of climate change on infrastructure and production in some sectors. Energy, agricultural, and other key sectors for economic performance will be impacted by climate change. Potential impacts of drought on infrastructure in Africa, for example, include reduced stream flows that could reduce hydropower production, leading to negative effects on industrial productivity, and costly relocation of industrial plants (Watson et al. 1997). Recent droughts in Brazil have contributed to a severe energy crisis, since 90% of the country's energy is generated by hydropower (Rohter 2001). In areas where drought is likely to increase, such energy reliance needs to be reconsidered. Countries must plan for appropriate response to drought, especially in areas where political conflict could escalate drought to famine. Vulnerable countries will need to consider food security issues in longer-term planning for gradual-onset events such as drought.

Gradual-onset events will require greater planning at the project level. Shifting regional weather patterns may change the nature of infrastructure projects needed. Infrastructure projects may be needed in areas where they previously were not, such as irrigation and agricultural storage systems in drought-prone areas, flood control infrastructure in areas previously less vulnerable to flood. Project planning must incorporate the uncertainty in climatic conditions at the project design stage over the life of the project. Incorporating considerations of climate change into infrastructure performance evaluations will become increasingly important (Downing et al. 1997). Housing building standards, transportation networks, and public water management systems will all need reevaluation to account for climate variability associated with climate change.

Failure to prepare systems for projected changes in climate could lead to capital intensive development of infrastructure or technologies that are ill-suited to future conditions, as well as missed opportunities to lower the costs of adaptation. Planning will be essential.

6.3 More resources for infrastructure and the poor needed

Climate change will increase demand for financial resources to restore damaged infrastructure and assist the poor. This demand will be fueled by two sources: increased direct damages and increased income support for the poor. International financial institutions will most likely look to the World Bank to play a leading role in addressing the increased financial demand. The World Bank plays a unique role in providing post-disaster infrastructure lending.

First, international financial institutions currently play a major role in providing poorer countries post-disaster financing to restore damaged infrastructure. These governments are currently highly dependent on such institutions for infrastructure funding (Gilbert and Kreimer 1999). Governments will need help in the future as they face greater demands for infrastructure investment and repair from increased damage levels.

Second, the World Bank plays a key role in financing infrastructure loss; the Bank's policy response is important for other institutions. The financing arranged by the World Bank to support countries after a disaster is a primary source of liquidity for infrastructure construction (Gilbert and Kreimer 1999). Other providers of capital to developing countries may be willing to support the reconstruction of some types of structures, such as schools. However, there is little interest in funding for bridges, roads, and other components of core physical assets. The funding for infrastructure projects post disaster is a special expertise of the World Bank (Kreimer et al. 1998).

This "lead lender" effect can positively develop new financial and other adaptation alternatives for client countries. To meet increased funding needs, future policy must consider ways to increase the coping ability of affected areas to deal with climate-related extreme events (Anderson and Woodrow 1989; Peterson et al. 1997).

Another key role for the World Bank is to support the search for alternative financing options. Literature focusing on financial tools to deal with infrastructure damage has proliferated, although implementation of these policy options has not been as rapid (Pollner et al. 2000). Authors have expanded understanding of the tools available for managing catastrophe risk. Initial research suggests that solutions to the catastrophe risk problem, due to its potentially devastating effects, cannot be accomplished without leveraging sufficient capital and assuring stable long-term capacity (Pollner 2000).[6] Pollner notes that through optimally structured risk sharing arrangements, markets can better absorb catastrophe losses and fund these risks, with governments and multilateral institutions supporting the development of self-sustaining structures. Multilateral development institutions play a role as international facilitators for improving the functioning of risk transfer mechanisms.

Finally, the poor will require more resources to absorb the impacts of rising climate-related extreme events and direct losses to infrastructure. The poor have three post-disaster resource demands: relief that protects livelihood, safety that covers vulnerability and poverty, and effective relief that articulates the voice and demands of the poor (Bhatt 2001; Hoogeveen 2000). Catastrophes exacerbate already difficult situations where livelihood, food and safe water, and shelter are tenuous. In emergency situations, the poor may be cut off from vital infrastructure-related services as well and may face unemployment. Of these vulnerabilities, livelihood might be the greatest concern of the poor. Greater resources will be needed to address targeted income support for the poor.

6.4 Conclusions

[6] Pollner suggests that national governments can implement risk management practices by better controlling 'exposure' through regulatory actions aimed at vulnerability reduction programs particularly for the low-income sectors, and by assuring that the local insurance sector has sufficient capital to absorb large losses. Pollner's research proposes enforcement of insurance coverage, both in the private and public sectors is needed, along with market incentives to

Climate variability has contributed to rising trends in total direct damage from extreme events in affected areas. Climate variability has contributed to rising trends in total direct damage from extreme events in affected areas. Of total direct damage, infrastructure loss as a component of the direct damage is $9.6 billion. In some years, total infrastructure losses are as high as $32 billion. These totals are rising. Beyond general trends in direct damage and estimates of infrastructure as a component of those losses, knowledge about specific infrastructure vulnerability to particular event categories is valuable for mitigation, adaptation, and future infrastructure project decisions.

The implications of exponentially increasing infrastructure vulnerability to extreme weather events are clear. Small increases in event magnitude and frequency, combined with underlying infrastructure vulnerability from under-investment or population and building patterns in hazard zones, will lead to exponential infrastructure vulnerability to damage in the future. Based on these findings, three recommendations will aid policy makers as they adapt future infrastructure lending policy to the uncertainties of climate change.

First, research in the future must fill the gap between regional knowledge of climate change impacts and country- and infrastructure-specific knowledge. Country-level analysis must be done in the future to aid policy makers in deciding the appropriate infrastructure mix in hazard prone areas. Reducing general conclusions about regional infrastructure vulnerability to a country-specific level will allow policy makers to make improved decisions about infrastructure management and construction in the face of hazard risk. More specific information will clarify which countries and which types of infrastructure are likely to experience infrastructure loss in the future. Research must focus on country- and infrastructure-specific vulnerability to weather related extremes. Wider use of catastrophe modeling, which provides a tool to identify infrastructure vulnerability at this level, could expand understanding of the disaggregate impacts of climate variability on infrastructure.

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monitor property risks and adjust premiums by rewarding owners and property holders who reduce physical risk exposures.

Second, planning for sudden- and gradual-onset events for countries and specific projects is essential for future infrastructure lending policy. There is considerable scope for reducing risk through appropriate planning efforts. Recommendations that catastrophe planning be incorporated into development activities have been made for years. Methods exist to plan for expected infrastructure losses. Despite the ability to plan for catastrophes, policy makers do not incorporate this activity into current country-level or infrastructure project planning. Ways must be found to incorporate planning for the uncertainties of weather-related events into infrastructure management, at the country and the project level. In planning, sudden- and gradual-onset events should be considered. Sudden-onset events like floods can affect post-disaster infrastructure reconstruction finance and may involve income support for the poor at the country level. For individual project planning, consideration of sudden-onset events can affect siting decisions and building standards. Similarly, gradual-onset events like drought require planning, and are associated with a different set of issues for countries and individual infrastructure projects. Ways must be found to incorporate the impacts of climate change into planning activities, especially in developing countries.

Finally, greater resources must be found to address increasing losses of infrastructure and to sustain the poor, who may bear the heaviest burden of catastrophes and climate change. In addition to playing a key role in providing post-disaster financing to restore damaged infrastructure, organizations such as the World Bank can pioneer alternative financing options for infrastructure and support for the poor. While the uncertainties of climate change pose many challenges, many pathways to appropriate adaptation also exist. Research such as that proposed here can help societies adapt to changes in gradual- and sudden-onset weather events, and reduce the vulnerability of infrastructure to climate variability and climate change.

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