American Samoa RSM: Numerical Modeling of Waves and Currents in the Utulei Beach Region

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PURPOSE: This Regional Sediment Management Technical Note (RSM-TN) describes studies of sediment related problems for the Utulei Beach region on the Island of Tutuila as part of the American Samoa Regional Sediment Management (RSM) Program. This document discusses (1) the existing shoreline conditions, (2) the oceanographic characteristics, and (3) the U. S. Army Engineer Research and Development Center (ERDC) Coastal Modeling System (CMS) numerical modeling conducted to identify sediment pathways in the region. The results of these investigations will be used to inform future decisions about potential RSM projects for the region. This study investigates sediment-related problems and opportunities in the village of Pago Pago in the Utulei Beach region on the Island of Tutuila, American Samoa.

BACKGROUND: RSM refers to the effective and regionally comprehensive use of littoral, estuarine, and riverine sediment resources in an environmentally sensitive and economically efficient manner. RSM was officially implemented at the U.S. Army Corps of Engineers (USACE), Honolulu District (POH), in February 2004. While POH has investigated RSM opportunities along several regions in Hawaii, this project is the first in the U.S. Territory of American Samoa.

All 10 existing federally authorized shore protection projects on the American Samoa Island of Tutuila where Utulei Beach is located consist of *hard* structural features, such as rubble mound revetments. In addition, the American Samoa Government has constructed similar projects that have reduced the amount of sandy shorelines in the territory. This trend will continue into the future in response to coastal storms and sea level rise impacts unless *soft* solutions for shore protection are implemented. The American Samoa Government has expressed concerns for the loss of sandy shorelines as it impacts subsistence and quality of life for the people of American Samoa.

American Samoa is composed of volcanic islands characterized by steep topography, narrow coastal plains, and surrounding fringing reefs. Beach sediment is primarily of marine origin (NPS 2008) and is in very limited supply. Construction along the shoreline has resulted in an increase of shoreline armoring and loss of many sandy beaches. An inventory of sediment resources (including federally authorized navigation projects) and sources of erosion (e.g., tropical cyclones, sea level rise, sand mining) is a first step toward protecting existing sandy shorelines and restoring those shorelines in danger of future hardening¹.

¹ Smith, T. D. In preparation. *Potential RSM Projects; Utulei Beach Region, American Samoa*. ERDC/TN RSM Technical Note. Vicksburg, MS: U. S. Army Engineer Research and Development Center.

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The Utulei Beach region extends from Tulutulu Point to Nuututai Point (Figure 1), approximately 0.8 mile of shoreline. The Utulei Beach region RSM initiative (1) evaluates recent changes and the existing condition of the shoreline, (2) quantifies coastal processes and sediment-related issues in the region, and (3) as presented in a companion Coastal and Hydraulics Engineering Technical Note (CHETN) by Smith¹ uses this information to identify potential RSM projects in the Utulei Beach region.

Figure 1. Utulei Beach region, inside Pago Pago Harbor on the Island of Tutuila, American Samoa.

EXISTING SHORELINE CONDITIONS: The existing conditions of the shoreline along the Utulei Beach region have been documented in the American Samoa Shoreline Inventory (USACE 2006, rev. 2012). The shoreline inventory is currently being updated with information from a July 2016 site visit. The Utulei Beach region is broken into four reaches (Figure 2).

Reach A extends from Nuututai Point to the lava rock outcropping just south of Sadie's by the Sea Hotel. The shoreline in this reach consists of newly constructed shore protection and a manmade swimming beach.

Reach B encompasses the shoreline from the lava rock outcropping south of Sadie's by the Sea Hotel to the Vailoa Stream mouth. This reach is characterized by a narrow beach that disappears at high tide, a cement-filled sandbag revetment, and a 150-feet (ft)-long rock revetment protecting a small tip that interrupts the beach in the northern section. This revetted tip separates the reach into sub-reaches B1 and B2. The sandbag revetment (Reach B1) is being undermined, exposing vertical rebars (Figure 3). The backshore area is a public park with a comfort station

and fales (thatched huts). In the offshore, a channel was dredged into the reef for either land reclamation purposes or to provide a safe swimming area. This park and beach are popular with the local community because it is one of the few beaches on the island suitable for swimming. The southern section of the beach (Reach B2) has a failing concrete rubble masonry seawall that has completely disappeared in some sections (Figure 4). There is also a newly constructed longboat house and a boat ramp near the Vailoa Stream mouth that may be impacting the longshore sediment transport.

Figure 2. Reaches A, B, C, and D in the Utulei Beach region.

Figure 3. The cement-filled sandbag revetment in Reach B1 is being undermined, exposing vertical rebar.

Figure 4. Failing concrete rubble from the American Samoa Shoreline Inventory masonry seawall protecting the park and fales in Reach B2. (USACE 2006, rev.2012).

Reach C is a 1,400 ft long engineered revetment that protects the road and a sidewalk.

Reach D, the last section to Tulutulu Point, consists of a narrow 200 ft long beach and two houses that are protected by a revetment, groin, and vertical boulder wall. Historical information from the current and past shoreline inventories shows that there is chronic erosion currently impacting the Utulei Beach shoreline.

Figure 5 shows a benthic habitat map for the Utulei Beach region created by P Pacific Consultants (2015) with data from the National Oceanic and Atmospheric Administration

(NOAA), National Center for Coastal Ocean Science (NOAA 2005). The area offshore of the Utulei Beach region is primarily a reef flat with some seagrass and a sandy substrate. The sandy areas are mainly fronting the beaches in the northern part of the region. The benthic habitat map also highlights the sandy channel that runs parallel to shore.

Figure 5. Benthic habitat offshore of the Utulei Beach region, Island of Tutuila, American Samoa (P Pacific Consultants 2015).

A shoreline volume change analysis was conducted for three sections of sand beach using historic imagery from Google Earth. The beach area was measured then converted to a volume. To estimate the quantity of sand represented in the shoreline changes, POH utilized a conversion value of 0.4 cubic yard (cy) of sand per 1 square foot (sq ft) of beach based on guidance provided by the Coastal Engineering Manual (USACE 2002). This guidance states that as an unarmored beach erodes, it maintains approximately the same profile above the seaward limit of significant transport. This conversion value of 0.4 cy/sq ft has been developed by POH for Hawaii study areas where there is limited profile data. Figure 6 shows the comparison of the shorelines and volume changes between 28 September 2009 and 26 August 2015. In Reach A, the beach diminished approximately 111 cy; in Reach B1 by 250 cy; and in Reach B2 by 1,035 cy.

Figure 6. Utulei Beach region shoreline change from 28 September 2009 to 26 August 2015 suggests the beaches are eroding (from Google Earth <https://www.google.com/earth/>).

OCEANOGRAPHIC CHARACTERISTICS: Physical oceanographic conditions describe the wind, wave, and tidal characteristics of the region. American Samoa has two main seasons—a wet summer season from November through April and a dry winter season from May through October. Figure 7 shows the wave exposure window for Pago Pago Harbor, American Samoa. Figures 8a and 8b present wind and wave roses derived from hindcast data developed by the USACE Wave Information Study (WIS) (<http://wis.usace.army.mil>). The trade winds prevail over this region throughout the year, coming from the east through southeast. Ocean waves predominantly come from the east through south-southeast and are generally less than 2 meters (m) (6.6 ft) (Figure 8b). Storms come from the east-southeast through the south bringing waves 2 to 4 m (6.6 to 13.1 ft) in height. This area also experiences cyclones, typically coming from the north. The largest cyclone since 1980 was Cyclone Heta in January 2004, with a peak significant wave height of 10.32 m (33.86 ft).

Figure 7. Wave exposure window for Pago Pago Harbor, American Samoa.

Figure 8. Wind rose (8a left) and wave rose (8b right) from WIS station 81129, located to the south of Pago Pago Harbor.

NOAA tide station 1770000 is located in Pago Pago Harbor (<https://tidesandcurrents.noaa.gov/stationhome.html?id=1770000>). The tides are semidiurnal (i.e., two high tides and two low tides each day) and have a mean range of 0.79 m (2.58 ft) (the difference between the mean high water and mean low water). An analysis of the tides show a sea level rise of 2.21 millimeters per year (yr) (0.72 ft per 100 yr).

COASTAL MODELING SYSTEM (CMS) NUMERICAL MODELS: An understanding of the sediment transport processes for the Utulei Beach region requires evaluation of waves and circulation in the region. A wave and flow modeling study was implemented to better understand the area hydrodynamics and infer general regional sediment transport patterns. Processes influencing the region's shoreline that were considered in setting up the numerical model include the following:

- complex bathymetry including a naturally deep harbor, steep reef face, shallow fringing reefs, offshore excavated channel, and manmade structure
- easterly trade winds occurring throughout the year
- narrow wave window due to harbor entrance.

The USACE Coastal Inlet Research Program CMS numerical models CMS-Wave and CMS-Flow (Demirbilek and Rosati 2011) were applied along the Utulei Beach region to simulate wave transformation and water circulation within the region. The models were used in 3-hour (hr) steering mode interval to capture the interdependence of tides, currents, wind, and waves. The CMS-Flow water surface elevation was forced with a spatially constant but time-varying water level using the NOAA tide station at Pago Pago Harbor. Wind input for both the flow and wave model (also spatially constant) was taken from the hindcast WIS Station 81129 (Figure 8a). Spectral wave time-series data applied at the CMS-Wave boundary were also supplied by WIS Station 81129.

Grid bathymetry for the wave and current models was created using the bathymetry dataset maintained by the University of Hawaii, School of Ocean, Earth Science, and Technology, Pacific Islands Benthic Habitat Mapping Center (<http://www.soest.hawaii.edu/pibhmc/>). These data are derived from multibeam data in deeper areas and from multispectral satellite imagery in shallower reef areas. Figure 9 shows the extent of the grid and the bathymetric contours in the harbor (note depths are in meters). The center of the harbor is naturally deep, reaching approximately 70 m (230 ft) depth. There is a steep transition to a shallow fringing reef, approximately 10 m (33 ft) deep and 50 to 250 m (164 to 820 ft) wide.

To discern the pathways of sediment transport in the Utulei Beach region, a wave event with a 1 yr recurrence interval (based on WIS hindcast data) was modeled as well as a more typical trade wind condition. The 1 yr event, which has an offshore peak significant wave height of approximately 3.5 m (11.5 ft), was modeled using three hindcast time periods with varying wave approach angles to determine if the direction of the incoming waves had an effect on the transformed waves and currents in the study region. The following events were selected:

- 4 to 10 September 2010: Peak significant wave height (H_{mo}) = 3.47 m (11.4 ft); peak period (T_p) = 10 seconds (sec); mean wave direction (Dir) = 149 degrees (deg) (SSE); 1 yr return period

- 14 to 20 August 2007: $H_{mo} = 3.51$ m (11.5 ft); $T_p = 10$ sec, Dir = 115 deg (ESE); 1 yr return period
- 6 to 12 September 2009: $H_{mo} = 3.58$ m (11.7 ft); $T_p = 15$ sec, Dir = 177 deg (S); 1 yr return period
- 18 to 24 September 2009: $H_{mo} = 2.2$ m (7.2 ft); $T_p = 8$ sec, Dir = 110 deg (ESE); trade wind conditions.

Figure 9. Bathymetry contours in Pago Pago Harbor. Inset of the bathymetry over the entire CMS grid extent.

The winds for the first three runs came from the southeast at 4 to 12 m/sec (9 to 27 miles/hr). For the trade wind condition, winds came from the east through at 5 to 9 m/sec (11 to 20 miles/hr). Each event was simulated using CMS-Wave and CMS-Flow in steering mode for 5 to 7 days based on the available wind, wave, and water level data. All directions are referenced to true north.

CMS-Flow results indicate that the currents in the deep areas at the middle of the harbor are predominantly tidally driven, changing direction with rise and fall of the tide. However, the currents in the shallow nearshore region of Utulei Beach appear to be more wave driven, especially during large wave events. Wave breaking over the reef generates radiation stress (transfer of momentum), which drives the longshore current northward. However, during an ebb tide, this northerly wave-driven current is intercepted in the northern reach of the region by the southward-driven tidal current flowing around Nuututai Point. Here, an eddy develops offshore. During a 1 yr wave event as shown in Figure 10, the wave-driven current becomes strong enough to drive northward flow around Nuututai Point despite the southward flow in the main part of the harbor. While the currents along the Utulei Beach nearshore still primarily flow northward during the trade wind condition, this pattern is not as consistent as during a large wave event. For example, Figure 11 shows that the nearshore currents are more complex during the ebb tide in

smaller wave conditions. The current flows south around Tulutulu Point but north in the upper region of Utulei Beach and south again around Nuututai Point. At the location offshore from Sadie's by the Sea Hotel, the currents intersect and flow offshore toward the deeper harbor. The maximum nearshore current velocities observed during the 1 yr wave event are approximately 1.0 m/sec (3.3 ft/sec) around Tulutulu Point. During the more typical trade wind conditions, the nearshore currents are less than 0.4 m/sec (1.3 ft/sec).

Figure 10. CMS-Flow results during 1 yr south-southeast event on 6 September 2010 at 0730. Alongshore current to the north while tidally ebb-driven flow is to the south during ebb tide.

Figure 11. CMS-Flow results during trade wind wave event on 21 September 2009 at 2200. Nearshore flow is more complex during ebb tide.

Figure 12 compares the wave results for the three 1 yr wave events. While the offshore wave heights were approximately 3.5 m (11.5 ft), wave heights in the harbor were approximately 1 to 2 m (3.3 to 6.6 ft) due to sheltering and refraction of waves. Modeled waves coming from the south-southeast direction (Figure 12a) resulted in the largest wave heights in the harbor despite having a slightly smaller peak wave height offshore, due to the orientation of the harbor entrance and direct wave approach angle. The model results also show that in all three runs, the study area is fairly sheltered from the incoming waves, with wave heights at the shoreline of approximately 0.5 to 1 m (1.6 to 3.3 ft) during the 1 yr return period event. Energy from the waves diffracting around Tulutulu Point is dissipated over the shallow reef. The trade wind condition, which has an offshore wave height of approximately 2 m (6.6 ft), also shows a similar sheltering pattern, although with smaller wave heights. While no field measurement data exist to validate the results of these model simulations, the wave and current magnitudes appear realistic based on knowledge of the area and were utilized to provide a general qualitative understanding of sediment transport patterns in the region.

Figure 12. CMS-WAVE results for the 1 yr storm event. Waves approach the harbor at different angles in each scenario: (A) south-southeast, (B) east-southeast, and (C) south.

CONCLUSIONS: From the results of the CMS-Wave and CMS-Flow models, it is concluded that sediment in the Utulei Beach region is primarily transported to the north, especially during large wave events. Thus, sand may be observed to accumulate at the north end of the littoral sub-cells. If sediment approaches Nuututai Point, it may be transported by the offshore-directed current in this area and deposited outside the nearshore littoral system. During calmer periods, it is probable there is an equilibration process whereby some sand is moved back to the south. This dominant northward transport of sediment has likely contributed to the erosion of these beaches over time. Without a natural sediment source such as an upland or offshore supply of sand within the beach profile, or a manmade supply of sand through beach nourishment, beach loss will likely continue. Additionally, discussions with the local community have indicated that there are other issues leading to sediment volume loss, including sand mining.

A companion CHETN by Smith¹ discusses potential RSM projects for this region. Options that were discussed include locating a sand source for beach nourishment, sand pushing, and sand recycling. If sand were placed on the beach in this region, it can be expected to be transported to the north, especially during the stormy winter season. When the waves are weaker and trade winds prevail, the sand may be redistributed over the region. However, the chronic erosion at this beach suggests that any sand placed on the beach would need regular re-nourishment.

POINTS OF CONTACT: This Regional Sediment Management Technical Note (RSM-TN) was prepared as part of the USACE National Regional Sediment Management (RSM) Program and was written by Lauren K. Molina and Jessica H. Podoski, U. S. Army Corps of Engineers Honolulu District (POH), Honolulu, HI, with input from the Hawaii RSM Project Delivery Team. David A. Lau is the USACE Pacific Ocean Division (POD) RSM Point of Contact (POC). Additional information pertaining to the POH RSM investigations can be found at <http://rsm.usace.army.mil/Hawaii> and pertaining to the USACE National RSM Program can be found at <http://rsm.usace.army.mil>.

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