Response to Advisory-Level Tsunamis in Tumon Bay and Agana Bay on Guam:

A User's Manual

Compiled by Charles 'Chip' Guard

Warning Coordination Meteorologist, NWS WFO Guam

Updated 9/22/2021 by Tropical Weather Sciences

From a Tsunami Modeling Study by

Dr Kwok Fai Cheung

Professor and Graduate Chair

Ocean and Resources Engineering

University of Hawaii

Funded through the Guam National Tsunami Hazard Mitigation Program

Grant Award Number NA16NWSS4670035

Response to Tsunamis in Tumon Bay and Agana Bay on Guam: A User's Manual

The purpose of this document is to provide guidance to decision makers for the necessary responses to tsunamis that don't meet Warning criteria but that do meet Advisory criteria for strong *currents* and wave runup less than 3 feet. These tsunamis are generated by earthquakes that occur in subduction zones where two oceanic plates collide, with one plate subducting beneath the other.

There are four important aspects of tsunamis inside harbors, marinas, and along coral reefs. These four aspects are *surge, drawdown*, *current* speed and *period*.

***Surge* is the increase in water level as the wave enters a harbor, a marina, or the ledge and platform of a coral reef. *Surge* can force ships/boats against the peers/slips and can cause flooding of coastal areas.**

***Drawdown* occurs when the water level decreases as water exits the mouth of the harbor or marina or off the reef platform. *Drawdown* can cause the bottom of a ship to hit the floor of the harbor/marina that could be mud, sand, or coral. The reef platform can become exposed.**

The *period* determines how frequently the *surge* and the *drawdown* occur and how often the *currents* reverse direction.

In General, *currents* can be dangerous if they reach a certain speed and if the direction drastically changes. *Currents* of 3 knots or less are usually not damaging. *Currents* with speeds between 3 knots and 6 knots can cause moderate damage to boats and marinas. *Currents* with speeds greater than 6 knots can cause more serious damages. The marina environment at the boat basin at Agana Bay is somewhat complicated by a direct channel from the marina through the reef to the open ocean and a current that enters from the west through a culvert under the road that connects the Agana treatment plant to Marine Corps Drive (Route 1). Thus, the *surges* and *drawdowns* can be out of phase with the *current* speed and direction, changing at different times.

***Eddies* are rather small circulations caused by the interaction between the *currents* and adjacent structures. When the *currents* change direction, the *eddies* can change location. This can make it very difficult to navigate when these changes are occurring over *periods* of a few minutes.**

This study by Dr. Kwok Fai Cheung, through sensitivity analysis, identifies the four major tsunami genesis areas that can affect Tumon Bay and Agana Bay with strong *currents*. Dr. Cheung used his NEOWAVE (Non-hydrostatic Evolution of Ocean Waves) model for the sensitivity analysis. The four areas are the same as for Apra Harbor and include:

- **The Marianas Trench that extends southwest to east and well north of Guam**
- **The Nankai Trough (and nearby Ryukyu Trench) near southern Japan**
- **The Mindanao (East Philippine) Trench east of Mindanao Island**
- **The New Guinea Trench (and nearby Manus Trench) north of Papua New Guinea**

Each of these areas can produce earthquakes of various moment magnitudes (Mw) that can generate tsunamis with unique characteristics that in turn can produce unique patterns of *surge*, *drawdown* and *current* speed and direction in and around Tumon Bay and Agana Bay. Although the source parameters only depend on the moment magnitude (Mw) of the earthquake, the resulting tsunami is also influenced by the local tectonics and water depth. The source regions are shown in Figure 1.

When an earthquake occurs in one of the four subduction zones, it can produce a tsunami wave that propagates across the ocean. The Pacific Tsunami Warning Center (PTWC) monitors the earthquakes and determines whether or not a significant tsunami wave was generated. PTWC then either indicates that there is no threat or issues Tsunami Watches, Warnings, or Advisories.

If a Warning is warranted, then local decision makers have specific procedures for dealing with the necessary evacuations. However, if only Advisory-level criteria are met for Agana Bay and Tumon Bay, how should the decision makers respond? The following procedures address the Advisories that deal with tsunamis from one of the four primary generation areas.

The US Coast Guard and tsunami specialists identified four critical locations/areas important for decision makers. These are: 1) the north end of Tumon Bay near Gun Beach and the Nikko Hotel; 2) the south end of Tumon Bay near the Hilton Resort and Ypao Beach; 3) the north end of Agana Bay near Onward Resort and Santa Fe Hotel.; and, 4) central Agana Bay, including the Paseo de Susanna, the boat basin marina, and the Agana treatment plant. These locations/areas are shown in Figure 2.

For each of these critical areas, Dr. Cheung produced a set of tables from his NEOWAVE model that maps the tsunami from its source to the two bays and shows the *surge*, *drawdown*, the *period* of each, and the *current* and *period of current* reversal in the bays. NEOWAVE has specialized features that enable it to model tsunamis in the shallow-reef environment of the Mariana Islands.

When PTWC issues a Tsunami Bulletin, the Coast Guard Watch Officer or other responsible person should make the necessary notifications for required assessments and activations. Once the first tsunami wave is within 3 hours of arrival, PTWC will issue a Tsunami Warning, a Tsunami Advisory, or a

cancellation. In the event that PTWC issues a Tsunami Warning or a Tsunami Advisory, perform the following procedures:

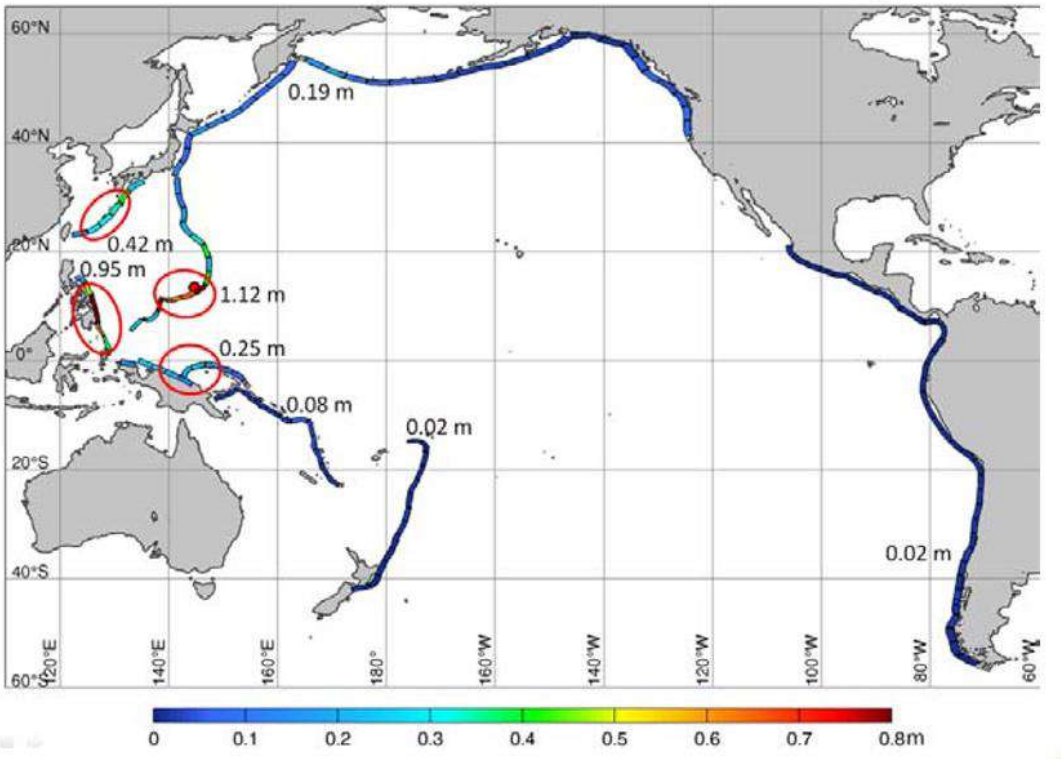

Figure 1. Sensitivity analysis of tsunami wave amplitude outside Tumon Bay and Agana Bay from hypothetical Mw 8.5 earthquakes at subduction zones in the Pacific Ocean. The red circles indicate the primary tsunami source areas.

Figure 2. Critical areas (yellow circles) at Tumon Bay and Agana Bay for compilation of tsunami wave summary tables.

In the event that PTWC issues a Tsunami Warning or a Tsunami Advisory, perform the following procedures:

1. Determine the location of the threat and review the characteristics of tsunamis from that location.

2. Next, Go to the associated Table and determine the location(s) of interest and match them to the indicated earthquake magnitude (Mw).

3. Determine the surge, drawdown, current speed, and the return time/period (or range of times) of subsequent waves and currents for the locations of interest.

4. Based on the information, make the required operational decisions regarding the Agana Boat Basin Marina. Except for Marianas Trench events, there will be some time to evacuate boats and people, if necessary. Marianas Trench events will likely require an immediate evacuation of people in low elevations including the Agana Marina and the Agana Bay and Tumon Bay beaches.

Marianas Trench

Figure 3 illustrates the maximum *surge*, maximum *drawdown*, maximum *currents* and *periods* at Mw 7.6, 7.8, and 8.0 earthquakes. On Guam and in the other Mariana Islands earthquake damage may be of a greater concern than the tsunami threat. However, the tsunami threat should not be ignored!

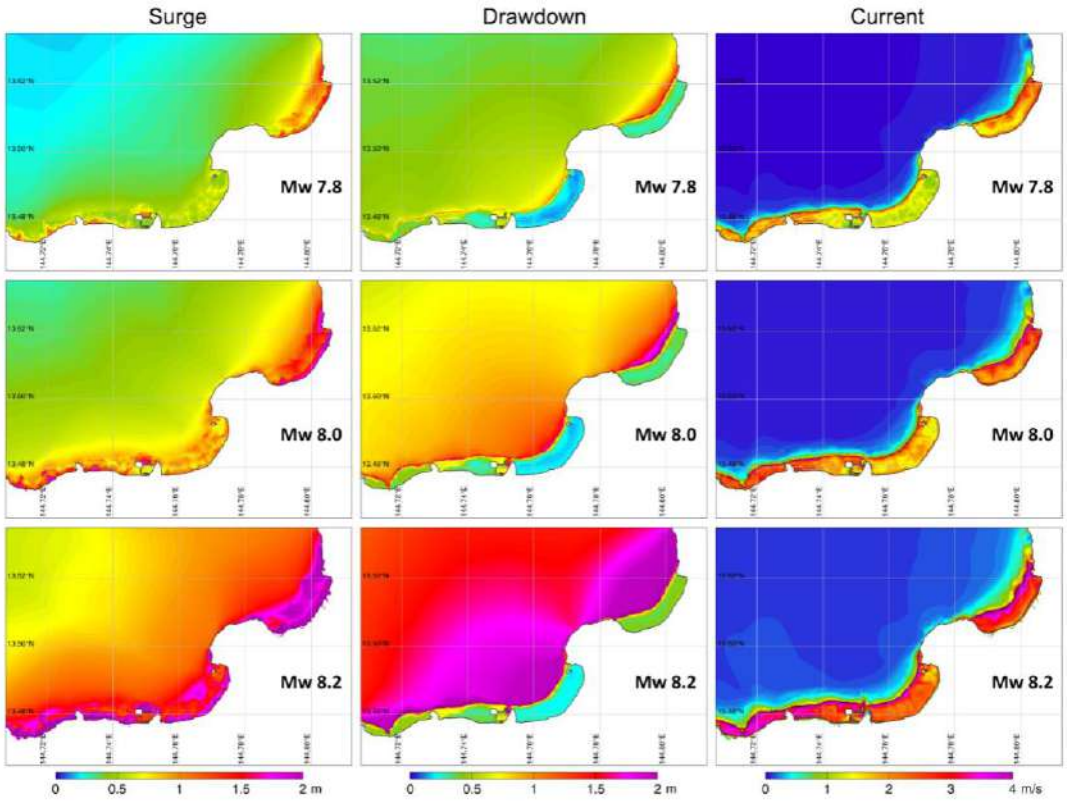

Figure 3. *Surge*, *drawdown*, *and current* at Tumon Bay and Agana Bay from Mw 7.8, 8.0, and 8.2 Mariana Trench earthquake scenarios.

The Marianas Trench is a special case. It is so close to the island that there likely won't be time for a Warning or Advisory. If there is a strong earthquake in the Marianas Trench, people will feel it and should duck, cover, hold on and then move to higher ground once the shaking stops. The first wave can arrive in as little as 10 minutes. Someone needs to monitor the location and magnitude of the earthquake and the arrival time of the wave as indicated by PTWC. It will take several minutes for the information to arrive from PTWC, and the first wave may arrive before any information from PTWC. If the magnitude is 7.7 to 8.0, strong currents and minor inundation can be expected. Clear beaches and get people out of the water. If the magnitude is greater than 8.0, a coastal evacuation to higher ground or into a hotel may be necessary.

Go to Table 1 and go to the specific bay location of interest. Refer to the Mw of the earthquake to determine the specific *surge, drawdown*, *current* speed and the range of return *periods,* such as 5 to 7 minutes (5,7).

Table 1. Maximum *surge*, *drawdown*, and current at Tumon Bay and Agana Bay from Mariana Trench source tsunamis. Follow instructions from Civil Defense.

Mariana Mw	Agana Boat Basin				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
7.7	3.6	3.0	5, 7	5.6	11, 7
7.8	3.9	3.9	7, 8	6.2	11, 7
7.9	4.6	4.6	7, 8	7.0	11, 7
8.0	5.9	6.2	7, 8	8.7	11, 8
8.1	7.9	8.2	7, 8	10.5	11, 8
8.2	10.8	11.2	7, 8	11.7	8, 13
8.3	13.1	17.4	7, 8	15.6	8, 13
	North Agana Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
7.7	2.3	3.0	7, 8	4.5	7, 8
7.8	2.6	3.6	7, 8	5.2	7, 8
7.9	3.3	4.9	7, 8	6.2	7, 8
8.0	4.3	6.9	7, 8	7.2	7, 8
8.1	5.6	8.9	7, 8	8.0	7, 8
8.2	7.2	11.5	7, 8	8.9	7, 8
8.3	10.8	16.1	7, 8	12.1	7, 8
	South Tumon Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
7.7	2.6	3.9	5, 7	5.2	5, 8
7.8	3.3	4.6	7, 8	5.8	8, 11
7.9	3.6	5.6	7, 8	6.4	8, 11
8.0	4.6	7.2	7, 8	7.2	8, 11
8.1	5.9	9.8	8, 7	8.4	8, 13
8.2	8.5	13.1	8, 7	9.9	8, 13
8.3	9.5	17.1	8, 7	12.2	8, 13
	North Tumon Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
7.7	4.9	5.2	5, 11	5.4	5, 10
7.8	5.9	5.9	10, 8	6.2	5, 10
7.9	6.6	6.9	10, 8	6.8	8, 10
8.0	7.5	9.2	8, 13	8.2	8, 10
8.1	8.9	12.1	8, 13	9.3	8, 10
8.2	9.5	17.1	8, 13	10.5	8, 10
8.3	10.2	21.7	8, 13	13.2	8, 10

Nankai Trough

If there is a strong earthquake in the Nankai Trough, the arrival time of the first tsunami wave is 3 hours over the 1242-nm (1429-statute mile) distance. PTWC may place Guam into an immediate Warning or Advisory. Japanese seismologists estimate that the next major Japan earthquake will be in the Nankai Trough. There is an 80-90% chance that there will be an 8.0-9.0 earthquake there in the next 25-35 years. A tsunami generated from this location will be directly oriented toward the Mariana Islands.

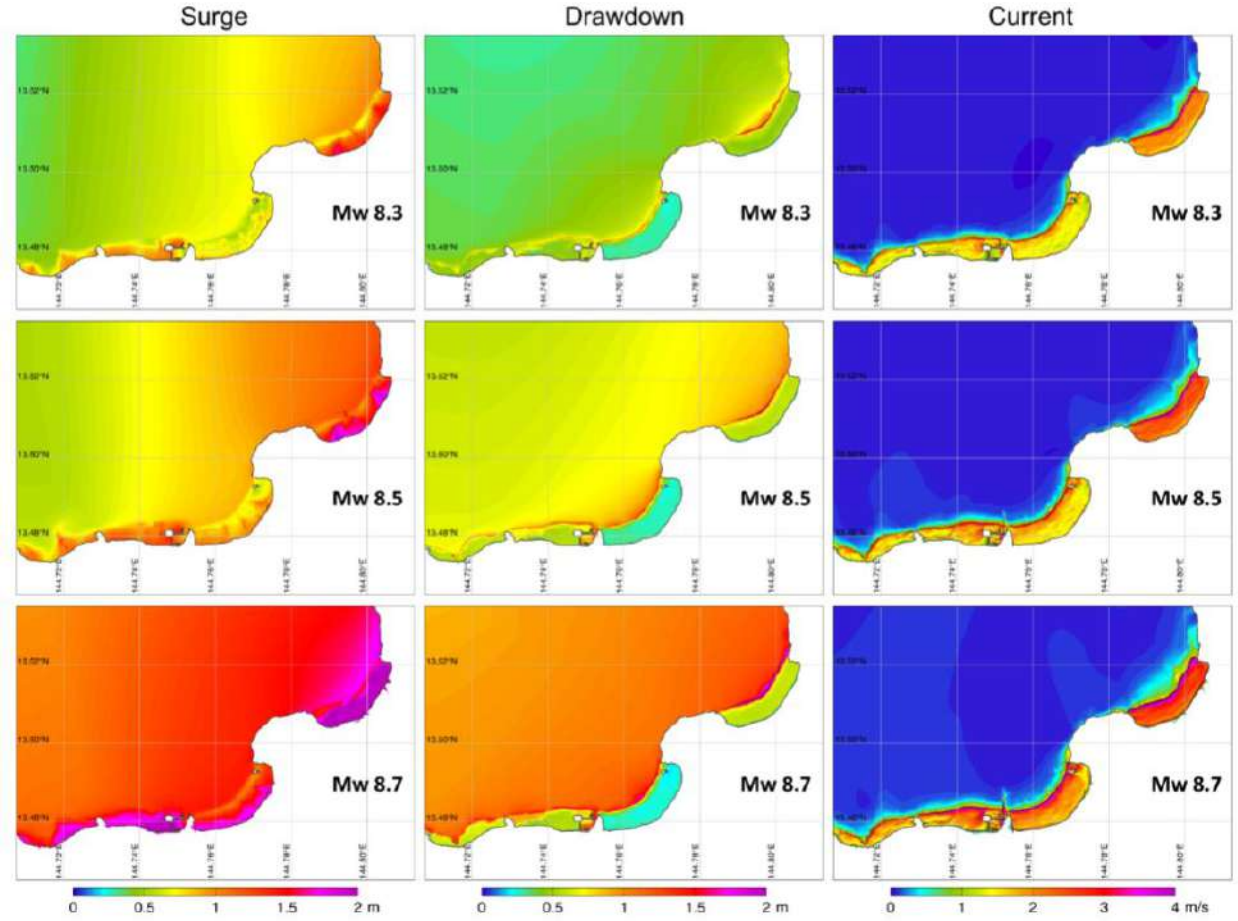

Figure 4. *Surge*, *drawdown*, and current at Tumon Bay and Agana Bay from the Mw 8.3, 8.5, and 8.7 Nankai Trough earthquake scenarios.

In case of a strong Nankai Trough earthquake, Go to Table 2 and the specific location of interest in Tumon Bay or Agana Bay. Then refer to the Mw of the earthquake as indicated from PTWC to determine the *surge, drawdown*, *current* speed and *periods*. For earthquakes of magnitude 8.1-8.6, get people out of the water and off the beaches. For magnitudes 8.7 or larger, evacuate to the hotel or

move to higher ground. Follow instructions from Guam Homeland Security Office of Civil Defense.

Table 2. Maximum *surge*, *drawdown*, and current at specific locations in Tumon Bay and Agana Bay from Nankai Trough tsunamis.

Nankai Mw	Agana Boat Basin				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
8.1	3.0	2.6	13, 15	6.0	13, 15
8.2	3.6	3.3	13, 17	7.0	13, 17
8.3	4.3	3.9	13, 17	7.6	13, 17
8.4	4.6	4.6	13, 17	8.6	13, 17
8.5	4.9	5.2	17, 13	9.1	13, 17
8.6	5.6	5.6	17, 14	10.7	13, 17
8.7	7.5	6.9	17, 14	12.6	13, 17
	North Agana Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
8.1	2.3	2.6	18, 14	4.5	17, 15
8.2	3.0	3.0	18, 24	4.9	17, 15
8.3	3.6	3.6	17, 24	5.2	17, 15
8.4	3.6	4.3	17, 24	5.8	17, 24
8.5	3.9	4.6	17, 24	6.6	17, 24
8.6	4.9	5.6	17, 24	7.6	17, 24
8.7	6.2	6.2	17, 24	9.5	17, 24
	South Tumon Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
8.1	2.6	2.3	17, 13	5.2	17, 13
8.2	3.0	3.0	17, 13	6.0	17, 13
8.3	3.6	3.3	17, 13	6.6	17, 13
8.4	4.3	3.6	17, 13	7.0	17, 13
8.5	4.6	3.6	17, 13	7.0	17, 13
8.6	5.2	4.6	17, 13	8.6	17, 13
8.7	6.9	6.2	17, 14	10.1	17, 13
	North Tumon Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
8.1	3.3	3.3	17, 13	6.4	13, 17
8.2	3.9	4.3	17, 13	7.2	13, 17
8.3	4.6	4.6	17, 13	7.6	13, 17
8.4	5.2	4.9	17, 13	8.2	17, 13
8.5	5.9	4.9	17, 13	8.2	17, 13
8.6	6.9	6.2	17, 13	9.3	17, 13
8.7	8.9	8.5	17, 13	10.9	17, 13

Philippine Trench

Tsunamis from the Philippine source have the most direct approach to Agana Bay and Tumon Bay. The arrival characteristics of tsunamis produced by Mw 8.0, Mw 8.2, and Mw 8.4 earthquakes in the Philippine Trench are shown in Figure 5. The travel time of 2.5 hours is shorter compared to Nankai Trough events due to the slightly shorter distance of 1080 nm (1243 statute miles) and deeper water in the East Philippine Sea.

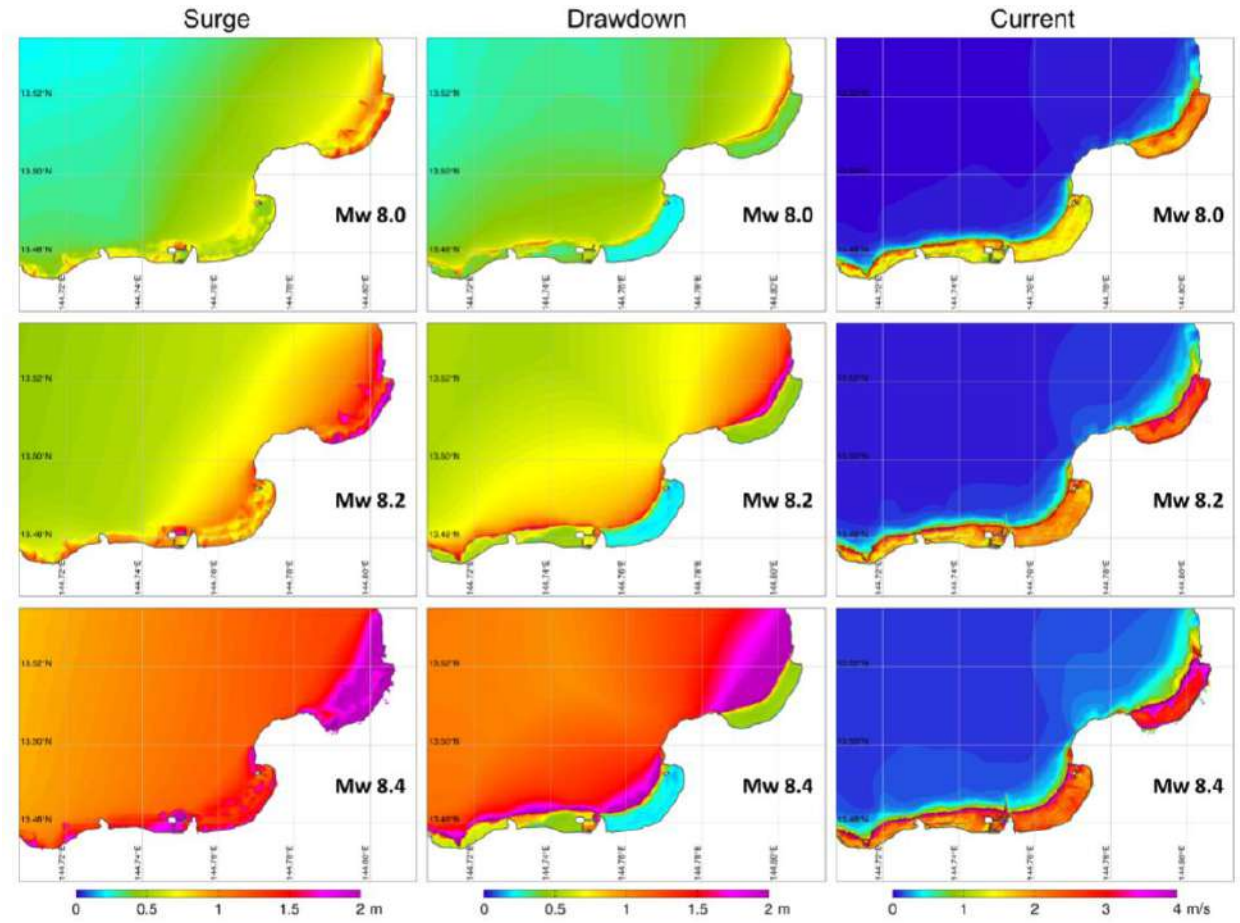

Figure 5. *Surge*, *drawdown*, and current at Tumon Bay and Agana Bay from the Mw 8.0, 8.2, and 8.4 Philippine Trench earthquake scenarios.

In case of a strong east Philippine Trench earthquake, Go to Table 3 and then go to the specific area/location of interest. Then refer to the Mw of the earthquake to determine the *surge, drawdown*, *current* speed and *periods*.

For earthquakes with a magnitude of 7.9-8.2, get people out of the water and clear the beaches. For earthquakes greater than 8.2, evacuate people to the hotel or to higher ground. Follow instructions from Guam Homeland Security.

Table 3. Maximum *surge*, *drawdown*, and current speed at specific locations in Tumon Bay and Agana Bay from Philippine Trench tsunamis.

Philippine Mw	Agana Boat Basin				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
7.9	3.3	2.6	5, 7	5.8	13, 10
8.0	4.3	3.6	6, 8	6.4	13, 10
8.1	4.9	4.6	6, 8	7.2	13, 10
8.2	5.9	5.6	6, 8	8.2	13, 10
8.3	6.9	7.2	8, 10	9.9	13, 10
8.4	8.2	9.8	10, 8	12.1	11, 13
8.5	10.5	12.8	10, 8	14.0	12, 17
	North Agana Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
7.9	2.3	2.3	7, 9	4.7	13, 9
8.0	3.0	3.0	7, 9	5.4	13, 9
8.1	3.6	4.3	9, 7	6.0	13, 9
8.2	4.9	5.6	9, 8	6.6	13, 22
8.3	6.2	7.5	9, 8	8.2	13, 22
8.4	7.2	10.2	9, 8	10.1	18, 22
8.5	9.8	13.1	9, 16	12.8	18, 22
	South Tumon Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Speed (knots)	Period (min)
7.9	3.0	2.3	5, 9	4.3	9, 13
8.0	3.6	3.6	9, 13	4.9	9, 13
8.1	4.6	4.9	9, 13	5.6	9, 13
8.2	5.6	6.6	9, 13	6.8	9, 13
8.3	6.6	8.2	9, 13	8.2	9, 13
8.4	7.5	10.5	9, 13	9.9	9, 13
8.5	8.5	13.5	9, 22	11.9	9, 22
	North Tumon Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Speed (knots)	Period (min)
7.9	3.9	4.3	9, 13	5.8	10, 13
8.0	5.2	4.9	13, 9	6.2	10, 13
8.1	6.6	6.6	13, 9	7.4	10, 13
8.2	7.5	8.5	13, 16	8.0	10, 13
8.3	9.2	10.8	10, 22	11.7	12, 22
8.4	11.8	13.5	10, 22	12.1	12, 22
8.5	13.8	16.4	10, 22	13.0	12, 22

New Guinea Trench

The New Guinea subduction zone is 972 nm (1118 statute miles) from Guam with a travel time of 2.4 hr. The fault plane characteristics make it inefficient at producing upward displacement of water. Also, its amplitude is somewhat diminished by its path across the Yap and Mariana Trenches. Thus, a very strong earthquake is necessary to effect Guam. Figure 6 illustrates the coastal and reef characteristics of Agana Bay and Tumon Bay for *surge*, *drawdown*, and current speeds for Mw 8.4, 8.6, and 8.8 earthquakes.

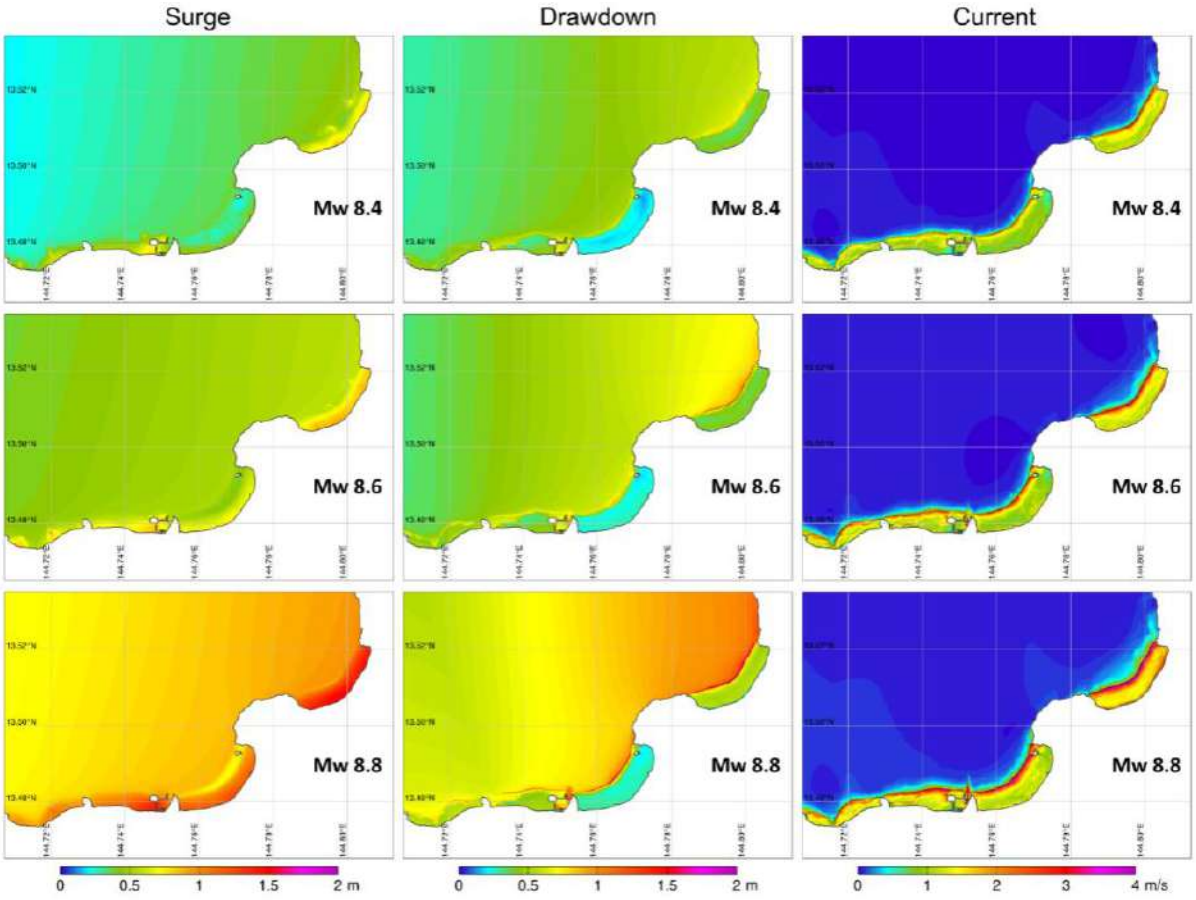

Figure 6. *Surge*, *drawdown*, and current at specific locations in Tumon Bay and Agana Bay from the Mw 8.4, 8.6, and 8.8 New Guinea earthquake scenarios.

When a strong earthquake of Mw 8.2 to 8.8 occurs in the New Guinea Trench, PTWC will likely issue a Tsunami Advisory for strong currents and minor inundation for Guam.

In case of a strong earthquake in the New Guinea Trench, Go to Table 4. Get people out of the water and off the beaches. Follow instructions from Guam Homeland Security Office of Civil Defense.

Table 4. Maximum *surge*, *drawdown*, and current at specific locations at Tumon Bay and Agana Bay from New Guinea Trench tsunamis.

New Guinea Mw	Agana Boat Basin				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
8.2	2.0	2.0	5, 8	4.1	12, 16
8.3	2.3	2.3	6, 8	4.7	12, 16
8.4	2.6	3.0	6, 8	5.2	12, 16
8.5	2.6	3.3	7, 9	6.2	16, 12
8.6	3.0	3.9	7, 9	7.2	16, 12
8.7	3.6	4.6	7, 17	8.2	17, 12
8.8	4.6	5.2	7, 17	9.5	17, 12
	North Agana Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
8.2	1.3	1.6	8, 15	3.5	16, 20
8.3	1.3	1.6	16, 8	4.1	16, 20
8.4	1.3	2.3	16, 8	4.7	16, 20
8.5	1.6	2.6	16, 8	5.1	16, 20
8.6	2.0	3.3	17, 9	5.8	17, 20
8.7	2.6	3.9	17, 9	7.0	17, 20
8.8	3.6	5.2	17, 12	8.6	17, 20
	South Tumon Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
8.2	1.3	1.3	16, 9	2.9	16, 12
8.3	1.6	2.0	16, 9	3.9	16, 12
8.4	2.0	2.6	16, 9	4.7	16, 12
8.5	2.0	3.0	16, 9	5.2	16, 12
8.6	2.6	3.3	16, 9	6.0	16, 12
8.7	3.3	4.3	17, 9	6.8	17, 12
8.8	4.3	5.2	17, 9	8.0	17, 12
	North Tumon Bay				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knots)	Period (min)
8.2	2.3	1.6	16, 12	3.9	16, 12
8.3	2.3	2.3	16, 12	4.7	16, 12
8.4	2.6	3.0	16, 12	5.4	16, 12
8.5	2.6	3.6	16, 12	6.0	16, 12
8.6	3.0	4.3	16, 12	6.8	16, 12
8.7	3.6	4.9	17, 12	7.6	17, 12
8.8	4.6	6.2	17, 12	8.7	17, 12

Notes:

Some of the illustration values are in meters and meters/second. To convert to feet and knots and miles/hour, use the following formulas:

1 meter (m) = 3.281 feet

1 meter/second (m/s) = 1.944 knots = 2.237 miles/hour = 3.281 feet/second

To convert from meters to feet, multiply the meters by 3.281;

To convert meters/second to knots, multiply the meters/second by 1.944

To convert meters/second to miles/hour, multiply the meters/second by 2.237.

The modeling work is based on the mean-sea level so that the *surge* and *drawdown* can be tabulated. These values need to be adjusted for the tide level during an actual event. This would mean adding 1-2 feet to the surge and subtracting 1-2 feet from the drawdown at high tide. For low tide, both the surge and drawdown would be slightly lower. During El Nino events, high tides and low tides could be up to a foot lower than normal. During La Nina events, high tides and low tides could be up to a foot higher than normal.

Moment magnitude (Mw) measures events in terms of how much energy is released. Mw was introduced in 1979 by Hanks and Kanamori to circumvent shortfalls in the Richter Scale. It is a more accurate scale for describing the size of earthquake events.

Groin, in coastal **engineering**, a long, narrow structure built out into the water from a beach in order to prevent beach erosion or to trap and accumulate sand that would otherwise drift along the beach face and nearshore zone under the influence of waves approaching the beach at an angle.