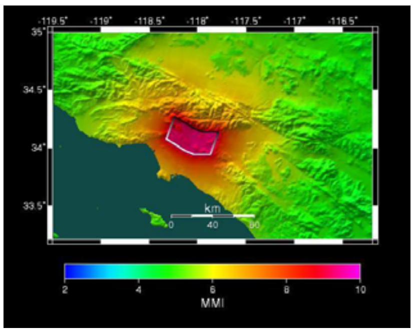
Consequences of Catastrophic Earthquakes in the US

The following scenarios address potential catastrophic earthquakes that have a reasonable likelihood of striking four major urban areas in the US over the next several decades: Los Angeles, Memphis, San Francisco Bay Area, and Seattle. The hazards are real, but the scenarios are followed by a section on steps that can be taken to reduce the impact of these events and prevent them from becoming catastrophic.

Los Angeles

Southern California has over 300 faults capable of producing damaging earthquakes, more than any other metropolitan area in the United States. Choosing any one possible event limits a full understanding of the risk. To illustrate the range, we describe here two events, a magnitude 8 on the San Andreas fault, and a smaller, magnitude 7 to 7.5 on a thrust fault near downtown Los Angeles. The geologic records tells us these events are inevitable; the only question is when.



The colors show the severity of shaking in a magnitude 7.5 earthquake in downtown Los Angeles.

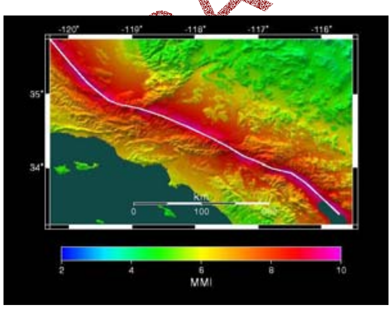
A magnitude 7 to 7.5 earthquake on one of the faults in the Los Angeles basin, such as the Puente Hills, Santa Monica or Hollywood faults, will produce the greatest damage to buildings because it would be so near so many older structures. A model from a FEMA HAZUS study of expected losses from the Puente Hills fault earthquake shown to the left predicts:

- 18,000 dead
- Financial losses of a quarter of a trillion dollars
- 300,000 displaced persons needing housing

Because there are several large faults in the Los Angeles basin, one event of this type occurs every 500-1000 years. Smaller earthquakes on these faults such as the 1994 Northridge earthquake (57 dead and $40 billion in losses) will happen more than twice per century on average. Such earthquakes will damage a large number of buildings in Los Angeles and displace hundreds of thousands of people from their homes. Severe business disruption would last months.

A different type of disaster will be caused by the great magnitude 8 earthquake on the San Andreas fault that repeats every one to two hundred years. Earthquakes this large involve movement of 20 feet or more feet along at least 250 miles of the fault. Thus, every structure crossing the fault, such as freeways, pipelines, power lines and railway tracks will be yanked apart by the fault. This would certainly lead to extensive disruption to the distribution system for all such necessities as water, power and food. Repairs could take months.

Fault offset in the 1995 Kobe earthquake moved the edge of this rice paddy 6 feet along the fault.



The colors show the severity of shaking from a magnitude 8.2 earthquake on the San Andreas fault. Notice how the severe damage area (red) is over 300 miles long and 50 miles wide.

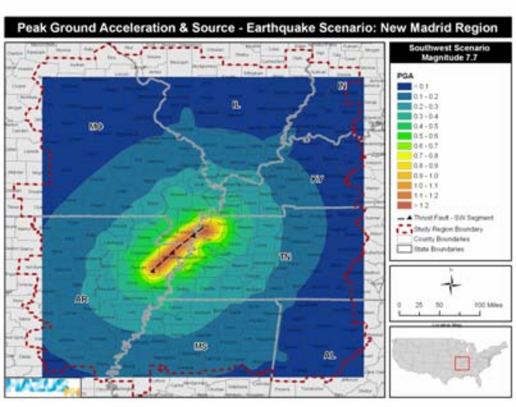
East of Los Angeles, the San Andreas fault dangerously traverses rapidly growing areas of the Inland Empire (San Bernardino-Riverside). In a Big One, northern Los Angeles County and the Palm Springs area will likely be the hardest hit. Because the older communities in that area have not been as aggressive as Los Angeles in eliminating older poor construction, many buildings will completely collapse, potentially killing thousands. With all southern California communities damaged, mutual aid for emergency response is going to have to come from much farther away and thus take longer to arrive.

The level of damage in Los Angeles will likely be higher than current models predict. Existing building codes have been designed largely based on the shaking generated by moderate earthquakes. A recent study from Caltech concluded that the energy produced in a magnitude 8 earthquake on the San Andreas could cause one or more high-rise buildings in downtown Los Angeles to collapse. The equivalent of a World Trade Center collapse could thus be only one part of a much larger disaster.

Secondary Effects. Just as the collapse of the levees in New Orleans turned a disaster into a catastrophe, so also secondary effects of an earthquake can be the most calamitous. Any of the major earthquakes that will strike the region could trigger a range of secondary effects depending on the exact fault, weakened infrastructure nearby and the weather. These include:

- **Fires.** Fires have always been a major problem after earthquakes, when ruptured gas lines and failed water delivery systems combine to make fire fighting very difficult. Fires destroyed much of San Francisco in 1906, and contributed to the loss of 100,000 lives in the great Tokyo earthquake of 1923. If an earthquake strikes Los Angeles during a time of hot, dry winds such as when the wildfires of 2003 occurred, firestorms could erupt throughout the city.
- **Landslides.** Landslides are another common result of earthquakes. Over 1,000 cases of Valley Fever were caused by the dust raised by landslides during the 1994 Northridge earthquake. If the earthquake happens during heavy winter rains, landslides could be widespread. One landslide triggered by an earthquake in the Soviet Union in 1957 covered a city, killing 50,000 people.
- **Dam failures.** The San Gabriel Mountains, north of the Los Angeles basin contain many old dams built in the 1920's and 1930's. The failure of even one of these structures could flood tens of thousands with major loss of life.
- **Aftershocks.** Large earthquakes trigger other earthquakes, sometimes at significant distance away from the mainshock. It would be very easy for the San Andreas event to trigger an aftershock of magnitude 6.5 - 7 in Los Angeles. Aftershocks can be even more damaging to buildings already weakened by the mainshock. A disaster similar to the 1994 Northridge earthquake could thus occur as a consequence of just one aftershock.

Memphis/Central US



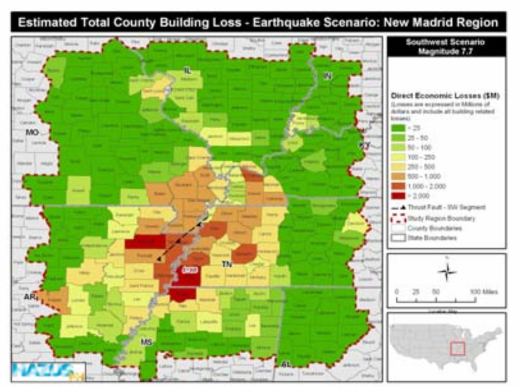
The colors show the severity of shaking (red is strongest) from a magnitude 7.7 earthquake in the southern New Madrid seismic zone

In the winter of 1811 and 1812, three earthquakes with magnitudes between 7.5 and 8.0 struck the lower Mississippi Valley over a two-month period. Although few people lived in the region at the time, the effects on the landscape remain clear 200 years later. Studies of the geologic record show that similar sequences of major earthquakes have happened previously, at least twice before about 1450 and 900 AD. The consequences of a repeat of such a sequence of earthquakes today would bear many similarities to those from Hurricane Katrina.

Significant structural damage to buildings would occur in at least 8 states. Lifelines crossing the region, including highways, bridges, and oil and gas pipelines leading to the northeastern U.S. would be severely damaged, particularly in the

Mississippi Valley. If the earthquakes were to occur when the Ohio and Mississippi Rivers were high, loss of levees is likely along with flooding of low-lying communities. The City of Memphis, with over 1 million people in its metropolitan area, would be the most affected urban center. Memphis has an aging infrastructure and many of its large buildings, including unreinforced schools and fire and police stations, are particularly fragile when subjected to ground shaking. Very few buildings were built using modern codes that have some provision for seismic-resistant design.

Landslides occurred along the bluffs from Mississippi to Kentucky in 1811 and 1812, and a similar scenario would be expected today in downtown Memphis. At least one highway and one railroad bridge crossing the Mississippi River are unlikely to survive a major New Madrid earthquake and many old overpasses would likely collapse. A major hazard in the New Madrid region is a type of soil failure called "liquefaction," which in 1811 and 1812 affected a region from south of Memphis to St. Louis. Liquefaction will cause soil to flow and form deep cracks that may make roadways in the Mississippi Valley of Arkansas and Missouri (such as I-55) impassible. The liquefaction will cause flooding of fields and roads with water, sand, and mud, disrupting agriculture for an extended period. Liquefaction and failure of levees and riverbanks would make the Mississippi River unnavigable, possibly for many weeks. Although Memphis is likely to be the focus of major damage in the region, St. Louis, Little Rock and many small and medium-sized cities would be damaged.



The colors indicate the direct economic losses by county from a magnitude 7.7 earthquake in the southern New Madrid seismic zone. Red is over $2 billion. Shelby County alone in southwesternmost Tennessee has $19 billion in losses

One characteristic of New Madrid earthquakes is particularly important to highlight. In 1811 and 1812 there was a sequence of large earthquakes, as opposed to a single large earthquake followed by smaller aftershocks. Many aftershocks occurred in addition, some of them quite strong. As noted above, the geologic evidence suggests that such sequences of major earthquakes are characteristic of the region. This means that during recovery efforts, earthquakes as strong as the first shock can be expected to occur and must be considered when deciding where to shelter people and when to start rebuilding.

The USGS estimates that there is about a 10% chance of a major New Madrid earthquake occurring in the next 50 years. In addition, while the damage would not be as widespread, the occurrence of a moderate sized earthquake located in close proximity to urban centers like Memphis or St. Louis could be equally devastating locally. The USGS estimates the chances of a magnitude 6.0 or larger earthquake occurring in the New Madrid region in the next 50 years is 25-40%. Results from a recent regional-scale loss estimation study using FEMA's HAZUS program suggest immediate losses from just one M7.7 New Madrid earthquake would total between $68 and $77 billion. However, additional studies will be required to assess potential losses from multiple earthquakes, and to provide such assessments at scales appropriate for mitigation and response planning within the most vulnerable, urban areas.

San Francisco Bay Area

The San Francisco Bay Area, home today to more than 7 million people, experienced large earthquakes in 1838, 1868, 1906, and 1989. The damage and destruction grew with each event as the region became more developed. A recent USGS study concluded that that there is more than a 60% chance of one or more future damaging earthquakes in the next 30 years on one of the seven major fault zones that cut across the region. The 1906 San Francisco earthquake ruptured 300 miles of the San Andreas fault, affecting all of northern California. Its direct shaking effects were compounded by triggered fires, soil failure, and landslides. In San Francisco alone more than 3,000 were left dead and 225,000 homeless out of a population of 400,000.

A repeat of that magnitude 7.9 earthquake today would have catastrophic consequences throughout the ten-county Bay Region, and also the entire state:

- Personal human toll would be overwhelming: 4,000 to 5,000 casualties if the quake occurred during daylight hours and between 100,000 and 160,000 families displaced from their homes.
- More than 20% (over 425,000) of the buildings will likely be at least moderately damaged; 37,000 buildings may be completely destroyed. Building-related losses are estimated at $60 billion; some analyses of the total economic impact suggest losses in excess of $100 billion.
- As in 1906 and again in 1989, ruptured gas lines will trigger fires in dense urban areas while broken waterlines will make fires difficult to fight and control. The devastating 1991 Oakland Hills fire burned out of control for 3 days, destroying 3,000 housing units, killing 25 people, and leaving $1.5 billion devastation in its path—all without an earthquake creating debris, chaos, and imperiling the water supply. Fire following earthquake will significantly escalate building and housing losses.
- Water supply may be further impacted by failure of aging levees on islands in the Sacramento River delta. Like the Mississippi delta, the islands here have subsided; thus levee failure would allow salt water to rush in, destroying agriculture and shutting down drinking water for more than 22 million Californians, including 20-30% of the southern California water supply.
- The Hetch Hetchy aqueduct carrying water from the Sierras, serving as the primary water source for 2.4 million Bay Area residents, is vulnerable to future quakes. A recent report concluded $38 billion in total losses related to failure of this system alone in a repeat of a 1906 earthquake. Bay area citizens recently passed a $3.6 billion bond measure for seismic upgrading and expanding the capacity of the system.
- Strong shaking will cause sandy, water-saturated fill and soil along the shores of San Francisco Bay to liquefy, potentially disrupting runways and facilities at all three international airports as well as the Oakland and San Francisco ports.
- If still in use, the old eastern span of the Bay Bridge will fail once again, however most of the other major bridges will likely remain functioning, having been seismically retrofitted over the past decade. However, roadway cracks and differential settlement will shut down numerous major arteries.
- State studies have shown that many CA schools and hospitals will be at risk of serious damage. Despite regulations mandating higher building standards for CA schools dating to

1931, a recent analysis concluded there are 8,000 public schools buildings statewide at peril of collapse in a major earthquake.

A somewhat smaller earthquake that is even more likely in the short term is a magnitude 6.9 on the Hayward fault, on the east of San Francisco Bay. It would have similar impacts on the Bay region because of the dense distribution of population and infrastructure along and crossing the Hayward.

Seattle

Unlike either New Madrid in the central United States or California, where large, catastrophic earthquakes have occurred in historical times, the earthquake record in the Pacific Northwest has, until very recently, been unknown. Scientists discovered the Seattle Fault in 1965 when studying geophysical data for the Puget Sound region. In 1987, scientists began finding evidence of great earthquakes of magnitude 8 to 9 in the Cascadia subduction zone off the Washington Coast; these earthquakes occur about every 500 to 600 years. Five years later, a team of scientists discovered the first evidence that the Seattle Fault was active and had generated a magnitude 7.3 earthquake that caused a tsunami in Puget Sound about 1,100 years ago. In the late 1990s, scientists began using high-resolution imaging and found evidence of other surface faults. Today, field evidence show large earthquakes with magnitude 6.5 or greater have occurred on eight major fault systems in the Puget Sound region.

The Earthquake Engineering Research Institute and Washington State Department of Emergency Management Division recently published a scenario (http://seattlescenario.eeri.org/) of a magnitude 6.7 earthquake on the Seattle Fault – a smaller event than occurred 1,100 years ago – to explore how it would affect the people and economy of the Central Puget Sound region. Specifically, the team wanted to know what this earthquake would do to the region's buildings and major structures, its lifeline and transportation systems, its people and communities, its emergency response and recovery, and its economy. The modeled earthquake was chosen to match field evidence of a past event found along the Seattle fault in Bellevue. Using those observations, ground motions were calculated on local soil sites for a three-county area. The effects on Seattle and the surrounding region are catastrophic. The magnitude 6.7 scenario earthquake and its aftermath will disrupt for weeks and months individuals, families, businesses and governments throughout the region. The USGS has estimated that there is a 4% chance of this earthquake occurring in the next 50 years. The disruption will be much greater than the February 2001 magnitude 6.8 Nisqually earthquake, which cost an estimated $4 billion.

Collapsed buildings or falling debris will kill or injure thousands of people, and trap hundreds of others. Hospitals closest to the fault may be unable to provide care to the injured because of damage to their facilities. Damages to the transportation system will impede emergency responders, prevent many commuters from returning home, and impede traffic and commerce for months. It is widely expected that the Alaska Way viaduct that carries 100,000 vehicles per day along the waterfront in downtown Seattle, will fail completely. Shelter space for people made homeless because of the quake will be limited in the immediate area because of damage to schools and community centers. Water for drinking and firefighting will be scarce because of pipeline breaks. Power and natural gas service will be out, and telephone and radio communications will be difficult for days. Untreated wastewater will pollute soils and waterways near sewer line breaks.

Scenario earthquake losses were estimated using HAZUS and teams of practicing engineers, economists, and emergency management then vetted the results. No dollar loss was included for the highway infrastructure, but replacement costs for the Alaska Way viaduct and Evergreen Point bridge are estimated at more than $5.0 billion. The economic impact of the scenario earthquake on the region and the State of Washington primarily depends upon how quickly the heavily damaged transportation system is placed back into service. A few of the losses highlighted include:

- Property damage and direct economic loss– at least $33 billion
- Indirect economic loss—at least $33 billion
- Deaths—more than 1,600
- Injuries—more than 24,000
- Buildings destroyed—about 9700
- Buildings severely damaged and unsafe to occupy—more than 29,000
- Buildings moderately damaged whose use is restricted—about 154,500
- Fires—about 130, damaging nearly a half-billion dollars in property

Preventing Earthquake Disasters

Our actions before the earthquake will help determine the losses during the event. Science can tell us the likely consequences of an earthquake and we can use that information to change the outcome. We can identify several steps that would significantly reduce losses, including:

Aerial photo of the Trans-Alaska Pipeline System where the line is supported by rails on which it can move freely in the event of fault offset. Here the line has moved toward the west end of the rails.

- **Lifelines**. We could reduce the vulnerability of our lifelines by adopting fault-crossing technologies that allow the fault to move without rupturing the pipelines and other transportation systems, such as was used to prevent damage to the Alaska Pipeline during the 2002 Denali earthquake of magnitude 7.9 (see right).
- **Retrofitting**. Trillions of dollars of building stock in southern California, built before the adoption of modern building codes, need to be retrofitted to modern standards. This could reduce losses by billions. Throughout the New Madrid seismic zone, there are many unreinforced masonry buildings that are particularly vulnerable to earthquake shaking. These buildings should be ranked in terms of how critical they are, their occupants at risk, and their vulnerability in order to prioritize their replacement.
- **Rapid information systems.** Modern seismic monitoring systems can provide information about the strong shaking and probable damage within minutes to support decisions by emergency responders. In some cases information about the probability of shaking can be delivered before the shaking begins.
- **Accurate scenarios.** We need to integrate the complete picture of what will happen in a future event from rupture on the fault, to shaking and damage of buildings and structures. We need to study and plan for the response of all levels of our infrastructure, the emergency response, to chart the road to full recovery of our society. Such analysis requires research on all aspects of the earthquake process and would give us a complete picture of where mitigation would do the most good. Complete scientific analysis would reduce the uncertainties. Further engineering evaluation would help reveal the actual level of vulnerability in our built infrastructure and lifeline systems, and help prioritize retrofitting.
- **Education.** Our citizens will eventually be the true first responders to the next disaster. They need to be educated on the likely consequences of earthquakes, how to recognize a safe building, the importance of retrofitting and how to respond safely. In particular, education is the only viable approach to encourage the securing of contents of buildings. Damage to contents caused $12 billion of the $40 billion losses the 1994.

Volcanic Eruption in the Cascade Range (WA, OR, CA)

The Cascade Range of the Pacific Northwest contains 13 volcanoes considered to pose a high threat to people on the ground and aircraft in the air. The geologic record indicates that these volcanoes collectively produce four or more eruptions per century. Avalanches of hot lava and volcanic gas, termed pyroclastic flows, generated by these eruptions can move down slope at hurricane speeds destroying everything in their paths. For example, a pyroclastic flow from Mount Shasta, Califorinia, could reach more than 6,000 people in the vicinity of the town of Weed in less than 10 minutes. Many of the Cascade volcanoes also contain large amounts of glacier ice, and should an eruption occur, melting of the ice will produce large mudslides, termed "lahars," that move down valleys at speeds of up to sixty miles per hour, threatening communities more than 30 miles from the volcano. Lahars from Mount Rainier could reach the town of Orting in as little as 40 minutes and continue downstream through the communities of Puyallup and Tacoma. Lahars produced by the eruption of Mount Baker could reach communities north of Bellingham. Volcanic ash injected into the air by explosive eruptions would threaten jet aircraft, closing air corridors and airports in the Pacific Northwest and ultimately in the western and central US as volcanic ash is transported thousands of miles eastward by prevailing winds.

There is a fair chance that a significant eruption of a Cascade volcano will occur within the foreseeable future, causing significant impact on life and property on the ground and to regional and national aircraft operations should an eruption occur. More than 150,000 people live in areas that would be affected by lahars initiated during a volcanic eruption from Mount Rainier alone. The 1980 eruption of Mount St. Helens serves as a good reference point for potential impact to people and property on the ground. 57 people died and the surrounding communities suffered over $1 billion in damages to the economy, agriculture, local businesses and structures. At least 200 homes were lost in the explosion. If such an eruption occurred at Mount St. Helens in 2005, economic losses would exceed $3 billion. An eruption of similar scale at Mount Rainier or Mount Shasta would result in greater loss. Based on the estimated $100 million damage to the aviation industry in Alaska as a result of the 1989-90 eruptions of Mount Redoubt, it can be expected that the financial impact of a significant explosive eruption of a Cascade volcano would run in the billions of dollars as a result of the greater air traffic and associated infrastructure in the affected area.

NEXT BIG DISASTERS WORKING GROUP

Cascadia Earthquake and Tsunami, Pacific Coast

Subduction Zone earthquakes, the strongest and most destructive of all earthquakes, caused the devastating 2004 Indian-Sumatran-Indonesian tsunami. The Cascadia Subduction Zone travels 700 miles along the U.S. Pacific Coast from Southwest Canada to Northern California and produces magnitude 8 to 9 earthquakes about every 500 years. The last earthquake in this region occurred in 1700 and resulted in a magnitude 9.0 earthquake and destructive tsunami that took lives as far away as Japan. Scientists estimate there is a 10 to 14 percent chance a magnitude 9.0 earthquake will occur in the Cascadia Subduction Zone in the next 50 years.

The Earthquake

- Ground shaking is likely to last several minutes, much like the Sumatra quake and the 1964 Alaska earthquake that devastated Anchorage. The earthquake and its associated terrestrial hazards – ground shaking, landslides, liquefaction, fires, and hazardous material spills – will create significant damage and potentially thousands of deaths and injuries.
- After the earthquake, there could be months of aftershocks which have the potential to do additional damage, particularly to already-weakened structures, and generate another tsunami, as was demonstrated in Sumatra in March 2005.
- The strong ground shaking combined with long duration and long-period waves will cause many structures and buildings to partly fail or entirely collapse. Damage is expected to be particularly heavy along the coast. Thousands of deaths may occur; rescue and recovery will be impeded by transportation infrastructure failures.

The Tsunami

- Residents of some Pacific Coast communities may have as little as 15-20 minutes before the first tsunami wave comes onshore following the earthquake. Individuals caught in the path of a tsunami have little chance to survive; debris may crush them or they may drown. Because of subsidence related to the fault slip during the earthquake, significant flooding will occur before the first tsunami waves strike.
- A tsunami comes onshore resembling a series of quickly rising tides. It withdraws with currents much like those of a river. Swift currents carrying debris commonly cause most of the damage from tsunamis. Waves can be many tens of feet high and may continue for hours. Later waves can be larger, more deadly, and more damaging. For example, the third and fourth waves to strike Crescent City, CA, following the 1964 Alaska earthquake killed 11 people there and caused $45-96 million in damage[1].
- Waves can travel inland a half-mile or more, depending upon the terrain. The tsunami that struck Sumatra traveled up to three miles inland in places.

Impact

Communities could be nearly entirely isolated for days as landslides and bridge damage along U.S. Highway 101 and through the Coast Range temporarily sever highway travel between the coast and inland areas to the east. Destruction of roads, airport runways, ports, and rail lines will leave some cities isolated. Buildings, roads, bridges and utility lines will suffer varying amounts of damage and destruction. Extensive injuries and fatalities will occur. Public health will become an issue due to the many casualties and limited medical help.

[1] Figures adjusted to 2005 dollars.

In the early hours after the earthquake and tsunami, residents and visitors will have to do much of the work to rescue those trapped in the rubble, provide temporary shelter, conduct immediate clean-up, and organize distribution of relief supplies as they become available. Outside assistance will be unavailable or unable to reach these communities except via helicopter or airdrop because of infrastructure damage.

Transportation closures for any significant period along the Interstate 5 / British Columbia 99 corridor – the center of the West Coast's north-south transportation network – would have far-reaching economic consequences. It could make transport of rescue workers and emergency supplies to the area difficult immediately following the earthquake.

Populations at Particular Risk from Tsunami

The projected at-risk coastal population in Washington is about 44,000 in the four coastal counties and about 63,000 in Oregon's seven counties bordering the Pacific. This does not include estimates of Tsunami impacts along the Straight of Juan de Fuca, which includes populous and important communities such as such as the Whidbey Island Naval installation, Bellingham, Anacortes and the San Juan Islands. Many seaside towns have special vulnerability due to significant development on the low-lying coastal plain and also because so many tourists are present at any given time. Tourism provides from 9 to 22 percent of the jobs in the four Washington coastal counties — compared to 4 percent statewide. Apart from the devastation of human impacts, the economic impact in the four Washington counties will be devastating.

Washington State's coast has many at-risk tribal communities including the Makah, Hoh, Quinault, Shoalwater, Quileute, and Lower Elwha Indian nations, each with small reservations in low-lying coastal areas. Most are impoverished with little to no infrastructure to support emergency planning and response.

[1] Figures adjusted to 2005 dollars.

Galveston/Houston

A Category 5 hurricane making landfall with its eye just southwest of Galveston and creating a peak storm surge pushing into Galveston Bay, a rare, but reasonable possibility, would cause massive social and economic damage to the region. A typical storm scenario could have a 25-mile maximum wind radius and move northwest at 15-20 mph pushing the hurricane's eye right over downtown Houston and producing more than 30 feet of storm surge.

Evacuees from Galveston, a barrier-island of 68,000, would move inland via the only means available – I-45 and small state highways. They must pass through the Nation's 4th largest city, Houston, in order to move out of harm's way.

A hurricane of great intensity (Category 4 or 5) making landfall in Galveston/Houston is expected to severely damage coastal residences, hotels, businesses, beaches, piers, boats and mobile homes. The Galveston Causeway (I-45) and the SanLuis Pass-Vacek Bridge would likely suffer water damage as well as structural damage. Ferry service would be suspended. Route 146 along the Galveston Bay and Route 87 along the Bolivar Peninsula would likely be impassable due to high tides and shore erosion.

Severe damage to the Houston Ship Channel, the Gulf Inter-Coastal Waterway and the Ports of Houston and Galveston is expected and would likely result in debris and channel blockages. The Bayport Industrial Complex is home to chemical and petroleum facilities, which could be damaged resulting in hazardous materials leaking into the Bay. The NASA Johnson Space Center also may suffer damage from high winds and storm surge. Oil platforms in the Gulf of Mexico would be shut down for days, disrupting oil pumping and refining and causing energy prices to skyrocket.

Across the Houston metropolitan area, much of the damage may be to roofs, power and telephone lines, trees and signs. Harris, Galveston, Chambers, Brazoria and Fort Bend counties would likely suffer the most damage. In Galveston and Brazoria counties, flooding from heavy rain in low-lying areas may cause more extensive damage than the winds or storm surge. Public schools, health facilities and hospitals would be severely damaged or destroyed by a Category 5 hurricane. Buildings and office complexes in downtown Houston would likely suffer major wind damage, complete with shattered windows and streets littered with broken glass and debris.

Approximately 800,000 people would be without power, 500,000 people would be without water and most of Galveston Island would be without telephone service. High winds and flying debris would likely damage cellular towers and service would be disrupted for days, if not weeks. Wastewater treatments plants throughout southern Texas would likely be flooded by the storm surge, leaving plants non-operational.

New York/New Jersey

A Category 3 hurricane making landfall in New York City or just to the southwest of New York City, rare but plausible scenario, would cause unprecedented devastation. Eight million people live in New York City alone; nearly 20 million people live in the greater metropolitan region. Many of these people live on barrier islands, coastal land, reclaimed swampland and the landfill that makes up much of Lower Manhattan.

A fast-moving storm (50-60 mph) would have a 35-mile radius of maximum winds and would likely be a Category 4 hurricane as it passed the Carolinas offshore. Downgraded slightly to a high-end Category 3 hurricane, this storm would produce 20-25 feet of storm surge in New York Harbor. A slow-moving Category 4 or 5 is essentially not possible as far north as New York. If the hurricane made landfall at high tide, the storm surge would escalate. From the onset of storm surge flooding, these surge heights could be reached in about 5 hours, rising 12 feet in the last hour. Maximum sustained winds could be 120-135 mph.

Due to the number of people in the region and the routes to safety, the New York City Office of Emergency Management estimates the city would need 36 to 48 hours prior to the arrival of gale force winds to evacuate nearly 500,000 to 1 million New Yorkers whose homes and businesses are in the path of catastrophic flooding. That decision would likely be made when the storm was still churning off of the North Carolina/South Carolina coast. In their preparedness materials, New York encourages individuals to find shelter with family and friends and advises that there is only room for 250,000 people in shelters across the region.

Once the hurricane made landfall, hundreds of buildings on Manhattan Island would be flooded above the second floor level, including multiple basement levels. Subway entrances in Lower Manhattan and the entrances of the Brooklyn Battery Tunnel, the Queens Midtown Tunnel and the Holland Tunnel would be completely flooded. In Brooklyn and Queens, Category 3 storm surge could flood as far as three miles inland. LaGuardia and John F. Kennedy Airports would be under 14 feet of water.

When winds reach more than 50 mph, most bridges (some carrying critical communication and fuel conduits) would be closed to vehicle traffic and would be subject to extensive engineering evaluations for safe use before reopening. After years of growth, the city's two million trees have wrapped their roots around underground phone, electric, gas and water lines. When they are uprooted in heavy winds, a lot of infrastructure above and below ground will be severely damaged. Utility officials on Long Island estimate that 900,000 customers would be without power for at least a month.

Hurricane force winds on high-rise structures are another major concern. During a Category 3 hurricane, winds at the upper levels of tall structures would likely exceed 150 mph. This would be extremely hazardous for building occupants and would cause broken glass and debris to rain onto the streets below.

Response to this hurricane would be immediate from within the region but receiving assistance from outside the region would likely be hampered by power outages, limited communications and lack of accessibility. There are no food warehouses on Long Island, leaving only local store stockpiles of food, hygiene supplies and pharmaceuticals. Receiving assistance via airplanes or helicopters would be problematic as flooding is expected at both major airports. There are no deep water ports in Nassau and Suffolk counties.

The region is home to the United Nations, the Financial District and more than 250,000 businesses. It also serves as the headquarters for most of the Fortune 500 companies. It is the world's telecommunications center, hosts hundreds of film productions, and educates students in more than 1,000 schools, universities and research centers. Additionally, there are more than 150 hospitals and hundreds of nursing homes, group homes and clinics in the area. The region hosts more than 50 million tourists annually.

The economic impact of such a storm would be staggering. Not only would the damaged infrastructure take many months to rehabilitate and rebuild, effectively isolating much of New York City from the world, the financial district, and the Wall Street area in particular, would be devastated by storm surge. Recovery would be measured in years. The cost to the metropolitan region would be in excess of $0.3 trillion; the cost to the Nation would be much more.

Top 3 Federal Actions Required to Mitigate

1. Locate emergency power generators in buildings with critical infrastructure and move critical equipment and materials above the first floor.
2. Harden critical communication conduits (e.g., transmission towers) to withstand the high winds and storm surge a hurricane will bring.
3. Provide outreach and education materials to individuals, business owners and managers of critical facilities as to how to be prepared, what to listen for and what to do before hurricane strikes.

NEXT BIG DISASTERS WORKING GROUP
Midwestern Flood

Flood hazards exist in every state and occur over a range of geographic scales. Losses average about $6 billion annually, but they vary a lot. In typical years, most losses are associated with relatively small events. However, big events happen, and they can be surprisingly costly. To illustrate, the scenario imagined below considers a repeat of the 1993 Midwest floods combined with a few exacerbating circumstances.

Heavy snowfall in the Rockies and Appalachians, possibly associated with La Nina, begin in late January. Rain clouds blanket the center of the country, replenishing regional aquifers and causing well above average flows on both the Ohio and Missouri Rivers. In early spring all major reservoirs in the upper Midwest are at or near capacity; however, the long-term forecasts suggest an average year for precipitation. Water managers, having recently experienced water shortages, are looking forward to a relatively easy year. They have recent memories of drought and they are reluctant to spill water. Therefore, water levels at many reservoirs approach, or encroach into, the capacity reserved for flood protection.

Surprisingly, rain continues into the spring without letting up and, as the snowpack melts, flooding occurs on many smaller rivers in the upper Midwest, including Minnesota and Wisconsin. Damage might be relatively light because, as noted by local floodplain managers, most of these communities manage their floodplains well. However, as the various flood waves enter the main stem of the Missouri and Mississippi rivers, water levels rise and overtop privately owned levees.

As in the floods of 1993, there is substantial damage to farmland throughout Iowa and Nebraska, as well as urban flooding in Ohio and Iowa. As floodwaters inundate critical infrastructure, such as the water treatment plant in Des Moines, local economies are temporarily shut down.

By April, flood waters from the Missouri and Mississippi rivers converge. Mainstream water levels exceed the flood stage experienced in 1993, and the discharge at St. Louis is comparable to what was experienced in 1844. Water levels are only 2 feet below the top of the levees protecting St. Louis.

(Note: At some point, the Governor of Missouri meets with the President and requests federal assistance. The President issues a disaster declaration, and orders the Army Corps of Engineers to "do whatever is necessary to protect the great city of St. Louis.")

Things go wrong. Hydraulic models suggest that backwater from the Ohio River floods will substantially reduce conveyance downstream from St. Louis; the water rises. The Army Corps of Engineers piles layers of sandbags on top of the St. Louis levees. However, structural problems are discovered in the levees protecting both South and East St. Louis. Although efforts are begun immediately to repair the problems, a difficult decision is made to breach levees protecting farmland downstream of St Louis. This temporarily reduces the stage at St. Louis. However, breaching levees destroy the railroad embankment along the east bank of the Mississippi River for several miles. Many roads also are flooded. This, combined with the closing of the Mississippi River to barge traffic (which would happen during a major flood), causes transportation delays throughout the Midwest.

Despite round-the-clock inspection of the St. Louis levees, during heavy rain on the morning of May 12th, a section of the levee south of St. Louis collapses. Rapidly flowing water enters the southern section of the city, carrying with it enormous quantities of sediment and debris. Fortunately, the evacuation warning is issued promptly and it is effective; unfortunately, 60 people who chose to stay behind drown.

Over a hundred thousand people are left homeless, seven major colleges and universities are forced to close their doors (four of which never reopen). The economic losses include hundreds of city buildings rendered unusable, tens of thousands of uninhabitable homes, much of the urban infrastructure damaged or destroyed, and an estimated $60 billion in direct economic losses.

The disaster is experienced as myriad personal catastrophes, particularly as citizens learn that their homeowner's insurance does not cover floods. Because the federal levees had been certified to withstand the 100-year flood, lenders had not required flood insurance; only a few percent of homeowners opted to pay the additional premium for flood coverage.