# Tsunami mitigation efforts on California's north coast

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**Abstract.** The 1992 Cape Mendocino earthquake raised concerns about tsunamis along the Cascadia margin. In the 9 years since the 1992 earthquake, a sustained tsunami mitigation program has been established in north coast California including:

- California Division of Mines and Geology earthquake planning scenario for a larger Cascadia earthquake and local tsunami.
- Redwood Coast Tsunami Working Group, an organization of emergency managers, agencies, and businesses from Humboldt, Mendocino, and Del Norte Counties that promotes and coordinates regional mitigation projects.
- Publications: 3 editions (225,000 copies) *Living on Shaky Ground: How to Survive Earthquakes and Tsunamis on California's North Coast*, and other publications.
- The Earthquake Education Through Theatre Arts Project producing public service announcements and drama productions with tsunami and earthquake safety themes in K–12 public schools.
- Tsunami curriculum materials and workshops for K–12 teachers.
- Emergency response planning and exercises that include a near-source tsunami.

Five assessment surveys conducted between 1993 and 2001 demonstrate the effectiveness of regional mitigation efforts.

## 1. Introduction

On 25 April 1992, a magnitude 7.1 ($M_w$) earthquake occurred near Cape Mendocino in Humboldt County, California. The earthquake, located onshore near the town of Petrolia, produced the highest ground accelerations ever measured in California, over $60 million in losses, coastal uplift, and a small local tsunami (CSMIP, 1992; Carver *et al.*, 1994; Oppenheimer *et al.*, 1993; González and Bernard, 1993). The location and orientation of rupture strongly suggested an origin on or near the Cascadia subduction zone (CSZ) (Oppenheimer *et al.*, 1993), confirming the capability of the CSZ to produce strong earthquakes and local tsunamis. The tsunami, although not damaging, raised the concerns of State and Federal agencies responsible for disaster planning and response. Oregon's Senator Hatfield convened Senate hearings to assess the tsunami vulnerability of the West Coast of the United States. As a result of those hearings, a series of workshops were held that led to the formation of the National Tsunami Hazard Mitigation Program (Bernard, 1998).

The 1992 earthquake and paleotsunami research showing evidence of prehistoric tsunamis in the region (Abramson, 1998; Garrison-Laney, 1998) have driven a number of earthquake and tsunami mitigation efforts on the North

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Coast. This paper summarizes these efforts and assesses the effectiveness of the mitigation program.

### 1.1 The Regional Setting

The north coast California counties (Del Norte, Humboldt, Mendocino) share many similarities with other coastal communities in the Pacific Northwest. The population is predominantly rural and concentrated in low-lying coastal areas and near the estuaries of large rivers. The economy is resource and tourist based and suffers from chronically higher unemployment than other parts of the state. The largest industrial centers are located along low-elevation coastal sand spits and near harbors, areas particularly vulnerable to both tsunami flooding and strong shaking damage. Populated areas are isolated from each other and from regional urban centers. Roads, communication links, and critical lifelines connecting populated areas are extremely vulnerable to disruption from strong shaking, tsunami inundation, and other likely effects of a large Cascadia earthquake.

In other aspects, at least part of the region differs from the rest of the Pacific Northwest. The coastal and offshore areas of Humboldt County are among the most seismically active areas in the United States (Dengler *et al.*, 1992). Since 1980, there have been five earthquakes of about magnitude 7, and an additional six of magnitude 6 or larger. In the past decade alone, seven earthquakes in the region have been strong enough to produce Modified Mercalli Intensities (MMI) of VII or greater. Nearly 100% of respondents to surveys (Section 3) have felt an earthquake and over half have experienced some damage. This contrasts significantly with much of the rest of the Pacific Northwest where large or damaging earthquakes have been much more infrequent in historical times.

The Crescent City region of Del Norte County has earned the reputation as the West Coast's tsunami capitol. Eleven lives were lost and more than $15 million in damages were caused by the 1964 tsunami (Fig. 1). Crescent City also experienced flooding in the tsunamis of 1946, 1952, and 1957 (Lander *et al.*, 1997).

## 2. Mitigation Efforts

Mitigating the effects of the next great Cascadia earthquake is a five-step process:

1. Recognizing that the Cascadia subduction zone poses a significant earthquake hazard,
2. Defining the nature of the hazards posed by great Cascadia quakes,
3. Developing messages and disseminating information about the hazard,
4. Developing mitigation tools and taking action to reduce the hazard,
5. Institutionalizing mitigation efforts into a sustained, long-term mitigation program.

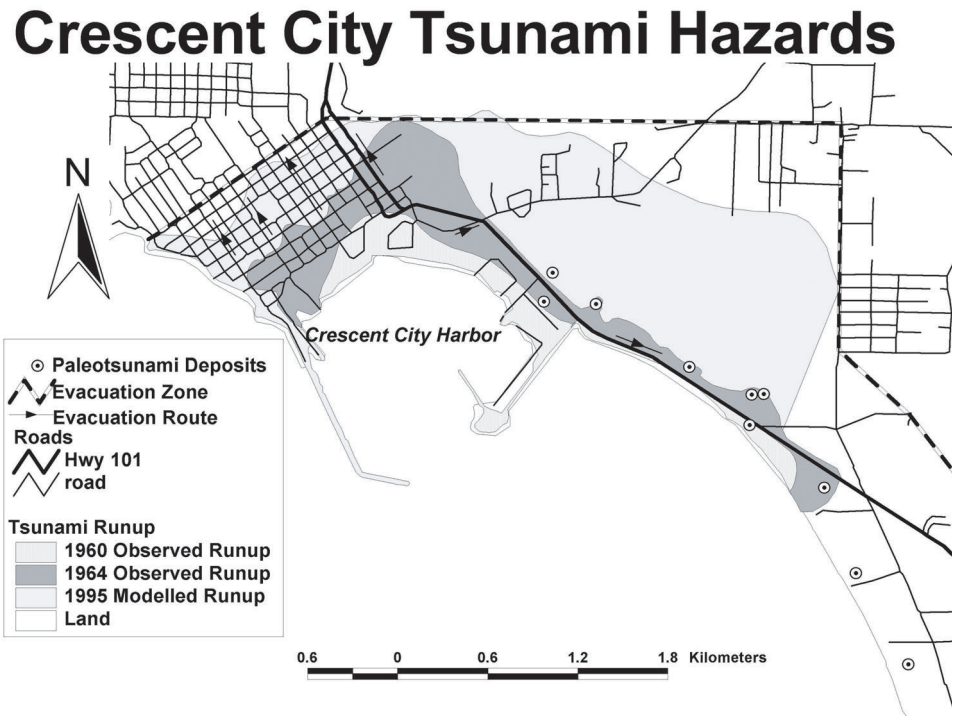


**Figure 1**: Crescent City tsunami hazards showing observed 1960 (Griffith, 2000) and 1964 (Griffith, 1984) run-up, paleotsunami deposits (Carver, 2000), NOAA modeled tsunami projection (Bernard *et al.*, 1994), and the tsunami evacuation zone. Arrows show the directions of tsunami evacuation. Map compiled by J. Patton, Humboldt State University.

The Cascadia subduction zone poses particularly difficult problems for tsunami hazard mitigation. Recognition of the CSZ is less than two decades old (Heaton and Kanamori, 1984; Heaton and Hartzell, 1987; Atwater, 1987; Rogers, 1988a, b; Adams, 1990; Clarke and Carver, 1992). Consensus among scientists, emergency planners, and governmental agencies on the general nature of the risk (Step 1) has only emerged in the last several years (Atwater *et al.*, 1995). The last significant event along the CSZ occurred prior to European settlement and written documentation, requiring an understanding of technical evidence to comprehend risk. Events along the CSZ recur on the order of hundreds of years (Atwater *et al.*, 1995), relatively infrequently by human standards, and estimates as to when the next earthquake is likely vary widely.

The CSZ also poses a previously unrecognized risk to West Coast residents, the locally generated tsunami with travel times on the order of minutes to tens of minutes. Although tsunami awareness has increased in the Pacific Northwest in recent years (Karel, 1998), there is still considerable public confusion over what a tsunami is, how quickly it can arrive, the hazard duration, and areas of risk and safety. Effective mitigation of a relatively new and unknown hazard requires information presented in a variety of formats

targeted at different audiences and a consistent message throughout (Mileti *et al.*, 1993).

### 2.1 The CDMG planning scenario

After the 1992 earthquake, the U.S. Federal Emergency Management Agency (FEMA) provided funding to the California Department of Conservation's Division of Mines and Geology (CDMG) to study the potential effects of a much larger earthquake along the CSZ in northern California. In March 1995 the results of this study, a *Planning Scenario in Humboldt and Del Norte Counties for a Great Earthquake on the Cascadia Subduction Zone* was released (Toppozada *et al.*, 1995). The CDMG scenario has provided the second step in the hazard mitigation program: a general description of the specific hazards posed to communities in Humboldt and Del Norte Counties.

The CDMG earthquake planning scenarios model in a general way the expected strength of shaking, distribution of liquefaction and landsliding, and damage to roads, utilities and other lifelines/critical facilities caused by a particular scenario earthquake. They are intended only to assist in planning emergency response and as an educational tool and not to be used for other planning purposes. The damage assessments are based upon the specific scenario earthquake and are general in nature and not intended as site-specific evaluations. An earthquake on a different fault or with a significantly different magnitude will likely result in a markedly different pattern of damage.

The North Coast scenario assumes a magnitude 8.4 earthquake that ruptures a 240 km long, 80 km wide fault extending from Cape Mendocino, California to just north of the Oregon border dipping at an angle of 11° to the east beneath the coast. The postulated fault surface is about 15 km beneath Eureka and 19 km beneath Crescent City. The scenario assumes concurrent movement and surface rupture along the Little Salmon fault located south of Eureka. The earthquake is expected to produce MMI intensities in the VII–IX range throughout the region, causing major damage to buildings and infrastructure and restricting to the arrival of emergency supplies for at least two weeks.

It was the concern about a locally generated tsunami and its potential for significant loss of life even in a sparsely populated setting that led to the allocation of resources to construct the scenario. CDMG contracted with the National Oceanographic and Atmospheric Administration's Pacific Marine Environmental Laboratory to run two-dimensional tsunami inundation models for the Humboldt Bay and Crescent City regions (Bernard *et al.*, 1994). The scenario earthquake is expected to deform the sea floor surface and produce a series of waves that will begin arriving along the coast within minutes of the earthquake. The scenario tsunami assumes a wave height of 10 m at 50-m water depths and is expected to inundate the Samoa Peninsula in Humboldt County, and produce flooding in Crescent City in excess of that caused by the 1964 Alaskan earthquake (Fig. 1). The period of potentially hazardous wave activity is expected to last many hours. The north

coast population at risk from the scenario earthquake is significant; about 20,000 people live or work in areas of potential inundation and even greater numbers travel through this region each year as tourists or other visitors.

The CDMG Cascadia scenario is not the largest earthquake that could occur along the Cascadia megathrust (Atwater *et al.*, 1995; Satake *et al.*, 1996). Because of the proximity of the megathrust surface, shaking strength in Humboldt and Del Norte counties is not expected to be significantly greater for a larger event (Toppozada *et al.*, 1995). A conservative estimate was chosen for the incident wave included in the scenario (Bernard *et al.*, 1994) because of uncertainties in modeling tsunamis and the large amplitudes of several recent locally generated tsunamis in Japan and Indonesia. Paleoseismic evidence from Del Norte Counties suggest a full rupture of the CSZ could produce inundation levels near the upper limits of those predicted in the scenario (Carver *et al.*, 1996). The scenario is limited to Humboldt and Del Norte counties and includes tsunami inundation estimates for only a small portion of the exposed coastline. Anyone using the scenario must recognize that ground shaking impacts from the scenario event will extend to adjacent counties and even, perhaps, to population centers at some distance from the epicenter. The tsunami has the potential to impact coastal areas well outside the planning scenario study area.

Since the scenario release, a number of agencies and organizations have developed mitigation projects and response planning aimed toward local tsunamis and great Cascadia earthquakes. A major thrust of these efforts has been public education and coordination of activities among the different North Coast groups engaged in mitigation. These efforts have been aided by the National Tsunami Hazard Mitigation Program and particularly the sharing of information among the state representatives in the program's Mitigation Subcommittee.

## 2.2 Redwood Coast Tsunami Work Group (RCTWG)

The Redwood Coast Tsunami Work Group (RCTWG) is an organization of local, state, and federal agencies, coastal land managers, and businesses from Del Norte, Humboldt, and Mendocino counties. The group was formed in July 1996 as an ad hoc interagency task force to define the needs of local jurisdictions to mitigate the tsunami hazard defined by the CDMG planning scenario and to promote a coordinated, consistent mitigation program for all coastal areas. In May 1997, the group received recognition by the Coastal Region, Governor's Office of Emergency Services, as a part of ongoing state hazard reduction efforts. Projects by member organizations have included evacuation route planning and signage in Crescent City (Fig. 1), publications (Section 2.3), tsunami hazards planning in Redwood National and State Parks, exhibits, workshops and other educational outreach efforts. In April 2000, the Humboldt County Board of Supervisors declared their support of " ... the Redwood Coast Tsunami Work Group and its member organizations to mitigate the effects of future great earthquakes ... " in their April 2000 earthquake awareness year proclamation.

A major effort of the RCTWG has been sponsorship of an

Earthquake/Tsunami Education room for the 11-day run of the Humboldt County Fair in 1999 and 2000. Educational institutions, government agencies, local organizations and businesses, and individuals donate time, money, and materials for exhibits and staffing. The Humboldt County Fair receives 60,000 to 75,000 visitors each year, approximately a third of whom visited the room. Exhibits include a tsunami wave tank, seismograph, Tsunami Theater, shake table and liquefaction display, paleotsunami cores, historic earthquakes, regional mitigation projects, preparedness information, and free publications.

### 2.3 Publications

Over 200,000 copies of a 24-page color earthquake awareness/preparedness magazine, *Living On Shaky Ground: How to Survive Earthquakes and Tsunamis on the North Coast* have been published by the Humboldt Earthquake Education Center at Humboldt State University since 1993 (Dengler and Moley, 1993, 1995, 1999). The magazine includes historical photographs of earthquake and tsunami damage within Humboldt and Del Norte counties, maps of seismic activity and the regional geologic setting, and safety diagrams such as how to anchor wood stoves and water heaters. The magazine contains information about recent seismic activity, the potential for great CSZ earthquakes, the local tsunami threat, and the CDMG scenario. Copies were distributed as an insert in several regional newspapers in 1993 and in 1995 and continue to be distributed at workshops, meetings, and the County Fair. The magazines are posted electronically at http://sorrel.humboldt.edu/~geodept/earthquakes/eqk_info.html.

There are many earthquake awareness and preparedness pamphlets, magazines, and booklets currently in print. *Living On Shaky Ground* differs from most of these by focusing on the north coast region and issues such as the modeled inundation for the Humboldt Bay and Crescent City areas, securing wood burning stoves and reinforcing pier and post foundations. The magazine has drawn heavily from the results of social science studies on how individuals respond to and process preparedness information (American Red Cross, 1992; Lopes, 1992; Mileti *et al.*, 1990, 1993). Regional risk is described in realistic, non-sensational terminology and the emphasis throughout is on taking positive actions.

Other publications include:

- *Living Safely In Your Schools On California's North Coast*, a 10-page flip-chart brochure developed by the Humboldt Earthquake Education Center and North Coast Schools Insurance Group and distributed to all public school teachers and staff in Humboldt and Del Norte Counties.
- *Tsunami—How to Survive This Hazard on California's North Coast* is a 1-page reproducible tri-fold pamphlet available in both English and Spanish.

### 2.4 Earthquake Education Through Theatre Arts

The Earthquake Education Through Theatre Arts Project began in 1994 as an interdisciplinary program of drama and science in the public schools. The nationally acclaimed Dell'Arte Education Through Arts Project, located in Blue Lake, California provides the dramatic guidance and the Humboldt Earthquake Education Center contributes technical information and scientific content. The collaboration has produced a series of videotaped public service announcements on earthquake and tsunami safety and developed plays with earthquake and tsunami themes. The program was recognized by the Western States Seismic Policy Council (WSSPC) by an Award in Excellence for outstanding outreach efforts in education in 1998.

The project goals are:

- To educate students, families and the school community about seismic and tsunami hazards.
- To educate the community at large and foster discussion through the production of interesting, thought-provoking and entertaining productions.
- To enfranchise elementary and high school school students by making their contribution essential to creating an important "real" product.
- To enlist the future general public in recognizing the importance of seismic and tsunami hazards.

The Cascadia subduction zone has received sensational treatment in the media causing interest and alarm among school children, school personnel and their families, particularly in schools located within potential tsunami inundation zones. Children are particularly vulnerable to tsunamis, which often select the most vulnerable as victims. This collaborative effort between the Dell'Arte Education Through Arts Project and the Humboldt Earthquake Education Center addresses misinformation and emphasizes real solutions for persons at risk.

Products and activities include:

- 1994: For All You Know Videotaped Earthquake Public Service Announcements
- 1995: Videotaped Earthquake/Tsunami Public Service Announcements
- 1995/96: Play—Samoa Peninsula Seismic Tsunami Vaudeville Extravaganza
- 1997: Play—Blue Lake From Quake to Quake
- 1999–2000: Videotaped Tsunami Vignettes

The assessment survey (see Section 3 below) conducted in January 1996 about 1 year after the initial airing of the PSAs on the local NBC affiliate in Humboldt and Del Norte counties found that 41% of respondents in the two counties recalled seeing one or more of the segments.

### 2.5 Curriculum materials and teacher training

Professional Development Courses (Geology 700) for teachers, students in the credential program, and interested community members are offered at Humboldt State University on tsunamis, earthquake education curriculum, and the faults of the Cascadia fold and thrust belt. The courses include a Friday evening and an all day Saturday session. Over 1200 people have enrolled in these classes since 1985. In 1997 a 10-activity tsunami curriculum package was developed by the Humboldt Earthquake Education Center. Activities cover elementary through high school levels and introduce distant and near-source tsunamis, tsunami travel-times, the Tsunami Warning System in the Pacific, tsunamis in myth and legend, the National Tsunami Hazard Mitigation Program, and "Tsurfin' tsunamis on the Web". The curriculum is currently being adapted for the web (http://sorrel.humboldt.edu/~geodept/earthquakes/tsunami!/Tsunami!_TOC.html).

### 2.6 Emergency response planning and exercises

Since its release, the CDMG scenario has formed the basis for earthquake response planning in Humboldt and Del Norte Counties. Revisions of the seismic safety element of the County General Plan and the Cities of Arcata and Eureka now include great Cascadia earthquakes and local tsunamis. Exercises based on the CDMG Scenario event were conducted by the state and counties in 1996, the cities of Eureka and Arcata in 1998, and Ferndale in 2000. In 1999, 78 emergency responders from Humboldt and Del Norte Counties participated in a FEMA-sponsored emergency management training seminar at Emmitsburg, Maryland, and conducted a functional Cascadia earthquake exercise including a local tsunami. In 1999 The Humboldt County Department of Health and the North Coast Emergency Medical Services obtained FEMA funding for the Cascadia Region Disaster Medical Preparedness Project. The project defines "isolated islands of humanity"—areas likely to be cut off from one another after a large earthquake. Medical supplies will be stored in each of these areas and local community members trained to use them in an emergency situation.

## 3. Assessment of Individual Preparedness and Awareness

Five telephone surveys have been conducted by the Humboldt Earthquake Education Center to assess awareness, preparedness, and the effectiveness of hazard mitigation programs in the north coast region. The first survey of Humboldt County residents was done in April 1993 about a year after the Cape Mendocino earthquake and a week before the first edition of *Living on Shaky Ground* was widely distributed in regional papers. A second survey was run 7 months later. The third survey was done in March 1995, the week before the CDMG scenario release, and a fourth survey was completed in January 1996 about 9 months after the scenario release and 4 months after the publication of the second edition of *Living on Shaky Ground*. The March

**Table 1**: Comparison of responses to the five assessment surveys (simple averages), Humboldt County residents only.

| | | Percent responding "Yes" | | | | |
|---|---|---|---|---|---|---|
| | **Question** | Apr. 93 | Nov. 93 | Mar. 95 | Jan. 96 | Mar. 01[a] |
| 1. | Felt an EQ | 99 | 99 | 100 | 99 | 99 |
| 2. | Experienced damage from EQ | 53 | 51 | 60 | 69 | 58 |
| 3. | Has 3 days of food/water | 64 | 61 | 75 | 73 | 79 |
| 4. | Water heater secured to wall | 61 | 65 | 68 | 65 | 85 |
| 5. | Wood stove secured | 34 | 38 | 27 | 41 | 47 |
| 6. | Out-of-the-area contact | 46 | 43 | 45 | 47 | 47 |
| 7. | Latches on kitchen cupboards | 29 | 25 | 29 | 26 | 25 |
| 8. | House bolted to foundation | 58 | 76 | 72 | 74 | 77 |
| 9. | Sought information on EQs | 28 | 28 | 32 | 31 | 49 |
| 10. | Attended an EQ talk or workshop | 20 | 20 | 19 | 28 | 24 |
| 11. | Knows what tsunami is | 78 | 84 | 92 | 91 | 97 |
| 12. | Tsunami can arrive minutes after EQ | 51 | 62 | 75 | 70 | 72 |
| 13. | Not safe after first wave retreats | 65 | 73 | 75 | 81 | 97 |
| 14. | Knows what CSZ is | 16 | 20 | 29 | 32 | 44 |
| 15. | Damaging EQ likely in 10 years | 72 | 73 | 91 | 94 | 79 |
| 16. | Had seen "On Shaky Ground" | – | 47 | 32 | 55 | 18 |
| 17. | Had kept *Living on Shaky Ground*[b] | – | 45 | 57 | 53 | 38 |
| 18. | Had used *Living on Shaky Ground*[b] | – | 43 | 60 | 49 | 60 |
| 19. | Had talked about earthquakes | – | – | 61 | 37 | 75 |
| 20. | People in affected area responsible | – | – | – | 67 | 51 |
| 21. | Government responsible | – | – | – | 18 | 37 |
| **Number of surveys** | | **601** | **609** | **621** | **648** | **120** |

[a]Survey in progress, results preliminary.
[b]Of people who had seen the magazine.

1995 survey expanded the region sampled to include coastal Mendocino and Del Norte counties in addition to Humboldt County, and the January 1996 survey covered all areas of the March survey plus residents of Curry County, Oregon. A fifth survey was run in March 2001. Widely felt and/or damaging earthquakes occurred in 1992 (4 events), 1994 (2 events), and 1995 (1 event). The region has been relatively quiet since 1996.

Each survey was conducted following the same methodology: phone numbers were selected at random from telephone directories and calls were made during a 2-week period by students trained in telephone survey techniques. A summary of Humboldt County results is shown in Table 1.

There is a high level of earthquake awareness in the region. In all surveys nearly all respondents had felt an earthquake and 50% or more reported some loss of personal property. This personal earthquake history likely influenced the very high expectations (over 70%) of a future damaging earthquake within the next 10 years. This contrasts with about a 50% expectation in the San Francisco Bay Area to a similar survey question (Mileti *et al.*, 1993).

Questions about tsunami awareness (11–15) show significant increases in positive responses from the initial survey (Fig. 2). The percent knowing what a tsunami is has increased from 78 to 97%, what the Cascadia subduction zone is from 16 to 44%. Only expectations for a future earthquake has shown

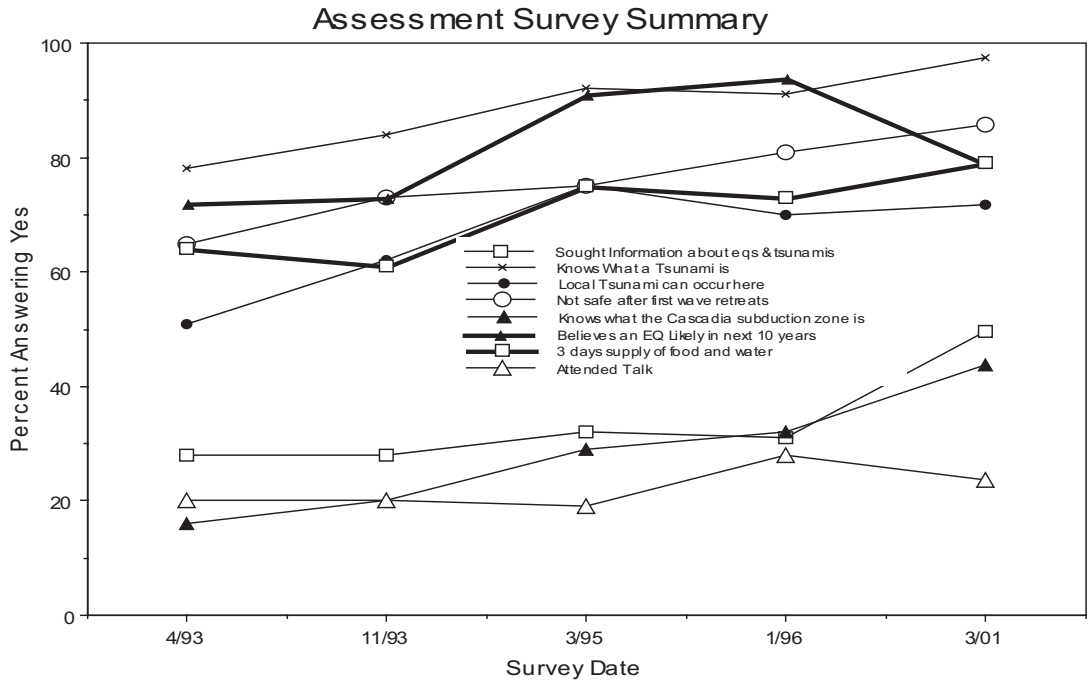


**Figure 2**: Assessment survey summary for Humboldt County. Approximately 600 respondents for 1993–1996 surveys, 2001 preliminary.

a decrease between the third and fourth surveys (about 90%) to the most recent survey (79%). This can be attributed to the high level of seismic activity between 1992 and 1995 and the relative quiescence since then. The increase in tsunami awareness may in part be attributed to other factors than local public education efforts. The 1994 Kuril Islands tsunami warning and the 1998 Papua New Guinea tsunami both received heavy local media coverage.

General earthquake preparedness questions (3–8) also show a general increase in most categories. The heavy flooding and associated power outages from storms in January, March, and December 1995 may have contributed to the stockpiling efforts of local citizens but the percent has remained high until the present. Questions showing lower or negligible increases include categories that require more effort on the part of respondents such as securing wood stoves and latches on cupboards.

Additional questions were added to the last three surveys. The 1995, 1996, and 2001 surveys asked respondents if they had talked about earthquakes in the previous 6 months (#19). Mileti *et al.* (1993) have shown that people interacting with one another to talk about risk is the key indicator for taking preparedness actions. The much higher positive responses in the March survey is most likely because of the strong earthquakes that had occurred during the previous 3 months. No widely felt earthquakes had occurred within a 10-month period prior to the January 1996 survey.

**Table 2**: Comparing responses of persons who had seen and not seen *Living on Shaky Ground*.

| | | Percent responding "Yes" | | | | | |
|---|---|---|---|---|---|---|---|
| | | Nov. 93 Did not see | Nov. 93 Did see | Mar. 95 Did not see | Mar. 95 Did see | Jan. 96 Did not see | Jan. 96 Did see |
| 3. | Has 3 days of food/water | 57 | 69 | 72 | 82 | 69 | 77 |
| 4. | Water heater secured to wall | 61 | 71 | 66 | 72 | 63 | 67 |
| 5. | Wood stove secured | 38 | 37 | 27 | 28 | 36 | 44 |
| 6. | Out-of-the-area contact | 42 | 47 | 44 | 48 | 41 | 52 |
| 7. | Latches on kitchen cupboards | 23 | 30 | 25 | 36 | 27 | 26 |
| 8. | House bolted to foundation | 73 | 82 | 72 | 71 | 69 | 74 |
| 9. | Sought information on EQs | 23 | 36 | 26 | 45 | 23 | 46 |
| 10. | Attended an EQ talk or workshop | 16 | 27 | 16 | 26 | 23 | 31 |
| 11. | Knows what tsunami is | 80 | 91 | 87 | 95 | 85 | 95 |
| 12. | Tsunami can arrive minutes after EQ | 60 | 66 | 72 | 77 | 75 | 78 |
| 13. | Not safe after first wave retreats | 69 | 81 | 69 | 85 | 72 | 86 |
| 14. | Knows what CSZ is | 14 | 33 | 23 | 41 | 19 | 41 |
| 15. | Damaging EQ likely in 10 years | 67 | 87 | 91 | 92 | 92 | 90 |
| 19. | Had talked about earthquakes | – | – | 57 | 69 | 33 | 41 |
| 20. | People in affected area responsible | – | – | – | – | 67 | 78 |

The high percentage of positive responses in the 2001 survey may reflect the Nisqually, Washington earthquake that occurred on 28 February and likely initiated many local discussions.

The 1996 and 2001 surveys asked who had the primary responsibility for response in the first 12 hours after a major earthquake. Both surveys showed a majority of Humboldt County residents believe people in the affected area have the primary responsibility to respond after a major earthquake (20). It is not clear why more respondents in the most recent survey believe the government is primarily responsible. One factor may be the disaster history of Humboldt County. In the past 17 years, Humboldt County has experienced 15 natural disasters sufficient for declaring a state or federal disaster declaration (2 earthquake, 12 storm/flood, 1 fire). Six disaster declarations were made between 1992 and 1997 and only one since then. This quiescence may have changed personal perceptions of response.

The original purpose of the surveys was to assess *Living on Shaky Ground* (Table 2). In nearly all categories, the magazine readers show a higher percentage of positive responses than non-readers. This is particularly noticeable in the awareness and sought information categories. Magazine readers were significantly more likely to have attended a talk about earthquakes or sought information about earthquakes from other sources. Seeking information in order to personalize risk is another key factor identified by Mileti *et al.* (1993) in taking preparedness action. Question categories requiring action on the part of individuals (3, 4, 6) showed some, but not as significant an increase between the readers and non-readers. Actions requiring major effort such as securing house to foundation or securing wood stoves showed little differences between the two groups. Magazine readers were also

more likely to consider individuals in the area affected to have the primary responsibility to respond immediately after an earthquake.

Perhaps the most significant outcome of the assessment surveys is that positive responses in all categories have either remained stable or increased even though the last 5 years have been seismically quiet on the north coast and personal expectations of an earthquake occurring soon have decreased.

## 4. Summary and Discussion

The first two steps in mitigating a Cascadia earthquake in north coast California has largely been completed. The CDMG scenario provides a general description of the nature of risk and distribution of hazards in the region. The agencies and organizations that make up the Redwood Coast Tsunami Work Group have initiated a wide variety of mitigation projects to address steps 3, 4, and 5 (Table 3). The assessment surveys attest to the general success of these efforts. However, there are notable gaps. The most important basis for tsunami mitigation is reasonable inundation projections. While projections are available for the Humboldt Bay and Crescent City areas, much of the coastline remains unmapped and there is considerable uncertainty for rural sections of the county including Orick and the mouth of Redwood Creek, Trinidad, McKinleyville, and Crescent City north of the harbor. No inundation information is available for tsunami bores that are likely to travel a considerable distance up the numerous large rivers in the 3-county area.

There is also need to update the existing inundation maps. New tsunami models and modeling techniques have been made in the 7 years since the NOAA study. Dredging of Humboldt Bay in 2000 significantly deepened and widened the mouth and the shipping lanes in the Bay. The NOAA inundation maps show the entire Samoa Peninsula overtopped. Recent geologic studies show this is highly unlikely for at least the northern part of the peninsula (Leroy, 1999). The modeling may not have used a sufficiently small grid size to delineate the high dunes on the Samoa Peninsula.

There are two other significant problems for north coast tsunami mitigation. Posting of signs on state or federal highways, in state parks or in lands under coastal conservancy jurisdiction require the endorsement of state agencies. Tsunami signs have been posted widely in Washington and Oregon, but Crescent City is the only community in California with any posted signage. The Coastal Conservancy and State Parks are concerned about the proliferation of signage in scenic coastal areas. Caltrans, the agency responsible for signs on highways, has not approved tsunami signage, and until the adoption of statewide sign criteria the plans of many coastal communities are in limbo. Discussions are currently underway with the agencies to overcome these barriers.

A second problem is the lack of tools to mitigate the recognized hazard. The National Tsunami Mitigation Program has sponsored a number of state and multi-state mitigation projects including the development of a State Tsunami Guidance manual for California emergency managers, information

**Table 3**: Cascadia earthquake mitigation efforts in Northern California.

**(1) Recognizing the Hazard**

1984–1991: Scientific awareness of the Cascadia subduction zone; local paleoseismic evidence of past great earthquakes

September 1991: First conference of emergency managers, utilities, and other agency representatives on the potential hazards of the CSZ, hosted by Humboldt State University, organized by Gary Carver, funded by the USGS

April 1992: Cape Mendocino earthquake sequence

**(2) Defining the Hazard**

1994: NOAA inundation models for Humboldt Bay and Crescent City

1995: CDMG Scenario for a magnitude 8.4 on the CSZ

1995–current: Paleoseismology and paleotsunami studies in Humboldt and Del Norte Counties

**(3) Disseminating Information about the Hazard**

1993: Publication of 1st edition of *Living on Shaky Ground* (100,000 copies)

1993: Earthquake Room, Humboldt County Fair

1995: Video public service announcements

1995: Publication of 2nd edition of *Living on Shaky Ground* (100,000 copies)

1995: Conference on CSZ Hazards for emergency managers northern California and southern Oregon

1996: CREW conference at Humboldt State University

1996: North Coast California Tsunami Pamphlet

1997: Draft Tsunami Curriculum completed

1997–2001: Geology 700 Tsunami! professional development course offerred at HSU

1998: "Living Safely in Your Schools" Pamphlet

1999: National Tsunami Program meeting at Humboldt State University

1999: Spanish version Tsunami Pamphlet

1999: Publication of 3rd edition of "Living on Shaky Ground" (25,000 copies)

1999, 2000: Tsunami Room, Humboldt County Fair

2000: Interpretive tsunami roadside signs posted in Redwood National Park

2001: Tsunami Public Service Announcements (in progress)

**(4) Taking Action to Reduce the Hazard**

1996: Formation of the Redwood Coast Tsunami Work Group

1996: OES table top exercise for emergency planners using CDMG scenario

1997: Pilot Sign Projects for Redwood National and State Parks, Crescent City, and the Samoa Peninsula

1998: Crescent City Evacuation routes, map, evacuation and hazard signs posted

1998: Tsunami hazard information posted at Freshwater spit, Redwood National and State Parks

1998: Table top exercises in Eureka and Arcata

1999: Cascadia Region Disaster Medical Preparedness Project

1999: Two county FEMA-sponsored emergency management training at Emmitsburg, MD and functional Cascadia earthquake/tsunami exercise

2000: Full-scale exercise in Ferndale

2000: Tsunami hazard information posted at Samoa dunes and at entrance to the King Range

2001: HAZUS training for emergency managers in Mendocino, Humboldt, and Del Norte Counties (planned)

**(5) Institutionalizing Cascadia Earthquake Mitigation**

1996–present: CDMG scenario basis for all earthquake planning exercises at city, county, and regional scales

2000: Inclusion of Cascadia earthquakes and tsunamis in Humboldt

on warning systems, and land use guidance. However, the critical issue of construction in areas subjected to both strong ground motion and high velocity debris-strewn water, criteria for using existing or new structures for vertical evacuation, and the application of tsunami abatement structures such as vegetation, barriers, or surface roughness is not available.

The biggest barrier to a comprehensive Cascadia earthquake mitigation program in northern California and elsewhere along the Cascadia margin is sustained financial commitment. The bulk of the projects described in this paper were initiated in large part by FEMA funding administered through the California Governor's Office of Emergency Services specifically targeted for Humboldt County recovery efforts resulting from the April 1992 earthquake. These were single event triggered, one time only expenditures that cannot support the sustained public outreach program which is needed to institutionalize tsunami mitigation in an all-hazard approach to risk reduction. The 1992 earthquake and the publicity surrounding recent scientific breakthroughs on the Cascadia subduction zone created much media and public interest on tsunamis. However tsunamis and Cascadia earthquakes are rare phenomena and not likely to occur within the next few years. Without a continued commitment to tsunami mitigation, interest may wane and the advances in awareness and preparedness of the past few years go to waste.

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