

2023 Annual Report to the NOAA Science Advisory Board from the Tsunami Science and Technology Advisory Panel

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1. Executive Summary

The purpose of this report is to provide an annual update to NOAA's Science Advisory Board on the Tsunami Science and Technology Advisory Panel's (TSTAP) activities and subject matter expert briefings for the 2023 calendar year.

Following the Quadrennial Report submitted to the NOAA Administrator in 2021, the TSTAP developed a work plan for 2023 and followed its long-term strategic plan focusing on specific topics to address gaps in knowledge and improve response outcomes. At the TSTAP in-person meeting in May 2023, the TSTAP was briefed on responses from NOAA to recommendations made in the 2021 TSTAP Quadrennial Report. NOAA outlined ongoing and future work plans to address recommendations about consolidating and improving the Tsunami Warning System. NOAA indicated that many of the recommendations should be addressed by the National Tsunami Hazard Mitigation Program (NTHMP). The TSTAP raised concerns about a number of recommendations which remained unaddressed and a lack of capability and support for the NTHMP to address other recommendations. Some of these concerns were raised in a stand-alone 2023 TSTAP "[white paper](#)" on tsunami alerting for complicated inland waterways where large population centers exist; the white paper is discussed in more detail in Section 4.3. The NOAA Quadrennial Report response and TSTAP engagement with NOAA regarding that response were a primary focus for 2023 and thus this annual report reflects those discussions, which are summarized in Section 6.

During 2023, subject matter experts briefed the TSTAP on topics summarized as follows:

- **Tsunami Vulnerability and Risk:** Two expert briefings and discussions were held (February 2023 with FEMA representatives and August 2023 with NTHMP

representatives); see discussion in Section 5.1. Concerns raised to the NOAA Science Advisory Board and NOAA about how tsunami hazards may be misrepresented and underestimated in FEMA's National Risk Index are summarized in Section 4.2.

- **TSTAP in-person meeting and NOAA Response to 2021 TSTAP Quadrennial Report:** See discussion in Section 5.2 and Section 6.
- **International Tsunami Program:** Dr. Laura Kong, Director, International Tsunami Information Center (ITIC), led the briefing in July. See discussion in Section 5.3.
- **National Tsunami Hazard Mitigation Program (NTHMP) briefing:** Representatives of NTHMP subcommittees discussed their views on NOAA's Response to the 2021 TSTAP Quadrennial Report and actions they may take to address some of the recommendations where the NTHMP's engagement was described in the NOAA Response. See discussion in section 5.4.
- **Briefing by NWS AFSSO Director:** The TSTAP was briefed by NWS AFSSO Director Allison Allen in October in place of NWS Director Ken Graham who could not attend. See discussion in Section 5.5.

All of the briefings to the TSTAP in 2023 focused on topics that require some amount of follow up. The TSTAP will continue to receive briefings from NOAA and subject matter experts and will use the observations and findings written in this report (and future annual reports) in its next Quadrennial Report. Some of the key findings discussed here may result in future recommendations to NOAA.

2. Background

The Tsunami Science and Technology Advisory Panel (TSTAP) was established by legislation (P.L. 115-25, Section 503, *et seq*). The TSTAP was formed in August, 2020 and is one of five standing NOAA Science Advisory Board (SAB) working groups.

The Charge to the TSTAP as described in its 2020 *Terms of Reference* is two-fold:

- 1) Every four years, beginning in 2021, the TSTAP will deliver a report to the SAB through the Environmental Information Services Working Group (EISWG.) Per the *Tsunami Warning, Education, and Research Act* (TWERA) component of The Weather Act (P.L. 115-25), the NOAA Administrator shall submit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a copy of the most recent Panel review report.

The first Report was submitted in December, 2021. ([Copy here](#))

- 2) In the years in which a report is not submitted to Congress by the NOAA Administrator, the TSTAP shall provide a report on its activities to the SAB at one of the SAB's in-person meetings. The first TSTAP Annual Update Report (2022) to the SAB was submitted and approved by the SAB in April, 2023. ([Copy here](#))

Following is the 2023 TSTAP Activities Report on the Panel's work during 2023. This report is intended as an update for the NOAA SAB and, unless the SAB directs, is not transmitted to Congress.

3. 2023 TSTAP Activities

3.1. Work Plan

The TSTAP Annual Work Plan for calendar year 2023 is an internal document meant to provide focus and direction on TSTAP reviews, observations, and findings on issues or concerns not previously discussed or investigated in-depth. The 2023 Work Plan was dynamic and changed based on what was presented from the NOAA Response to the 2021 TSTAP Quadrennial Report. On a regular basis throughout the year, the TSTAP reviewed a list of topics to consider, and prioritized them through an informal ranking process.

The following items and discussion topics are included in the 2023 TSTAP Work Plan and in this Report:

- TSTAP in-person meeting
- NOAA Response to 2021 TSTAP Quadrennial Report
- Briefings and further discussion on tsunami vulnerability and risk, International Tsunami Program and International Tsunami Ready activities, NWS Management updates
- Reports: Statement on FEMA's National Risk Index, White Paper on Protecting Large Population Centers and Complicated Inland Waterways

For "Expert Briefings, Section 5," we summarize the observations and findings from the presenters. The TSTAP has initiated a review of these findings to determine their urgency and importance for suggested, more immediate action by NOAA. The "Initial TSTAP findings" in each Expert Briefing section summarizes the discussions and status of the TSTAP review.

3.2 TSTAP In-Person Meeting

The TSTAP was given approval to hold its first in-person meeting, but due to budget limitations, the meeting was held on the NOAA Sand Point Campus in Seattle rather than the preferred location of Hawaii at the Pacific Tsunami Warning Center. This meeting was held May 1 - 3, 2023. More discussion on the outcomes of this meeting are in Section 5.2 and Section 6.

3.3 Filling TSTAP Vacancies

Two original members of the TSTAP resigned in 2022; one for requirements for work, and another for personal reasons. The TSTAP discussed potential candidates who would fill the gaps created from these vacancies. Two highly qualified professionals were identified and appointed: 1) Dr. Elena Suleimani of the University of Alaska Fairbanks Earthquake Center was appointed in September, 2023, and 2) Dr. Elizabeth Vanacore of the University of Puerto Rico was appointed at the end of December, 2023.

3.4 Updating of TSTAP Terms of Reference

The original TSTAP Terms of Reference were written by the SAB Chair in February 2020. The TSTAP began its work in August, 2020.

Since then as the TSTAP has established itself, prepared reports, and interacted with the SAB, its Working Groups, and NOAA, an update of the TSTAP Terms of Reference was needed.

Three changes were made in this revision:

1. Codified the Co-chair rotation scheme with overlapping two-year terms to provide continuity.
2. Defined member terms of service and method to fill vacancies to be consistent with SAB procedures.
3. Decoupled administratively from the EISWG but retained the EISWG liaison. This change eases the EISWG workload.

The revised TSTAP Terms of Reference were accepted by the EISWG and the SAB in November, 2023 with agreement to transmit a recommendation to NOAA that the TSTAP be decoupled from the EISWG and become a standing working group of the SAB. This recommendation was transmitted to NOAA in early January 2024. When the NOAA Administrator approves the recommendation, which we anticipate in early 2024, the updated TSTAP Terms of Reference will be posted on the SAB website.

4. 2023 TSTAP Documents and Reports

4.1 2022 SAB Update

Per terms of enabling legislation, in the years in which a report is not submitted to Congress by the NOAA Administrator, the TSTAP shall provide a report on its activities to the SAB at one of the SAB's in-person meetings.

The 2022 SAB Update Report was reviewed and approved by the EISWG and presented to the SAB in April. It was approved and transmitted to NOAA. ([Copy here](#)).

4.2 National Risk Index Statement

The TSTAP may, at its discretion, write a report about an activity that has time-sensitive implications for tsunami-related issues.

The TSTAP developed a [statement](#) based on concerns that FEMA's National Risk Index's (NRI) treatment of tsunami hazards underestimates actual levels of risk from tsunamis relative to other hazards. This could lead to coastal communities with significant tsunami threats being excluded from potential Community Disaster Resilience Zones Act (CDRZA) financial and technical assistance as well as a national misrepresentation of tsunami risk. In its statement, the TSTAP recommends that NOAA:

1. Communicates to FEMA leadership and Federal decision makers that the NRI currently misrepresents tsunami risk and that these errors can have negative impacts to community preparedness, local and county planning, mitigation funding opportunities, access to funding, and policy making.
2. Supports its Federal, state, and territory partners to develop interim tsunami hazard maps for local and distant tsunami sources for NRI use based on subject matter expertise that includes consistent hazard mapping assumptions and includes attributes relevant to the NRI (e.g., threat levels, annualized frequencies, and historic loss ratios).
3. Works with its partners to develop national probabilistic tsunami maps for local and distant tsunami sources that are updated every four years to align with the building code cycle and the USGS National Seismic Hazard Map.

The *NRI Statement* was presented to the EISWG and SAB by the TSTAP Co-Chairs and on approval by both groups, was provided to NOAA on August 8, 2023. ([Copy here](#)).

As of the end of December, 2023, (end of reporting period), the TSTAP was informed that instead of this statement being sent to FEMA as the SAB requested in its transmittal letter, the statement was referred to the National Weather Service for a response to the TSTAP. This was not what was expected or requested by the SAB or TSTAP. Considering the time period for sharing this statement with FEMA was best to be done in July 2023, this letter will not be as effective due to action/processing delays. The TSTAP hopes that NOAA will forward this statement and the transmittal letter to FEMA as originally requested and approved by the SAB.

4.3 White Paper on Prioritizing Upgrades to Tsunami Forecast Capabilities to Protect Public Safety in Large Coastal Population Centers and Complicated Inland Waterways

In the 2021 Quadrennial Report the TSTAP highlighted the need for upgrades to the tsunami warning system to better detect, forecast, and alert U.S. coastlines. These include: 1) increasing location-specific, numerical forecast amplitude information for regions like Hawaii and inland waterways in Washington; 2) adding location-specific forecast alert regions for San Francisco Bay and Honolulu to separate alerts from adjacent higher hazard areas of the coast, and 3) initiating “Special Procedure Areas” (SPA) for unique conditions such as the crustal faults within inland waterways such as the Puget Sound in Washington for tsunami threats which could reach large cities in mere minutes. The NOAA response to the Quadrennial Report did not fully address the concerns of the TSTAP when it came to these issues. Increasing forecast amplitudes and forecast areas could be addressed through changes to existing forecast alert software, which NOAA has indicated they have done in the past but no longer have the capability to do. Addressing the SPA issues are more complicated problems that likely will require improvements to field instrumentation and alert communication networks.

To better describe the current alerting system, gaps, potential fixes that could be made to the existing system, and consequences if left as is, the [TSTAP prepared a white paper](#) which goes into more detail on the existing alerting and forecasting procedures for these areas. This white paper will be presented to the SAB for approval during the March 2024 meeting. Pending approval of the SAB, this white paper will be a stand alone report that can be referenced in future reports and discussions regarding tsunami alerting needs and gaps for prioritizing upgrades to tsunami forecast capabilities to protect public safety in large coastal population centers and complicated waterways.

5. 2023 TSTAP Expert Briefings

5.1 Tsunami Vulnerability and Risk

5.1.1 Summary of Presentations: Emiliano Gonzalez-Santin, Betsy Hicks, Lauren Schmied, and Casey Zuzak of FEMA provided a briefing on how FEMA approaches understanding people and infrastructure in hazardous places (February 2023).

NTHMP Mitigation and Education Subcommittee (MES) Co-Chairs Nicholas Arcos (NOAA National Centers for Environmental Information) and Todd Becker (California Governor's Office of Emergency Services) briefed the TSTAP on tsunami vulnerability and risk metrics (August 2023) as considered by states.

States and territories have different methods for assessing tsunami hazard zones and the number of people at risk. There are also regional differences in adaptive capacity and assets that enable people to prepare, respond, or recover from tsunamis. The TSTAP is concerned about the lack of consistent methodologies to estimate the number of people at risk and how to determine numbers for those unable to safely evacuate. The lack of consistent national data weakens both FEMA's perception of the national tsunami threat and resources available to build resilience. This is information that needs to be part of National Risk Index methodology. The NTHMP MES is discussing consistent processes for identifying who is in tsunami hazard zones. This cannot be done by using State/Territory evacuation maps because each region uses different methodologies.

The current NTHMP plan is to get the information together and then work with FEMA to get it implemented into the NRI. Funding to complete this analysis is an issue as NTHMP cannot apply for funding because it is not an independent government entity. Only states or territories (NTHMP members, but not the NTHMP itself) may apply for funding, states would need to agree to a common methodology, and then one eligible entity/state/territory would need to volunteer to request funding and collate all the data in a format that FEMA would, in theory, accept.

5.1.2 Initial TSTAP findings:

- NTHMP and TSTAP to continue discussions with FEMA's NRI team as to what data they will be using and how they are going to weigh it.
- Dr. Nate Wood (USGS hazard vulnerability expert and NTHMP member) is actively working on this issue with FEMA and the NTHMP and TSTAP will follow Dr. Wood's work.

- TSTAP should monitor and track progress with the different entities working on this issue.

FEMA gave a presentation on the National Risk Index (NRI) to the TSTAP (February 2023). TSTAP has a number of concerns that were highlighted in the [NRI statement](#) (section 4.2).

5.2 TSTAP In-person Meeting

The TSTAP met in person May 1 - 3, 2023, at the NOAA Pacific Marine Environmental Lab, Sand Point Campus, Seattle, Washington.

Discussions and outcomes from this meeting are listed below.

5.2.1: Briefing by NOAA on Response to 2021 TSTAP Quadrennial Report

A primary focus of our meeting was to review NOAA's response to the Quadrennial Report, ask questions, discuss areas of concern or confusion, and determine TSTAP's next steps and action items. This is summarized in Table 1 in Section 6 of this report.

5.2.2 Tour of NWS Seattle Weather Forecast Office (WFO), DART facility, and Discussion with the National Center for Tsunami Research (NCTR)

As part of the in-person meeting the TSTAP toured the NOAA Deep-ocean Assessment and Reporting of Tsunamis (DART) facility where they saw DART buoys and learn about how bottom pressure sensors are used to detect tsunamis and send those data to the tsunami warning centers for use in forecast and alert development.

The TSTAP received a demonstration of the Advanced Weather Interactive Processing System (AWIPS) at the NWS Seattle Forecast Office by the Warning Coordination Meteorologist (WCM) Reid Wolcott. Some of the main takeaways for the AWIPS and WCM meeting were:

- WCMs are the officials who review TsunamiReady applications, do approval, and provide TsunamiReady recognition. WCMs work with state emergency managers more closely in some states than others, and they are the primary contact for TsunamiReady communities.
- There is flexibility for groups (such as local or state emergency managers) to work with WCMs to send out warnings, but this is not the norm.
- Potential points of failure stood out during the WCM AWIPS demonstration - some TSTAP members worried about the number of human-directed steps in sending weather warnings, meaning more possibility for human error for that type of warning. Note: The Tsunami Warning Centers, not the WFOs, issue tsunami

alerts such as warnings; however, WFOs do activate the Emergency Alert System to disseminate tsunami warnings via that method.

- The staff of the WFO push alerts to the Emergency Alert System (EAS), so if they are unable to do it, it's a potential point of failure.
- Tsunami.gov is populated automatically when the TWCs issue an alert at any level. WFOs have no input to information displayed on tsunami.gov.
- Education and training of NWS-WFO staff is crucial - people may be the weak part of the system and it is imperative for all staff to be trained and to conduct regular exercises.

The discussion with the NCTR focused on the group's role in NOAA and projects they work on. It was interesting to learn that NCTR is a part of the Oceanic and Atmospheric Research Line Office of NOAA and is not part of the NWS Line Office. A main objective of NCTR is to do research and development in support of TWC operations. This includes tasks such as DART systems development and upgrades, tsunami detection, observation, and forecasting technology, and working with and for other partners and entities on tsunami science and research. The TSTAP would like to continue to receive briefings and updates from the NCTR.

5.2.3 Field Trip of Seattle Fault Zone (Field trip handout available in stand alone Appendix B)

On the last day of the in-person TSTAP meeting, members took a field trip to see geologic evidence of the Restoration Point earthquake along the Seattle fault zone in the year 923–924 CE. This earthquake uplifted a block of land between what is now West Seattle and Bainbridge Island, deforming the seabed in Puget Sound, and generating a large tsunami.

The group traveled by ferry from downtown Seattle to Bainbridge Island. On the ferry across Puget Sound, the group was able to visualize the impact a similar tsunami would have on the heavily developed Seattle waterfront and Port of Seattle, and on the immense amount of maritime traffic. On Bainbridge Island at Restoration Point, the group visited a coastline that shows an offset of 7 meters (23 feet) that formed during a single earthquake. The group was able to gain an indelible impression of the hazards of a future tsunami event in a complicated waterway that is criss-crossed by faults, far outside the typical subduction zone tsunami setting that the TWCs routinely alert on (Note: this issue is further explained in the TSTAP White Paper summarized in Section 4.3).

Additionally, the group was able to meet with locals on the island who were able to learn from TSTAP experts and local emergency managers and to share with the TSTAP some of the challenges in receiving information about tsunami hazards, alerting, and potential mitigation options.

5.3 International Tsunami Ready and International Tsunami Program Efforts

5.3.1 Presentation Summary: Dr. Laura Kong, Director, International Tsunami Information Center (ITIC) presented the TSTAP with an overview of the U.S. TsunamiReady® recognition program and its extension to island countries as part of the United Nations Decade of Ocean Science for Sustainable Development¹.

The International Tsunami Ready Programme identifies twelve indicator activities that lead communities through a sequence of tsunami hazard assessment, community preparation, and mitigation steps culminating in recognition of the community achieving Tsunami Ready designation. Participation in International Tsunami Ready is voluntary and does not provide communities with financial or political benefits. Instead, participation raises awareness of the tsunami hazard through education and outreach and establishes response protocols that are exercised within the context of standard operating procedures.

The twelve Tsunami Ready indicators are grouped into four categories:

1. Assessment - Activities and efforts that first identify seismic fault zones having the greatest potential to generate a tsunami impacting a community and then numerically model flooding (inundation) from tsunamis originating from these zones.
2. Preparedness - Activities and efforts to develop evacuation maps based on modeled flooding results. Maps identify areas to be evacuated and assembly locations chosen through a process of community engagement and comment.
3. Response - Activities and efforts to establish or update tsunami response plans, incorporate them into standard operating procedures, and ensure, through exercises, that emergency agencies are prepared to act.
4. Recognition - A celebration of a community achieving Tsunami Ready recognition.

As part of the United Nations Decade of Ocean Science for Sustainable Development, the U.S. TsunamiReady® program is being mirrored to bring awareness of the tsunami

¹ <https://oceandecade.org/>

hazard to vulnerable island countries. Supported by UNESCO / IOC, the International Tsunami Ready Programme² is an adaptation of U.S. TsunamiReady® that includes the same twelve assessments (in addition to 4 more assessment indicators that are U.S.-specific), preparedness, and response indicators and remains voluntary.

A unique response partnership exists between the NOAA NWS and country Weather Service Offices (WSOs). Country WSOs serve as transfer points where forecast responsibility is shifted from NOAA to the country after the NWS alert messages are sent. The NOAA NWS continues to provide WSOs with alert messages throughout the duration of a weather or natural hazard event, including tsunami.

There was also a discussion about the work of the International Union of Geodesy and Geophysics (IUGG) Tsunami Commission which, similar to the TSTAP and NTHMP, focuses on addressing tsunami science, technology, preparedness, and mitigation issues.

5.3.2 Initial TSTAP findings:

The domestic TsunamiReady® program is well established and provides communities with a structured checklist of activities and efforts aimed at raising tsunami awareness and preparedness in communities along vulnerable shorelines. Essential elements are education and ensuring that community leaders and the public can quickly interpret warning messages and know what actions to take in the event of forecasted tsunami waves.

Program effectiveness and the procedures in place to ensure that NWS products meet community needs is unclear. Also unclear is the relationship between NOAA NWS and island countries that rely on alert messages as well as where forecast accountability ultimately lies.

Although NOAA participates in the IUGG Tsunami Commission meetings, participation by TSTAP and NTHMP members may help foster international collaborations, learn about potential beneficial international projects, and facilitate improvements to future Federal, State, and local tsunami science and planning efforts.

² In the international context, the IOC programme is called “Tsunami Ready” with approval from the NOAA Legal Office since the term “TsunamiReady” has a registered trademark – ®.

5.4 Briefing by National Tsunami Hazard Mitigation Program (NTHMP)

5.4.1 Presentation Summary: NTHMP representatives Dr. Summer Ohlendorf, Dr. Liz Vanacore, Maximilian Dixon, and Dave Snider discussed what elements brought to the NTHMP from the NOAA Response to the 2021 TSTAP Quadrennial Report may be addressed by NTHMP subcommittees.

In NOAA's response to the TSTAP's Quadrennial Report, many of the TSTAP's findings fell on NOAA to resolve, and some of them crossed into areas where NOAA collaborates with states/territories and other agencies (see Table 1 in Section 6 for the complete list and where NOAA recommended NTHMP as a partner). Several responses to recommendations indicated the NTHMP as a method/platform to address some of the issues. There are structures within NTHMP, such as the Warning Coordination Subcommittee (WCS) and Mapping & Modeling Subcommittee (MMS), that can address some of the TSTAP's recommendations. The goal of this briefing was to understand whether the NTHMP was aware of the recommendations, and whether the committees have been working towards addressing them.

5.4.2 Initial TSTAP findings:

This was a valuable discussion with many insights into the NTHMP and its subcommittees, and how NOAA/NWS/TWCs engage with these groups. The following are some main takeaways by the TSTAP following the NTHMP briefing:

- The WCS is in the process of discussing their work plan and deciding what realistic tasks (recommendations from TSTAP among the potential options) to include.
- In order to best serve local decision making, the provider of forecast data (the TWCs) first need to understand the decision-making process for every constituent. WCS is currently working on gathering user requirements.
- The focus of the TWCs should be on data quality and its ability to support decision making, rather than on volume of information.
- Since there are different levels of data that are in theory possible to provide, it is important to identify what type of foundational data (such as forecast amplitudes and arrival times, inundation models, or maps) would be useful. This could be clarified by the TSTAP and in conversations with NTHMP.
- Unusual events with limited data and information, like the Tonga tsunami, will continue to happen, and TWCs will need to make timely decisions using limited data. Not every partner has the ability to make evacuation decisions based on limited data: some states/territories are more advanced than others.

- There is a need for more granularity in tsunami alert regions from partners such as Washington State, but there is a variability in how it applies to other partners, and how it should be performed. TWCs have to define the need for requiring a different breakpoint before they consider using it. As of today, another breakpoint cannot be added. This is a problem due to a lack of capability to update alerting software (see the TSTAP White Paper and Section 4.3 of this report).
- TWCs are in the process of transitioning to a new system, and they are not making any adjustments at this point. When they get to the second version of the system, they will likely move towards using alert region polygons. The use of polygons eliminates the need for breakpoints.
- NTHMP has not evaluated the cost of going back to the existing system and adding breakpoints or forecast locations. This activity would require redirecting staff and/or additional funds, availability of which is outside of their control. Therefore the decision was made not to explore this further.
- TSTAP clearly outlined needs, gaps, and requirements. NOAA's progress is slow, but changes are happening.
- TSTAP was informed by the WCS that the items from recommendations that can be done easily have been already completed. Moving forward is complicated due to lack of resources and the fact that WCS doesn't have the authority to direct changes to TWC products or workflows.
- The current status for NTHMP and WCS work is determining steps and priorities, and figuring out how to better advocate for more support from NOAA. The suggestion from the WCS is to break down processes into smaller steps and to focus on partial solutions which can be accomplished.
- The MMS is working on a plan to develop a standardized framework for characterizing, selecting, and using consistent tsunami sources between states.
- The MMS is open to working to improve guidelines for evacuation maps to improve consistency between states/communities and develop a national online repository. This specific recommendation relies on goodwill and agreement of all states and territories to accomplish.
- The TSTAP recommendation to conduct evacuation modeling, feasibility studies, and risk analyses for vertical evacuation structures (VES) was broadly referred to the NTHMP, but not to a particular subcommittee. NTHMP's Mitigation and Recovery Planning Work Group has taken on a task to address how to plan and request funding to construct VES.

The TSTAP will continue to request briefings from the NTHMP and NOAA on how progress is going on TSTAP recommendations that were referred to the NTHMP.

5.5 Discussion with the Director of the National Weather Service Analyze, Forecast, and Support Office

5.5.1 Presentation Summary: Ms. Allison Allen, NWS Analyze, Forecast, and Support Office Director, briefed the TSTAP on October 18, 2023. Presentation highlights are summarized here.

Director Graham included the Tsunami Program among his top 10 initiatives requiring priority attention. Ms. Allen described the work of the Tsunami “Ken’s 10” group that she is leading.

Ms. Allen said that they are working to achieve a single common organizational chain of command for the TWCs and tsunami program and to provide a common layer of analytic guidance. More information will follow when possible.

Several contracts for Tsunami Program improvements have been awarded. 1) Redesign of tsunami.gov; 2) social science to look at the language used in tsunami watches, warnings, and advisories; and 3) addressing information technology vulnerabilities at both tsunami warning centers.

Developing and implementing the AWIPS Tsunami Operations Messaging Service (ATOMS) which will harmonize tsunami alerting between both TWCs is planned for launch and completion in FY25 (Note: NOAA Response indicated delivery in FY24.)

Scoping for what would constitute the Common Analytical System (CAS) has been done, with the hope the CAS will be ready by FY26 if resources permit.

The NWS TsunamiReady® Program will continue to be used as the benchmark measure of tsunami preparedness for the United States; however, the NWS is continuing to evaluate the effectiveness of the program to increase its value at the local level.

5.5.2 Initial TSTAP findings:

Ms. Allen described promising outcomes that will improve the nation’s tsunami preparedness and warning coordination capabilities. Time will tell if the actions will be delivered and implemented as envisioned. The TSTAP is pleased that its recommendation to conduct an appropriate social science study specific for ocean-based alerting is being implemented via awarding a contract for this work. We look forward to a briefing on the results of the study. Further, the TSTAP is pleased that a

contract was awarded to redesign tsunami.gov (Recommendation #3.2, 2021 TSTAP Quadrennial Report).

Establishing the common chain of command for the NWS Tsunami Program has been one of the most pressing recommendations of the TSTAP (Recommendation #1, 2021 TSTAP Quadrennial Report). We are delighted to hear that action on this harmonization is moving forward. This concept has been brought to high levels of the NWS since the National Academies of Sciences Report *Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program and the Nation's Preparedness Efforts* was published in 2011 and initially recommended this action.

With uncertainties in support for developing the CAS, it could take many years before it becomes operational and issues identified in the TSTAP White Paper can be addressed. Potential short-term solutions remain options.

6.TSTAP Summary and Discussion of NOAA Response

In December of 2021 the TSTAP submitted to NOAA its first Quadrennial [Report](#) with recommendations to the NOAA Administrator on matters regarding tsunami science, technology, and regional preparedness. This report provided eight major recommendations with 22 more specific sub-recommendations relating to improving tsunami research, detection, forecasting, warning, mitigation, resiliency, and preparation, all of which are the TSTAP's charges under the *Tsunami Warning, Education, and Research Act of 2017*.

In April 2023 NOAA submitted a [response](#) to the TSTAP report and recommendations. Following the NOAA response, the TSTAP held their in-person meeting to discuss the NOAA response, among other topics. NOAA concurred with or supported many of the recommendations the TSTAP made; however, for many of the recommendations NOAA did not commit resources or provide actionable responses. The TSTAP has identified areas where additional follow-up is needed with NOAA, the NTHMP, or other entities. The TSTAP addressed some issues with the NOAA response during meetings and others are addressed through the TSTAP "White Paper" titled *TSTAP White Paper on Prioritizing Upgrades to Tsunami Forecast Capabilities to Protect Public Safety in Large Coastal Population Centers and Complicated Waterways*. In the table below, the TSTAP provides summaries of each TSTAP recommendation, NOAA's plans to address or not address each recommendation, and next steps to ensure the TSTAP recommendations and NOAA's plan to address the recommendations are on track.

Initial TSTAP findings:

The TSTAP appreciates NOAA's response to the 2021 Quadrennial Report and the discussions that were had at the 2023 in-person meeting to review NOAA's response. While NOAA committed to working on several of TSTAP's recommendations, such as TWC unification, TWC backup, and an enterprise-wide technology upgrade for the warning system, there are many recommendations in which NOAA has referred the recommendation to another organization or did not commit resources or provide actionable steps to complete. The TSTAP has requested NOAA develop work plans and schedules to address each recommendation. The TSTAP will continue to ask for updates from NOAA on how activities addressing each of these recommendations are progressing. It was also clear that NOAA's priorities are focused on regional tsunami detection, forecasts, and warnings and not TSTAP recommendations related to research, mitigation, resilience, and preparation as well as state/local forecasts, warning, and response needs. For a number of the recommendations NOAA referred the recommendation to another entity, primarily the NTHMP which does not have the authority to direct NOAA activities. The TSTAP has identified areas where additional follow-up is needed with NOAA, the NTHMP, or other entities.

Table 1: NOAA Progress on TSTAP Recommendations in the 2021 Quadrennial Report

This table is color coded based on TSTAP understanding of NOAA's commitment and progress to undertake these recommendations. NOAA may be working on these recommendations and making progress but may not have communicated that to the TSTAP as of December 30th, 2023.

The TSTAP color coded the recommendations in the Quadrennial Report based on briefings from NOAA, the NTHMP, NWS leadership, and SME briefers accordingly:

GREEN: Progress is being made by NOAA and funding and or staff resources have been allocated and TSTAP is aware of progress.

YELLOW: NOAA generally concurs with this recommendation and may be looking for resources or opportunities to address this recommendation.

RED: NOAA partially concurs or is open to this recommendation but no indication of how this recommendation will be addressed or completed has been provided to TSTAP. For many of these recommendations NOAA suggested that other partners, such as the NTHMP, work on this.

Major Recommendations	Sub-Recommendations: It is recommended that the NOAA Administrator... [TSTAP 2023 Annual Report color code]	NOAA Responses and TSTAP Follow-Up
1. Improve unification and capabilities of the Tsunami Forecast System.	1.1. Align and consolidate TWCs and overhaul the forecast system to unify detecting earthquake parameters and produce the same products (e.g., forecast wave heights). [GREEN]	NOAA mostly concurred. Some alignment issues will be implemented through installation of Tsunami AWIPS communication system (Q2FY24) and common analytical system (CAS; unknown completion data). However, NOAA indicated that the priority for expanding forecast location products may not be addressed until "second phase" of Tsunami AWIPS which has no timetable to be completed. TSTAP requests updates from NOAA on this work and will reference their "white paper" which identifies several remaining issues with needed forecast products.
	1.2. Undertake a comprehensive, enterprise-wide technology upgrade for the warning system/program. [GREEN]	NOAA concurred. The transition of legacy TWC product and message generation software to AWIPS and the development and fielding of the TWC common analytic system will address this recommendation. TSTAP requests updates from NOAA on this work.
	1.3. Strengthen the collaborative relationship and expand MOU with the USGS for identifying earthquake parameters and source mechanism. [YELLOW]	NOAA generally concurred with this recommendation, defending its ongoing relationship with the USGS. NOAA is confident this collaborative effort can be adequately supported through the existing NOAA/USGS MOU. TSTAP requests updates from NOAA, especially on meetings with the USGS and actions/outcomes from those meetings and exercises regarding improvements to the TWS. TSTAP also requests that NOAA ensure that the needs of state/local officials are being met and the results are being communicated to those locals/states.
	1.4. Ensure sufficient backup capabilities for tsunami forecasting and alerting. [YELLOW]	NOAA indicated it is fully committed to complying with this recommendation. NOAA believes by pursuing the TWC alignment activities (i.e., AWIPS and CAS), full service back-up between TWCs will be achieved. TSTAP requests updates from NOAA on this work and will reference their "white paper" which identifies several remaining issues with common and consistent forecast products.
2. Improve tsunami detection and observation systems.	2.1. Increase development and improve dissemination of observation networks like tide gauges, web-cameras, and real-time observer programs. [RED]	NOAA partially concurs. The NOAA position is that only deep ocean pressure measurements (DART) provide the information needed for tsunami forecasts. Tide gauges, web-cameras, and other real-time observer programs cannot substitute for deep-ocean measurements. TSTAP will follow up with NOAA. TSTAP believes that with the high number of DART outages and high cost of maintenance, alternatives to supplement DARTs should be sought for at least forecast validation during events. TSTAP requested that other NOAA programs responsible for ocean observing (e.g., tide gauges) be consulted.
	2.2. Expand detection capabilities to all seismic and non-seismic sources. [RED]	NOAA concurs with this recommendation. However, this is a research and development (R&D) effort as there are no reliable indicators of tsunami generation by non-seismic sources before impact to a coastline. TSTAP will follow-up with NOAA on progress of R&D work. TSTAP requested an annual status report/briefing of new technologies evaluations (e.g., Ionospheric tomography and GPS occultation) and examples of non-seismic source capabilities (e.g., Barry Arm landslide in Alaska).
	2.3. Work with NSF and international partners to share and expand the use of GNSS to determine fault rupture extent and movement. [GREEN]	NOAA concurs with this recommendation to expand the use of GNSS. NOAA is engaged with USGS and NASA to add improved earthquake and tsunami characterization capability into tsunami warning center operations. TSTAP requested NOAA provide status report or briefing on outcome of operational testing of GNSS scheduled in Calendar Year 2023.
	2.4. Further consider the use of airborne and satellite observing platforms. [RED]	NOAA concurs with this recommendation. NOAA is actively pursuing airborne and remote-sensing observation platforms for the purpose of tsunami detection and measurement as R&D resources permit. TSTAP is uncertain about the NOAA commitment to pursuing airborne and remote-sensing observation platforms. TSTAP has requested NOAA provide a status report or briefing on achievements, outcomes, and next year funding status.
3. Provide more extensive, consistent, and accurate tsunami messages and products.	3.1. Improve the integration of TWC warning functions with USGS, state, and local warning needs and functions. [RED]	NOAA concurred with this recommendation. Ongoing dialogue with the USGS regarding capabilities such as ShakeAlert has led to enhanced interagency coordination. Integration of Earthquake Early Warning (EEW) into NOAA tsunami forecasts and warnings, while ensuring messaging consistency. This is an area of ongoing discussion between NOAA, USGS, and state partners. There appears to be no commitment from NOAA other than to continue to talk about it. TSTAP requested a progress report/update from NOAA on discussions with USGS regarding tsunami alert integration into EEW platforms.

Major Recommendations	Sub-Recommendations: It is recommended that the NOAA Administrator... [TSTAP 2023 Annual Report color code]	NOAA Responses and TSTAP Follow-Up
	<p>3.2. Improve tsunami message composition and dissemination methods including updating the tsunami.gov website, creating a single domestic bulletin, and early messaging before a tsunami forecast is developed. [YELLOW]</p>	<p>NOAA concurs with this recommendation. NOAA is actively pursuing a complete tsunami.gov re-design starting in fiscal year (FY) 2023. AWIPS is expected to greatly improve the quality of tsunami product generation and messaging. TWC are reviewing if and how core partners can be provided with additional, early real-time information as TWC duty scientists conduct live tsunami analysis. NOAA is evaluating the best way to convey the entirety of the tsunami threat in actionable, consistent terms. Consolidating domestic bulletins is one option being considered.</p> <p>TSTAP requests briefings on progress into improvements to Tsunami.gov, bulletins, and messaging/communication during the first several hours during an event where a forecast is still being evaluated, which may include evaluation of state early messaging templates and sharing of ATFM data within the first 30-60 minutes.</p>
	<p>3.3. Make available foundational forecast data from propagation models and inundation model results to constituents. [RED]</p>	<p>NOAA is open to this suggestion. TWC standard operational procedures are cautious not to issue speculative information in the typically high-uncertainty, high pressure environment that follows tsunami generation in order to limit confusion. NOAA is open to sharing pre-decisional foundational data and analysis with core partners. NOAA will address this in CY23 through the WCS of the NTHMP.</p> <p>TSTAP requests briefings on evaluations and progress by NOAA and recommendations by the NTHMP WCS. TSTAP will reference their "white paper" which addresses some issues related to this recommendation.</p>
<p>4. Develop enhancements to Tsunami Warning Center forecasts and alert systems.</p>	<p>4.1. Expand granularity in tsunami alert regions where complicated waterways exist (e.g., Puget Sound, San Francisco Bay, etc.). [RED]</p>	<p>NOAA partially agreed with this recommendation. NOAA thinks it is better to more broadly describe the threat because of technical difficulties providing more detailed forecasts in complex waterways. NOAA believes it will also be able to better address this during the AWIPs and CAS upgrades and will work with the NTHMP WCS to help rectify.</p> <p>TSTAP requests continued updates on this topic and has addressed the more specific and clarifying requests through their "white paper" to assist with follow up questions, especially if NOAA will follow recommendation from the NTHMP WCS which it does not have to do. TSTAP is also concerned if and when AWIPs can address this recommendation and that the CAS is unsupported and uncertain if and when it will be completed.</p>
	<p>4.2. Update special procedure areas, threat database thresholds, breakpoints, and forecast point locations. [RED]</p>	<p>NOAA partially agreed with this recommendation. NOAA agrees that replacing "procedural" areas with dynamic forecasts and alerts based on real-time data is important as long as this is done carefully and in full consultation with core partners. NOAA indicated that this will be addressed through the NTHMP WCS in CY23 and changes in product or message generation will be enabled through the transition to AWIPS as part of the TWCU effort.</p> <p>As with Recommendation 4.1, these topics are the primary focus of the TSTAP "white paper." TSTAP is concerned about NOAA commitment to complete this work and if NOAA will follow the NTHMP WCS recommendations. TSTAP requested briefings from the NTHMP and NOAA at the end of CY 23 to learn about what has been done on this recommendation.</p>
<p>5. Improve consistency in tsunami preparedness and mitigation products for communities.</p>	<p>5.1. Develop a standardized framework for characterizing, selecting, and using consistent tsunami sources between states. [RED]</p>	<p>NOAA is open to this suggestion, though states have the sole authority to implement it. NOAA will refer this to the NTHMP Modeling and Mapping Subcommittee (MMS) to evaluate the value of establishing common source parameters to be used by all states and territories, understanding that risk assessments may vary. Referred to NTHMP MMS.</p> <p>TSTAP has requested updates from NOAA and the NTHMP MMS regarding this recommendation. Uncertainties exist in the responsibilities and capabilities of the MMS, and NOAA's support for funding development of logic trees and a probabilistic (PTHA) framework for consistent regional tsunami sources and modeling these PTHA sources for consistent mapping products, such as the FEMA National Risk Index (NRI). Work being completed by the states and federal partners through the USGS Powell Center Tsunami Source Workgroup is a good initial step. Follow up with FEMA regarding support for this work is a possibility.</p>
	<p>5.2. As the sponsor of the NTHMP <u>ask</u> the NTHMP to update guidelines for evacuation maps that ensures consistency between states/ communities; further, the NWS should update the tsunami map page on the NTHMP website. [RED]</p>	<p>NOAA is open to this suggestion, though states and local entities have sole authority for evacuation maps. This will be addressed in CY23 within the NTHMP MMS and through website contractors hired by NOAA.</p> <p>TSTAP will request briefings from NOAA and the NTHMP MMS about updating evacuation maps and the associated NTHMP website. Developing a plan and schedule will be helpful. Like other recommendations, support/funding to do this work remains an issue so recommendations for NOAA to engage other funding agencies, such as FEMA, might provide the support needed for producing consistent evacuation maps and NRI products.</p>

Major Recommendations	Sub-Recommendations: It is recommended that the NOAA Administrator... [TSTAP 2023 Annual Report color code]	NOAA Responses and TSTAP Follow-Up
	5.3. Prioritize probabilistic tsunami hazard mapping at a national scale, especially for updating ASCE/Building Code "Tsunami Design Zone" maps. [RED]	<p>NOAA is open to this suggestion, though considered outside of scope of NOAA. NOAA understands the value in a national probabilistic database to support common design and construction concerns. NOAA will raise this issue within the appropriate NTHMP subcommittees, as well as through consultation with the Department of Homeland Security (or FEMA) and National Institute of Standards and Technology (NIST) and consider further actions as resources permit.</p> <p>TSTAP will request briefings from NOAA and the NTHMP about support for consistent PTHA maps. Developing a plan and schedule will be helpful. Like other recommendations, support/funding to do this work remains an issue so TSTAP agrees with NOAA that raising this issue with FEMA and NIST could share support for PTHA products. NOAA's continued work with the USGS Powell Center Tsunami Source Workgroup should continue.</p>
6. Produce guidance for improving long-term community resilience to tsunami hazards.	6.1. Develop guidance and products for tsunami mitigation/recovery consistent with and leveraging climate change adaptation strategies. [RED]	<p>NOAA is open to this suggestion however it is considered outside of scope of Tsunami Program. While climate change certainly contributes to tsunami impacts, it does not directly impact NOAA's detection, forecast, and alerting capability. NOAA will discuss potential next steps with the Office of Oceanic and Atmospheric Research (OAR) and National Ocean Service (NOS) leadership.</p> <p>TSTAP requests updates from the NOAA and would like to participate in discussions with the OAR and NOS to help clarify the recommendation. A plan and timeline for this work would help it progress.</p>
	6.2. Conduct evacuation modeling, feasibility studies, and risk analyses for vertical evacuation structures. [RED]	<p>NOAA is open to this suggestion however it is considered outside of NOAA's purview. Vertical evacuation is an important consideration of a comprehensive tsunami impact mitigation strategy. NOAA will work with NTHMP Partners and other government and industry experts, as resources allow, to explore establishing common standards. NOAA will also encourage states to consider incorporating vertical evacuation studies in their NTHMP grant proposals.</p> <p>TSTAP requests updates from the NOAA and NOAA facilitation of meetings between the NTHMP and FEMA. A plan identifying resources and examples of successful VES work would help this process.</p>
7. Improve tsunami hydrodynamic modeling.	7.1. Improve tsunami modeling capabilities in the following conditions/areas: variable landscapes (i.e., surface roughness), heavy vegetation, built environment, and dynamic river systems. [RED]	<p>NOAA partially concurred with this recommendation, however the type of fine-scale modeling suggested here would normally be outside NOAA's operational alerting scale. However, NOAA admits this is a high priority recommendation for states like Washington and California with high populations in complex coastal environments like the Puget Sound area and San Francisco Bay, as well as populated areas along rivers. NOAA will look for opportunities to partner with NTHMP member states and territories to advance this scale of modeling capability as resources permit.</p> <p>TSTAP requests reports or progress updates from NOAA as well as a plan to support resources needed to improve modeling capabilities. Although a relatively low priority for NOAA's operational forecast system, NOAA should assist states and communities where this is an admitted high priority.</p>
	7.2. Conduct a greater number of high-resolution bathymetric surveys. [RED]	<p>NOAA concurred with this recommendation and will address as resources permit. NOAA has a well-defined procedure, led by the NOS and the National Weather Service Office of Water Prediction, for establishing priorities for bathymetric surveys. With increasing emphasis on terrestrial and coastal flooding, this will include areas important for tsunami warning and mitigation. NOAA ensured that the concerns of the TSTAP are emphasized in future year budget and program planning processes.</p> <p>TSTAP will ask NOAA for progress updates and to identify any support needed to fulfill this recommendation. A plan and schedule for engaging other programs within NOAA will be requested.</p>
	7.3. Develop a data portal for detailed information for advancing research and model development. [RED]	<p>NOAA concurred with this recommendation and will look to provide this sort of portal in FY23 through the NOAA OAR.</p> <p>TSTAP will ask NOAA for progress updates and to identify any support needed to fulfill this recommendation. A plan and schedule for engaging other programs within NOAA would be helpful. TSTAP can assist NOAA in identifying datasets to include or link to.</p>
8. Develop tsunami research priorities and leverage research opportunities	8.1. Coordinate with Federal, state and territory agencies that have funded research that includes tsunami to leverage and prioritize research opportunities and provide consistent and useful products. [RED]	<p>NOAA concurred with this suggestion. NOAA indicated it will be raised as an agenda item with the Interagency Council for Advancing Meteorological (ICAM) Services as a potential Interagency working group.</p> <p>TSTAP will ask NOAA for progress updates and to identify any support needed to fulfill this recommendation. A plan and schedule for engaging other programs within and outside NOAA will be requested.</p>

7. Closing Remarks

The purpose of this report is to provide an update to NOAA's Science Advisory Board on the Tsunami Science and Technology Panel's (TSTAP) activities and subject matter expert (SME) briefings for the 2023 calendar year. 2023 TSTAP activities included:

- Subject Matter Expert briefings on tsunami vulnerability and risk, the International Tsunami Ready Programme, and international tsunami program efforts.
- Approval of the 2022 TSTAP Annual Report.
- The 2023 TSTAP Work Plan.
- Update to the TSTAP Terms of Reference.
- Development of a statement and recommendations to NOAA regarding FEMA's National Risk Index.
- Completion of a [White Paper](#) about improving tsunami alerting for complicated inland waterways where large population centers exist.
- An in-person TSTAP meeting including site visits to the National Weather Service Office in Seattle, the NOAA Center for Tsunami Research, and a field trip to see geologic evidence from a past earthquake on the Seattle fault.
- Discussions with NOAA leadership and the NTHMP on progress made to date on the TSTAP recommendations.

The TSTAP will continue to ask for updates from NOAA, the Tsunami Warning Centers, the National Tsunami Hazard Mitigation Program, and others on TSTAP recommendations from the 2021 Quadrennial Report. It was encouraging to hear that NOAA is making plans to address some of the TSTAPs highest priority recommendations and that there are several contracts and organizational changes in the works. The TSTAP looks forward to more progress being made in 2024 and to continue to work to better prepare the nation for tsunamis.

8. Appendices

List of Appendices:

Appendix A: List of TSTAP members and liaisons

Appendix B (stand alone Appendix, found [at this LINK](#)): Field trip Handout for the Seattle Fault from the 2023 TSTAP in-person meeting

Appendix A

List of TSTAP members for 2023

Co-Chairs:

- Ms. Corina Allen, Chief Hazards Geologist for the Washington State Geological Survey
- Dr. Rocky Lopes, Emergency Manager Emeritus, Applied Social Scientist, formerly supporting the NOAA/NWS Tsunami Program. Retired.

Members:

- Dr. Lori Denger, Emeritus Professor of Geology, CalPoly Humboldt University
- Ms. Marie Eblé, Oceanographer (retired), formerly with the NOAA Pacific Marine Environmental Laboratory
- Dr. Carrie Garrison-Laney, Tsunami Hazards Specialist and NOAA Center for Tsunami Research/Pacific Marine Environmental Lab Liaison, Washington Sea Grant
- Dr. Diego Melgar, Assistant Professor of Geophysics, University of Oregon (resigned March 2023)
- Dr. Aurelio Mercado, Retired Professor of Oceanography, University of Puerto Rico (resigned August 2023)
- Dr. Elena Suleimani, Tsunami Modeler, University of Alaska Fairbanks, Alaska Earthquake Center (appointed September, 2023)
- Dr. Elizabeth Vanacore, Research Scientist, Puerto Rico Seismic Network and Geology Department Faculty, University of Puerto Rico at Mayagüez (appointed December, 2023)
- Mr. Rick Wilson, Senior Engineering Geologist, California Geological Survey

NOAA/NWS Representative:

- Mr. Michael Angove, NWS Tsunami Program Lead (retired end of 2023)

USGS Representative:

- Dr. Paul Earle, Director of Operations, USGS National Earthquake Information Center

Environmental Information Services Working Group Liaisons:

- Dr. Thomas W. Altshuler, Senior Vice President Defense Strategy and Business Development, Teledyne Marine (stepping down, December, 2023)
- Dr. Jeremy Berman, Data & Applied Scientist, Weather Expert, Microsoft