Swiss Re

Reframing Risk & Resiliency in the Columbia River Basin

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The Practicum is an initiative in the Energy Resources and Environment Program at Johns Hopkins School of Advanced International Studies (SAIS), in which four-person student teams partner with key organizations on projects aimed at addressing critical international environmental policy challenges. SAIS is widely recognized for its leadership in international economics and creative and practical approaches to problem solving.

As part of this effort, SAIS collaborated with Swiss Re to explore solutions to a pressing policy challenges: natural disaster response and increasing resiliency to climate change. Swiss Re and the SAIS team shared their collective experience to further the understanding of natural disaster management policy in the United States and develop a platform for expanding catastrophic risk insurance coverage, while also unlocking resources for investment in climate-resilient infrastructure.

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The Columbia River Treaty (CRT), a bilateral treaty signed by the United States and Canada for power sharing and flood control within the Columbia River Basin (CRB), is currently undergoing review for potential renegotiation in 2024. The CRT has required Canada to operate three dams in the upper basin that together provide 15.5 million acre-feet of storage. Canada and the United States were to share the increased power benefits at downstream U.S. dams. Policy makers on both sides of the border are currently deciding whether to modernize the treaty by amending the payment structure, including ecosystems benefits, and accounting for the future effects of climate change. Treaty negotiations over regional hydropower resources are complicated by the already evident climate impacts that have shifted rainfall patterns, decreased snowpack, and resulted in increased electricity demand during the longer and hotter summer months. Resource allocation decisions between the U.S. and Canada, states and provinces, and Tribal governments and First Nations must account for these shifts in resource availability and the greater vulnerability of the region and its residents to the changing climate. The Treaty review and renegotiation creates a good opportunity to revisit the natural disaster risk profile of the (CRB). Against this backdrop, this report provides and analysis of natural disaster risks in the CRB, identifies major challenges in disaster risk governance and financing, and proposes solutions for greater risk protection at the regional and local level.

I. Major natural disaster risks in the Pacific Northwest

The Columbia River Basin is located in the Pacific Northwest (PNW), with 10 percent of British Columbia (BC) and larger proportions of Washington, Oregon, Idaho, and Montana lying within the river's catchment area. The CRB is among the world's largest international drainage basins, covering 416 822 square miles. There are 2 500 square miles of waterways and lakes within the CRB, accounting for approximately 219 000 square miles of drainage in seven western states. The CRB contributes to the economic dynamism and prosperity of the PNW in hydropower, irrigation, navigation, and recreation sectors.[1]

Figure 1:
Pacific Northwest geographical overview

Source: Swiss Re CatNet

A. Natural Catastrophe Possibilities in the Columbia River Basin

The CRB is exposed to a series of natural catastrophes, including floods, earthquakes, coastal erosion, drought, dust storms, wildfires, landslides, tsunamis, volcanic eruptions, and windstorms. Climate-related catastrophes occur throughout various seasons with regularity, and severe seismic disasters occur every 500 to 600 years. Major natural disasters occur infrequently, with the impacts fading from public memory after a few years, making it difficult for policymakers to prepare for infrequent but severe events.

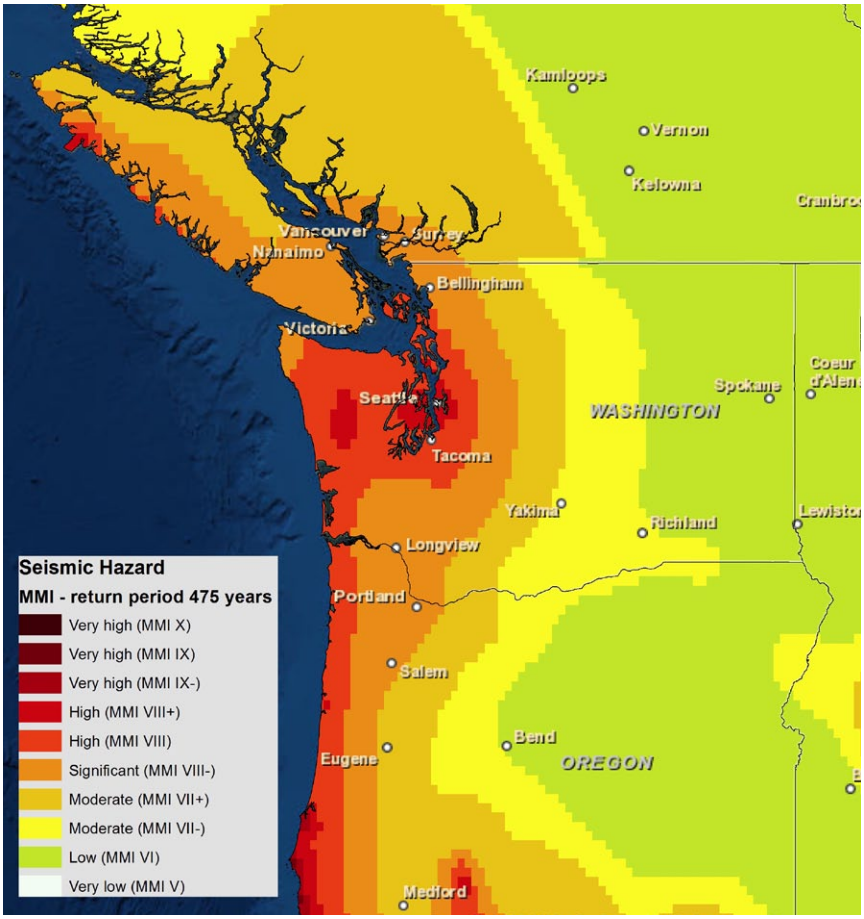
Flooding
Floods in the CRB generally occur from October through April, when large-scale weather systems from the Pacific Ocean generate prolonged rainfall or rain-on-snow events that result in excess snowmelt and runoff. Riverine flooding occurs when the excess precipitation and runoff exceed the capacity of rivers or stream channels, and coastal flooding is caused by storm surges associated with tropical hurricanes. Flooding, which can be aggravated by human activity that alters the streams through channelization or wetland loss, is responsible for Oregon and Washington's largest natural disaster-related economic losses and casualties.

Climate change has caused snowmelt and peak flows earlier in the season. Consequently, there is more runoff in early spring when less water is needed for human use and that less water will be available to help satisfy early summer water demand. Climate change is also predicted to cause sea-level rise along the Northwest coast by 4 to 56 inch (9–143 cm) relative to the year 2000 by the end of the twenty-first century, possibly generating higher frequency of coastal flooding, storms and changes in the coastal ocean ecosystem.[2] The cumulative effects of climate change will also cause fire, insects, and tree diseases to the forestry system, which will harm agriculture, human health, and indigenous populations.

Earthquakes

Large portions of California, Oregon, Washington, and southern British Columbia are located in the Cascadia Subduction Zone, where the North American Plate collides with a number of smaller plates. The largest of these is the Juan de Fuca Plate, flanked by the Explorer Plate to the north and the Gorda plate to the south. Throughout history, seven catastrophic earthquakes in the region have been recorded, and there is evidence that tsunamis accompany every earthquake. Major cities that would be affected by a potential earthquake include Vancouver and Victoria in British Columbia, Seattle in Washington, Portland in Oregon, and Sacramento in California. According to geologist predictions, there is a 10 percent to 14 percent probability that the Cascadia Subduction Zone will produce an earthquake of magnitude 9.0 or higher in the next 50 years. From the graph below, most places in the Cascadia Subduction Zone have a "significant" to "very high" rating on the Modified Mercalli Intensity (MMI) Scale. During an earthquake, places with "significant" MMI will experience considerable damage to buildings, including partial collapses, as well as greater damage to poorly built structures. Places with "very high" MMI will suffer more extreme damage to substantial buildings, with partial collapse and foundation shifts.

Figure 2:
Earthquake risk overview in the Pacific Northwest



Source: Swiss Re CatNet

B. Water Management and the Columbia River Treaty

Within the CRB, snow accumulates in mountainous areas, melting in the spring to power both the region's rivers and economy by generating 40 percent of America's hydropower electricity. This supplies about two-thirds of the region's electricity, with enough excess to export 2 to 6 million Megawatt hours per month. The great rivers, lakes, streams, and wetlands in the Northwest provide a habitat for wildlife, support transportation, sustain commercial fisheries, and supply irrigation for agricultural use.

A comprehensive water management system has been designed to better utilize the Columbia River flow based on the historical timing of snowmelt runoff. Snowpack acts as a natural water reservoir by storing water during the cool season and gradually releasing water in the spring and early summer. However, projected future snowpack reductions, shifts in streamflow timing, warmer and drier summers, and increased water demand will pose challenges for water management. For instance, a shift in the timing of peak flows by several weeks to a month could result in an earlier release of water from reservoirs to create space for flood control and a loss of storage supply for other objectives, including irrigation and hydropower production for peak use.

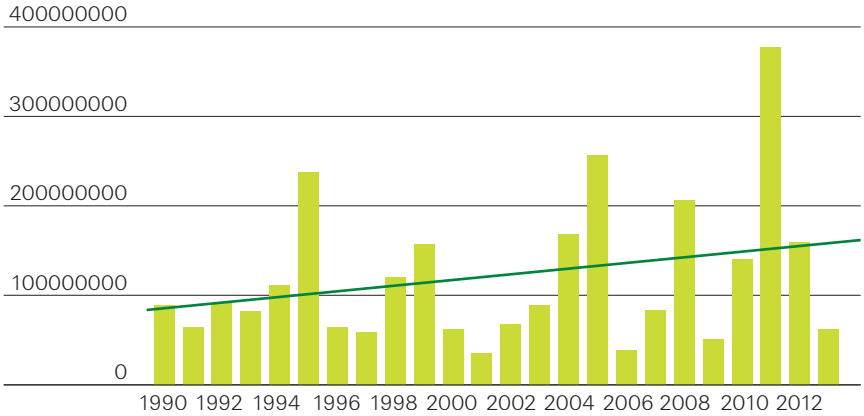
The United States and Canada signed the Columbia River Treaty in 1964 to provide a long-term water management strategy considering the Pacific Northwest region relies on the Columbia River system for environmental benefits, energy exports and supply, public safety, and economic wellbeing. The CRT includes provisions on the development and operation of dams in the upper CRB, which support power and flood control in both countries. The CRT includes an option for either country to terminate treaty provisions after 60 years with 10 years advance notice, making 2014 a critical year for the United States and Canada to review the treaty.

In December 2013, the U.S. Entity[3] created by the CRT developed regional recommendations in collaboration and consultation with the region's states, federally recognized tribes, and a variety of stakeholders. This constituted an extensive, multi-year process known as the CRT. The review concludes that "a modernized Treaty should consider impacts from climate change to hydropower, flood risk management, etc."[4] Moreover, the review urges the United States and Canadian Entities' Hydro-meteorological Team to collaborate and share the best available climate change data, which implies the necessity of multi-jurisdictional cooperation.

II. Natural disasters: Who pays?

Natural disasters are becoming more costly worldwide. Direct losses from catastrophes have trended upwards over the past two decades, with much of this rise attributable to increases in wealth concentration in disaster-prone areas.[5] The rise is likely to be further exacerbated by the expected increase in the frequency and intensity of weather-related events due to climate change.[6]

Figure 3:
Direct losses from global natural disasters (billion USD, 2013)



Source: EM-DAT Database

When a disaster hits, states and individuals look to several sources of funding to pay for response, recovery, and reconstruction efforts. While some homes, businesses and public structures are covered by private insurance, the federal government is often the principal funding entity for post-disaster recovery. Federal government funding encompasses the FEMA Disaster Relief Fund, the National Flood Insurance Program, and the Department of Transportation's Federal Highway Emergency Relief Program, among others. These are detailed below.

FEMA Disaster Relief Fund (DRF)

In 1988, the U.S. Congress signed into law the Robert T. Stafford Disaster Relief and Emergency Assistance Act. Referred to as the Stafford Act, the legislation created a systematic process through which federal funds could be channeled to states and households affected by major natural disasters. Stafford Act funding is triggered by a presidential disaster declaration and administered by the Federal Emergency Management Agency (FEMA). FEMA directs disaster response and recovery efforts through the Disaster Relief Fund (DRF), which is financed through congressional appropriations. The DRF is authorized to provide three types of assistance:[7]

- Public Assistance funds are allocated to state and local governments for debris removal, emergency response, repair work on critical infrastructure, and longer-term reconstruction efforts. The cost of public assistance is shared between federal and state governments, with the federal government contributing 75 percent. The president can increase this share to 90 percent when the event exceeds certain per capita disaster costs.
- Individual assistance funds are available to disaster victims to cover expenses that are not otherwise met through insurance or low-interest Small Business Administration loans. This includes temporary housing, unemployment compensation, and crisis counseling, among other expenses. IA is determined based on individual needs and covered at 100 percent, up to USD 31 900.
- The Hazard Mitigation Program provides funding for long-term disaster mitigation efforts and is typically not a source of funds for immediate response and recovery.

National Flood Insurance Program (NFIP)
The NFIP was established through the National Flood Insurance Act in 1968. The program sought to fill a gap in private coverage left by insurers who had traditionally been reluctant to underwrite flooding due to the catastrophic nature of events and inadequate capacity to predict flood risk.[8] The federal government sets the premium rates and coverage limits, and assumes full liability under the policies. Private insurance companies, on the other hand, sell the policies and process the claims, but do not bear any of the financial risk. Participation in the NFIP is mandatory for properties located within a 100-year floodplain that are backed by federally insured mortgages. However, many homeowners obliged to purchase insurance do not do so, or do not renew policies after they have lapsed. Ahead of Hurricane Sandy, for example, only two-thirds of one- to four-family homes located in high-risk areas had NFIP insurance.[9]

Federal Highway Emergency Relief Program (FHWA ER)
Managed by the Federal Highway Administration, the Emergency Relief Program provides funding for the repair of federal roads and highways that have sustained serious damage during a natural disaster or another external event. FHWA ER is a cost-sharing partnership between the federal government and state or local highway authorities. Repairs necessary to restore essential traffic are covered by the federal government at 100 percent. Longer-term restoration work is paid for by the federal government at 90 percent (for interstate highways) and 80 percent (for all other federal highways). In general, estimated repairs must cost at least USD 700 000 before the FHWA will consider the damage to be eligible for funding. Total funds are capped at USD 100 million per state, per event.[10]

Private Insurance
While typical homeowner policies cover wind damage – for example, from a tornado or a hurricane – they expressly exclude coverage for storm-related flooding. This exclusion stems from the market distortion caused by the NFIP, which offers coverage at subsidized rates. Earthquake insurance can be purchased separately, but the number of policies available, as well as the number of companies offering coverage, is relatively small. For example, direct earthquake premiums written in Washington State in 2009 were USD 113 million, compared to the USD 1.3 billion in homeowner policies written that same year.[11]

III. The future "financing gap" in the Pacific Northwest

A. Historical cost of natural disasters

Flooding

Oregon and Washington's geography and climate make the states particularly susceptible to flooding. Typically caused by heavy rainfall or rapid snowmelt, floods cause millions of dollars in damage annually and frequently overwhelm state resources. Oregon and Washington have received 28 and 46 major disaster declarations, respectively, since such declarations were first issued in 1953. The vast majority of these – 68% in Oregon and 72% in Washington – covered flooding, either by itself or in combination with another event. In Washington, economic damages from floods have exceeded those of all other natural disasters.[12] Several major flooding events, as well as the financial response, are described below.

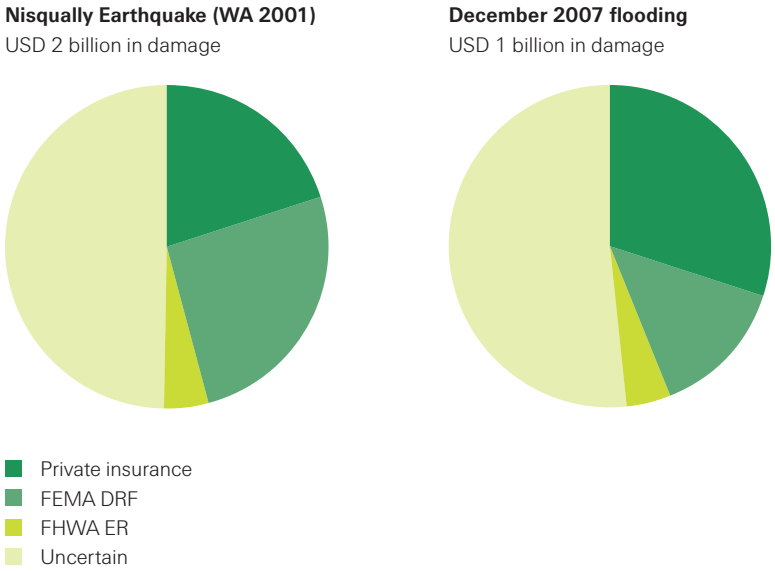
Pacific Northwest floods, February 1996

Record rainfall and rapid snowmelt caused by warm temperatures resulted in severe flooding across much of the Pacific Northwest. Damages from the event were estimated at around USD 1 billion (1996 USD)[13], with much of those incurred in Oregon and Washington. A major disaster declaration was issued almost immediately for both states, making federal funding available for relief and recovery efforts. Assistance under the Stafford Act totaled USD 90.3 million in Oregon and USD 113 million in Washington, while the NFIP paid close to USD 62 million in claims throughout the region[14].

Washington and Oregon floods, December 2007

In December 2007, three storms hit the Pacific Northwest in the space of three days, causing widespread flooding, landslides and mudslides. Six-hour rainfall totals were near 100-year event levels in both states and a portion of Interstate 5, which connects Portland and Seattle, was covered by 10 feet of water. The storms caused USD 1 billion in damage throughout the region, with property damage in Washington State alone reaching USD 197 million[15]. The event resulted in an immediate presidential disaster declaration. Stafford Act disaster assistance totaled approximately USD 63 million and USD 75 million in Oregon and Washington, respectively. The FHWA ER program also allocated USD 44.8 million to Washington to repair damaged roads and bridges.

Figure 4:
Examples of natural disaster coverage gaps



Earthquakes
Both Oregon and Washington are at risk of three types of earthquakes. Crustal earthquake are shallow and may occur along faults across the states. Because these happen near the surface, even small quakes may cause significant damage. Deep earthquakes occur along the subduction zone – the region where one tectonic plate glides beneath another – deep within the portion of the ocean plate that has already slid beneath the continental crust. Finally, subduction zone earthquakes occur along the boundary of two tectonic plates. In the case of the Pacific Northwest, the Cascadia Subduction Zone (CSZ) is formed by several ocean plates descending beneath the North America Plate. Full subduction zone earthquakes can be extremely damaging and may produce tsunamis. The last earthquake along the CSZ occurred in 1700. The event, which is believed to have measured M9.0 on the Richter scale, released 1 500 times more seismic energy than the 2001 M6.8 Nisqually quake (discussed below).[16]

Nearly 17 000 earthquakes of magnitude 6.0 or lower have been recorded in Washington and Oregon since 1970; approximately 15–20 such events are felt in the region each year.[17] Earthquake awareness rose markedly in 1993, when Oregon experienced two quakes several months apart. Prior to that year, the last significant quake in the region occurred in 1965, a magnitude 6.5 event centered in Renton, Washington. The quake caused USD 50 million in damage (equivalent to USD 370 million today) and was felt across the Northwest and British Columbia. The two costliest earthquakes of the past two decades are described below.

Scotts Mills Earthquake, Oregon, March 1993
A 5.6 magnitude crustal earthquake hit on March 25 near the town of Scotts Mills, about 34 miles south of Portland. Although no casualties were reported, the earthquake caused approximately USD 30 million in damage.[18] It remains the most destructive earthquake in Oregon's history in terms of property loss. The event resulted in a presidential disaster declaration, issued a month after the quake occurred. Information on post-disaster funding for this event is not publicly available.

Nisqually Earthquake, Washington, February 2001
A magnitude 6.8 deep earthquake shook Puget Sound on February 28. Centered approximately 50 miles south of Seattle, the earthquake was felt as far north as Vancouver, as far south as Portland, and as far southeast as Salt Lake City. Various estimates of total damage exist, ranging from USD 1 to USD 4 billion. A 2002 study carried out by the University of Washington estimated damages of USD 1.5 billion to nearly 300 000 households.[19] The earthquake was followed by an immediate presidential major disaster declaration. The state received approximately USD 156 million in Stafford disaster assistance, while FHWA ER has provided close to USD 94 million to date.[20]

B. Projecting the future financing gap

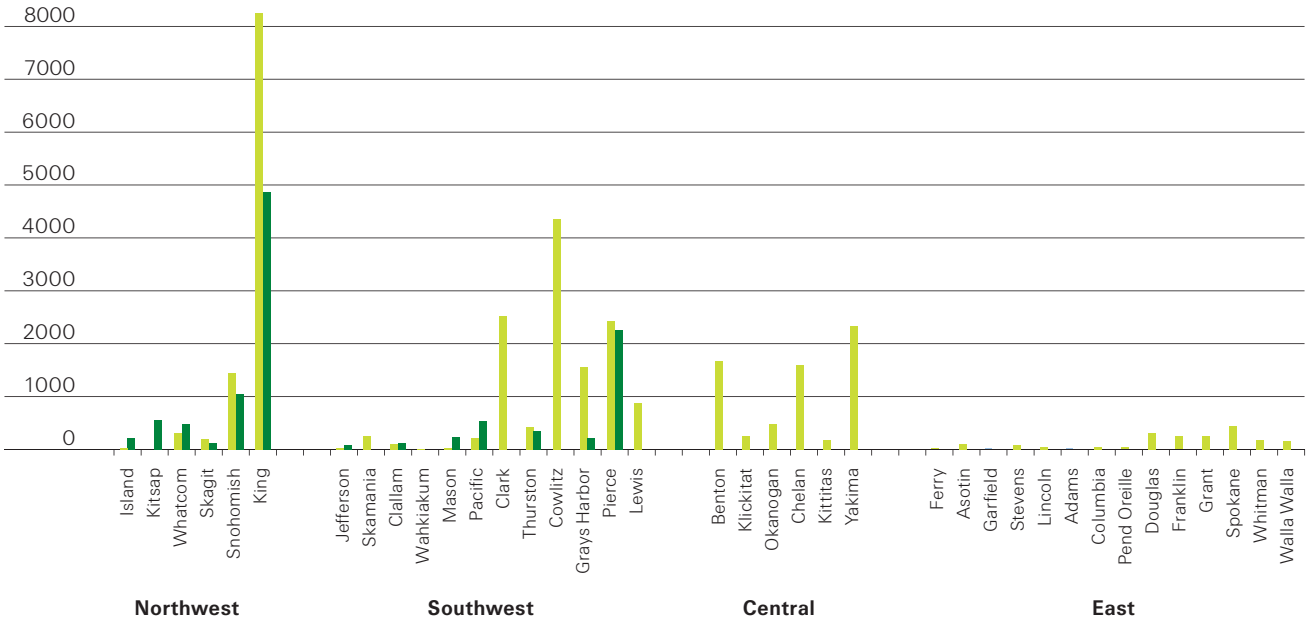
The Pacific Northwest is susceptible to a host of natural disasters. Thus far, however, the region has been largely spared from the scale of catastrophic losses experienced by states in other parts of the U.S. The Columbia River Basin's extensive system of dams and reservoirs has provided important flood protection, while seismic activity – Oregon and Washington are among the top ten states in terms of earthquake risk[21] – has been relatively muted. But as cities grow, faults shift, and the climate becomes more unpredictable, the region's exposure to natural disasters will become more pronounced. At the same time, as federal disaster relief is stretched thinner, adequate funding for recovery and reconstruction will be far from certain. In this section, we assess the Pacific Northwest's financial vulnerability to natural disasters by using Monte Carlo sampling to model the gap between potential economic losses and available post-disaster funding following a major flooding or earthquake event. Washington State is used as a case study because its exposure – financial, climatic, and geological – is higher than any other state in the region.

Estimating economic losses

Flooding

In May 2013, the Emergency Management Division (EMD) of Washington State's Military Department issued an updated State Hazard Mitigation Plan. The plan included a detailed assessment of the state's exposure to natural hazards, including an analysis of its economic exposure to flooding. The authors used Hazus MH-2.1 software, FEMA's risk assessment tool, to model potential damage from an 100-year flood event[22] in each of the state's counties. The results of the assessment showed estimated riverine losses ranging from just under USD 3 million in Kitsap County to over USD 12.7 billion in King County, which encompasses Seattle. The range of coastal flood losses was narrower, from USD 8 million in Wahkiakum County to nearly USD 9.0 billion in King County.

Figure 5:
Estimated flood losses, by county and region (millions USD)*



*Although the y-axis is capped at USD 8 000 million, King County riverine losses total USD 12 680.
Source: Authors, based on loss estimates provided in the Washington State Hazard Mitigation Plan.

The data presented in the State Hazard Mitigation Plan has served as the basis for our team's statewide flood loss estimates. The loss curve was derived by fitting a Pareto distribution through two points: the potential damage and annual probability of occurrence for a very small flood, theorized to cause damage slightly below the 10-year flood level, and estimated damage from a 100-year flood. The minimum allowable loss value – the first point – was obtained by adjusting the historical damage estimates for similar size flooding, while the latter was derived by summing the estimated county-wide losses from a 100-year flood as outlined in the State Hazard Mitigation Plan. The scaling parameter was determined based on the location of these two points. Finally, the right tail of the distribution was truncated at USD 100 billion to reflect the fact that, while scalable, potential losses are not infinite. This process was repeated for both riverine and coastal flooding. A more detailed look at the inputs used to determine the statewide loss curves for flooding and earthquakes is available in Appendix B.

Earthquake

To estimate potential losses from earthquakes, we relied on the Washington State Seismic Hazards Catalog – a database that contains physical and economic damage estimates for the most serious potential earthquakes anywhere in Washington State. The Catalog covers sixteen crustal, two deep, and one subduction zone earthquake scenario. As above, statewide potential loss estimates were determined by fitting a Pareto distribution to available data. Here, the minimum allowable loss value was largely theoretical and reflected our best estimate for losses associated with an M5.5-6 earthquake, the lowest likely to cause structural damage. The second point along the distribution was determined based on the estimates outlined in the Seismic Hazards Catalog for crustal, deep, and subduction zone events. The scaling parameter was determined based on the location of these two points. As above, the right tail of the distribution for crustal and deep earthquakes was truncated at USD 100 billion, which reflects the damages from the 1994 Northridge quake in California, the costliest such event in U.S. history (adjusted for inflation). The subduction zone earthquake distribution was bound at USD 300 billion, approximately the cost of the 2011 Japan earthquake.

Estimating post-disaster funding

The principal source of post-disaster funding for catastrophic flooding and earthquake used in this analysis was the FEMA DRF, the NFIP, and the FHWA ER. For flooding, private insurance is not included because the amount of flood insurance policies written outside of the NFIP is negligible. Similarly, NFIP payments are excluded for earthquakes. Although other government agencies may provide some post-disaster funding, the amounts are small relative to the three mentioned here and have therefore been excluded. To the authors' knowledge, there are no statewide risk transfer mechanisms or disaster relief funds in Washington State.

Payments from each source were allowed to fluctuate according to a normal distribution and reflected percentage figures of total damage. The mean values were obtained by comparing the mean damage estimated by the Pareto distribution for each event with the amount of funding provided by each source for historic events of similar size (in terms of financial losses). It is important to note that the actual post-event payment received may vary significantly based on the issuance of any supplemental appropriations. A more detailed look at the inputs used to determine the possible payments is available in Appendix C.

Estimated financing gap

The financing gap has been estimated based on a simple calculation. First, whether an event occurs was drawn randomly from a binomial distribution with the probability of success equivalent to the likelihood of that event happening in a given year. We assumed the smallest flood causing significant damage is a 10-year flood, which has an annual probability of 0.1. The probabilities associated with each earthquake scenario were obtained from a variety of seismic studies. The academic consensus regarding the likelihood of each type of earthquake is as follows: 15% in next 50 years (crustal ≥M6.5), 84% in next 50 years (deep ≥M6.5), and 10% in next 50 years (subduction zone ≥M9.0).[23] If a scenario produced an event, the projected financing gap was derived by subtracting the "total inflow" from the "total outflow" of funds. If no event occurred, the total gap was zero. Projected losses, drawn randomly from the Pareto distribution, comprised the "total outflow" of money. The sum of funding from all sources for each event was drawn randomly from the normal distribution and produced the "total inflow" figure. The expected financial gap has been estimated by running this calculation for 10 000 observations.

Figure 6 shows both the full and lower portion of the distribution of modeled financial gaps. As expected, the range of observations is wide, from USD 0 (no event occurs) to more than USD 60 billion, although the majority of observations are concentrated below USD 1 billion. The expected financial gap, represented by the square marker, fluctuates with each Monte Carlo simulation but generally hovers around USD 130 million. The horizontal line, which shows the boundary below which 95 percent of all observations fall, also fluctuates but generally remains around USD 250 billion.

Figure 6:
Modeled financing gap for flooding and earthquake scenarios, complete distribution and 95th percentile

IV. Policy and governance barriers to closing the financing gap

As natural disasters become more costly, their impacts will put increasing strain on government budgets. The two programs most vulnerable to increasingly costly natural catastrophes are FEMA's Disaster Relief Fund and the NFIP.[24]

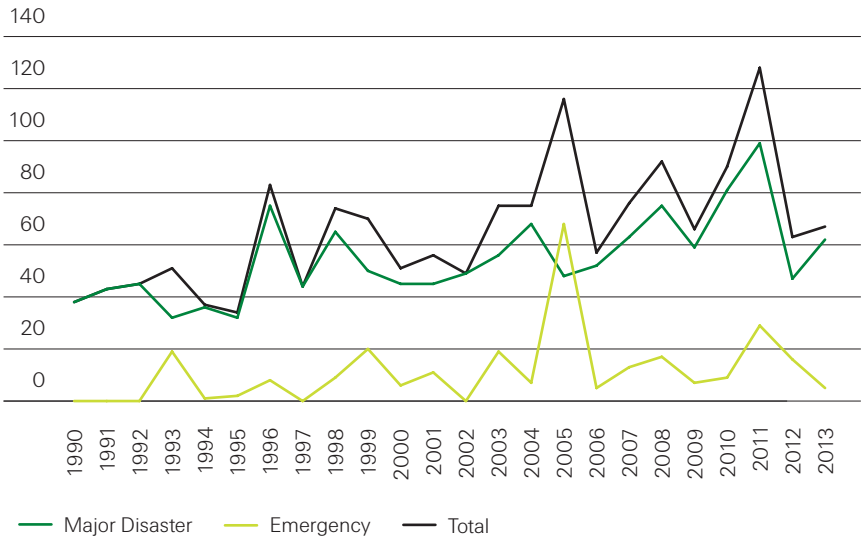
FEMA Disaster Relief Fund (DRF)

FEMA forms its annual budget requests for Congressional appropriations using 5-year averages of historical obligations, excluding catastrophic events (costing above USD 500 million).[25] This obscures the reality of disaster frequency from policy makers.[26] Budget estimates based on 5-year averages, however, often underestimate true need. Between 2000 and 2006, catastrophic disasters occurred in four of seven years, raising important questions regarding the true infrequency of these events. According to a 2008 report by the U.S. Government Accountability Office, excluding costs associated with catastrophic disasters in annual funding estimates "prevents decision makers from receiving a comprehensive view of overall funding claims and trade-offs."[27]

In addition, FEMA receives frequent supplemental appropriations from Congress to remedy DRF shortfalls.[28] Between 2005 and 2011, the average base appropriation for the Fund was roughly USD 1.75 billion. The average monthly spend-out rate for the same time period was USD 383 million, or approximately USD 4.6 billion annually.[29] Without supplements, the DRF would have faced an average yearly funding deficit of nearly USD 3 billion for the majority of the last decade. See Appendix B for DRF base and supplement appropriations 2003–2013.

Since FEMA first began operations in 1979, there has been a gradual increase in the number of events that have qualified for DRF funding, with many relatively small events receiving major disaster status.[30] FEMA has been asked to respond to many natural disasters that had previously been handled entirely by state and local governments.[31] As FEMA Administrator Craig Fugate stated in 2011, "Our balances got to such a point that it was a concern of mine. What would have happened if an earthquake or a large-scale event had occurred?"[32]

Figure 7:
Disaster and emergency declarations, 1990–2013



Source: Authors, based on FEMA reporting.

When a disaster is declared, the agency commits funds to pay the estimated recovery costs. FEMA cannot recover or redirect any unused funding until it 'closes' the case by certifying that work on all related projects has completed. Disasters take an average of ten years to close now, compared to five years during the 1990s.[33] This implies that a significant amount of funding remains tied to open events and is unavailable to respond to new emergencies.[34]

The National Flood Insurance Program (NFIP)
The NFIP is also facing sustainability challenges. Until 2004, the program was largely able to cover its claims payments with earned premiums. Hurricanes in 2005 forced the NFIP to borrow USD 16.8 billion as claims surged, and the U.S. Treasury authorized an additional USD 9.7 billion in borrowing authority after Superstorm Sandy. The NFIP is approximately USD 24 billion in debt as of May 2013.[35]

In this national context, there are six key policy and governance barriers to the appropriate mitigation of risk from natural disasters in the Pacific Northwest.

A. Over-dependence on federal funding for disaster relief

The federal Stafford Act outlines coordination guidelines for disaster response efforts and identifies the roles and processes at each level of government when a disaster is declared. Federal government measures such as the Stafford Act cover both public and private assets, but local owners of these assets are not paying insurance premiums commensurate with their risk exposure. As a result, the DRF and NFIP shoulder much of the financial burden of disaster response.[36] This may create costly moral hazard. In particular, "the NFIP is the second largest financial risk and liability of the federal government behind Social Security."[37]

Over-dependence extends to pre-disaster mitigation efforts, as well.[38] Under the federal Hazard Mitigation Grant Program (HMGP), state and local governments are responsible for only 25 percent of the cost of natural disaster mitigation efforts, with the federal government responsible for the remainder. There is political momentum in favor of widening the gap between state and local responsibility, as a recent report from the United States Conference of Mayors advocated increasing the federal government's share of responsibility for mitigation efforts to 100 percent.[39] However, this general dependency may not be tolerated by federal budgets indefinitely.

After Hurricane Katrina, federal actors waived the rules and regulations governing federal contract bidding processes so that aid could flow more quickly to affected areas. However, "such waivers occur ad hoc, creating uncertainty and thus contributing to confusion and inefficiency."[40] A lack of predictability has affected the speed with which public entities can respond to disasters.[41] According to the U.S. Conference of Mayors, "current practices delay the rebuilding or repairs of the damaged public asset" through bureaucratic complications of disaster relief.[42]

B. Lack of data on the value at-risk

The lack of comprehensive data stems from an incomplete accounting of risk. Current exposure to potential flood losses is not completely mapped by the NFIP, creating geographic 'blind spots' where economic growth has raised the value of assets but insurance coverage has not kept pace.[43] Efforts to improve mapping in the Pacific Northwest (PNW) have yet to close the knowledge gap.[44]

Current policy frameworks imply two cognitive errors. First, FEMA employs past disasters to predict future calamities, reducing the ability to foresee the real impact of catastrophic events. The average obligation level depends on a lagging index, excluding 'catastrophes,' defined as events with losses in excess of USD 500 million. This obscures the importance of events that inflict the costliest damages. Furthermore, the emphasis on financial damages is useful but omits other potential metrics. Most notably, the Center for Strategic and International Studies has proposed employing the metric of "time without services" to measure disaster preparedness.[45] Second, climate change is altering the global risk profile without a commensurate response from policy makers in the PNW. Swiss Re estimates that climate risk to the energy system in the United States Gulf Cost may rise by over 15 percent, or USD 7.3 billion, by 2030. The global reach of climate change means that the PNW will not be immune to such weather volatility.

C. Outdated policy standards

Both the DRF and the NFIP require reform to account for new risks and new comprehension of risk. In addition to its aforementioned approach to calculating budget requests, the DRF employs the categories of "emergencies" and "major disasters" without including a "catastrophe" designation.[46] This is not the result of an inability to define catastrophic disasters. The National Response Framework defines "catastrophic events" as:

"Any natural or manmade incident, including terrorism, that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, and/or government functions."[47]

Furthermore, the fund does not contain authorization measures for grants to small businesses, instead allowing only loans.[48] This constitutes a serious potential risk to the economic resilience of PNW communities, as 30 percent of small businesses close permanently after a declared disaster.[49]

The NFIP was structured to underprice risk upon its inception in 1968. This structure consists of subsidies for insurance premiums and policies.[50] Purchasers of subsidized flood insurance policies pay 45 percent of the flood risk cost and those who purchase full-risk policies still benefit from artificially depressed rates based on outdated exposure data.[51] In spite of these artificially depressed rates, many potential policy-holders fail to purchase the ostensibly mandatory NFIP insurance. The result is that at-risk institutions and individuals in the PNW underpay for insurance relative to their risk.

Efforts to reform the NFIP in light of this information have met opposition. The Biggert-Waters Flood Insurance Reform Act of 2012 requires insurance premium increases through the elimination of subsidies and the use of rates that reflect true risk premiums. However, the federal government recently rescinded much of this reform in response to complaints from coastal interests.[52]

D. Lack of inter-state coordination

Throughout the Pacific Northwest, efforts to coordinate inter-state planning and budgeting for natural disasters are under-developed. The King County CEO Summit recognized this in 2013, concluding: "One of the greatest challenges to recovery planning is the need for alignment among the many existing federal, state, and local efforts."[53] Furthermore, current "city-to-city and/or state-to-state mutual aid agreements to immediately trigger funding and liability protection during major or catastrophic emergencies" require formal disaster declaration, limiting flexibility.[54]

This has practical effects for those affected by natural disasters. Most notably, credit access and other financial services may be restricted following a catastrophic event without coordination improvements. This, in turn, affects both recovery time and the response flexibility of individuals.[55]

E. Over-reliance on ex-post financing

Ex-post financing refers to disaster relief and recovery funding that is secured after the occurrence of a natural disaster. In contrast, ex-ante financing is secured and allocated before the catastrophe. Ex-ante funding can be disbursed more quickly after an event and may be leveraged to secure additional funding, with proper planning. The timing and arrival of ex-post funding from the federal government depends on a lengthy and often confusing disaster declaration process, outlined in the Stafford Act. This process can last several months.[56] For example, President Obama did not sign the emergency supplemental appropriations measure for Hurricane Sandy until January 29, 2013, roughly three months after the storm hit.

Figure 8
Stafford Act disaster declaration process

Sources:
Washington Military Department, Emergency Management Division. "Public Assistance Program Process," 2014. http://www.emd.wa.gov/disaster/documents/disaster_PA_PublicAssistanceProgramProcess_2014.pdf
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State budgets for emergency management in the Pacific Northwest reflect a relative and absolute dearth of ex-ante funding (see Appendix E). The operating budgets for the Washington and Oregon State Emergency Management agencies were USD 3.8 million and USD 2 million respectively in 2012. Washington's budget ranks 22nd among all states, while Oregon's budget ranks 38th.[57] This has occurred while each state has increased 2014 budget appropriations for education, healthcare, and corrections.[58] This indicates that prioritization, and not scarcity, may be at the heart of funding decisions in the PNW.[59]

F. An inhospitable regulatory environment, with signs of life

The gap between economic exposure and available post-disaster financing is compounded by a lack of strong natural disaster management policies that help states address their risk and unlock private investment to enhance their resiliency to catastrophic events. However, there are causes for hope in the policy space. Most notably, public-private partnerships (PPPs) show signs of moving from ad-hoc associations to enduring alliances. Organizations like the West Coast Infrastructure Exchange seek to formalize and accelerate ex-ante mitigation efforts in coordination with private actors.[60] This is critical to future disaster relief success.

However, private risk transfer for natural disasters remains uncommon for two key reasons. First, private insurers are unable to compete with subsidized NFIP rates. This is due, in part, to the fact that potential losses arising from large-scale natural disasters far exceed the premiums companies can collect. For high-frequency events, the market cost of insurance can be more than twice the actuarial cost (measured in expected annual loss). For lower frequency risks, the price can be up to four times the expected loss.[61] Second, it has been difficult to diversify risk among policyholders when an event is likely to impact the majority of policyholders in a given area. Altogether, this constitutes a significant opportunity cost to institutions and individuals in the PNW. Climate change provides further impetus to innovate, and two-thirds of Washington state homeowner insurers have indicated that weather volatility will affect future coverage.[62]

V. Potential solutions to close the financing gap

The Pacific Northwest, in this case Oregon and Washington, face a triple threat when it comes to disaster risk management. Despite these challenges, there are governance and financial mechanisms that can be employed to improve the region's resilience to catastrophic natural disasters. The World Bank and other multilateral development institutions outline numerous disaster risk management practices that developing nations should employ to insulate themselves from the risk associated with catastrophic events. Despite the obvious differences between developing nations and U.S. states, U.S. coastal states face many similar challenges, such as growing populations, outdated infrastructure, and lack of spare public budget capacity.

A. Inter-state risk assessment and planning

To manage the region's diverse risk profile we recommend designing and implementing a regional disaster risk management facility that is able to help states set policy priorities, provide high-level guidance, and manage the regional disaster risk management process to ensure common policy, regulatory, and financial policies. An inter-state governance structure is best suited for the region due to the cross-border nature of many of the impacts from natural disasters. Furthermore, cross-border cooperation has a history in the region. Regional bodies, such as the Western Climate Initiative and the Pacific Northwest Electrical Power and Conversation Planning Council, demonstrate the effectiveness of regional governance in the Pacific Northwest.

The regional body should adopt on three major focal areas:
1) Risk identification and risk assessment
2) Adaptation and mitigation
3) Risk transfer

Washington and Oregon have a strong history of risk mapping and identification. Oregon's Natural Hazards Mitigation Plan provides a high-level of detail on the state's vulnerability to earthquakes and other natural disasters, including an interactive platform that citizens can use to assess the direct risk to their assets. However, this work could be improved by scaling it up to include analysis of the region as a whole, providing a comprehensive analysis of the potential impacts from major catastrophes.

The second focal area, adaptation and mitigation, should include best practices for adjusting and improving policies and regulations that increase the region's vulnerability to natural disasters, such as updating out of date building codes or reducing incentives for people to live in disaster prone locations. The regional body should work with existing organizations, such as the West Coast Infrastructure Exchange, to identify shovel-ready green and grey infrastructure projects that improve communities' resilience to natural disasters and the more gradual impacts of climate change. Finally, this focal area should include a regional outreach and education program to properly educate people about natural disaster risk and strategies they can take to reduce their risk. A multi-state initiative will help facilitate a culture of risk management at a regional level, ensuring that people throughout the region receive a similar, high-quality level of information.

Developing inter-state risk pooling or risk transfer strategies or mechanisms, the final focal area of the recommended regional organization, is likely the most difficult due to the complicated regulatory and financial requirements behind risk pooling and risk transfer facilities. Despite the complexity of execution, risk transfer is the most important of the three focal areas due the immense fiscal challenge state governments face in the time period immediately after a natural disaster.

As laid out above, ex-post disaster financing takes time to materialize forcing states to utilize scarce public resources, either by transferring funding from existing programs or issuing new debt, to fund immediate disaster response and recovery efforts. As outlined earlier, states should diversify their disaster financing strategies to reduce their dependence on disaster relief funding from the federal government due to increasingly large public expenditure required for disaster relief and the time it takes to arrive.

This liquidity gap translates into economic consequences for states looking to restore basic services, as they often have to shift funds from more productive public investments, such as education, to cover the restoration of basic services. The financial burden placed on governments for relief and recovery efforts can lead to a direct reduction in economic output post-disaster. The IMF estimates that countries with low insurance coverage ratios and limited budgets lose up to one percentage point off their gross domestic product in the short-term and 2.6 percentage points in the long-term due to the indirect losses associated with a natural catastrophe.[63]

Natural disasters can also have a negative fiscal impact. For middle-income and advanced economy countries, natural disasters lead to an average increase in government expenditures of 15 percent and lower revenues by 10 percent, resulting in an overall increase in budget deficits of 25 percent.[64] For example, after the 2009 tsunami, Samoa's fiscal deficit increased by 3 percent of GDP to 7.5 percent and external public debt rose by more than 8 percent in the year following the event.[65] As a result, Samoa is exploring politically unpopular fiscal consolidation measures to reduce their debt levels. The impact of this increase on debt sustainability depends largely on how countries finance their recovery costs. While this analysis does not apply directly to states in the Pacific Northwest, it highlights the fiscal challenges associated with over-reliance on ex-post disaster financing.

Despite the ever-increasing fiscal and macroeconomic cost of natural disasters, state governments lack adequate financing options to close the "liquidity gap," have underdeveloped risk management cultures, and are underinvesting in resilient infrastructure. However, there are strategies to address these challenges. Parametric insurance can be a useful, cost-effective tool for governments to help manage their residual risk and reduce the liquidity gap because parametric insurance payouts are triggered by pre-arranged physical parameters of an event, such as wind speed or magnitude and location of an earthquake.[66] Parametric insurance tools pay out almost immediately after an event, injecting much needed liquidity into the public sector. Governments can transfer their risk to the capital markets, through risk sharing facilities or other measures.

A. Regional risk transfer mechanisms

Caribbean Catastrophic Risk Insurance Facility

Caribbean countries are highly exposed to natural disasters. According to the World Bank, at least one hurricane, on average, and multiple tropical storms cross the region each year.[67] Due to their small size, Caribbean countries lack the financial capacity to respond to natural disasters and the disasters have a large impact on the region's economic health as the small nations lack the economic diversity required to sustain growth in the aftermath of a major disaster.[68] To address this growing threat, the Caribbean Community (CARICOM) partnered with the World Bank to design and implement the world's first multi-country risk pool, the Caribbean Catastrophic Risk Insurance Facility (CCRIF).

The CCRIF was formed in 2007 to help Caribbean states reduce the cost of reinsurance policies through pooling their risk and using a central entity to manage their risk profiles and insurance policies. CCRIF was initially capitalized with USD 47 million from three donor countries and two development banks, but now the facility is financed solely through premium income and membership fees. CCRIF helps member countries access insurance markets at a lower cost than if they maintained their own disaster relief fund or purchased unilateral insurance products. CCRIF aggregates the region's risk, countries pool their individual risk into a larger, more diversified portfolio, resulting in a 40 percent reduction in premium costs.[69] In 2012–2013, CCRIF's aggregate exposure for written policies was just over USD 625 million; USD 25 million in capital retention and USD 120 million in reinsurance policies supported the facility's ability to pay claims.[70] To-date, CCRIF has paid out eight times to seven member countries for a total of USD 32 million.[71]

The success of the CRIFF model is helping spur risk pooling efforts in other highly vulnerable regions, such as Southeast Asia and sub-Saharan Africa. Recent initiatives, such as Pacific Catastrophe Risk Insurance Pilot (CRIP), are expanding catastrophic parametric insurance coverage into previously under-insured markets. A similar model could be applied to Washington and Oregon and expanded to include the entire Columbia River Basin plus northern California in the future. To fully appreciate the benefits of risk pooling, as has been done in the Caribbean, the facility would have to include the other states in the region and potentially two Canadian provinces.

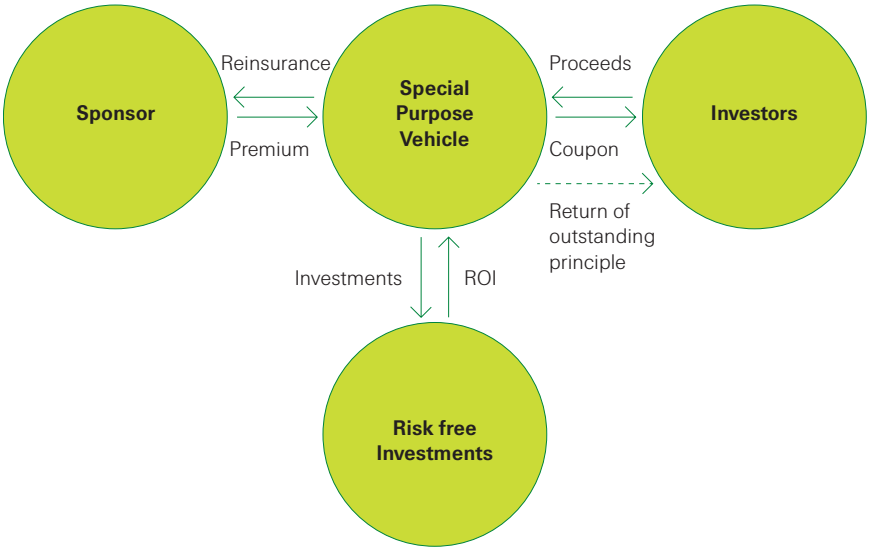
A risk pooling facility of this size and complexity would require substantial political will and technical assistance. Furthermore, the development of a governance structure and capitalization of the facility would require an innovative public-private partnership that incorporates the reinsurance companies, state governments, regional philanthropic organizations, and the federal government.

Mexico's Catastrophe Bonds

Catastrophe bonds are another potential mechanism for the Pacific Northwest to transfer some of its residual risk at a regional level. Catastrophe bonds are generally used to provide catastrophic (re)insurance protection for governments, corporations, reinsure companies, and insurance companies, and can be deployed as a parametric or traditional indemnity insurance product. Catastrophe bonds are used to provide catastrophic (re)insurance protection for governments, corporations, reinsurance companies, and insurance companies. Over the last decade almost USD 40 billion in catastrophe bonds have been issued and as of 2013 there is USD 19 billion outstanding.[72] According to BNY Mellon, the entire insurance linked securities (ILS) market could grow to USD 150 billion by 2018 with catastrophe bonds making up USD 50 billion of the total. Currently, 75% of the ILS market is focused on major earthquakes and windstorms in the United States.[73]

The majority of catastrophe bonds are issued in the United States and other OECD countries; however, Mexico's Multi-Cat bond is often cited as an innovative example of a country transferring exposure from multiple disasters to the capital markets. Mexico is exposed to multiple natural disasters, from hurricanes in the Caribbean to earthquakes along its West coast.[74] To address the high human and economic cost of natural disasters, Mexico created a fund, FONDEN, as part of its federal budget to help cover recovery and reconstruction costs. As part of the creation of FONDEN, Mexico also instituted a framework that institutionalized disaster preparedness and outreach and education.

Figure 9:
Catastrophe bond mechanics



1. The sponsor enters a reinsurance (or other coverage) contract with the SPV
2. The SPV is capitalized by the proceeds from the Cat Bond's issuance in the market
3. Proceeds are invested to provide a stable, low-risk return
4. If no event occurs during the lifetime of the bond, 100% of the notational amount is returned to investors. If an event that meets the cat bond's triggers does occur, the SPV will pay out the appropriate amount to the cat bond's sponsor

Source: Swiss Re, Practicum Team Research

FONDEN employs numerous tools to support state governments and other local entities' response to natural disasters. In 2006, FONDEN issued the first sovereign parametric catastrophe bond. The instrument, known as CatMex (priced at 2.35 points above the London interbank offered rate), provided USD 160 million in parametric (re)insurance protection against earthquake risk over three years.[75] After CatMex matured in 2009, Mexico partnered with the World Bank to issue the world's first multi-catastrophe bond that pooled risk from multiple catastrophes in multiple regions within Mexico. MultiCat was successfully launched in 2012 and provides parametric insurance coverage against hurricanes on the Atlantic and Pacific coasts and earthquake protection in three regions around Mexico City.[76] The success of Mexico's MultiCat bond demonstrates how governments can use ILS to reduce the pressure on public budgets by transferring a diverse pool of risk to the capital markets and locking in natural disaster coverage for multiple years at a fixed price. Most importantly, Mexico's transition from ex-post to ex-ante natural disaster financing helps the country manage budgets and reduce fiscal volatility in the aftermath of a major natural catastrophe.

Drawing on Mexico's example, a multi-peril catastrophe bond, for earthquakes and flooding could help the Pacific Northwest close the gap between the cost of natural disaster recovery and available financing. As demonstrated earlier in the report, a catastrophe bond could help Washington and Oregon by providing ex-ante protection against earthquakes and extreme flooding. For a catastrophe bond to be successful, the region needs to have a strong legal and regulatory framework in place for disaster risk financing that will facilitate the implementation of the instrument. Furthermore, it is imperative the region develop sophisticated data on the probability and severity of catastrophic events. Catastrophe bonds are based on specific triggers and generally only cover high-cost yet rare events, so properly defining the trigger and event parameters will ensure the states are properly protected.

VI. Risk Transfer Proposal

In addition to the creation of a regional body dedicated to improving inter-state coordination on risk management, the region should also explore creating a regional, sub-national risk transfer facility to provide low-cost earthquake and flooding insurance to the Pacific Northwest states. This type of facility has a demonstrable track record of success, and would help the region address the challenges natural disasters pose to state governments' short term-liquidity and long-term economic health. According to a 2009 study by the European Commission, Mckinsey and Company, Swiss Re, and others, risk transfer is the most efficient way of providing additional coverage low frequency but high-impact events.

A regional risk pooling facility would provide ex-ante natural disaster insurance at a lower cost than if the states approached the (re)insurance market individually. For example, CCRIF estimates that its member states pay 40 percent less in premium than they would individually. The first step in this process would be to create an independent, non-profit insurance company, similar to the CCRIF, and capitalize the facility through a mixture of public and private funds. Once the facility is completed, including the necessary governance structures and safeguards, then states would need to conduct an analysis of their individual risks and purchase the appropriate policies. The states should be able to tailor their policies to address their individual exposure to natural disasters. The facility would then be able to use the donor capital and premia income, paid by the participating states, to approach the reinsurance market as a common pool, thus leveraging donor capital and state premiums into an additional leverage of coverage. The funding for state premium payments will have to go through the state budgetary process, which could present political hurdles. However, the states will realize tangible improvements in their financial resiliency through risk pooling and transfer. Caribbean states face similar pressures, limited budgetary capacity with numerous competing priorities, but since 2007, the 16 CCRIF member states have all signed up for either earthquake or windstorm coverage every year. The commitment has helped the facility pay out more than USD 32 million over eight major events. CCRIF's parametric-based policies pay out in less than two weeks, providing much needed liquidity to immediately fund relief and initial reconstruction efforts. For example, after the 2010 earthquake in Haiti, CCRIF funds paid out in less than two weeks and were used to keep the Haitian government running in the immediate aftermath of the earthquake.

As the diagram above demonstrates, risk transfer is only one component of an effective disaster risk management framework. The Pacific Northwest states must also invest in green and grey infrastructure that helps mitigate their exposure to earthquakes and the impacts of climate change. Government budgets do not have the capacity to fund the level of infrastructure required; however, the private sector is not prepared to invest in resilient infrastructure as there is often a disconnect between viable green and grey infrastructure projects and major investors such as large financial firms or institutional investors. To catalyze private investment in resilient infrastructure, the states should create an investment fund that can be capitalized through rebates on premium or the difference between premiums between years (i.e. pay a fixed premium as exposure decreases).[77] The fund could provide concessional financing to resilient infrastructure projects in the states, based on their most immediate needs. This structure would help unlock private investment by reducing the risk born by traditional lenders and helping develop a pipeline of high-quality projects. An investment fund built into the risk transfer facility would be able to recycle some of the savings states realize through ex-ante disaster financing, reducing the region's overall economic exposure to natural disasters and climate change.

Achieving this goal would have the direct benefits as outlined above, but it would also 1) highlight the Pacific Northwest's leadership through an actionable program with quantifiable results, 2) demonstrate the benefits of collective action for improving communities' resiliency, 3) illuminate the process by which collective action can lead to public goods, 4) provide a model for self-sustaining development programs with local ownership, and 5) demonstrate the effectiveness of innovative public private partnerships in unlocking investment for climate adaptation.

VII. Conclusion

The unique natural disaster profile of the PNW including flood, earthquake, coastal erosion etc. creates multiple challenges for disaster risk management. In terms of disaster relief financing, the region is unprepared to pay for a Cascadia earthquake or a severe riverine flood. A series of policy barriers impede the sufficiency and timely payout of disaster relief funding. These policy barriers include over-reliance on federal and ex-post funding and the lack of inter-state coordination. To solve these problems, there is no silver bullet. First, the state government of Oregon, Washington, Idaho, Montana and British Columbia should enhance multi-state coordination in understanding and combating current challenges in disaster risk management. Second, a multi-jurisdictional risk pooling facility should be established to allow stakeholders to spread catastrophic risk across the region. Finally, to enhance disaster resilience in the long run, the risk pooling facility should recycle savings on premia into public investment fund for natural disaster resiliency projects and other infrastructure investments.

Appendix A:
Major disaster declarations in Oregon and Washington, 1990–2013*

Year	Oregon		Washington	
	Number	Type	Number	Type
1990	1	Flooding, Severe Storms	2	Flooding, Severe Storms
1991	0		2	Fires, Severe Storms
1993	2	Earthquakes	1	Severe Storms
1994	1	El Niño effects	1	El Niño effects
1995	1	Flooding	0	
1996	2	Flooding, Severe Storms	2	Flooding, Severe Storms
1997	1	Flooding, Severe Storms	4	Flooding, Severe Winter Storms, Landslides
1998	1	Flooding	2	Flooding, Landslides
2001	0		1	Earthquake
2002	1	Severe Winter Storms	0	
2003	0		1	Flooding, Severe Storms
2004	1	Severe Winter Storms	0	
2006	2	Flooding, Severe Storms, Landslides	2	Flooding, Severe Storms, Landslides, Tidal Surge
2007	2	Flooding, Severe Storms, Landslides	2	Flooding, Severe Storms, Landslides
2009	1	Flooding, Severe Winter Storms, Landslides	2	Flooding, Severe Winter Storms, Landslides,
2011	2	Flooding, Severe Winter Storms, Landslides, Tsunami wave surge	1	Flooding, Severe Winter Storms, Landslides
2012	1	Flooding, Severe Winter Storms, Landslides	2	Flooding, Severe Winter Storms, Landslides,

* Years with no declarations for either state have been excluded.
Source: Authors, with data from FEMA.

Appendix B:
Statewide economic loss estimates, flooding and earthquake

1) Probability of event occurrence, binomial distribution

Event	Probability of success
Riverine flood (>10 year)	0.1
Coastal flood (>10 year)	0.1
Crustal earthquake (>M6.5)	0.003
Deep earthquake (>M6.5)	0.017
Subduction zone earthquake (>M9)	0.002

2) Key inputs for flood loss, Pareto distribution

Input	Key parameters (USD figures in billions)
Riverine	$X_{min} = 0.5$ $X_{100\text{-}yr} = 19.5$ $P(x \geq X_{100\text{-}yr}) = 0.01$ $X_{max} = 100$ $\alpha = 0.77$
Coastal	$X_{min} = 0.3$ $X_{100\text{-}yr} = 11.1$ $P(x \geq X_{100\text{-}yr}) = 0.01$ $X_{max} = 100$ $= 0.78$

Note 1: The figure associated with 100-year flooding was obtained by summing losses for the 19 counties also exposed to coastal flooding. This was done to 1) make coastal and riverine flooding comparable, and 2) reflect the fact that it is highly unlikely for one event to cause 100-year floods across all counties.
Note 2: The Scaling parameter (α) was obtained through the following formula:
$\ln P(x \geq X_{100\text{-}yr})/\ln(X_{min}/X_{100\text{-}yr})$

3) Key inputs for earthquake loss, Pareto distribution

Input	Key parameters (USD figures in billions)
Crustal	$X_{min} = 0.03$ $X_{>M6.5} = 3.99$ $P(x \geq X_{>M6.5}) = 0.003$ $X_{max} = 100$ $\alpha = 1.19$
Deep	$X_{min} = 0.5$ $X_{>M6.5} = 11.07$ $P(x \geq X_{>M6.5}) = 0.017$ $X_{max} = 100$ $\alpha = 1.32$
Subduction zone	$X_{min} = 1.00$ $X_{>M9} = 21.0$ $P(x \geq X_{>M9}) = 0.007$ $X_{max} = 300$ $\alpha = 1.63$

Note 1: Because their probability of occurrence is largely similar, the figures associated with the second X value for the crustal, deep, and subduction zone earthquakes were obtained by averaging the damage estimates of all earthquake scenarios of that type as outlined in the Seismic Hazards Catalog. Because the catalog contained only one full subduction zone earthquake scenario, that figure, rather than an average, was used to determine the CSZ loss curve.
Note 2: The Scaling parameter (α) was obtained through the following formula:
$\ln P(x \geq X_{>6.5/9})/\ln(Xmin/ X_{>6.5/9})$

Appendix C:
Post-disaster funding, flooding and earthquake

1) Key inputs for post-flood funds, Normal distribution

Input	Value (% of damage)
FEMA DRF	Mean: 30% Std. Dev.: 5%
FEMA NFIP	Mean: 8% Std. Dev.: 3%
DOT FHWA Emergency Relief Program	Mean: 5% Std. Dev.: 0.5%
Private insurance	Mean: 0% Std. Dev.: 0%

2) Key inputs for post-earthquake funds, Normal distribution

Input	Value (% of damage)
FEMA DRF	Mean: 30% Std. Dev.: 5%
FEMA NFIP	Mean: 0% Std. Dev.: 0%
DOT FHWA Emergency Relief Program	Mean: 10% Std. Dev.: 5%
Private insurance	Mean: 0.7% Std. Dev.: 0.1%

Appendix D:
FEMA DRF Base and Supplemental Appropriations, 2000–2013

Year	Base (constant 2013 USD)	Supplemental (constant 2013 USD)
2003	USD 1,012	USD 1,805
2004	USD 2,219	USD 2,729
2005	USD 2,435	USD 51,399
2006	USD 2,045	USD 6,933
2007	USD 1,685	USD 4,597
2008	USD 1,514	USD 11,858
2009	USD 1,387	USD 0
2010	USD 1,709	USD 5,448
2011	USD 2,796	USD 0
2012	USD 7,179	USD 0
2013	USD 6,089	USD 50,500

Source: Authors with data from the Congressional Research Service (https://www.fas.org/sgp/crs/misc/R40708.pdf; http://www.fas.org/sgp/crs/misc/R42869.pdf)

Appendix E:
Disaster designations, payouts in Oregon and Washington State from 2011–2012

	Disaster Desig-nations	FEMA Disaster Relief Obligation, 2012	USDA Federal Crop Insurance	Highway Emergency Relief	State Totals
Oregon	3	USD 38 million	USD 40 million	USD 32 million	USD 305 million
Washington	13	USD 55 million	USD 131 million	USD 100 million	USD 389 million
U.S. Total	359	USD 9 billion	USD 31 billion	USD 2 billion	

Source: Weiss, Daniel J., Jackie Weidman, and Stephanie Pinkalla. States of Denial: States with the Most Federal Disaster Aid Sent Climate-Science Deniers to Congress. Center for American Progress (CAP), September 11, 2013.

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