

Appendix¹
NOAA Comments on the NAS Report Entitled
“Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami
Program and the Nation's Preparedness Efforts”
October 2013

1. Aligning Priorities with Societal Risks from Tsunamis

Recommendation 1:

NOAA and its NTHMP, in collaboration with researchers in social and physical sciences, should complete an initial national assessment of tsunami risk in the near term to guide prioritization of program elements. The national assessment should (1) incorporate the best possible relevant science (social and behavioral, geography, economic, engineering, oceanography, and geophysics) and (2) include broad stakeholder and scientific participation to ensure that efforts are responsive to the needs of at-risk communities and decision makers.

NOAA Response:

The National Oceanic and Atmospheric Administration (NOAA) agrees with this recommendation and considers it nearly complete based on the following accomplishments and projects in progress.

NOAA and the National Tsunami Hazard Mitigation Program (NTHMP) recognize the importance of this recommendation. In August 2008, NOAA's National Geophysical Data Center (NGDC) and the U.S. Geological Survey (USGS) completed a NOAA Tsunami Program Special Report for the NTHMP: “*U.S. States and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves.*” This was a comprehensive qualitative national assessment of tsunami risk and included a summary of a pilot study conducted in Seaside, Oregon, by NOAA, the USGS, and the Federal Emergency Management Agency (FEMA) concerning probabilistic tsunami hazard assessment. The National Assessment also identified gaps in current knowledge of tsunami sources, or areas for further review. In July 2012, the NTHMP Mapping and Modeling Subcommittee (MMS) held a quantitative hazards analysis workshop, included the topics of source determination and probability analyses.

NOAA and the NTHMP realize that there is on-going work needed in this area, and have a mechanism (NTHMP's MMS) in place to carry out projects to address tsunami risk assessment and prioritization of program elements. To ensure an accurate and widely accepted quantitative risk assessment, a comprehensive approach including the best scientific data is required. This includes tsunami source hazard and probability studies by the U.S. Geological Survey (USGS), tsunami inundation studies by NOAA and the NTHMP, and vulnerability studies by the Federal Emergency Management Agency (FEMA). FEMA has funded a \$1 million vulnerability study

¹ Cost estimates throughout this document are as of April 2012.

project to develop a tsunami module for Hazus (Hazards US), a GIS-based loss estimation software program that currently has modules to address earthquake, wind, and flood hazards. NOAA does not believe a national risk assessment as described in the NAS report is needed in the near-term to guide the prioritization of program elements, as this prioritization is addressed in the NTHMP Strategic Plan. Although ultimately, a national loss estimation is beyond the scope of the NTHMP, local and regional loss estimations are activities that can be supported by the NTHMP. Eventually, local and regional estimations could be collated into a single national loss estimation in a phased approach over time.

Cost Estimate:

Component	One-time	Recurring
Complete a robust and comprehensive qualitative National Tsunami Risk Assessment	\$20M	\$2.5M (for 14 additional years)

Time to Complete:

Component	Time to complete
Complete a robust and comprehensive qualitative National Tsunami Risk Assessment	15 years

Recommendation 2:

NOAA and its NTHMP partners should institute a periodic assessment of the sources of tsunamis that threaten the United States, focusing mainly on earthquakes, but also on landslides and volcanoes.

NOAA Response:

NOAA agrees with this recommendation and considers it complete based on the following accomplishments.

NOAA and the National Tsunami Hazard Mitigation Program (NTHMP) recognize the importance of this recommendation. In August 2008, NOAA’s NGDC and the USGS completed a NOAA Tsunami Program Special Report for the NTHMP: “*U.S. States and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves.*” This was a comprehensive qualitative national assessment of tsunami risk and included a summary of a pilot study conducted in Seaside, Oregon by NOAA, the USGS, and FEMA concerning probabilistic tsunami hazard assessment. The National Assessment also identified gaps in current knowledge of tsunami sources. In 2012, the NTHMP Mapping and Modeling Subcommittee (MMS) held a quantitative hazards analysis workshop, which included the topics of source determination and probability analyses.

NOAA and the NTHMP realize that there is on-going work needed in this area, and have a mechanism (NTHMP’s MMS) in place to carry out projects to assess sources of tsunamis that threaten the United States. NOAA has funded inundation modeling initiatives through the NTHMP that include construction of inundation maps for at-risk coastal communities and

associated modeling of tsunami affects based on earthquake, submarine landslides, and volcanoes. The foundation of these efforts requires assessment and modeling of the sources of tsunamis. Grants for work in this area have been provided to the following states: Washington, Alaska, California, Hawaii, and Oregon, as well as for the Commonwealth of Puerto Rico. A grant was also funded for tsunami source and inundation modeling from submarine landslides in the Gulf of Mexico.

The USGS is the appropriate Federal agency to coordinate additional work on this recommendation in a consistent manner throughout the United States in collaboration with NOAA, FEMA, and the NTHMP State Partners.

To facilitate periodic re-evaluation of tsunami risks, NOAA, USGS, and the NTHMP State Partners agree with the NAS recommendation to identify tsunami sources as a research priority within the USGS' Earthquake Hazards Program. NOAA and NTHMP also recommend initially focusing on near-field sources, as called for in the NAS report. As part of this effort, NOAA recommends USGS coordinate with NOAA and the NTHMP State Partners to design the objectives of the project. When an initial tsunami source assessment is completed, USGS will inform NOAA and the NTHMP of the results. These results will be used as input for the periodic review of tsunami sources and for NTHMP inundation modeling and mapping efforts.

Cost Estimate:

Component	One-time	Recurring
Periodic (5-Year) Tsunami Source Assessments	\$0	\$1.5M
NTHMP source workshops	\$0	\$70K

§ Following early discussions with NOAA of this recommendation (#2), USGS has developed a preliminary plan, schedule and cost estimation for the initial tsunami source assessment and its periodic updating. The work will: 1) extend the USGS National Seismic Hazard Mapping project to include source characterization relevant to tsunamigenic faults; 2) integrate work at the USGS National Earthquake Information Center that defines the geometry of subduction thrust faults that produce most of the world's damaging tsunamis into the NOAA Pacific Marine Environmental Laboratory (PMEL) database (a.k.a. SLAB 1.0) and extend that work; 3) undertake critical testing of the seismic magnitude estimates of pre-instrumental earthquakes/tsunami-sources through hydrodynamic modeling to match reported runups and marigrams; 4) Begin a multi-year, circum-Pacific effort to improve the knowledge of volcanic tsunami sources using a combined field and modeling approach; 5) correct or redefine the characterization of non-subduction zone, plate-boundary faults (e.g., Queen Charlotte fault, Cayman transform faults) that are currently in NOAA/PMEL's Forecast Propagation Database; and 6) Begin a sustained effort to improve the knowledge of tsunami sources using a combined field and modeling approach.

Time to Complete:

Component	Time to complete
Periodic Tsunami Source Reviews	On-Going
NTHMP source workshops	1 year, in 2012

Recommendation 3:

To improve tsunami inundation modeling, the NTHMP, through workshops convened with the USGS and academic institutions, should periodically review progress in hydrodynamic models, including peer reviews of modeling codes and discussions on how to better incorporate variations in coastal bathymetry, topography, vegetation, and buildings into inundation models.

NOAA Response:

NOAA agrees with this recommendation and considers it complete.

The National Tsunami Hazard Mitigation Program (NTHMP) conducted a hydrodynamic model validation and verification workshop during the week of March 31, 2011, at the Mitchell Campus of Texas A&M University at Galveston. The purpose of this workshop was to begin the process of standardizing mapping products produced by U.S. States and their partners through a systematic review of hydrodynamic models currently in use and those of potential interest. All models, ranging from a full application of the 3-D Navier-Stocks equations to the depth-averaged nonlinear shallow-water equations, were run through benchmarks as proposed by Synolakis et al. (2008) and all were tested to be capable of predicting propagation and runup of long waves. A draft Workshop Proceedings publication is available for download as a PDF on the NTHMP web site. Publication of the final Workshop Proceedings was available as of June 2012. The NTHMP Strategic Plan has a performance measure that establishes standards for all NTHMP-funded models to meet by 2012. The NTHMP has decided that it will fund only hazard mapping that uses validated models starting in 2013.

The NTHMP Mapping and Modeling Subcommittee (MMS) also held a Landslide Source Modeling workshop in March 2011 to review current scientific research, modeling, and findings related to submarine/subaerial mass movements and the hazard they pose to the U.S. coasts.

To ensure advances in research modeling benefit the public, NOAA and the NTHMP will periodically host workshops to review and update current NOAA standards, and to validate new or improved models to the NOAA standards for use in inundation modeling and hazard mapping.

Cost:

Component	One-time	Recurring
MMS Workshops	N/A	\$100K

Time to Complete:

Component	Time to complete
MMS Workshops	1 year

Recommendation 4:

NTHMP should reduce unnecessary and costly disparities in inundation modeling approaches among states and territories in their approaches to inundation modeling. The NTHMP should conduct modeling efforts consistently across political boundaries and execute efforts through a cooperative partnership among NOAA, USGS, and NTHMP members.

NOAA Response:

NOAA agrees with the recommendation and considers it complete.

NOAA supports the NTHMP’s ongoing efforts to ensure consistent, quality modeling across political boundaries through a collaborative partnership. To facilitate this process, the NTHMP MMS developed a common set of Guidelines and Best Practices for Inundation Modeling and Hazard Mapping. As outlined in Recommendation 3 of this response, a validation workshop was held in March 2011 to identify tsunami inundation models that meet NOAA standards of accuracy. Only models that meet these standards of accuracy will continue to receive funding by the NTHMP as outlined in its strategic plan.

The goal of the NTHMP Mapping and Modeling Subcommittee is to attain consistency in tsunami inundation modeling and mapping between the states and their federal partners (USGS/NOAA/FEMA), state to state, and between the states and local communities on an individual basis. To achieve this consistency, a set of tsunami inundation guidelines has been developed and a workshop was held in Spring 2011 during which numerical models currently in use were tested through a series of benchmarks. Future model validation will confirm appropriate application of each numerical model and which models provide results within accuracy tolerances. Completion of, and adherence to, the Tsunami Inundation guidelines will ensure consistent products across state boundaries.

Overall mapping efforts are an ongoing process because each state brings a special expertise (mapping techniques, source identification, field work, etc.) from which other states benefit. The states are also innovative in producing and sharing the techniques to create new mapping products, like those for maritime and land-use planning communities. Ultimately, the states provide invaluable support and contribution for modeling efforts that match the needs of the local communities.

Cost:

Component	One-time	Recurring
NTHMP Model Validation	\$0	See Rec. 3

Time to Complete:

Component	Time to complete
NTHMP Model Validation	1 year

Recommendation 5:

The NTHMP Mapping & Modeling subcommittee should develop guidelines on evacuation-map production that fosters consistency in format and quality across the United States; and a national, online repository for tsunami evacuation maps. To improve public access to evacuation maps, the NTHMP should develop an on-line repository for all tsunami evacuation maps and host a consistent on-line mapping application for all tsunami evacuation zones across the United States.

NOAA Response:

NOAA and the NTHMP agree with this recommendation. It is the responsibility of the NTHMP’s Mitigation and Education Subcommittee (MES) to develop Evacuation Map Guidelines.

In September 2011, the MES finalized a set of guidelines and best practices for production of Tsunami Evacuation maps and made these available for download on the NTHMP website (<http://nthmp.tsunami.gov/index.html>). These guidelines represent an important step in achieving consistent and reliable tsunami evacuation maps in order to minimize confusion among the public. All tsunami evacuation maps developed after 1 January 2012 have adopted the specified guidelines.

Evacuation Map guidelines developed by the MES incorporated American National Standards Institute (ANSI) and cartographic standards while maintaining the ability for the maps to be tailored to local content.

The NTHMP repository project was completed in June 2012 and provides accessibility to evacuation maps and other materials via website or other electronic media. The NTHMP has also developed a National Media Guidebook. The guidebook and repository are available on the NTHMP Web site (<http://nthmp.tsunami.gov>).

Cost:

Component	One-time	Recurring
NTHMP Repository	See Rec. 9	See Rec. 9
Developing Standard for state/local Web-based evacuation maps	Complete	\$0
Develop and Maintain a single Web-map database and Web-based interface for evacuation maps	\$1M	\$200K
Populating Web-based evacuation map database	\$400K	\$200K

Time to Complete:

Component	Time to complete
NTHMP Repository	See Rec. 9
Developing Standard for state/local Web-based evacuation maps	6 months

Develop and Maintain a single Web-map database and Web-based interface for evacuation maps	2 years
Populating Web-based evacuation map database for Web-based interface (database would need to be created first)	2.5 years

Recommendation 6:

NTHMP should periodically inventory the number and type of people in tsunami hazard zones at intervals no less frequent than the U.S. Census, with special attention to children, the infirm, tourists, and other groups whose heightened sensitivity to tsunamis could constrain their ability to prepare for and evacuate from future tsunamis. The NTHMP should expand MMS to explicitly include community vulnerability. The NTHMP should establish a Science Advisory Committee to help develop the guidelines on consistent approaches for identifying and mapping populations in tsunami prone areas. The NTHMP should provide guidelines on how to use this information to tailor evacuation planning and education efforts.

NOAA Response:

While conducting a detailed inventory of the demographics within each tsunami hazard zones may yield some useful data, NOAA believes there are higher priorities in tsunami hazard mitigation to address. Additionally, completing an inventory of the demographics (children, the infirm, tourists, and other groups) within each tsunami prone community is a long-term effort that will require significant resources.

In September, 2011, the Mapping and Modeling Sub-committee (MMS) of the NTHMP completed guidelines for evacuation modeling, which includes identifying and mapping populations in tsunami-prone areas. The purpose of these guidelines is to address the minimum requirements to develop consistent and reliable tsunami evacuation maps. Groups and agencies producing tsunami evacuation maps with NTHMP funds are required to adopt these guidelines for all maps produced after January 1, 2012. These guidelines are available at: <http://nthmp.tsunami.gov/>. NOAA and NTHMP State Partners feel that the MMS and other NTHMP members (USGS, FEMA, NOAA, and State Partners), in lieu of a Science Advisory Committee, have the scientific expertise needed to continue to address this recommendation and will consult with the appropriate scientific experts as needed.

Cost:

Component	One-time	Recurring
Complete tsunami vulnerability inventory	\$1.5M	\$1.5M

Time to Complete:

Component	Time to complete
Complete tsunami vulnerability inventory	5-10 years

Recommendation 7:

For all communities with close or intermediate proximity (i.e., arrival times ranging from minutes to about an hour) to a potential tsunami source, the NTHMP should conduct evacuation modeling studies to assess the likelihood of successful horizontal evacuations. These studies should include the potential impacts of preceding earthquakes on key egress routes and consideration of any special needs populations in tsunami-prone areas. In communities where the time required for at-risk individuals to reach higher ground is likely greater than predicted tsunami wave arrival times, the NTHMP should conduct feasibility and effectiveness studies of various vertical-evacuation strategies (e.g., buildings, engineered berms) that include engineering considerations and social and economic constraints of at-risk communities.

NOAA Response:

NOAA agrees with this recommendation, and considers it complete.

The NTHMP has held workshops to investigate the feasibility of designing structures to withstand large earthquakes and be appropriate for shelter-in-place, or vertical evacuation. NTHMP and FEMA partnered to develop FEMA P-646, "Guidelines for Design of Structures for Vertical Evacuation from Tsunamis." The NTHMP funded California to create "Guidance for Local Jurisdictions to Develop or Review Tsunami Evacuation Plans for a Post-Earthquake, Local-Source Tsunami," evacuation modeling pilot projects in California and Washington, and is supporting community-based pilot projects to implement FEMA P-646 in Oregon and Washington. FEMA recently funded and completed improvements to P-646 based on recent research funded by the National Science Foundation (NSF). FEMA is in the process of publishing a second edition of P-646.

2. Education and Preparedness of Individuals, Communities, and Decision Makers**Recommendation 8:**

Faced with limited resources, the NTHMP should give priority to systematic, coordinated perception and preparedness studies of communities with near-field tsunami sources, in order to discover whether at-risk individuals are able to recognize natural cues of tsunamis and to take self-protective actions. Consistent, evidence-based approaches from the social and behavioral sciences should be used in the various study areas to allow the NTHMP to compare communities and prioritize future education efforts and resources.

NOAA Response:

NOAA agrees with the intent of this recommendation.

After consulting with the scientific team that has completed similar studies as recommended by the NAS in six at-risk communities, NOAA estimates that such a study could cost roughly \$80 million to accomplish, assuming each of the 800 identified communities exposed to a tsunami hazard were studied.

NOAA and the NTHMP State Partners could achieve similar results by conducting a random sample survey of 100 at-risk communities to assess their knowledge of risk and natural cues, as well as the appropriate response to natural warnings and messages from the TWCs. This sample survey will cost an estimated \$400 thousand, including the development of a standard assessment tool. NOAA and the NTHMP recommend this approach over the more intensive study recommended by the NAS.

Cost estimate:

Component	One-time	Recurring
Survey of Communities to assess awareness and response	\$400K	\$400K

Time to Complete (estimate):

Component	Time to complete
Survey of Communities to assess awareness and response	2 years

Recommendation 9:

To increase the effectiveness of tsunami education, the NTHMP should:

- (1) Develop consistent education efforts among its members using evidence-based approaches,*
- (2) Tailor tsunami education to local circumstances focusing on at-risk individuals and tourists,*
- (3) Create and maintain an on-line repository of education efforts,*
- (4) Develop and implement an evaluation program of the effectiveness of education efforts,*
- and*
- (5) Leverage hazard-education efforts and expertise of other NOAA entities.*

NOAA Response:

NOAA agrees with this recommendation and considers it complete.

NOAA and the NTHMP completed a National Education Plan and Guidelines. This effort includes an evaluation of existing tsunami education efforts at Federal, State, and local levels. The NTHMP Education Plan defined a consistent approach to NTHMP education efforts, including helping individuals interpret and respond to natural and official tsunami warnings, using evidence-based approaches while ensuring education can be tailored to local circumstances. The NTHMP is also examining materials directed at the tourism industry to determine best practices and guidelines for education in that arena.

The NTHMP Strategic Plan (2008) has a milestone to develop a repository of all NTHMP-related materials, including educational materials, by the end of calendar year 2013. The NTHMP hired a contractor in 2010 to develop the repository, which created a catalog of each NTHMP State Members' education materials. The Tsunami Program made this catalog available on the NTHMP Web site in June 2012.

Cost:

Component	One-time	Recurring
NTHMP Education Plan ¹	Complete	\$600K
NTHMP Repository ²	\$600K	\$150K

1) The NTHMP Education Plan and Repository was developed with the use of funds from the WARN Act (Pub. L. 109-347 (Oct. 13, 2006), which expired on September 30, 2012. The NTHMP will require \$150K annually to continually implement and improve the Education Plan, and an additional \$150K annually to continually maintain and improve the NTHMP Repository.

Time to Complete:

Component	Time to complete
NTHMP Repository	3 years

Recommendation 10:

The NOAA Tsunami Program could strengthen the TsunamiReady Program by modeling it after the Emergency Management Accreditation Program (EMAP).

Background

According to the NAS report, effectiveness of the TsunamiReady program has not been demonstrated since the program lacks the following elements:

- 1. a professional standard to guide its development,**
- 2. metrics to assess baseline readiness and community needs,**
- 3. evaluative criteria to assess community performance during a tsunami,**
- 4. accountability measures to ensure recognized communities meet and continue to meet mandatory requirements,**
- 5. local points of contact with training in community preparedness, and**
- 6. criteria and guidance on what constitutes effective public outreach and preparedness efforts.**

NOAA Response:

NOAA agrees with the recommendation and is working with the NTHMP and other partners to improve the TsunamiReady™ program. As part of this effort, NOAA is:

- Engaging with social and behavioral scientists;
- Developing metrics to assess baseline readiness and community needs;
- Developing evaluation criteria to assess community performance during and after a tsunami (supported through an NTHMP Post-Tsunami Survey);
- Creating a publically accessible, digital database of all actions taken by TsunamiReady™ communities as part of the NTHMP repository, and
- Creating accountability measures to ensure recognized communities meet, and continue to meet, mandatory requirements including:
 - Identification of local points of contact with training in community preparedness, and
 - Developing criteria and guidance on what constitutes effective public outreach and preparedness efforts.

The National Weather Service (NWS) has recognized 131 new TsunamiReady™ communities since 2005, bringing the national total to 144. This is a tremendous accomplishment, not only for the NWS and the NTHMP State Partners who assist in this work, but more important, for the communities, which have been recognized as TsunamiReady™. Communities must initiate the process to become TsunamiReady™ and then utilize their resources to attain this status. NOAA/NWS is able to supplement the activities of some local jurisdictions to meet the requirements of the TsunamiReady™ program, but significant effort on the part of local leaders is required for the community to gain recognition.

The NTHMP has addressed the additional TsunamiReady™ related actions recommended by the NAS including:

1. Completed an NTHMP Baseline Survey (November 2010) to collect data on the preparedness levels and education activities for all at-risk U.S. communities, and completed the final survey report.
2. Developed guidelines as to what constitutes effective public outreach (part of its National Education Plan).

NOAA recommends that the NWS maintain TsunamiReady™ as a recognition program and continue to work with the NTHMP State Partners to improve the tsunami program.

Cost:

Component	One-time	Recurring
TsunamiReady™ Improvement Plan	\$1.2M	\$900K
Baseline Assessments	\$50K	\$50K
NTHMP Education Guidelines	See Rec. 9	See Rec. 9
Preparedness Plan Guidelines	\$100K	\$100K

Time to Complete:

Component	Time to complete
TsunamiReady™ Improvement Plan	3 years
Baseline Assessments	6 months
NTHMP Education Guidelines	See Rec. 9
Preparedness Plan Guidelines	2 years

Recommendation 11:

NOAA/NWS should remedy current differences between TWCs and other NWS warning products and ensure consistency in the future. A mechanism should be put in place so that pending and future inconsistencies are quickly identified and acted upon so that products from the TWCs and the NWS match.

NOAA Response:

NOAA agrees with this recommendation.

The NWS and NTHMP partners formed a working group in 2007 to modify the Tsunami Advisory product in order to be consistent with other NWS products, and to provide the TWCs with a lower level alert (advisory) than a warning. This successful effort went into operation at the WCATWC in early 2008 and at PTWC in early 2010. The new advisory product provided the proper level of alert for areas along the U.S. west coast during the 2009 Samoa and 2010 Chile tsunamis.

The NAS report points out differences between the Tsunami Watch product and other NWS Watch products. The report is correct in stating that the Tsunami Watch has created confusion concerning TWC products. The NWS considered discontinuation of the Watch product in early 2011, and presented a proposal to do so to its Emergency Management partners during the Annual NTHMP Warning Coordination Sub-Committee (WCS) Meeting in February 2011. The NTHMP WCS recommended that the NWS not discontinue its Tsunami Watch product but increase education and outreach about its product suite. Future product changes will be monitored by the NTHMP WCS to ensure alignment with other NWS products.

The NAS report notes that not all customers understand the relation between message types and tsunami impact. The NTHMP and NOAA completed a National Tsunami Guidebook for Media, which provides educational information on tsunami products and other aspects of response. TWCs provide educational outreach about their products to emergency management organizations and NWS Weather Forecast Offices to support proper response during events. NOAA also issued a grant in 2010 to a social science group to examine TWC products and recommend improvements using evidence-based approaches.

The TWCs have both domestic and international responsibilities. Significant changes to international messages require approval by the appropriate Intergovernmental Oceanographic Commission (IOC) Coordinating Group. Significant changes to domestic messages need approval by the NTHMP WCS.

Cost:

Component	One-time	Recurring
Update TWC brochures and Educational Materials	\$50K	\$20K

Time to Complete:

Component	Time to complete
Update TWC brochures and Educational Materials	15 months*

*Assuming concurrence of NTHMP partners, and IOC Coordinating Groups as necessary.

Recommendation 12:

The NWS should establish a committee of experts in the social science of warning messaging to review the format, content, delivery channels and style of TWC messages. If distinct messages are to be produced by the two TWCs, then the messages should be consistent. Ideally, the committee recommends that one message be released by the two TWCs that internally covers information for all areas of responsibilities.

NOAA Response:

NOAA agrees with this recommendation.

In September 2010, NOAA awarded a social science grant to East Tennessee University to review and recommend improvements to the format, content, delivery channels, and style of TWC warning messages. NOAA is also in the process of: 1) developing a single TWC Web site (<http://www.tsunami.gov> is the single Web site that was successfully transitioned to the National Weather Service Internet Dissemination System (NIDS) in December 2011); 2) consolidating the TWC message generation software; and 3) resolving product inconsistencies through improved NWS policies for the TWCs. NOAA received a final report from Eastern Tennessee University in January 2012 and began to implement accepted recommendations in 2013.

International TWC responsibilities and procedures are determined by agreement and in coordination with United Nations Educational, Scientific, and Cultural Organization (UNESCO) IOC tsunami programs. Changes to the format and content of international messages require approval by the appropriate IOC Coordinating Group. NOAA is continuing work with the IOC toward making international and domestic TWC messages as consistent as possible.

Cost:

Component	One-time	Recurring
Social Science Study	\$200K	\$0
Common Web site Development	\$400K	\$200K
Consolidation of TWC Message Generation Software	\$200K	\$0

Time to Complete:

Component	Time to complete
Social Science Study	2 years
Common Web site Development	1 year
Consolidation of TWC Message Generation Software	1 year

Recommendation 13:

The NOAA/National Weather Service (NWS) should better integrate the TWC warning functions with the state, county, and city warning functions with regard to message content and dissemination methods for the public by developing formal TWC outreach plans and assessing needs and priorities of TWC customers.

NOAA Response:

NOAA agrees with this recommendation and is complying with it.

In January 2010, NOAA initiated the effort to utilize social science expertise to review and recommend improvements to the format, content, delivery channels, and style of TWC warning messages. A three-year grant was awarded to East Tennessee State University in August 2010 to evaluate Tsunami Warning Center Products and recommend improvements.

Messages broadcast to individual communities are created at the state/county level. The NTHMP’s Warning Coordination Sub-Committee (WCS) is the primary forum NOAA/NWS utilizes to coordinate and integrate TWC warnings with state, county, and city warnings for message format, content, and dissemination methodologies. The TWCs also work through the NTHMP WCS and state tsunami working groups to assess the needs and priorities of TWC customers.

TWCs continue to support state tsunami working groups whenever possible. The Washington State/Local Tsunami Workgroup is mentioned by the NAS report as one example. TWCs and other NOAA entities such as Weather Forecast Offices (WFOs), the IOC’s International Tsunami Information Center (ITIC), and PMEL support the national, State, and local tsunami outreach planning efforts throughout the country.

Cost:

Component	One-time	Recurring
Coordination of TWC Messages ¹	\$0	\$0
TWC Outreach Plan Development and Implementation ²	\$400K	\$400K
Implement Post-Event Effectiveness Questionnaire	See Rec. 16	See Rec. 16

Time to Complete:

Component	Time to complete
Coordination of TWC Messages ¹	On-going
TWC Outreach Plan Development and Implementation ²	1 year
Develop Post-Event Effectiveness Questionnaire Procedures	See Rec. 16

1) The coordination of TWC messages and content with state, county, and local warning functions is already achieved through the NTHMP WCS and state tsunami working groups.

2) The TWC Outreach Plans recommended in this report was completed in 2011. .

Recommendation 14:

The NTHMP should actively encourage all members to develop and maintain strong tsunami working groups to help facilitate and coordinate tsunami education, preparedness, and warning dissemination. The NTHMP should work to communicate efforts of various working groups across the NTHMP and help disseminate best practices. To ensure local efforts are evidence-based, state working groups should actively encourage the involvement of social scientists trained in risk communication regarding public education to increase public knowledge about hazards and motivating public preparedness, tsunami risk, and emergency management.

NOAA Response:

NOAA agrees with this recommendation, and considers it complete, but recognizes that this is an on-going effort.

The NTHMP Strategic Plan (2008) has a strategy to support these groups’ organization and execution, stating that, “All states with a high or very high level of tsunami hazard create and utilize a high-level structure to address tsunami response at the state level by 2012.” Of the 10 NTHMP member states and territories with high or very high hazard level, 5 have created the recommended working groups, and the NTHMP will continue to encourage the development of and collaboration between these groups.

Several of the NAS recommendations (i.e., Recommendations 7, 8, and 13) can be supported by community involvement in these tsunami working groups. NOAA will encourage the tsunami working groups to focus on community education and preparedness.

Cost:

Component	One-time	Recurring
Encourage the formation of Tsunami Working Groups	\$0	\$0

Time to Complete:

Component	Time to complete
Encourage the formation of Tsunami Working Groups	Complete

Recommendation 15:

To ensure that managed evacuations for far-field tsunamis are effective and minimize societal and economic interruptions, the NTHMP should develop guidelines on the design of effective exercises for use by emergency-management agencies.

NOAA Response:

NOAA agrees with the intent of this recommendation, however, developing guidelines for designing effective exercises is not a responsibility of NOAA or the NTHMP. FEMA's Homeland Security Exercise and Evaluation Program provides such guidelines, including those for tsunami evacuation exercises.

Recommendation 16:

Social science post-event research audits should be performed after all tsunami "warning events" that hold the potential to document important lessons to be learned.

NOAA Response:

NOAA agrees with this recommendation and considers it complete, as processes are in place to complete tsunami post-event research audits.

NOAA agrees that social science post-event research audits are valuable tools to determine lessons learned after warning events. NOAA and the UNESCO's IOC have processes in place to ensure social science studies are a part of post-tsunami event surveys, as outlined in National Weather Service Instruction (NWSI) 10-703.

NOAA's ITIC is the coordinating office for post-event surveys, which include investigations into tsunami impact, runup, and damage, as well as social science aspects concerning the public's response to the event. NTHMP is also involved in post-event audits at the state level.

Recommendation 17:

Tsunami field surveys should be conducted by multi-disciplinary personnel including physical and social scientists, engineers, disaster-mitigation planners, and sociologists. A quick dispatching capability is crucial for tsunami surveys, in order to capture as much information as possible. Tsunami runup marks, destruction patterns, and other detailed tsunami-affected features can disappear within a few weeks. NOAA should take a more proactive role in the coordination for tsunami surveys with other agencies, in particular USGS and NSF.

NOAA Response:

NOAA agrees with the recommendation and considers it complete, as processes are in place to complete tsunami post-event field surveys.

NOAA and the UNESCO IOC have processes in place to ensure post-tsunami field surveys involving U.S. Federal Agencies are coordinated and include multi-disciplinary personnel, as

outlined in National Weather Service Instruction (NWSI) 10-703. The International Tsunami Information Center (ITIC) is leading efforts to enhance post-tsunami survey work, and submitted an abstract for a revised IOC International Post-Tsunami Field Survey Guide (2nd edition) to the American Geophysical Union (AGU) for their December 2011 meeting. In order to ensure participation among U.S. Government agencies is coordinated, NOAA will continue to work with its Federal partners (e.g., USGS, FEMA, and NSF) to define the roles and responsibilities between the agencies for post-tsunami field surveys.

Cost:

Component	One-time	Recurring
Utilize NTHMP Representative for Post-Event Surveys	\$0	\$15K

Time to Complete:

Component	Time to complete
Utilize NTHMP Representative for Post-Event Surveys	On-going

3. Threat Detection and Forecasting

Recommendation 18:

NOAA and USGS could jointly prioritize the seismic stations needed for tsunami warnings. These needs could be communicated with partner agencies and organizations to advocate for upgrading and maintenance of these critical stations over the long-term.

NOAA Response:

NOAA and the USGS agree with this recommendation.

NOAA documented TWC operational requirements, including seismic data. A prioritized list of seismic data stations critical for tsunami warnings was completed and shared with the USGS; however, this will be an on-going effort.

Prioritizing the importance of the hundreds of seismic stations contributing to tsunami warning requires quantitative analysis to determine how each station contributes to the following network- based metrics: 1) Earthquake magnitude detection threshold; 2) Earthquake detection time; 3) Earthquake location and depth uncertainty. The USGS is conducting research on how best to calculate these metrics.

The NAS report states that the global seismic network (GSN) is sufficient for detecting tsunami-producing earthquakes. However, it is not sufficient for meeting TWC fast response requirements. Much greater seismic network density is required in some tsunami source locations, such as U.S. Pacific Islands, to meet TWC response time requirements for U.S. events. The USGS is the lead agency for the country for obtaining observational seismic data.

In Alaska and Hawaii, NOAA provides more than 75 percent of the funding support for permanent broadband seismic networks. NOAA’s ability to continue to operate and maintain these seismic networks, specifically those in support of TWC operations (i.e., CRESTnet and Alaska and Hawaii networks), will depend on future agency funding.

The TWCs also require international seismic data. NOAA will continue to seek access to additional seismic data needed to meet TWC requirements.

Cost:

Component	One-time	Recurring
Transition O&M responsibility for CRESTnet, Hawaii, and Alaska seismic networks to USGS ¹	\$1.25M	\$1.25M

¹) This cost is based on actual NOAA costs to operate and maintain CRESTnet and NOAA’s operational seismic networks in Alaska and Hawaii.

Time to Complete:

Component	Time to complete
Transition O&M responsibility for CRESTnet, Hawaii, and Alaska seismic networks to USGS	9 months

Recommendation 19:

Among the methodologies employed by NEIC is the W-phase algorithm for estimating earthquake magnitude. The committee recommends that the TWCs work jointly with NEIC to test the potential utility of the W-phase algorithm in the tsunami warning process, using both a sufficient dataset of synthetic seismograms and a set of waveforms from past great earthquakes, paying particular attention to the algorithm’s performance during “tsunami earthquakes” and to the assessment of a lower-magnitude bound for its domain of applicability.

NOAA Response:

NOAA agrees with this recommendation. NOAA and the USGS’s National Earthquake Information Center (NEIC) are complying with this recommendation.

NEIC computes and communicates W-phase computations in near real-time to the TWCs for use in tsunami warning decision making. The W-phase technique is also in testing at the PTWC. The USGS has shown that the W-phase technique is accurate to a magnitude of 5.8 and is currently conducting a thorough W-phase analysis using past earthquakes.

Although W-phase is currently producing useful results, significant work is required to bring the W-phase algorithm into full operation at NOAA and the USGS. The algorithm is in conditional operations at the NEIC.

The NAS report states that W-phase potentially provides more accurate earthquake characterizations for great earthquakes versus the primary technique used at the TWCs, which is known as Mwp. However, the W-phase technique will not meet the TWC response time requirements and cannot be used in the initial tsunami alert. The Mwp technique provides the most accurate magnitude available within TWC warning time constraints, although it may underestimate the size of earthquakes over magnitude 8. Even with an underestimation of earthquakes this size, Mwp will allow the TWCs to issue timely alerts. For example, using the Mwp technique, the magnitude 8.8 Chile earthquake was initially sized at 8.5. This estimate led to the same level of alert for the appropriate area as would have a magnitude 8.8 determination. The greatest benefit of W-phase technique at the TWCs will be to provide moment magnitude used in the tsunami forecast models, which are computed after the initial alert is issued.

Cost:

Component	One-time	Recurring
Complete testing and implement W-phase technique at NEIC and provide core code to the TWCs for implementation.	\$135K	\$0

Time to Complete:

Component	Time to complete
Complete testing and implement W-phase technique at NEIC and provide core code to the TWCs for implementation.	1 year

Recommendation 20:

Two important concerns regarding the entire coastal sea level network employed by the TWCs in their warning activities need to be addressed soon, as follows:

- 1) A priority list of the coastal sea level stations should be constructed, based at first on the experience of the TWC forecasters, and later updated from the results of the more objective coverage analysis described in the previous section*
- 2) A risk assessment of the data flow from the highest priority stations should be performed.*

NOAA Response:

NOAA agrees with prioritizing sea-level stations and has completed a priority list based on TWC forecaster experience.

NOAA documented TWC operational requirements, including all sources of sea-level data (e.g., DARTs and coastal sea-level gauges). Based on the requirements, NOAA will develop a more objective prioritized list of sea level stations including all relevant factors (e.g., importance to tsunami forecasting, elapsed time to measurement, redundancy, etc.). Prioritized requirements will be coordinated with data providers (e.g., National Data Buoy Center (NDBC), NOAA's Center for Operational Ocean Products (CO-OPS), etc.).

NOAA will assess the risk to TWC performance resulting from loss of data from the highest priority stations, and will use the results to drive enhancements to the sea-level network. Risk assessments of individual stations are performed by the sea level station operator.

As a result of the funding increase received by the program in 2005 and the WARN Act, NOAA has the resources to properly maintain their operational sea-level networks.

A permanent sea-level data archive was established at NOAA's National Environmental, Satellite, Data and Information Services' (NESDIS) National Geophysical Data Center (NGDC) in 2006. Both the West Coast/Alaska Tsunami Warning Center (WCATWC) and Pacific Tsunami Warning Center (PTWC) are sending sea-level data to the archive.

Cost:

Component	One-time	Recurring
Prioritization and Risk Assessment Studies for Sea-Level Stations	\$200K	\$100K
International Sea-level Networks Operations and Maintenance	N/A	\$400K

\$100K provided to UH each year for sea-level stations. Funding for the international sea-level networks are currently supported by WARN Act funds, which expired on September 30, 2012.

Time to Complete:

Component	Time to complete
Prioritization and Risk Assessment Studies for Sea-Level Stations	1 year

Recommendation 21:

The Committee endorses the following recommendations of the NTHMP report (2007) for NOAA TWCs to:

- (1) Create a formal data archive for both CO-OPS and TWC data and metadata including, 15s data;*
- (2) Address 1-minute and 15-second quality control issues in unison with the archive issue to ensure quality of the archive;*
- (3) Enact Federal Geographic Data Committee (FGDC) compliant station meta data; and*
- (4) Create an operational website providing a portal for 15s tsunami station water level data.*

This Committee did not undertake an assessment of the processing, distribution, archiving, and long-term access to tsunami-relevant sea-level data originating from international sea-level stations. As previously stated the near-real-time tsunami-relevant sea-level data available to the TWCs via the GTS (and archived at the IOC's SLSMF <http://www.vliz.be/gauges>) is not quality controlled.

NOAA Response:

NOAA agrees with this recommendation and considers it complete.

Processes are in place to continue to address the four sub-projects associated with this recommendation. Archival of tsunami data is performed at NOAA's National Geophysical Data Center (NGDC).

The NOAA Tsunami Program implemented a single long-term archive for NOAA tide gauge and DART data at NOAA's NGDC (and co-located World Data Center) in 2006 and 2007, respectively. As of 2008, NOAA's CO-OPS 1-minute tide gauge data and related standards-based metadata were archived to National Archive and Records Administration (NARA) standards at NGDC's data archive. In 2009, the archive expanded to include the 15-second tide gauge data and metadata from the WCATWC. In 2010, the 15-second data from the PTWC were added to the archive.

NGDC is continuing to work with CO-OPS to implement integrated discovery, access, and delivery of high-resolution tide gauge data from the CO-OPS Web site along with delivery via Web services and offline options. The NOAA Tsunami Program is funding the acquisition, archive, and delivery of DART and tide gauge data, including the quality assurance and on-line delivery of DART 15-second data.

Each sub-project is addressed as follows:

1) NOAA created a formal archive for CO-OPS and TWC tide gauge data at NGDC and it is operational, archiving the TWC (both Hawaii and Alaska) data hourly and CO-OPS data on a weekly basis. Only the TWC data is archived at 15 seconds. The CO-OPS data are currently collected and potentially available at 15-second values but are only transmitted from the stations as 1-minute values for archive and access.

2) CO-OPS does not quality control the 1-minute data, as they do 6-minute data. NGDC is implementing retrospective quality control measures for DART data, and will implement 15-second or 1-minute tide gauge “tsunami event data only” quality control. The archive will contain:

- raw 15-second DART data, processed 15-second event data, station metadata (near completion)
- raw 15-second TWC tide gauge data, station metadata*, and processed 15-second event data
- raw 1-minute CO-OPS tide gauge data, station metadata**, and processed 1-minute event data (which is not yet initiated)

* TWC station metadata partially initiated with XML schemas

** CO-OPS station metadata delivered from CO-OPS weekly; could be integrated with data delivery system

NOAA will continue to support the quality assurance and delivery of 15-second and 1-minute tide gauge data for tsunami capable stations.

3) DART and CO-OPS data are described with FGDC compliant station metadata. NGDC is working with CO-OPS to implement a Web service and is striving to put resources (either at NGDC or at CO-OPS) toward the auto-generation of the metadata record and packaging it with data requested for distribution.

4) CO-OPS has the operational Web site to provide access to 1-minute tide gauge data for tsunami (<http://tidesandcurrents.noaa.gov/1mindata.shtml>). NGDC has the Web service to deliver TWC 15-second data to CO-OPS, and this is in a testing phase. NGDC continues to engage CO-OPS about a tsunami tide gauge Web site. This will require a significant effort at both NGDC and CO-OPS.

Cost:

Component	One-time	Recurring
Archive NOAA 1-minute or 15-second coastal tide gauge data ¹	\$0	\$80K
Complete Quality Assurance of all 1-minute and 15-second NOAA tide gauge data	\$0	\$80K
Archive and deliver additional NOAA tsunami tide gauge data and metadata	\$0	\$20K

1) This effort is currently funded with WARN Act Funds which will expire on September 30, 2012. \$80K is required to continue archiving of 1-min and 15s coastal tide gauge data after the WARN Act funding expires.

Time to Complete:

Component	Time to complete
Archive 1-minute or 15-second coastal tide gauge data	Completed for existing stations; new stations in Caribbean & Pacific need to be added
Quality assure 1-minute and 15-second coastal tide gauge data (funds required)	Develop methods: 2013 QA data: 2016
Archive and deliver additional tsunami tide station data and metadata (funds required)	Within 1 year of station operational capability (NOAA Pacific & Caribbean)

Recommendation 22:

NOAA should regularly assess the numbers, locations and prioritizations of the DART stations, in light of constantly changing fiscal realities, survivability experience, maintenance cost experience, model improvements, new technology developments (even new DART designs), increasing international contributions, and updated information on the entire suite of siting issues listed previously.

NOAA Response:

NOAA agrees with this recommendation and is complying with it. NOAA has a mechanism in place to address continued work in this area.

The NWS Tsunami Program is currently working with the TWCs, PMEL, NOS, and NDBC representatives (an informal NOAA Tsunami Sea Level Working Group) to evaluate the sea-level networks (coastal and DART network) for the Tsunami Warning System. This group will use the criteria called for in Recommendation 28 once they are established. This evaluation will also take into consideration: TWC operational requirements; usefulness of coastal sea-level data for scaling forecast models past data return rates; seismic source areas and their potential danger to U.S. sites; foreign networks; bathymetry; ocean currents; maintenance costs; etc. The Sea-level Working group will provide recommendations to optimize sea-level observational requirements for the Tsunami Warning System as a result of this evaluation.

Cost:

Component	One-time	Recurring
NOAA Tsunami Sea-Level Working Group	\$15K	\$15K
Sea-Level Optimization Software Development and Maintenance	\$35K	\$20K
Complete evaluation of sea-level networks	\$0	\$0

Time to Complete:

Component	Time to complete
NOAA Tsunami Sea-Level Working Group	Immediate
Sea-Level Optimization Software Development and Maintenance	2.5 years
Complete evaluation of sea-level networks	3 years

Recommendation 23:

In order to bring NDBC into compliance with Public Law 109-424 (sic), NDBC should engage in a vigorous effort to improve the reliability of the DART stations and minimize the gaps caused by outages.

NOAA Response:

NOAA agrees with this recommendation and considers it to be complete, improving the reliability of DART stations.

NOAA has implemented several improvements to buoy moorings and the sub-surface equipment to improve reliability of the DART network. NDBC has employed more sophisticated mooring modeling techniques to analyze and modify designs to address some potential failure modes. NOAA has modified mooring handling procedures to better protect them from damage during fabrication, shipping, and deployment. These improvements have resulted in higher reliability of the DART Network, demonstrated by a decrease in failure rate since the beginning of FY10.

Recommendation 24:

The committee encourages NDBC to establish rigorous quality control procedures, perform relentless pre-deployment tests of all equipment, and to explore new maintenance paradigms, such as simplification of DART mooring deployment and maintaining a reserve of DART stations for immediate deployment.

NOAA Response:

NOAA agrees with this recommendation and considers it to be complete.

NOAA NDBC established a Safety, Quality, and Reliability Assurance Office that resides with the Office of the NDBC Director to bolster existing quality control efforts and new reliability activities. NOAA began implementing new quality control and testing procedures early in 2010 in an effort to reduce the rate of premature equipment and system failures and increase DART operational performance. These quality control and test procedures include:

- Updating nylon rope purchase specifications and inspection procedures;
- Improving rope length measurement accuracy;
- Improving water depth measurement accuracy;
- Test plans to determine impacts of manufacturer’s pre-stretching and pre-shrinkage processes and NDBC storage environment on nylon rope service life;
- Developing improved fabrication and inspection procedures.

Recommendation 25:

The NDBC should improve its efforts at failure analysis, especially through more vigorous attempts to recover both buoys that have gone “adrift” and the mooring remnants that are left on site.

NOAA Response:

NOAA agrees with this recommendation and considers it complete.

NOAA implemented new procedures to reduce future failures and increase DART station availability. NOAA has installed a mooring component test facility at NDBC, purchased a microscope with digital imaging to classify causes of nylon rope failures, and has begun conducting more extensive routine inspections and evaluations of deployed moorings during servicing and retrieval.

NOAA has deployed one recoverable DART mooring that will allow for both thorough inspections during service opportunities and recovery of the bottom mooring piece for analysis and testing following a failure. These new mooring designs should be deployed across high-risk portions of the network to replace the existing non-recoverable moorings as budget allows.

Cost:

Component	One-time	Recurring
Test and Deploy Improved Recoverable DART Moorings ¹	\$3M	\$0

1) Cost includes: 1) Procurement of acoustic releases and deep-water subsurface floats in support of recoverable moorings to support forensic analysis of mooring failures and good ocean stewardship practices, and 2) Additional ship time to recover remnants of failed mooring in a timely manner before all forensic evidence of failure is destroyed by months of drifting at sea.

Time to Complete:

Component	Time to complete
Test and Deploy Improved DART Moorings and collect forensics	2 years

Recommendation 26:

NOAA should encourage access to the DART platform (especially, use of the acoustic and satellite communications capabilities) by other observational programs, on a not-to-interfere basis; that is, the primary application (tsunami warning) justifies the cost, but DART presents an outstanding opportunity as a platform to acquire long time series of oceanographic and meteorological variables for use for climate research and other nationally important purposes. Broadening the user base would be expected to enhance the sustainability of the DART program in the future.

NOAA Response:

NOAA agreed with this recommendation to examine the opportunity of using the DART platform for other observational programs, but initial testing and evaluation on integrating weather and climate sensors into the existing DART platform has not been fully successful.

More recently, NOAA developed and has begun initial testing of a new modular buoy platform designed for multi-mission capabilities that could be deployed across the range of NOAA's buoys to include DART.

Cost:

Component	One-time	Recurring
Deployment of new modular buoy platform	\$4M	\$0

Time to Complete:

Component	Time to complete
Deployment of new modular buoy platform	3 years

Recommendation 27:

NOAA should assess on a regular basis the appropriateness of the spatial coverage of the current DART sea level network and coastal sea level network (U.S. and international), in light of constantly changing fiscal realities, survivability experience, maintenance cost experience, model improvements, new technology developments, and increasing or decreasing international contributions. Especially, NOAA should understand the vulnerabilities of the detection and forecast process to the following: (1) gaps in the distribution of existing gauges; and, (2) failures of single or multiple stations.

NOAA Response:

NOAA agrees with this recommendation and is complying with it. NOAA has a program in place to continue to address this issue.

The NWS Tsunami Program reconvened an informal Sea-Level Working Group (see Action for NAS Recommendation 22). The Working Group will evaluate sea-level networks (coastal and DART network) for the Tsunami Warning System once the criteria called for in Recommendation 28 are established. This evaluation will also take into consideration: TWC Operational Requirements; usefulness of coastal sea-level data for scaling forecast models past data return rates; seismic source areas and their potential danger to U.S. sites; foreign networks; bathymetry; ocean currents; maintenance costs; etc. The Sea-level Working Group will provide recommendations to optimize sea-level observational requirements for the Tsunami Warning System as a result of this evaluation.

Cost:

Component	One-time	Recurring
NOAA Tsunami Sea-Level Working Group	See Rec. 22	See Rec. 22
Sea-Level Optimization Software Development and Maintenance	See Rec. 22	See Rec. 22

Time to Complete:

Component	Time to complete
NOAA Tsunami Sea-Level Working Group	Immediate
Sea-Level Optimization Software Development and Maintenance	15 months

Recommendation 28:

NOAA should prioritize the existing DART stations and coastal sea level gauges (both U.S. and international) according to their value to tsunami detection and forecasting for both U.S. territories and other AORs of the TWCs. Furthermore, this priority list should be merged with the results from the network coverage assessment (above) to determine the following: (1) maintenance priorities and schedules; (2) network expansion priorities; and, (3) identification of critical stations that are not under U.S. control and may require either augmentation with new U.S. gauges or operations and maintenance support.

An important aspect of this activity would be to develop and publish criteria, such as the following examples: (1) value of a station for initial detection of a large tsunami near an active fault zone, to maximize warning lead time; (2) value of a station for initial detection of a medium to small tsunami, to mitigate false alarms; (3) value of a station for scaling forecast models of inundation of U.S. territories; (4) value of a station for after-the-fact model validation; and, (5) density (sparsity) of the observing network in the region.

NOAA Response:

NOAA agrees with this recommendation to prioritize all sea-level stations, particularly considering the continued constrained budget environment.

The NWS Tsunami Program reconvened an informal Sea-Level Working Group (see Action for NAS Recommendation 22). As part of addressing Recommendations 22 and 27, the NOAA Sea-Level Working Group will develop and establish criteria to prioritize and optimize sea-level networks for the Tsunami Warning System.

NOAA will work with its observational sea-level data providers to prioritize tsunami requirements in light of other non-tsunami requirements (e.g., weather, fisheries, etc.).

Cost:

Component	One-time	Recurring
Develop criteria to evaluate sea-level networks	\$20K	\$20K

Time to Complete:

Component	Time to complete
Conduct prioritization and Risk Assessment Studies for Sea-Level Stations	2 years

Recommendation 29:

NOAA should assess on a regular basis the vulnerabilities to, and quality of, the data streams from all elements of the sea level networks, beginning with the highest priority sites determined per the recommendations above.

NOAA Response:

NOAA agrees with this recommendation.

The operator of each sea-level network is responsible for meeting expected TWC reliability metrics and determining vulnerabilities to their network(s).

NOAA will produce a software tool to routinely or on-command assess the current status of the sea level networks and identify problems, weaknesses, and areas where TWC requirements are compromised or otherwise not being met. NOAA will use the output from this tool to routinely report on the status of the sea level networks and to drive each network operator’s routine and urgent maintenance, repair, and upgrade of sea level network equipment.

Cost:

Component	One-time	Recurring
Conduct prioritization and Risk Assessment Studies for Sea-Level Stations	See Rec. 20	See Rec. 20
Develop and implement “on-demand” software to assess sea-level network status at TWCs	\$200K	\$50K

Time to Complete:

Component	Time to complete
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Conduct prioritization and Risk Assessment Studies for Sea-Level Stations	See Rec. 20
Develop and implement “on-demand” software to assess sea-level network status at TWCs	2 years

Recommendation 30:

In view of (1) the declining performance of the DART network, (2) the importance of both the DART and coastal sea level networks for tsunami detection and forecasting, and (3) the overlapping jurisdictions among federal as well as non-federal organizations, NOAA should establish a “Tsunami Sea Level Observation Network Coordination and Oversight Committee” to oversee and review the accomplishment of the recommendations listed above.

NOAA Response:

NOAA agrees with this recommendation and considers it complete.

The NWS Tsunami Program reconvened an informal Sea-Level Working Group (see Action for NAS Recommendation 22).

Based on the fact that the majority of the actions related to sea-level recommendations (Recs. 20-29) are in progress or considered by NOAA to be completed, a second high-level working group would not be necessary to ensure that recommendations are on track to be completed. NOAA will utilize its existing management structure to continue to address the remaining open recommendations.

Cost:

Component	One-time	Recurring
Establish NOAA Tsunami Sea-Level Working Group*	See Rec. 22	See Rec. 22

*A successful mechanism already exists within the program that addresses this recommendation.

Time to Complete:

Component	Time to complete
Establish NOAA Tsunami Sea-Level Working Group*	See Rec. 22

Recommendation 31:

TWCs and the NOAA Center for Tsunami Research at PMEL should continue to work together to bring the SIFT tsunami forecast methodologies into full operational use. The utility of the methodologies could be improved by ensuring that TWC staffs undergo a continuous education and training program as the forecast products are introduced, upgraded, and enhanced.

NOAA Response:

NOAA agrees with this recommendation and has a program in place to address this issue.

NOAA is continuing the process (implemented in 2009) to transition the Short-term Inundation Forecasting for Tsunamis (SIFT) system into TWC operations. This process was highlighted as a successful effort by the GAO in their April 2010 Report on the Tsunami Program. The transition process involves the Tsunami Program Manager, TWCs, and PMEL in developing the SIFT transition plan, requirements, test and training plans, and operational acceptance criteria.

The Tsunami Program transitioned SIFT V3.1 to the TWCs for operational testing and evaluation (OT&E) at the end of 2011. The established transition process will be utilized for future versions of SIFT.

Cost:

Component	One-time	Recurring
Complete Transition of SIFT V3.1 and future versions into TWC Operations ¹	\$700K	\$700K

Time to Complete:

Component	Time to complete
Complete Transition of SIFT V3.1 and future versions into TWC Operations	Expected in 2013

¹) This effort is currently funded with WARN Act Funds which expired on September 30, 2012

Recommendation 32:

For the purpose of developing more rapid and accurate warnings of local tsunamis, especially along the Washington and Oregon coasts, the committee recommends that the TWCs coordinate with the NEPTUNE Canada and the Ocean Observatories Initiative (OOI) managers to ensure that their seismic and bottom pressure data are (or will be) made available in near-real-time to the appropriate telecommunications gateways. Data interpretation tool(s), jointly applied to the seismic and bottom pressure data, will need to be developed to realize the most rapid tsunami detection possible.

NOAA Response:

NOAA agrees with this recommendation.

The TWCs will work with NEPTUNE and OOI data managers to determine necessary steps to obtain their data in real time. If the data can be made available in real time, the TWCs will work with the appropriate personnel to determine how the data can be sent to the TWCs and if/how the data will be integrated with seismic and sea-level/forecasting processing systems.

Several steps are necessary for data streams to eventually support TWC operations. Decisions will have to be made at each step as to whether the benefit justifies the cost of the next step. For example, if cabled pressure sensor data proves to be more expensive to acquire than DART data and DART data are transmitted from the same area, there will be no need to continue with that aspect of the transition.

The TWCs will continue to evaluate existing and emerging technology that has the possibility of improving TWC response to, and analysis of, far-field and near-field tsunamigenic events. NOAA will use the completed Tsunami Program Research to Operations Policy to identify and evaluate emerging tsunami research, and transition appropriate new science and technology into operations.

There is a wide range of costs for this project. The final cost depends on the difficulty of integrating cable data with other data types, and how many types of data will be acquired at the TWCs.

Cost:

Component	One-time	Recurring
Incorporate Neptune Canada and OOI seismic data into TWC operations	\$200K	\$0

Time to Complete:

Component	Time to complete
Incorporate Neptune Canada and OOI seismic data into TWC operations	36 months

Recommendation 33:

The committee recommends that NOAA and the TWCs consider the use of arrays and networks such as Hi-Net and EarthScope Array National Facility to determine rupture extent and moment of great earthquakes. The networking and computational requirements are significant and would need to be included in TWC upgrades in the future.

NOAA Response:

NOAA agrees with this recommendation.

NOAA and others have conducted studies demonstrating the utility of using seismic array data to quickly determine the direction and extent of fault rupture for great earthquakes. The TWCs

have set up a data sharing agreement with the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) and are already receiving data from some of the CTBTO International Monitoring System (IMS) seismic arrays on a trial basis.

NOAA is including a seismic array processing capability in its TWC IT Modernization Project and will integrate the analysis into the TWC decision support system.

Cost:

Component	One-time	Recurring
Develop and implement Seismic Array Processing Software at TWCs ¹	\$500K	\$100K

1) This is part of an on-going effort to modernize the Operational IT systems at the TWCs. This effort is currently funded with WARN Act Funds which expired on September 30, 2012.

Time to Complete:

Component	Time to complete
Develop and implement Seismic Array Processing Software at TWCs	3 years

Recommendation 34:

NOAA should explore further the operational integration of GPS data into TWC operations from existing and planned GPS geodetic stations along portions of the coast of the U.S. potentially susceptible to near-field tsunami generation including Alaska, Cascadia, the Caribbean and Hawaii. Where GPS geodetic coverage is not adequate NOAA should work with NSF and the states in extending coverage including the long-term operation and maintenance of the stations.

NOAA Response:

NOAA agrees with this recommendation and has a mechanism in place to address this issue.

NOAA is currently involved in a research project investigating the utility of using GPS data for tsunami warnings. Implementing the complete recommendation will require three stages (with decisions to continue based on cost/benefit as determined at each stage):

- determine the utility of GPS in TWC operations;
- if determined that GPS data will support TWC operational improvements, develop an operational process compatible with the Modernized IT systems with existing real-time GPS data, and
- based on success of previous elements, support extended GPS networks

Cost:

Component	One-time	Recurring
Determine the utility of GPS in TWC operations	\$50K	\$0
Develop an operational process compatible	\$500K	\$0

with the Modernized IT systems with existing real-time GPS		
Support extended GPS networks for tsunami requirements (USGS or appropriate agency)	0	\$2M

Time to Complete:

Component	Time to complete
Determine the utility of GPS in TWC operations	1 year
Develop an operational process compatible with the Modernized IT systems with existing real-time GPS	3 years
Support extended GPS networks for tsunami requirements (USGS or appropriate agency)	4 years and on-going

4. Long-Term Reliability and Sustainability of TWC Operations

Recommendation 35:

NOAA/NWS should harmonize and standardize checklists, tsunami warning products, and decision support tools and standard TWC software tools and applications should be used in the TWCs, following current software engineering practices and taking advantage of current programming language best practices.

NOAA Response:

NOAA agrees with this recommendation.

The harmonization of TWC message formats and content will be achieved to the greatest extent possible, but the effort must take into consideration different threats to different areas, differing response capabilities and procedures across domestic and international political boundaries, and different domestic and international governance structures. Implementation of Recommendation 39 will facilitate the long term harmonization of “software tools and applications while taking advantage of current programming language best practices” proposed in this recommendation.

In addition, the Tsunami Program revised NWS Directives for the TWCs in 2011. The revisions to NWS Instruction 10-701 address policy for TWC product consistency.

Cost:

Component	One-time	Recurring
See Rec. 39	See Rec. 39	See Rec. 39

Time to Complete:

Component	Time to complete
See Rec. 39	See Rec. 39

Recommendation 36:

The TWCs should consider alternative warning message composition software (considering software technology and product generation that results in current generation software and web products (e.g., XML, SMS (Simple Messaging System) formats) and should improve protocols by undertaking an external review by IT specialists in the area of communication technology to identify the latest technology in message composition software and formats, and to ensure compatibility with current and next generation information and communication (web and cell-phone) technology for message dissemination.

NOAA Response:

NOAA agrees with this recommendation.

Presently, TWCs issue messages in standard NWS formats as well as RSS and SMS, with limited ability to issue in CAP/XML (current WCATWC is able to do this but PTWC is not). The official NOAA tsunami.gov Web site (<http://www.tsunami.gov>) seamlessly integrates both TWCs’ products. A goal of the IT Modernization project is to develop a TWC message system that will include CAP/XML products.

NOAA is also finalizing requirements and other project planning documents for the TWC IT modernization project. Once planning is complete, Centers will share consistent product generation software. The IT Modernization project is being led by the NWS Office of Science and Technology (OS&T), which has the NWS expertise on technology and communications. The first build of the modernized TWC IT System is expected to be delivered in mid-2013.

Cost:

Component	One-time	Recurring
Common Web site Development	See Rec. 12	See Rec. 12
Consolidation of TWC Message Generation Software	See Rec. 12	See Rec. 12

Time to Complete:

Component	Time to complete
Common Web site Development	See Rec. 12
Consolidation of TWC Message Generation Software	See Rec. 12

Recommendation 37:

The tsunami warning program should undertake a comprehensive, enterprise-wide long-range technology planning effort, consistent with international technology process and product standards, in order to develop both an enterprise-wide technology architecture for TWC operations and the accompanying enterprise-wide technology support processes.

NOAA Response:

NOAA agrees with this recommendation.

NOAA is finalizing requirements for the TWC IT Modernization. The TWC IT Modernization effort is being executed by NWS’ OS&T to ensure compliance with current software engineering and programming language best practices. The IT Modernization effort will result in an IT architecture for TWC operations that is a part of the NWS’ comprehensive, enterprise-wide long-range technology planning effort. The NWS’ enterprise-wide technology development and planning efforts are consistent with domestic and international technology processes and product standards.

Cost:

Component	One-time	Recurring
Reorganize TWCs under single management structure	\$0	\$0
Complete TWC IT Modernization	\$8M	\$1.5M

Time to Complete:

Component	Time to complete
Reorganize TWCs under single management structure	3 years
Complete TWC IT Modernization	3 years

Recommendation 38:

Given the importance of technology, particularly (IT), in the overall process of detecting and warning, and the rapid evolution of IT, NOAA/NWS should provide the TWCs with stronger IT commitment and leadership, and greater resources for software and hardware personnel, planning, development, operations, maintenance and continuous process and product improvement.

NOAA Response:

NOAA agrees with this recommendation (see Recommendation 37).

Recommendation 39:

IT staff should be provided to the TWCs so that IT hardware and software design, development and maintenance are not a collateral duty of a watchstanding scientist, as is the case presently. An external IT Advisory Board, with membership from the USGS, other seismic network operators, human factors, information technology, and other large-scale, safety-critical systems professionals should be established to advise the TWCs. The Board should meet on at least an annual basis and provide TWC management and operational personnel with guidance and expertise in building, developing, maintaining and nurturing a highly effective, large-scale distributed, tsunami warning system.

NOAA Response:

NOAA agrees with this recommendation with the exception of the establishment of an external IT Advisory Board.

This recommendation is being addressed through the TWC IT Modernization Project led by NWS’ OS&T division. The enterprise solution currently under development for the TWCs (see Recommendation 37) will ensure centralized support for system hardware and logistics, software development, configuration and change management, and documentation, as exists for NWS WFOs. As with the WFOs, the TWCs require a dedicated Information Technology Officer.

Both TWCs were provided an additional FTE through Strengthen the United States Tsunami Warning Program (SUSTWP) funds.

Cost:

Component	One-time	Recurring
Information Technology Officer at the PTWC*	\$200K	\$200K

* The WCATWC has a dedicated Information Technology Officer

Time to Complete:

Component	Time to complete
Information Technology Officer at the PTWC*	1-2 years

Recommendation 40:

NOAA/NWS and the TWCs should adopt national, and where applicable, international, standards, best practices and lessons learned for all functions, technology, processes and products. Specifically, the TWCs should develop platform-independent hardware and software architectures, applications and interfaces; and employ international hardware and software planning, development, operations and maintenance product and process standards, including the Software Engineering Institute’s Capability Maturity Model and the software development life cycle (Carnegie Mellon Software Engineering Institute, 2010).

NOAA Response:

NOAA agrees with this recommendation.

This recommendation is being addressed through the TWC IT Modernization Project led by NWS' OS&T. The enterprise solution currently under development for the TWCs (See Recommendation 37) will result in the development of a platform independent hardware and software architecture, which will adhere to Department of Commerce and national IT standards.

Cost:

Component	One-time	Recurring
See Rec. 37	See Rec. 37	See Rec. 37

Time to Complete:

Component	Time to complete
See Rec. 37	See Rec. 37

Recommendation 41:

The TWCs should also regularly and systematically apply continuing process and product improvement models for hardware and software planning, development, operations and maintenance; organizational processes; and develop a learning organizational culture.

NOAA Response:

NOAA agrees with this recommendation.

See Recommendation 37 in response to the need to regularly and systematically apply continuing process and product improvement models for hardware and software planning, development, operations and maintenance.

See Recommendation 43 in response to the need to regularly and systematically apply continuing process and product improvement models for organizational processes.

The NWS is launching an initiative within current resources to develop a learning organization culture, and to identify future skill sets and requirements for all of its mission critical positions. The results of this initiative will help NWS management develop training curriculums and opportunities for all personnel.

Cost:

Component	One-time	Recurring
Implement and maintain a learning organizational culture at the TWCs	\$0	\$0

Time to Complete:

Component	Time to complete
Skill set and needs assessment	2 years

Recommendation 42:

Because of the importance of technical and scientific expertise to the TWCs function, TWC human capital requirements and TWC recruiting, training, re-training, development, mentoring and professional exchange needs should be included, reassessed and updated as part of the NOAA/NWS enterprise-wide technology planning effort, and be consistent with NOAA- and government-wide standards, so that technology, human and organizational requirements can be considered and developed together by tsunami program members and their customers.

NOAA Response:

NOAA agrees with this recommendation.

The Tsunami Program conducted a Workforce Study of the TWCs in 2009 and 2010 resulting in recommendations to expand both staff and training opportunities at the TWCs. The report noted that the TWC's watchstander positions require unique education and expertise that is not typically found within the NWS. New TWC watchstanders require up to a year of training prior to being proficient on shift. This timing significantly limits the TWCs' capabilities to train and replace watchstanders quickly.

See Recommendation 41 in response to the NWS launching an initiative to continue to develop a learning organization culture.

The current staffing profile prevents some training opportunities for staff due to the need to cover three shifts per day to meet 24x7x2 staffing requirements. The WCATWC watchstander staff works approximately 98 percent of their shifts in operations. This leaves little or no flexibility in filling shifts when operational staff is on leave, in travel status, attending training, or when vacancies occur. The PTWC works a "stand-by" shift schedule that allows for more flexibility with respect to scheduling and training.

Cost:

Component	One-time	Recurring
Ensure succession capability at TWCs	\$600K	\$600K
Increase West Coast Alaska Tsunami Warning Center watchstanding Staff (1 FTE each)	\$200K	\$200K
Maintain staff exchange and expand external training opportunities for TWC staff	\$70K	\$70K

Time to Complete:

Component	Time to complete
Ensure succession capability at TWCs	1 year
Increased watchstander staff	1 year
Maintain staff exchange and expand external training opportunities for TWC staff	1 year

Recommendation 43:

Organizational structures for the two TWCs should be evaluated and fully described as part of the enterprise-wide technology planning effort previously described. Whether there should be a single or multiple TWCs, or whether the TWC operations should be consolidated in a different location, should be addressed in the enterprise-wide long-range planning effort.

NOAA Response:

NOAA agrees with this recommendation and is complying with it.

The Tsunami Program conducted a Workforce Study of the TWCs in 2009 and 2010. The report delivered to NOAA/NWS/CFO recommended staff and training requirements for the TWCs. The TWC Workforce Study and the NOAA Chilean Tsunami Communications Assessment identified a recommendation to move the TWCs under a single management structure. As with all programs, NOAA will continue to evaluate the need for any changes to its Tsunami program’s organizational structure, including options to consolidate operations. However, any proposal to change the organizational structure including consolidation would have to result in both a significant increase in operational efficiency and significant cost savings.

Cost:

Component	One-time	Recurring
Reorganize TWCs under single management structure	\$0	\$0

Time to Complete:

Component	Time to complete
Reorganize TWCs under single management structure	3 years

Recommendation 44:

NOAA/NWS and the TWCs should undertake on-going, joint or NOAA-wide continuous process improvement activities for their functional, technological, organizational and human capital initiatives, including the following:

- *Developing measures of performance and benchmarking individual, organizational and technical performance against industry and agency metrics,*
- *Identifying areas for improvement,*
- *Setting short- and long-term performance goals,*
- *Developing reward and incentive systems for such goals, and*
- *Celebrating TWC and agency accomplishments as performance improves, in order to raise the level of TWC performance to that expected of a high reliable organization*

NOAA Response:

NOAA agrees with this recommendation and considers it complete.

The Department of Commerce initiated a series of performance plan audits across all bureaus, which included the NWS.

The TWCs take part in development of annual operating plans, strategic plans, and strategic implementation plans. Measures and milestones are set and must be met by TWC operations. The OMB Program Assessment Rating Tool (PART) process acknowledged that the Tsunami Program set up challenging measures and milestones, and was given the highest marks of 33 Department of Commerce programs involved in the PART process through 2008. NOAA's TWCs will continue to be involved in the planning and execution phases of the NOAA Tsunami Program, including the change in NOAA from the Planning, Programming, Budgeting, and Execution System (PPBES) to the Strategic Evaluation and Execution (SEE) process.