International Workshop on M9 Disaster Science
Final Report on GIF Funding

Overview

GIF funding was provided to partially support an International Workshop on M9 Disaster Science in March, 2019. This workshop brought together researchers from the US (primarily UW), Japan, and Chile who study Magnitude 9 earthquakes and related hazards. The workshop is described in more detail below.

Not all of the funding was used for the workshop, and with permission of GIF some of the remaining funds were used to support follow-up collaboration activities involving workshop participants:

- Partial travel support was provided for several UW researchers to visit Japan in November, 2019, to participate in a conference, workshop, and field trip.
- Travel was supported for a Chilean researcher to visit UW in early 2020 at the same time a collaborator from Japan was here, and to support their fieldtrip to Westport.

These activities are also described later in this report.

Links with additional information, slides from talks, etc. can be found at:
http://depts.washington.edu/ptha/M9-Disaster-Science-Workshop-2019/

Workshop: March 13-14, 2019

This workshop brought together 44 researchers who study large subduction zone earthquakes and related hazards, in particular tsunamis and landslides, from several different viewpoints: geophysics, numerical modeling, engineering, urban design, resilience and mitigation, social science, and public policy. The list of participants can be found below, and included 24 researchers from the US (primarily UW), 12 from Japan (primarily from Tohoku University), and 8 from Chile. Many of the UW participants are involved in the M9 Project (https://hazards.uw.edu/geology/m9/), a highly multidisciplinary consortium of researchers at UW funded by an NSF Hazard-SEES grant starting in 2014. Many of the Japan participants are involved in the International Research Institute of Disaster Science (IRIDeS, http://irides.tohoku.ac.jp/eng/) at Tohoku University (TU), while the Chilean participants are associated with the Research Center for Integrated Disaster Risk Management (CIGIDEN, http://cigiden.cl/en/). All of these groups have similar multi-disciplinary approaches to the study of subduction zone earthquake hazards, and considerable expertise due to their proximity to subduction zones. The goal of the workshop was to exchange ideas and to foster new international collaborations on topics of joint interest, with an emphasis on initiating some

concrete projects. To this end, most of the time at the workshop was spent in break-out group discussions rather than lectures.

Funding and support.

The workshop was supported in part by the UW Global Innovation Fund and the UW / Tohoku University Open Academic Space project (UW-TU:AOS), with substantial travel support also provided by both Tohoku University and CIGIDEN. Additional funding was provided by the UW M9 Project (from an NSF Hazard SEES grant), the Department of Applied Mathematics, and the Department of Civil and Environmental Engineering. Meeting space was provided in part by the UW eScience Insitute.

Logistics.

Details of the workshop schedule can be found on the website,
http://depts.washington.edu/ptha/M9-Disaster-Science-Workshop-2019/

Day 1. The first morning consisted of brief overview talks about activities in each of the hazard research centers, followed by a series of 2-minute lightning talks. Together with another hour of lightning talks in the afternoon, all participants had a chance to introduce themselves and their interests. The lightning talk slides can be found on the workshop webpage. The remainder of the afternoon consisted of break-out group discussions about possible collaborations. Participants were split into 7 groups based on their interests and 23 extended abstracts that were solicited in advance about potential research topics:

- Group 1: Observations and early warning
- Group 2: Remote sensing
- Group 3: Planning and risk assessment
- Group 4: Tsunami modeling
- Group 5: Landslide/rockslide modeling
- Group 6: Subduction zone seismology, tsunami sources, PTHA
- Group 7: Structural engineering

The break-out group participants are listed on the workshop webpage, along with all the abstracts. Although many participants have interests that span several groups, for these initial discussions we wanted to insure roughly uniform size and that each group have representation from all three countries. The day ended with reports from each break-out group and general discussion, and a buffet dinner.

Day 2. The second day was devoted entirely to continuing to discuss in small groups and in many cases to initiate specific research projects and make plans for joint work to continue. Below we list some of these outcomes.

Fieldtrip. On March 15, 2019, immediately following the workshop, there was a field trip to view some of the geological evidence of past tsunamis on the coast of Washington. Such evidence is very important in gaining an understanding of past events and future probabilities, and several participants work on collecting such evidence and/or combining observations with modeling results. This field trip was led by Brian Atwater (USGS / UW ESS) and Carrie Garrison-Laney (Washington Sea Grant), two local experts on this topic, and had 18 participants. The group also visited the Port Townsend Marine Science Center to hear about evacuation maps and planning in this community.

Workshop Participants.

Prof. Dan Abramson, Urban Design & Planning, UW
Dr. Diego Arcas, NOAA Center for Tsunami Research
Prof. Pedro Arduino, Civil & Environmental Engineering, UW
Prof. Paula Aguirre, Pontificia Universidad Catolica de Chile
Dr. Brian Atwater, USGS researcher (retired)
Prof. Anne Bostrom, Evans School, UW
Prof. Patricio Catalan, Universidad Tecnica Federico Santa Maria, Chile
Prof. Youngjun Choe, Industrial Engineering, UW
Prof. Jorge Crempien, Pontificia Universidad Catolica de Chile
Dr. Brendan Crowell, Pacific Northwest Seismic Network
Prof. Juan Carlos de la Llera, Pontificia Universidad Catolica de Chile
Mr. Alexander Dolcimascolo, graduate student, Central Washington University
Prof. Alison Duvall, Earth & Space Sciences, UW
Prof. Marc Eberhard, Civil & Environmental Engineering, UW
Mr. Yukio Endo, graduate student, Tohoku University
Dr. Robert Frietag, Institute of Hazards Mitigation Planning & Research, UW
Prof. Yo Fukushima, Tohoku University
Dr. Carrie Garrison-Laney, Researcher, Washington Sea Grant, UW
Dr. Frank Gonzalez, Affiliate Professor, Earth & Space Sciences, UW
Prof. Gabriel Gonzalez, Universidad Catolica del Norte, Chile
Mr. Juan Gonzalez, graduate student, Universidad Catolica del Norte, Chile
Prof. Dawn Lehman, Civil & Environmental Engineering, UW
Mr. Takuya Inoue, graduate student, Tohoku University
Prof. Shunichi Koshimura, Tohoku University
Prof. Naoko Kuriyama, Kobe University, Japan
Prof. Jorge Leon, Universidad Tecnica Federico Santa Maria, Chile
Prof. Randy LeVeque, emeritus, Applied Mathematics Dept, UW
Prof. Liz Maly, Tohoku University
Prof. Bre MacInnes, Central Washington University
Prof. Erick Mas, Tohoku University
Prof. Monika Moskal, Forestry, UW
Prof. Mike Motley, Civil & Environmental Engineering, UW
Prof. Shuji Moriguchi, Tohoku University

Dr. Luis Moya, Tohoku University
Ms. Lan Nguywn, graduate student, Urban Design & Planning, UW
Dr. Jerry Paros, Paroscientific
Prof. David Schmidt, Earth & Space Sciences, UW
Prof. Anne Sheehan, University of Colorado
Prof. Anawat Suppasri, Tohoku University
Prof. Kenjiro Terada, Tohoku University
Prof. Harold Tobin, Earth & Space Sciences, UW
Dr. Alejandro Urrutia, researcher, CIGIDEN, Chile
Prof. William Wilcock, Oceanography, UW
Prof. Yuya Yamaguchi, Tohoku University

Outcomes.

World Bosai Forum. One significant outcome was that many participants made plans to attend the World Bosai Forum (WBF) in Sendai, Japan, November 9-12, 2019 as described further below.

New Collaborations. Discussions during the M9 workshop between participants from Japan, Chile, and the US led to the exchange of many ideas and the beginning of several new collaborations. Many of these efforts have continued beyond the workshop, and in some cases future in-person visits or student exchanges have already happened or are planned. Some of these collaborations are described further below.

Japan trip: November 2019

The World Bosai Forum (WBF) was held in Sendai, Japan, November 9-12, 2019 (http://www.worldbosaiforum.com/2019/english/). A special session was organized at the WBF specifically to follow up on collaborations formed during the M9 workshop, see http://depts.washington.edu/ptha/M9-Disaster-Science-Workshop-2019/WBF2019/ for the schedule and speaker slides.

Bosai is a traditional Japanese term, indicating a holistic approach to reduce human and economic losses from disasters, which represents activities in all disaster phases, including prevention, recovery, response and mitigation. This is an international forum on disaster risk reduction held in partnership with the International Disaster and Risk Conference (IDRC) in Davos, Switzerland. The previous 2017 WBF attracted 947 participants from 42 countries, and involvement of UW researchers in the 2019 conference may lead to additional new international collaborations. [update for 2019]

Six researchers from UW participated: faculty members Dan Abramson (Urban Design and Planning), Loyce Adams (Applied Math), Randy LeVeque (Applied Math), Mike Motley (CEE), along with Carrie Garrison-Laney (Washington Sea Grant) and Lan Nguyen (PhD student in

Urban Design and Planning). Much of this travel was funded by Tohoku and Kobe Universities, and funds were also provided by Washington Sea Grant, and the CEE and Applied Mathematics Departments. The breakdown is available in the separate Budget Report.

Due to the civil unrest in Chile at the time, only one Chilean workshop participant (Jorge Leon) was able to attend WBF, although another (Patricio Catalan) gave a video presentation.

After the WBF workshop a 2-day field trip of areas affected by the 2011 tsunami was organized by our Tohoku University colleagues for the M9 group and all 6 UW researchers participated. This field trip was extremely valuable to gain a better understanding of the tsunami effects and also to see the massive reconstruction efforts that have gone on since, including many ways in which better protection against future tsunamis is being incorporated. All of the UW participants are involved in tsunami resilience planning. A Google Earth presentation was developed by this group (https://tinyurl.com/TohokuFieldtrip) that provides a virtual tour and has many photographs taken by the group embedded in it. This presentation was used for an M9 Seminar at UW to report on this trip, and versions of it have also been used for other purposes, including a presentation to the Washington State Inner Coast Tsunami Working Group, composed of emergency managers and planners from around Puget Sound. Future presentations are also planned. Garrison-Laney also gave a recent talk on this trip in the Sea Grant Liasons webinar series, which is available at https://www.seagrant.noaa.gov/liaisons.

While in Sendai, Garrison-Laney, LeVeque, and Adams also participated in the AIWEST 2019 workshop (https://irides.tohoku.ac.jp/eng/event/aiwest-dr2019.html) organized at IRIDEs, which brought in many researchers from Indonesia who study earthquakes and tsunamis. This led to the development of new international collaborations.

Abramson and Nguyen stayed in Japan for a few days longer and participated in another fieldtrip with Japanese colleagues, visiting the city of Fukushima and some neighboring towns to learn about the evacuation and rebuilding of that area following the nuclear power plant disaster.

Field trip to Washington coastal communities, March 1-2, 2020

GIF funds were used to partially support a visit by Jorge Leon from Universidad Tecnica Federico Santa Maria, Chile to UW for several days in late February and early March, to collaborate with Abramson, Nguyen, and others working on urban design and coastal resilience issues. At the same time, Naoki Kuriyama was visiting from Kobe University. One activity was a 2-day field trip to several communities on the Washington Coast to meet with local emergency management personnel and other community leaders, and discuss earthquake and tsunami preparedness. This trip included a tour of the Ocosta Elementary School in Westport (the first tsunami vertical evacuation structure built in the US) and related sites. Scott Cameron, a member of the National Academy of Sciences Board on Earth Sciences and Resources and coastal resident, also participated in this field trip and wrote up some notes that are attached as an appendix and give more details.

New Collaborations

Exploring Data Assimilation for Tsunami Forecasting with Sparse Networks

This collaboration is primarily between William Wilcock (UW), Anne Sheehan (CU), Diego Arcas (NOAA Center for Tsunami Research), Patricio Catalan (CIGIDEN, Chile).

Current tsunami warning systems rely on predicting tsunamis using models of earthquake source rupture derived from seismic and GNSS data, and then refining these predictions using observations of the far-field tsunami obtained with a global network of seafloor pressure buoys. Such validation comes too late to be useful for tsunami warnings in the near field and even if pressure recordings were obtained closer to the source, it is challenging to recompute tsunami source models sufficiently quickly to incorporate the new observations. Data assimilation is an alternative approach to forecasting tsunamis that utilizes the observations of the tsunami itself as sources that are then propagated forward in time. Data assimilation has been shown to work well when dense networks of pressure observations are available and there are studies which show that it can usefully be applied to sparse networks. However, more research is required to understand the minimal density and distribution of observations necessary to provide reliable forecasts.

We plan to investigate the feasibility of data assimilation for tsunami prediction in Cascadia and Chile. In Cascadia we will evaluate the performance of the current configuration of seafloor pressure sensors on the Ocean Observatories Initiative Cabled Array, Ocean Networks Canada NEPTUNE cables observatory and NOAA tsunami warning buoys, using both recordings of small tsunamis such as the 2018 Alaska tsunami and simulations of M9 Cascadia events. We will investigate how additional seafloor sensors would be optimally added to enhance and also explore the feasibility of utilizing ships equipped with real time GPS to enhance observations. In Chile there are presently no offshore pressure sensors except for several tsunami buoys, so here will make use of data from a temporary network of ocean bottom seismometers equipped with differential pressure sensors deployed in 2012-13 in the source zone of the 2010 M8.8 Chile earthquake. The 9 OBS of the Chile-PEPPER experiment, PI A. Trehu, were deployed on the outer accretionary wedge that lies along the Chile coast above the rupture zone of the 2010 Maule, Chile earthquake. This network offshore Chile recorded the tsunami from the magnitude 7.3 August 27, 2012 El Salvador earthquake.

Planning and risk assessment.

The application of disaster-scientific models and engineering solutions to community planning and risk assessment can be advanced through the development of a comparative framework.

The comparative framework developed in this project will afford insights into adaptive planning and anticipatory action regimes across the multiple political-economic, cultural and biophysical contexts in Chile, Japan, the US, and potentially New Zealand and the Philippines. The framework includes characterizing for each context: historical experience, local (non-scientific) disaster knowledge, and the development of "seismic culture," as well as governance systems at and across all scales of social and spatial organization and timeframes. Seismic culture and governance systems manifest themselves specifically in how planning and action takes place for: (1) pre- and post-disaster relocation and resettlement; (2) disaster preparedness and response; and (3) other related dimensions of planning and decision-making, including land use, housing and infrastructure provision, and various social services and environmental management. Important indicators of successful application of disaster science in planning and risk assessment include: (1) increasing social inclusivity in decision-making, (2) reducing wealth and power disparities; and (3) increasing the regime's capacity to respond to new, probabilistic, and uncertain disaster and geologic time-scale science with (4) creative, robust, and locally-appropriate policies, programs and environmental/structural designs. Next steps in collaboration include participation at the World Bosai Forum in Sendai, November 2019, by at least three of this group's participants: Dan Abramson, Liz Maly and Naoko Kuriyama, where an initial framework for international comparison will be presented in the UW/TU session event. Abramson and Ann Bostrom are also pursuing aspects of the group's topic in applications for future funding from WA Sea Grant, NSF Coastlines and People (CoPe), and other sources, and Lan Nguyen is preparing her general exam and dissertation proposal on topics especially related to (1) and (2) above.

Comparative study of earthquake early warning perceptions.

Workshop participants from Tohoku University and the University of Washington also developed further their plans to complete a comparative study of earthquake early warning perceptions, based on survey research representative of the populations in their respective communities. Survey data have been collected in both regions and initial analyses have been conducted for the data within each region. Once data-sharing issues have been resolved comparative analyses will be conducted (this summer), facilitated by Liz Maly and Ann Bostrom, for a joint publication. Given that earthquake early warning has long been available in Japan, is only now rolling out on the U.S. West Coast, and is not yet publicly available in the Pacific Northwest, this project should provide useful insights for planners and policy makers, in addition to advancing risk communication and warning research.

Subduction zones and stochastic tsunami sources.

The first goal of this international Chile/Japan/USA project is the development of a methodology to create suites of stochastically generated seismic events for the Central Chile, Cascadia and the Nankai trough subduction zones. The ranges of the earthquake magnitudes should vary between Mw 8.5 and 9.0. This goal requires basic research to improve our understanding of subduction zone physics so that scientifically defensible ranges of seismic model parameters can be specified that are specific to each subduction zone region. Such

geophysically constrained suites of stochastic seismic events are the heart of probabilistic seismic and tsunami hazard assessment studies (PSHA and PTHA, respectively). Valuable discussions involving many workshop participants has helped to move forward related work on generating stochastic subduction zone earthquakes being pursued by Jorge Crempien and Alejandro Urrutia in Chile, and by Frank Gonzalez and Randy LeVeque at UW, along with Diego Melgar at the University of Oregon, who was not able to attend the workshop but has engaged in on-going email discussions. Collaboration is also planned on the use of the GeoClaw software to model tsunamis arising from large suites of stochastic sources.

Motivation for this research includes the concern that single deterministic tsunami hazard assessment studies convey information to community members and decision-makers that is not adequate to deal with issues that can be truly existential in nature and involve remedies that can be extremely costly and/or can create serious social disruption. The second goal of this project is therefore the use of these stochastically generated earthquake rupture databases to conduct regional- and site-specific PSHA and PTHA studies that can provide quantitative measures of uncertainty to practicing engineers and communities at risk as an aid in decision-making and planning. Finally, the third goal involves the engagement of social scientists with communities to design and conduct educational meetings, workshops, surveys and other efforts to determine the effect of probabilistic study results on such issues as individual perception and understanding of the risk, and individual and community planning and preparedness.

Following the workshop, collaboration that was initiated between the CIGDEN research group and Diego Melgar resulted in the publication "A hybrid deterministic and stochastic approach for tsunami hazard assessment in Iquique, Chile" (https://link.springer.com/article/10.1007/s11069-019-03809-8). They are also working on another related paper on tsunamigenic stochastic scenarios and PTHA techniques in the south-central Chile seismic gap.

Response-surface-based probabilistic tsunami hazard assessment with extensive use of numerical simulations.

This project, joint between Prof. Youngjun Choe at UW and several participants from Tohoku, is currently being written up as a paper by T. Kotani, S. Takase, S. Moriguchi, K. Terada, Fukutani, Y. Otake, K. Nojima, M. Sakuraba, and Y. Choe

Abstract: A method of response-surface-based probabilistic tsunami hazard analysis (PTHA) is proposed on the premise of extensive use of highly developed numerical simulations. The basic idea is based on a reliability-based design scheme developed in the research field of geomechanics. The key advantage of the method is its use of a response surface (RS) of a target event, which is obtained from the results of tsunami simulations. Furthermore, the uncertainties of the RS parameters are quantified. These processes are preparatory to performing a Monte Carlo simulation (MCS). We apply the proposed method to the tsunami

that was induced by the 2011 Great East Japan earthquake as an application example. The coastal tsunami heights are evaluated, and the uncertainties in the fault slip and rake as well as the modeling error associated with the numerical analysis are taken into account. Sendai, Ishinomaki, and Kamaishi are selected as target points, and the RS at each point is obtained from the numerical simulation results. Finally, probability density functions of tsunami height are obtained by performing an MCS. In addition, the contribution ratios of the uncertainties are quantified, and the effects of the uncertainties are discussed.

Tsunami test problems and benchmarks.

The US Tsunami Hazard Mitigation Program (NTHMP) has held several workshops in which several international tsunami modeling groups have come together to compare simulation results on a common set of problems. Many of the core benchmark problems were developed before the large tsunami events of the past decade that have provided a wealth of new observations to compare against. Participants agreed that it would be valuable to develop new benchmark problems, although it was also recognized that it is challenging and time consuming to do this properly, with suitable input data and metrics of success that make it possible to compare diverse models. Discussion at the workshop let to extensive emails discussions afterward that have been broadened to include several other tsunami modelers involved in NTHMP and/or the Global Tsunami Model (http://edanya.uma.es/gtm/), an international network that aims to assess and provide community-based standards, good practices and guidelines for Probabilistic Tsunami Hazard and Risk Analysis. Patricio Catalan has volunteered to help coordinate new efforts in this direction. In May, 2019, Shunichi Koshimura from Tohoku visited Catalan's group in Chile and began working on a new benchmark problem based on field data from the 2011 tsunami inundation on the Sendai plane. This would be a valuable test problem since the extensive inundation over several hours was heavily documented. In the past it has been difficult to obtain open source high-resolution topography data in this region, but Koshimura is now working on making this available. This also ties in with data archiving and sharing issues that are discussed next.

Data sharing.

Several breakout groups discussed the possibility for improving efforts to archive and share data related to natural disasters, to make this data more broadly accessible internationally. Examples include engineering data from seismic structural tests or tsunami wave tank experiments, simulation results from tsunami or earthquake benchmark problems, observation data from a variety of seismic or tsunami sensors, and data collected in post-tsunami surveys or in fieldwork performed in the search for tsunami deposits or other evidence of past earthquakes. A number of databases already exist, and valuable information was exchanged at the workshop regarding efforts already underway. Participants are now pursuing some ideas that came out of the workshop, with the goal of enhancing these efforts. For example:

-The Japanese database http://tsunami-portal.bosai.go.jp/en/index contains a wealth of information and is actively being developed as a national repository. Many of the webpages are currently in Japanese, and interest from Chile and the US may help spur development of English versions.

-DesignSafe-CI is the web-based research platform of the NHERI Network that provides the computational tools needed to manage, analyze, and understand critical data for natural hazards research (https://www.designsafe-ci.org/). Use of DesignSafe was demonstrated at the workshop to encourage international participation. Shortly after the workshop, Ellen Rathje, lead PI of DesignSafe, visited UW, and several workshop participants met with her to further discuss archiving additional datasets. Since the workshop Prof. Terada and Mr. Yamaguchi at Tohoku University have also been exploring the DesignSafe database for sharing benchmarking data related to fluid-structure interaction problems.

-The National Centers for Environmental Information (https://www.ncei.noaa.gov/) develop and archive many datasets related to natural hazards, e.g. topography/bathymetry, tide gauge and DART buoy records used in tsunami modeling. Shortly after the workshop discussions were initiated with NCEI personnel about the possibility of archiving additional data related to benchmark problems or field work, with a positive response.

Modeling sediment transport during tsunamis.

A new collaboration between Anawat Suppasri and Carrie Garrison-Laney was developed based on conversations during the workshop and post-workshop field trip. Anawat's presentation on tsunami sediment transport modeling, followed by the field trip to examine tsunami deposits at Discovery Bay, led by Carrie, inspired a collaborative project to model potential tsunami sources based on the tsunami deposit characteristics. Although there are many described tsunami deposits along the U.S. west coast, and a small number of sediment transport studies that have modeled tsunami sediment transport by Cascadia tsunamis, there are no sediment transport studies that have used the deposits to test for different tsunami sources. Discovery Bay is an ideal setting to test various tsunami sources because it has a greater number of tsunami deposits than known Cascadia earthquakes. The other deposits may represent tsunamis from previously unidentified northern segment Cascadia events, or tsunamis from Alaska, or tsunamis from unidentified local sources, which may include crustal faults or submarine landslides. A tsunami sediment transport model developed by Tohoku University (TU) will be applied to deposits at Discovery Bay to identify potential tsunami sources. At present (June 2019), detailed bathymetry and topography data from Alaska to Discovery Bay has been prepared and is undergoing final review before pre-run of the sediment model by TU. Further analysis of characteristics of a tsunami deposit suspected to be from the 1964 Alaska Good Friday earthquake tsunami will be done by UW and this data will be used as input for TU's sediment transport model for an Alaska source. Results of this study will help identify the range of sources that may cause tsunamis in the Strait of Juan de Fuca, and will improve tsunami hazard assessments for the area. Additional discussions took place at Tohoku University in November, 2019.

Studying the effect of coastal forests on tsunamis.

LeVeque worked with Tohoku participants Terada and Moriguchi to assist in the completion of a paper titled "Multiscale Evaluation Method of the Drag Effect on Shallow Water Flow through Coastal Forests based on 3D Numerical Simulations". The lead author on the paper is Reika Nomura, a PhD student at Tohoku who was not able to attend the workshop but who previously visited UW for several weeks to work with LeVeque and others, funded by Tohoku University. This paper has been submitted to the Coastal Engineering Journal.

Appendices.

- Notes on March 1-2, 2020 field trip to Ocosta Vertical Evacuation Structure and related sites.
- Some photographs from the workshop and fieldtrip in March, 2019.
- For photographs from the Japan trip, see the Google Earth project https://tinyurl.com/TohokuFieldtrip

Notes: March 1-2, 2020 field trip to Ocosta VES and related sites.
Provided by Scott Cameron.

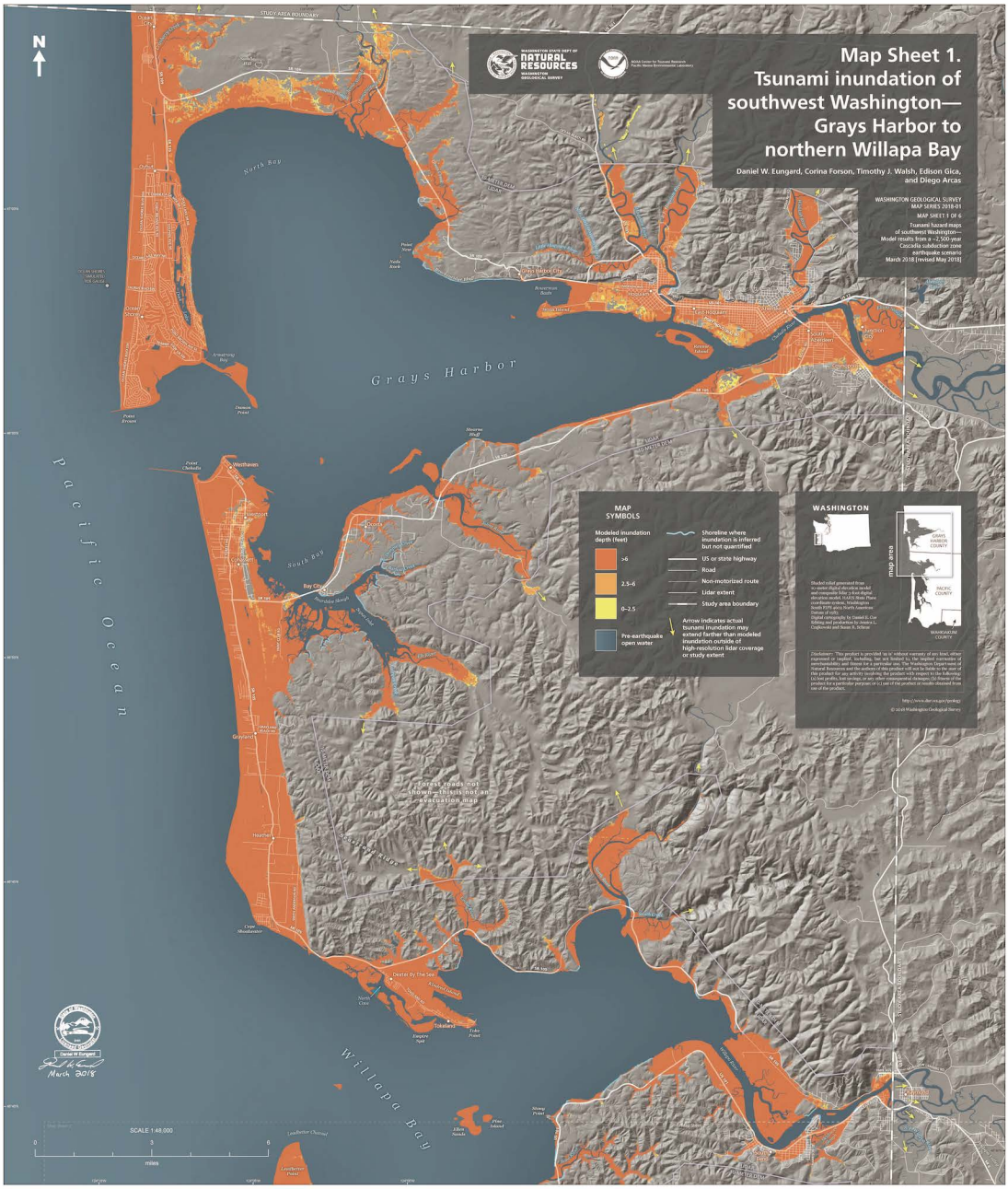
On March 1-2, 2020 several of us undertook a field trip to the Grays Harbor area, to visit the Ocosta School Vertical Evacuation Structure (VES) as well as other candidate VES sites associated with schools and communities in the region. The group included:

- Dan Abramson of the Urban Design and Planning Dept. faculty at UW, Seattle.
- Naoko Kuriyama of the Architecture Dept. faculty at Kobe University, Japan.
- Jorge Leon of the Architecture Dept. faculty at Universidad Tecnica Federico Santa Maria, Chile.
- Robert Hutchison of the Architecture Dept. faculty at UW, Seattle. Rob attended on Day 1 only.
- Scott Cameron of the NAS Board on Earth Sciences and Resources, and a geologist, Seabrook.

Day 1 (March 1): Westport, Grayland, Tokeland

The group first met in Westport, at the Westport Maritime Museum facility, for a general orientation to the overall trip. Our hosts there were two members of the Westport Tsunami Hazard Committee: John Shaw,Executive Director of the Westport South Beach Historical Society, and Kevin Goodrich,City of Westport Public Works Director. Dan reviewed the goals of a cooperative project that he, Naoko, and Jorge are undertaking to share lessons learned between Japan, Chile, and the USA about VES and other tsunami evacuation applications; relocation of housing and public facilities out of tsunami hazard zones; and other long-term coastal hazards resilience strategies, especially considering the ways prior experience of tsunamis informs decision-making on such strategies. Kevin provided an overview of the tsunami hazard in the Greys Harbor area associated with the 2,500-year "L1" event of a Cascadia Subduction Zone (CSZ) megaquake, as documented in 2018 Cascadia tsunami modeling of the Washington DNR (summarized and depicted in Washington Geological Survey Map Series 2018-01, or WGS MS2018-01):[1]

[1] Eungard, D. W.; Forson, Corina; Walsh, T. J.; Gica, Edison; Arcas, Diego, 2018, Tsunami hazard maps of southwest Washington— Model results from a ~2,500-year Cascadia subduction zone earthquake scenario: Washington Geological Survey Map Series 2018-01, originally published March 2018, 6 sheets, scale 1:48,000, 11 p. text. [http://www.dnr.wa.gov/publications/ger_ms2018-01_tsunami_hazard_southwest_washington. zip]



The group also looked at the current state of ground surface evacuation information published as a Tsunami Evacuation Walk Times map for Aberdeen, Hoquiam, and Cosmopolis:[2]

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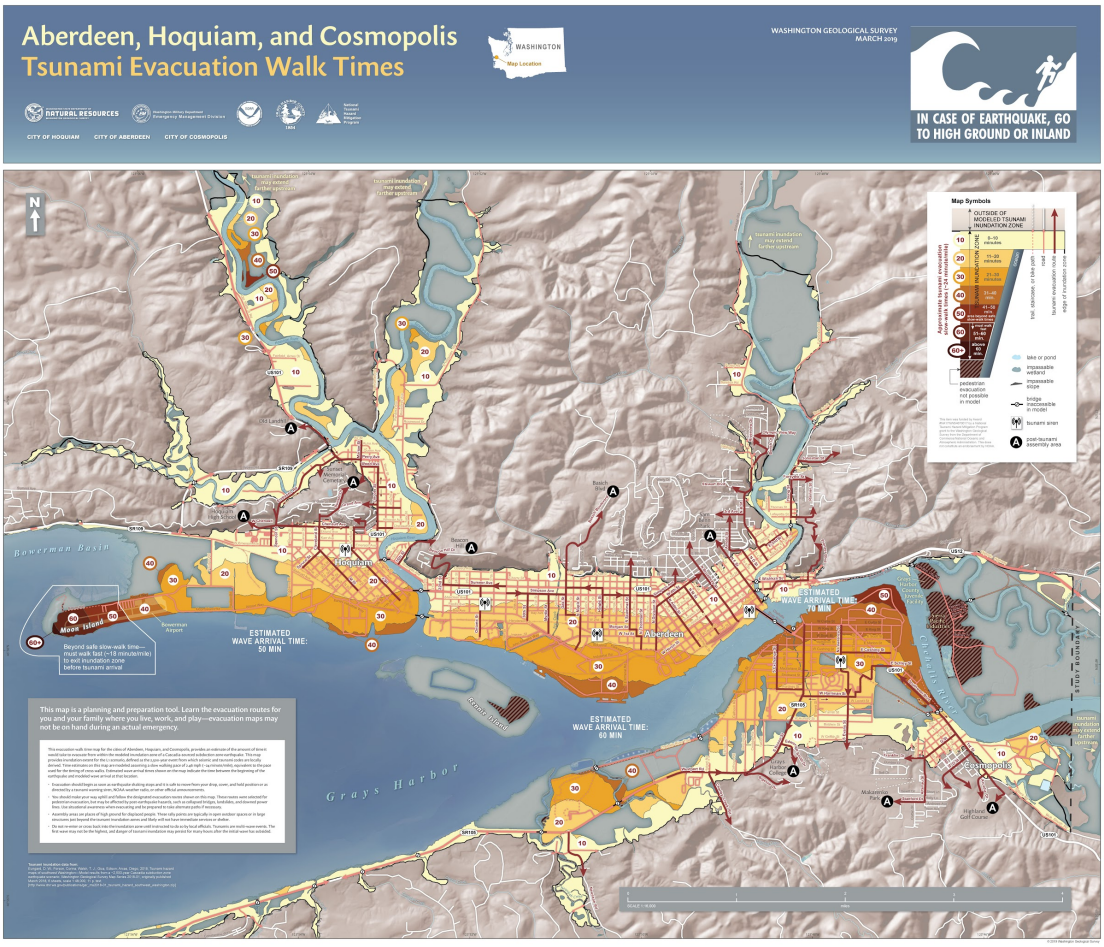
[2] Washington Geological Survey, 2019, Aberdeen, Hoquiam, Cosmopolis Tsunami Evacuation Walk Times: Washington Department of Natural Resources, Washington Geological Survey, 1 sheet. [https://fortress.wa.gov/dnr/geologydata/tsunami_walkmaps/ger_tsunami_walkmap_aberdeen_hoquiam_cosmopolis.zip]



John shared some of the history of the Ocosta School VES facility, and efforts in the nearby Aberdeen school district to address the most pressing tsunami threat, at Stevens Elementary. We then visited the Westport harbor and port, lighthouse, and the nearby beachfront condominiums for orientation on the tsunami hazard and local topography. We briefly visited the Ocosta School VES to examine the exterior of the project, and its position on the highest ground in the Westport area. It is protected in part by relict beach ridges on the seaward side. Ocosta School VES is discussed further below.

We then drove south toward Tokeland, on the north shore of Willapa Bay. We visited the cranberry fields near Grayland, and drove up one of the tsunami evacuation routes in the bluffs rising abruptly to the east of Grayland. Similar routes locally provide potential evacuation corridors elsewhere to the south, before Washaway Beach is reached. But some localities along this stretch that are distant from these routes would benefit from VES platforms (including some WA State Park lands along the shore). The latest tsunami modeling forecasts inundation depths generally exceeding 20-25 ft. west of SR 105 along this stretch of coastline (WGS MS2018-01).

A brief stop was made at Washaway Beach, one of the most active sites of coastal erosion in the USA (owing to vigorous long shore transport). I noted between 700 to 1400 ft. of lateral retreat of the shoreline could be observed here since ca. 2008, based on comparing the shoreline indicated by the 2008 vintage GPS maps in my car with the current shoreline. The road itself is currently at the shoreline edge for much of this area (and only preserved by active engineering mitigations).

At Tokeland, we visited the site of the proposed (and we heard now funded) Shoalwater Bay VES platform, about halfway down the peninsula. The latest tsunami modeling forecasts inundation depths of about 15 ft. at this location (WGS MS2018-01). This structure would be the first "single purpose" VES platform in the area, and the prototype for a number that have been proposed to only be used for tsunami evacuation, of ca. 400 people. It would provide shelter for those who would not be able to reach the high ground near the Casino at the northern, landward end of the peninsula in a timely manner.

We stayed at the Tokeland Hotel and discussed day's activities over dinner, along with Kevin and his wife.

Day 2 (March 2): Westport, Aberdeen, Ocean Shores

We visited three school districts on Day 2, and talked with three current and former superintendents.

We began back at Ocosta School in Westport, where we met again with Kevin and Steve Schmeling, the Facilities/Services Manager for the district. He led our tour of the multi-purpose Ocosta School VES. It was constructed in conjunction with replacement and expansion of the district's only elementary school. All of the district schools and facilities are located together at a single site at Ocosta. This site is modeled to be just above the inundation zone in the latest tsunami modeling (WGS MS2018-01). The VES facility includes a two story, multiple purpose area below, and the roof top evacuation deck on the top (third floor effectively). The lower floors include the school cafeteria, kitchen, gym, music center, student area, and restrooms. This is directly connected to the main classroom wing, and is an attractive facility itself. Above is the VES deck. This deck is about 55 ft. above sea level, and can accommodate the 700 plus students and staff of the school district in the event of a tsunami, who would access it via 4 separate stair towers. Key supplies (water, rations) for short term used are stored there. The deck could actually accommodate up to 2000 persons in total (about the population of Westport) as needed, but focus is on the students and staff. They practice evacuation drills twice a year, and can fill the facility in about 8-10 minutes (first waves are modeled to arrive at Westport in between 15-20 minutes after an earthquake – WGS MS2018-01). The incremental cost for adding the VES elements (enhanced foundation and frame of building, evacuation deck, extra height) was about $2 mln. The entire project (and all of the incremental cost of the VES) was

funded by the local community through a bond election, and received 70% support from voters (property taxes fund most of the costs for school projects like this in WA). We chatted briefly with the current Ocosta Superintendent, Heather Sweet. Like Kevin and Steve, she indicated the dual-purpose nature of the facility was popular with the community and a source of local pride.

We next made an opportunistic stop at Stevens Elementary School in the nearby Aberdeen School District. Aberdeen is a larger city and has multiple school campuses, located on both sides of the Chehalis River. Stevens is located on the south side of the river, in an area underlain by river deposits/wetlands and fill from historic development, and hence is vulnerable to liquefaction in case of an earthquake. Differential land settlement and local flooding are evident in the area today. The school dates from the 1950s, and is the top priority project for replacement within the district. We met with Principal Arnie Lewis who provided an overview of the history, status and plans. The school lies within the tsunami inundation zone. Water depths of 8 ft are forecast at this site in the latest tsunami modeling (WGS MS2018-01). The current evacuation plan calls for the students and staff to walk nearly a mile south to high ground. But given the age of the students (including pre-school children as young as age 3) and the likely disruption of the ground surface by shaking, two options were considered for a new building. Moving the campus to high ground was the original plan, and a site identified. But the incremental cost was very high compared to the alternative, and significantly much of the local community was opposed to moving the school, which is a key resource for the neighborhood. In addition, there is a nearby Junior High School of more recent vintage, which shares the same risks for overland evacuation and would benefit from a VES at Stevens. So the current plan calls for a new elementary school to be built on city land adjacent to the current Stevens campus, with a VES deck on top. It would be sized to accommodate nearly 1500 persons (all the students and staff of Stevens and the Junior High). Initial funds for preliminary engineering work have already been secured from FEMA. It was proposed to the voters in a very recent bond issue and failed by a single vote. The School Board will resubmit the bond at the earliest opportunity.

In the afternoon we drove to Ocean Shores, which is probably the most vulnerable community in the area to tsunami threat. The community extends north to south for several miles along a narrow peninsula. It is low lying, and in the latest tsunami model (2018) none of Ocean Shores would be spared from inundation. The only exit route is the two-lane highway to the north. The peninsula is dissected by a number of natural lakes and man-made canals, which control access and exit to neighborhoods, and are crossed by only a few key bridges. It is likely most of the bridges will be compromised in a major earthquake. For these reasons, emergency planners identify Ocean Shores peninsula as a candidate area for VES mitigation. At one time the Quinault Lodge and Casino, at the north end of the peninsula, considered a building a dual purpose parking garage/VES tower to serve that facility, but that proposal is currently on hold. The latest tsunami modeling forecasts inundation depths of 30+ ft. here (WGS MS2018-01). We learned that the

city of Ocean Shores has recently been awarded a $500,000 grant from the state for VES studies.

Our goal was to visit the North Beach School District facilities here, and the superintendent Andy Kelly (who has been in this role about 1.5 years). This district serves all of the North Beach communities, from the city of Ocean Shores to Moclips (and even some of the students from Taholah on the Quinault Reservation), a total of ca. 700 students (similar number as for Ocosta). The district serves these various communities with three campuses: a high school/junior high and bus barn just north of the Ocean Shores city limit, a recent vintage elementary school in Ocean Shores, and an old elementary school (vintage mid 1950s) in Pacific Beach.

Andy and his team have considered how to upgrade their district facilities to address the challenge of earthquakes and tsunamis. His current thinking is to propose a major construction bond issue in early 2022, after the current bonds are retired in late 2021. It would include a comprehensive construction plan to mitigate these hazards, at all three campuses.

Pacific Beach Elementary: This is the top priority as this school was just ranked as the second most vulnerable campus in the state for seismic hazards. It lies within the inundation zone as identified in WGS mapping in 2000 (updated in 2014). Fortunately, there is an available school site on high ground uphill from town, near the fire station (GHCFD #8). The plan is to build a new school out of the inundation zone that would accommodate both the current Pacific Beach students and the satellite Montessori school campus at Seabrook. It could be sized to also accommodate elementary students from Taholah (where the current campus also lies in the inundation zone).

Ocean Shores Elementary: This school is within the city of Ocean Shores and was built in the mid 2000's. It is separated by a canal from the main evacuation route off the peninsula, with one key bridge for exit, so VES is the only option here given the inundation depths forecast in the latest tsunami models. The latest tsunami modeling forecasts inundation depths of 20+ ft. here (WGS MS2018-01). Fortunately, the campus has space for an extension to the south wing of the school, and it would be possible to add an instructional wing here with a VES deck on top, to accommodate at least all the students and staff. Growing enrollments at this campus help make the case for the expansion.

North Beach Junior-Senior High School: Located just north of the city limits of Ocean Shores, this campus also houses the bus barn, sports fields, and administrative offices for the district. The latest tsunami modeling forecasts inundation depths of 30+ ft. here (WGS MS2018-01). The schools are vintage 1990s, and still have useful life. What is missing in the district is any sort of performance center/auditorium for district events. The proposal is to construct such a facility, with a VES deck on top, which could serve not only the district needs but also those of the larger Ocean Shores area community. The existing Convention

Center is not ideal for concerts/plays/theatre functions, so it could be a real multiple-use asset. Depending on the size of the performance hall, the VES deck could be quite large and accommodate both students and staff, but also nearby persons in the community.

Further discussions are needed to mature these options, and Andy mentioned he has scheduled a meeting with local Ocean Shores city leaders to discuss some of these options. There may be opportunities to leverage some of the funds already allocated from the state for supporting studies on these and other options.

We concluded our field trip with a dinner discussion with Harry Carthum and Paula Akerlund to learn more about how the Ocosta School VES project came to successful implementation. Paula was the Superintendent at the time and Harry was the School Board President.

Paula noted that shortly before she assumed the role, a bond issue to replace the old Ocosta Elementary School failed. When she came on the scene, the lessons from the Tohoku tsunami were fresh in the public mind. She and her team realized the district needed not only a new school but also a VES facility to provide safety for the students, based on the best available science. They worked with scientists and emergency managers to make the case on the hazards and mitigation, with architects and engineers on the design options for multi-purpose structure, and with all members of the Ocosta district community (from Westport to Tokeland) to make the case. The process from kickoff to the bond issue took about 12 months. She told the community that if the measure failed the first vote, it would keep returning until the dual needs for the educational and safety facilities were addressed. In the end, after unsuccessfully seeking external federal and state support, the voters were told they would pay the incremental $2 mln for the VES enhancements themselves. The measure passed with 70% support, including support from both the town itself but significant support from the outlying communities. A key factor of course was the desire to keep the children safe, especially when the parents were away at home or work.

Harry noted that clear focus on the end in mind – the key objectives, was reiterated throughout and helped win the day. It was also noted that a survey of the district community helped provide key input to the process and likely helped buy-in from the community. The Ocosta management team's experience provides some key lessons for others considering such a project, especially for school districts spanning multiple communities.

Harry provided an update on subsequent efforts by the South Beach Tsunami Hazard Committee to add additional VES structures in the area. So far, only Shoalwater Bay is moving ahead (with a single purpose tower). An attempt to build a large parking/VES structure for Westport did not succeed, and cost was one issue. Two other approaches are being considered now.

- It appears that multipurpose structures/towers have more attraction than single purpose towers. A two-floor design is being considered for the port area of Westport, with a covered floor for events and an upper VES deck, both of which would be at sufficient height for safe evacuation.
- Increasing cost pressures are a challenge, and it appears that some estimates for publicly funded projects are significantly higher than for privately funded projects of comparable design/materials (costs of labor were cited as one issue for example). There may be options for communities to seek private parties to build projects and then buy them back, at considerable cost and time saving, and perhaps with greater economies of scale.

Some photos from the M9 Disaster Science Workshop
and field trip in March, 2019


PNSN
Pacific Northwest Seismic Network
Moderate Shaking Expected
VOLCANO
VACUATION
ROUTE
TSUNAMI
EVACUATION
ROUTE


CAUTION
MUD FLATS ARE
DANGEROUS
PLEASE KEEP OFF


東北大・津波工学