Assessment of the National Tsunami Hazard Mitigation Program

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NTHMP REVIEW COMMITTEE CONSENSUS STATEMENT

The NTHMP has established a unique partnership among multiple states and federal agencies that has been developed over the past decade, has set challenging goals, and met many of them. This program has institutionalized a partnership between federal and state members that is unmatched by other hazard and risk management programs. The reviewers unanimously agree on the following points:

- NTHMP was established well before the Sumatra tsunami and its goals have been validated by the impacts of that event. Recognition of a broader regional vulnerability to tsunamis, coupled with the success of the NTHMP provided the foundation for the Tsunami Warning and Education Act.

- Despite modest budget allocations, the program has achieved much because the state and federal agency partners have made investments of time and effort that go beyond normal expectations.

- All state and federal NTHMP representatives were highly engaged in the activities of the program and committed to its success.

- The program has expanded beyond a narrow focus on mitigation to include community resiliency. The reviewers endorse this expanded interpretation of the program's goals

- The representatives recognize that the technology developed and used by the program must be tied to education and awareness in order to be effective.

- The program has allowed states to experiment with alternative methods of achieving tsunami safety. This has resulted in a variety of innovative approaches that now provide an opportunity to develop assessment tools for evaluating their relative effectiveness.

- Since products such as inundation maps have been implemented at the local level, NTHMP is in a unique position to establish performance standards and standardized assessment tools for evaluating its effectiveness.

- There is a strong need for the National Academy of Sciences' review of the forecast/warning system and an external review of the *TsunamiReady* community program.

- The expansion of the NTHMP from the five Pacific states to 29 coastal states, commonwealths, and territories and the passage of the Tsunami Warning and Education Act offers a unique opportunity to strengthen the organizational structure of the program and enhance tsunami resilience in the United States.

- The lessons learned from the existing program should now be transferred to the additional 24 members that have joined the expanded program.

- The overarching goal for all partners is to continue to demonstrate the program's value over the next five years and to achieve a sustainable program.

PROFESSOR MICHAEL K. LINDELL'S INDIVIDUAL ASSESSMENT

I concur with the preceding NTHMP Review Committee Consensus Statement and offer additional comments, which are divided into two sections. The first section addresses the NTHMP's achievement of its current goals and provides recommendations for revisions of these current goals. The second section recommends additional goals. The rationale for many of the recommendations can be found in a report on interviews conducted with local officials in Washington and Oregon coastal counties (Lindell & Prater, 2007a). Some of the recommendations involve tasks that are relevant to other hazards. Funding for such activities could be coordinated with the National Science Foundation's programs on Infrastructure Management and Disaster Response and on Decision, Risk and Management Science.

NTHMP Goal Achievement and Recommendations

One general comment relevant to all 13 NTHMP goals is that performance goals should be specific, measurable, and achievable. Thus, despite its many successes in reducing the nation's tsunami vulnerability, the NTHMP has failed to meet many of its goals because they do not meet these essential criteria. Extremely challenging goals have the benefit of being highly motivating and sometimes producing spectacular successes. Nonetheless, it can be very difficult to explain to outsiders why they have not been achieved. This is definitely not an admonition for the NTHMP to set only very easily achieved goals in the future because this would not serve the nation's interests in reducing tsunami vulnerability. Rather, the NTHMP partners should try to be more realistic about the goals that can be achieved, given their limited staff and budgets. As the requirements for reports to Congress give the program increasing national visibility, it will be especially important to ensure program goals are specific, measurable, and achievable.

Goal 1: Tsunami inundation maps

Achievements. There has been significant progress toward meeting this goal, but it has not been met. There is substantial variability among states and, in some cases, between communities within states in the availability and quality of tsunami inundation maps. The shift in mapping responsibilities to the states appears to have been somewhat problematic because some states lack some basic data they need and appear to have assumed (whether realistically or not) they would receive from federal agencies. NTHMP partners have also begun to define tsunami inundation maps in terms of recurrence intervals to make them comparable to FEMA Flood Insurance Rate Maps, which is the form that is likely to be most useful to local jurisdictions.

Recommendations. High resolution inundation maps defined by recurrence intervals will not be universally available in the near term. Consequently, NTHMP needs to establish a long-term plan for developing and disseminating tsunami inundation maps. This plan should recognize that local planners and emergency managers can do much planning for hazard mitigation, emergency response preparedness, and disaster response preparedness with approximate maps produced from low resolution data while they are waiting for more definitive maps.

Some NTHMP documents have advocated the development of a tsunami inundation model for HAZUS-MH, although the cost of this module has been estimated at $10M (General Accountability Office, 2006). Quite aside from the difficulty of assembling a budget of this size, it is not obvious that funding a tsunami module would be the most cost-effective use of NTHMP budgets. In the past, the Texas A&M University Hazard Reduction & Recovery Center generated a significant amount of useful hurricane hazard vulnerability information for Texas coastal counties by using available Geographical Information Systems to analyze data on census tracts and tax assessor parcels. Such analyses are more labor intensive than HAZUS analyses conducted by a proficient analyst, but analyst proficiency requires state and local jurisdictions to invest significant amounts of time (and, thus, money) on training and practice. Few local jurisdictions in the Pacific region will be able to make these investments. Thus, even if the federal government funded a tsunami inundation model for HAZUS-MH, it is likely to need to make further financial commitments to ensure local utilization after the module is developed.

Instead, the tsunami inundation mapping goal should be expanded to address broader issues of tsunami impact characterization. First, the NTHMP should analyze the effects of dunes and vegetation barriers in attenuating tsunami depth and flow velocity. The available scientific evidence suggests that these could serve as effective land use management tools for reducing tsunami vulnerability. Second, the NTHMP should develop a guidance document that explains what resources are available and how rural jurisdictions should conduct social vulnerability analyses. This document should explain how variations in social vulnerability can be addressed by hazard mitigation, emergency response preparedness, and disaster recovery preparedness measures. Third, the NTHMP should examine the feasibility of using Sea Grant universities to provide technical assistance to local jurisdictions in conducting hazard/vulnerability analyses for tsunami hazard. Fourth, the NTHMP should develop guidance for local jurisdictions on methods for assessing the cross-hazard impacts (e.g., among tsunamis, earthquakes, landslides, wildfires, flooding, coastal storms) of alternative hazard mitigation measures.

Goal 2: Consistent evacuation maps.
Achievements. There has been significant progress toward meeting this goal, but it has not been met. Most local jurisdictions have evacuation maps, but they lack consistency in their resolution and symbology.

Recommendations. The success of evacuation as a population protective action for tsunamis depends in part on the source's proximity (which determines the amount of forewarning) and intensity (which, together with the topography, determines the distance of the inland inundation boundary). It also depends on the population's evacuation time which, in turn, depends on the evacuation route system's capacity and the time dependent demand for this capacity. When the source is extremely remote and evacuation times are very low, population protection is almost certain. When the source is close (e.g., the Cascadia Subduction Zone) and evacuation times are high (resort communities on summer weekends), a significant loss of life is almost certain. However, the outcomes are less obvious when the source is remote and evacuation times are high or when the source is close but evacuation times are low. In such cases, analysis is needed to determine what proportion of the population can be evacuated before tsunami arrival. In cases where the entire population cannot be evacuated out of the inundation zone in time, analyses can be used to identify the optimal locations of tsunami shelters within the inundation zone that

people could reach by car or on foot. Thus, evacuation models for vehicular and pedestrian evacuation would be useful for some coastal communities. Evacuation analysis is currently an active area of research and development for hurricanes and hazardous materials incidents (e.g., the March 2007 of the Journal of Urban Planning and Development), so there is no need for NTHMP to allocate funds for computer program development. However, NTHMP members should recognize the utility of current and future evacuation analysis programs for identifying the need for tsunami shelters and the optimal location of such shelters.

More specifically, the NTHMP should define the evacuation mapping goal more broadly to address a wider variety of issues associated with evacuation. These include:

- Developing computer-based analysis tools for multi-modal (pedestrian and vehicular) household evacuations.
- Developing computer-based analysis tools for analyzing transit-dependent evacuations.
- Developing computer-based analysis tools for analyzing special needs facility (e.g., schools, hospitals, nursing homes, jails) evacuations.
- Developing guidance for local emergency managers to use in planning for warning dissemination and evacuation response in coastal communities.

Few of these issues are specific to tsunami evacuation, so funding for the development of these tools should be sought from NSF's program on Infrastructure Management and Hazard Response—perhaps in collaboration with the U.S. Department of Transportation.

Goal 3: Warning dissemination times.
Achievements. There has been significant progress toward meeting this goal, but it is not clear if it has been met. The reviewer briefing presented data indicating detection and dissemination times have generally decreased over time. However, it is not clear if these data were for WCATWC alone or for WCATWC and PTWC combined. Moreover, the trend line does not appear to be linear, raising questions about what caused a transient increase in TWC warning dissemination times. Finally, neither annual sample sizes nor uncertainty bands were provided so it is not possible to determine if the unexpected increase was due to sampling fluctuations.

Recommendations. NTHMP should conduct research on tsunami warnings to identify disparities between the intended and actual notification chain between the tsunami warning centers and local jurisdictions. Such research would build on previous findings of Preuss (1995), Jonientz-Trisler (2001), and OEM (2005) by explicitly including news media sources and including examination of message content and timing of message receipt.

Goal 4: Tsunami impact forecasts
Achievements. Consistent with this goal, NOAA has demonstrated a capability to issue site- and event-specific forecasts of maximum tsunami flooding depth and inland penetration with an average *rms* error (substantially) less than 50%. Since the goal did not specify whether the forecast would be a demonstration forecast or an operational forecast, it appears to have been met.

Recommendations. Future goals of this type should more specifically distinguish between demonstrated capabilities and operational capabilities.

Goal 5: Graphical displays

Achievements. NOAA has met this goal by developing a graphical product that state and local emergency managers will eventually find to be as useful for tsunami monitoring as HURREVAC is for hurricane monitoring. Indeed, I found this to be one of NTHMP's most exciting scientific achievements to date.

Recommendations. As the development of these products progress, it will be extremely important to determine how to display *uncertainties* about impact parameters such as wave amplitude and wave train duration. Research is currently underway at the Texas A&M University Hazard Reduction & Recovery Center to examine users' (e.g., local emergency managers and senior elected officials) processing of probabilistic information about hurricane impact parameters (track, forward movement speed, intensity, and size). The development of future tsunami forecast products should take advantage of findings from this research on the usability of hurricane forecast products (Lindell & Prater, 2007c).

Goal 6: Local warning systems

Achievements. This goal has been met but, by any reasonable interpretation of the term *evacuation notification system*, it was already met before the goal was set. Local jurisdictions have always had local warning systems available—even if nothing more than door-to-door and route alert (emergency vehicles with loudspeakers) systems. Any future goals regarding local warning systems should be more specific about the percentage of local population warned within specific time period such as 30-, 60-, 90, and 120-minutes (Lindell & Prater, 2007b). More generally, it is not clear why the state partners would commit themselves to goals potentially unachievable because they are unlikely to have any significant degree of control over warning system acquisition and deployment. To the best of my knowledge, Washington is the only state that has ever assumed responsibility for installing such a geographically widespread warning system for any natural or technological hazard. In all other cases, this responsibility has been left to the counties, jurisdictions such as cities or fire protection districts, or hazardous facility operators (e.g., nuclear power plants and chemical facilities).

Recommendations. Unless there is reason to believe other state governors and legislatures are prepared to commit the funds for warning system implementation, NTHMP partners should focus on achievable goals such as providing technical assistance to local jurisdictions in the selection and deployment of local warning systems. Despite the limited role for the states in this area, it is quite reasonable for NOAA to set goals for its Weather Radio (NWR) coverage because that is within the agency's control. In particular, interviews with local officials have made it clear that there are many mountainous areas in which NWR's *actual* coverage is significantly smaller than its *nominal* coverage (Lindell & Prater, 2007a). It would be quite feasible for NOAA to work with the states to perform two tasks. First, the NTHMP partners should map NWR actual coverage (some local emergency managers have already done this informally). Second, the results of the mapping study should be used to make decisions about either increasing transmitter signal strength or installing repeaters to increase the actual NWR coverage area.

In addition, the NTHMP should expand the scope of this goal to develop guidance documents and decision aids that would support local emergency managers in planning for and deciding when to implement evacuations. This goal should also be expanded to address post-incident studies of warning reception and response by households, businesses, and special facilities. Such post-incident studies could be conducted in collaboration with NSF-funded quick response studies administered by the Natural Hazards Center at the University of Colorado.

Goal 7: False alarm rates

Achievements. It is clear from discussion among the NTHMP partners that this is not a well-formulated goal. First, there is disagreement about the appropriateness of the term. Second, as NOAA representatives have acknowledged, there is not an obviously reasonable measure even if one does accept the common definition of the term "false alarm".

Recommendations. A number of NTHMP partners are extremely concerned about tsunami predictions that do not result in damaging tsunamis. They fear this will cause a loss of credibility for the tsunami warning centers and, ultimately, a major loss of life if risk area residents disregard tsunami warnings when a major event does occur. There has also been concern expressed about the cost of an unnecessary evacuation. Some studies (e.g., Tsunami Hazard Mitigation Federal/State Working Group, 1996) have cited an unpublished report from Hawaii and concluded such an evacuation could cost approximately $70M in current dollars (General Accountability Office, 2006). On the other hand, other members reject the label "false alarm" and regard such events as little more than unscheduled evacuation exercises.

There appears to be some merit in studying this issue systematically. First, the technology of tsunami warnings is leading toward inundation forecasts (wave height and wave train duration) that are more closely analogous to hurricane size/intensity forecasts than they are to hurricane strike probabilities. Thus, "inundation forecast error" would seem to be a more accurate, not to mention less emotion-laden, term than "false alarm". Regardless of the terminology used, there is a need to collect, peer review, and publish data on the cost of such evacuations. Development of a tsunami evacuation decision support system could rely on current research on hurricane evacuations that is examining these costs (Lindell, Lu & Prater, 2005). However, in addition to evacuation cost (the cost of a "false positive decision"), effective evacuation decisions should also consider the deaths that would result from a failure to evacuate (the cost of a "false negative" decision) and the probabilities of these events. In this regard, the new graphical displays shown in the briefings have no uncertainty bands. Since these forecasts will not be perfectly accurate, efforts should be made to estimate the forecast uncertainties. These uncertainties, coupled with the infrequency of significant tsunamis, will make it difficult to establish simple program goals for reductions in forecast error.

Second, there is some concern about tsunami "warning fatigue" that appears to be based on anecdotal evidence of tornado "warning fatigue". However, the latter is likely to be due to the dozens of times per year that tornado warnings are received in the plains states. By contrast, research on hurricane evacuations has repeatedly confirmed that "unnecessary evacuations" do *not* decrease people's expressed willingness to evacuate or their actual evacuation during later hurricanes. This is likely to be due to the relative infrequency of hurricanes (which rarely strike a given area multiple times per year). By extension, it seems quite unlikely that there will be a

significant "warning fatigue" effect for tsunamis because they occur so infrequently (i.e., fewer than 20 warnings in the past 25 years). Nonetheless, the NTHMP should support research to address these issues.

Goal 8: Community resilience
Achievements. This goal has been achieved only in its narrowest interpretation. That is, social science tools (specifically population surveys) have been used (at least a few times) to address at least one aspect (tsunami hazard awareness) of NTHMP effectiveness.

Recommendations. This goal should be expanded in three ways. First, the NTHMP should develop simplified guidance for small and rural jurisdictions on pre-impact disaster recovery planning. Second, the program should conduct a needs assessment that compares the typical tsunami planning and response demands on coastal emergency managers with their capabilities (especially their training) and the capabilities of collaborating agencies (e.g., land use planning departments) their jurisdictions. The NTHMP should use this needs assessment to identify critical training shortfalls and recommend training opportunities that can be used to remediate the shortfalls. Such training opportunities should involve minimal travel and other costs that are likely to exceed the resources of these jurisdictions.

Goal 9: TsunamiReady program participation
Achievements. This goal has not been met.

Recommendations. The current criteria for *TsunamiReady* membership are sufficiently low that many communities should be able to qualify, but they do not imply that these communities are adequately prepared for tsunami impact. The NTHMP should 1) assess local government's incentives and impediments for joining the *TsunamiReady* program, 2) design a program for increasing the incentives and overcoming the impediments, 3) implement the program, and 4) evaluate the program's effectiveness.

When designing incentives, the NTHMP should work with the *TsunamiReady* program to define grades of membership—similar to the grades of qualification within the National Flood Insurance Program. There is research currently being conducted on defining indicators of community disaster preparedness that could be consulted here. The credit for *TsunamiReady* program membership toward NFIP rate adjustments is a very important start but additional incentives (perhaps points toward qualification for predisaster hazard mitigation grants) should be explored.

In addition, the NTHMP partners should develop a guidance document that specifically explains the similarities and differences among tsunamis, coastal storms (including hurricanes), and riverine flooding in terms of their community impacts. Moreover, the program should establish clearer integration between the objectives and procedures of the National Tsunami Hazard Mitigation Program and the National Flood Insurance Program.

Goal 10: Public outreach

Achievements. There are three components to this goal, but there is no evidence any of them has been met. Equally significant, there is no economically reasonable way to collect the data required to determine if the goals have been met.

Recommendations. The NTHMP partners should set realistically achievable goals for 1) collecting and assessing existing outreach materials, 2) developing model outreach materials and assessment instruments, 3) providing guidance for local officials on how to adapt and implement the model materials within their communities, and 4) periodically coordinating or conducting assessments of the effectiveness of these materials (note that it is the materials that should be assessed, not the local jurisdictions).

In particular, NTHMP partner states and local governments have developed many maps, brochures, lectures, and other tsunami hazard awareness materials. However, no assessments have been conducted to determine whether these items individually or collectively provide all the information those in tsunami inundation zones need. Such an assessment can be performed by using the principles of *Instructional System Design (ISD)*, which has four stages—assessment, design, implementation, and evaluation. The first stage of the ISD process, *needs assessment*, has already been substantially accomplished—especially by NSF funded research. Social science research has clearly established that people are most likely to take protective action if they receive information from credible authorities that leads them to personalize the risk. That is, they need to believe there is a real threat to the safety of themselves, their loved ones, and their property. In addition, they need to be informed about the actions they can take to achieve protection and provided with accurate information about the attributes of these protective actions. In the case of hazard mitigation and emergency preparedness actions, such attributes include efficacy in protecting persons and property, utility for other purposes, and requirements for money, time and effort, specialized knowledge and skill, specialized tools and equipment, and required cooperation from other people (Lindell & Perry, 2004). In the case of emergency response, people also need to be informed about how they will know when to take protective action (e.g., environmental cues such as ground shaking or suddenly receding water levels, as well as social warnings transmitted through NWR, sirens, commercial radio and television, and route alerting). Those at risk also need information about conditions during an evacuation that would facilitate (e.g., evacuation assistance for those with mobility limitations or who lack personal vehicles) or impede (e.g., evacuation routes that may be blocked by collapsed bridges or traffic jams) their egress from the inundation zone. Finally, people need information about sources of further information during normal conditions and emergencies.

ISD's *design* stage involves three steps—the specification of learning objectives, development of a lesson plan, and development/acquisition of materials—that could be performed by an NTHMP committee. The materials could be assigned to modules that would be organized according to function and degree of difficulty. For example, there might be a basic hazard awareness module that is used for radio or television public service announcements. More advanced modules could address basic emergency response (able-bodied households with vehicles or within walking distance of high ground), advanced emergency response (evacuation for mobility impaired households), and hazard mitigation. Some of these materials can be adapted from public outreach programs for other hazards (hurricanes, nuclear power plants, toxic chemical facilities). The final

materials could then be distributed to state and local personnel who would select the trainers, select the training methods/techniques (lecture, demonstration, etc.), and schedule the programs. In the third stage, *implementation*, state and local personnel would deliver the programs.

ISD's fourth stage, *evaluation*, would require an NTHMP committee to define program evaluation criteria—which are determined by the training objectives defined in the design stage. In addition, the committee would provide an inventory of standardized questionnaire items and provide state and local jurisdictions with technical assistance in designing and conducting surveys, quasi-experiments, and field experiments. Such studies could, for example, assess the extent to which people accurately recall and accept training information; understand inundation maps; and intend to engage in appropriate mitigation, preparedness, and emergency response actions. In addition to testing people's responses to paper and pencil items measuring knowledge, it would also be possible to administer items measuring their emotional responses to see if tsunami evacuation drills actually make people more "fearful" and less likely to return to coastal vacation areas.

In addition, NTHMP should establish an information clearinghouse, or at least a single web site, where local officials can obtain the information they need for community tsunami hazard management. This clearinghouse could be operated by a Sea Grant university conducting tsunami hazard/vulnerability analyses. In addition, materials from this training development process could be archived at the International Tsunami Information Center.

Goal 11: Tsunami resistant/resilient construction guidance
Achievements. The activities needed to achieve this goal are well under way and a portion is nearly complete, but the goal itself has not been achieved.

Recommendations. NTHMP should expand the scope of this goal in three ways. First, it should examine the need for, and feasibility of, developing special tsunami resistance standards for special needs facilities. Second, NTHMP should analyze the planning, legal, and behavioral issues associated with vertical evacuation from tsunamis. This should include an examination of the feasibility of incentives, such as density bonuses, that could be offered to local developers considering building such structures. Third, the program should develop a computer-based decision support system to assist local emergency managers, land use planners, and elected officials in choosing a suitable portfolio of tsunami hazard management measures.

Goal 12: Tsunami hazard integration into business continuity plans
Achievements. There is no evidence that his goal has been achieved. Indeed, there is no way to determine if the goal has been achieved other than by conducting extensive surveys of coastal businesses, which is not a reasonable allocation of the NTHMP's limited funds. Moreover, it is quite probable that less than 25% of the potentially threatened businesses have *any* business continuity plans, let alone ones that include a tsunami component.

Recommendation. It would be more reasonable for the NTHMP partners to follow the general procedure recommended for public outreach. First, the NTHMP should set a goal of assessing existing business continuity planning guidance (e.g., Federal Emergency Management Agency, no date) to see if tsunami threat requires any supplementary material. Second, the program

should assess the incentives and impediments for business continuity planning by coastal businesses. Third, the NTHMP should develop any necessary supplementary materials. Fourth, the program should disseminate the existing business continuity planning guidance (with supplementary materials if those are developed). Fifth, the NTHMP should assess the effectiveness of the dissemination program.

Goal 13: Coordination with the National Response Plan

Achievements. The National Response Plan currently is, and should continue to be, an all-hazards plan. Consequently, the NRP should not address tsunami hazard (or any other hazard) specifically.

Recommendation. A more reasonable goal would be for the NTHMP partners would be to determine if there are any aspects of the NRP that might be impediments to tsunami response and recovery. If so, they should work to eliminate these impediments.

RECOMMENDED ADDITIONAL GOALS

Goal 14: Expand the scope of planning to include a regional catastrophe. The implicit focus of most NTHMP research and operational activity is community disasters, not regional catastrophes. However, the Indian Ocean tsunami and Hurricane Katrina demonstrated quite vividly the difficulties of responding to events that are the magnitude of a major Cascadia earthquake and tsunami. Greater integration is needed across jurisdictions within states, between states, and between states and federal government to prepare for a Cascadia event that would generate a major tsunami. In particular, there is a need to institutionalize a planning basis that includes events that can produce multiple threats (e.g., a major Cascadia event that would initiate shaking damage to buildings and infrastructure, landslides and liquefaction, hazmat releases, and a tsunami that would in turn initiate many of these threats in other locations). One useful task would be to assess the impacts of a major Cascadia event and compare those to multiple threat events in other regions of the country (e.g., a major New Madrid earthquake). Among other preparations for such an event, Pacific Northwest residents need to be told to prepare for a much longer duration of self-sufficiency than 3-7 days.

Goal 15: Develop a stronger linkage to social science research. There are many areas in which NTHMP activities make assumptions about the behavior of individuals, households, and businesses or seek to change the behavior of these social units. The Emergency Management Agency's Emergency Management Institute recently published a document (Lindell, Prater & Perry, 2006) that should prove quite useful as a guide to social science findings related to tsunami hazard management. In addition, the National Academy of Sciences (Committee on Disaster Research in the Social Sciences, 2006) recently identified needs for future social science research on environmental hazards and disasters.

The NTHMP, including its NSF representative, should work with the Tsunami Research Program to develop stronger mechanisms for linking to the social science research community. A social science research coordinating committee should be established that has a significant degree of continuity of membership and meets frequently enough to ensure its ability to effectively translate NTHMP programmatic needs into research priorities and also to translate research findings into nontechnical summaries that are disseminated to local emergency

managers, land use planners, and public administrators. This committee should identify social science research needs related to tsunami hazard management, identify funding sources for such research, and publicize the availability of research funding for the social science research community. An additional mechanism for accomplishing this objective would be to hire a social scientist to work during the summers at one of the NOAA facilities supporting the NTHMP. This procedure has been followed by the Department of Defense, which has contracted for many years with the American Society for Engineering Education (ASEE). ASEE publicizes summer research fellowships at military research laboratories, processes applications, submits lists of applicants to the laboratories (which choose the applicants most suitable to them), and handles the employment logistics. This would be an excellent mechanism to obtain highly qualified contributions at modest cost.

Goal 16: Promote adoption and implementation of best practices. The NTHMP should develop a mechanism for promote adoption and implementation of best practices for tsunami hazard management. In particular, this should include encouraging other states to require tsunami evacuation exercises for schools in inundation zones. It might also include the development of standardized reporting procedures for community-wide evacuation exercises that could provide the data that will be needed to refine evacuation models of households (vehicular and pedestrian), transit-dependent populations, and special facilities.

Goal 17: Assess budget priorities among program areas. This is a procedural rather than a substantive goal. It is common to hear that accurate inundation maps are the foundation for effective hazard mitigation and that such maps require precise models using high-resolution input data. Of course, it is true that more accuracy is better than less accuracy but it is also true that each increment in data and model accuracy comes at increasing cost. Or, in economic terms, there is generally a decreasing marginal return on each dollar invested. The NTHMP needs to examine its budget allocations to determine if there are significant disparities in the returns on investment between modeling/mapping, forecasting/warning, and mitigation/outreach (and also within each of these three domains). As an extreme example, perfect maps are worthless if none of the users can interpret them correctly (between 33-67% of Texans surveyed could not correctly identify the hurricane risk area in which their home was located, even when a map was enclosed in the survey packet—Arlikatti, Lindell, Prater & Zhang, 2006; Zhang, Prater & Lindell, 2004). Of course, it is equally true that a perfect ability to understand maps is of little use if the maps are totally inaccurate. The balance between mapping and outreach is undoubtedly is somewhere between these two extremes but, unfortunately, there is insufficient data available to determine whether there has been an adequate emphasis in all three areas (modeling/mapping, forecasting/warning, and mitigation/outreach) or if the return on investment is substantially higher in some areas than in others.

It is not well established what is the return (measured in terms of increased tsunami safety) on increased model/map accuracy, but it would seem to be *moderate at best* because it is likely to produce very little change in the average quality of building construction. This is because even a perfectly enforced building code only affects new construction (which is a very small proportion of the total building stock); almost none of the existing construction is affected. Thus, it takes many years to provide a return on investment. However, it does seem likely that the *cost* of increased model/map accuracy is high.

Similarly, it is not well established what is the return (again measured in terms of increased tsunami safety) on increased outreach, but it would seem to *moderate at worst*. It is true that public outreach programs consistently show only modest success before an emergency occurs, but his is generally achieved at only modest cost. Moreover, there are significant informal warning effects (an entire group can respond effectively even if only one person understands that swiftly receding water is a cue to tsunami onset). Thus, measurement of effectiveness in terms of the percentage of the target population responding correctly to a set of survey items *before impact* tends to underestimate the percentage of the target population that will respond appropriately *in an emergency*. In summary, it seems likely increased efforts on tsunami outreach would provide a greater increase in tsunami safety than other activities.

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