Response to Tsunamis at Agat Marina, Guam: A User's Manual

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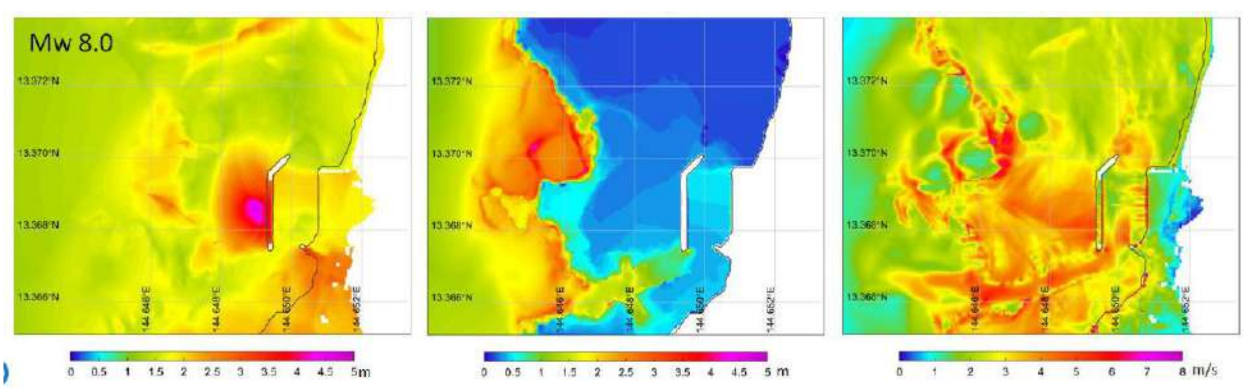

Response to Advisory-Level Tsunamis at Agat Marina and Nearby Nimitz Beach: A User's Manual

The purpose of this document is to provide guidance to decision makers for the necessary responses to tsunamis that impact the Agat Marina and Nimitz Beach but that don't meet Warning criteria but do meet Advisory criteria for strong *currents* and wave runup less than 3 feet. These tsunamis are generated by earthquakes that occur in selected subduction zones where two oceanic plates meet with one moving downward beneath the other. As the plates move against one another, stresses build up to a point where there is a big jerk—that is the earthquake. This creates a displacement of water. Such a vertical displacement creates a tsunami (wave).

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

***Surge* is the increase in water level as the tsunami wave enters the harbor or marina. *Surge* can force ships against peers and boats against slips, and can cause minor flooding of coastal areas.**

***Drawdown* occurs when the water level decreases as water exits the mouth of the harbor or the channel servicing the marina. *Drawdown* can cause the bottom of a boat to hit the floor of the marina that could be mud, sand, coral or rocks. A drawdown exceeding 4 feet is considered potentially damaging for boats near reefs and in marinas. Models can indicate drawdown values quite large when water spills over the steep reef ledge.**

The *period* determines how frequently the *surge* and the *drawdown* occur and how often the *currents* reverse direction. As currents move through channels, they create eddy pairs that rotate in opposite directions. When the currents change direction, the eddies change their rotation. This can greatly affect boats either at anchor or navigating.

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 greater than 3 knots to 6 knots can cause moderate damage. *Currents* with speeds greater than 6 knots can cause more serious damages. The Agat Small Boat Marina is a rather simple, compact marina with a single entrance channel, four parallel docks, and a total of 99 slips.

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

This study by Dr. Kwok Fai Cheung, through sensitivity analysis, identifies the four major subduction areas that can generate tsunamis that affect Agat Marina with strong *currents*. Dr. Cheung used his NEOWAVE (Non-hydrostatic Evolution of Ocean Waves) model for the sensitivity analysis. The four areas include:

The Marianas Trench
The Nankai Trough (and nearby Ryukyu Trench)
The Philippines (Mindanao) Trench
The New Guinea Trench (and nearby Manus Trench)

Each of these subduction areas can produce earthquakes of various strengths, as measured in terms of moment magnitude (Mw), that can generate tsunamis with unique characteristics that in turn can produce unique patterns of *surge*, *drawdown* and *current* speed and direction in the Agat Marina. Although the source parameters only depend on the moment magnitude (Mw), the resulting tsunami is also influenced by the local underwater geology and water depth. The source regions are indicated by red ovals as shown in Figure 1.

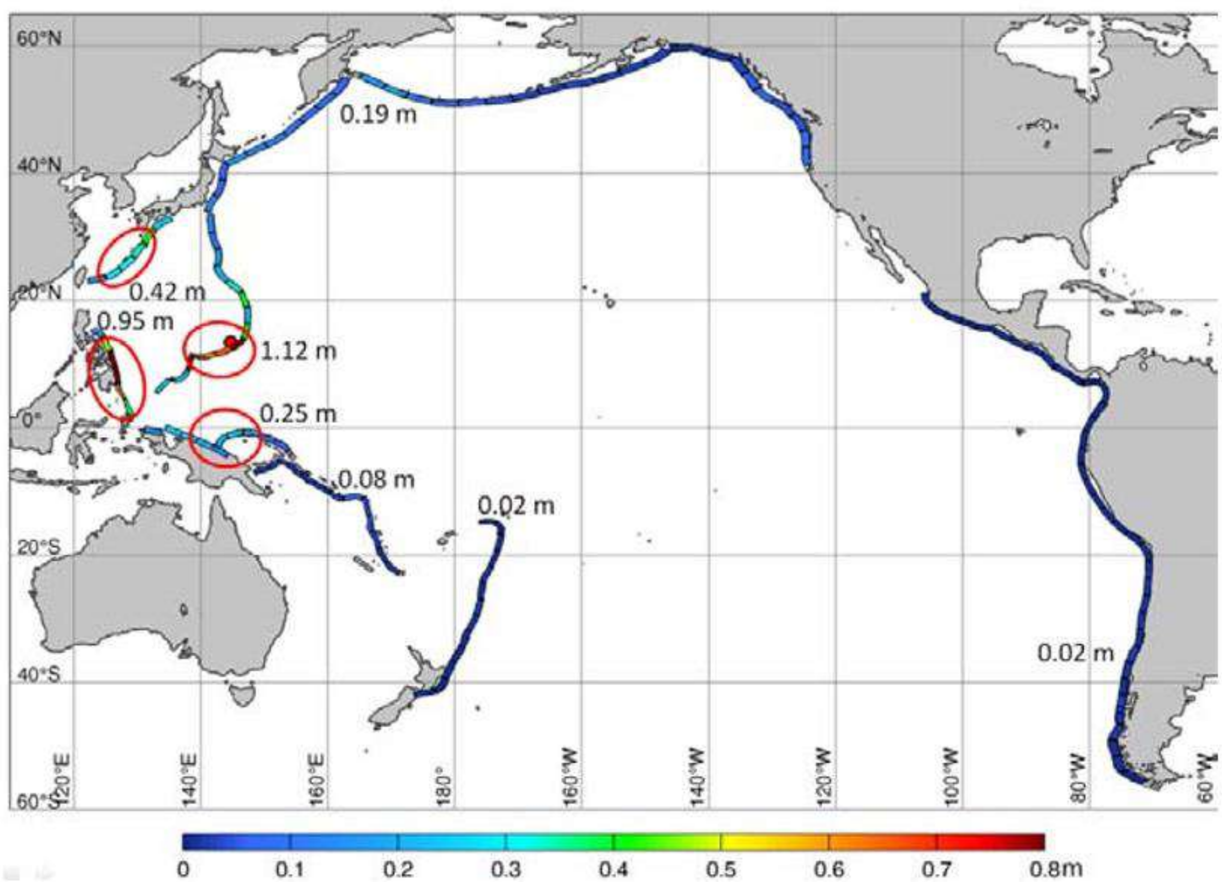

Figure 1. Sensitivity analysis of tsunami wave amplitude outside Agat Marina from hypothetical Mw 8.5 earthquakes at subduction zones in the Pacific Ocean.

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) may have been generated. PTWC then either indicates that there is no threat or issues a Tsunami Watch, Warning, or Advisory.

If a Warning is warranted, then decision makers for Agat Marina (namely the US Coast Guard Commander) and nearby Nimitz Beach (the Governor of Guam) have specific procedures for dealing with the necessary evacuations. However, if only Advisory-level criteria are met for Agat Marina, how should the decision makers respond? The following procedures address actions that are needed to deal with Advisory-level tsunamis from each of the four primary tsunami generation areas.

Agat Marina is a small boat marina consisting of a single entrance/exit channel, four docks, and a total of 99 slips. A view of the marina from the air is shown in Figure 2.

Figure 2. View of Agat Marina from the air showing the marina entrance at the left, the four docks and the 99 slips. The building at the right (blue roof) is the restaurant and the building at the left (blue roof) is the marina operations office. (Picture taken from www.portofguam.com)

Agat Marina customers have identified three critical locations/areas important to decision makers. These are the Marina itself, the channel between the Marina and the open ocean, and the adjacent Nimitz Beach. These locations/areas are indicated by the red borders shown in Figure 3.

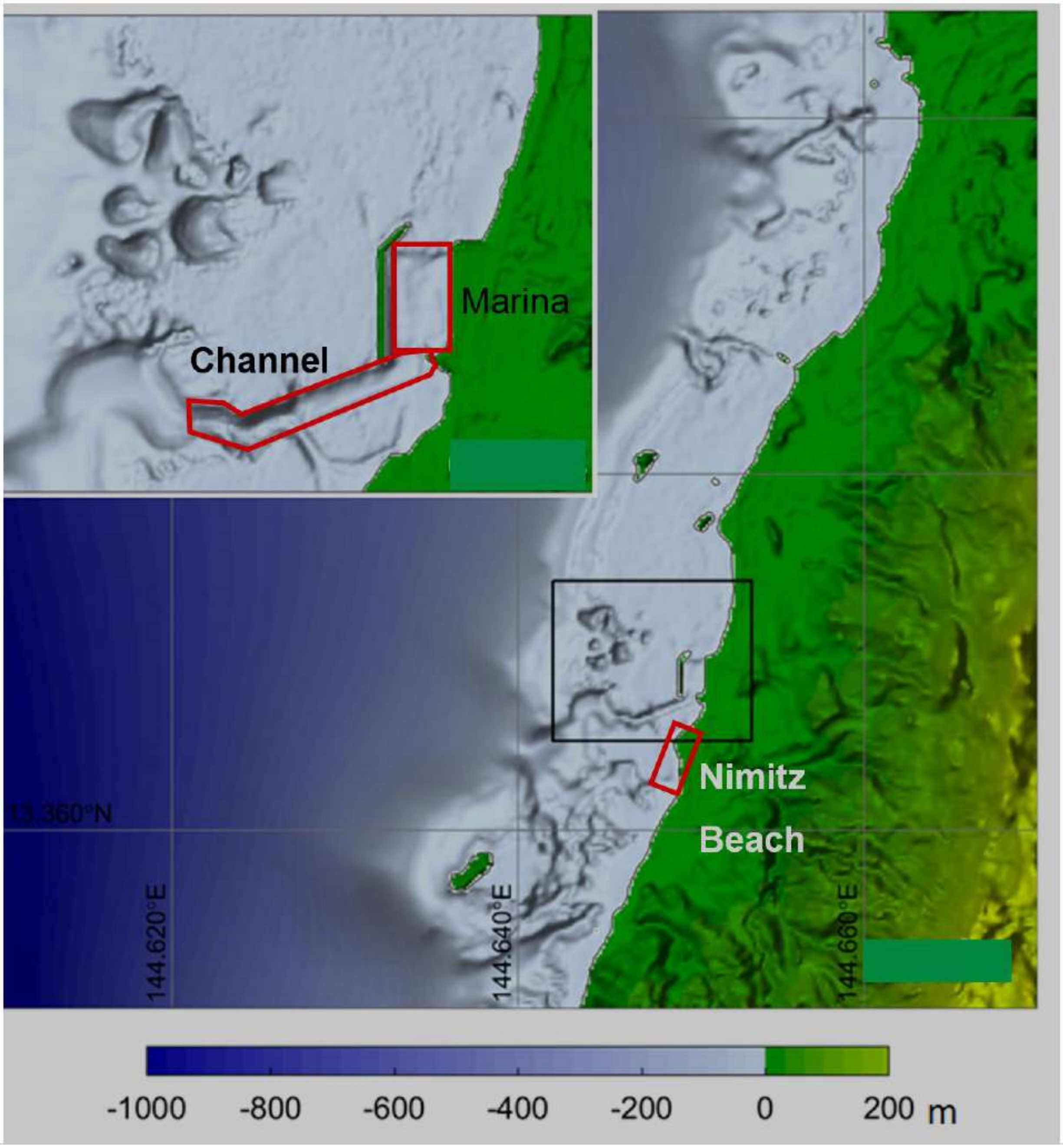

Figure 3. Critical locations at the Agat Marina (outlined in red) used for compilation of the required summary tables of critical parameters.

For each of these locations, Dr. Cheung derived a set of critical parameter tables from his NEOWAVE model. That model maps the tsunami (wave) from its source to the Agat Marina and Nimitz Beach locations, and shows the maximum *surge* and *drawdown*, and the *period* or time it takes to go from the crest of one wave to the crest of the next. It also maps the *current speed* and the *period of current* reversal in the critical areas. The NEOWAVE model provides several potential time periods in minutes that can occur between successive waves. The top two choices are listed in the period columns. The two choices can represent a range of times; the actual period will likely occur somewhere between the two values. In practice, one can indicate this range as the likely time period between subsequent waves.

The determination of the parameters is done for a range of earthquake moment magnitudes (Mw), in one-tenth Mw increments, that produce Advisory-level tsunamis. NEOWAVE has specialized features that enable it to accurately model tsunamis in the shallow-reef and steep reef-front environment of the Mariana Islands.

When PTWC detects a Pacific region earthquake and issues a Tsunami Bulletin, the US Coast Guard Watch Officer or responsible person should make the necessary notifications for required assessments and activations. Once the first tsunami wave is predicted to arrive within 3 hours, PTWC will issue a Tsunami Warning, a Tsunami Advisory, or perhaps a cancellation, if the cancellation has not already been issued. 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 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 Agat Marina and Nimitz Beach.

Marianas Trench

Figure 4 illustrates the maximum *surge*, maximum *drawdown*, and maximum *current speed* for Mw 7.8, 8.0, and 8.2 earthquakes. For the Marianas Trench, real-time earthquake damage may be a greater concern than the tsunami threat. However, the tsunami threat must be quickly assessed and addressed.

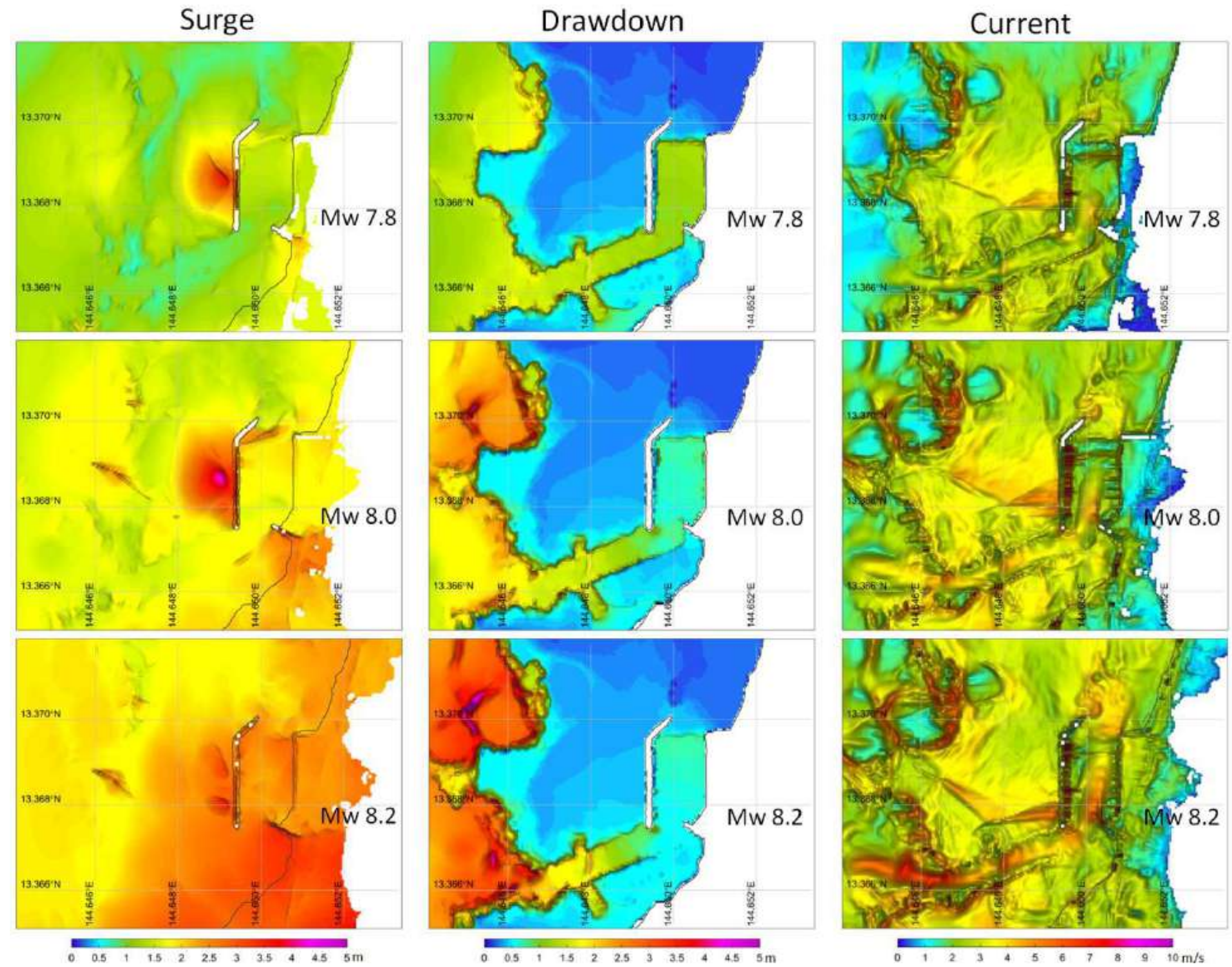

Figure 4*. Surge*, *drawdown*, *and current speed* at Agat Marina from Mw 7.8, 8.0, and 8.2 Marianas Trench earthquake scenarios.

The Marianas Trench is a special case. It is so close to the island that there won't be time for a Watch, Warning or Advisory, and likely not even a report of the actual magnitude of the earthquake. If there is a strong earthquake in the Marianas Trench, people will easily feel it and should duck, cover, hold on, and once the shaking stops, move inland to higher ground if they are in a near-coastal location. The first wave can arrive at Agat Marina in as little as 8 minutes.

The Guam Homeland Security/Office of Civil Defense will monitor the location and magnitude of the earthquake and the arrival time of the wave via information from PTWC. It will take several minutes for the information to arrive from PTWC. If the magnitude is around 8.0 or stronger, a coastal evacuation will likely be necessary. For such earthquakes, the currents can be very strong, exceeding 10 knots. Inside the Agat Marina, strong, damaging *currents* can be expected with Marianas Trench earthquakes of a Mw as low as 7.6.

Once the magnitude of the earthquake has been determined, Go to Table 1 and select the marina location of interest to determine the *surge, drawdown*, *current speed* and the range of of the wave and current return *periods*. If there are two different period times indicated, they represent a range of likely times.

For Nimitz Beach, the strong *currents* and *surge* can lead to significant coastal erosion, to coastal inundation and flooding, and with danger to beach goers, especially for earthquakes with an Mw greater than 8.0. For Advisory-level events, people are told to stay out of the water and off the beaches.

Table 1. Maximum *surge*, *drawdown*, *current speed,* and the *period* between one tsunami wave and the next wave at Agat Marina, the Marina Channel and Nimitz Beach from Marianas Trench source tsunamis.

Mariana Mw	Agat Marina				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
7.6	3.1	3.5	8, 10	6.7	7, 10
7.7	3.7	4.3	8, 10	7.3	8, 10
7.8	4.5	3.9	8, 10	8.7	8, 10
7.9	5.7	2.7	8, 10	7.9	8, 10
8.0	6.7	1.7	8, 10	9.5	8, 10
8.1	7.9	2.2	8, 10	11.2	8, 10
8.2	9.4	2.5	8, 10	12.3	8, 10
8.3	10.9	2.8	8, 10	12.6	8, 10
	Agat Channel				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
7.6	2.3	3.6	8, 10	6.3	7, 10
7.7	2.6	4.2	8, 10	6.6	8, 10
7.8	3.1	4.3	8, 10	7.0	8, 10
7.9	4.3	5.3	8, 10	9.6	8, 10
8.0	5.5	5.9	8, 10	10.2	8, 10
8.1	7.9	6.1	8, 10	10.6	8, 10
8.2	9.6	6.4	8, 10	11.1	8, 10
8.3	12.4	6.4	8, 10	11.5	8, 10
	Nimitz Beach				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
7.6	4.5	4.3	8, 10	6.9	7, 10
7.7	4.6	4.3	8, 10	7.8	8, 10
7.8	5.4	5.0	8, 10	9.5	8, 10
7.9	7.3	5.2	8, 10	10.2	8, 10
8.0	8.5	5.6	8, 10	10.7	8, 10
8.1	8.7	6.1	8, 10	11.3	8, 10
8.2	10.6	6.2	8, 10	11.5	8, 10
8.3	12.8	6.7	8, 10	12.5	8, 10

Nankai Trough

If there is a strong earthquake in the Nankai Trough or the adjacent Ryukyu Trench, the arrival time of the first tsunami wave is about 3 hours over the 1250-nm (1438-statute mile) distance.   PTWC may place Guam into an immediate Warning or Advisory. If the earthquake magnitude is 8.1 or greater, strong *currents* can cause moderate or worse damage to boats and docks at the marina. If the magnitude is 8.5 or greater, a coastal evacuation will likely be necessary.

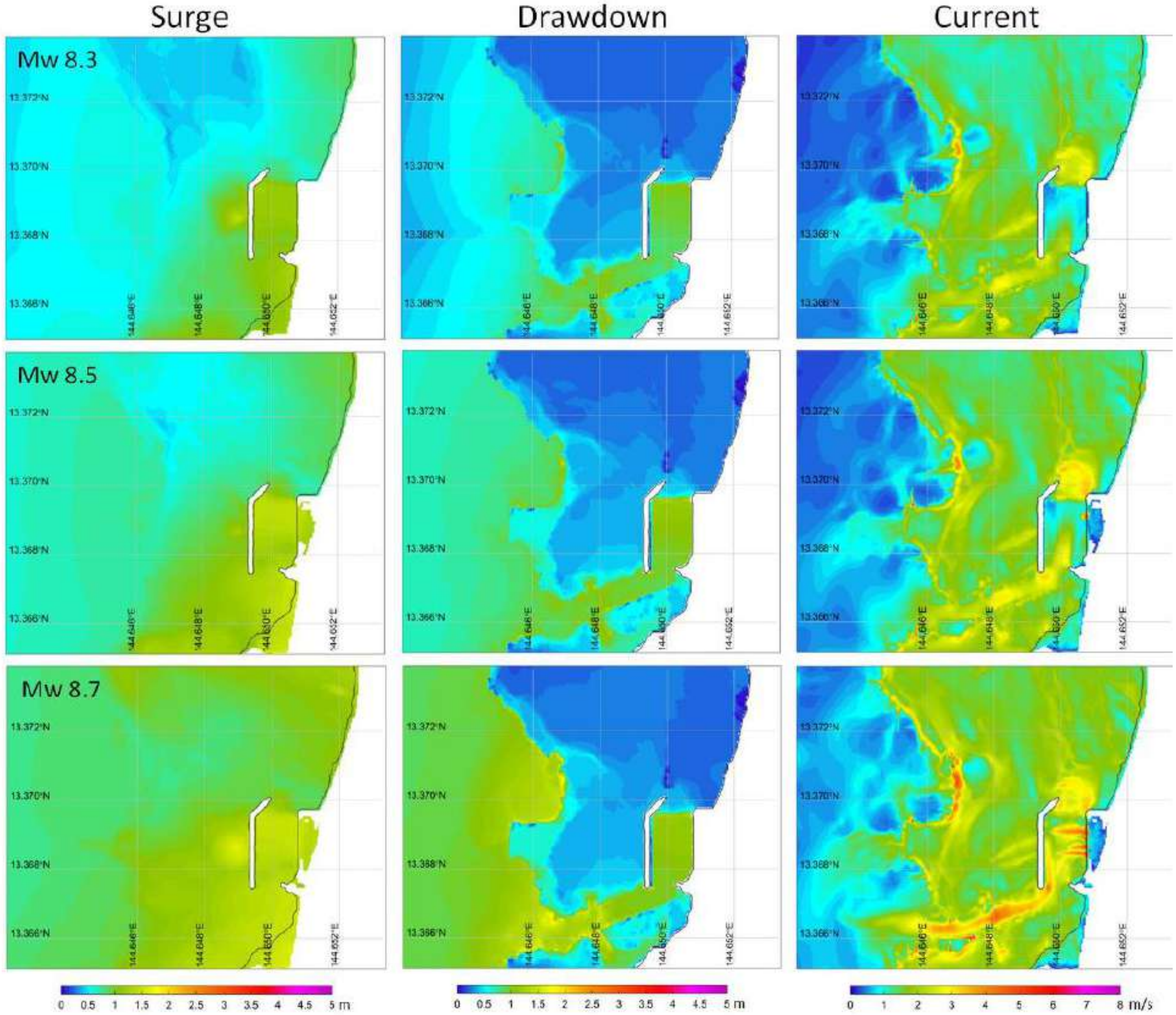

Figure 5. *Surge*, *drawdown*, and *current speed* at Agat Marina from Mw 8.3, 8.5, and 8.7 Nankai Trough or nearby Ryukyu Trench earthquake scenarios.

If the earthquake source is the Nankai Trough or the Ryukyu Trench, Go to Table 2 and determine the Mw of the earthquake, then go to the marina location of

interest to determine the *surge, drawdown*, *current speed* and the ranges of time of wave and current return *periods*.

Table 2. Maximum *surge*, *drawdown*, *current speed* and *periods* (times between the arrival of one wave and the arrival of the next wave) at Agat Marina from Nankai Trough or nearby Ryukyu Trench tsunamis.

Nankai Mw	Agat Marina				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
8.1	2.8	3.1	8, 9	4.1	8, 9
8.2	3.3	3.3	7, 9	4.5	8, 15
8.3	4.0	3.4	7, 15	4.8	7, 15
8.4	4.5	3.5	7, 15	5.3	7, 15
8.5	4.6	3.8	7, 15	5.7	7, 17
8.6	4.5	3.9	7, 17	5.4	7, 17
8.7	4.8	3.8	7, 17	8.2	7, 19

	Agat Channel				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
8.1	2.6	2.8	8, 9	4.1	8, 9
8.2	3.2	3.1	7, 9	5.0	8, 15
8.3	3.8	3.3	7, 15	5.6	7, 15
8.4	4.3	3.3	7, 15	5.9	7, 15
8.5	4.5	3.6	7, 15	5.9	7, 17
8.6	4.5	3.9	7, 17	6.2	7, 17
8.7	4.7	5.0	7, 17	8.7	7, 17
	Nimitz Beach				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
8.1	2.8	3.2	8, 9	4.7	8, 9
8.2	3.4	3.6	7, 9	5.7	8, 15
8.3	3.9	4.2	7, 15	6.0	7, 15
8.4	4.6	4.2	7, 15	6.0	7, 15
8.5	4.9	4.0	7, 15	5.9	7, 17
8.6	4.8	4.3	7, 17	5.9	7, 17
8.7	4.9	5.1	7, 17	6.5	6, 17

Philippine Trench

Tsunamis from the Philippine source have the most direct approach to Agat Marina. This is 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 the deeper water in the East Philippine Sea. If the Mw is 7.9 or greater, Agat Marina can expect strong *currents* (Advisory impacts), while nearby coastal areas may reach Warning criteria and a coastal evacuation may be needed.

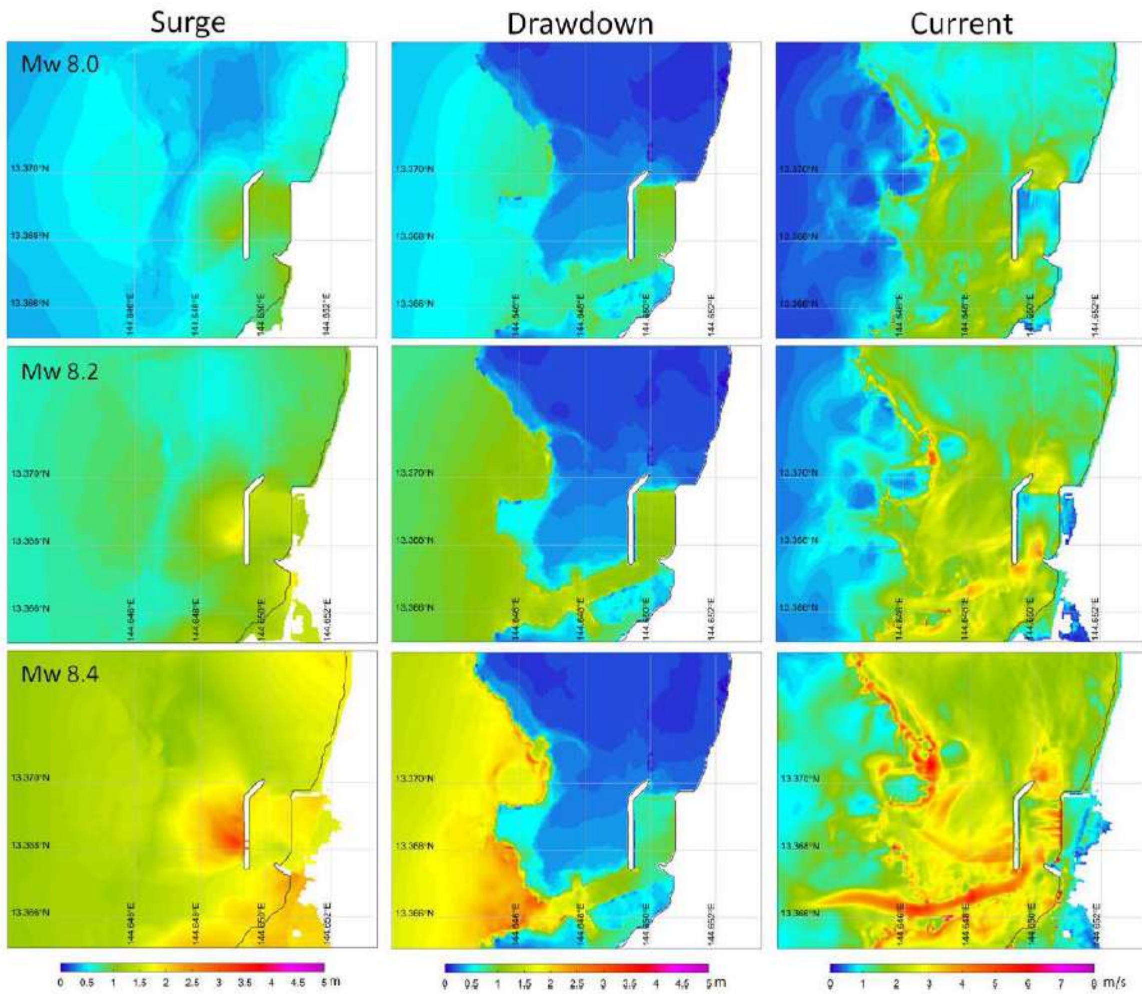

Figure 6. *Surge*, *drawdown*, and current at Agat Marina and Nimitz Beach from the Mw 8.0, 8.2, and 8.4 Philippine Trench earthquake scenarios.

If the source of the earthquake is the Philippine (Mindanao) Trench, Go to Table 3 and match the Mw of the earthquake, then go to the marina location of interest to

determine the *surge, drawdown*, *current* speed and the ranges of time of wave and current return *periods*.

Table 3. Maximum *surge*, *drawdown*, and current at the Agat Marina from Philippine Trench tsunamis.

Philippine Mw	Agat Marina				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
7.9	2.9	2.7	7, 9	4.5	7, 9
8.0	3.5	3.5	7, 9	5.6	7, 9
8.1	4.1	3.8	7, 9	6.4	7, 9
8.2	4.8	3.9	7, 9	8.0	7, 9
8.3	5.4	4.0	7, 9	9.6	7, 9
8.4	6.2	3.0	7, 9	8.0	7, 9
8.5	7.1	1.2	7, 9	7.8	7, 9

	Agat Channel				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
7.9	2.1	2.2	7, 9	4.5	7, 9
8.0	2.8	3.1	7, 9	5.6	7, 9
8.1	3.5	3.7	7, 9	6.2	7, 9
8.2	4.1	4.7	7, 9	7.1	7, 9
8.3	4.9	5.3	7, 9	8.5	7, 9
8.4	6.2	6.4	7, 9	11.3	7, 9
8.5	7.4	6.5	7, 9	11.9	7, 9
	Nimitz Beach				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
7.9	2.4	2.4	7, 9	3.4	7, 9
8.0	3.2	3.2	7, 9	4.8	7, 9
8.1	4.1	4.3	7, 9	5.7	7, 9
8.2	4.9	5.2	7, 9	6.3	7, 9
8.3	5.8	5.8	7, 9	6.6	7, 9
8.4	6.8	6.1	7, 9	8.1	7, 9
8.5	8.1	6.5	7, 9	9.2	7, 9

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 Agat Marina and Nimitz Beach *surge*, *drawdown*, and *current* speeds for Mw 8.4, 8.6, and 8.8 earthquakes.

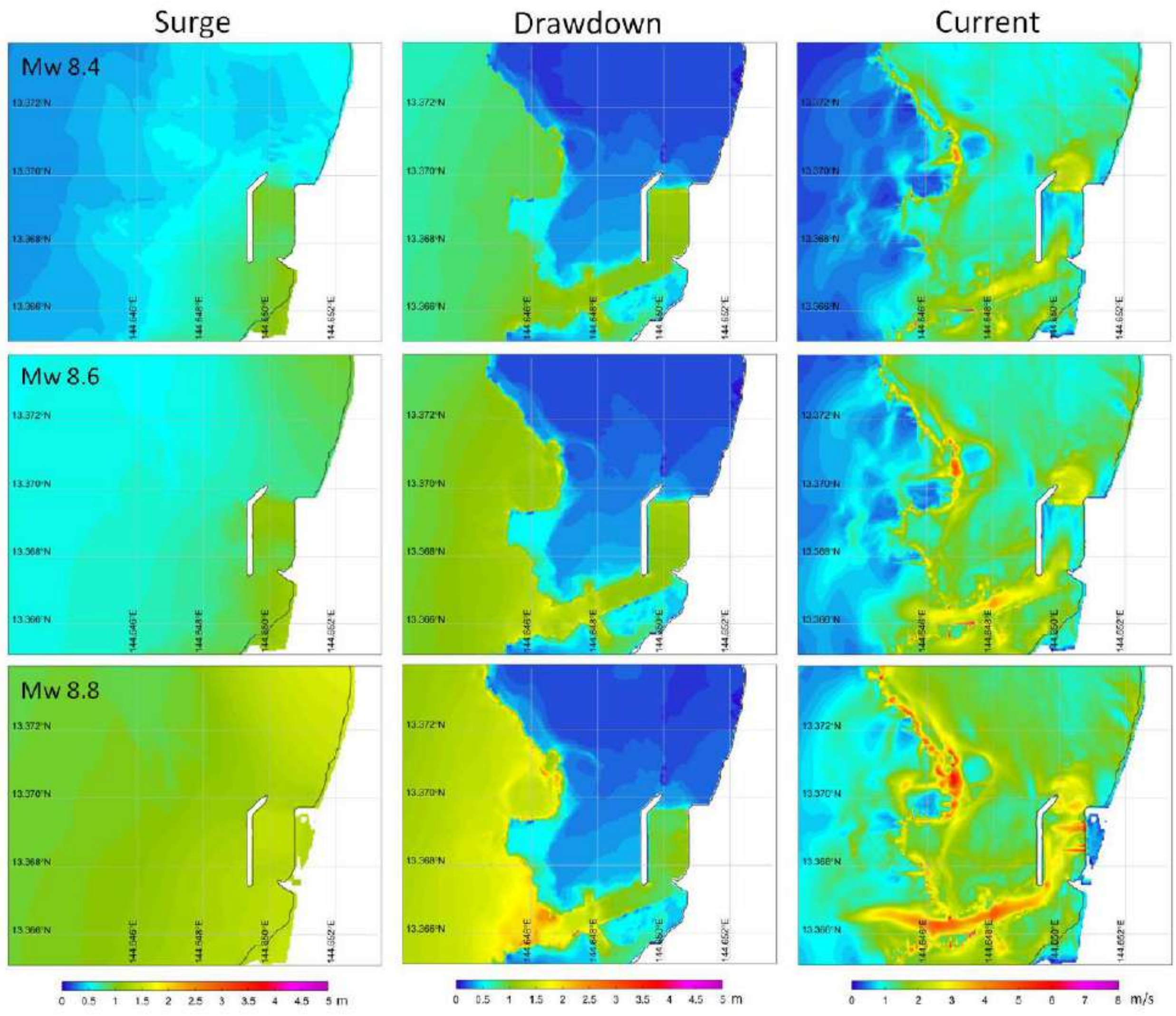

Figure 7. *Surge*, *drawdown*, and current at Agat Marina and Nimitz Beach from the Mw 8.4, 8.6, and 8.8 New Guinea earthquake scenarios.

When a strong earthquake of Mw 8.5 or greater occurs in the New Guinea Trench, PTWC will likely issue a Warning or Advisory for Guam. While coastal areas may

be in a Warning, Agat Marina will only experience Advisory-level strong *currents*. However, some damage to boats caused by surges, drawdowns, and currents can occur with a New Guinea or Manus Trench earthquake of Mw 8.2 or greater.

If the source of the earthquake is the New Guinea Trench or the Manus Trench, Go to Table 4, and match the earthquake magnitude to the location(s) of interest to determine the *surge, drawdown*, *current* speed and ranges of time of wave and current return *periods*.

Table 4. Maximum *surge*, *drawdown*, and current at Agat Marina and Nimitz Beach from New Guinea Trench tsunamis.

New Guinea Mw	Agat Marina				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
8.2	3.1	3.2	8, 9	4.5	7, 8
8.3	3.2	3.7	8, 9	4.7	7, 8
8.4	3.3	4.0	8, 9	4.9	7, 8
8.5	3.4	4.0	7, 8	5.2	7, 8
8.6	3.8	4.0	7, 8	5.2	7, 8
8.7	3.7	4.0	7, 10	5.8	7, 8
8.8	4.8	3.6	7, 10	5.8	7, 10
	Agat Channel				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
8.2	3.0	3.0	8, 9	4.9	8, 9
8.3	3.1	3.6	8, 9	5.3	8, 9
8.4	3.3	4.1	8, 9	5.8	7, 8
8.5	3.3	4.7	7, 8	6.8	7, 8
8.6	3.5	4.9	7, 8	7.4	7, 8
8.7	3.5	4.9	7, 10	8.1	7, 8
8.8	4.6	5.7	7, 10	9.7	7, 10
	Nimitz Beach				
	Surge (ft)	Drawdown (ft)	Period (min)	Current (knot)	Period (min)
8.2	3.2	3.0	8, 9	4.3	7, 8
8.3	3.4	3.8	8, 9	5.1	7, 8
8.4	3.5	5.2	8, 9	5.8	7, 8
8.5	3.6	4.9	7, 8	6.1	7, 8
8.6	3.8	5.2	7, 8	6.3	7, 8
8.7	3.7	5.7	7, 10	6.5	7, 10
8.8	4.7	6.3	7, 10	6.7	7, 10

Notes:

The values in the distance and speed color scales of figures 4, 5, 6, and 7 are in feet and knots. To convert to meters and meters/second and miles/hour, use the following formulas:

1 foot (ft) = 0.3048 meters (m)

1 knot (kt) = 1.15078 miles per hour (mph) = 0.5144 meters per second (m/s) = 1.688 feet/second

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.