Understanding Tsunami Debris and Sediment Planning and Mitigation

A Guide for Local Debris Planners

Oregon Department of Emergency Management (OEM)
and the National Tsunami Hazard Mitigation Program (NTHMP)

Contents

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Apologies to anyone missed in this list

Introduction

Every coastline possesses unique beauty and charm, but hidden beneath the tranquil waves lies a natural force that, when awakened, can unleash unimaginable devastation. Understanding Tsunami Debris and Sediment Planning and Mitigation: A Guide for Local Debris Planners provides the knowledge, tools, and insights needed to face the looming threat of tsunamis and to emerge resilient.

This guide delves into the science of tsunamis, the dynamics of tsunami debris, and debris management. Each chapter provides a deeper understanding of the forces at play, the risks involved, and the strategies required to safeguard lives and communities.

The National Tsunami Hazard Mitigation Program (NTHMP) and the Oregon Department of Emergency Management (OEM) recognize that not all communities have equal resources or face the same challenges. Our commitment to social equity runs as a thread throughout, ensuring that everyone, regardless of background, has access to the information and resources needed to prepare for and recover from tsunamis.

Intended Audience for This Document

The NTHMP and its collaborative partners nationwide have jointly developed a comprehensive guidance document titled "Understanding Tsunami Debris and Sediment Planning and Mitigation: A Guide for Local Debris Planners." This document is an invaluable resource for individuals newly appointed to emergency management roles, public officials, and those interested in actively contributing to their community's swift recovery by strategically planning for tsunami debris management.

Document Description

The document provides practical insights, best practices, and a step-by-step framework to aid new emergency managers and public officials in effectively addressing the challenges associated with tsunami debris. It covers essential topics like developing tailored debris management plans, establishing coordination plans with relevant agencies, and leveraging available resources for efficient and sustainable debris removal.

The document incorporates lessons learned from past events, offering real-world examples to illustrate successful strategies and emphasizing the importance of community engagement in the planning process. The guidance document focuses on promoting resilience and underscores the significance of proactive planning to minimize the impact of debris on public safety, infrastructure, and the overall well-being of communities affected by tsunamis.

This resource provides accessible and actionable guidance to equip its target audience with the knowledge and tools to navigate the complexities of tsunami debris planning and contribute to a more expedited and effective recovery process.

The Cascadia Subduction Zone: A Looming Danger

Tsunamis can occur along any coastline in the world. This document addresses tsunami debris planning for any coastal location, regardless of the source of the tsunami threat. The following example is that of a local tsunami source that threatens the entire Pacific Northwest.

The Cascadia Subduction Zone is a fault line where tectonic plates meet. Two distinct tectonic plates—Juan de Fuca and Gorda plates—dive beneath (subduct) the North American plate at an area known as the Cascadia Subduction Zone. Unlike the more well-known San Andreas Fault in California, the Cascadia Subduction Zone isn't characterized by frequent, small quakes. This fault line builds up stress over centuries before releasing it in massive megathrust earthquakes.

These earthquakes are characterized by their extreme magnitude, sometimes reaching 9.0 or higher. The resulting ground shaking can last several minutes, causing widespread damage to buildings, infrastructure, and roads. Older structures that are not built to withstand powerful earthquakes are particularly vulnerable.

The subsequent tsunami compounds the disaster, potentially causing more destruction than the initial earthquake. The sudden uplift of the seafloor during the earthquake displaces a colossal volume of seawater, producing a tsunami. These massive waves, racing across the Pacific Ocean, can reach heights of 30 feet or more upon reaching the coast.

The human toll from a Cascadia Subduction Zone earthquake and tsunami is potentially devastating. Coastal communities may experience the immediate impact of the earthquake and subsequent inundation by tsunami waves, which may reach the shoreline in as little as 20 minutes. Prompt evacuation can be challenging, especially for those with mobility issues, older adults, children, and tourists unfamiliar with the area and its hazards. Emergency response efforts and evacuation may be hampered by damaged infrastructure from the earthquake.

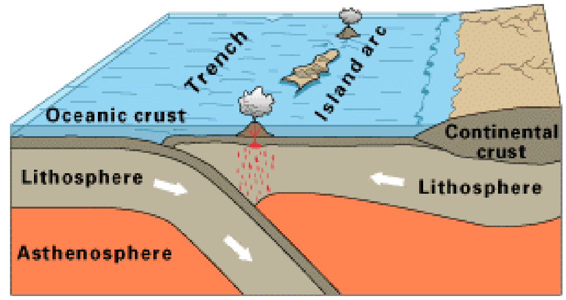

Figure 1. block diagram of a subduction zone when two oceanic plates converge. (public domain, USGS)

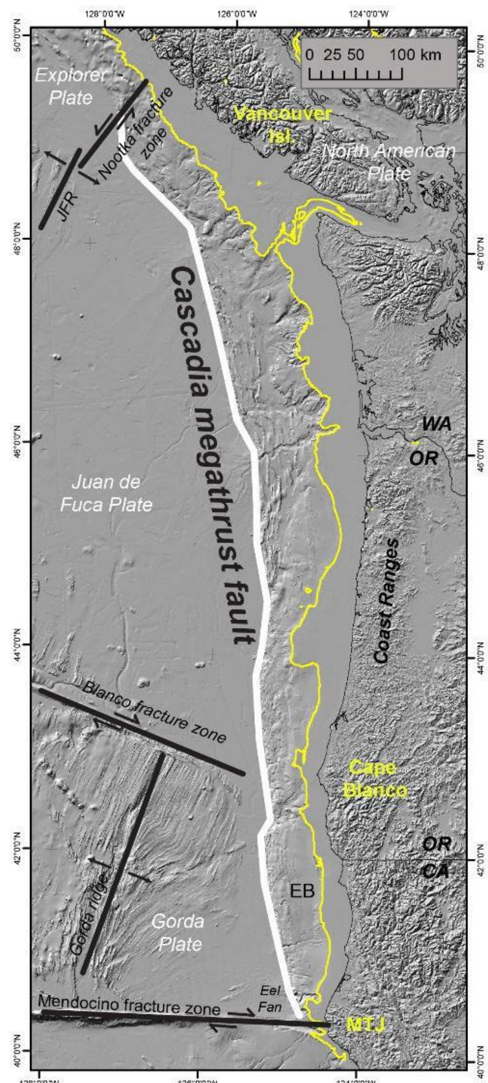

Figure 2. Topo-bathymetric map of the Cascadia Subduction zone. Cascadia megathrust fault (white line): Approximate shelf break along 200m isobath (yellow line). Mendocino Triple Junction. (Public domain, USGS)

The built environment in the Pacific Northwest faces significant risks from such an event. Older buildings and bridges constructed before modern seismic standards may suffer extensive damage or collapse. Tsunami debris, the solid objects swept up in the tsunami's wreckage, will include remnants of these structures, shipping vessels, and other materials carried onto the shore by the force of the wave. The millions of tons of debris swept into roadways, homes, and other structures, paired with the anticipated impacts to infrastructure and lifelines, including water and power systems, roads, and communication networks, will severely delay emergency response and recovery efforts.

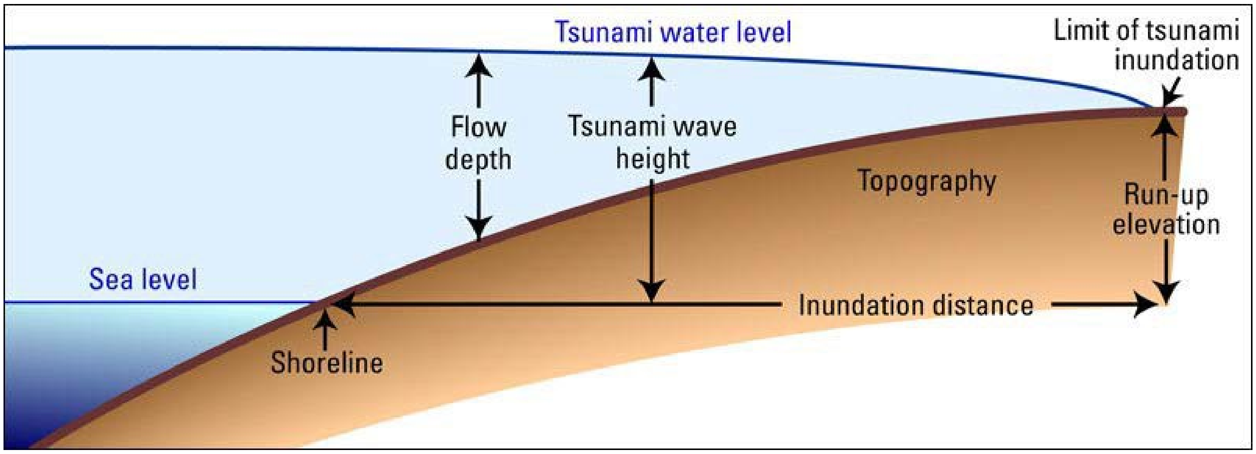

Figure 3. Illustration by Bruce Jaffe and Laura Torresan, USGS

While the threat of the Cascadia Subduction Zones is sobering, communities in the region are taking proactive steps to enhance preparedness and resilience. Earthquake-resistant building codes have been adopted, retrofitting efforts are underway, and early warning systems are in place. Emergency management agencies conduct drills and educate residents about evacuation routes, protective actions, and safety measures.

What is a Tsunami?

A tsunami, often triggered by seismic events such as earthquakes, volcanic eruptions, or underwater landslides, is a series of powerful and fast-moving ocean waves. These waves can travel vast distances across oceans at high speeds. Upon reaching shallow coastal waters, they increase in height and can cause catastrophic damage upon landfall.

This phenomenon, often known as "harbor waves," in English, highlights this significant amplification of wave height as tsunamis approach shallow coastal harbors. The term "tsunami" is derived from the Japanese words "tsu" meaning harbor and "nami" meaning wave, aptly describing its impact on coastal areas. Historically, due to its geographic location, Japan has been particularly vulnerable to tsunamis, leading to the coinage of this term. The etymology underscores the sudden and devastating effect these waves can have on coastal communities.

Timeline of a Tsunami

Earthquake trigger: The process begins with a massive megathrust earthquake with a 7.0 magnitude or higher. This earthquake occurs when the stress built up along a subduction zone is released suddenly, uplifting the seafloor. Coastal areas sometimes subside or drop during these subduction zone earthquakes, increasing the flood potential.

Seafloor displacement: The uplift of the seafloor displaces an enormous volume of seawater vertically. This sudden movement generates powerful waves beneath the ocean's surface.

Tsunami formation: A vertical seafloor movement causes the water above to move abruptly, causing a large wave. These waves are characterized by their long wavelengths and tremendous energy.

Wave propagation: The tsunami waves travel up to 600 mph—like a jetliner—across the open ocean. They may not initially appear large, but their energy is concentrated and travels in a deep-water wave.

Approaching coastal areas: As the tsunami approaches shallower coastal areas, the wave's energy is compressed, causing the waves to slow down to approximately 30 mph and grow in height. This is when the tsunami becomes most destructive.

Inundation: When the tsunami reaches the coastline, it can suddenly rise to significant heights, inundating low-lying coastal areas with a wall of water. The force and volume of water can lead to extensive flooding and destruction of coastal communities.

Multiple waves: A Subduction Zone tsunami is often characterized by multiple waves, with the first wave not necessarily being the largest. Subsequent waves can be equally or more devastating, making evacuation and safety measures critical. Tsunami waves can continue for more than 24 hours.

Long-lasting impact: The impact of a Subduction Zone tsunami can be long-lasting, causing extensive damage to infrastructure, resulting in vast amounts of debris, loss of life, and disrupting communities for an extended period.

Understanding Tsunami Inundation

Tsunami inundation occurs when a tsunami wave moves inland and floods coastal areas. The amount of time it takes for a tsunami to reach a coast depends on the location of the source relative to where it may strike land. Therefore, tsunamis are often referred to as either local or distant.

Local tsunamis result from a source close to a coast and may arrive at nearby coasts in less than one hour, sometimes minutes. Local tsunamis, also called local-source tsunamis and near-field tsunamis, pose the greatest threat because tsunamis are most damaging near their source, and there is little time to issue official warnings and evacuate.

The source of a distant tsunami is far away from the coast, sometimes on the other side of the ocean. This means there is more time to issue and respond to warnings (usually at least three hours).

Figure 4. Tsunami inundating Yamada, Japan, in 2011 (NOAA, 2019).

For example, a tsunami generated off Russia will reach the Pacific Northwest coastline of the U.S. in seven to eight hours, and a tsunami generated off Chile will reach southern California in about 13 hours. However, distant tsunamis can still have significant impacts on coastal communities and ports/harbors. Distant tsunamis are also called distant-source tsunamis, far-field tsunamis, and teletsunamis.

A tsunami arrives at a coast in successive crests and troughs. It may look like a fast-rising floor or a wall of water and will not look or act like a normal wind-driven wave. Tsunamis rarely become great, towering, breaking waves.

Sometimes, a tsunami arrives trough-first, and the ocean suddenly recedes, showing the ocean floor, reefs, and fish like a very low tide. The tsunami arrived trough-first in Phuket, Thailand, on December 26, 2004. Not recognizing the danger, many people ventured out to explore the newly exposed ocean bottom, only to be swept up in the rising crest of the first wave.

Chapter 1: The Importance of Tsunami Debris Planning

The importance of tsunami debris planning cannot be overstated, as it plays a pivotal role in safeguarding communities and ecosystems in the aftermath of a devastating tsunami. An effective debris management plan establishes a swift and coordinated response and recovery effort. When such a plan is in place, it streamlines removing and disposing of tsunami-generated debris, ensuring that vital transportation routes are cleared, with critical infrastructure restored promptly. This facilitates the rapid return of a community to normalcy, providing residents with a semblance of stability and enabling them to rebuild their lives more efficiently.

The Federal Emergency Management Agency (FEMA) defines debris as:

> *"Scattered items and materials either broken, destroyed or misplaced by a disaster."*

On average, debris management makes up 27% of the costs of disasters.[1] Existing waste management systems are overwhelmed by tsunami debris, and a lack of planning can increase the recovery time. Past disasters show that communities with debris plans had better access to FEMA Public Assistance. Having a debris plan gives local communities more control over their response and recovery efforts and makes it easier to seek FEMA reimbursements when accurate records are kept.[2]

Figure 5. Natori, south of Sendai, Jaffe noted that damage indicated a 10-meter flow depth (depth of the water from the tsunami). (Public Domain, USGS)

A well-structured plan minimizes the adverse impacts on humans and the environment, reducing the potential health hazards associated with debris, such as contamination and the spread of disease. Enabling the efficient use of resources and controlling costs ensures that disaster response efforts are sustainable in the long term. A comprehensive debris

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[1] Brown, C., Milke, M., & Seville, E. (2011). Disaster waste management: A review article. Waste management, 31(6), 1085-1098.

[2] Crowley, J. (2017). A measurement of the effectiveness and efficiency of pre-disaster debris management plans. *Waste Management*, 62, 262-273.

management plan aids in compliance with local, state, tribal, territorial, and federal regulations, making it an indispensable tool for disaster preparedness and recovery.

All disasters – whether they involve earthquakes, tsunamis, floods, landslides, wildfires, or other hazards – can result in disaster debris. Increasingly, managing debris generated by disasters is a major expenditure in the immediate aftermath and longer-term recovery effort. For example:

- The California Governor's Office of Emergency Services (CalOES) estimates that up to 45% of disaster costs can go to debris management and related issues.[3]
- In the aftermath of Hurricane Hugo in 1989, the volume of debris reduced the lifetime capacity of the landfills by 17 years in Charleston, S.C.
- The cost of handling the 43 million cubic yards of disaster debris[4] following Hurricane Katrina in 2005 exceeded $4 billion in a post-disaster recovery effort that lasted more than three years.

The Tsunami Debris Issue – How is Tsunami Debris Unique?

The debris generated by tsunamis is often more complicated to handle than other types of debris. According to the United Nations Environmental Program (UNEP, 2012), this is due to several factors, including:

Debris Movement: A tsunami tends to move a substantial amount of debris from its original location, making identifying and recovering the material difficult.

Debris mixing: Tsunami waves mix up materials from everything in their path, causing various kinds of debris – from hazardous to non-hazardous and biodegradable and recyclable to non-recyclable waste – to be combined into piles. This can cause entire mounds of personal items and reusable debris to deteriorate rapidly, making recovery and recycling more difficult.

Saltwater exposure: The debris is washed with salt water, increasing corrosion and degradation in the short term and making downstream processing, such as incineration and biodegradation, more difficult.

Marine debris: Massive quantities of debris will often be carried back to the sea with the return waves. Heavy materials will be deposited in the coastal area, and lighter materials will tend to float out to sea, where they can remain for months or even years. This debris can cause hazards to marine life, affect shipping and fishing industries, and wash up on distant shores.

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[3] https://www.caloes.ca.gov/cal-oes-divisions/recovery/disaster-mitigation-technical-support/technical-assistance/debris-management

[4] Luther, Linda. 2008. *Disaster Debris removal after Hurricane Katrina: Status and Associated Issues.* Congressional Research Service.

Marine sediments: Tsunami waves can carry large volumes of marine and beach sediments inland. Depending on the quality of the sediment and where it has been deposited, this may also need to be handled as disaster debris.

Coastal subsidence: After large local earthquakes that generate tsunamis, permanent ground subsidence of up to several meters could submerge coastal areas, complicating tsunami debris removal efforts.

Figure 6. Scientists running a transect at the Sendai airport. (Public domain. USGS)

Impact of Tsunami Debris on Coastal Communities

Tsunami debris has complex impacts on communities by potentially exacerbating existing vulnerabilities as communities grapple with the aftermath of tsunami events. The most important thing is the impact on human life during and after a tsunami. Debris can hamper the rescue of people trapped or stranded during the tsunami and the recovery of remains immediately after tsunami activity ceases. In addition to the immediate life-safety concerns, other impacts must be understood and addressed.

Public Health Considerations

In the aftermath of a tsunami, public health concerns are multifaceted, involving immediate and long-term issues that require comprehensive planning and response. These include physical injuries from being struck by or submerged in water or from debris carried by the waves. Drowning is a primary cause of death in tsunamis, and the force of the water can result in blunt trauma, lacerations, and fractures.

Beyond the immediate physical injuries, there are significant concerns about waterborne diseases. Tsunamis often compromise local water supplies through contamination with saltwater, sewage, chemicals, or the introduction of pathogens. This situation can lead to outbreaks of diseases such as cholera, typhoid, and hepatitis A, especially in regions with limited access to clean water and sanitation facilities.

Mental health issues are another critical aspect of public health following a tsunami. Survivors may suffer from acute stress disorder, depression, and anxiety. The loss of loved ones, homes, and livelihoods, combined with the traumatic experience of the event, can have profound and lasting psychological impacts. Mental health support, including counseling and community support systems, is essential for helping individuals and communities recover.

In the longer term, public health concerns shift toward rebuilding and rehabilitation. This includes restoring safe drinking water, food supply chains, and healthcare services. There is also a need to manage environmental health risks, such as standing water that can breed mosquitoes and spread vector-borne diseases like malaria, dengue fever, and West Nile Virus.

Tsunami debris management is a significant challenge and an essential aspect of post-disaster recovery. Debris can include a wide range of materials, from natural debris like trees and soil to human-made items like vehicles, building materials, and hazardous substances like asbestos or chemicals. Proper handling, sorting, and disposal of debris is vital to prevent further health risks and environmental contamination and to pave the way for rebuilding efforts.

Effective management of public health concerns in the wake of a tsunami requires a coordinated approach involving multiple stakeholders. This includes local, state, and federal agencies; health care providers; non-governmental organizations; and international aid agencies. Planning should focus on immediate medical needs, mental health support, disease prevention, and environmental health management.

Physical Impact on Infrastructure

Structural damage to buildings, roads, and critical infrastructure creates post-tsunami recovery challenges. Buildings face varying degrees of damage, from partial destruction to complete collapse. The variability of structures' resilience necessitates insights into disaster-resistant building codes.

Roads and bridges, vital for transportation, evacuation, and emergency response, often suffer damage. This disrupts rescue efforts and hinders long-term recovery. Real-world examples illustrate the severity of road damage post-disaster, highlighting challenges in restoring connectivity.

Critical infrastructure, including utilities and communication networks, is vulnerable to tsunamis. This natural disaster can impact power plants, water supply, and telecommunications. Case studies emphasize the cascading effects of such damage, underscoring the importance of resilience in infrastructure planning.

Coastal Erosion and Sedimentation

Coastal erosion and sedimentation following a tsunami present significant challenges. Investigating the impact of sediment transport and erosion caused by strong tsunami currents is crucial in understanding the lasting effects on coastal landscapes and ecosystems. Coastal features like beaches and dunes, vital for various species and storm surge protection, may change due to erosion exacerbated by tsunami debris. Tsunami currents can also scour sediment where strong turbulent currents occur, undermining the foundations of structures on land and within ports and harbors. Hazard materials can become mixed with sediment deposits, complicating sediment removal.

The long-term effects on coastal landscapes have complex ecological ramifications. Altered sedimentation patterns can affect water quality and disrupt marine and terrestrial ecosystems. Shifts in biodiversity and ecosystem dynamics may occur as nesting and feeding grounds for various species are impacted. Communities relying on coastal resources, especially fishing, may face challenges as the distribution of marine species changes.

Investigating the effects of sediment transport and erosion is essential to understanding and addressing the complex challenges that coastal structures, infrastructure, and ecosystems face. This knowledge is pivotal for implementing effective strategies that promote sediment protective measures, coastal restoration, and sustainable management, which fosters resilience in the aftermath of tsunamis.

Economic Consequences

The economic aftermath of a tsunami extends beyond immediate destruction, requiring a focused assessment of the disruption to local economies. This involves understanding the fallout from damage to businesses, fisheries, and tourism and investigating long-lasting financial implications for communities.

Tsunamis cause structural damage, inventory loss, and disruptions to the supply chain for businesses. Assessing economic fallout involves understanding the scale of these disruptions, the impact on employment, and the challenges in resuming operations. This analysis informs tailored support and financial assistance needed for local business recovery.

Coastal communities dependent on fisheries face challenges due to damaged or destroyed maritime and fishing assets. Evaluating the economic consequences includes assessing the extent of damage, estimating recovery time, and implementing measures to revive the fisheries sector, such as financial support and capacity-building initiatives.

The tourism sector faces declines in arrivals and local business revenue after a tsunami. Economic fallout assessment involves understanding the decline in tourism, its impact on local businesses, and the measures needed for sector revival, including marketing strategies, infrastructure reconstruction, and safety measures.

Economic repercussions persist as communities rebuild. Understanding long-term implications involves assessing recovery capacity, identifying persistent challenges, and implementing sustainable economic development strategies. Long-term financial planning and community engagement are crucial for resilient economic foundations.

Economic consequences after a tsunami demand a focused assessment of disruptions to local economies. By understanding the impact on businesses, fisheries, and tourism and addressing long-lasting financial implications, communities can formulate targeted recovery strategies, fostering resilience and rebuilding economic foundations.

Recovery Costs and Resource Allocation

The aftermath of a tsunami, especially related to debris management, places substantial financial burdens on communities and governments. This necessitates a careful examination of recovery costs and resource allocation strategies.

The widespread destruction after a tsunami prompts communities to rebuild homes, restore services, and support residents' livelihoods. Simultaneously, governments face significant costs for emergency response, infrastructure repair, and long-term resilience measures.

Cleanup and reconstruction costs involve debris removal, infrastructure repair, and rebuilding homes, businesses, and critical facilities. Governments must invest in resilient infrastructure to mitigate future risks and prioritize housing and community services.

Efficient resource allocation is crucial in maximizing the impact of available funds. Governments must prioritize key areas based on immediate needs, including emergency response and long-term resilience measures. Engaging the local community in these endeavors ensures that recovery efforts address their needs and priorities.

With the potential limitations of available resources in the recovery process, collaboration with international organizations and neighboring countries becomes crucial. Such collaborations enable important conduits for additional resources and expertise to support recovery. For example, the 2004 Indian Ocean Tsunami and the 2011 Great East Japan Earthquake and Tsunami demonstrated effective resource allocation from multiple sources.

Navigating the financial aspects of post-tsunami recovery involves understanding the burdens on communities and governments, delineating recovery costs, and implementing efficient resource allocation. Through community engagement and international collaboration, affected regions can achieve resilient and sustainable recovery.

Social and Cultural Impact

The social and cultural impacts of tsunamis include displacement, injuries, loss of life, and profound psychological effects on communities.

Tsunamis and related recovery efforts force widespread displacement, which disrupts social structures. Beyond the immediate loss of life, displacement introduces challenges in finding shelter and rebuilding lives. This impacts the affected population's sense of stability and belonging.

Tsunamis result in injuries and tragic loss of life. Understanding the social impact involves assessing the scale of injuries and loss and addressing challenges in providing medical care, support, and bereavement services.

Survivors grapple with trauma and grief. Witnessing destruction, losing loved ones, and experiencing displacement leave lasting mental health scars. Recognizing the psychological impact is vital for implementing effective mental health support services and community resilience programs.

Building community resilience is crucial for mitigating the social impact. Strengthening social support networks, fostering solidarity, and providing emotional support contribute to the overall resilience of communities in the face of disasters. Studies[5] have shown that communities with high levels of social capital tend to recover from disasters more quickly than those with less robust social ties.

Addressing the social and cultural impact of tsunamis requires a holistic approach. Integrating immediate relief and recovery efforts with long-term strategies for mental health support, community resilience, and cultural heritage preservation is essential for a comprehensive and sustainable recovery.

Cultural Heritage Loss

Figure 7. Photo of inundation of Pago by tsunami waves.

The loss of cultural heritage to tsunamis impacts both physical structures and the identity of affected communities. Indigenous communities along the Cascadia Subduction Zones have intergenerational experiences of past megathrust earthquakes, evident in oral histories and the local geology. Tsunamis and debris can destroy or damage historical sites and artifacts, erasing tangible links to the past that form crucial cultural resources. Strategies for preservation and rebuilding cultural identity post-disaster are components of comprehensive recovery efforts.

Cultural preservation efforts should focus on documenting and cataloging surviving artifacts, fostering community engagement, and leveraging technology for digital archiving. Collaborative initiatives involving local communities, historians, and preservation experts contribute to safeguarding cultural identity.

Cultural heritage loss emphasizes the importance of community resilience. Adaptive strategies include integrating heritage preservation into disaster preparedness and mitigation plans, raising awareness, and establishing community-driven initiatives for sustainable heritage site management in partnership with local and tribal governments.

Educating communities about cultural heritage's value and advocating for its preservation are critical. This involves integrating cultural education into school curricula, organizing awareness campaigns, and engaging local leaders to champion the cause.

Addressing cultural heritage loss requires a community-centric approach incorporating education, advocacy, and adaptive measures. By integrating traditional knowledge,

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[5] Kawamoto, Kiyomi and Kim, Karl. (2019). Efficiencies of bonding, bridging, and linking social capital: Cleaning up after disasters in Japan. *International Journal of Risk Reduction*. (33) 64-73.

fostering community resilience, and engaging in international collaboration, affected communities can work toward restoring and preserving their cultural heritage post-disaster.

Environmental Considerations

Tsunami debris poses significant ecological threats to marine and coastal ecosystems. Investigating the environmental consequences of a tsunami and formulating strategies for recovery are essential components of sustainable environmental stewardship efforts.

Debris, comprising various materials, can strongly impact marine and coastal environments. Plastics, metals, hazardous substances, and timber, among other debris, may damage critical habitats like coral reefs and seagrass beds, disrupting the balance of marine ecosystems.

Tsunami debris threatens marine life through entanglement, ingestion, and habitat degradation. Sea turtles, seabirds, and fish can suffer injuries or fatalities due to entanglement, while the ingestion of plastic particles can disrupt the food chain, affecting the health of marine ecosystems.

Cleanup operations should focus on systematic debris removal and habitat rehabilitation efforts such as replanting natural areas and restoring coastal shores. Enhancing the resilience of coastal habitats is essential for effective environmental restoration.

Long-term conservation entails policies to reduce plastic pollution, regulate coastal development, and establish marine protected areas. Public awareness initiatives are crucial in promoting sustainable practices and preserving marine ecosystems. Local communities must be engaged in cleanup, restoration, and sustainable resource management projects. Such involvement aids in physical restoration and fosters a sense of responsibility and stewardship among residents.

Continuous research and monitoring programs help develop an understanding of the ecological effects and evaluate the success of restoration efforts. Scientific studies inform adaptive management strategies, ensuring ongoing improvement based on evolving knowledge and environmental conditions.

A holistic approach to environmental considerations post-tsunami involves investigating ecological impacts, implementing restoration strategies, engaging communities, and fostering international collaboration. These efforts are crucial for safeguarding the health and resilience of marine and coastal ecosystems in the aftermath of a tsunami.

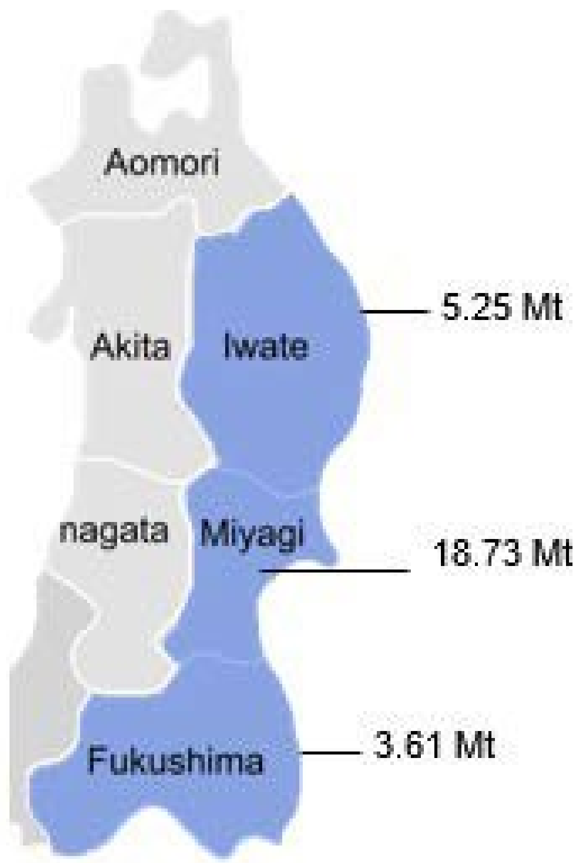
Lessons Learned from the March 11, 2011, Great East Japan Earthquake

Recent disasters, such as the 2004 Indian Ocean and 2011 Great East Japan earthquake-generated tsunamis and the 2022 Tonga volcano-generated tsunami, exhibited the importance of tsunami-resistant infrastructure in high-risk coastal areas. The failure of critical infrastructure in tsunami-stricken communities has led to a recent emphasis on extreme loading conditions associated with tsunami mitigation.

On March 11, 2011, a magnitude 9.0 earthquake struck the Tohoku region of Japan, followed by a devastating tsunami that caused the vast majority of the 20,000 deaths associated with this natural disaster and triggered a nuclear meltdown at the Fukushima Daiichi nuclear power plant. The tsunami resulted in more than 27 billion tons of debris in Japan and billions of dollars in debris removal costs that impacted the Japanese coastline and other countries around the Pacific for years after the event.[6]

The tsunami debris contained construction and building rubble, organic and vegetative debris, vehicles, marine vessels, human remains, and tsunami sediments.[7] Over 350,000 buildings were fully or partially destroyed, costing more than $200 billion in economic damages.[8]

Although the devastation of this event should not be ignored, the 2011 Great East Japan tsunami provides an example of how tsunami debris can impact a large swath of coastal communities in the U.S. By studying historical data like this, researchers can:



- **Model debris movement:** Understand how debris is distributed during and after tsunami events, considering factors like topography and coastal features.
- **Predict high-impact zones:** Identify areas at the highest risk of debris impact during worst-case scenarios, enabling targeted planning and resource allocation.
- **Improve evacuation planning:** Develop more efficient evacuation plans based on historical patterns of debris movement and impact.

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6 Sendai City Environmental Bureau, 2012

7 Norton, Terri R. 2017. Lessons Learned in Disaster Debris Management of the 2011 Great East Japan Earthquake and Tsunami. 47: 67–88. doi:10.1007/978-3-319-58691-5_5.

8 Norton, Terri. 2017. Debris Management and Restoration of the Miyagi Prefecture Following the 2011 Great East Japan Earthquake and Tsunami. Proceedings of the 16th World Conference on Earthquake Engineering. Santiago, Chile.

- **Enhance mitigation strategies:** Implement infrastructure improvements and zoning regulations to mitigate the impact of debris during tsunamis.

Processing Tsunami Debris

Figure 8. volunteer from Tokyo cleans up a home in Higashimatsushima, Miyagi Prefecture, seven weeks after the disaster. (AP/ Kyoto News)

The aftermath of a tsunami such as the 2011 tsunami in Japan presents a monumental challenge in terms of debris management, requiring innovative and efficient solutions to address the scale and complexity of the task. In the wake of such disasters, temporary privately owned incinerators played a crucial role in expediting waste treatment generated by the tsunami.[9] These incinerators provide a quick and effective means of disposal, helping to alleviate the burden of debris on affected communities.

However, managing tsunami debris is not a one-size-fits-all endeavor; different regions face distinct challenges. In mountainous areas, where temporary housing space is already limited, finding suitable locations to store and dispose of debris becomes a critical concern. The topography poses a significant obstacle, with narrow valleys surrounded by towering mountains accumulating more debris than flatter terrain. This exacerbates the scarcity of open space for essential recovery efforts, hindering progress in debris management.

One of the notable challenges encountered in these mountainous regions[10] is the difficulty of separating debris from tsunami sediments. Traditional methods may prove inefficient, prompting the exploration of alternative techniques. In response, Kamaishi City implemented innovative approaches, such as the crane-shake method and using hoses on conveyors.[9] These methods aim to streamline the separation process and enhance the overall efficiency of debris management in challenging terrains.

Another layer of complexity arises from the toxic materials within the tsunami debris. The inclusion of hazardous substances adds an extra layer of difficulty to the effective

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[9] Norton, Terri R. 2017. Lessons Learned in Disaster Debris Management of the 2011 Great East Japan Earthquake and Tsunami. 47: 67–88. doi:10.1007/978-3-319-58691-5_5.

[10] Imai, K.; Hashimoto, T.; Mitobe, Y.; Masuta, T.; Takahashi, N.; Obayashi, R. Development of a Practical Evaluation Method for Tsunami Debris and Its Accumulation. Appl. Sci. 2022, 12, 858. https:// doi.org/10.3390/app12020858

management and disposal of debris. Toxic materials require specialized protocols and technologies to handle them safely, minimizing the environmental and health risks associated with their presence.

The salt water of the tsunami increases the difficulty of safely managing the debris. Processing tsunami-generated waste and debris follows several steps: sorting and separation, removal, temporary storage, and disposal or recycling. Tsunami debris can quickly overcome landfill capabilities, so Japan recycled much of the waste. After the Great East Japan earthquake and tsunami, FEMA and the Japan Society of Material Cycles and Waste recommended recycling to speed up recovery efforts.[11] It took Japan three years to process the tsunami debris before major restoration work could begin.

Recycling Debris

With coastal communities experiencing several feet of permanent coseismic subsidence, recycled concrete and tsunami deposits were used to elevate reconstruction projects. Eighty-five percent of the recycled concrete and almost all the tsunami sediment deposits were used in public works projects, such as raising the elevation of roads and restoration of levees and parks.[12] Sorted and treated recycled concrete and tsunami deposits can be compacted to provide a stable base for construction.

Figure 9. Clean-up pile at Iwakuma Seaside Park, South of Natori. (Source: USGS)

Debris Fire

The salt water of the tsunami is more conductive than fresh water and can short-circuit electrical systems. Sparks from the ignition can start fires in the debris and oil-contaminated water. Fires in tsunamis can spread, fueled by flammable oil, other liquids, and organic tsunami debris[12]

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[11] Norton, Terri R. 2017. Lessons Learned in Disaster Debris Management of the 2011 Great East Japan Earthquake and Tsunami. 47: 67–88. doi:10.1007/978-3-319-58691-5_5.

[12] Imai, K.; Hashimoto, T.; Mitobe, Y.; Masuta, T.; Takahashi, N.; Obayashi, R. Development of a Practical Evaluation Method for Tsunami Debris and Its Accumulation. Appl. Sci. 2022, 12, 858. https:// doi.org/10.3390/app12020858

Months after the Great East Japan tsunami, fires broke out as organic material decomposed.[13] Tsunami debris contains organic and inorganic materials. The Japanese Fire and Disaster Management Agency reported 278 fires after the earthquake and tsunami. Some of these fires were urban conflagrations unrelated to the tsunami. All the large-scale fires were in the tsunami inundation zone.[14]

Some leading causes of post-tsunami fires are floating oil from industrial areas with oil tanks, decaying organic matter, and house or car fires that spread. The entire inundation zone is a fuel bed that could cause fires and conflagrations.[16]

Fire suppression is hampered by earthquake and tsunami damage. Much of the equipment and infrastructure needed to respond to fires were damaged or destroyed. Access to the fire is impeded by debris fields.[16]

Figure 10. A pile of debris burns in the open in Minamisanrikucho, Miyagi Prefecture, 14 April 2011. (Winifred Bird)

Marine Debris

One of the enduring consequences after a tsunami is the generation of marine debris, a silent threat that leaves a lasting imprint on coastal ecosystems.

The West Coast of the U.S. bore witness to the arrival of marine debris in the years following the 2011 tsunami. Notable instances included the appearance of Japanese fishing vessels, buoys, and even small boats washing ashore in California, Oregon, and Washington. These objects, remnants of a distant disaster, highlighted the interconnectedness of oceanic systems and the far-reaching consequences of tsunami disasters.

The influx of marine debris had ecological ramifications, affecting coastal ecosystems and marine life. Invasive species attached to debris could potentially disrupt local habitats and outcompete native species. Moreover, the entanglement of marine life in discarded fishing gear and other debris posed a threat to the health and well-being of aquatic species, creating an additional layer of complexity for coastal conservation efforts.

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[13] Murasawa, N., Koseki, H., Iwata, Y., and Sakamoto, T. (2014), Study on causes of the fires in rubble piles produced after the Great East Japan Earthquake, 2011, *Fire Mater.*, 38, pages 777–788, doi: 10.1002/fam.2220

[14] Takeyoshi Tanaka, 2012, Characteristics and problems of fires following the Great East Japan earthquake in March 2011, *Fire Safety Journal*, Volume 54. 197-202

The economic consequences of marine debris from the 2011 Japanese tsunami were felt along the U.S. West Coast. Coastal communities faced challenges related to cleanup costs, potential damage to local industries such as tourism and fishing, and the strain on local resources to manage the influx of foreign debris. These economic repercussions underscored the need for proactive measures to mitigate the impact of such events on local economies.

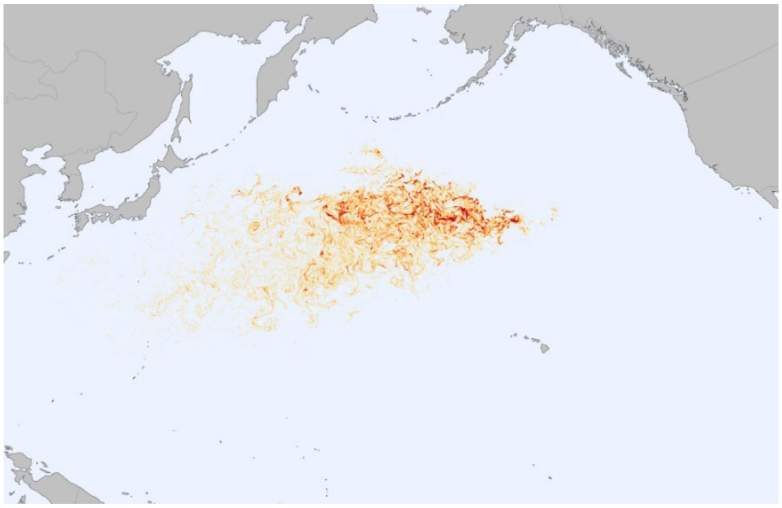

Figure 11. Surface Currents for Diagnostic (SCUD) to simulate where debris would disperse. (Source: NASA)

Community Responses and Lessons Learned

In response to the challenges posed by tsunami-induced marine debris, communities along the U.S. West Coast mobilized cleanup efforts, engaging volunteers, environmental organizations, and governmental agencies. These collaborative initiatives aimed to remove debris from coastal areas and raise awareness about the broader issues of marine pollution and the importance of preparedness.

Lessons learned from the 2011 Japanese tsunami highlighted the need for improved international cooperation in tracking and managing marine debris. Early warning systems, enhanced communication between nations, and standardized protocols for dealing with transboundary debris events became key considerations for coastal resilience.

Figure 12. USGS oceanographer Bruce Jaffe standing next to a boat thrown ashore in Pago Pago, American Samoa, by the tsunami that hit the island on Sept. 29, 2009. (Source: USGS)

The arrival of marine debris from the 2011 Japanese tsunami on the U.S. West Coast is a stark reminder of the interconnectedness of our oceans and the lasting consequences of disasters. As coastal communities grapple with the aftermath, there is a growing recognition of the need for global cooperation to address marine debris and develop strategies to mitigate its impact on ecological systems and local economies. By learning from past experiences, communities can better prepare for the challenges posed by future tsunamis and work toward a more sustainable and resilient coastal future.

Communities separated by an ocean can all be impacted by marine tsunami debris, as is seen in the story of *Kamome*, a boat which originated in Rikuzentakata, Japan, that was washed by the 2011 tsunami and landed on the shore of Crescent City, California. The boat was returned to Japan through fundraising efforts of high school students in both regions, and a bond was developed between students in these two cities. The connection between these two communities was further highlighted because of the high tsunami risk faced by both regions because of the Cascadia subduction zone just offshore of Crescent City. The story was the focus of a documentary aired during the 2021 Summer Olympics in Japan (https://rctwg.humboldt.edu/kamome-goes-olympic-games).

Chapter 2: Equity in Debris Planning

Planning for how to remove the tons of tsunami debris that will hamper recovery efforts in the aftermath of a tsunami is essential. Failing to address equity in debris planning, including how and when the debris is removed, can have dire consequences. Vulnerable communities are more likely to experience:

Protracted recovery: Neglecting equity can result in slower recovery times for vulnerable communities, further exacerbating their precarious situations.

Health risks: Debris can harbor environmental hazards and pose health risks, particularly to vulnerable individuals such as children and older adults.

Displacement: Inadequate debris removal planning can force vulnerable populations to relocate, further destabilizing their lives.

Economic strain: Vulnerable communities may lack the financial resources to manage debris cleanup effectively, leading to long-term economic strain.

Factors to consider:

Inclusive planning: How can we ensure that all members of the community are included in the planning process? How can we make sure that the voices of underserved communities and socially vulnerable populations are heard?

Accessibility: How can we make sure that disaster debris management programs are accessible to all members of the community, regardless of their socioeconomic status, race or ethnicity, disability or housing status, or language they speak?

Environmental justice: How can we ensure that disaster debris management programs do not disproportionately impact low-income communities or communities of color? How can we ensure that these communities have access to the same resources as other communities?

Trust-building: How can we build trust with communities that may distrust government entities due to a history of discriminatory practices and miscommunication?

Safe and proper management: How can we ensure that debris are managed in a safe, proper and timely manner? What environmental issues arise in such situations and how can they be handled?

Recognizing Vulnerable Communities

To ensure equity in debris planning, it is crucial to identify vulnerable communities effectively. This can be achieved through a combination of geographic analysis, social indicators, and community engagement.

Geographic analysis: Start by mapping areas prone to disasters and overlay them with data on poverty levels, population density, and environmental hazards. This will highlight areas where vulnerable communities are more likely to be affected.

Social indicators: Assess social factors such as income levels, access to healthcare, educational opportunities, and the prevalence of disabilities. These indicators can help pinpoint communities in need of additional planning and outreach considerations.

Community engagement: Engage with local communities, non-profit organizations, and advocacy groups to gain insights into the specific challenges and vulnerabilities of different areas. Communities themselves are the best source of information about their area.

Accessible Information and Communication

Accessible information and communication are fundamental to creating an inclusive disaster preparedness and recovery framework. This involves making sure that all individuals, regardless of their abilities, languages spoken, or communication preferences, have access to critical information. In the context of debris planning, accessible information and communication can significantly impact the well-being of all community members, particularly those who are vulnerable.

Ensuring equity in debris planning means recognizing that a one-size-fits-all approach does not suffice. Accessible information and communication must be tailored to meet the specific needs of these diverse populations.

Strategies for Accessible Information and Communication

To address communication challenges and promote equity in debris planning, the following strategies are essential:

Multilingual communication: Provide information in multiple languages commonly spoken within the affected community. This ensures that non-English speakers can access crucial information.

Disability-inclusive formats: Create information in accessible formats, such as Braille, large print, or electronic formats compatible with screen readers, to reach individuals with visual impairments or other disabilities.

Plain language: Use plain, clear, simple language in all communication materials to enhance understanding, especially for those with cognitive impairments or limited literacy.

Sign language interpretation: Ensure that sign language interpreters are available during public briefings or communication sessions for individuals who are Deaf or hard of hearing.

Accessible technology: Leverage technology to spread information widely, including through websites and mobile apps designed to be accessible to all. Use simple links that are easy to remember and type.

Community engagement: Involve community members, especially those from vulnerable populations, in the development of communication strategies to understand their unique needs and preferences.

Equitable Resource Allocation

Allocate resources based on the level of vulnerability. Ensure that areas with a high concentration of vulnerable populations receive the necessary attention and resources for debris removal. Equitable resource allocation in debris planning ensures that vulnerable communities receive the support they need to recover effectively. Here are key strategies to achieve this goal:

Community involvement: Involve vulnerable communities in the decision-making process and actively seek their input to better understand their unique needs and challenges.

Data-driven allocation: Use data-driven approaches to allocate resources, ensuring that areas with a higher concentration of vulnerable populations receive appropriate attention and resources.

Environmental considerations: Choose debris disposal sites with a focus on minimizing environmental impact, particularly in areas near vulnerable communities.

Equitable access: Ensure that all members of the community, regardless of socioeconomic status or abilities, have equal access to debris removal services and other resources.

Public health risk: Choose debris disposal sites with a focus on prioritizing life safety considerations, particularly in areas near vulnerable communities.

Regular monitoring: Continuously monitor the progress of debris planning and adjust strategies as needed to address emerging challenges and vulnerabilities.

Tailored outreach: Customize outreach and communication strategies to be accessible and inclusive to all, including people with disabilities and those who speak languages other than English.

Chapter 3: Understanding Debris and Sediment Behavior

Tsunami debris can include materials such as natural items like trees and rocks, and human-made objects like buildings, cars, plastics and household items. The overwhelming force of a tsunami can turn these materials into dangerous projectiles. Debris can also pose a significant threat to marine life, damage coastal ecosystems, and create navigational hazards for ships. Understanding how debris disperse is essential for post-tsunami recovery efforts.

Figure 13. Photo taken about 100 meters inland at Kalmunai on Sri Lanka's east coast. (source: Public domain)

How Tsunamis Damage the Built Environment

When debris are carried by a tsunami, this can make the water's force stronger against buildings and other structures. This is because all the floating items, like pieces of wood or parts of buildings, add to the water's pushing power. This makes it more difficult for structures to withstand the tsunami's impact. As debris move through the water, they create resistance, hindering the water's flow and increasing the force exerted on structures by water. This heightened drag can have severe consequences for buildings and infrastructure, potentially leading to increased damage when debris collides with these structures.

Tsunami debris can increase damage when they hit buildings and infrastructure and when they cause damming and water accumulation.[15] When debris collide with existing structures during a tsunami event, the damage can be catastrophic. The force of the impact, coupled with the increased hydrodynamic drag, can compromise the structural integrity of buildings, bridges, and other infrastructure. This not only poses a direct threat to human safety but also results in substantial economic losses as communities struggle to recover and rebuild.

Coastal harbors and marinas add to the tsunami debris load with unsecured objects like boats and shipping containers.[19] Tsunami-borne debris can also obstruct water flow when large objects such as shipping containers and boats lead to the formation of temporary dams. As

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[15] Koh, M. J., Park, H., & Kim, A. S. (2024). Tsunami-driven debris hazard assessment at a coastal community: Focusing on shipping container debris hazards at Honolulu Harbor, Hawaii. Coastal Engineering, 187, 104408.

water accumulates behind these barriers, the risk of flooding in coastal regions intensifies, causing further damage to structures and exacerbating the overall impact of the tsunami.

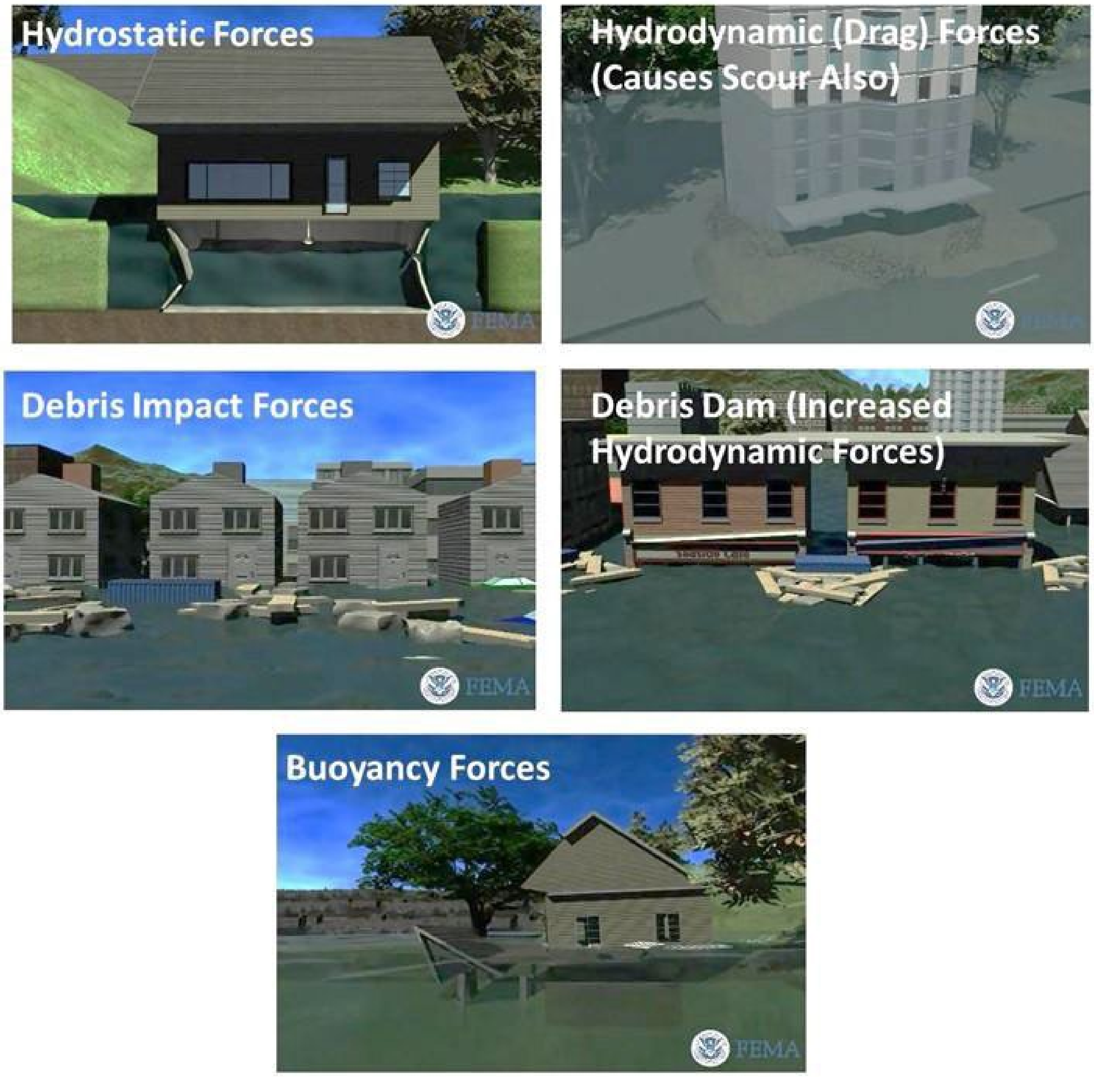

Figure 14. Examples of various tsunami forces and effects including those caused by debris movement and sediment scour (stills from FEMA P-646 video; youtube.com/watch?v=_h26_DUKMzA).

Tsunami sediment transport can also result in scouring of foundations under structures and infrastructure, as well as bringing pollutants to locations inland where sediment is deposited. Scour can destabilize structures and damage and expose infrastructure. Sediment deposition, or sedimentation, could cause hazardous environmental conditions and long-term delays in removal and recovery.

Tsunami Debris and Sediment Analyses

Tsunami debris and sediment distribution models have several applications that can help mitigate the impact of tsunamis on communities. One of the primary applications of debris distribution models is in disaster preparedness. By understanding how debris will spread in the event of a tsunami, communities can develop plans for placing vertical evacuation structures (where needed), plan for short- and long-term debris removal management, and plan and design resilient infrastructure to reduce the potential disaster impact.

Another important application of debris distribution models is in search and rescue operations. When a tsunami strikes, search and rescue teams rely on debris distribution models to determine where survivors might be trapped and prioritize their efforts accordingly. These models help identify areas where people are most likely to be stranded and guide rescue teams and resources to those locations first.

Tsunami debris can have significant environmental impacts, from damaging coral reefs to polluting coastlines with plastic waste. Models help in assessing and mitigating these ecological consequences. Governments and aid organizations use debris distribution models to allocate resources more efficiently during the cleanup and recovery process. These models help determine which areas are most in need of assistance, and which resources are required to address the environmental impact of the disaster. Sharing the results of debris distribution modeling with the public can help raise awareness about the potential consequences of a tsunami. This, in turn, encourages people to take disaster preparedness measures more seriously.

Movement of tsunami debris is complicated and difficult to predict and model. Debris do not move only in one direction. Debris can be carried inland during the initial surge, but then can be carried back out and in again. Some debris will remain in the ocean and cause shipping and environmental hazards far from the coast.

Types of Tsunami Debris

Various natural hazards create a wide range of debris types. Understand the types of materials you will need to plan for after a tsunami so you can have plans and agreements in place to deal with all of it.

Vegetative Debris

The natural debris generated by a tsunami consist primarily of plant material. These debris typically include uprooted trees, branches, shrubs, grasses, and other vegetation that is ripped from the land by the force of the tsunami waves. Coastal forests, mangroves, and inland vegetation near the shoreline are often heavily affected by the surge of water during a tsunami event.

As the tsunami inundates coastal and inland areas, it can uproot entire trees and tear apart vegetation, carrying this material inland or out to sea. Once the water recedes, the vegetative debris can accumulate in large piles, causing blockages in waterways, damaging infrastructure, and posing challenges for debris removal efforts.

In some cases, vegetative debris can also contribute to secondary hazards, such as clogging drainage systems or fueling fires. However, if managed correctly, vegetative tsunami debris can be composted or repurposed for land restoration projects after the disaster.

Construction and Demolition (C&D)

Includes materials from buildings and infrastructure that were in place prior to the tsunami. This can include wood, steel, concrete, bricks, glass, insulation, roofing materials, and more. Homes, offices, bridges, roads, and seawalls can be torn apart by the waves, scattering these materials across a wide area.

Demolition debris refers to the remains of structures that have been completely or partially destroyed by the force of the tsunami. This can include entire sections of buildings, collapsed walls, roof panels, shattered windows, and support beams. In coastal industrial areas, demolition debris might also include heavy machinery, vehicles, and hazardous materials such as chemicals or fuel.

This type of debris poses several challenges. Sharp objects, large debris pieces, and hazardous materials are a serious risk to human health and safety during cleanup operations. Construction and demolition debris can block roads, obstruct emergency services, and damage critical infrastructure like power lines, water systems, and communication networks. Chemicals, asbestos, and other toxic substances from damaged industrial facilities or old construction can contaminate soil and water, posing long-term environmental hazards.

Hazardous Waste

Waste with properties that make it potentially harmful to human health or the environment. Hazardous waste is regulated under the Resource Conservation and Recovery Act (RCRA). In regulatory terms, an RCRA hazardous waste is a waste that appears on one of the four hazardous waste lists or exhibits at least one of the following four characteristics: ignitability, corrosivity, reactivity, or toxicity. The state or Tribal environmental office and the U.S. Environmental Protection Agency (EPA) provide first response in the event of commercial, agricultural, industrial or toxic waste spills.

Hazardous wastes can be spread within and around harbors. When harbor infrastructure and vessels become damaged, fuel and sewage can be released into the water.

There is also a risk posed by household hazardous waste (HHW). Items such as bleach, ammonia, and other toxic cleaning agents can be dispersed by tsunami waves to contaminate soil and water. Paint cans, thinners, varnishes, and solvents may break open and spill, releasing harmful chemicals into the environment. Tsunamis can displace garden chemicals, including herbicides, pesticides, and fertilizers, leading to potential contamination of soil and water. Household batteries and electronics such as televisions, computers, and appliances contain toxic heavy metals like lead, mercury, and cadmium. When damaged, these items can leak harmful substances. Tsunami waves can also pick up motor oil, antifreeze, brake fluid, and gasoline stored in homes or garages, causing environmental pollution and increasing the risk of fires.

When released into the environment, hazardous waste can cause widespread contamination of water supplies, damage ecosystems, and pose health risks to both cleanup crews and the public. Proper identification, containment, and disposal of hazardous materials in tsunami debris are critical components of post-disaster recovery and environmental protection.

Electronic Debris

Refers to damaged or destroyed electronic devices and appliances that are swept away by tsunami waves. This type of debris, often referred to as e-waste, includes a wide range of consumer electronics and household items, all of which can be hazardous if not properly handled.

Large screens, often containing lead and other toxic substances, can be broken and scattered during a tsunami. Computers and laptops contain heavy metals like mercury, cadmium, and lead, which can leach into the environment when exposed to water or when components break apart. While smaller, mobile phones and tablets are also hazardous e-waste. These devices contain lithium-ion batteries that can become explosive or highly flammable when damaged.

Large items such as refrigerators, washing machines, and microwaves are swept away by the force of the tsunami, contributing to the overall debris. These appliances may contain refrigerants or other chemicals that are harmful to the environment. Many electronic devices contain batteries, which can leak corrosive materials and toxic heavy metals when damaged or submerged in water.

Electronic debris poses several significant challenges during tsunami debris cleanup. Heavy metals and chemicals from electronic devices can leach into the soil and water, leading to long-term contamination and harm to ecosystems. Improper handling of e-waste can expose cleanup crews to toxic substances, increasing the risk of respiratory, skin, or other health issues. E-waste requires specialized handling and recycling processes to safely extract valuable materials and dispose of hazardous components. Tsunamis complicate this process by spreading the debris across large areas, often in hard-to-reach locations.

White Goods

Refers to large household appliances typically used for cooking, cleaning, and food storage. These appliances are often made of white enamel or steel, hence the name. In the context of tsunami debris, white goods can become part of the debris field when homes and buildings are destroyed or swept away by the waves.

Heavy, bulky washing machines and dryers are frequently found in tsunami debris. While they do not usually contain hazardous materials, they contribute to the large volume of debris. Like other white goods, dishwashers are large and difficult to move, making cleanup and disposal a challenge after a tsunami. Stoves and ovens are often made of heavy metals and steel, these appliances add significant weight to tsunami debris fields. In addition to containing metal components, air conditioners often hold refrigerants and other chemicals that can harm the environment when released. Refrigerators and freezers also contain refrigerants.

In tsunami debris management, white goods present a unique challenge due to their size, weight, and, in some cases, the hazardous materials they contain. Refrigerants and chemicals in appliances like refrigerators and air conditioners can cause environmental damage, while the bulkiness of these items complicates removal and disposal efforts. Proper disposal, recycling, or repurposing of white goods is essential in the aftermath of a tsunami to minimize environmental impact and facilitate recovery efforts.

Soil, Mud and Sand (Sediment)

Tsunamis can strip away topsoil from coastal and inland areas, especially in agricultural regions, leading to the loss of fertile land. The soil can be deposited inland or washed out to sea, causing land degradation and making recovery efforts more challenging.

As the tsunami waves recede, they leave behind thick layers of mud in low-lying areas, including roads, buildings, and farmland. This mud can create hazardous conditions, obstruct recovery operations, and damage infrastructure.

Fine particles like sand, silt, and clay are suspended in the tsunami's waves and transported over long distances. This sediment can accumulate in unexpected areas, blocking waterways, filling harbors, and creating new landforms such as sandbars. Tsunami sediment deposits are often thick and widespread, causing significant cleanup challenges.

Vehicles and Vessels

Vehicles and marine vessels represent some of the largest and most hazardous items carried by tsunami waves. When a tsunami strikes, it can sweep away cars, trucks, boats, and other watercraft, turning them into dangerous debris that can cause additional damage to infrastructure and pose environmental hazards.

Cars, trucks, and motorcycles are often swept from roads, parking lots, and garages. Vehicles in tsunami debris pose several challenges due to their size, weight, and hazardous materials like fuel, motor oil, antifreeze, and batteries. Vehicles can cause physical damage by colliding with buildings, infrastructure, or other debris, further complicating rescue and recovery efforts. Damaged vehicles often release gasoline, diesel, and other automotive fluids, which can lead to pollution in both terrestrial and marine environments. Oil spills from cars can cause long-term harm to marine life and ecosystems.

Large marine vessels, including fishing boats, sailboats, yachts, and commercial ships, can be washed ashore or dragged inland by tsunami waves. These vessels are often heavy and unwieldy, making their removal challenging.

Like vehicles, boats and ships typically contain fuel, lubricants, and other chemicals that can spill into the ocean or onto land, posing significant environmental hazards. Boats can have sharp or heavy equipment like anchors, propellers, and nets that can be dangerous to recovery teams and wildlife. In addition to boats themselves, docks, piers, and other harbor structures are often destroyed, contributing to the volume of debris and creating obstacles in the water and along shorelines.

Both vehicles and marine vessels contribute to pollution through the release of hazardous materials, which can cause long-term damage to ecosystems and water quality. Large items like cars, trucks, and boats can obstruct roads, waterways, and critical infrastructure, hampering rescue and recovery operations.

The removal of vehicles and vessels requires specialized equipment and coordination. In some cases, boats may need to be refloated or disassembled, while vehicles may need to be towed or hauled away. Cars and boats are a unique types of debris, as their removal and disposal may be the owners' responsibility and must be coordinated by appropriate governing authorities.

Putrescent Debris

Organic material that decays or decomposes quickly, producing foul odors and potentially harmful byproducts. In the context of tsunami debris, putrescent waste typically includes food waste, animal carcasses, vegetation, and other organic matter that is washed away or left stranded by the tsunami. As this waste decomposes, it can lead to a range of problems for public health and the environment.

Perishable food items from homes, restaurants, and stores can quickly spoil, especially in warm and humid environments. When mixed with other tsunami debris, decomposing food can attract pests and contribute to health hazards.

Both livestock and wildlife can be killed by the force of the tsunami, leaving behind carcasses that decompose in the debris field. These remains can harbor pathogens and increase the risk of disease transmission.

Organic matter includes plant debris, such as leaves, branches, and uprooted trees, that begins to decompose when stranded onshore. While less harmful to human health than food or animal remains, decomposing vegetation can still contribute to foul odors and attract insects.

As putrescent waste decomposes, it can produce harmful bacteria and pathogens that pose a risk to human health, especially in the immediate aftermath of a tsunami when access to clean water and sanitation may be limited. Decomposing organic matter can attract pests like rodents, flies, and other insects, which can spread disease and further contaminate the area. In the Pacific Northwest, this can include large predators such as coyotes, bears and cougars.

The decomposition of organic material produces strong, unpleasant odors, which can further complicate recovery efforts and reduce the quality of life for those in affected areas. If not properly managed, putrescent waste can contaminate water sources, including rivers and groundwater, leading to longer-term environmental and public health concerns.

It is crucial to prioritize the removal of putrescent waste during tsunami cleanup operations to minimize the health risks and prevent the spread of disease. Organic waste should be properly disposed of in designated landfills or composting sites to reduce environmental impact. In some cases, incineration may be necessary for animal carcasses or other hazardous organic materials.

Infectious Waste

Waste materials that pose a potential risk of infection to humans and animals due to the presence of pathogens such as bacteria, viruses, parasites, or fungi. In the aftermath of a tsunami, healthcare facilities, homes, and businesses may contribute to the spread of infectious waste, which can exacerbate health risks for cleanup crews, first responders, and the public.

Medical waste includes items from hospitals, clinics, and care facilities, such as used bandages, syringes, needles, surgical gloves, and other medical supplies that may have been exposed to blood, body fluids, or infectious agents. Human and animal remains or body parts may be washed away or exposed during a tsunami. There can also be waste from compromised sanitation systems, including sewage, soiled diapers, and hygiene products. These materials may carry pathogens and require specialized handling. The breakdown of infrastructure during a tsunami can result in the release of untreated waste, increasing the risk of disease outbreaks such as cholera, typhoid, or hepatitis.

Infectious waste contains harmful microorganisms that can spread diseases through direct contact, air, or contaminated water. This risk is heightened in disaster zones where sanitation systems are disrupted. Sharp objects, such as needles and broken medical equipment, can puncture the skin and expose individuals to bloodborne pathogens like HIV or hepatitis. Flooding from the tsunami can spread infectious waste over large areas, contaminating water supplies and soils, which increases the risk of waterborne diseases.

Proper identification of infectious waste is critical. Special care must be taken to separate it from other debris to prevent contamination and reduce health risks. Cleanup crews handling infectious waste must use PPE such as gloves, masks, face shields, and protective suits to minimize the risk of exposure to pathogens. Infectious waste requires specialized disposal methods. It is typically incinerated at high temperatures to destroy pathogens or treated in autoclaves before disposal. In some cases, secure landfills designed for hazardous materials may be used. Areas affected by infectious waste may need to be disinfected with chemical agents to kill pathogens and reduce the spread of disease.

If not properly handled, infectious waste can lead to outbreaks of diseases in the aftermath of a tsunami, especially in environments where water, sanitation, and healthcare systems are compromised. Effective management of infectious waste is essential to protect public health and ensure the safety of cleanup workers.

Chemical, Biological, Radiological, and Nuclear (CBRN) -Contaminated Debris

Chemical, Biological, Radiological, and Nuclear (CBRN)-Contaminated Debris refers to debris from a tsunami or other disaster that has been exposed to hazardous materials in one or more of the CBRN categories. This type of contamination poses serious risks to human health, the environment, and recovery operations, as it involves dangerous substances that require specialized handling, decontamination, and disposal.

Chemically-contaminated debris have been exposed to harmful chemicals such as industrial chemicals, hazardous household substances (e.g., cleaning agents, paints, solvents), pesticides, or toxic waste. Tsunamis can sweep through industrial areas, refineries, and chemical storage facilities, dispersing these substances into the environment

Chemical contamination can lead to respiratory issues, burns, poisoning, and long-term environmental damage such as soil and water pollution. Specialized teams with hazardous material (HAZMAT) expertise are needed to identify and safely handle chemically contaminated debris. The affected areas must be decontaminated before recovery operations can proceed.

Debris contaminated with biological agents includes material that has been exposed to pathogens, medical waste, animal carcasses, or sewage. Tsunamis can destroy hospitals, laboratories, and sewage systems, releasing biological hazards into the environment. Exposure to biological contaminants can lead to infectious diseases, outbreaks of illnesses, and long-term health effects if not properly contained. Biological waste must be separated and incinerated or treated using sterilization methods. Cleanup personnel must use personal protective equipment (PPE) to minimize exposure risks.

Radiological contamination occurs when debris are exposed to radioactive materials, such as those from nuclear power plants, medical facilities, or industrial sites. In a tsunami, flooding can spread radioactive materials over wide areas. Radiological contamination poses severe health risks, including radiation poisoning, cancer, and genetic damage. It can also render large areas uninhabitable for extended periods. Specialized equipment is required to detect radiation levels in debris. Radiological waste must be contained, transported, and stored in designated facilities for radioactive materials. Decontamination protocols must be strictly followed to prevent the spread of radiation.

Nuclear contamination results from the exposure of debris to nuclear materials or fallout from nuclear accidents or explosions. A tsunami hitting a nuclear power plant or facility storing nuclear material can lead to widespread contamination. Exposure to nuclear materials can cause acute radiation sickness, long-term health effects, and environmental devastation. Nuclear contamination can also make areas uninhabitable for years or even decades. Managing nuclear-contaminated debris requires extreme caution, with specialized teams using advanced protective equipment. Contaminated debris must be carefully monitored for radiation levels, safely transported to nuclear waste disposal facilities, and subjected to long-term containment measures.

Two-Level Approach to Tsunami Debris

Tsunamis and tsunami debris can impact coastal communities in or near the water (beaches, marshland, harbors, piers, etc.) as well as inland areas, depending on the size of the tsunami amplitudes, the tidal conditions and other factors influencing flooding. This section addresses some of the specific characteristics unique to these two levels of tsunami and debris movement.

Tsunami Debris Confined to Water

Ports and harbors are the first areas to be impacted by tsunamis and tsunami debris. These are within or near the water that can be impacted by tsunamis greater than 1 foot, but typically less than 3 feet, in wave height. Tsunamis this size and larger can cause strong currents within the water, which can damage docks and piers, and erode sediment within the water and along the beach. For tsunamis in the 1-to-3-foot range, also known as a tsunami "Advisory" level in the U.S., damage, debris and sediment movement will be confined within the existing ocean boundaries and will not typically impact land areas.

Examples of tsunami debris issues occurring at this level include the 2011 Japan tsunami that impacted the coasts of Hawaii, California and Oregon, primarily in harbors and ports. Wilson and others (2012) determined that at least 27 California harbors sustained damage at a cost of over $100 million.[16] The two hardest hit harbors were in Crescent City and Santa Cruz. Oregon's Brookings Harbor and Port Orford also suffered damages. Both California and Oregon had federally declared disasters, and debris and sediment issues caused nearly a year of rebuilding delays. The environmental complications of debris and sediment removal delayed recovery efforts and caused a loss of business and the related income needed to reconstruct.

Figure 15. Post-tsunami debris field in a Japanese community after the 2011 Great East Japan tsunami. (Wilson)

In California, the primary federal and state agencies involved with tsunami debris and sediment removal were the U.S. Coast Guard and the California Office of Spill Prevention and Response. Both agencies helped lead day-to-day debris removal and oil-spill prevention, and worked with communities, FEMA ,and the California Governor's Office of Emergency Services to secure federal and state disaster recovery funding.

When most of the debris movement is contained within the water, tsunami

[16] Wilson et al. 2012. Tsunami Hazard analysis and products for harbors in California. Geological Society of America Abstracts with Programs. Vol. 49, No. 6doi: 10.1130/abs/2017AM-306344

analysis and clean-up techniques will be different than those on land.

Tsunami Debris on Land and in Water

Larger tsunamis, typically greater than 3 feet in wave height, can damage harbors and inundate and damage structures on land. This type of event typically has a higher hazard level, such as a large, local-source tsunami that could inundate and impact coastal communities for some distance inland within the first hour (e.g., Cascadia affecting Washington, Oregon, and Northern California). Planning and response for this level of tsunami will likely include consideration of debris from facilities in the water and on land.

Tsunami Debris and Sediment Distribution Modeling

Harbor and waterfront areas are particularly susceptible to tsunami debris accumulation due to their proximity to the sea, maritime activities, and urban development. The types of debris can range from natural materials, like driftwood and seaweed, to man-made items, such as plastics, abandoned vessels, floating docks, and industrial waste. Identifying these sources and understanding their distribution is vital for maintaining the functionality and ecological health of these regions.

Figure 16. Post-tsunami debris field in a Japanese community after the 2011 Great East Japan tsunami. Note the damaged wood-frame structures pushed to the edge of the inundation area.

Tsunami debris distribution modeling is a critical area of research that aims to understand the movement of debris generated by tsunamis. It involves the use of mathematical and computer models to predict the movement and accumulation of debris following a tsunami event. These models consider a variety of factors, including the initial force of the tsunami, local topography, coastal geography, and ocean currents. The study of debris distribution modeling involves the use of various methods to simulate the input of debris from tsunamis. One such method is the *uniform release method,* which considers a uniform distribution of material released along the coast. Another approach is the *weighted release method,* which combines measured tsunami runup heights with data describing coastal population density.

Debris is defined as solid objects dragged within the inundating flows and can range from construction materials to shipping vessels. The emphasis of tsunami loading has led to recent progression in the understanding of debris loads and effects, particularly in evaluating the impact of a single debris piece on a structure.

Due to the random nature of debris motion and recent consideration to probabilistic tsunami hazards design, a probabilistic design approach is most beneficial to assess the likelihood of debris loads occurring, which would be a function of the proximity of debris sources, debris properties and surrounding environment.

After an event, a scenario-based (deterministic) modeling approach might be useful to help with types and locations of debris distributed. Although the tsunami source might be difficult to accurately define in the hours or days following a tsunami, tsunami source specialists should consult with the numerical tsunami modelers to come up with the input data needed to complete these models. MOUs or contracts with these specialists should be in place to complete this modeling as quickly as possible.

Chapter 4: Tools and Products for Planning

The process of creating numerical models to assess tsunami events typically involves the following steps:

- **Data collection:** To build an accurate model, scientists gather data on the tsunami event, including its strength, direction, and duration. They also collect information about localgeography and topography, and oceanographic data such as currents and tides. Accurate maps of the local building inventory, infrastructure, and location use cases are necessary to model sources and distribution of debris.
- **Numerical simulations:** Using computational methods, researchers simulate howthe tsunami wave propagates and interacts with coastal features. These simulations help predict how debris will be transported and deposited.
- **Field validation:** Model predictions are compared to real-world observations to ensure their accuracy. Data collected from post-tsunami surveys and satellite imagery plays a crucial role in this validation process.

Sediment from offshore areas and beaches can be transported inland during a tsunami, adding to the force of the tsunami to entrain large debris while also increasing scour under building foundations and carrying contaminants.

Effective management, mitigation, and recovery planning begins with an understanding of the sources, locations, and amounts of tsunami debris. This section is intended for state and local planners outlining the process of identifying the sources and movement of debris through historical references. The section addresses the benefits of field and GIS geospatial surveys, the types of numerical modeling and assessment, and the available statistical and visualization planning tools. Planners should work with tsunami experts from state governments, academic institutions, and private engineering firms to help gather tsunami information and ensure the quality of the data being used.

Examples of Tsunami Debris Products

Accurate results from the tsunami debris models and analyses will help form the basis for local debris and sediment preparedness, mitigation, and recovery planning. Each type of planning can benefit from the various types of products available. We provide the following summary of tsunami debris and sediment product types and other useful results; more examples will be available on the NTHMP website.

Historical Information

Planners can use information and examples from historical events to demonstrate thehazards produced by tsunami debris and sediment movement and potential lessons learned from past events. You can find information from historical tsunamis at the following sources:

The National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI): They provide comprehensive datasets on past tsunamis, including debris impacts.

FEMA and United States Geological Survey (USGS): Reports on hurricanes and other coastal flooding events that include debris impacts.

UNESCO's International Oceanographic Commission (IOC): Offers global tsunami databases with detailed event histories.

Research Journals and Case Studies: Published in journals or university libraries.

Photographic Evidence

Pictures of tsunami debris fields and videos of active tsunami movement show the power and composition of large tsunamis.

Figure 17. Video still from the Sendai plain during the 2011 Great East Japan tsunami. Note the muddy, viscous nature of the tsunami and the buildings and debris suspended and moved during the tsunami.

Photos of tsunami sediment scour and maps illustrating sediment movement provide vital visual evidence of the destructive power of tsunamis. These visuals highlight how sediment is displaced, eroding foundations and destabilizing structures, which often leads to further damage. This sediment redistribution can severely impact coastal infrastructure, homes, and natural environments.

Figure 18. Sediment erosion around building foundation during the 2011 Great East Japan tsunami causes tilting of the structure along the Sendai plain in Japan. (Photo by Rick Wilson, CGS)

Data from other large-scale coastal flood events, like hurricanes, helps contextualize the scale and complexity of debris management. For instance, hurricanes produce significant debris fields that require extensive cleanup efforts, similar to post-tsunami scenarios.

Information from these events can inform the expected costs, timelines, and strategies for managing tsunami debris, aiding in better preparation and resource allocation. By comparing the impacts of hurricanes and tsunamis, officials can draw parallels for the labor-intensive nature and long-term costs of debris removal and restoration efforts.

Model Illustrations and Simulations

The results of tsunami debris and sediment modeling can be represented graphically to help visualize where and what type of debris will travel. This can include maps showing the distribution and volumes of expected debris and the types of debris based on where the debris originated.

Animations from tsunami debris models and GIS analysis can help identify areas where significant accumulations occur (aka *hotspots*) and where likely pathways for movement take place (aka *heatmaps*). Heatmaps can also be reversed in direction to focus on what areas will likely contribute debris to a selected inland site of interest. Understanding and analyzing the information from hotspots and heatmaps can help quantify volumes of debris and analyze where targeted mitigation strategies and cleanup efforts should be focused.

Debris Distribution Maps

These maps illustrate the expected flow of debris from the point of impact out to sea or across coastal and inland areas. Debris can be carried by both the incoming and receding tsunami waves, with different materials traveling at different speeds and distances depending on their buoyancy and size.

Tsunami debris distribution maps often categorize the types of debris (e.g., vegetative debris, construction materials, vehicles, marine vessels) and show where each type is likely to accumulate. Lighter materials, such as wood or plastic, may be carried farther, while heavier debris like vehicles or large appliances may remain closer to the shoreline.

Certain areas along coastlines may serve as hotspots where debris are more likely to collect due to factors such as coastal morphology, topography, or ocean currents. Highlighting these areas is important for guiding cleanup efforts.

Debris distribution maps show how far debris are expected to travel inland. The distribution may vary greatly depending on the tsunami's strength and local topography, with some areas experiencing significant debris accumulation far from the coast while other areas may see limited debris deposition. Tsunami debris distribution maps can also show the time it takes for debris to reach certain areas, especially when modeling debris movement across the open ocean. This is important for understanding the long-term impacts of debris on marine environments and for planning recovery operations.

Maps may also extend beyond the coastline to show the spread of debris in the ocean. This is particularly relevant for tracking how debris might impact marine ecosystems or drift toward other coastlines across the globe. For example, the 2011 Japan tsunami debris was tracked as it crossed the Pacific Ocean and reached the west coast of the United States.

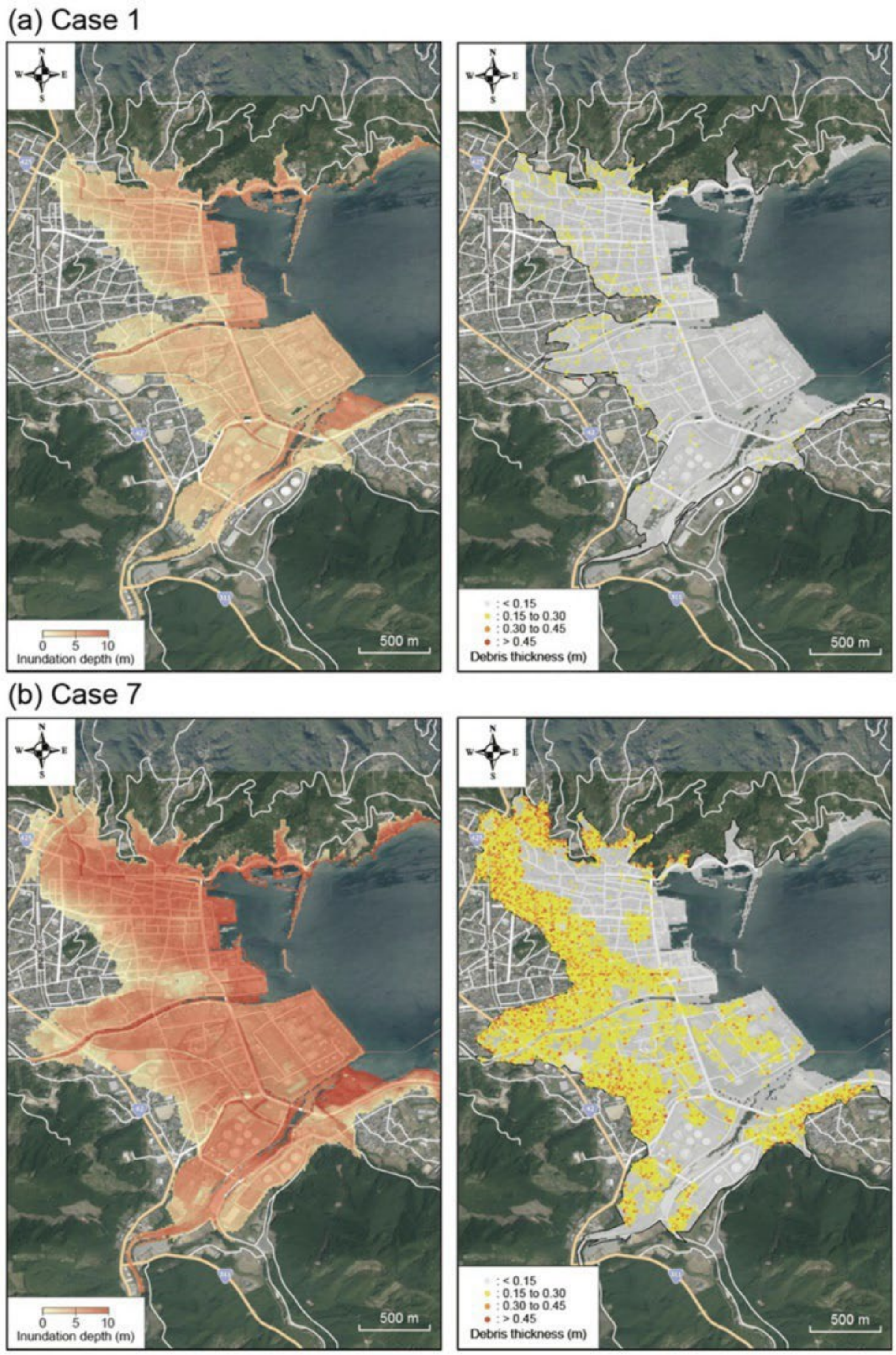

Figure 19. Tsunami inundation areas and distributions of accumulated debris thickness in Owase City according to (a) Case 1 and (b) Case 7 attribution of debris accumulation. The solid lines indicate the route network, the white lines indicate prefectural route with 2 lanes or less, and the ivory lines indicate large national route with two or more lanes. (Imai et al, 2022)

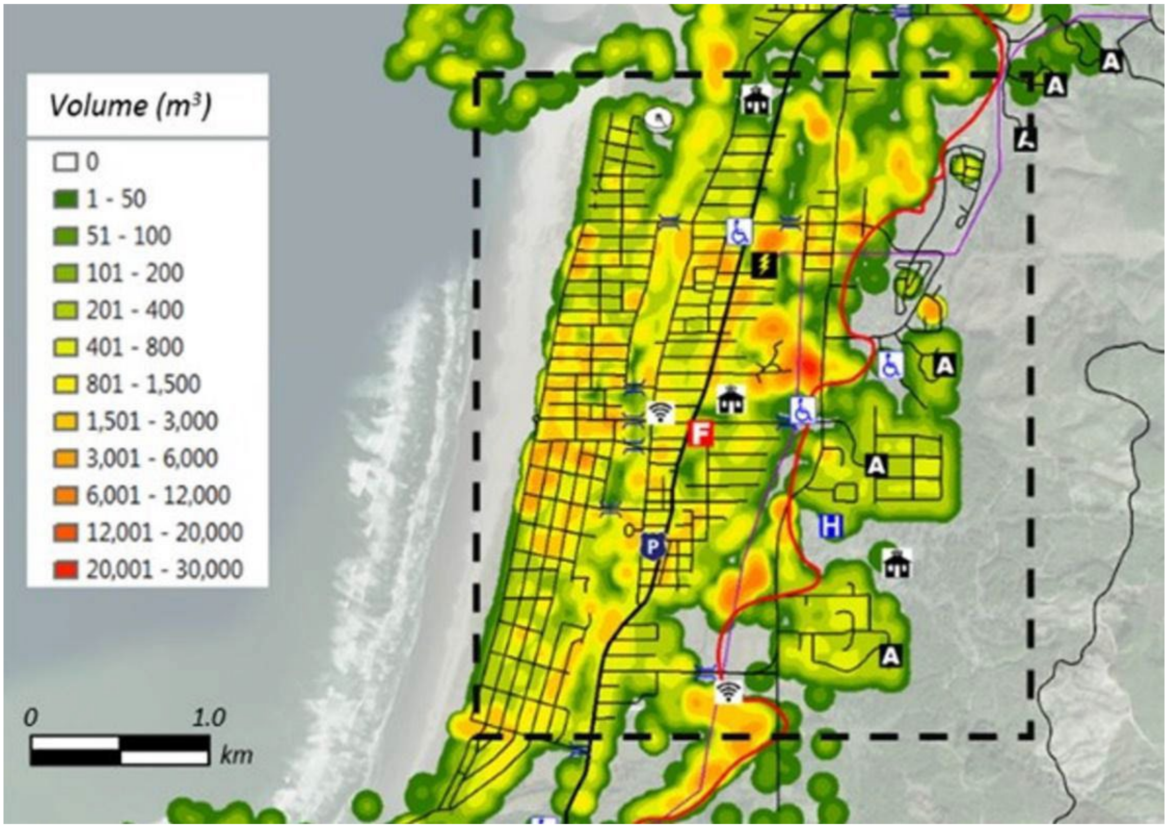

Figure 20. Example of modeled potential volumes of tsunami debris from a probabilistic tsunami hazard analysis model in Seaside, OR. (Cox et al., 2019)

Debris Volume Estimate Maps

These maps display estimates of how much debris will be deposited in different geographic areas, typically measured in cubic meters or tons. The volume of debris can vary significantly depending on factors such as wave height, coastal topography, and the density of development in affected areas.

To make the volume estimates easily understandable, the maps often use color coding or shading to indicate areas with different levels of debris volume. For example, areas with the highest expected debris volume may be shaded red, while areas with lower debris accumulation might be shaded green or yellow.

Volume estimate maps can also indicate the likely sources of debris, whether from natural materials (e.g., vegetation, sediment), residential areas (e.g., buildings, household items), or infrastructure (e.g., roads, bridges, vehicles). This helps responders understand the nature of the debris they will be dealing with.

These maps often differentiate between urban and rural areas, as urban areas with higher population densities typically produce more construction and demolition debris, whereas rural areas may generate more vegetative or natural debris.

Debris volume estimate maps account for both coastal and inland zones, showing how debris volumes change as the tsunami moves further inland. In coastal areas where the force of the waves is strongest, debris volumes tend to be higher, but significant volumes can also accumulate inland depending on the terrain and the strength of the waves.

In addition to showing debris volume by location, these maps may provide cumulative estimates for the entire affected area, giving planners an overall sense of the total amount of debris.

Some debris volume estimate maps are developed using different time frames, such as the immediate aftermath of the tsunami and the longer-term debris deposition. This helps in planning for both short-term emergency response and longer-term cleanup efforts.

Tsunami Flow Path

Animations or simulations can show real-time debris movement during a tsunami. These maps illustrate the direction of tsunami waves as they move inland from the point of impact. Arrows or flow lines are often used to show how the water progresses over time, indicating the pathways the waves follow due to topography and coastal features.

Tsunami flow path maps often include information on the speed of the tsunami waves. Areas where waves travel quickly are highlighted, helping responders anticipate the level of force the water will have when it hits infrastructure. The maps can also indicate how man-made structures such as buildings, roads, and bridges affect the flow of tsunami water. Structures can deflect or block water, creating secondary flow paths or concentrating water in certain areas, leading to increased damage and debris accumulation.

These maps show the inland reach of tsunami waters, marking the maximum point of inundation. This helps planners understand how far the water is likely to travel, providing insight into which areas will be flooded and the extent of potential damage. The maps take into account local topography, including hills, valleys, and other natural features that influence how tsunami waves move. For example, valleys may funnel water and increase flow speed, while hills can create flow barriers that reduce the inland spread of the water.

Since tsunamis often involve multiple waves, tsunami flow path maps can show how the flow changes over time as successive waves hit. These maps may depict the paths of the initial wave and subsequent waves, helping to illustrate how water and debris are redistributed during the event.

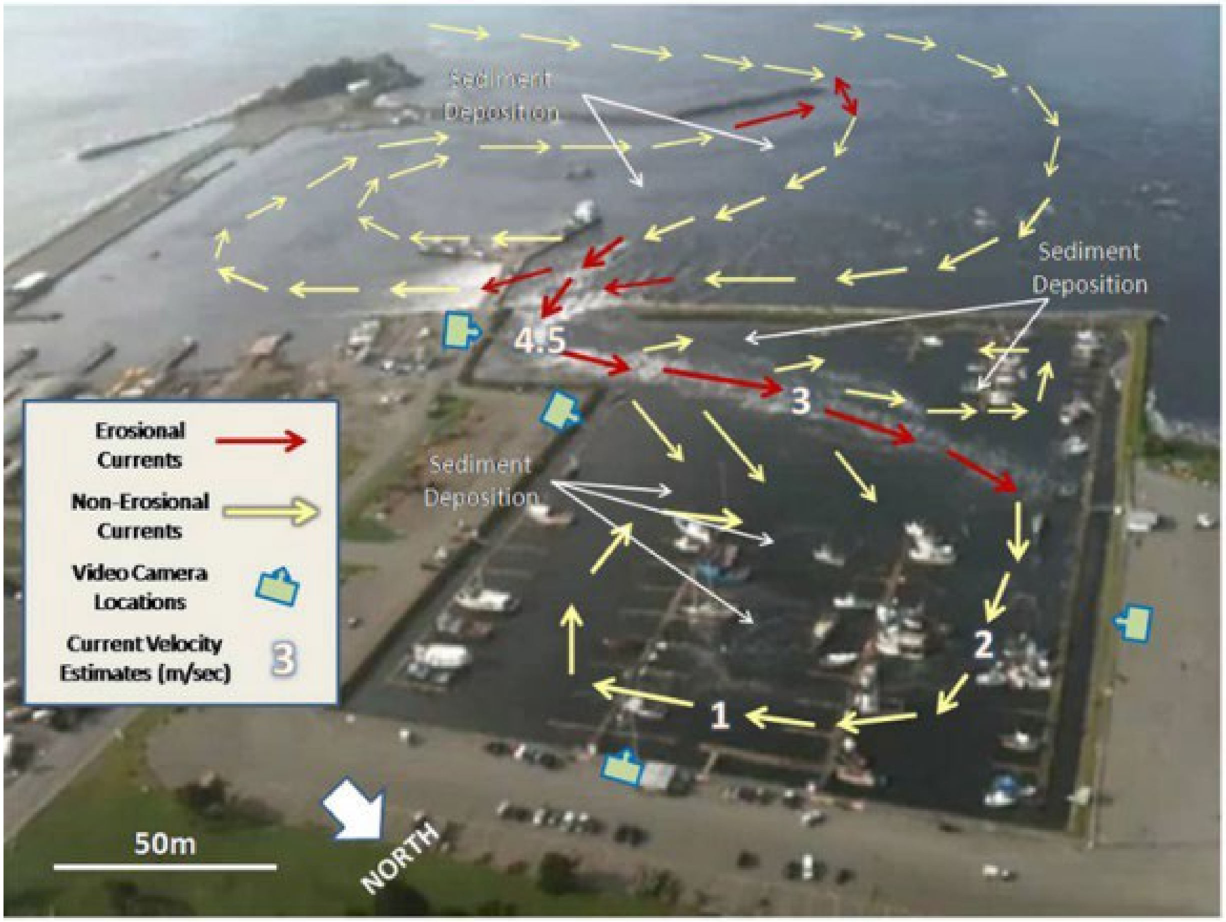

Figure 21. Tsunami flow-regime map for Crescent City Harbor, CA. Current directions and velocities, and areas of sediment erosion and deposition are based on observations of the various (30) ground-level and aerial video, pre- and post-tsunami bathymetry, and sediment analyses. (Wilson et al, 2012)

Sediment Scour Maps

These maps showing areas where sediment erosion has occurred due to debris movement. Sediment scour maps highlight areas of varying depths of sediment removal. Color gradients represent the depth of scour, with darker colors indicating deeper erosion and lighter colors showing shallower scour or areas unaffected by erosion.

The maps show specific regions where sediment has been eroded by tsunami waves. These areas often include beaches, riverbanks, and coastal infrastructure. Sediment removal can also occur inland, especially in low-lying areas where water has flowed with enough force to strip away the topsoil. Areas where scour has occurred around man-made structures, such as roads, bridges, buildings, or seawalls, are highlighted. Scour around foundations can destabilize infrastructure, making these areas a priority for post-tsunami inspections and repairs.

Sediment scour maps reveal how the landscape has changed due to erosion. These maps help assess the modification of the coastal terrain, such as the creation of new channels, depressions, or exposed bedrock where sediment once existed.

These maps can also illustrate patterns of erosion caused by the flow of tsunami water. For example, areas where water converges, such as valleys or river mouths, may experience more intense scour, while areas with natural barriers may see less erosion.

In addition to showing where sediment has been removed, some sediment scour maps also indicate where eroded materials have been deposited. This can be crucial for understanding how sediment transport changes the landscape.

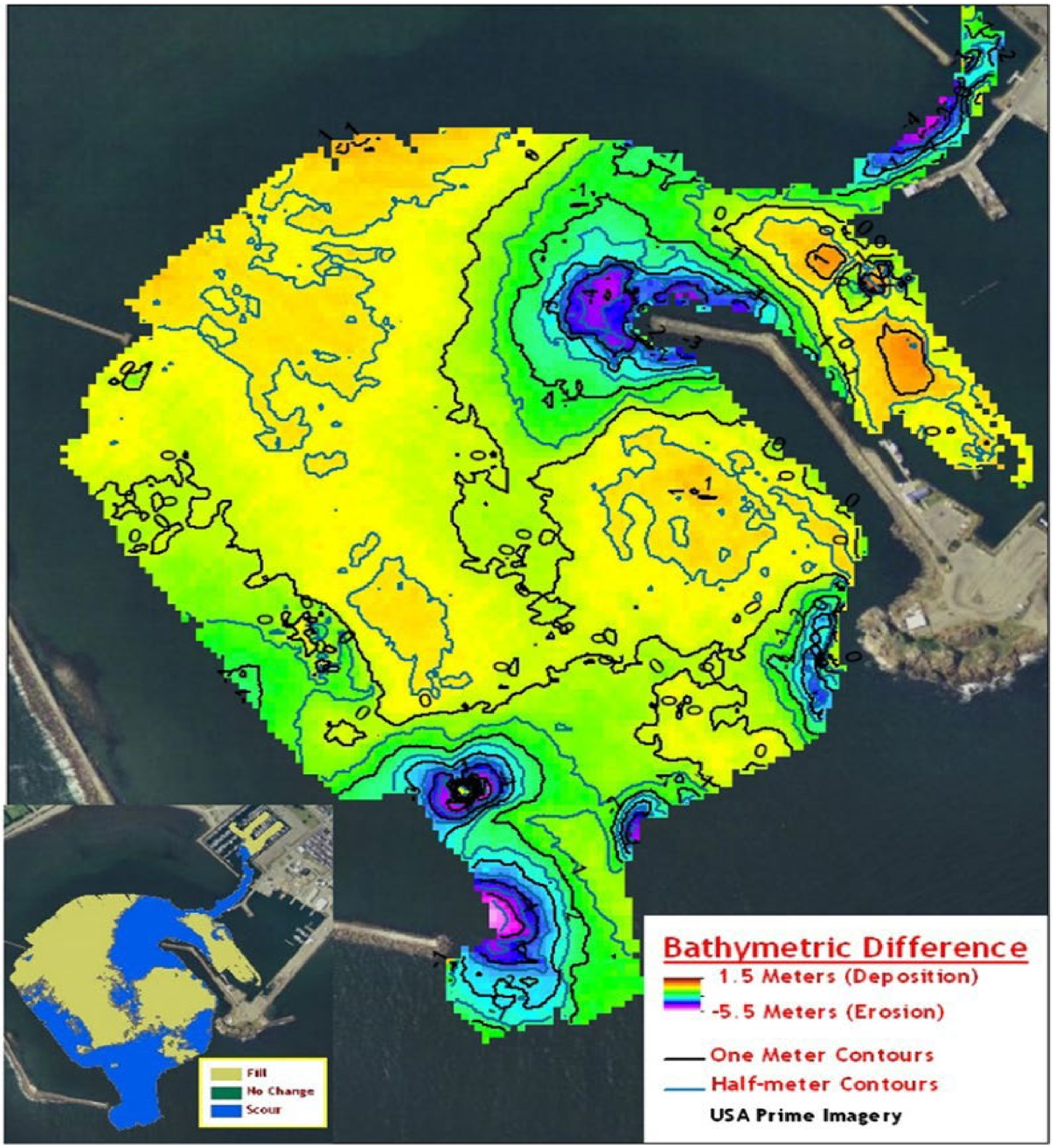

Figure 22. Bathymetric difference (Wilson et al, 2012)

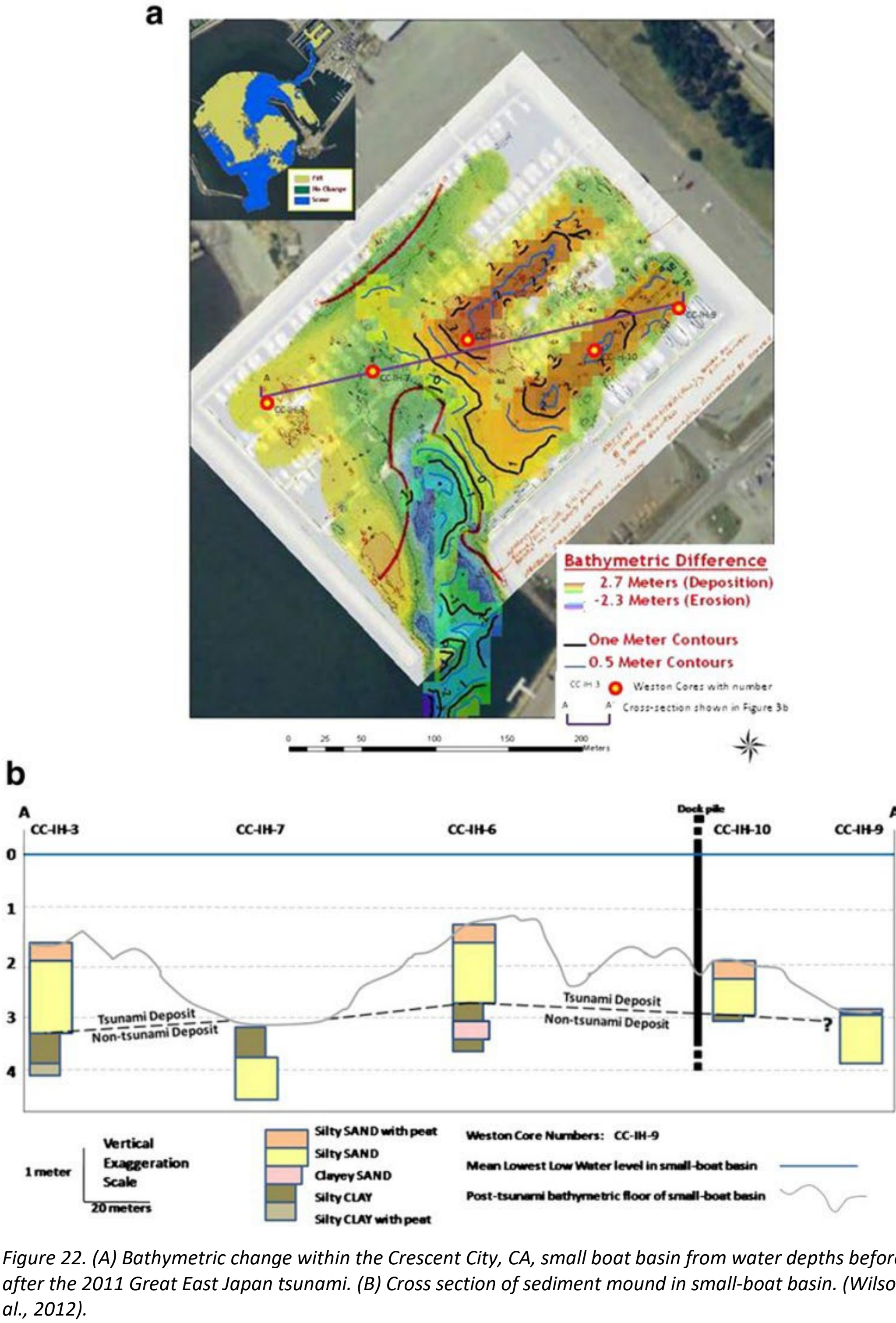

Figure 22. (A) Bathymetric change within the Crescent City, CA, small boat basin from water depths before and after the 2011 Great East Japan tsunami. (B) Cross section of sediment mound in small-boat basin. (Wilson et al., 2012).

Figure 23. The distribution of tsunami debris in Otsuchi area A, estimated by using a DSM and a DEM with 1 m resolution. (a) An example showing the corrected positions of buildings after the removal of trees at the inundation boundary. (b) The corrected tsunami debris thickness distribution estimated from the difference between the DSM and DEM. (Imai et al., 2022)

Debris Resting Point Maps

These maps highlight the specific areas where debris is likely to settle after the tsunami waters recede. The resting points are typically located where the energy of the water dissipates or where physical barriers like buildings, hills, or other landforms cause debris to stop moving.

Debris resting point maps can categorize different types of debris, such as household items, vehicles, vegetation, or construction materials. This classification helps responders know what kind of materials they will encounter in each area, aiding in cleanup and disposal planning.

These maps often indicate areas of high debris accumulation, where large volumes of debris are expected to collect. The maps consider the topography of the land, showing how natural features such as hills, valleys, rivers, and coastal cliffs affect the movement and eventual resting points of debris. For example, debris may accumulate at the base of hills or in low-lying areas where water slows down. Coastlines and valleys may naturally trap debris due to the topography or the layout of the built environment.

Resting point maps often show how man-made structures, such as buildings, seawalls, bridges, or roads, influence where debris will stop. Structures can act as barriers, causing debris to pile up against them, or they can be washed away and contribute to the debris field.

These maps may show the movement of debris over time, providing a dynamic view of how debris is carried by the tsunami and eventually deposited in its final resting locations. Understanding these patterns helps in predicting the spread of debris and planning response efforts.

Quantitative Analyses

Other tools are available to make estimates of the type, size and volume of debris, which can be useful for pre-tsunami planning. Assessments of debris sources, the size of the material that can move, and volumes of the different types of material provide more detailed data for the models, which will improve the quantitative results. Methods for quantifying the debris can vary from data output from the tsunami models to established risk-assessment models like FEMA's HazUS models.

Planners should also understand the uncertainties in the models they use in order to not overestimate the value of the data collected and to have contingency plans in place if needed.

Planning Needs

The movement and accumulation of tsunami debris and sediment can be difficult to model with precision, as tsunami currents and debris interactions are complex and difficult to predict. However, tsunami models can estimate of movement and accumulation for various planning purposes. Models can also help planning officials and the public visualize where debris will start, move, and amass.

Education and Preparedness Planning

Educating local officials and the public about the impacts and costs of tsunami debris and sediment movement will help gain support to address these impacts. Tools and products that could be used include videos and pictures from past events, as well as simplified animations and simulations of scenarios showing debris movement and accumulation. Easy-to-understand graphics showing the amounts and costs of debris and sediment cleanup will help demonstrate the future impacts to communities. Maintain pre-vetted debris removal contractor selection lists as well as pre-positioned debris removal contracts per FEMA guidance.

Mitigation Planning

Improving the understanding of the tsunami debris problem will help identify where mitigation measures like avoidance, land-use planning, and living-shoreline or other engineered structures can be used. Animations showing debris and sediment movement pathways and areas of accumulation can estimate the types and locations of needed preventative strategies and mitigation measures.

Reviewing lessons learned from past events, such as limiting the exposure of near-shore hazardous materials and debris sources or ensuring that they have protections that are designed for the maximum considered tsunami can reduce the amount of damage from tsunami debris fields. For example, Fukushima Daiichi was the only nuclear power plant out of several that were exposed by the 2011 tsunami that experienced a meltdown because its tsunami protections assumed a smaller magnitude earthquake than the other plants.

Recovery Planning

Cleaning up after a tsunami can take a long time: weeks to months. The duration of cleanup efforts depends on how much debris there is, what kinds, and how well the area was prepared before the tsunami. Good preparation includes guessing what debris might show up, where they will be, and how much there will be. Knowing this helps local officials plan for things like money and contracts to speed up recovery. It's also useful to have plans for tracking different types of debris from where they land to where they're finally thrown away. Detailed information about debris is needed to get federal help through FEMA, especially if the damage is extensive enough to require a Presidential Disaster Declaration.

Choosing Appropriate Hazard Level(s) for Analysis and Planning

Worst-Case Scenario (Deterministic) Approach

Data collection and research are essential for refining debris distribution models. A comprehensive database of past tsunami events and their aftermath is invaluable for creating more accurate models.

The worst-case scenario approach to hazard analysis and planning is rooted in the idea of identifying and preparing for the most severe event within a particular hazard category. In the context of tsunamis, this approach involves considering the most devastating tsunami that could occur, given the geological and historical data available.

The deterministic approach has strengths and weaknesses.

Pros of the Worst-Case Scenario Approach

- Clarity and Certainty: The worst-case scenario approach provides a clear and certain picture of the potential consequences of an extreme event, enabling planners to prepare for the absolute worst.
- Risk Minimization: By focusing on the worst-case scenario, communities can minimize risk, potentially reducing loss of life and property damage.
- Resource Allocation: This approach helps allocate resources to areas most vulnerable to the worst-case scenario, optimizing response and recovery efforts.

Cons of the Worst-Case Scenario Approach

- Limited Realism: Worst-case scenarios may be exceedingly rare, and focusing on them alone may neglect more likely, though less severe, events.
- Resource Intensiveness: Preparing for worst-case scenarios can be resource-intensive, and it may divert resources from addressing more common hazards.
- Potential Overpreparation: Overemphasis on worst-case scenarios could lead to unnecessary preparedness efforts and costs.

Risk-Based (Probabilistic) Approach

Due to the random nature of debris motion and recent attention to probabilistic tsunami hazard models, a probabilistic approach is needed to assess the likelihood of debris loads occurring, which includes considering the proximity of debris sources, debris properties, and the surrounding environment.

The risk-based approach shifts the focus from preparing for a single worst-case scenario to assessing the likelihood of various scenarios. In the context of debris planning for tsunamis, it involves considering a range of factors that influence the likelihood and severity of debris loads:

- Debris Sources: Identifying potential sources of debris, such as coastal structures, buildings, and vegetation, and assessing their vulnerability to tsunami impacts.
- Debris Properties: Evaluating the physical characteristics of debris, including size, weight, buoyancy, and how it may fragment during tsunami inundation.
- Surrounding Environment: Considering the topography, coastal features, and infrastructure in the affected area, which influence how debris travels and accumulates.
- Historical Data: Incorporating historical data on tsunami events and their associated debris motion patterns to inform the probabilistic model.

Data collection and research are pivotal in refining debris distribution models for tsunamis and other hazards. Comprehensive databases of past tsunami events and their aftermath serve as invaluable resources for creating more accurate models. These databases should include information on the size, scale, and impact of past tsunamis, as well as their geographic and geological characteristics.

Benefits of the Risk-Based Approach

- Realism: It provides a more realistic representation of the range of hazards, reflecting their inherent variability.
- Informed Decision-Making: Decision-makers can allocate resources more efficiently by focusing on areas with higher probabilities of debris impact.
- Improved Mitigation Strategies: The approach helps identify areas where mitigation efforts, such as vegetation management and building reinforcement, will be most effective.
- Enhanced Resilience: By understanding the full spectrum of risks, communities can build resilience that goes beyond preparing for a single worst-case scenario.
- Cost-Efficiency: Targeted mitigation and preparedness efforts can be more cost-effective, as they align with the probabilities of debris impact.

Steps to analyze and model tsunami debris

The level of analysis of tsunami debris and sediment movement will depend on the planning needs of local and state officials. Choosing the tsunami experts and modelers to work with is an important first step in this process.

Generally, the following five steps should be taken to better understand the tsunami analysis process, the types of products available, and the delivery of those products:

1) Select tsunami modelers and other expert(s) and ensure the numerical models being used have been “verified” (benchmarked) with the National Tsunami Hazard Mitigation Program (NTHMP) test cases.

2) Discuss the following with your tsunami expert(s):

- Historical examples
- Tsunami source(s) to use
- The resolution and other conditions of the terrain data required
- Product needs to ensure the planning needs are met

3) Work with the tsunami expert(s) to develop and evaluate the modeling inputs, including the tsunami source characteristics, the required resolution and other conditions of the digital elevation model (DEM), and the digital representation of the potential debris sources.
4) Perform tsunami debris and sediment modeling and associated debris and sediment analyses.
5) Evaluate both visual and numerical results to ensure they meet the planning needs.

Step 1	Step 2	Step 3	Step 4	Step 5
Selecting a tsunami modeling expert	Planning with the tsunami modeling expert	Developing and evaluating tsunami model inputs	Performing tsunami debris and sediment modeling and assessments	Evaluating tsunami debris model results and products

Step 1: Selecting a Tsunami Modeling Expert

State and local officials interested in obtaining information about potential tsunami debris and their movement can collaborate with tsunami experts at state geological surveys, public and private universities, or private consultants to run numerical models and create the products needed.

State geological surveys and universities who are partners within the NTHMP have numerical modelers that they work with and can help supplement resources through numerous federal and state grants. Private consultants also have the expertise to perform this work using benchmarked models and guidance like this about how to collect the initial input data and create the final products. Modelers should check with your NTHMP state representatives to determine which numerical models are appropriate for use modeling tsunami debris and sediment movement.

The NTHMP Mapping and Modeling Subcommittee has developed a website with tsunami model benchmark information and related tsunami modeling and mapping guidance.

1. Identify Potential Sources for Tsunami Modeling Experts:

- **State Geological Surveys:**
  - Leverage partnerships with state geological surveys that participate in the NTHMP.
  - Contact state or territory NTHMP representatives to identify available modelers. You can find a list of state and territory partners at the NTHMP website.

  - Inquire about federal and state grants for modeling projects.
- **Public and Private Universities:**
  - Seek out universities with established tsunami research programs.
  - Ensure modelers have experience with benchmarked models and have access to federal grants for conducting research.
- **Private Consultants:**
  - Consider consultants with expertise in tsunami modeling using approved models.
  - Ensure private consultants follow industry standards, including the NTHMP's guidelines for tsunami debris and sediment modeling.

2. Criteria for Selecting a Tsunami Modeling Expert:

- **Relevant Experience and Expertise:**
  - Verify experience with **tsunami debris and sediment movement** modeling.
  - Ensure knowledge of **NTHMP benchmarked models** and other relevant numerical models.
  - Review case studies or past projects where experts have successfully conducted similar modeling tasks.
- **Affiliations and Collaborations:**
  - Check affiliations with **NTHMP Mapping and Modeling Subcommittee** or partnerships with state geological surveys.
  - Verify past collaborations with state or local governments for tsunami-related modeling projects.
- **Access to Data and Resources:**
  - Ensure access to appropriate databases, tools, and software necessary for high-quality modeling.
  - Confirm ability to utilize federal and state grants to fund large-scale modeling projects, especially in collaboration with academic institutions or government agencies.
- **Knowledge of Regional Considerations:**
  - Select experts familiar with the **local coastal geology and tsunami risks specific to the region.**
  - Assess expertise in incorporating **region-specific data** into models for debris movement and sedimentation analysis.

3. Decision-Making Rubric for Selecting a Tsunami Modeling Expert:

- **Experience with Tsunami Debris Modeling (30%)**

  - Proven track record with tsunami modeling, including tsunami debris and sediment analysis.
  - Experience working on similar projects for state/local governments or private sector.
- **Affiliation with NTHMP Partners or Benchmarked Models (25%)**
  - Is the expert affiliated with state geological surveys, NTHMP partners, or has experience using benchmarked models approved by the NTHMP?
  - Demonstrated collaboration with the NTHMP Mapping and Modeling Subcommittee.
- **Technical Expertise and Tools (20%)**
  - Access to advanced tsunami modeling tools and databases.
  - Knowledge and utilization of the American Society of Civil Engineers (ASCE) 7-22 standards for tsunami resilience in related modeling efforts.
- **Grant and Funding Utilization (15%)**
  - Experience in leveraging federal or state grants to supplement project funding.
  - Proven success in acquiring and managing external resources for modeling work.
- **Communication and Collaboration (10%)**
  - Ability to clearly communicate model results to non-experts, such as state or local officials.
  - Strong collaborative skills to work with multiple stakeholders, including community leaders, environmental experts, and local government agencies.

4. Recommendations for Collaboration and Consultation:

- **Check with NTHMP Representatives:**
  - Consult with state NTHMP representatives to confirm which numerical models are appropriate for debris and sediment movement in the specific region.
- **Use NTHMP Resources:**
  - Review the NTHMP Mapping and Modeling Subcommittee’s online resources, including tsunami model benchmark information and model/mapping guidance.
- **Consider Long-Term Partnerships:**
  - Establish ongoing collaborations with state geological surveys, universities, or private consultants for future tsunami risk assessments, debris movement predictions, and disaster preparedness.

Step 2: Planning with the Tsunami Modeling Expert

The tsunami debris landscape consists of areas of debris generation, pathways for debris movement, and areas of debris accumulation. Consideration should also be given to the tsunami sources being used and the amount, size, and types of debris that can move. Historical events should be evaluated for causing tsunami debris and sediment movement to help understand what can happen in the future and what lessons may be learned from those events. As expected, tsunamis that have larger flow depths and stronger currents will move larger amounts of debris. Urban settings not only have more debris potential, but they also are more complicated to understand and model. For example, smaller buildings which are wood frame or lightweight are prone to being pushed off their foundations and becoming part of the debris field.

The purpose of the planned use of the tsunami debris and sediment products should be well articulated to the scientists, engineers, and modelers working on the project. These experts can help officials research historical events, determine the appropriate tsunami sources to use, select the best resolution to accomplish planning goals, and ascertain the best outputs and products for the project in question.

Historical Events

Prior to the tsunamis of 2004 in Indonesia and 2011 in Japan, little was known about tsunami debris and sediment movement. Photos and videos of tsunami debris, as well as lessons learned from these events, demonstrated the power of large tsunamis and the potential for significant tsunami debris and sediment movement. For example, in Japan, aerial videos taken during the tsunami captured strong tsunami waves destroying wood-frame homes and causing large debris fields of moving vessels, vehicles, and damaged structures. In Crescent City Harbor in California during the same tsunami, comparison of pre- and post-event bathymetric surveys showed significant scour and sediment buildup caused by the tsunami.

In both Japan and California, lessons were learned about improving tsunami debris and sediment mitigation and recovery efforts, which would have significantly reduced impacts and delays. This information can be valuable examples of what improvements in planning efforts should be considered. Visit the Global Historical Tsunami Database website for more information about notable historical tsunamis and damage estimates.

Tsunami Sources

Local officials should request a source(s) based on their planning needs. The worst-case scenario(s) are beneficial for the community preparedness, response, and recovery planning. Probabilistic tsunami hazard analysis (PTHA) sources provide an event return period and hazard level consistent with other locations and can be used for comparative risk analyses and mitigation planning for other hazards (e.g., seismic, coastal storm flooding, sea-level rise). Particular local- or distant-source scenarios can be helpful for tsunami response exercises and planning. Discuss the potential tsunami sources with the tsunami expert to determine if certain sources, such as PTHA, are available for your region and most applicable for local planning.

Digital Elevation Models (DEMs)

New and high-resolution terrain data input for tsunami model provides the planners with the most accurate results. The planning project leads should discuss the benefits of using high-resolution data, evaluate what terrain data is available, and determine if the built environment should be included in the tsunami debris and sediment movement models. The most common terrain data, or digital elevation model (DEM), available for tsunami modeling is through the National Center for Environmental Information DEM website. These DEM data are typically "bare earth" (which eliminates buildings) and have an average resolution of 10 meters so they can capture most subtle changes in the landscape. Higher resolution light detection and radar (LiDAR) DEMs are available for most coastlines. If a local planner would like more precise tsunami flow patterns and the model is capable of including it, higher resolution LiDAR DEMs that show large buildings, and other structures can be integrated into the "bare earth" DEMs.

Potential Products

Tsunami deposit and sediment transport products could include calculation of the amounts of debris, the locations where debris initiated and where they were deposited, and pathways showing where debris traveled during the tsunami. Examples of these products are provided throughout this section.

Figure 24. Compacted tsunami debris and sediment is used as a base to elevate roads in an area of Japan which experienced co-seismic subsidence. (Source: Rick Wilson)

Identifying the types, volumes, and locations of tsunami debris and sediment will greatly enhance planning for future removal efforts and overall recovery. Detailed evaluation of tsunami debris sources helps identify the types and volumes of material that could be transported. The more potential tsunami debris sources can be subdivided prior to modeling, the easier the debris field can be partitioned for reclamation and/or clean-up (removal). For example, reclaimed tsunami sediment and debris can be utilized as road base in areas where co-seismic subsidence has occurred. Static maps of the modeled post-event debris field will help identify the resting point for the debris. Knowing the source and amount of debris can also help calculate the generalized volume and weight of debris material which will help aid clean-up efforts.

In addition to the use of static model results and maps, development of model simulations and animations can enhance the understanding of tsunami debris and sediment movement. These types of products are useful for general outreach to the public as well as response, mitigation, and recovery planning. For example, a tsunami debris movement animation generated for the Port of Los Angeles shows where debris in the main port channels will likely accumulate and block passage of large vessels into and out of the Port. This can help the Port and the U.S. Coast Guard plan and mitigate for this scenario.

Step 3: Developing and Evaluating Tsunami Model Inputs

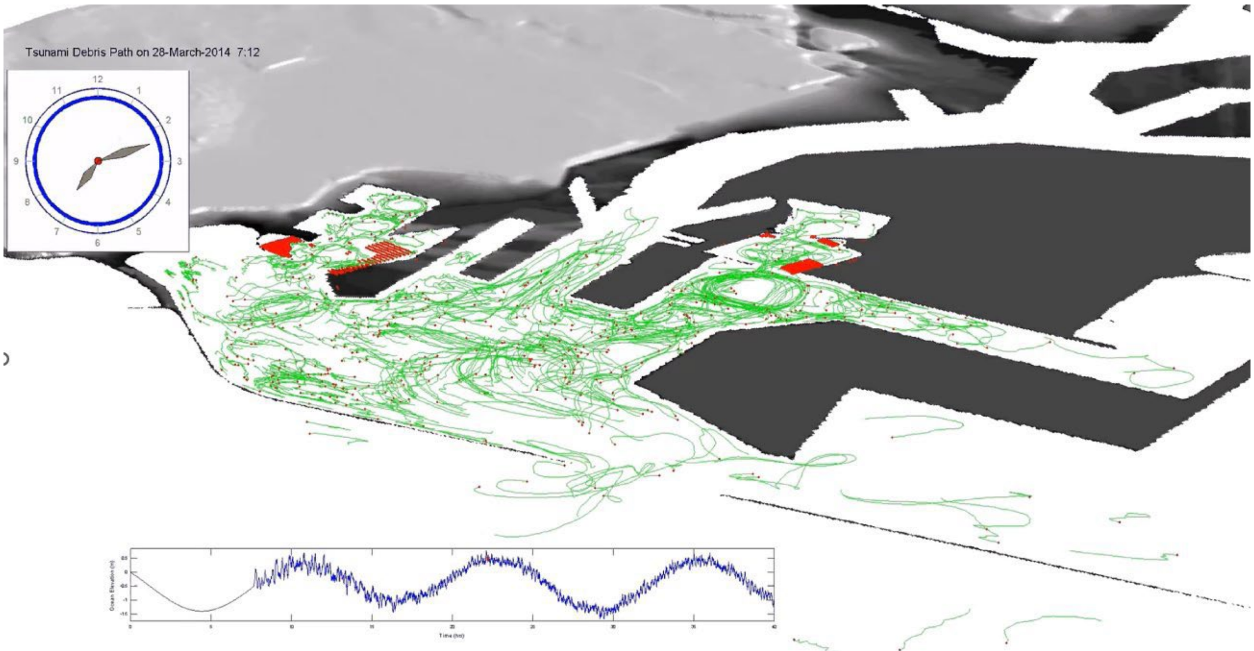

Figure 25. Still image from a simulation showing tsunami debris originating from small boat basins within the Port of Los Angeles, CA, moving into a possibly blocking the larger shipping channels. (Source: Lynette, USC, 2014)

After discussions with local planners, tsunami modelers and experts should generate inputs for the tsunami debris model. These data inputs include digitally integrating the locations and types of tsunami debris sources being modeled and the underlying DEM (terrain layer) being used. All data should be initially created using available information resources and then checked in the field. Planning officials and tsunami experts should validate all input data prior to running the numerical models (Step 4).

Characterizing Tsunami Sources

As discussed in Step 2, the tsunami sources used should be appropriate for the planning needs of local officials. Tsunami modelers and other experts will create the tsunami sources by characterizing the location and size of the scenario(s). These characterizations are the "initial conditions" which are input into the model. Initial conditions consist of the magnitude (if it is an earthquake source), the three-dimensional representation of the source rupture plane, and the amount slip or displacement along the fault plane itself which will deform the seafloor and generate the tsunami. Tsunami source information is also available from the NTHMP state science representatives upon request.

Digital Elevation Models (DEMs)

As discussed in Step 2, DEMs represent the terrain (bathymetry and topography) required for tsunami debris modeling. The resolution and terrain representation ("bare earth" vs. built environment) needed will depend on the type and scale of planning being completed. Once the draft DEM is developed, both tsunami experts and local officials should go into the field together to ensure that the terrain is accurately represented. Field surveys offer the advantage of direct data collection.

Specific areas and conditions that should be evaluated include:

- The layout and water depths within coastal and inland waterways such as bays, estuaries, and rivers.
- The layout of beaches, hills and gullies, and other portions of natural landscape.
- Engineered barriers that could inhibit flow (seawalls, structures, levees, etc.) or pathways that could increase the flow potential (alleyways, canals, etc.), both especially important in an urban setting where a built environment DEM might be used.

The DEMs should be updated with the results of these field surveys prior to modeling (Step 4).

Digital Debris and Sediment Representation

As previously discussed in Chapter 3, the types and amount of tsunami debris will depend on the size and energy of the tsunami and the potential available debris sources. In general, the closer a location or community is to the coast or harbor, there will be a higher likelihood of strong tsunami currents and impacts from debris.

The accurate location and classification of debris and sediment sources is critical to modeling the movement of these materials during a tsunami. This requires field surveys and spatial GIS (geographical information system) analysis to identify where and what type of debris exists in the harbor, waterfront, or other locations in the inundation area.

Field surveys are an essential tool in the process of identifying sources of debris. Teams of experts physically inspect and document the state of potential debris, assessing the type, quantity, and location of debris. Experts can collect physical samples of debris, categorize them, and note their origin.

Spatial GIS analysis is another critical component of identifying significant sources of debris. It involves using GIS to analyze spatial data and identify patterns in the distribution of debris. GIS analysis can help identify areas where debris are concentrated, as well as areas where debris are less prevalent. GIS can integrate spatial information into detailed maps to illustrate the distribution of debris sources in inundation areas.

GIS analysis can also help identify the type of debris present in different areas. For example, it can help determine whether debris consist primarily of natural materials such as wood and vegetation, or man-made materials such as plastics and metals. This information is valuable for pinpointing the sources and formulating effective mitigation strategies. The pertinent field information to be collected includes:

- Recent sets of aerial photography and land-use maps for coastal areas to identify where debris might be generated and where hazardous materials might be released.
- Classification of the buildings in the inundation area to help determine the debris potential.
- Areas of potential debris sources on or near the water, such as boats, docks, vehicles, lumber, crates, and shipping containers.
- Locations of fuel and sewage docks, chemical container sites, and other environmentally hazardous materials.

Step 4: Performing Tsunami Debris and Sediment Modeling and Assessments

Tsunami debris distribution modeling incorporates mathematical and computer models to predict the movement and accumulation of debris following a tsunami event. These models take into account a variety of factors, including the initial force of the tsunami, local topography, coastal geography, and ocean currents. Contacting the NTHMP state tsunami science representative to ask about verified numerical models should improve the results of the debris analysis.

Model predictions are compared to real-world observations to ensure their accuracy. Data collected from post-tsunami surveys and satellite imagery plays a crucial role in this validation process. A number of recent working groups and workshops have highlighted the capabilities of various numerical tsunami models and assessment tools. Numerical modeling and debris specialists should be familiar with this work.

Recent Timeline of Tsunami Modeling and Assessment Tools

- Pre-2016 – NTHMP Mapping and Modeling Subcommittee held numerical model benchmark workshops to test the ability to model tsunami inundation and current velocities. Benchmark problems and verified models are available at this website.
- 2016 – The American Society of Civil Engineers (ASCE) Tsunami Loads and Effects Subcommittee ASCE 7-16 and related state building codes includes a strategy to determine the potential for debris impact at the site of an essential or critical facility.
- 2019 – The State of Oregon held a tsunami debris workshop where several models and techniques were used to assess debris movement.
  Cox (Oregon State University; OSU) has developed methods for probabilistic debris movement and debris amount estimates.
  Bauer (Oregon Department of Geology and Mineral Industries; DOGAMI) presented methods using FEMA's Hazus risk assessment tool to calculate estimates of volume of debris coming from damaged buildings.
  Wilson (California Geological Survey; CGS) presented results from tsunami sediment and debris transport models developed by USC that are included in CGS' "Harbor Improvement Reports."
- 2023 – An NTHMP-supported tsunami debris model benchmark workshop co-led by Lynett (University of Southern California; USC) and Cox (OSU) was held at the Hatfield Marine Science Center in Newport, OR.

Lynett (USC) presented a tsunami debris movement product that animates the volume of debris moved via likely pathways as a "heat map," illustrating that likely debris pathways can be useful for mitigation planning. As of March 2024, results from this workshop are pending.
- 2023 – An NTHMP-supported tsunami sediment movement model benchmark workshop co-led by Kirby (University of Delaware) and Grille (University of Rhode Island) was held in Portland, OR. As of March 2024, results from this workshop are pending.

Tsunami Debris Modeling

Tsunami debris modeling aims to understand the movement of debris generated by tsunamis. The study of debris modeling involves the use of various methods to simulate the input of debris from tsunamis. One such method is the *uniform release method,* which considers a uniform distribution of material released along the coast. Another approach is the *weighted release method,* which combines measured tsunami runup heights with data describing coastal population density. Due to the random nature of debris motion and recent consideration to probabilistic tsunami hazards design, a probabilistic design approach is needed to assess the likelihood of debris loads occurring, which would be a function of the proximity of debris sources, debris properties, and surrounding environment.

In addition to the numerical models discussed, there are other methods and tools available for calculating the potential tsunami debris volumes. FEMA's Hazus multi-hazard model and Incident Waste Decision Support Tool (I-WASTE) can be used to estimate general tsunami debris impact and volume.

Hazus has a debris estimation tool for earthquake damage-related debris, but it does not have a tsunami-specific debris estimate. However, for local tsunami events, an approximation of potential debris within the tsunami inundation area can be estimated indirectly, based on the likely flow depths that would cause complete or partial destruction of earthquake-damaged buildings. This approximation is then used to replace the earthquake-related debris estimates within the specified inundation area. Earthquake-related damage could then be added for the areas outside of the inundation zone to get a complete multi-hazard estimate.

Hazus divides earthquake-related debris into two categories:

- Debris Type 1 is lighter materials such as brick, wood, and other debris (glass, furniture, plaster).
- Debris Type 2 is heavier materials such as reinforced concrete and steel members.

The distinction is made based on the difficulty of removing the debris (for example, bulldozers for Type 1 and special equipment for Type 2). However, this separation could also indicate what and where debris (Type 1) is likely to be moved by a tsunami. Hazus requires debris parameter inputs, such as weight in tons of debris for each building type per square foot and debris created defined as a percent of weight of elements (structural and non-structural) (see the Hazus manual). The results can be plotted visually in GIS to help identify source areas where debris might come from.

Step 5: Evaluating Tsunami Debris Model Results and Products

Once the tsunami debris modeling, quantitative analysis, and interim products are completed, the planner should go over each of these items with the tsunami modeling and other experts. Debris model results should be reviewed spatially in the office and then in the field to ensure debris sources, flow paths, and accumulation areas/volumes make sense. Any potential erroneous model results should be re-modeled to check the accuracy. Changes to the DEM might be required to improve modeled debris flow paths and accumulation locations.

Quantitative tsunami debris analysis results should be evaluated to determine if they appear correct. Debris volumes in the source region(s) should be close to matching the volumes in the areas of debris accumulation. The margins of error, statistically called the *standard deviation,* should also be quantified and understood by the planners so the data is not overvalued.

For example, if the volume is estimated to be 2,543 tons with a standard deviation of 300 tons, volumes should be stated to the appropriate significant figure and reported as “approximately 2,500 tons” or “2,500 tons plus or minus 300 tons.” Also remember that model results are only as good as the input data included during the modeling process.

Visual products from the tsunami debris analysis should be evaluated to make sure they appear accurate. Draft illustrations and animations from tsunami model simulations will help with evaluation of the models themselves.

Planners should make sure any final products and maps from the tsunami experts have correct marginalia (e.g., scale for distance, north arrow for orientation, primary street gris, legends describing what is on the map) and be usable for publications and understandable for the audience. Planners should have the data and ability to alter the products if the need arises.

Once the tsunami debris and sediment analyses and products have been verified and finalized, planning teams should review all products to determine their usefulness for preparedness, mitigation, and recovery planning. They should also evaluate including these products in various planning documents, websites, and/or presentations.

Funding tsunami debris planning and mitigation

National Tsunami Hazard Mitigation Program (NTHMP) Grants

NTHMP grants aim to improve tsunami hazard preparedness, mitigation, response, and recovery. Funding is available to states and territories that are part of the NTHMP and can be used for a range of projects, including modeling tsunami debris movement, mapping, planning, and mitigation activities.

- **Eligible Recipients**: Coastal states and territories that participate in the NTHMP.
- **Use of Funds**: Projects may include tsunami debris modeling, development of debris management plans, and improving public education on debris impacts after a tsunami. The NTHMP does not fund physical mitigation measures.

- **How to Apply:** States apply through NOAA, with allocations often tied to cooperative agreements with NTHMP partners.

National Oceanic and Atmospheric Administration (NOAA) Coastal Resilience Grants

This grant program supports projects that improve coastal community resilience to natural hazards, including tsunamis. It focuses on reducing the risks from coastal hazards and protecting coastal ecosystems. Tsunami debris management planning could be included in a larger coastal resilience project.

- **Eligible Recipients**: State, local, and tribal governments; nonprofits; academic institutions.
- **Use of Funds**: Can fund debris modeling, planning, and implementation of mitigation strategies to manage debris post-tsunami.
- **How to Apply**: Proposals are typically submitted in response to NOAA's Coastal Resilience Grants announcement.

NOAA Marine Debris Program

This national program offers grants and technical assistance for addressing marine debris issues, including tsunami debris. The program has a Marine Debris Emergency Response Guide and provides funding for community-based debris removal projects. Grant opportunities through NOAA can help local governments plan for and respond to tsunami debris events.

FEMA Hazard Mitigation Grant Program (HMGP)

FEMA's Hazard Mitigation Grant Program provides funding for long-term hazard mitigation measures following major disaster declarations. States and local governments can use these grants to develop and implement hazard mitigation plans, including tsunami debris planning.

- **Eligible Recipients**: State and local governments, as well as certain private nonprofits.
- **Use of Funds**: These funds can be applied toward planning and mitigation activities, including developing tsunami debris management strategies and resilience-building measures.
- **How to Apply**: States apply through their State Hazard Mitigation Officer (SHMO) following disaster declarations.

FEMA Building Resilient Infrastructure and Communities (BRIC) Program

The BRIC program supports pre-disaster mitigation projects to reduce risk and build resilience to natural hazards, including tsunamis. It can fund planning projects that address tsunami risks, including debris management. BRIC focuses on pre-disaster mitigation, including resilience-building projects. Funding from BRIC can support tsunami debris mitigation planning, infrastructure improvements, and community resilience efforts.

- **Eligible Recipients**: State, local, tribal, and territorial governments.
- **Use of Funds**: Can be used to develop debris management plans as part of larger tsunami preparedness and hazard mitigation strategies.

- **How to Apply**: Applications are submitted through FEMA's BRIC program in collaboration with state and local emergency management agencies.

Environmental Protection Agency (EPA) Disaster Debris Recovery Tools and Funding

While not solely focused on tsunamis, the EPA offers grants and technical assistance for disaster debris recovery planning, which could be applied to tsunami debris management.

- **Eligible Recipients**: State, local, tribal governments, and nonprofits.
- **Use of Funds**: Can support planning and response to debris generated by natural disasters, including debris management post-tsunami.
- **How to Apply**: Check with the EPA for specific grant opportunities related to disaster debris management.

State and Local Funding Options

In addition to federal programs, state and local governments play a key role in funding tsunami debris mitigation efforts. States with significant coastal exposure often allocate funds for hazard mitigation planning and emergency management initiatives.

State Hazard Mitigation Programs: Many states offer their own hazard mitigation grants, often leveraging federal funding from FEMA to provide additional support for local governments. These programs can be used to develop tsunami debris management plans and conduct public awareness campaigns.

Local Government Budgets: Coastal municipalities can allocate funds from their emergency management or environmental services budgets to support debris mitigation. Establishing dedicated funds for disaster preparedness and response can ensure that financial resources are available when a tsunami occurs.

Bond Measures and Taxes: Some communities choose to fund disaster mitigation projects through local bond measures or taxes, providing a dedicated revenue stream for tsunami debris management and other hazard mitigation efforts.

Private and Nonprofit Sector Support

Partnerships with private companies and nonprofit organizations can provide additional funding and resources for tsunami debris mitigation.

Private Sector Involvement: Businesses, particularly those in coastal areas, have a vested interest in ensuring that their communities are resilient to disasters. Private companies can contribute to funding debris management efforts through corporate sponsorships, in-kind donations, or public-private partnerships.

Nonprofit Organizations: Environmental nonprofits and community-based organizations are often involved in marine debris removal and environmental restoration projects. Partnering with these organizations can provide access to grants, volunteers, and technical expertise. For example, nonprofits focused on coastal conservation may have specific grants available for tsunami debris cleanup and habitat restoration.

International Aid and Grants

In the event of a large-scale tsunami, international aid may be available to assist with debris removal and disaster recovery.

International Organizations: Organizations such as the United Nations and the World Bank provide funding for disaster relief and recovery efforts, including debris management. These organizations can offer grants and loans to help rebuild infrastructure and remove debris from coastal areas following a significant tsunami event.

Best Practices for Securing Funding

Successfully securing funding for tsunami debris mitigation requires proactive planning and collaboration with multiple stakeholders. The following best practices can help ensure that financial resources are available when needed:

- **Develop Comprehensive Tsunami Debris Management Plans**: A well-defined debris management plan is critical for securing funding. Plans should include debris modeling, removal strategies, and cost estimates to demonstrate the need for financial resources.
- **Leverage Multiple Funding Sources**: Combining federal, state, local, and private funding sources can help maximize available resources and ensure that projects are fully funded.
- **Build Partnerships**: Collaborating with other governmental agencies, nonprofit organizations, and private companies can strengthen funding proposals and create new opportunities for financial support.
- **Stay Informed of Grant Opportunities**: Continuously monitor federal and state agencies for new grant announcements. Subscribe to updates from agencies like NOAA, FEMA, and NTHMP to ensure local governments are aware of available funding opportunities.
- **Engage the Community**: Public support can play a crucial role in securing local funding for tsunami debris mitigation projects. Engaging residents and businesses in the planning process can build community buy-in and increase the likelihood of funding approval through bond measures or local taxes.

Chapter 5: Mitigating Tsunami Debris

Land-use planning

Significance of Land-Use Planning in Coastal Areas:

Land-use planning is a comprehensive process that involves assessing and regulating the use of land in a way that promotes sustainable development and minimizes risks. In coastal areas, where the threat of tsunamis is ever-present, effective land-use planning is crucial. Planning enables communities to identify and designate areas prone to tsunami impact, taking into consideration factors such as elevation, geological features, and historical tsunami data.

By strategically planning land use, authorities can direct development away from high-risk zones and prioritize establishing buffer zones or green belts that can absorb the impact of tsunami waves. This proactive approach not only protects human lives but also helps preserve the natural environment and reduces the amount of debris generated during a tsunami event.

Regulations to Restrict Construction in Vulnerable Zones:

To ensure the effectiveness of land-use planning in tsunami debris mitigation, strict regulations are necessary to restrict construction in vulnerable zones. Building codes and zoning ordinances should be designed to reflect the potential risks associated with tsunamis. This includes enforcing setback requirements from the coastline, limiting construction in low-lying areas, and implementing guidelines for structures that can withstand the impact of tsunami waves.

Community awareness and education play a pivotal role in the success of these regulations. Residents and developers need to understand the importance of adhering to building codes that prioritize safety over convenience. Clear communication and engagement with the public can foster a sense of responsibility within the community, encouraging a collective effort to mitigate the risks associated with tsunamis and their aftermath.

Balancing Development Needs with Disaster Resilience

Balancing development needs with disaster resilience requires careful consideration of economic, social, and environmental factors. Coastal areas are prime locations for economic activities such as tourism, fisheries, and trade. However, the pursuit of development goals must not compromise the safety and well-being of the communities inhabiting these regions.

Incorporating disaster resilience into development plans involves innovative solutions such as constructing buildings on elevated platforms, utilizing resilient materials, and designing infrastructure that can withstand the impact of tsunamis. Additionally, incentives for sustainable and resilient development practices can be implemented to encourage businesses and residents to invest in long-term safety measures.

Strategic Relocation

As the frequency and intensity of tsunamis continue to pose significant threats to coastal communities, a novel approach gaining traction is "planned retreat." This strategic concept involves organized and purposeful relocation away from vulnerable coastal areas to mitigate the impact of tsunamis and reduce possible debris. This section explores the concept and importance of planned retreat, strategies for organized relocation, and case studies highlighting successful initiatives in tsunami-prone regions.

Concept and Importance of Strategic Relocation

Planned retreat is a forward-thinking strategy that acknowledges the dynamic nature of coastal environments, and the inherent risks associated with living in tsunami-prone areas. Unlike traditional approaches that focus solely on fortifying existing structures, planned retreat involves the deliberate withdrawal of communities from high-risk zones to safer inland locations. The importance of this approach lies in its potential to save lives, preserve ecosystems, and minimize the economic and environmental toll of tsunami events.

By embracing planned retreat, communities foster resilience by breaking the cycle of rebuilding in the same vulnerable areas after each disaster. This strategy recognizes the need to adapt in the face of changing climate conditions and increasing threats from natural hazards.

Strategies for Organized and Strategic Relocation

Organized and strategic relocation in the context of planned retreat requires a multifaceted approach, involving careful planning, community engagement, and infrastructure development in safer locations. Some key strategies include:

- **Risk Assessment and Zoning**
    - Conducting thorough risk assessments to identify high-risk areas.
    - Implementing zoning regulations that restrict new development in vulnerable zones.
- **Community Engagement**
    - Facilitating open and transparent communication with the community about the risks of living in tsunami-prone areas.
    - Involving residents in decision-making processes and fostering a sense of ownership in the planned retreat initiative.
- **Infrastructure Development**
    - Investing in infrastructure and amenities in safer inland locations to accommodate the needs of relocating populations.
    - Ensuring that new developments adhere to sustainable and resilient building standards.
- **Economic Transition**
    - Supporting affected industries in transitioning to alternative economic activities.
    - Offering financial incentives for businesses and individuals to relocate and rebuild in safer areas.

Case Studies: Successful Planned Retreat Initiatives

Several global examples showcase the success of planned retreat initiatives in mitigating the impact of tsunamis and reducing the generation of debris:

Japan

After the devastating 2011 Great East Japan earthquake and tsunami, Japan implemented a comprehensive planned retreat strategy, relocating entire communities to higher ground and establishing buffer zones along the coastline.

United States

In response to rising sea levels and increased hurricane risks, Louisiana has been implementing managed retreat strategies, including relocating entire communities affected by coastal erosion and hurricanes.

There is an ongoing effort in Alaska to relocate the entire village of Newtok, which has been threatened by increased erosion and flooding.

New Zealand

Following the 2011 Christchurch earthquake, New Zealand initiated a planned retreat program in certain coastal areas, encouraging residents to relocate to safer zones and implementing policies to restrict new developments in high-risk areas.

Vunidogoloa, Fiji

Relocated inland due to rising sea levels, setting a precedent for other Pacific Island communities.

Odisha, India

Villages moved to higher ground after devastating cyclones, with improved housing and infrastructure.

Planned retreat to move communities away from vulnerable coastal areas offers both benefits and challenges, especially in the context of tsunamis. Here are some pros and cons:

Design Principles for Tsunami-Resistant Infrastructure

The design of tsunami-resistant infrastructure is paramount in safeguarding coastal communities from the devastating impacts of tsunami events. Fundamental design principles create structures that can withstand tsunamis, with a focus on elevation and structural considerations. Considering the long-term impact of a tsunami, there is also a need for robust drainage systems to minimize debris accumulation.

Elevation

Infrastructure in tsunami-prone areas should be elevated to minimize direct exposure to tsunami waves. Elevated structures reduce the likelihood of inundation and damage caused by wave impact.

Structural Considerations

Employing robust and flexible building materials and designs that can absorb and dissipate the energy of tsunami waves.

Incorporating reinforced concrete and steel structures to enhance the overall strength and integrity of buildings.

Foundations

Designing deep and robust foundations that can withstand the forces exerted by tsunamis. Pile foundations, for instance, offer greater stability in areas prone to liquefaction during a tsunami event.

Flexible Design

Creating structures with a degree of flexibility to absorb shock and deformation without catastrophic failure. This can involve the use of innovative engineering solutions such as base isolators.

ASCE 7 Chapter 6 Standards for Tsunami-Resistant Structures

The American Society of Civil Engineers (ASCE) 7 Chapter 6 provide comprehensive guidelines for designing structures to withstand various natural hazards, including tsunamis. These standards can guide the development of tsunami-resistant structures, outlining compliance requirements and incorporation into coastal development projects. These standards aim to ensure the safety and resilience of buildings and infrastructure in the face of dynamic environmental forces.

Compliance Requirements and Guidelines

Site-Specific Analysis

ASCE 7 Chapter 6 emphasizes the importance of site-specific analysis to determine the tsunami hazards a structure may face, ensuring that design considerations are tailored to the specific risks of the location.

Load Combinations

The standards outline load combinations that consider the simultaneous effects of wind, seismic forces, and tsunami loads, ensuring that structures are designed to withstand the cumulative impact of these forces.

Performance Categories

ASCE 7 Chapter 6 categorizes structures based on their importance, prescribing different design approaches for various categories to meet the required level of resilience.

Incorporating ASCE 7 Chapter 6 into Coastal Development Projects

Professional Engineering Expertise

Engaging qualified structural engineers with expertise in tsunami-resistant design to ensure compliance with ASCE 7 Chapter 6 standards.

Design Review and Approval

Incorporating a rigorous design review process that considers ASCE 7 Chapter 6 standards at each stage of a coastal development project, seeking approval from relevant regulatory authorities.

Construction Oversight

Implementing robust construction oversight measures to ensure that the designed tsunami-resistant features are accurately and securely incorporated into the infrastructure.

Effective infrastructure design plays a pivotal role in mitigating the impact of tsunamis on coastal communities. By adhering to design principles that prioritize elevation, structural resilience, and effective drainage systems, along with incorporating ASCE 7 Chapter 6 standards, communities can build resilient structures that withstand the forces of tsunamis and minimize debris accumulation. As coastal development projects continue, the integration of these design principles and standards will be crucial in fostering the safety and sustainability of vulnerable regions.

Systems to Minimize Debris Accumulation

Open Spaces and Permeable Surfaces

Designing open spaces and permeable surfaces to allow water to flow through rather than accumulate. This reduces the potential for debris to get trapped and cause blockages.

Stormwater Management

Implementing effective stormwater management systems to rapidly drain water from the area, preventing the accumulation of debris and reducing the risk of structural damage.

Debris Screens and Barriers

Installing debris screens and barriers in drainage systems to catch and contain debris, preventing it from spreading and causing further damage.

Coastal Vegetation

Role of Coastal Vegetation in Mitigating Tsunami Impacts

Natural Buffer Zone

Coastal vegetation, such as mangroves, seagrasses, and coastal forests, acts as a natural buffer zone, absorbing and dissipating the energy of tsunami waves before they reach the shore.

Stabilization of Coastal Soils

The roots of coastal vegetation stabilize coastal soils, preventing erosion and reducing the risk of land loss during a tsunami event. This stabilization also contributes to the overall resilience of coastal ecosystems.

Wave Energy Dissipation

The complex structure of coastal vegetation helps break down and dissipate the energy of incoming tsunami waves, reducing their height and impact on coastal infrastructure.

Biodiversity and Ecosystem Services

Coastal vegetation provides habitat for diverse marine and terrestrial species, contributing to biodiversity. Additionally, these ecosystems offer valuable services such as water filtration and carbon sequestration, enhancing overall ecosystem health.

Preservation and Restoration Strategies

Community Education and Engagement

Raising awareness among coastal communities about the importance of preserving existing coastal vegetation and encouraging sustainable practices that protect these ecosystems.

Regulatory Measures

Implementing and enforcing regulations that restrict destructive activities such as logging, overharvesting, and land reclamation in coastal areas with significant vegetation cover.

Afforestation and Reforestation

Initiating afforestation and reforestation projects to restore and enhance coastal vegetation. This involves planting native species and restoring degraded areas to bolster the protective capacity of coastal ecosystems.

Green Infrastructure Planning

Integrating green infrastructure planning into coastal development projects, emphasizing the preservation of existing vegetation and incorporating strategies to enhance the resilience of coastal ecosystems.

Collaborative Efforts Between Communities and Environmental Organizations

Community-Led Conservation Initiatives

Fostering collaboration between local communities and environmental organizations to implement community-led conservation initiatives. This involves engaging residents in planting and protecting coastal vegetation

Research and Monitoring Programs

Collaborating on research and monitoring programs to assess the health of coastal ecosystems, identify threats, and develop effective strategies for preservation and restoration.

Capacity Building

Providing training and capacity-building programs to local communities, empowering them to actively participate in the protection and restoration of coastal vegetation.

Policy Advocacy

Working together to advocate for policies at local, national, and international levels that prioritize the preservation and sustainable management of coastal vegetation.

Coastal vegetation serves as a resilient and effective defense against the impacts of tsunamis, offering a natural and sustainable solution to mitigate the devastation caused by these powerful events. Preserving and restoring coastal vegetation requires collaborative efforts between communities and environmental organizations, emphasizing the crucial role of education, regulatory measures, and active community participation. As communities and ecosystems continue to face the threats of tsunamis, recognizing the significance of coastal vegetation and implementing strategic conservation efforts will be instrumental in building resilience and fostering sustainable coexistence between nature and human settlements.

Appendix A: Presenting Analysis Results - Debris and Sediment Estimates

This appendix provides an outline for how tsunami debris and sediment modeling data can be presented in a standalone report. The planner or person writing this report should reference Chapter 4 in this guide, which summarizes the steps taken to analyze tsunami and sediment transport and the products which can be developed.

Scenario: A coastal city is conducting a tsunami preparedness exercise and needs to present its tsunami debris and sediment analysis to local emergency planners and policymakers.

Use Case: Appendix A can be used to structure a detailed presentation of debris and sediment estimates derived from numerical tsunami models. The city could provide:

- Graphical representations of debris distribution and sediment accumulation.
- Quantitative data on expected debris volume, type, and deposition areas.
- Model outputs that inform resource allocation, response strategies, and post-tsunami cleanup plans.

This analysis aids decision-makers in visualizing impacts, prioritizing resources, and effectively planning debris removal and infrastructure recovery.

I. Executive Summary

Brief overview of the tsunami debris planning analysis and report.

This report presents a comprehensive analysis of tsunami debris and sediment deposits for [community name]. In response to the tsunami threat posed by [tsunami source] to the community of [community name], this report analyzes the sources of tsunami debris and sediment to provide a basis for tsunami debris planning.

Our approach integrates current best practices to include [brief description of methods]. This methodology predicts the sources, movement and dispersion of tsunami debris and sediment. This methodology incorporates data from [brief description of data sources].

Data analysis synthesized the collected data and model outputs to identify vulnerable areas, estimate potential debris accumulation, and predict sediment transport dynamics. The results provide actionable insights for emergency preparedness, response planning, and long-term coastal management strategies.

This report serves as a vital resource for the [community name], offering a scientifically grounded foundation for decision-making in the face of potential tsunami debris and sedimentation. The findings empower local authorities to implement proactive measures, safeguarding the community against the impact of future tsunami events.

II. Introduction

- Background on the importance of tsunami debris planning and the need for a standardized analysis and reporting template.
- Discuss the purpose of completing the analysis.
- Summarize any methods or references that were used.

III. Methodology

- Explanation of the methodology used for analyzing tsunami debris and sediment estimates.
- Reference the relative accuracy of the methods and how errors are accounted for.

IV. Data Collection and Preparation

- Details on the data sources and data preparation processes.
- Consideration of tsunami hazard modeling and data.

V. Debris Analysis

- Debris Categories, Locations, and Amounts
- Breakdown of debris categories (e.g., wood, metal, plastic).
- Geographic distribution of debris in affected areas.
- Quantitative estimates of debris amounts.
- Debris Sources, Categories, and Locations
- Identification of potential debris sources (e.g., buildings, infrastructure).
- Classification of debris into specific categories.
- Mapping of debris locations.

VI. Sediment Analysis

- Sediment Sources, Categories, and Locations
- Identification of sediment sources (e.g., rivers, coastal erosion).
- Categorization of sediment types (e.g., sand, silt).
- Spatial distribution of sediment sources and categories.

VII. Impact Assessment

- Impacts on Structures and Infrastructure
- Evaluation of the damage and disruption to buildings, roads, bridges, and other infrastructure due to debris and sediment.
- Quantitative and qualitative assessments of structural damage.
- Impacts from Contaminants
- Examination of the potential for contaminants in debris and sediment to affect water quality, ecosystems, and human health.
- Assessment of contamination risks and impacts.

- VIII. Reporting and Visualization
- Guidelines on how to effectively present analysis results in reports and visual aids.
- Best practices for creating maps, charts, and graphs to communicate findings.

IX. Conclusion

- Summary of the key points discussed in the template.
- Emphasis on the importance of standardized analysis for effective tsunami debris planning.
- Summary of how these data and products will be used (planning, mitigation, recovery).

X. References

- Citation of relevant sources and references used in the template.

XI. Appendices

- Additional resources, data tables, or supplementary information for users of the template.

Appendix B: Federal and State Requirements and Services

Federal Requirements

FEMA has several documents outlining requirements and guidance for debris removal. The EPA also provides guidance documents, along with the program I-WASTE, a debris estimation tool.

FEMA-325 Public Assistance Debris Management Guide (2007)

This document provides an outline for determining eligibility for Public Assistance (PA) grants to deal with debris removal operations. It also discusses debris management planning concepts which if properly executed may better position a community for Public Assistance grants. The basic concepts of debris management entail forecasting the amount of debris, the collection of debris, identifying debris management storage sites, plans for reducing and recycling the anticipated waste, and final disposal of the remaining non-recyclable or burnable debris.

The document includes chapters on each of the facets of a debris management plant to aid in identification and estimation at each of the stages. The appendices provide the following: a sample outline for a debris management plan; methodology used to estimate hurricane debris; useful FEMA forms; an example of debris collection and management site hazard analysis; a demolition checklist; FEMA policies and fact sheets; and include federal agency authorities for debris removal.

FEMA-327 Public Assistance Debris Monitoring Guide (2021)

This document provides an outline for eligible agencies of Public Assistance grants to ensure debris removal operations are efficient, effective, and eligible for funding. FEMA encourages the monitoring of debris removal operations and documentation of the quantities and associated expenses incurred from the point of collection to the final disposal. Failure to monitor this process properly could jeopardize Public Assistance grant funding. This document outlines important checklists to include in an agency's debris management plan.

FEMA-329 Debris Estimating Field Guide (2010)

This document describes the FEMA process of assessing the preliminary damage after a disaster (called a Preliminary Damage Assessment or PDA) and this is used in part to determine if the event qualifies for disaster declaration. Different methods of estimation, such as ground measurements, aerial imagery, and/or modeling can all be used in estimating debris volume (using HAZUS). Each of these methods is outlined in detail, with recommendations provided describing circumstances under which each method is most appropriate.

EPA Planning for Natural Disaster Debris (2019)

This document outlines the planning process for dealing with debris from natural disasters. The document is not specific to tsunamis, but many of the ideas and examples are relevant to tsunami debris management planning. The main recommendation is for local government and stakeholders to create a debris management plan ahead of disasters, as this saves valuable time and resources during the initial response to the disaster and allows for more effective and environmentally responsible disposal of waste streams.

The EPA encourages communities and stakeholders to work together ahead of a disaster and identify personnel and perform relevant decision-making in advance. Additionally, it is preferable to have contracts in place for timely removal of waste, an identified area for a debris management site, and methods identified for each type of waste stream. The document provides recommendations on how to dispose of different types of debris and available resources to aid with decision-making on how to dispose, recycle or reuse the different types of debris. The EPA's website lists a non-exhaustive list of harmful materials that may be found in debris from residential property.

Oversight and Management of Debris Removal Operations (OIG-11-40)

This document addresses crucial aspects of overseeing and managing debris removal operations, particularly in the context of disaster response and recovery. The Office of Inspector General (OIG) is generally tasked with evaluating the effectiveness and efficiency of government programs, and in this specific report, it likely provides insights into the oversight mechanisms and management practices related to debris removal after disasters. The document likely offers recommendations for improving these operations, ensuring accountability, and enhancing the overall resilience of communities in the face of natural or man-made disasters. It serves as a valuable resource for governmental agencies, policymakers, and stakeholders involved in disaster response and recovery efforts.

Disaster Debris Management: Requirements, Challenges, and Federal Agency Roles, a Congressional Research Service document (Updated 2017)

This document provides a comprehensive overview of the essential aspects associated with handling debris in the aftermath of disasters. It delineates the specific requirements that must be met to effectively manage and mitigate the impact of debris resulting from natural or man-made calamities. Addressing the challenges inherent in debris management, the document delves into various strategies and considerations for optimizing response efforts. It also clarifies the crucial roles played by federal agencies in coordinating and executing debris management plans, emphasizing the collaborative and multifaceted approach necessary for successful disaster recovery. This document serves as a valuable resource for emergency management professionals, policymakers, and stakeholders involved in enhancing resilience and preparedness for disaster-induced debris challenges.

PA Fact Sheet: Private Property Debris Removal (2019) (sdao.com)

This document, available on sdao.com, is a concise and informative resource offering insights into the procedures and guidelines for private property debris removal in the context of Public Assistance (PA). Tailored to the year 2019, the document outlines key considerations, eligibility criteria, and the process involved in securing assistance for the removal of debris from private properties in the aftermath of disasters. This fact sheet is likely to be a valuable reference for individuals, communities, and local authorities seeking clarity on navigating the complexities of debris removal, particularly when it comes to accessing Public Assistance programs.

Federal Services

NOAA Marine Debris Program, a national resource dedicated to addressing marine debris issues. This program provides valuable tools, including a Marine Debris Program Response Team and an Emergency Response Guide, which are designed to support debris management efforts following marine disasters. Notably, NOAA has extensive experience with tsunami-related debris, such as the 2011 Japan tsunami, which dispersed debris across the Pacific and affected the U.S. coast. Their resources, data, and expertise on debris movement, collection, and disposal could greatly enhance local tsunami debris planning and response efforts. By incorporating NOAA's established guidelines and leveraging their national program, emergency managers can tap into a wealth of information and support, potentially streamlining debris management strategies and ensuring a more efficient response. Including this program in planning documents would enhance resilience and preparedness for future tsunamis.

State Requirements

Oregon

For the most accurate and up-to-date information on Oregon's specific requirements, check with the Oregon Department of Emergency Management (OEM) or other relevant state agencies responsible for disaster preparedness and response. They may have official documents, guidelines, or contact information for assistance with specific inquiries related to disaster debris planning in Oregon.

- Oregon Department of Emergency Management
- Oregon Department of Environmental Quality, Disaster Debris Management

Washington

To obtain the most accurate and up-to-date information on Washington's specific requirements, you should refer to official documents from the Washington State Emergency Management Division or other relevant state agencies responsible for disaster preparedness and response. They may have guidelines, regulations, or contact information for specific inquiries related to disaster debris planning in Washington.

- Washington Department of Emergency Management
- Washington Emergency Debris Management

California

Cal Recycle (https://www.calrecycle.ca.gov/) lists helpful resources for developing debris management plans, especially on the disaster recovery page, for cities and counties, businesses, as well as individual property owners. The disaster recovery page is specific to recovery from recent firestorms in California, but many of the resources listed here can be used for other types of disasters. The website also provides case studies of disaster response and recovery.

The State of California has an Integrated **Waste Management Disaster Plan** (1997), also found at the Cal Recycle website. This document is split into four sections, the first of which focuses on government coordination, pre-disaster planning, and debris management programs. The next section focuses on emergency management and is followed by a section describing case studies from the 1991 Oakland firestorm and the 1994 Northridge Earthquake disasters. The final section provides checklists for use by the designated debris management team. This document outlines the **State Natural Disaster Assistance Program,** which outlines how a state emergency is declared, available public assistance funds after a state emergency declaration, and how to apply for these funds.

Appendix C: Glossary of Terms

Here is a glossary of terms related to tsunami debris planning and sediment transport modeling. This glossary aims to provide clarity on key terms used in the context of tsunami debris planning and sediment transport modeling.

Bathymetric Survey: The measurement and mapping of underwater terrain, providing data on water depth and underwater topography.

Bathymetry: The measurement of water depth in bodies of water like oceans, seas, rivers, or lakes.

Cascadia Subduction Zone: A fault line off the Pacific Northwest coast where two tectonic plates (the Juan de Fuca and North American Plates) meet, capable of producing massive earthquakes and tsunamis.

Coastal Morphology: The study of the shape and form of coastal areas, including landforms like beaches and dunes.

Community Engagement: The process of involving local communities, especially marginalized groups, in planning efforts, ensuring their concerns and perspectives are considered.

Computer Model: A simulation using mathematical equations to predict the movement of debris and sediment over time.

Data Integration: Combining data from various sources into a unified dataset for analysis, often using Geographic Information Systems (GIS).

Displacement: The movement of water caused by earthquakes, underwater landslides, or volcanic eruptions, which can generate tsunamis.

Emergency Managers: Individuals responsible for coordinating and managing emergency response and recovery efforts.

Ensemble Kalman Filtering Inversion: A technique used to quantify uncertainty in tsunami sediment transport modeling.

Environmental Justice: The fair treatment and meaningful involvement of all people in environmental policy development, ensuring that no group is disproportionately impacted by hazards like tsunami debris.

Equity Lens: An approach that emphasizes fair and just distribution of resources, ensuring that vulnerable populations are not disproportionately affected by planning decisions.

Field Surveys: The collection of data directly from affected areas, including debris and sediment samples, for laboratory analysis.

Flow Depth: The depth of tsunami water measured onshore at various locations.

Flow Velocity Models: Numerical models used to simulate the speed and direction of tsunami currents, providing insight into potential damage and debris movement.

Geographical Information System (GIS): A system used to capture, store, analyze, and manage geographic data, often used in tsunami debris planning.

Geological Evidence: Data gathered from the Earth's structure and processes, such as past earthquakes and tsunamis, through scientific studies.

Hydrodynamics: The study of fluid motion, particularly water, including the behavior of currents and waves.

Inundation: The flooding of land caused by tsunami waves, which can destroy coastal communities.

Inundation Distance: The horizontal distance inland that a tsunami penetrates, measured perpendicular to the shoreline.

Inundation Line: The inland limit of a tsunami's penetration, sometimes marked by the boundary between living and dead vegetation.

Megathrust Earthquake: A massive earthquake along a subduction zone, such as the Cascadia Subduction Zone, with the potential to cause powerful tsunamis.

Model Calibration: The process of adjusting model parameters to improve the agreement between predictions and observed data.

Model Validation: The process of verifying the accuracy of a model by comparing its predictions to real-world data.

Morphological Change: Changes in the shape or structure of coastal areas, often caused by sediment movement during a tsunami.

National Tsunami Hazard Mitigation Program (NTHMP): A U.S. initiative that brings together federal, state, and local agencies to develop strategies for mitigating tsunami hazards, including debris management.

Numerical Modeling: Using mathematical algorithms in computer simulations to predict physical processes like debris movement and sediment transport.

Paleotsunami: A tsunami that occurred before written historical records, often identified through geological evidence.

Public Officials: Government representatives involved in planning and implementing strategies for tsunami debris management.

Remote Sensing: The use of satellites or aircraft to collect data about the Earth's surface from a distance, often used in tsunami monitoring.

Resilience: The ability of communities to prepare for, respond to, and recover from disasters like tsunamis.

Risk Assessment: The evaluation of potential risks associated with tsunamis, including the impacts on infrastructure, geography, and population.

Run-up: The maximum vertical height a tsunami wave reaches as it moves inland, measured relative to sea level.

Run-up Elevation: The elevation above sea level that a tsunami reaches at the farthest point of inland penetration.

Sediment: Material like sand, silt, and clay that is carried by tsunami waves and deposited inland.

Sediment Transport: The movement of sediment in water, influenced by currents, waves, and turbulence during a tsunami.

Semi-Empirical Parameters: Parameters in a model that are based on both empirical data and theoretical assumptions.

Sensitivity Analysis: The study of how changes in model inputs affect the outputs, identifying the most influential factors in tsunami modeling.

Simulation: The imitation of a real-world process using a model to predict its behavior under different conditions.

Spatial Analysis: The examination of geographic data to identify patterns and relationships in the context of tsunami debris and sediment movement.

Tsunami: A series of powerful waves typically caused by underwater earthquakes, capable of devastating coastal areas.

Tsunami Debris: Materials like vehicles, vegetation, and buildings carried by tsunami waves and deposited onshore or swept out to sea.

Tsunami Debris Planning: The process of preparing for and managing debris generated by tsunamis, including debris removal and recovery efforts.

Tsunami Hazard Assessment: The probability that a tsunami of a particular size will strike a specific section of coast.

Tsunami Propagation: The movement of tsunami waves outward from the source, influenced by underwater topography and water depth.

Tsunami Wave Height: The difference between the highest water mark left by the tsunami and the normal sea level.

Vulnerability Assessment: The identification and analysis of communities or areas most at risk from tsunami debris and sediment movement.

Visualization: The creation of maps, charts, and other graphical tools to communicate complex data related to tsunami risks and debris movement.

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