California Geological Survey Tsunami Event Response Program: Tonga Tsunami 2022

1 MALA AMMA WAY HEART (PEAR to trough) = 1.75 m

Tide Gage - San Francisco

Tide Gage - Alameda

Fide Gage - Redwood City

Tide Gage - Monterey

Tide Gage - Port San Luis

Гide Gage - Santa Barbara

Tide Gage - Santa Monica

Tide Gage - Los Angeles

Tide Gage - La Jolla

Tide Gage - San Diego

White Marker Marker and Marker Marker and Marker Marker Marker Marker Marker Marker Marker Marker Marker Marker

- Forecast --- Observation --

Forecast — Observation ~

The California Geological Survey (CGS) operates a statewide natural hazard event response program that can be activated during and following these events. Activations may include opening the California Earthquake Clearinghouse and/or the deployment of field teams to gather observations of perishable features. Following the eruption of the Hunga Tonga-Hunga Ha'apai volcano in the Kingdom of Tonga, the National Tsunami Warning Center released a Tsu nami Advisory for California. Shortly afterwards, the CGS deployed field teams to document the tsunami as it arrived and sent post-tsunami field teams to evaluate the impact of the tsuna mi. These teams were composed of staff from the CGS, the California Governor's Office of Emergency Services, the U.S. Geological Survey, Cal Poly Humboldt, and the University of Southern California. Teams collected physical observations of the tsunami impact using ESRI Field Maps and gathered interviews using ESRI Survey123.

Teams made co-tsunami observations in San Francisco Bay, Half Moon Bay, and the Los Angeles/Long Beach harbors. Phase I of the post-tsunami response was prioritized based on the potential for significant impact. Tide gages with the largest tsunami total water elevations were Crescent City 3m, Arena Cove 2.94m, & Port San Luis 2.94m (MLLW), so teams were deployed to these areas including Santa Cruz where damage was reported. For Phase II, teams were de ployed to places where we learned more about the tsunami impact during Phase I period: Ven tura, Marin, Sonoma, Mendocino, & San Diego counties. Noyo Harbor has no tide gage, so se curity video footage was combined with a level survey between a U.S. Army Corps of Engineers survey benchmark and a staff plate mounted to the pier to show a maximum water surface elevation of 2.66±0.003m (MLLW). Details about total water levels, observable damage, response protocols, and lessons learned will be summarized and posted on the CGS website tsunami. ca.gov/tonga.

Event Response

CGS Event Response

The California Geological Survey responds to a variety of natural hazard events including volcanic eruptions, landslides, post-fire events, earthquakes, and tsunami. Most of these efforts are closely coordinated with our response partners from other organizations.

Each appropriate unit runs their specific response which includes a variety of information gathering methods. These information gathering methods include the activation of field teams that collect observations of perishable features.

For example, during the 2019 Ridgecrest Earthquake Sequence, dozens of CGS geologists collaborated with USGS and academic geologists to document evidence for surface rupture from the M 6.4 and M 7.1 earthquakes.

CGS Tsunami Response

The Tsunami Response Program activated field teams in three phases.

The first phase was to make observations of the tsunami waves as they rolled in. Team members visited locations in close proximity to their residences.

The second phase involved three main teams deployed across the state where there was evidence for significant waves based on tide gage data or based on observations of significant impact found on social media or the news.

The third phase included additional places identified to have been impacted by the tsunami.

Tide Gage Data

The tsunami waves arrived earlier than expected in many places due to the atmospheric effects and this can be seen on some records very clearly. These tide gage data are plotted in figures to the right.

For each figure, the upper plots are relative to Mean Lower Low Water (MLLW). The forecast and observation are plotted in different colors.

The lower plots show the difference between the forecast and observation (the "residual"), which is a combination of sea state factors like atmospheric pressure, currents, and tsunami.

Terminology

Amplitude - the height of the water surface elevation (WSE) above the ambient level of water surface (i.e., the sea state) **Wave Height** - the vertical distance between the peak and trough

Max Elevation - the highest WSE for a given tsunami sequence

For each dataset, the maximum amplitude, maximum wave height, and maximum elevation are shown. These maxima are summarized in the table below.

Tsunami Size: Tide Gages in California			
	Max Wave	Max	Max
Station	Height (m)	Amplitude	Elevation (m)
Crescent City	1.73	0.99	3.00
North Spit	0.55	0.36	2.57
Noyo Harbor	0.75	0.58	2.55
Arena Cove	2.14	1.34	2.94
Point Reyes	1.75	0.83	2.50
San Francisco	0.57	0.36	2.16
Richmond	0.61	0.22	2.15
Martinez	0.40	0.20	1.77
Alameda	0.51	0.24	2.29
Redwood City	0.05	0.14	2.62
Monterey	1.42	0.81	2.50
Port San Luis	2.61	1.36	2.94
Santa Barbara	1.11	0.70	2.17
Santa Monica	0.96	0.63	2.25
Los Angeles	0.76	0.47	2.04
La Jolla	0.40	0.32	1.88
San Diego	0.60	0.47	2.21
Wave Height: height of	fwave above ambie	nt water surface el	evation

Amplitude: wave size measured from peak to trough

Elevation: height of wave above mean lower low water (tidal datum)

--• Crescent City

Following the 2011 tsunami, the boat basin was reconstructed to withstand higher current veloties. This is probably why there was no damage in the CC boat basin from the Tonga Tsunami. CGS staff interviewed the harbor master and people in the fishing industry. There was no significant damage in Crescent City. CGS staff observed evidence for overland flow across an abraision platform northwest of the harbor.

--• Novo Harbor

There is no active tide gage in Noyo Harbor (Fort Bragg). However, the Anna Neumann (NH Harbor Master) provided security video. There is a staff plate attached to a piling in the view of the video camera. CGS and Cal OES staff use a U.A. Army Corps of Engineers benchmark to provide a vertical reference for this staff plate. Using tidal datum analyses from a NOAA tide gage installed in the 1970s, the staff plate reference elevation is placed into a MLLW reference frame. Using the video footage, CGS staff here prepare a marigram for this location in Noyo Harbor. CGS staff use the NOAA tidesandcurrents tidal forecast to calculate the amplitude. This video referenced marigram is shown below.



--• Arena Cove

There was a fresh deposit of seaweed and woody debris along the banks of Point Arena Creek, initially thought to be from the tsunami (the creek flow goes subsurface at the top of the beach). However, the Arena Cove Harbor Master did not see waves reach this elevation. The elevation of the beach berm is about 1 meter higher than the highest water surface elevation observed on the tide gage.

-- Strawberrv Damage to floating dock as it was ripped away during the tsunami.



---• Santa Cruz

The CGS and USGS staff collaborated to collect observations of inundation, flow depth, tsunami flood elevation, and damage to infrastructure. There was extensive damage to docks, pilings, dredge equipment, and flooding onland. The tsunami waves left behind high water marks and woody debris wrack lines (the pavement was still wet in places at the time of the survey). CGS and USGS staff are collaborating to use videos of tsunami elevation and an elevation survey to establish the sise of the tsunami (like was done for Noyo Harbor)

---• Moss Landing

Docks broke loose around 10:00 - 10:10am. These docks broke up and pilings were bent over. A boat resident claimed that some of the piles were no longer embedded into the seafloor. The tsunami left behind high water marks on bridges. There are also observed woody debris wrack lines.



--• Morro Bay

Video screen capture from https://www.youtube.com/watch?v=VD7UQtTeGwI Video records tsunami currents in Morrow Bay as viewed from the Morro Bay Yacht Club. Note how boats in main channel flip direction with the ebb and flow of the tsunami. The buoys moved about 30 feet during each flow according to the Harbor Patrol.

The dock also rises and falls and CGS staff plan to establish the vertical reference for these pilings to generate a marigram at this location. To the north of here a kayak rental business claimed water level went up and down 7 feet in 5 minutes or less.

--• Gaviota Beach

The debris in the photo to the right is interepreted to be from typical coastal processes and not the tsunami.

--• Cat Harbor, Catalina

At Cat Harbor, the western side of Two Harbors, there were strong currents and cm scale tsunami waves recorded on videos posted online. The screenshots from

https://www.youtube.com/watch?v=3RZtmbPxLzQ were recorded aroud 2pm localt time.



Survey Location Tide Gage (NOAA) Field Observation raphy: Ryan et al., 2009

50 mi

100 km

).1029/2008GC002332.

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Tsunami and Impact Observations

--• Little River

posed of wood and seaweed.

----• Humboldt Bay

The Tsunami in Humboldt Bay was ob served by members of the Humboldt Bay Yacht Club. Here are some marks that Stephen Buck made during the tsu nami. The wave height in the marina was less than that observed at the North Spit Tide Gage, which is closer t the bay entrance.



Near the mouth of the Little River, there is evidence for overland and upstream channel flow in the form

of sediment drapes, cm scale assymetric bedforms in stream and beach sand, and wrack lines com-

Maximum Amplitude = Maximum Amplitude = Maximum Amplitude = Maximum Wave Height (peak to trough) = 0.75 m Maximum Mave Height (peak to trough) = 0.75 m	Max Elevation: Max Amplitude: Max Wave Height:	2.55 m Staff Plate - Noyo Harbor 0.58 m Staff Plate - Noyo Harbor 0.75 m Observation
Maximum Amplitude = Maximum Wave Height 0.58 m (peak to trough) = 0.75 m Im menne 1 m	Mater Surface vation (mllw, m)	Maximum Elevation
	E	Maximum Amplitude = 0.58 m (peak to trough) = 0.75 m
1/15/2022 9:36:00 tsunami.ca.gov	1/15/2022 7:12:00 tsunami.ca.gov	1/15/2022 9:36:00 Time (PST)



Berkeley

CGS staff observed tsunami currents during the 1st phase of the response. The strongest currents (screenshot from video at right) occurred between 9:15 and 10:20am. Water level change was 1-2 feet. Boats tried to enter harbor several times, unsuccessfully. Current velocity was between 2 and 4 knots. No damage in the marina.







alert, were in the water since 7am and did not notice any

unusual currents





--• Cayucos

The tsunami left woody debris wrack 🛛 🕳 lines along Cayucos Creek and along the beach at Cayucos. Tsunami flowed upstream, leaving behind bent grass stems.





Harbor police reported that the maintenance vard and parking lot got flooded by the tsunami, much like





--• Ventura Harbor

Screenshot of video provided by Daniel Wall shows strong currents in northern entrance channel of Ventura Harbor. Other photos show extensive damage to docks and dock infrastructure. Flow velocity, estimated from video footage, is about 7 knots. Some yachts were pulled from their docks and floated around, but no damage was reported for most of these. There was one Harbor Patrol (?) boat that got flooded and sank partially.

---- San Diego

At Shelter Island, a floating "JetDock" was folded during the passage of tsunami currents (first photo >>>) and an aluminum-framed boat washing station was damaged as it was forced to open and close during the tsunami surge (other photos >>>). In Mission Bay, no damage was reported. At Coronado, no wrack lines were identified. In Oceanside, there was some movement of a bait dock and buoys were dragged around by the tsunami currents. The county activated their Emergency Operations Center (EOC) and sent out county alert messaging, including a Wireless Emergency Alert (WEA) to coastal residents.







Amanda Admire (Cal Poly Humboldt, Dept. of Geology runs an ADCP sensor in the main channel of Humboldt Bay. They observed higher currents but have not yet finalized their analyses.

Plot on right are from our in tial review of these data.

---- Navarro River

Upstream of the mouth of the Navarro River there are multiple evidences for overland flow including wrack lines composed of wood and bull kelp, preserved mud bubbles, and 3- to 5-cm wavelength asymetric





The higher of two debris



The water surface was cal and there was no evidence for higher water lines at Bai Island Marina or West Point Harbor. Rowers at West Point, aware of the tsunami













To the north of Morro Rock, along the beach, there were deposited woody debris as a wrack





it does during larger storms. However, this tsunami flooding left no evi-





Tsunami deposited woody debris as a wrac line just seaward of the Avila Beach Dr. bridge that crosses San Luis **Obispo Creek. Further** upstream is a stealhead gateway (check dam)

_---- Avila Beach







ide Gage - North Spit