US Army Corps
of Engineers ®
Honolulu District

Appendix C

American Samoa Final Watershed Plan

Engineering Analysis

July 2022

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AEP	Annual Exceedance Probability
ASPA	American Samoa Power Authority
ASVD02	American Samoa Vertical Datum 2002
BFE	Base Flood Elevation
EC	Engineer Circular
ECB	Engineering and Construction Bulletin
ETL	Engineer Technical Letter
EM	Engineer Manual
ENSO	El Nino Southern Oscillation
ER	Engineer Regulation
FEMA	Federal Emergency Management Agency
FRM	Flood Risk Management
HEC	Hydrologic Engineering Center
MOM	Maximum of Maximum
NPDES	National Pollutant Discharge Elimination System
NWS	National Weather Service
RSLC	Relative Sea Level Change
SLC	Sea Level Change
SWEL	Still Water elevation
SST	Sea Surface Temperature
USACE	United States Army Corps of Engineers
WA	Watershed Assessment
WRDA	Water Resources Development Act

1 Introduction

1.1 Purpose and Scope

The purpose of this report is to describe the hydraulic analysis conducted in support of the Watershed Assessment (WA) for American Samoa. This final report is an addendum to the draft Watershed Plan. This report communicates the coastal and hydrologic technical analysis used to support conclusions reached for this WA. It incorporates available information from existing data, reports and, on-going efforts from local and federal agencies to provide a suite of recommendations to enhance community resiliency and improve watershed management.

1.2 Background

Authority for this Watershed Assessment (WA) is provided by Section 729 of the Water Resources Development Act (WRDA) of 1986 (P.L. 99-662), as amended. Funding for this WA was provided in response to Tropical Cyclone Gita, which impacted American Samoa in February 2018. Gita generated destructive wind and torrential rainfall causing widespread power outages. Approximately 1,000 people were evacuated to 12 shelters. Multiple mudslides occurred, uprooting many trees, and the intense rainfall caused flash flooding in low lying areas and near small streams.

This assessment recognizes and builds on the inherent resilience of Pacific Islands' cultures developed over thousands of years of oceanic living, and *fa'asamoa*, the traditional way of governance. The intent of this WA is to provide recommendations both within and outside of U.S. Army Corps of Engineers (USACE) authorities that will help to rehabilitate and improve the resiliency of damaged infrastructure and natural resources, reducing risks to human life and property from future natural hazards in American Samoa. For a list of all contributing assessment partners please reference the main report.

1.3 Location

American Samoa is an unincorporated territory of the United States located in the mid-South Pacific Ocean, a part of the Samoan Islands archipelago in Polynesia (Figure 1). American Samoa consists of 70 villages across five main islands (Tutuila, Aunuu, Ofu, Olosega, and Tau), a smaller privately owned island (Swains Island), and one coral atoll (Rose Atoll) (Figure 2). Tutuila is the largest and most populous island, with approximately 48,000 residents and a 58 square mile land area. Aunu'u Island is 0.59 square miles and located one mile southeast of Tutuila, with less than 450 residents. The islands of Ofu, Olosega, and Tau, located approximately 70 miles east of Tutuila, are collectively referred to as the Manu'a Islands and have a combined population of 850.

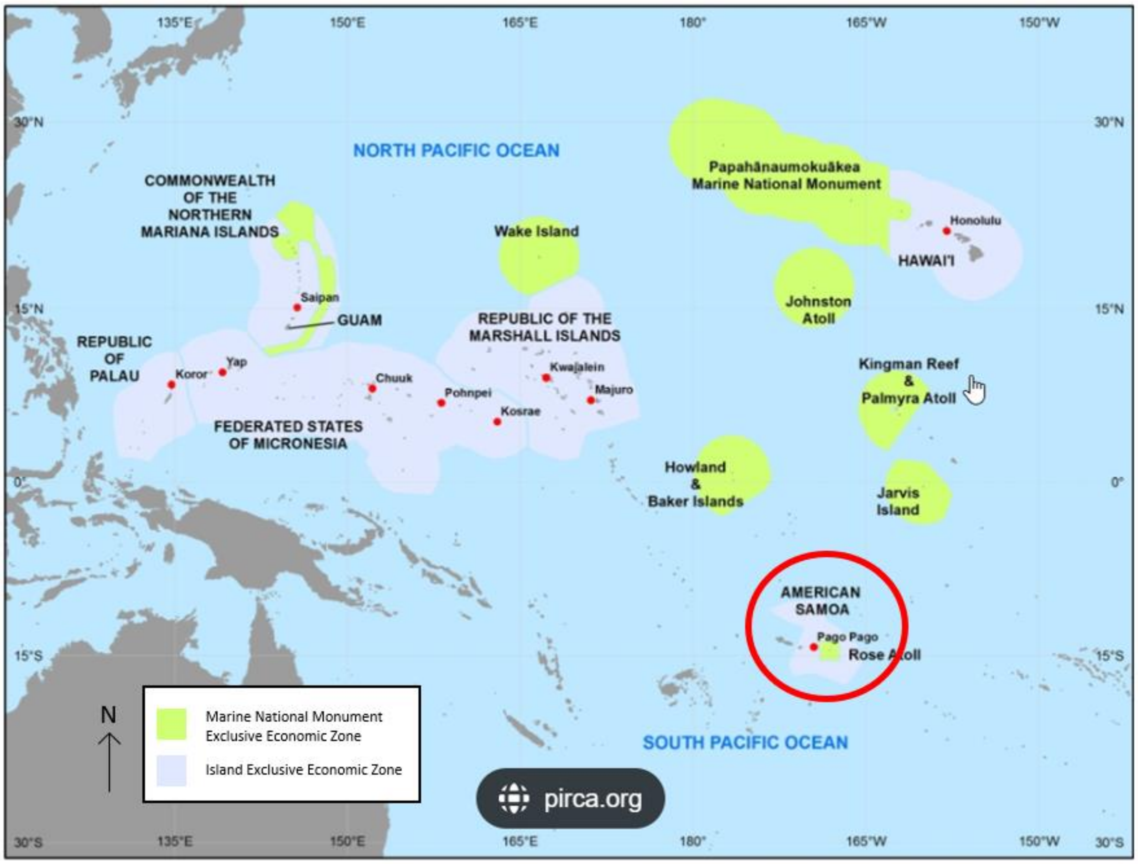


Figure 1. Map of the U.S. Pacific Islands Region (PIRCA.org 2018)

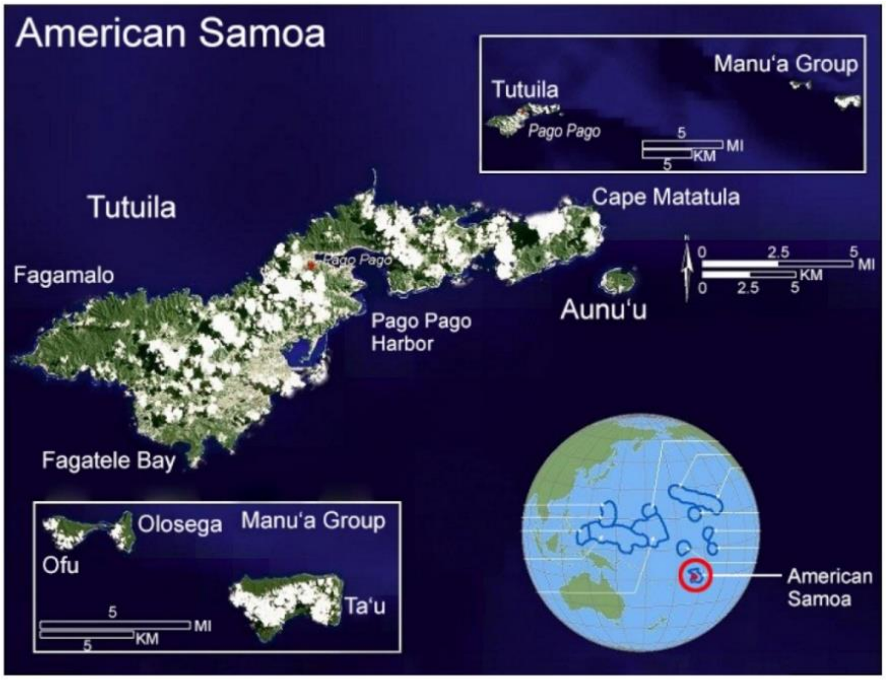


Figure 2. American Samoa Islands

American Samoa is represented by Congresswoman Aumua Amata (R), a delegate to the U.S. House of Representatives.

Due to the steep terrain of the islands, most development, including critical infrastructure such as the Lyndon B. Johnson (LBJ) Tropical Medical Center, the primary petroleum tank farm, and the primary roads are located along narrow areas between the mountains and the shoreline. Even Pago Pago harbor, which is central to the economy of American Samoa, is built within very limited space between steep slopes and the coast. The Tafuna-Leone Plain on the southwestern area of Tutuila is the largest relatively flat area of all the islands and subsequently is the largest area of development.

The wet season in American Samoa is generally December through March; however, 300 days of the year rainfall is recorded. American Samoa is located 14 degrees south of the equator, maintains 73-to-93-degree Fahrenheit temperatures, with humidity ranging between 73 to 84%. Trace precipitation occurs 300 days a year with rainfall exceeding 0.10 inches 175 days a year. Rainfall averages are between 125 and 250 inches per year and are locality dependent.

2 Inventory and Forecasting of Existing Conditions

2.1 Datum

The primary benchmark of Pago Pago designated “1770000” S TIDAL (PID DE8786 in the NGS Integrated Database) was adopted as the datum origin benchmark for the American Samoa Vertical Datum 2002 (ASVD02).

For more information on this effort please refer to the document labeled “Development of Comprehensive Geodetic Vertical Datums for the United States Pacific Territories of American Samoa, Guam, and the Northern Marianas” at the URL below:

https://www.ngs.noaa.gov/PUBS_LIB/2009DevelopmentOfComprehensiveGeodeticVerticalDatumsForTheUSPacTerritoriesASGUNM)SaLIS.pdf#:~:text=American%20Samoa%20Vertical%20Datum%202002%20%28ASVD02%29%20Definition%20The,for%20the%20American%20Samoa%20Vertical%20Datum%202002%20%28ASVD02%29.

Datums for Pago Pago NOAA gauge 1770000 are shown in Figure 3. These datums are shown relative to the station datum, which is ASVD02.

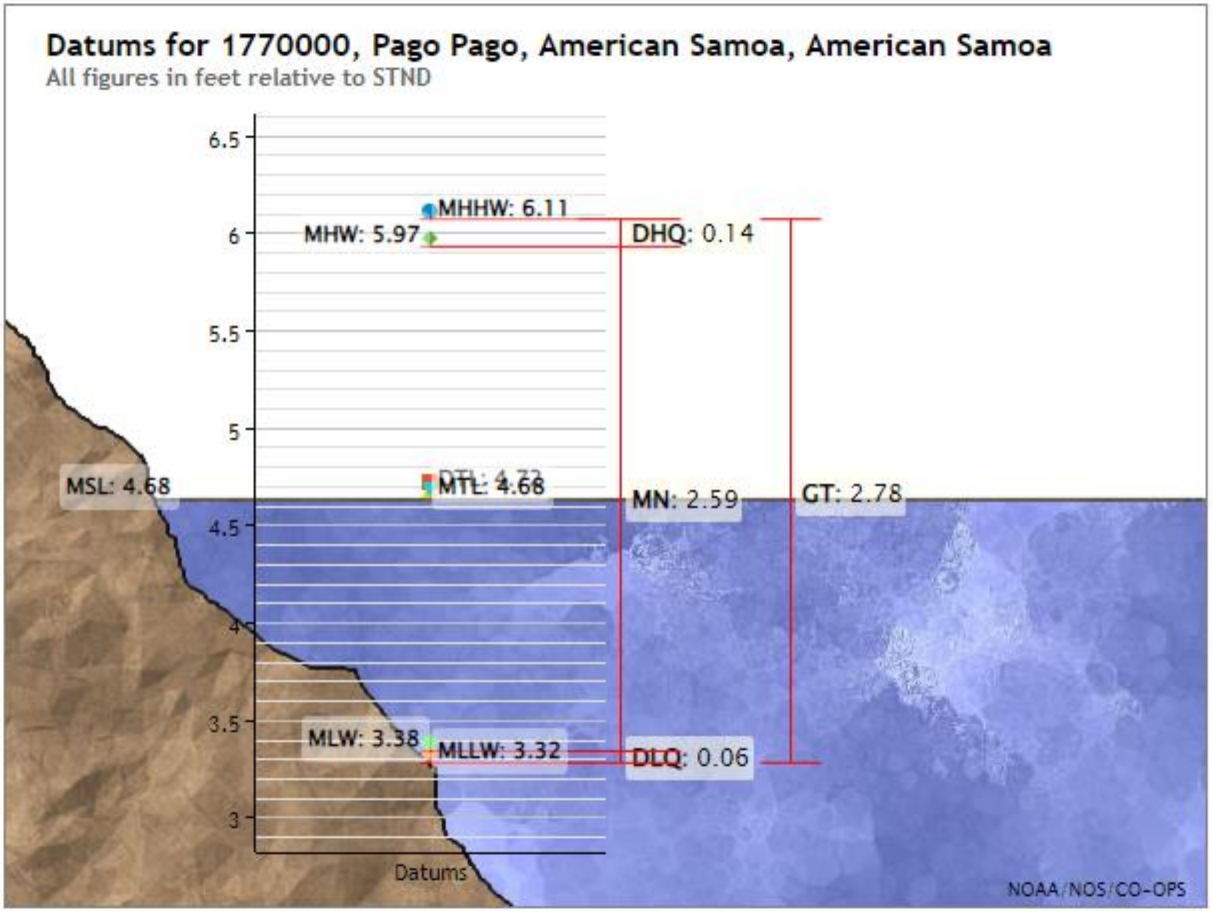


Figure 3. Datums for Pago Pago NOAA Gage 1770000, Relative to ASVD02

2.2 Hazard Assessment / Existing Conditions

2.2.1 Climate

The territory of American Samoa lies roughly 14 degrees south of the equator and 170 degrees west longitude, east of the Pacific date line in the Central South Pacific. Due to the location in the tropics, relatively small seasonal variations in annual air temperature exist in the region. Only 2 to 6 degrees Fahrenheit difference exists between the warmest and coolest months. The wet season in American Samoa is generally December through March, however, 300 days of the year rainfall is recorded. Trace precipitation occurs 300 days a year with rainfall exceeding 0.10 inches 175 days a year. Rainfall averages are between 125 and 250 inches per year and are seasonally and locality dependent. Humidity ranges between 73 to 84% (NOAA, 2013). Annual temperature averages have increased by 3 degrees Fahrenheit between 1957 and 2017 (USACE, 2020) and annual maximum temperatures have departed from 29-year normals (1991-2020) by roughly 0.5 degrees Fahrenheit (NOAA, NCEI) and are illustrated in Figure 4.

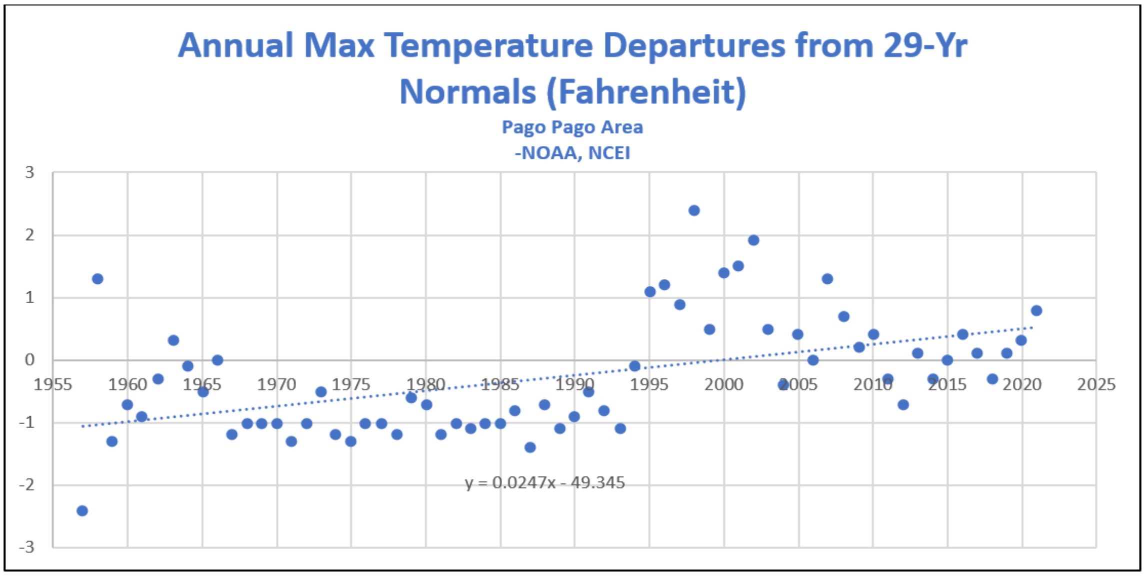


Figure 4. Pago Pago Annual Maximum Temperature Departures from Normals

Annual precipitation has also slightly increased by roughly 8 inches from 29-year precipitation normals (1991-2020) and are illustrated in Figure 5.

Engineering and Construction Bulletin (ECB) Number 2018-14 outlines guidance for incorporating Climate Change Impacts to Inland Hydrology in Civil Works, Designs, and Projects. The ECB requires application of several tools available on Climate Preparedness and Resilience CoP Applications Portal, however those tools do not cover the geographic region of American Samoa, so they were not able to be applied for this study. The intent of the requirements of the EBC, which include an analysis and comprehensive literature review of observed and projected climatic trends, has been met based on the information presented.

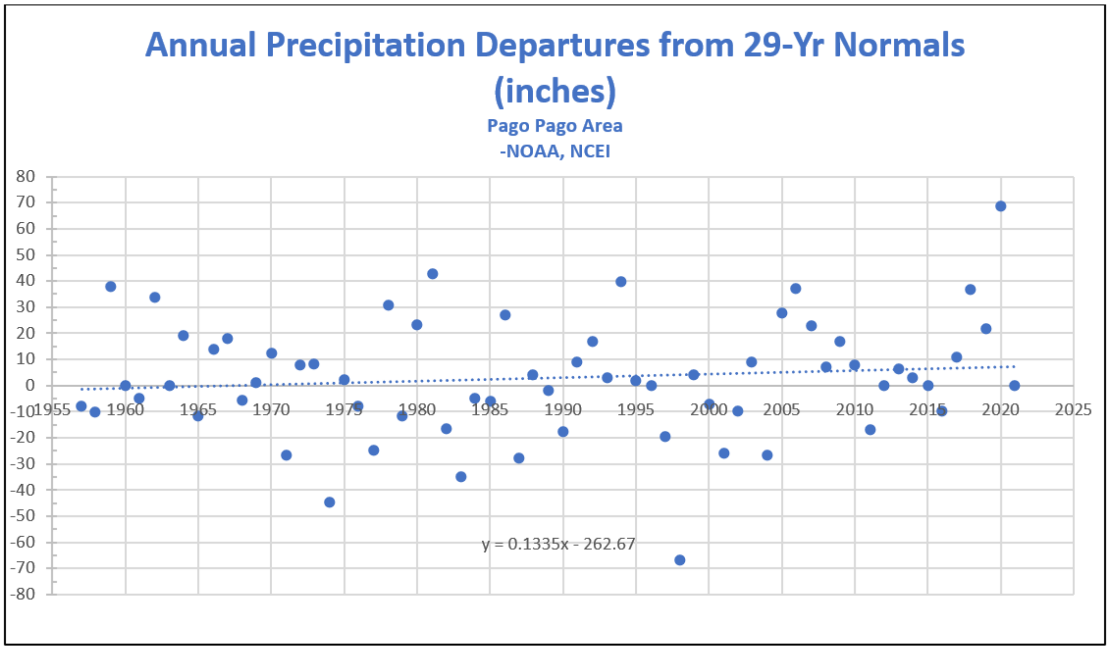


Figure 5. Pago Pago Annual Precipitation Departures from Normals

Climate impacts sea level, coastal storm surge, tropical cyclone intensity, agriculture, transportation, power, and economy and is significantly tied to El Nino Southern Oscillation (ENSO) fluctuations. ENSO consists of three phases, Neutral, El Nino and La Nina, with average durations between 9-18 months.

The relationship between El Nino and La Nina cycles and the Southern Oscillation is a relationship between oceanic sea surface temperatures (SSTs) and the atmospheric pressure gradient, respectively. In neutral conditions the Pacific trade winds are driven westward owing to changes in the atmospheric pressure gradient across the Pacific, where lower atmospheric pressures in the western Pacific and higher pressure to the east drive trade winds and warmer SSTs westward.

Consequently, cooler SSTs are observed in the eastern Pacific. SST's transfer heat to the atmosphere, which, in turn, change the pressure gradient. In other words, the pressure gradient affects the SST's and the SST's affect the pressure gradient. This circulation is referred to as the Walker Circulation. Under El Nino conditions, trade winds weaken, allowing warmer western Pacific waters to migrate eastward. This results in lower sea levels and SSTs in the western Pacific and higher sea levels and SSTs in the eastern Pacific. Sea surface elevations can fluctuate from El Nino and La Nina events by as much as 0.7 to 1.0 feet (IPRC, 2014). During El Nino the western Pacific experiences reduced rainfall and drought conditions, while the eastern Pacific experiences wetter conditions. Under La Nina conditions, trade winds increase, resulting in significant pooling of warm water and higher SSTs in the western Pacific, increased sea levels, and increased convection. Correspondingly, lower SST's, lower sea levels, and reduced convection occurs in the eastern Pacific (NOAA, 2021). See Figure 6 below for an illustration of ENSO cycles.

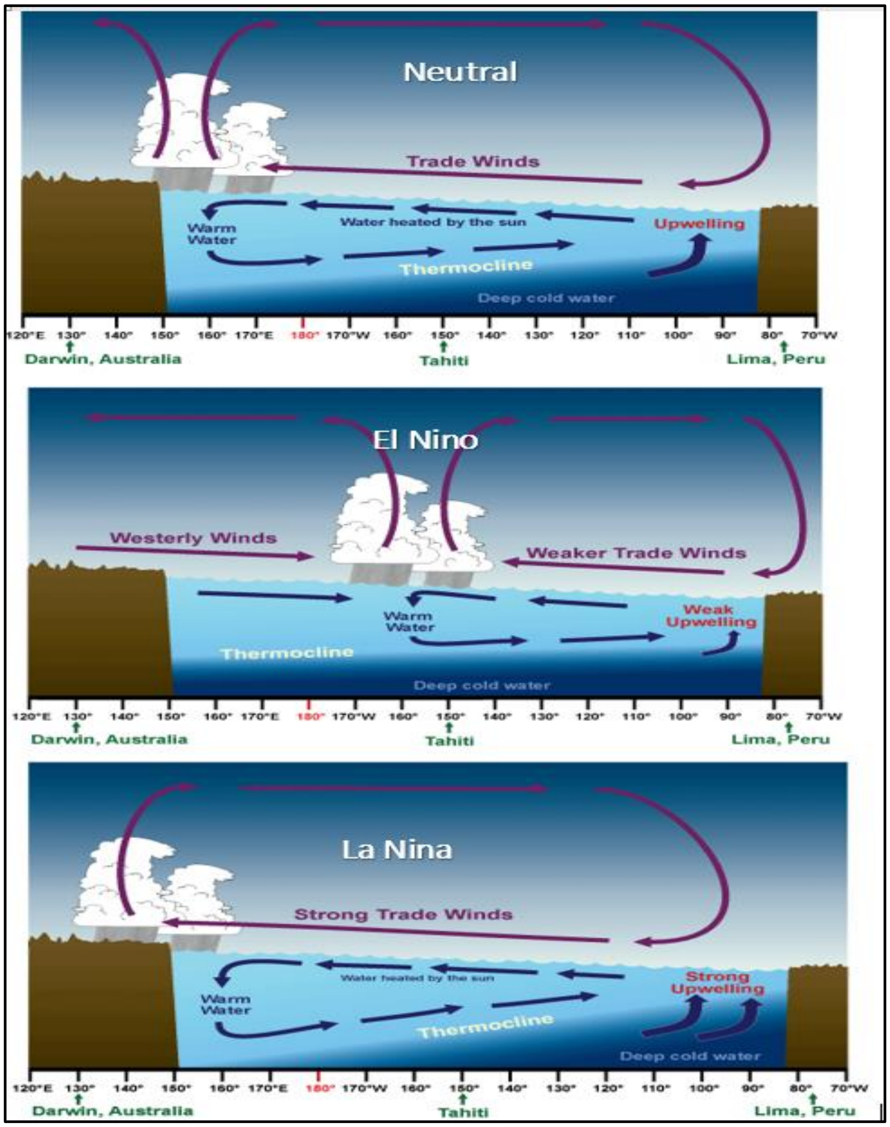


Figure 6. ENSO fluctuations in the Pacific: Neutral, El Nino, and La Nina

Drought conditions are also prevalent and act as a driver in reduced water supply, agricultural impacts, and economic stress. Not only do reductions in run off result in reduced aquifer recharge and therefore increased salinity in drinking water supply, but water supply is also inextricably tied to business. Between the years of 1974 to 2011, the two largest employers on the island, StarKist Tuna™ and government, were closed multiple times. In one instance the cannery was closed for six months. In 2011, when rainfall was 26-60% of normal, the U.S. Coast Guard was required to deploy a desalination ship. Schools are also closed during water shortages (Caplan Consulting, 2020). These drought conditions occurred during La Nina years.

Tropical cyclones thrive off warm ocean waters. El Nino effectively discharges heat into the ocean, leading to intensified tropical cyclones (Rupic, et al., 2018).

ENSO affects climate and weather patterns which impact precipitation, cyclones, and sea levels, saltwater intrusion, aquatic life, and reef mortality.

2.2.2 Riverine and Urban Flooding

American Samoa has recorded over 208 riverine and flash flood events since 1967. Steep terrain and limited shoreline constrain development along limited alluvial flats. These concentrated developments are typically estuarine environments which are prone to riverine flooding. Impervious roadways and infrastructure exacerbate flash flooding from intense rainfall events. Heavy rainfall of 2-3 inches in an hour is not uncommon and the NWS issues flash flood warnings when observations suggest 1-2 inches of rainfall within an hour. When monsoonal troughs move through the region American Samoa experiences as much as 13 inches of rainfall in less than a week. Monsoon and tropical cyclones establish antecedent conditions that further allow trace amounts of rainfall to respond with significant runoff. Although the Tafuna Leone area has good sedimentation for infiltration, most of the island contains thin erodible soils on steep slopes. The Tafuna plain is also highly developed, low lying, and highly impervious. The roadways experience deep sheet flow due to poor storm water drainage and many unpaved roads contain erodible material.

Landslides and mudflows occur along riverine reaches and at the base of steep slopes during flash flooding. In December of 2007 a flash flood and riverine flooding from Faganeanea to Pago Pago and caused debris flows through the LBJ Medical Center parking lot and into the surgical room. Fortunately, the NWS provided warning time for the hospital to prepare (Territory of American Samoa, May 2020).

The NWS office in American Samoa does not have radar capabilities. They depend on satellite data which does not refresh live data as quickly (10 minutes vs. 2-minute refresh rates). A typical flash flood warning threshold is 0.08 inches of rain in 5-minutes or when 2.0 inches in an hour are expected. Satellite data also lacks wind information, and the NWS has several weather (Wx) stations located across the island for wind data, however satellite data does not perform as well in warm process rainfall using infrared (Personal communication Kevin Kodama - NWS, HI). The islands no longer monitor their streams with USGS gages. The network of gages was removed. The only real time gage on Tutuila is at Pago Pago airport by the NWS office. Therefore, flood producing rainfall and streamflow are ungagged and without live updates except for delayed satellite information.

Figure 7 through Figure 11 reflect Federal Emergency Management Agency (FEMA) coastal and estuarine flood zones for a 1% annual chance of exceedance (ACE). FEMA flood zones are areas that the FEMA has defined according to varying levels of flood risk. These zones are depicted on a community's Flood Insurance Rate Map or Flood Hazard Boundary Map. Each zone reflects the severity or type of flooding in the area. For areas that are a high risk from flooding from riverine or coastal areas FEMA has defined these zones as described in the table 1 below. For more information regarding definitions of FEMA Flood Zone Designations please refer to the FEMA Maps Service Center URL below:

http://msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=- 1&content=floodZones&title=FEMA%20Flood%20Zone%20Designations

Table 1. FEMA High Risk Areas- Riverine and Coastal

Zone	Description
A	Riverine areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.
AE	Riverine areas where the base floodplain where base flood elevations are provided. AE Zones are now used on new format Flood Insurance Rate Map instead of A1-A30 Zones.
V	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones.
VE	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.

The inundation maps are expressed as the 1% Annual Exceedance Probability (AEP) wave run-up over mean sea level (the equivalent for the American Samoa local datum) for coastal (V) (A) and estuarine flood zones. VE or AE zones include a Base Flood Elevation (BFE) without the wave run up calculation (FEMA, April 2006). A zone marked V/VE designates a wave run-up that is greater than three feet above a 1% AEP still water elevation (SWEL or BFE). A SWEL assumes a static water line without shoaling or dune effects incorporated in modeling wave run-up. The SWEL is a flood water surface above high tide. An A/AE/AO zone designates a wave run-up depth that is 1-1.5 feet above the SWEL (AO designated sheet flow at 1-1.5 feet of depth). If this zone is adjacent to a V/VE zone it is typically due to raised topography at the location or due to reef or engineered protection. Coastal flooding is escalated by development and impervious roads and infrastructure.

Gages indicated in the figures are monitoring wells (utilized by the American Samoa Power Authority, ASPA), NWS wind gages, and several stream gages recently installed under a land grant to the University of Hawaii (Chris Shuler) but need further funding for telemeters to enable live data feeds to ASPA, NWS, and University of HI water quality research. The highlighted gage at the Pago Pago airport is the NWS only real time rain gage (although the National Park Service may collect manual data like the Ito gages). Gages marked “Ito” are literally a past volunteer, named Ito, that manually read and recorded daily data for the NWS.

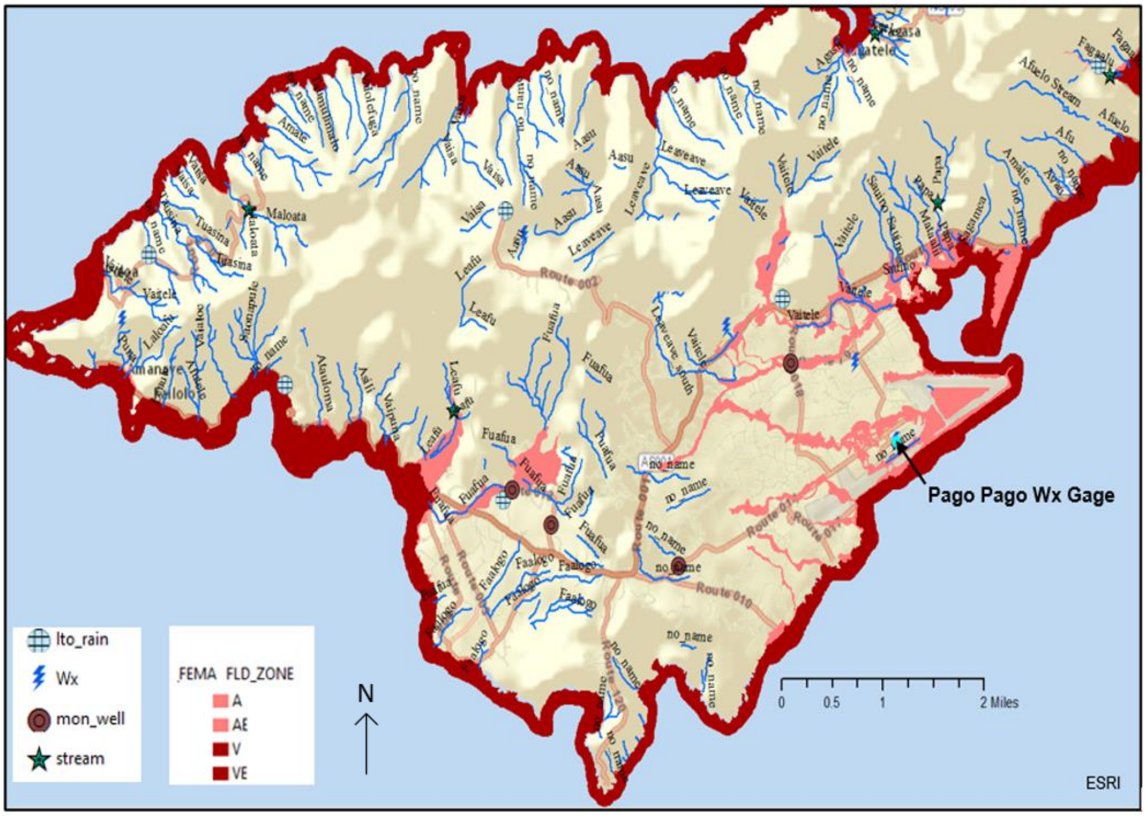


Figure 7. Western Tutuila, FEMA Riverine and Coastal 1% AEP Flooding (NOAA NHC, 2021)

Note the west to east oriented flood zone on Vaitele Stream, north of the airport, is coincident with two major roads (Route 1 and Route 19). These areas suffer persistent flooding. The Hawaiian District USACE is presently completing a feasibility study for the Leaveave tributary to Vaitele, however further downstream flooding and sedimentation analysis is needed where the stream enters Pala Lagoon, east of the airport.

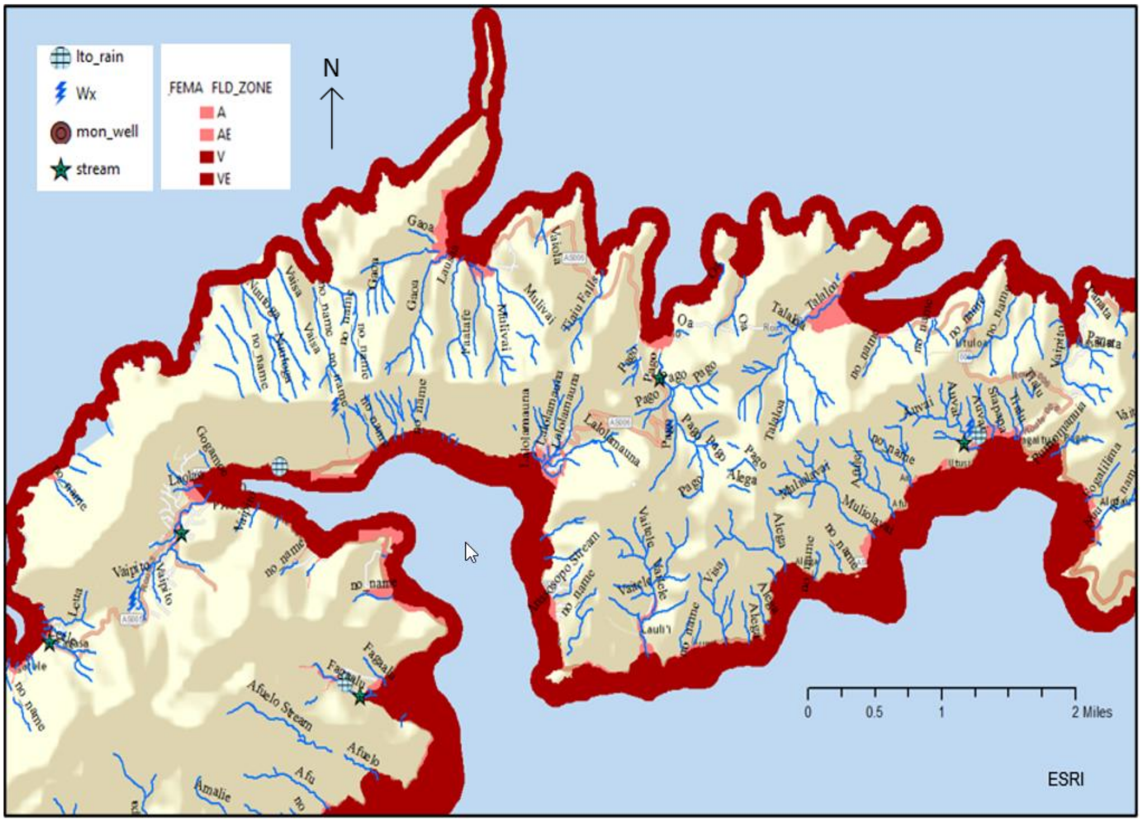


Figure 8. Central Tutuila, FEMA Riverine and Coastal 1% AEP Flooding (NOAA NHC, 2021)

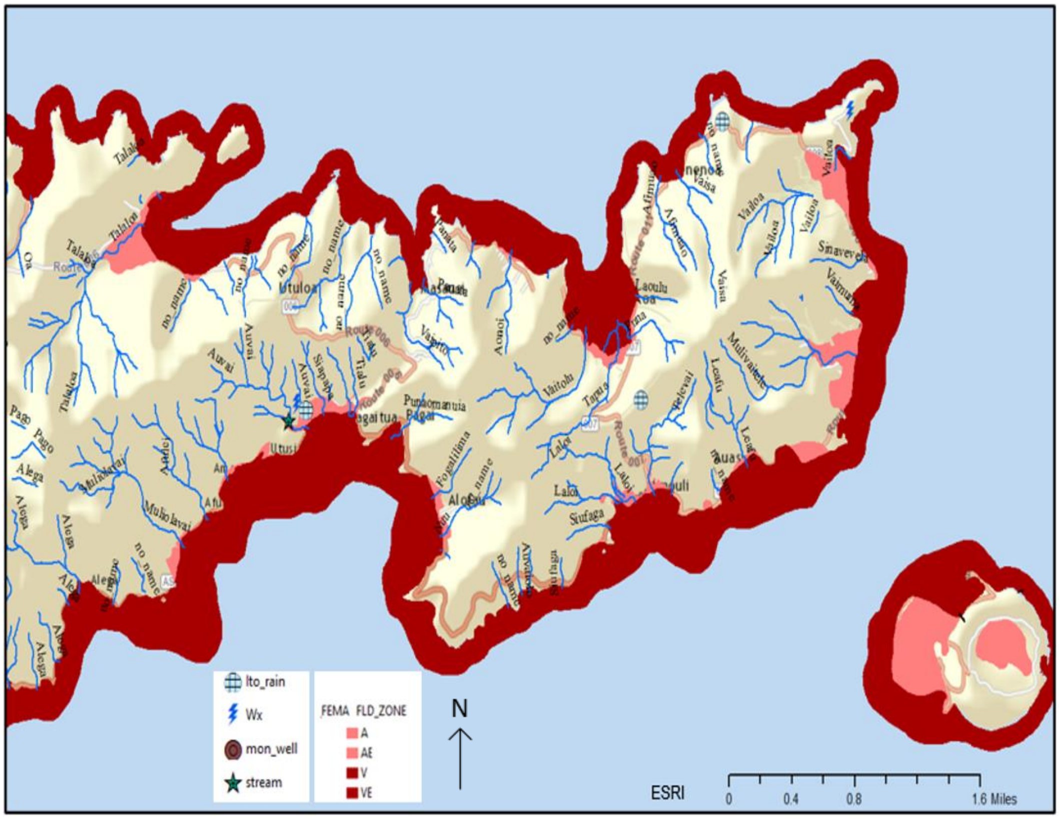


Figure 9. Aunu'u and Northern Tutuila, FEMA Riverine and Coastal 1% AEP Flooding (NOAA NHC, 2021)

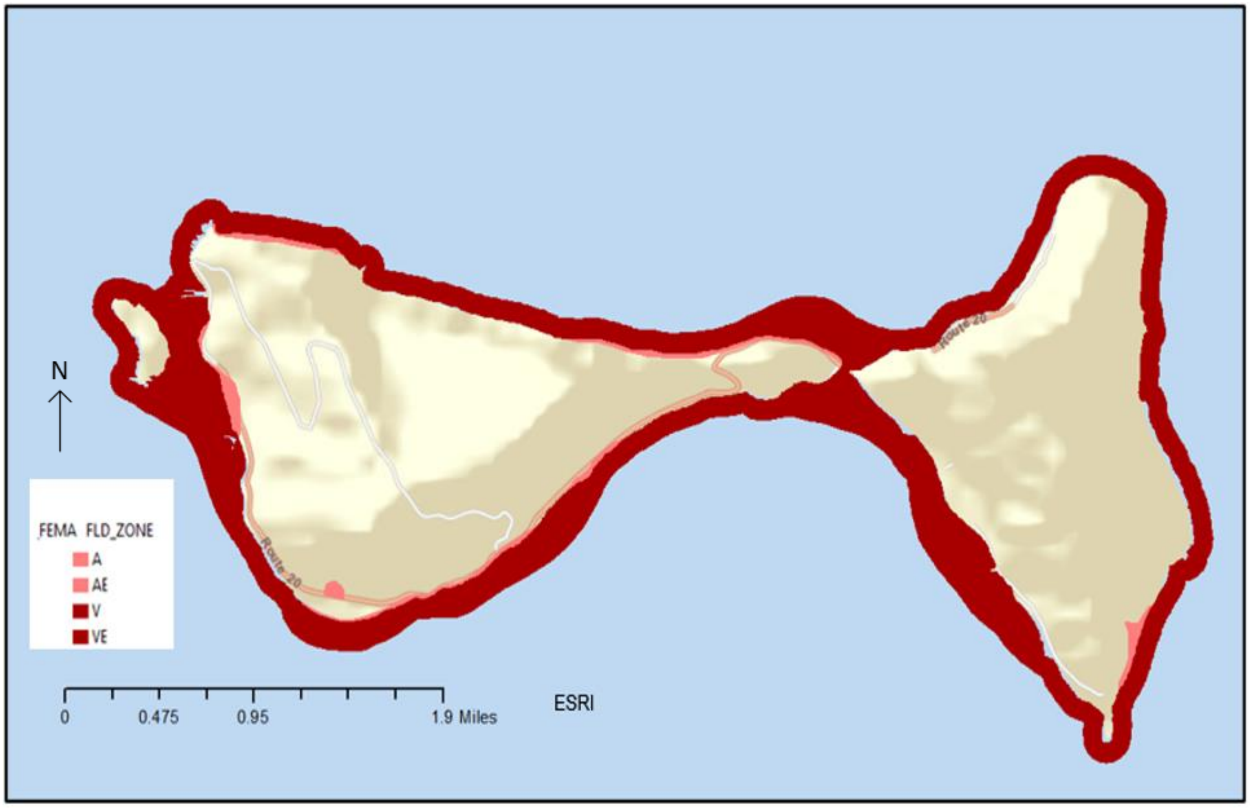


Figure 10. Ofu and Olosega, FEMA Riverine and Coastal 1% AEP Flooding (NOAA NHC, 2021)

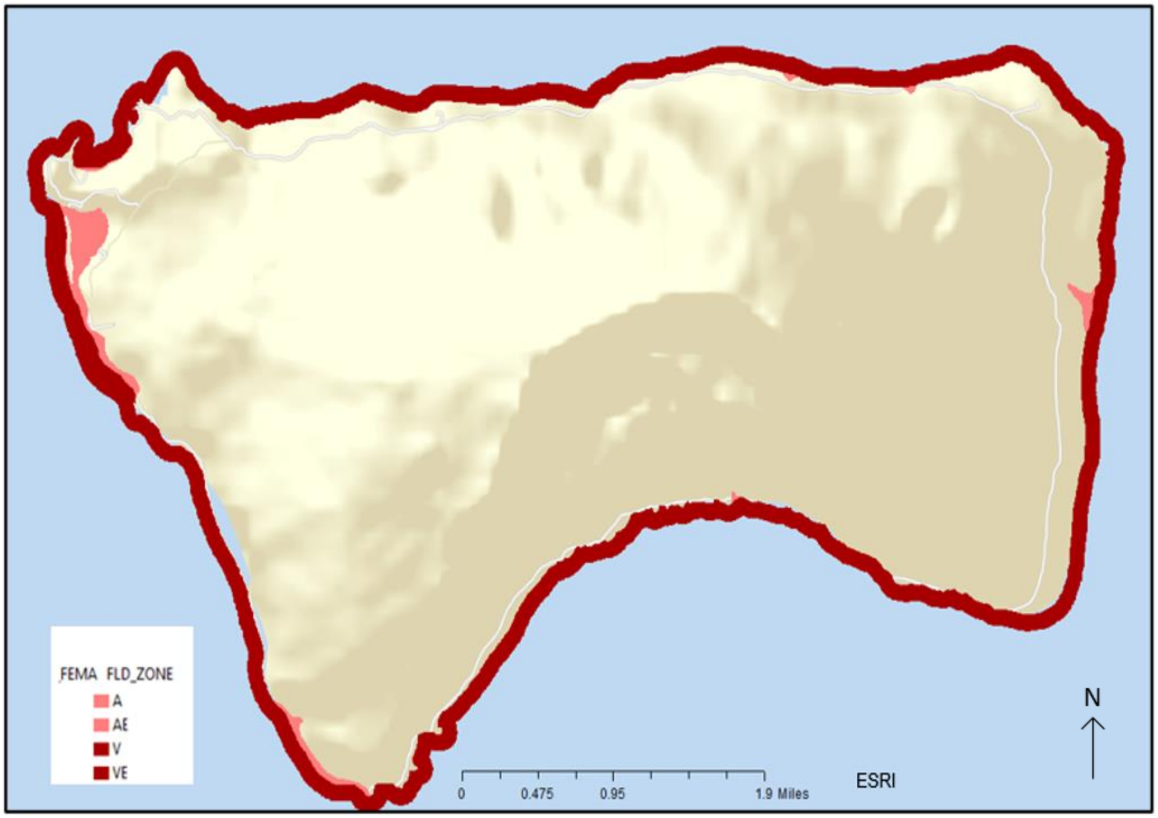


Figure 11. Tau, FEMA Riverine and Coastal 1% AEP Flooding (NOAA NHC, 2021)

2.2.3 Coastal Flooding

Due to the steep geographic conditions in American Samoa, less than 30% of the territory contains slopes less under 30 percent. Development is therefore constrained to low lying coastal zones. Businesses, schools, hospitals, and residents are predominantly confined to these vulnerable zones. Most of the coastal flooding events in American Samoa are related to tropical storms and cyclones and 98% of Samoans state their homes or businesses are at risk to storms and cyclones (Jamie Caplan Consulting, LLC, 2020). Since 1950, American Samoa has experienced approximately nine tropical storms and 15 tropical cyclones (NOAA, NCEIb). Although coastal flood damages are greatest owing to storm surge, the higher number of fatalities are tied to high surf events. Since 1950, 92 high surf events have occurred and caused seven fatalities, compared to no fatalities from tropical storms or cyclones. Large storm events typically come with greater awareness and observable cues compared to an offshore storm or high-pressure atmospheric disturbance which catches locals off guard on a sunny day.

Coastal inundation is controlled by the steep bounding mountain terrain. The limited flat terrain that accommodates development is coastal and inundated by high surf and storm surge. Figure 12 through Figure 16 represents potential "maximum of maximum" (MOM) tropical cyclone condition for storm surge inundation, including wave run up. MOM storm surge inundation extents are based on thousands of NOAA ("SLOSH" modeled) historic and potential cyclone tracks and intensities and are downloadable through HURREVAC (NOAA NHC, 2021). HURREVAC inundation mapping is limited to grid size evaluation and does not account for erosion or subsidence and are intended for planning and awareness only.

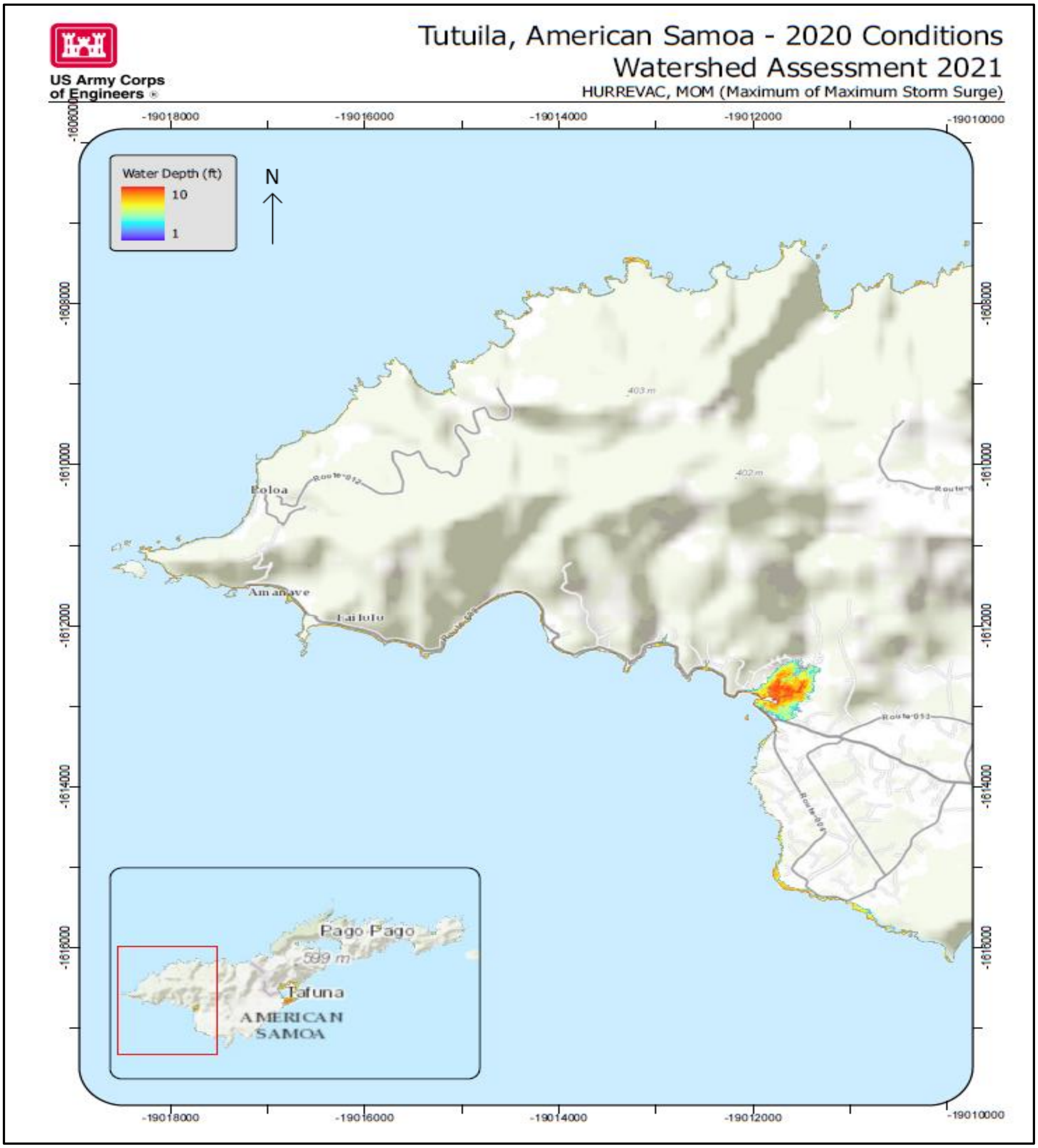


Figure 12. Western Tutuila HURREVAC MOM Storm Surge Under Existing Conditions (NOAA NHC, 2021)

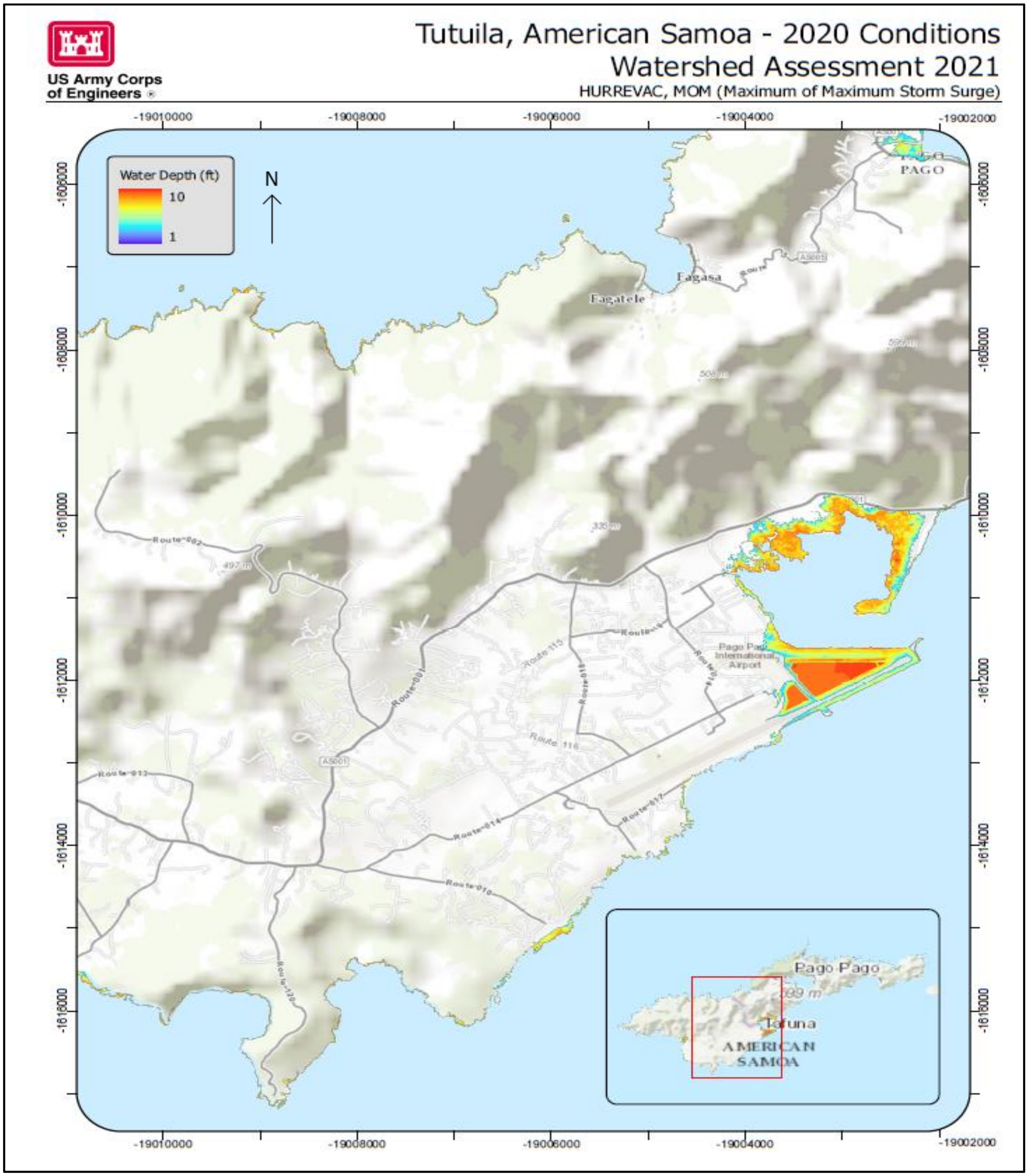


Figure 13. Central Tutuila HURREVAC MOM Storm Surge Under Existing Conditions (NOAA NHC, 2021)

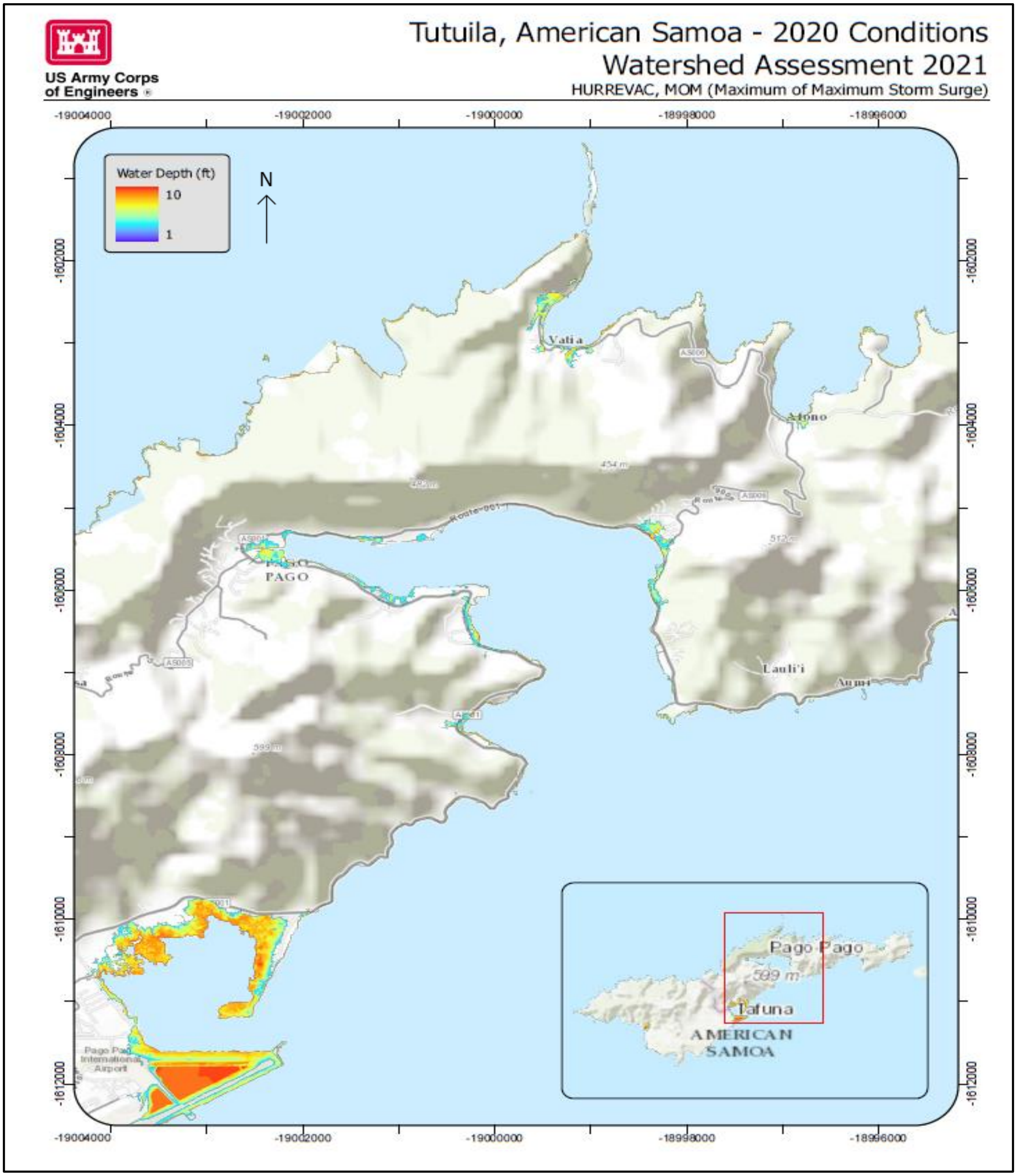


Figure 14 . East-Central Tutuila, HURREVAC MOM Storm Surge Under Existing Conditions (NOAA NHC, 2021)

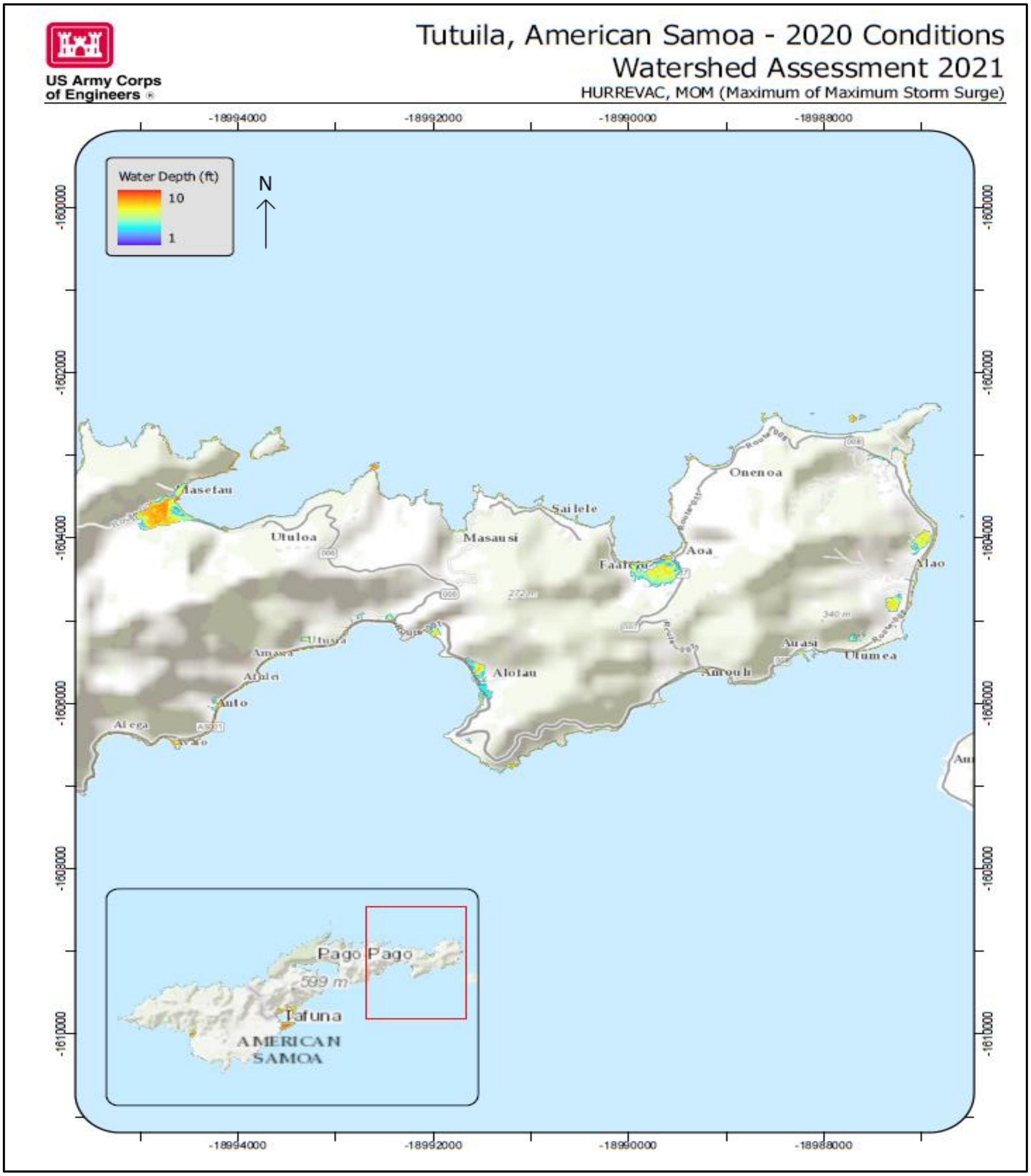


Figure 15. Eastern Tutuila, HURREVAC MOM Storm Surge Under Existing Conditions (NOAA NHC, 2021)

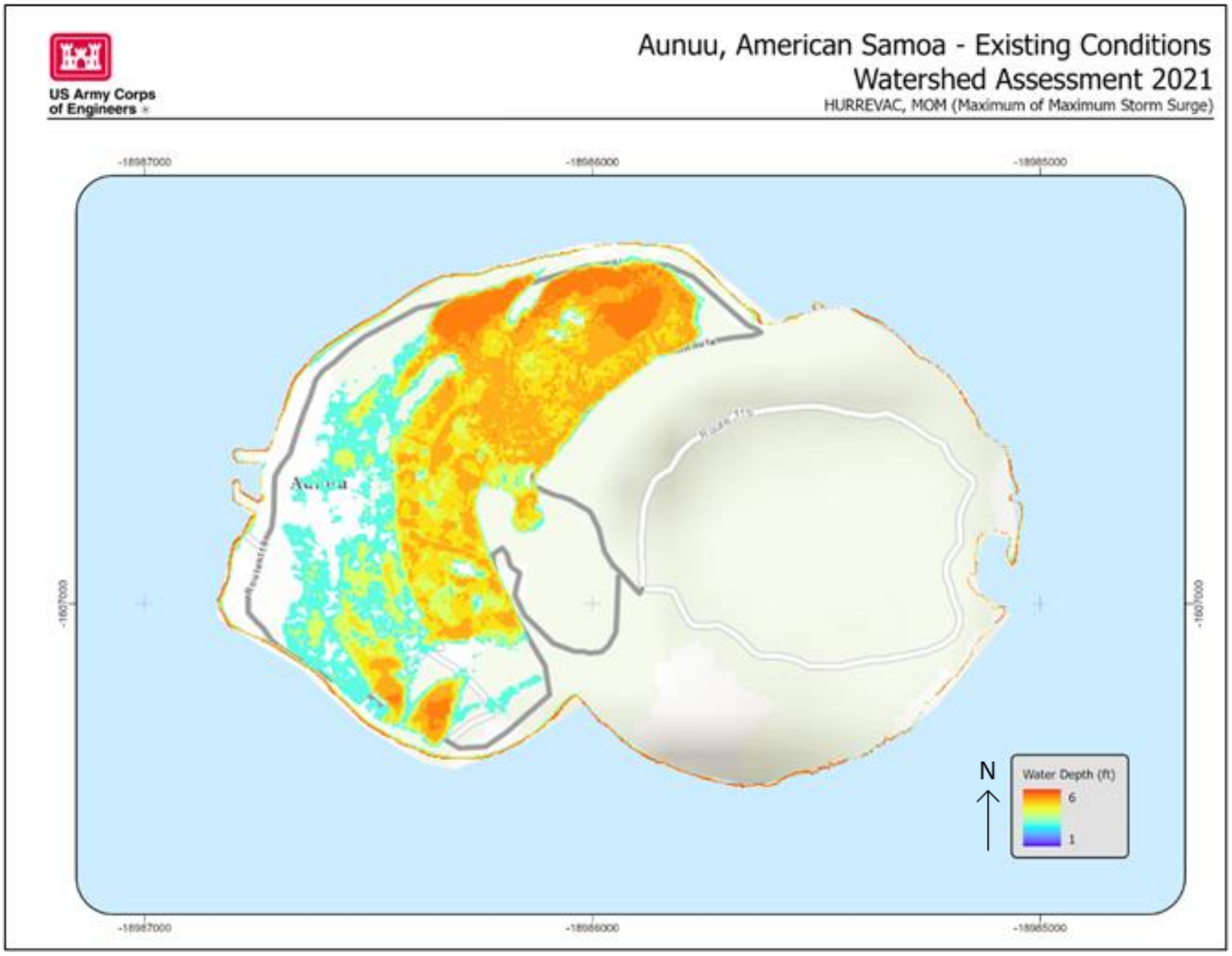


Figure 16. Aunu'u HURREVAC MOM Storm Surge Under Existing Conditions (NOAA NHC, 2021)

These data should not act as a substitute for locally generated storm evacuation zones. HURREVAC MOM maps depict a potential worst-case storm surge this WA uses for planning purposes (HURREVAC data for the Manu'a islands are not available). See Main Report for potential economic impacts from the MOM inundation.

To evaluate coastal inundation for the Manu'a islands, in the absence of HURREVAC depth maps, FEMA 1% AEP hazard maps were utilized to analyze wave run up.

To create a depth raster from a FEMA inundation polygon requires hydraulic modeling with terrain and cross sections. Hydraulic modeling of five islands was outside the project scope, therefore GIS automated cross sections were created along the coastline every 50 feet from a MSL zero point to the inundation boundary high point. DEM values were then subtracted for depth. The synthesized depth maps for the FEMA inundation are coarse but adequate for planning purposes.

Figure 17 through Figure 20 illustrate existing conditions for a 1% AEP FEMA wave run up (inundation). Inland flood zones were not evaluated, only coastal zones. Where estuarine influences were coincident to coastal (V/VE) flood hazard zones, their inundation is included. Inland flood impacts are discussed under the riverine flooding section.

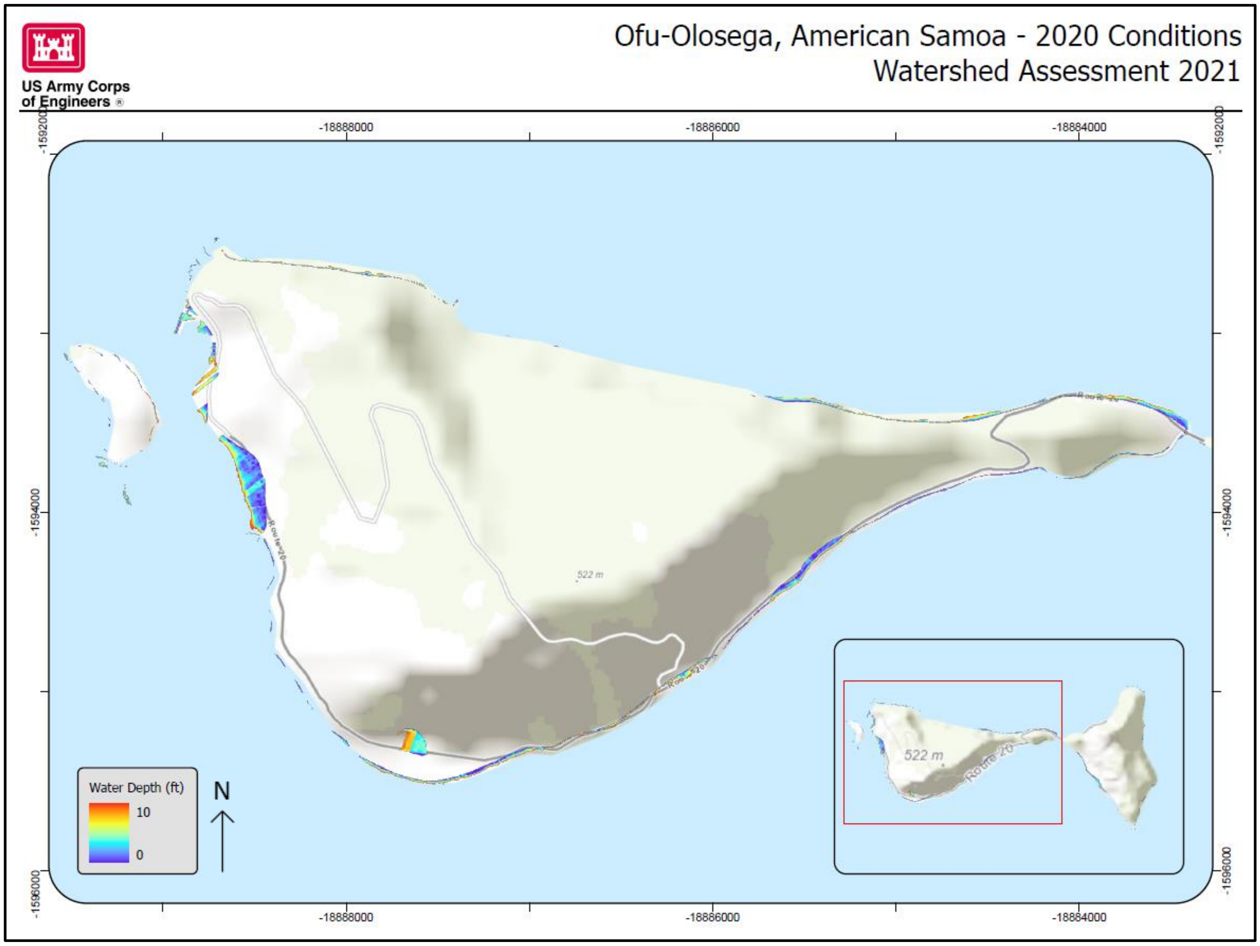


Figure 17. Ofu, FEMA 1% AEP Flood Depths, Existing Conditions (NOAA NHC, 2021)

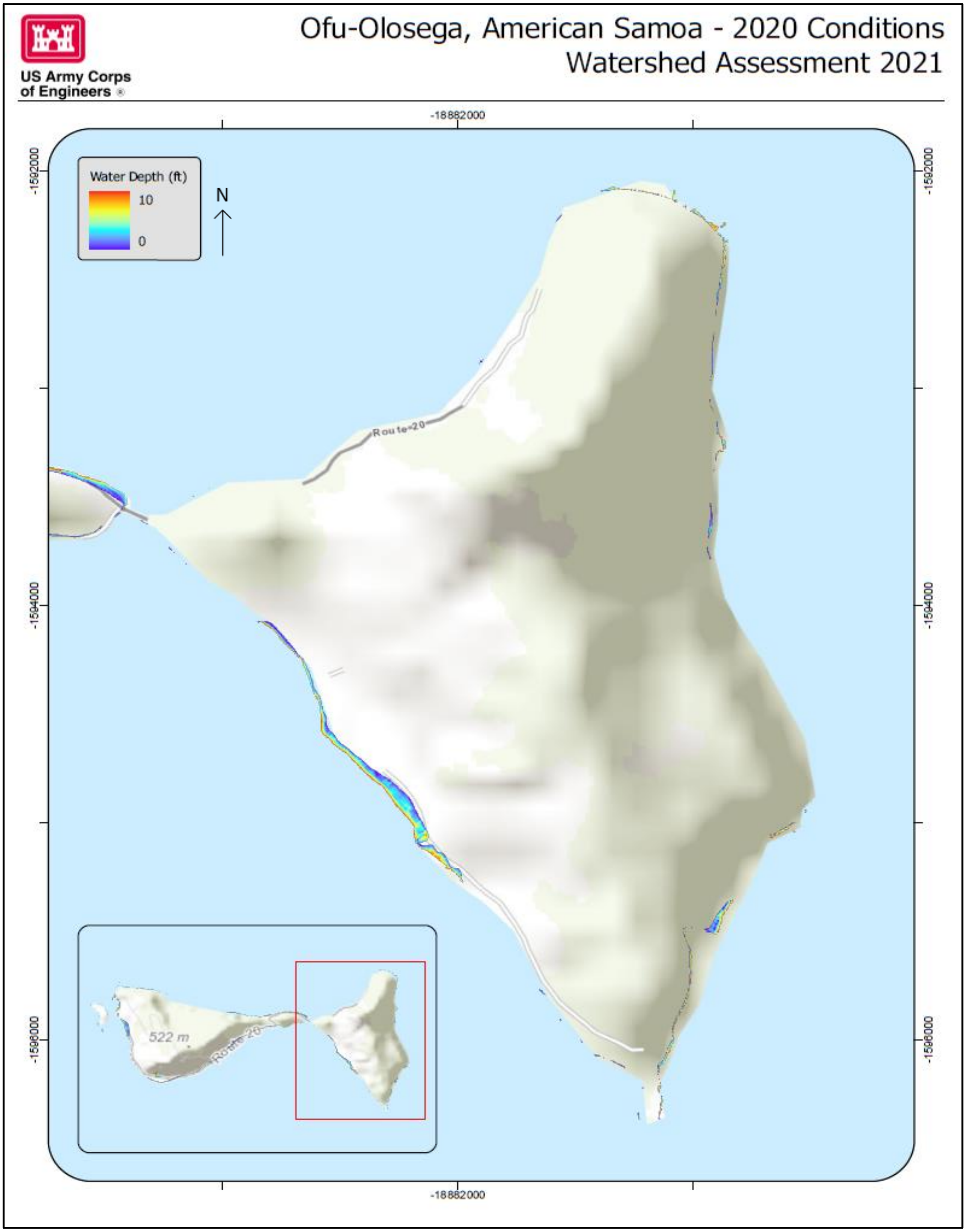


Figure 18. Olosega, FEMA 1% AEP Flood Depths, Existing Conditions (NOAA NHC, 2021)

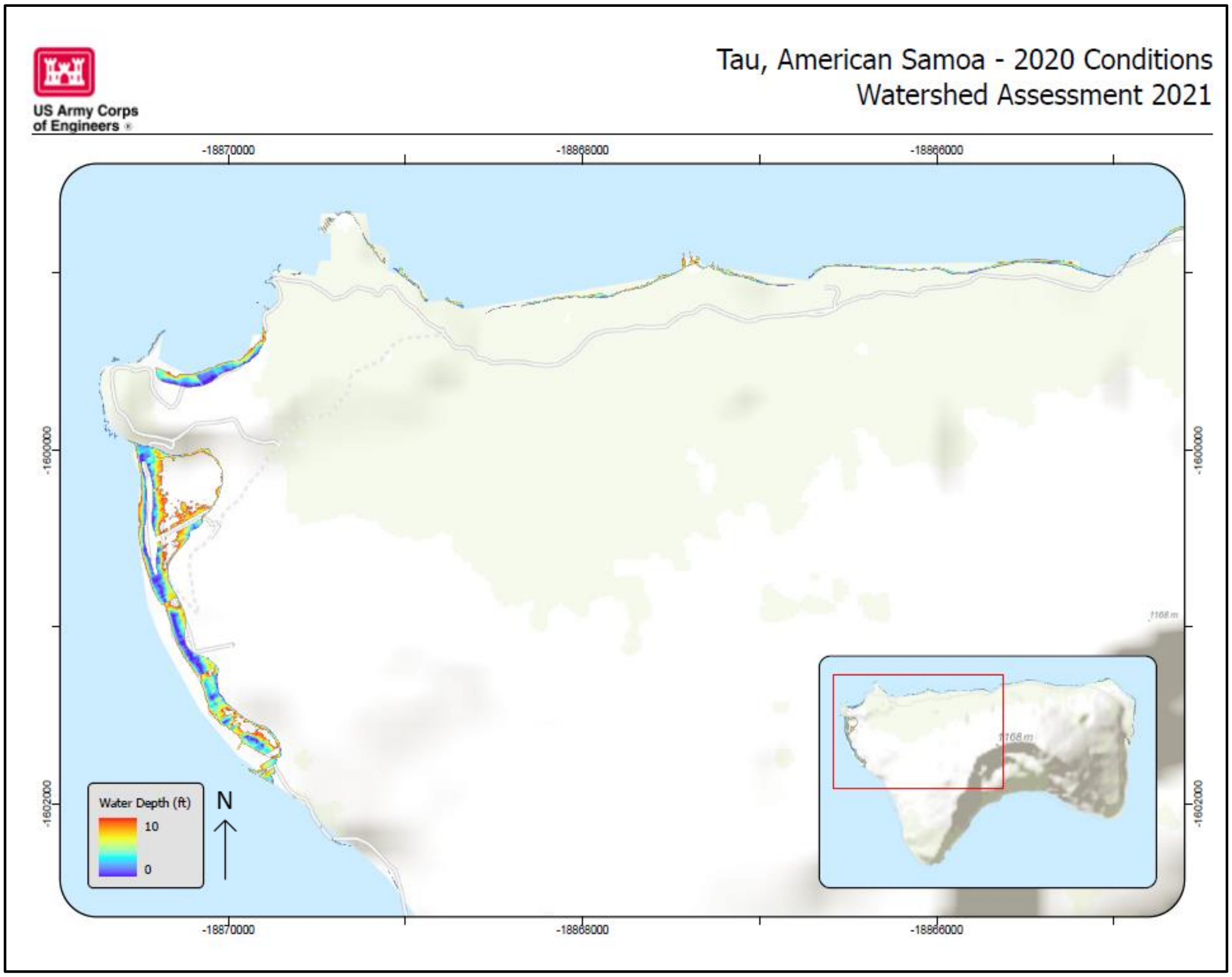


Figure 19. Northwest Tau, FEMA 1% AEP Flood Depths, Existing Conditions (NOAA NHC, 2021)

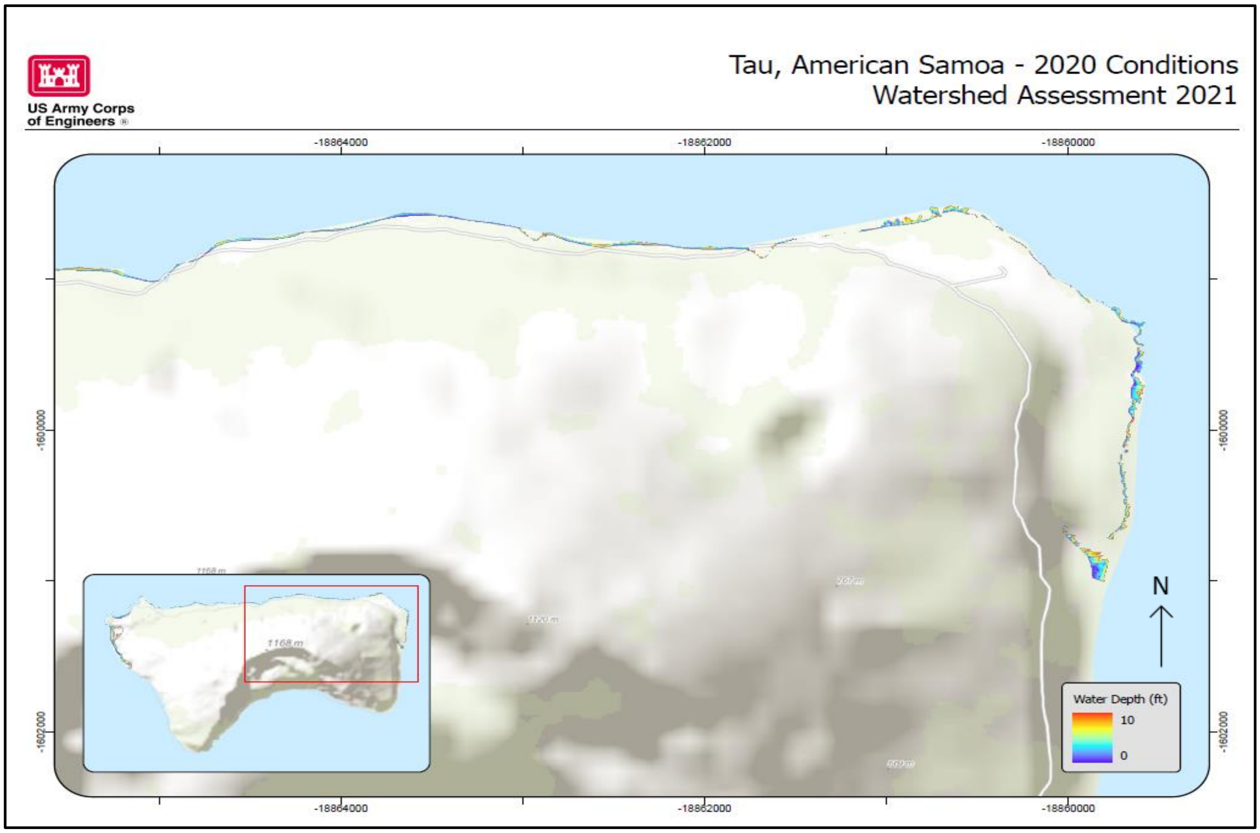


Figure 20. Northeast Tau, FEMA 1% AEP Flood Depths, Existing Conditions (NOAA NHC, 2021)

2.3 Riverine Erosion

The steep volcanic mountains and narrow valleys in American Samoa occupy much of the territory landform, permitting only a narrow coastal fringe. The only sizeable area with gentle slopes is the plain between Nuuuli and Leone on Tutuila. About one half of American Samoa contains slopes of 70% or more. The soils within the coastal fringe range from poorly drained to excessively drained silty clays and sand (USDA, 1984). Steep slopes result in pollution to streams and prevent soil development and productivity for agriculture. Soils low in clay and organic content are more erodible (silts and sands). Erodible soils are conveyed to water supply wells, streams, and near shore coastal waters which leads to reef and benthic life mortality and loss of soil. The USDA estimates 100-1000 years are required for one centimeter of soil to form. Erosion is more than a transport issue to vulnerable habitat; it is a near irreplaceable resource in a remote island environment.

Figure 21 and Figure 22 illustrate Natural Resource Conservation Service's soil erodibility data for Tutuila and Aunu'u due to steep slope (greater than 30%, indicated in grey), and moderately erodible soil factors (indicated in pink). Steep slopes experiencing heavy rainfall can lead to erosion, however, regions with erodible soils on steep slopes exacerbate soil loss.

Figure 21. Western Tutuila Vulnerable Locations for Erosion (ESRI)

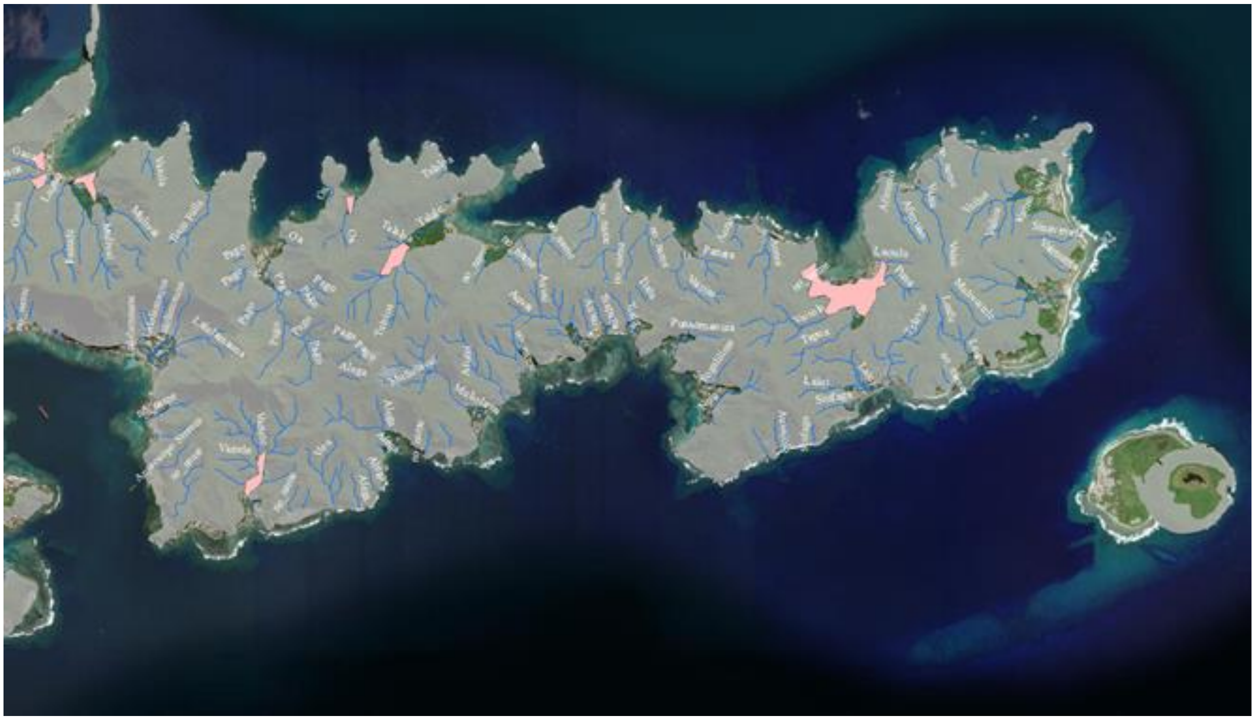


Figure 22. Eastern Tutuila and Aunu'u Vulnerable Locations for Erosion (ESRI)

The two soil groups most erodible in Tutuila are the Leafu stony silty clay and Aua stony silty clay. Table 2. Locations with Moderate Erodibility in Tutuila lists locations with moderately erodible soils, their soil name, and impacted stream. Tutuila is prone to erosion island wide, owing to steeply sloping terrain, however areas categorized with erodible soil types are listed for focus. The list is not intended to replace a comprehensive survey of conditions.

Table 2. Locations with Moderate Erodibility in Tutuila

Location	Affected Stream	Soil Name
Nuuuli, Pala Lagoon	Sauino, Mataali, PaPa, Sagamea, Amalie	Leafu Stony Silty Clay
Lauli'i	Vaitele	Leafu Stony Silty Clay
Asili	Leaveave South	Leafu Stony Silty Clay
Faalefu	Vaitolu, Tapau, Puna, Laoulu	Leafu Stony Silty Clay
Afono	Oa	Leafu Stony Silty Clay
Masefau	Talaloa	Leafu Stony Silty Clay
Vatta	Gaoa, Muliua'i	Aua Stony Silty Clay
Fagatele	Agasii	Aua Stony Silty Clay

There are seven wells in the Tafuna Leone well field providing most of the drinking and cannery water to Tutuila. Well number 33 produces 20% of that well field supply and is frequently closed (in addition to other nearby wells) due to sediment wash conveyed through lava conduits and fractures. Note in Figure 23 the Leaveave South drainage feeds this plain (well 33 highlighted in blue) and would benefit from sediment mitigation efforts focused in the Leaveave South watershed in addition to those entering Pala Lagoon.

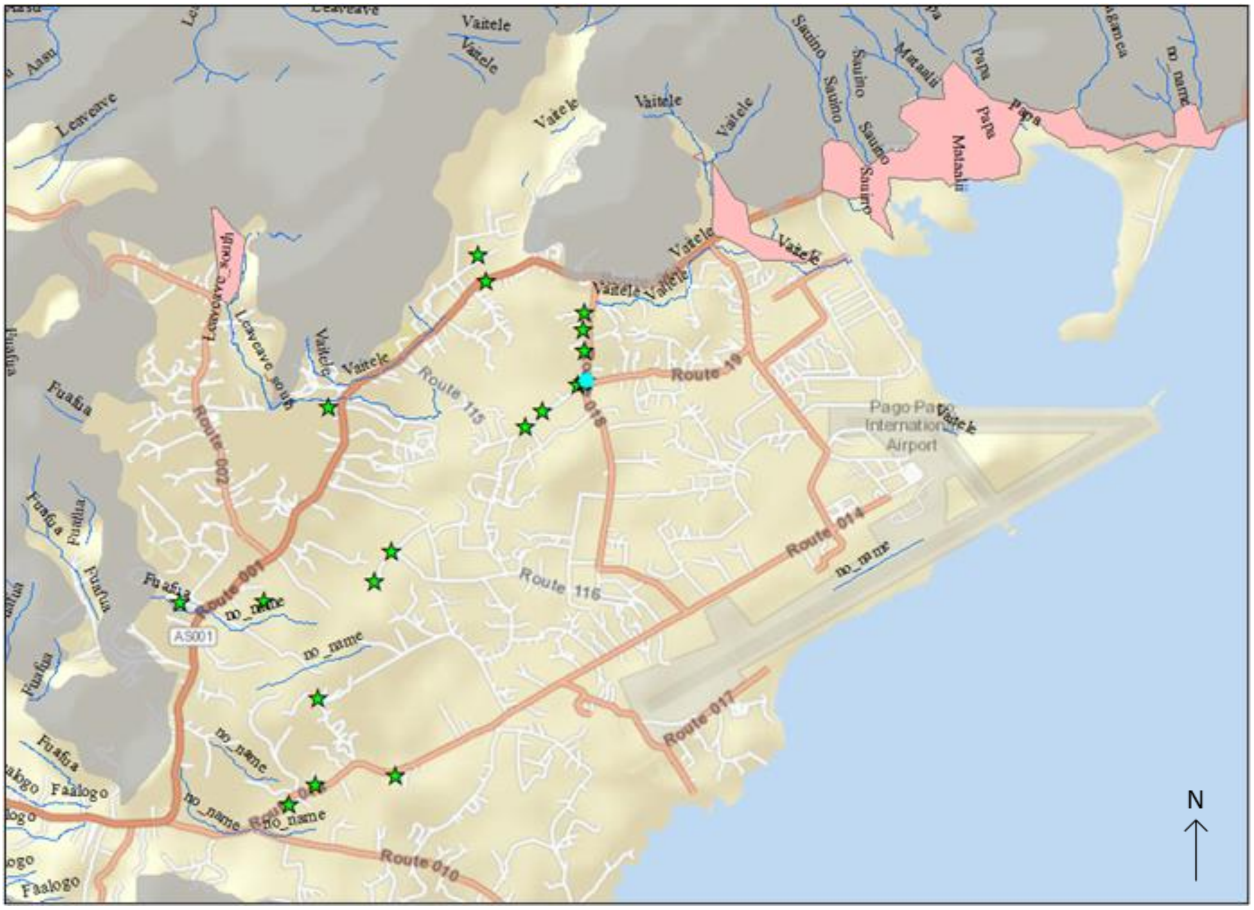


Figure 23. Tafuna Leone Well Field and Erodible Headwaters

2.4 Water Quality

Several sources contribute to declining water quality and water supply in American Samoa. One challenge associated with water quality is on-site disposal systems and cesspools. These systems were found to be unreliable and prone to leaking during heavy rainfall events. The ASEPA and prioritized updating septic and on-site disposal systems during Fiscal Year 2020.

Water quality in certain areas was also found to have a high bacteria load from animal waste facilities and piggeries. For example, improper piggery management led to contamination of Afuelo Stream (Matu'u Watershed) with high levels of bacteria, thus exposing water sources to leptospirosis and *E. coli*. Regular stream water monitoring, public education and outreach, facility inspections, and enforcement of environmental and public health regulations helped reduce the leptospirosis risk and led to declines in *E. coli* concentrations. In addition to agricultural practices, underlying geology (volcanic conduits) and storm events contribute to sedimentation, further reducing water quality. The steep topography of American Samoa coupled with the naturally occurring high phosphate concentrations in the underlying volcanic rock increase the volume of phosphate-rich sediment which enters the downstream waterways. Agricultural practices and development of impermeable surfaces also lead to a degradation in water quality and have negative effects for coral reef, mangroves, and sea grass beds. The degradation of these aquatic habitats also leads to a decline in aquatics species dependent on these habitats. Historically, droughts have also affected water quality, inflicting business closures and leading to saltwater intrusion in some areas (e.g. groundwater aquifers). Four significant droughts have been documented since 1974. In 1983 schools were closed for one week and the cannery (a major economic generator) was closed for six months. In 1998, the sole drinking water spring on Aunu'u dried up completely.

2.4.1 Groundwater Pollution/Sediment

The Tafuna-Leone plain is the site of the majority of American Samoa's residential and business development. The plain is also the site of many of the wells that pump ground water for distribution. Because volcanic stratum of Tutuila is highly permeable and does not have a great capacity to filter, there is a constant risk of groundwater contamination as pollution migrates from the surface with rainwater. The greatest threats to groundwater quality in American Samoa are pesticide residues, pollutants associated with automobiles, and pathogen and nutrient pollution from poorly constructed human and pig waste disposal systems. As in many small tropical islands with highly permeable soils, the freshwater aquifer floats on a layer of salt water beneath the ground. Rare dry periods of two- to three-months duration can result in critical drinking water shortages as salt water intrudes on the depleted freshwater lens. (ASEPA, 2020).

2.4.2 Surface Pollution/Sediment

The greatest threats to near-shore water quality and to the health of the reefs in American Samoa are from runoff from the land, especially pathogen and nutrient pollution from poorly constructed human and pig waste disposal systems as well as increased turbidity and nutrients from erosion. Solid waste, i.e., improperly disposed of trash, is another source of pollution in open coastal waters and embayment. Pago Pago harbor is the most industrialized embayment in the Territory, with over a century of development subsequent to the creation of the Territory under the United States. As well as the sources of water quality impairments mentioned above for embayment's in general, Pago Pago Harbor is affected by pollution from marina and port traffic, a small shipyard, and in the outer harbor effluent from the tuna canneries and sewage treatment plant. All point sources have National Pollutant Discharge Elimination System (NPDES) permits. Due to the segregation and transportation of cannery waste beyond the inner harbor, better treatment of sewage, and more effective monitoring and prosecution by the Coast Guard of commercial vessels that pollute the harbor, the water quality in the inner harbor has greatly improved in the last three decades. (ASEPA 2020).

2.4.3 Saltwater Intrusion

As on all islands, American Samoa's groundwater resources depend on rainfall. On Tutuila Island, where most of the territory's population resides, groundwater stored in the freshwater lens—a layer of fresh groundwater that floats on top of denser saltwater—is the source for nearly all public drinking water supplied by ASPA. Yet seawater located beneath the freshwater lens limits the rate that groundwater can be used in island settings. Saltwater intrusion from over-pumping currently affects water quality in a number of Tutuila's wells and aquifers. (U.S. Climate Resilience Toolkit, n.d.)

2.5 Water Supply

2.5.1 Drought

American Samoa is divided into 41 major watersheds, each roughly 1.5 sq. miles in size. Average monthly rainfall amounts of less than three inches per month for three consecutive months are indicative of potential drought in American Samoa, as was the case in 1974 and 1983. The 1998 drought was declared after nine consecutive months of less than half the average monthly rainfall. The effects of drought tend to be long lasting throughout the Territory, as impact on agricultural crops is often devastating, and recovery time can be one or more growing seasons in length. Extended drought periods also present a fire hazard. Table 3. Summary of Significant Drought Years below shows a summary of significant droughts through 2020. No significant drought impacts were experienced in American Samoa since the 2015 plan update. However, below average rainfall did occur because of the El Nino year in 2016 which resulted in severe drought impacts throughout the Pacific. Drought occurrences in American Samoa coupled with human uses of water during droughts can deplete groundwater supplies. (HMP 2020).

Table 3. Summary of Significant Drought Years

Year	Area	Impacts
1974-1975	All islands	Dried up underground water sources. Sediment made water undrinkable. Vegetation dried up, many crops damaged, causing food shortages. Drought broke with several days of heavy rainfall that caused devastating landslides. Water rationing, closure of schools, curtailment of fish cannery operations, reduction of work hours for government employees. Territory-wide recession.
1983-1984	All islands	Water rationing, school closure for one week. Cannery closed for six months, concurrent with renovations. Reduction of work hours for government employees. Territory-wide recession.
1988	All islands	Wells in Tualauta District started to taste salty as groundwater levels were depleted. Only 10.11 inches of rain recorded by the weather bureau at Tutuila's airport from April to August. Several wells and rivers dried up, the Aunu'u natural spring evaporated, and the catchment area at Malaeloa completely dried up.
September 2011	All islands	This event was less severe than previous occurrences and was quenched by rainfall the following month. However, it did prompt a U.S. Coast Guard/New Zealand team to send a ship with a desalination plant on board.

2.5.2 CUC/ASPA Utilities

The USGS has indicated that if the Territory receives steady rainfall, at least 16 million gallons of water seeps into the freshwater zone per day. In 1998, water usage per day averaged about 8 million gallons, with 2 million gallons utilized by the local canneries, 2 million gallons for residential use, 1 million gallons to other businesses, and 1 million lost through leaks. The old underground pipes of Pago Pago and Fagatogo areas were notorious for leaks before recent mitigation efforts. (AS HMP 2020).

The comment below is a reference from an interview by Australian Aide. The full article can be found at: https://waterpartnership.org.au/addressing-wastewater-and-nonrevenue-water-challenges-in-american-samoa-insights-from-the-aspa/#1565043713516-49e93661-a3af

"Most of the water supply system in American Samoa was built in the early 20th century by the US Navy with additional construction of asbestos-cement pipes in the 1960's. The system is composed of approximately 150 miles of water mains and 150 miles of service laterals from the mains to structures.

Approximately 60% of the system's water is lost to non-revenue losses such as leaks and unmetered withdrawals. Leak detection is a priority for ASPA and is done primarily through acoustic leak detection for the mainlines which are generally located beneath the road infrastructure. When combined with the terrain's ability to absorb water, these pipes can cause a challenge to leak detection due to no visible indication of a leak. Crews also conduct surveys within the villages to observe and repair meters and identify any unmetered withdrawals.

ASPA is upgrading their system to iPerl smart meters to start using advanced metering infrastructure which will further advance the ability to quickly detect system leakages and repair damaged infrastructure. Rough order estimates for the replacement of approximately 50 miles of the asbestos-cement and HTPE pipes with PVC pipes is in the range of $200 million."

2.6 Vulnerability and Exposure / Future Without Project

USACE projects, programs, missions, and operations have generally proven to be robust enough to accommodate the range of natural climate variability over their operating life spans. However, recent scientific evidence shows that in some places and for some impacts relevant to USACE operations, climate change is shifting the climatological baseline about which that natural climate variability occurs and may be changing the range of that variability as well. This is relevant to USACE because the assumptions of stationary climatic baselines and a fixed range of natural variability as captured in the historic hydrologic record may no longer be appropriate for long-term projections of the climatologic parameters, which are important in hydrologic assessments for inland watersheds (USACE, 2020).

To evaluate the impacts of climate change on the study area's hydrometeorology a qualitative climate assessment is carried out in accordance with ECB 2018-14, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects. As indicated by the flow chart in Figure 24, the qualitive assessment includes a literature review examining trends in historic, observed, and projected, future temperature, precipitation, and streamflow. The literature review is conducted at both the western Pacific (regional) and Island (local) scale. The assessment requires a quantitative evaluation of trends and nonstationarities in observed hydrometeorological records relevant to the study area and purpose. The final component of the ECB 2018-14 analysis is a review of projected climate changed hydrology and a screening level vulnerability assessment specific to the USACE business lines associated with the study objective.

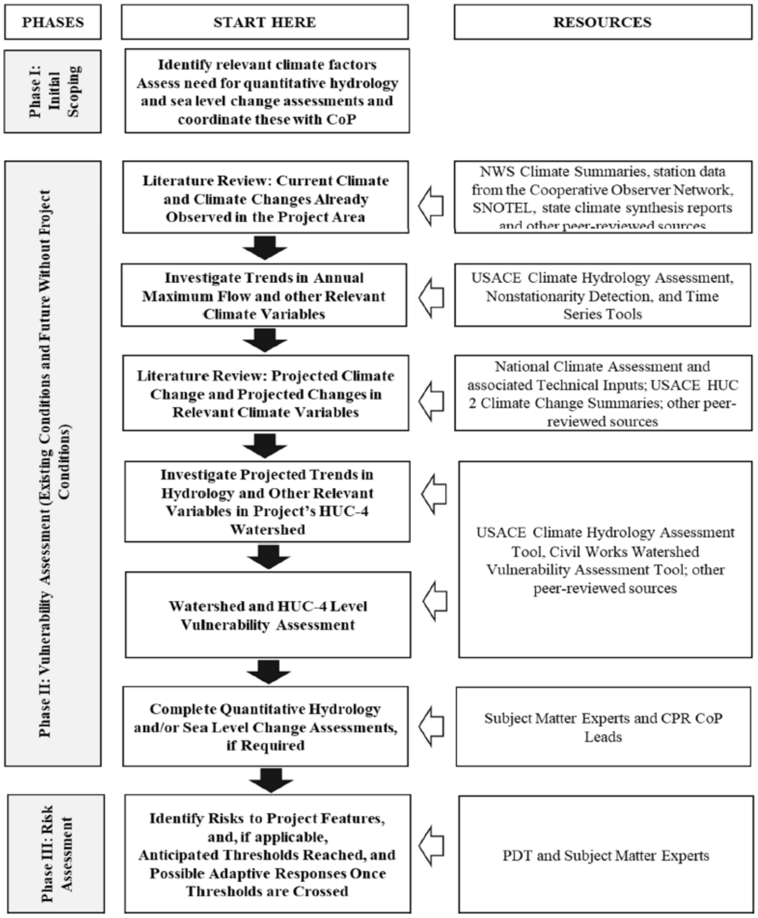


Figure 24. Flow Chart Describing Steps for a Qualitative Assessment of Impacts of Climate Change in Hydrologic Analyses (USACE1, 2022).

2.6.1 Literature Review

To summarize trends in observed and projected temperature, precipitation, and streamflow the Climate Science Special Report from the Fourth National Climate Assessment (NCA4) (USGCRP, 2018) and the USACE's synthesis of Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers- Hawaii Region (USACE (2015)) are referenced but do not explicitly describe America Samoa. Other sources used in developing this report are referenced. In this document projections of temperature, precipitation and streamflow are predominantly analyzed using existing gauge data.

2.7 Assessment of Climate Change Impacts to Inland Hydrology

The focus of the inland hydrology assessment is the flood risk management business line and the high flow regime. Large-scale floods can instigate streambank erosion and are critical to future project performance. Consequently, the focus of the first order statistical analysis conducted as part of this assessment is on peak flow. Observed data is analyzed using the annual instantaneous peak flow records on the Island. Projected, future streamflow data cannot be visualized using the Vulnerability Assessment Tool as these products have only been developed for Hydrologic Unit Codes (HUC)'s within the Continental US.

2.7.1 First Order Statistical Analysis – Observed Streamflow Gauges Analyzed

ECB 2018-14 requires a first order statistical analysis of timeseries relevant to the study purpose. First order statistical analysis encompasses a range of easily applied statistical tests including trend analysis and nonstationarity analysis. The focus of first order statistical analysis is trend and nonstationarity in annual instantaneous peak streamflow data, observed at the nine USGS stream Gauges on American Samoa of HUC 22030000. Annual peak streamflow is appropriate for this analysis because infrequent, large-scale floods can instigate streambank erosion. Nonstationarity analysis of peak streamflow can detect changes, gradual or abrupt, in hydrologic processes over the period of record and an analysis was conducted for the four gauges listed in Table 4 below:

Table 4. American Samoa Gauge Stations

Site Number	Station Name	Drainage Area (sqm)	Period of Record	30 Years of Continuous Record?
16912000	Pago Stream at Afono, Tutuila	0.6	1959 - 2008	Yes
16920500	Aasu Stream at Aasu, Tutuila	1.03	1959 - 1989 1991 - 2002	No
16931000	Atauloma Stream at Afao, Tutuila	0.24	1959 - 1996	Yes
116948000	Afuelo Stream at Matuu, Tutuila	0.25	1959 - 1991, 1994 - 1996	No

2.7.2 Nonstationarity & Trend Analysis

ETL 1100-2-3, Guidance for Detection of Nonstationarities in Annual Maximum Discharges is applied to evaluate the assumption of stationarity in the study area. The USACE Nonstationarity Detection (NSD) Tool were applied to assess whether the annual instantaneous peak streamflow records collected at the gauge locations listed above are representative of stationary hydrologic conditions. For trend analysis, a p-value threshold of 0.05 is adopted to be indicative of statistical significance. Results described in this document have been created using the tools available in the Time Series Toolbox located at https://climate-test.sec.usace.army.mil/tst_app/.

For a nonstationarity to be considered strong it must demonstrate a degree of consensus and robustness. To show consensus the nonstationarity must trigger two or more tests within a range of five years for the same statistic (distribution, mean, etc.). To demonstrate robustness, it must trigger two or more tests within a range of five years for different statistics. A strong nonstationarity must also show significant change in the magnitude of the standard deviation and/or mean (USACE, 2017). results of the Nonstationarity test and the Trends Analysis are described in Table 5 and Table 6 below. All graphics resulting from the application of the TST supporting these analyses are located as plates in the back of this document.

Table 5 Nonstationarity Test Results

Site Number	Station Name	Nonstationarity (NS) Test Results
16912000	Pago Stream at Afono, Tutuila	NS analysis for the full period of record- No nonstationarities detected.
16920500	Aasu Stream at Aasu, Tutuila	NS detected in 1986, 1988 & 1992. Analysis for the 1959-1989 or 1991-2002 period detected- No nonstationarities.
16931000	Atauloma Stream at Afao, Tutuila	NS analysis for the full period of record- No nonstationarities detected.
116948000	Afuelo Stream at Matuu, Tutuila	NS analysis for the full period of record- No nonstationarities detected.

Table 6. Trend Analysis Results

Site Number	Station Name	Trend Analysis
16912000	Pago Stream at Afono, Tutuila	1959-2019 - No statistically significant trends were detected. - Analysis shows a mildly rising trend.
16920500	Aasu Stream at Aasu, Tutuila	1959-1989 - No statistically significant trends were detected. - Analysis shows a mildly rising trend. 1991-2002 No statistically significant trends were detected. - Analysis shows a mildly decreasing trend.
16931000	Atauloma Stream at Afao, Tutuila	1959-1996 - No statistically significant trends were detected. - Analysis shows a mildly rising trend.
116948000	Afuelo Stream at Matuu, Tutuila	1959-1991 - No statistically significant trends were detected. - Analysis shows a mildly rising trend.

2.7.3 Climate- Future Conditions

Rising temperatures and carbon dioxide (CO_2) levels are projected to continue, even with human mitigation efforts. Greenhouse gasses (GHG's) include water vapor, CO, methane, and nitrous oxide. Between 1980 and 2015, GHG's roughly doubled (USACE, 2020). The future of climate variability and GHG emission projections are based on human activity. Engineering and Construction Bulletin (ECB) Number 2018-14 outlines guidance for incorporating Climate Change Impacts to Inland Hydrology in Civil Works, Designs, and Projects.

Although there is not yet consensus on predictions regarding future storm intensity, any potential future increases in storm intensity and wave run-up (coastal inundation) would enhance coastal erosion and damage to communities and harbors along the shoreline. Erosion and flooding are presently a significant vulnerability and increasing sea levels will overwhelm the existing conditions. Warmer temperatures will tax habitat and native plant species, dry soils needed for agriculture, further acidify oceans, and stress corals. Wind damage is a major cause of crop and property damage. Warm waters are fuel for cyclone intensification which will exacerbate wind damage and interrupt power generation. Water supply is inextricably tied to power (pumping of ground water) and is therefore a disruptor to water supply and economic dependencies to water and power.

Increases in earth's surface temperatures (land and sea) are causing large melt events to land-based glaciers as well as thermal expansion of ocean waters, both of which are contributing to global sea level rise. Relative SLC is a combination of this global change in sea level with subsidence, or sinking, of the tectonic plates. This phenomenon is occurring in American Samoa and was hastened by a powerful combination of near simultaneous fault and thrust earthquakes that occurred in the Tonga Trench in September 2009 (Scientific American, 2010; National Science Foundation, 2010). Based on Pago Harbor tide gauge data, this event caused Tutuila to initially rise about 2 to 3 inches at the time of the earthquake event, and then sink down about 7 to 9 inches over the next 2 to 3 years due to the more immediate "relaxation from the earthquake deformation." Since then, the ongoing subsidence is estimated to be occurring at a rate of about 0.5 inches per year and is expected to continue in addition to anticipated climate related sea level rise.

Historically, NOAA estimates that Tutuila has experienced an average of 2.41 mm per year of SLC, however this greatly changed following the 2009 earthquake. In the ensuing 11 years relative sea levels rose 250 mm, or about 22.7 mm per year, due to a large increase in the amount of land subsidence triggered by the earthquake. NOAA and USGS expect this subsidence to continue, although the rate will slow over the next 2-3 decades. Due to these effects, along with uncertainty in the region due to strong influences of ENSO forcing, a larger sea level change rate of 8.9 mm per year is utilized.

Sea level change curves reflect varying acceleration assumptions tied to differing human mitigation activities. A low acceleration rate depicts high mitigation efforts and higher acceleration (high curve) represents a business-as-usual response. SLC is not uniform from region to region and is based on ocean circulation patterns, land subsidence, and tectonic movement. In American

Samoa, tectonic activity and land subsidence play a significant role in sea level change and acceleration.

Figure 25 illustrates the high, intermediate, and low relative sea level change estimates at the Pago Pago NOAA gauge (ER 1100-2-8162) utilizing the SLC rate previously discussed. This study relies on the high curve (shown in red) which is in alignment with territory and other agency projections for SLC. The USACE Sea Level Change Calculator utilized provides a way to visualize USACE and other authoritative SLC scenarios for any tide gauge that is part of the NOAA National Water Level Observation Network. The calculator includes inputs on the unique local sea level change rate that accounts for subsidence and estimates between 2.4 and 4.6 feet of relative sea level rise in American Samoa by 2070 and 3.1 to 7.5 feet by 2100 on the low and high curve, respectively. In addition, a rise of 3 feet within the next 30 years is highly consequential. Figure 26 shows the relative sea level change overlayed with historical mean sea level measurements.

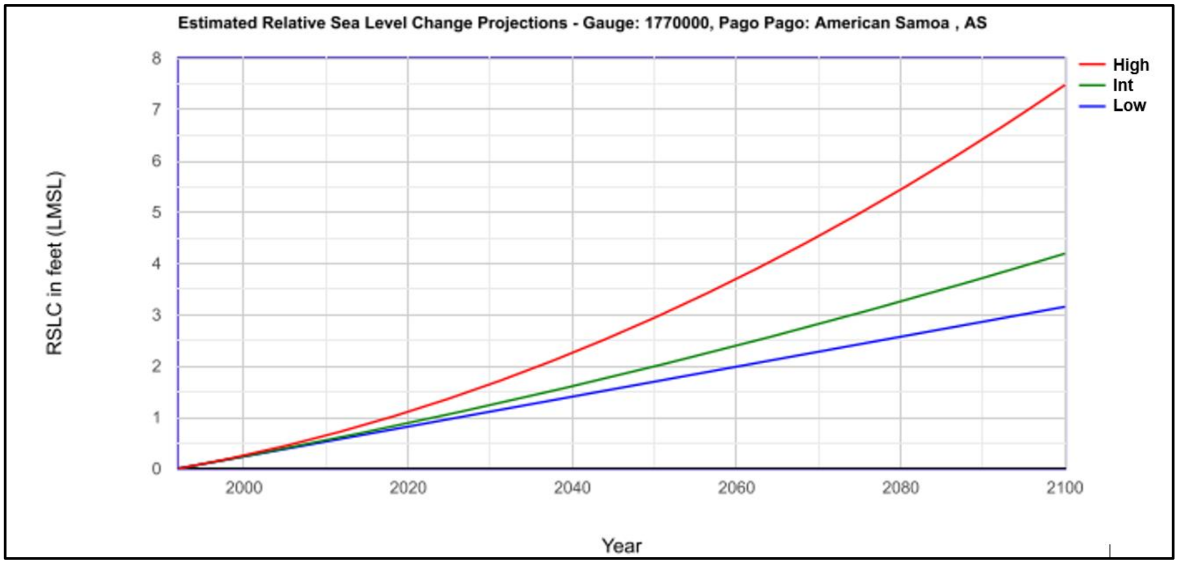
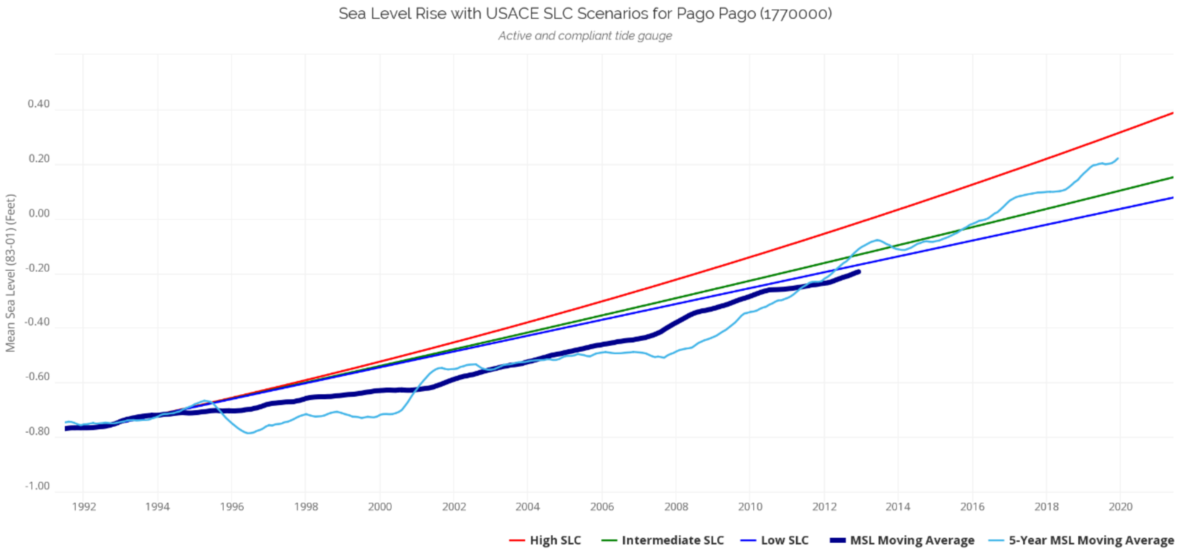


Figure 25. Relative Sea Level Change - American Samoa



USACE Sea Level Change Predictions for Pago Pago (NOAA Tidal Gauge #1770000) for user selected datum: MSL.

Figure 26. Relative Sea Level Change and Historical Mean Sea Level - American Samoa

Although future estimates of rainfall are difficult to quantize, increasing rainfall and temperature trends are presently observed. A warming ocean and atmosphere increase precipitable water in the atmosphere and intensifies rainfall and tropical cyclones. There is a clear El Nino connection where tropical storm activity is increased in the central north and south Pacific. Longer storm lifetimes and intensities are correlated with warm SST's (IPCC, 2007). Increased cyclone intensities are projected to increase 133%, relative to 1986-2005, by 2035 (NOAA, 2018).

2.7.4 Coastal Flooding, Future Conditions

An analysis of existing coastal flooding from cyclone and storm surge for existing and future conditions was performed using Department of Homeland Security (DHS), HURREVAC inundation data and NOAA SLC data respectively. Future conditions evaluate conditions through the year 2072 and utilize the high RSLC curve projections (Figure 25).

Figure 27 through Figure 31 illustrate projected tropical cyclone flooding under future conditions using both HURREVAC and Figure 32 through Figure 35 represent Flooding under future conditions FEMA sources. Understanding risk thresholds relating to SLC with more precise data in areas of vulnerability would help with resiliency planning. This is cited as a recommendation for coastal hazards in the Main Report (Section 6.4.2.3).

Future conditions mapping included the USACE 2070 projected RSLC high curve values have been added to existing HURREVAC MOM inundation water surface values. As Figure 25 illustrates, the RSLC for future conditions in 2070 is estimated to be approximately 4.6 feet. However, the NOAA SLC raster data are only available in integer values, therefore the inundation maps for five feet were selected for presentation and comparison. Although this 0.4-foot difference is insignificant relative to the uncertainty of SLC and based on the exponential subsidence and SLC conditions for the region, the 0.4 feet difference would roughly suggest a resulting five-year difference (2075) in comparison. HURREVAC data, only available for Tutuila and Aunu'u, includes different assumptions than the FEMA coastal wave run up shown. FEMA inundation is based on storm surge and hydrologic runoff while HURREVAC does not consider hydrologic inputs and estuarine additions to storm surge volume.

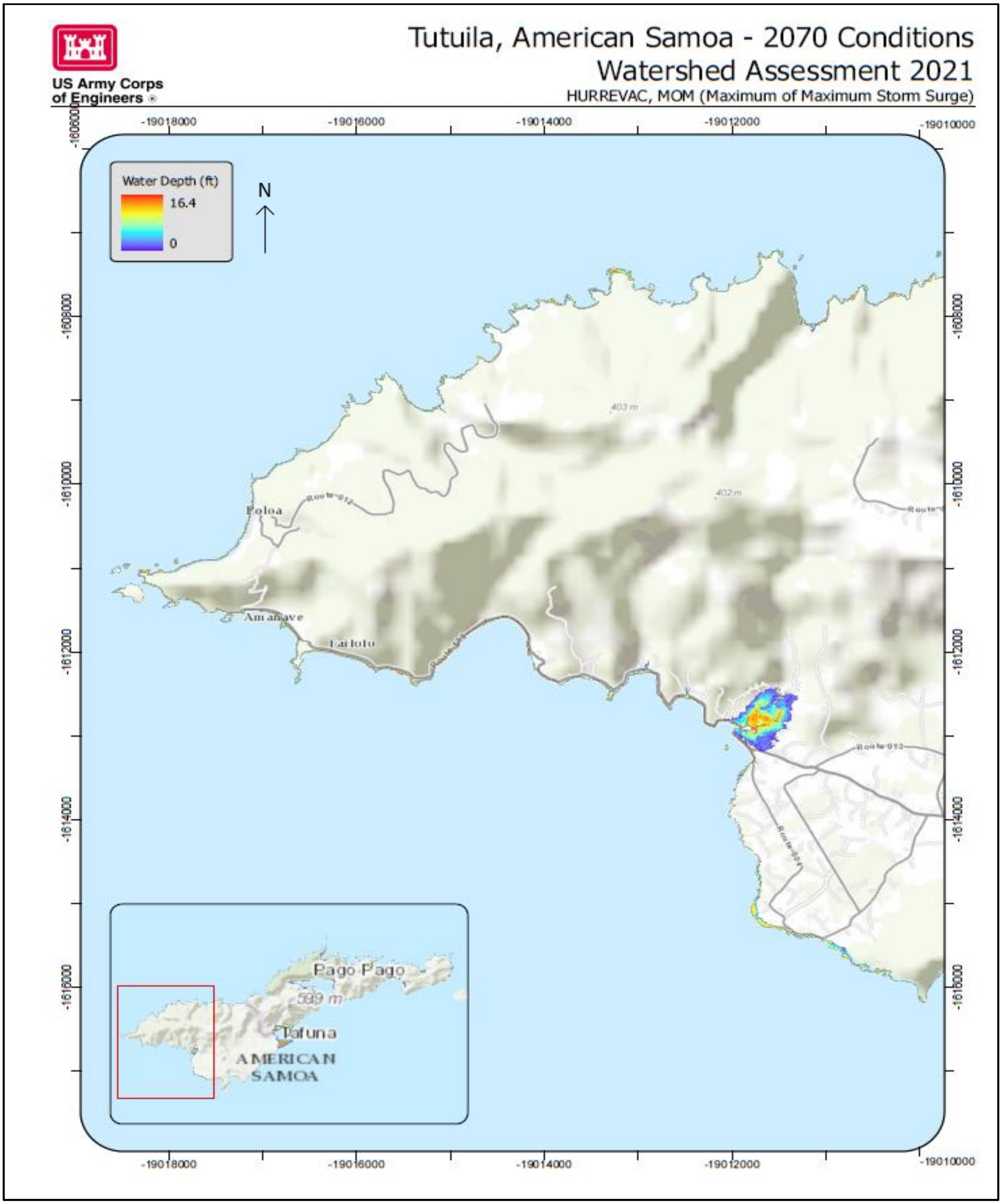


Figure 27. Western Tutuila, HURREVAC MOM Storm Surge Under Future Conditions

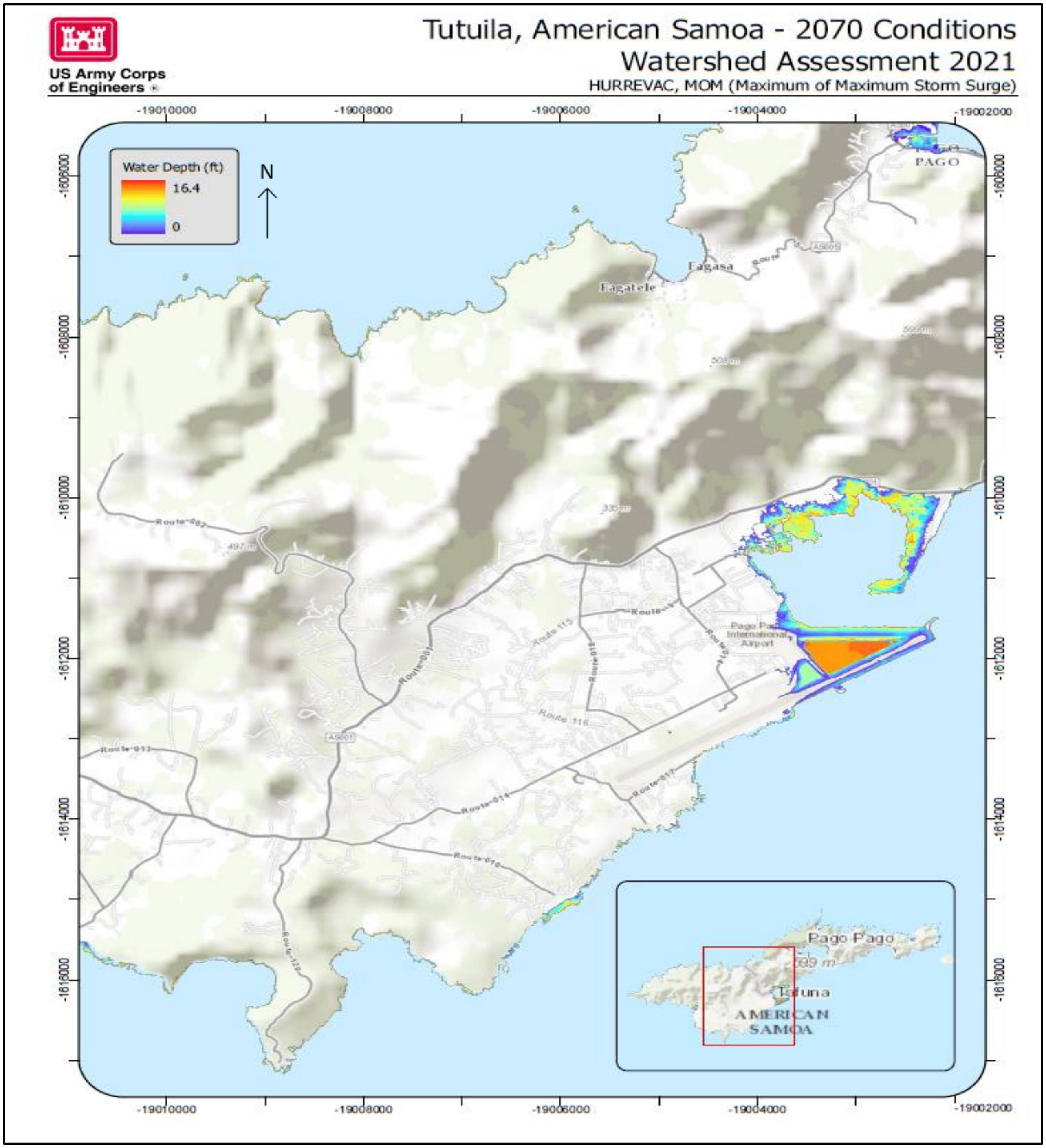


Figure 28. Central Tutuila, HURREVAC MOM Storm Surge Under Future Conditions

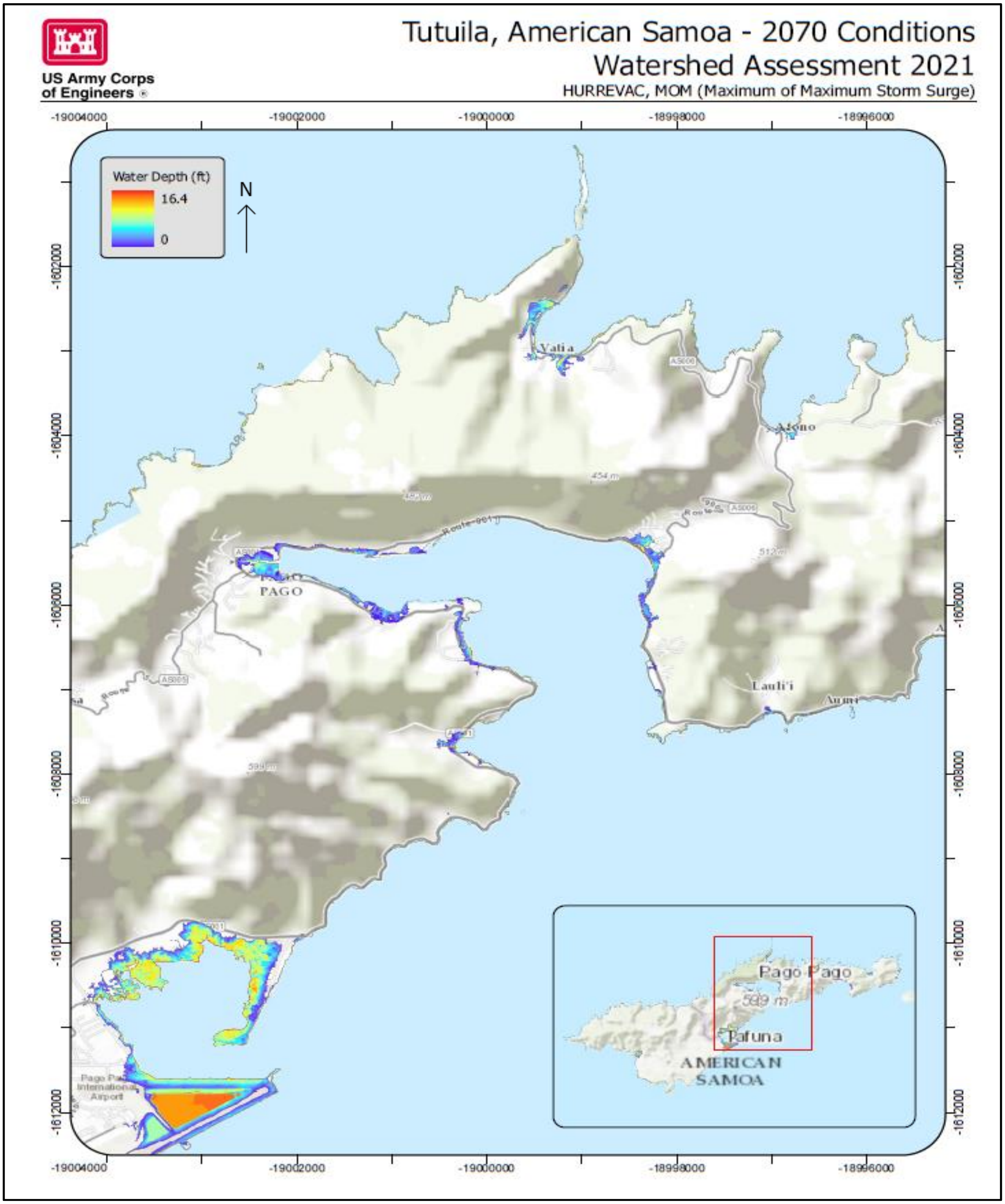


Figure 29. East-Central Tutuila, HURREVAC MOM Storm Surge Under Future Conditions

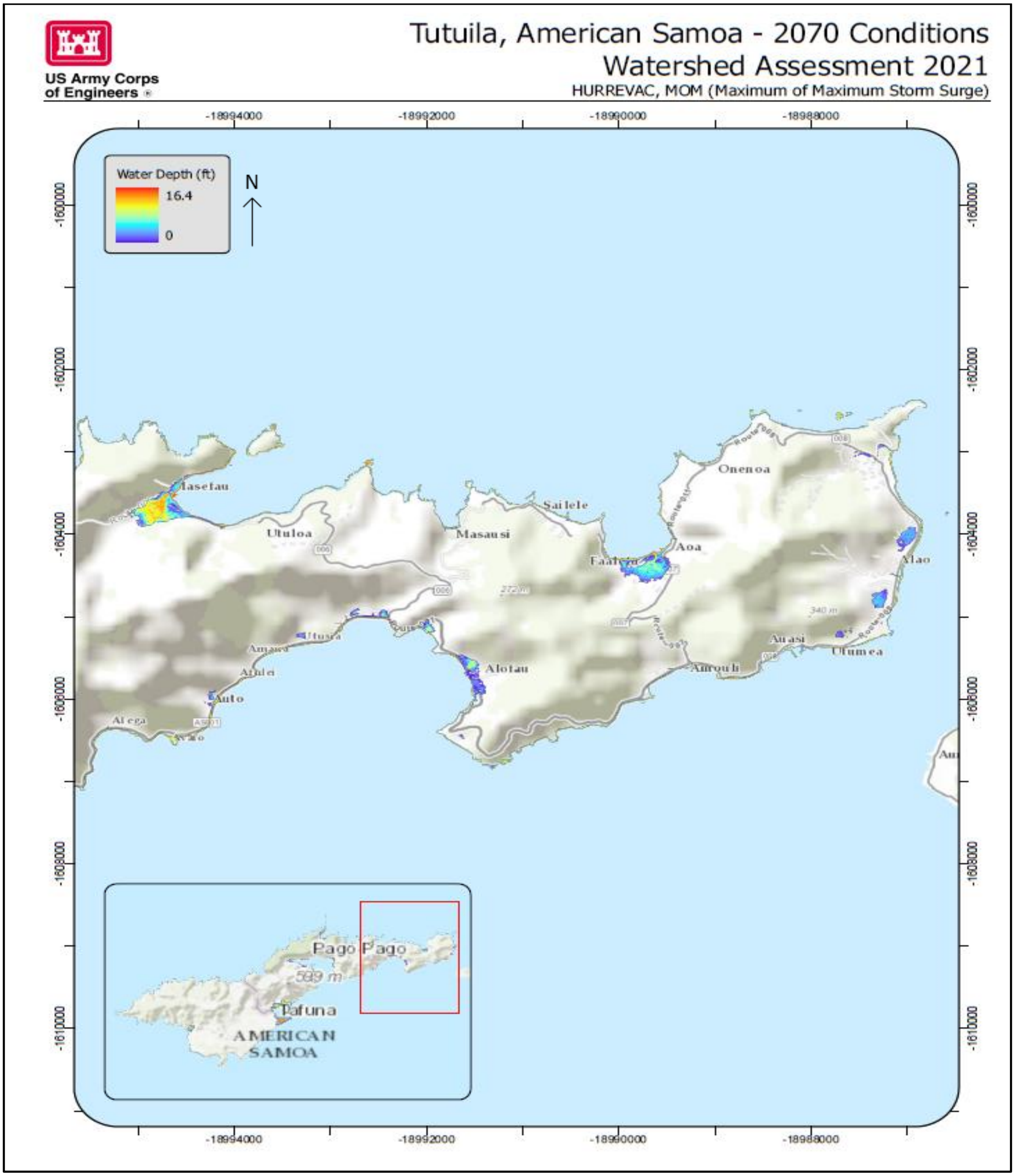


Figure 30. Eastern Tutuila, HURREVAC MOM Storm Surge Under Future Conditions

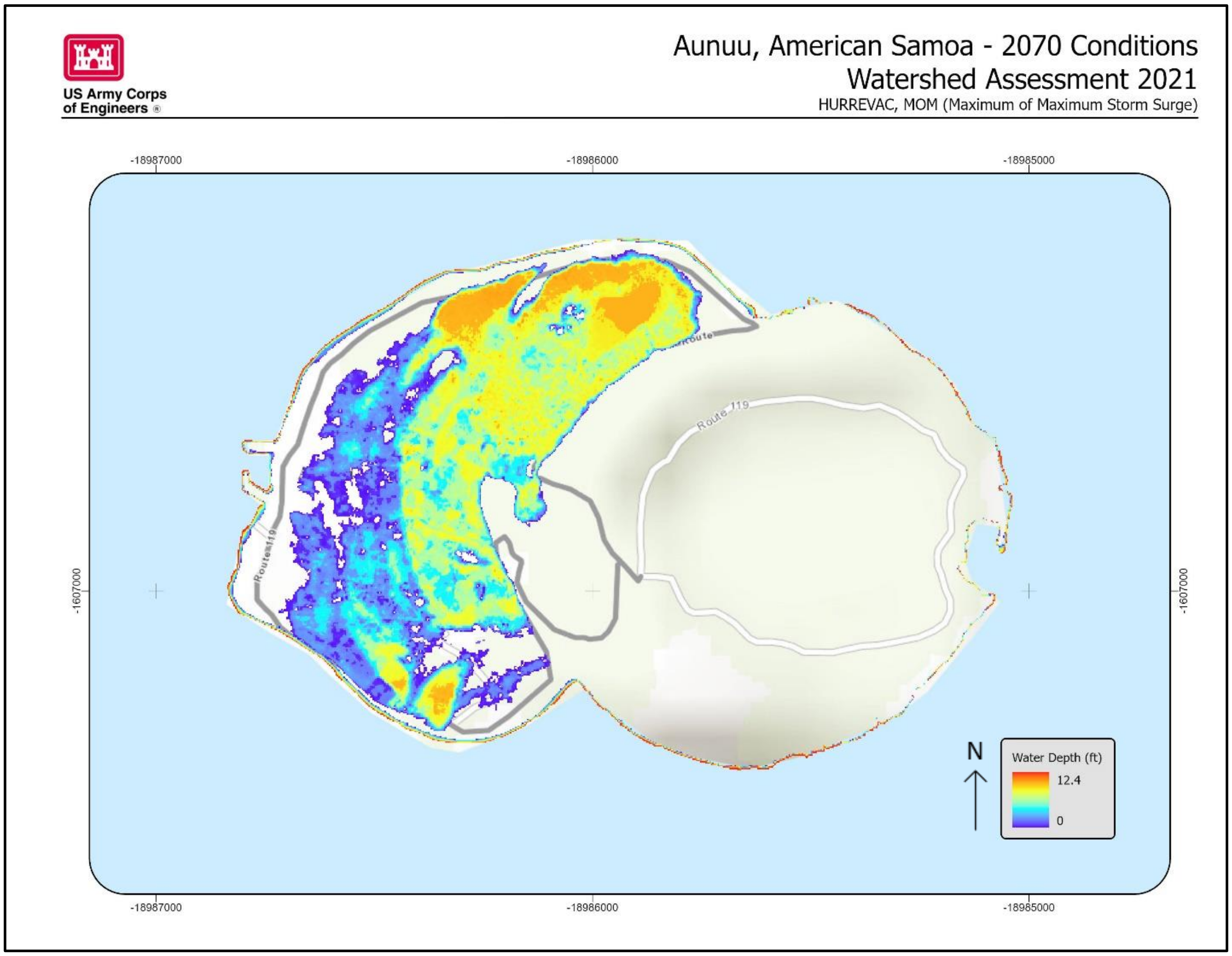


Figure 31. Aunu'u HURREVAC MOM Storm Surge Under Future Conditions

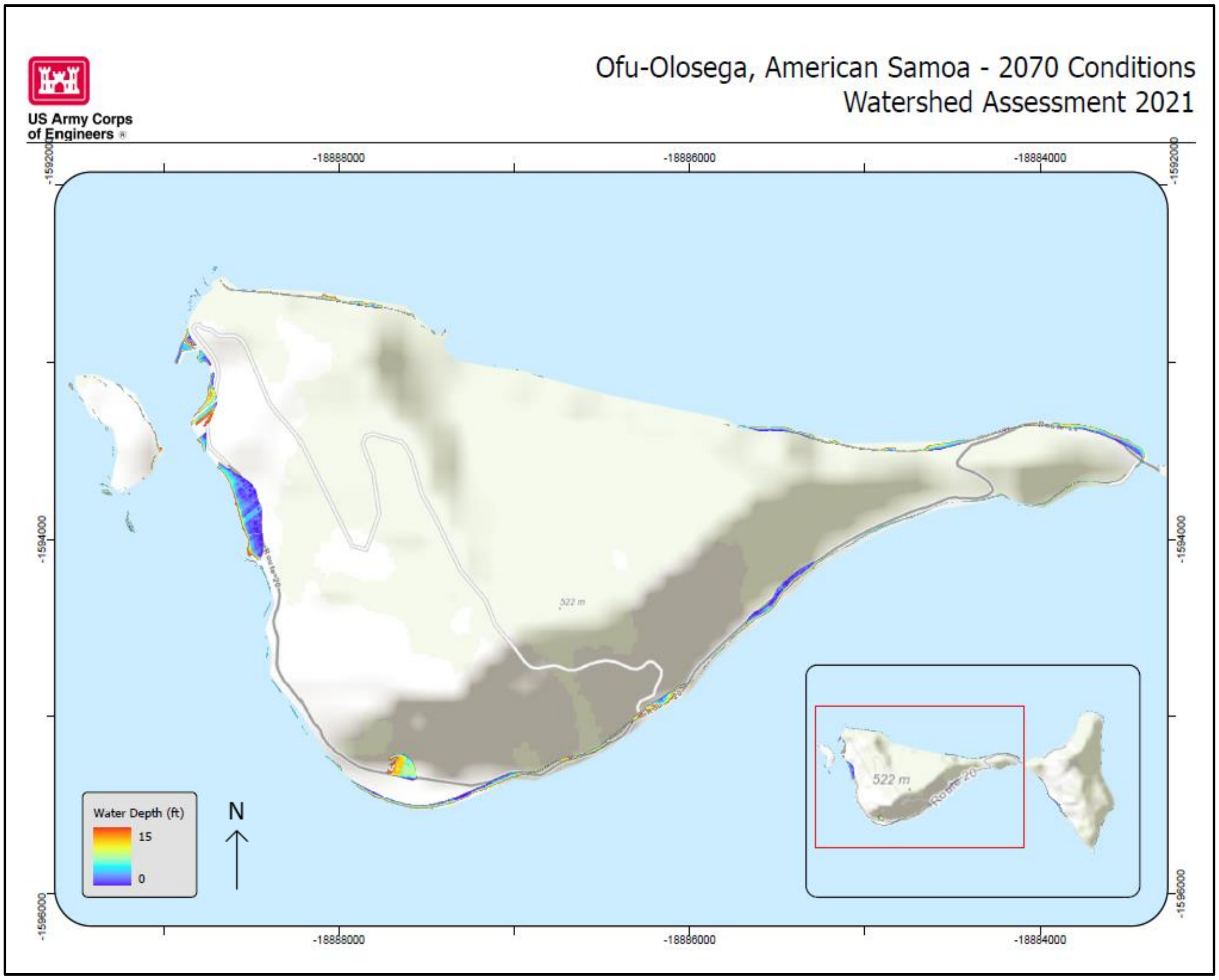


Figure 32. Ofu, FEMA 1% AEP Flood Depths, Future Conditions

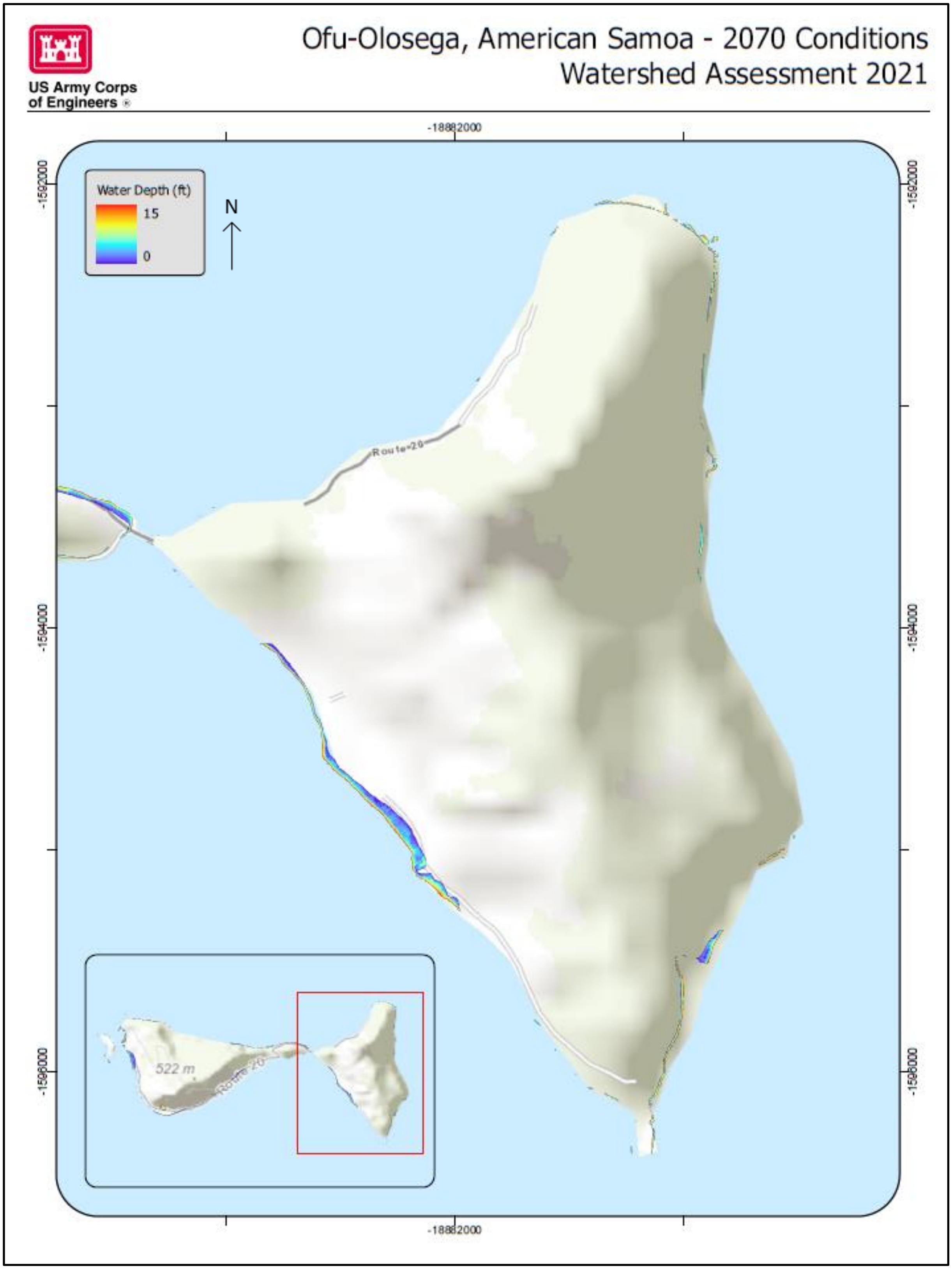


Figure 33. Olosega, FEMA 1% AEP Flood Depths, Future Conditions

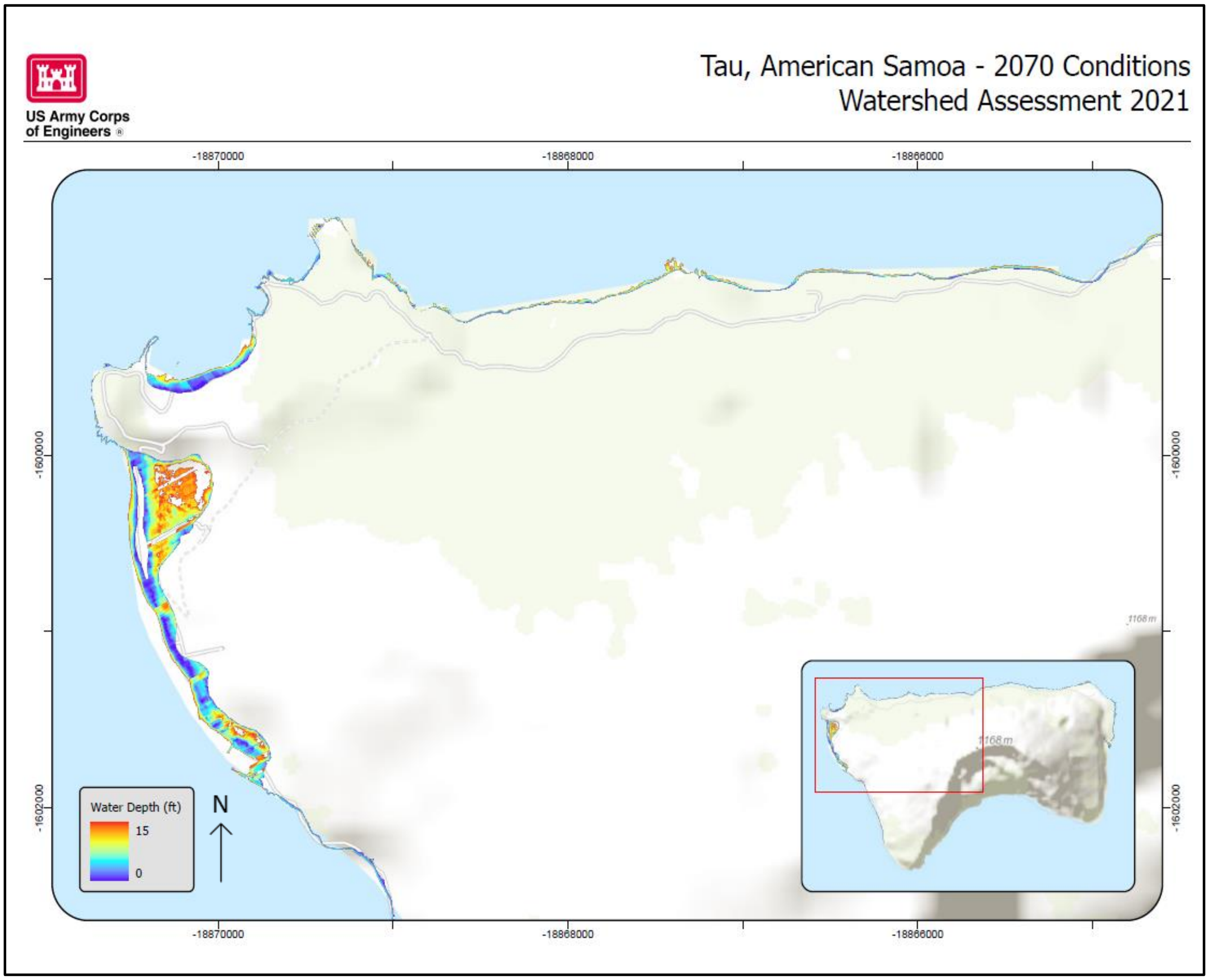


Figure 34. Northwest Tau, FEMA 1% AEP Flood Depths, Future Conditions

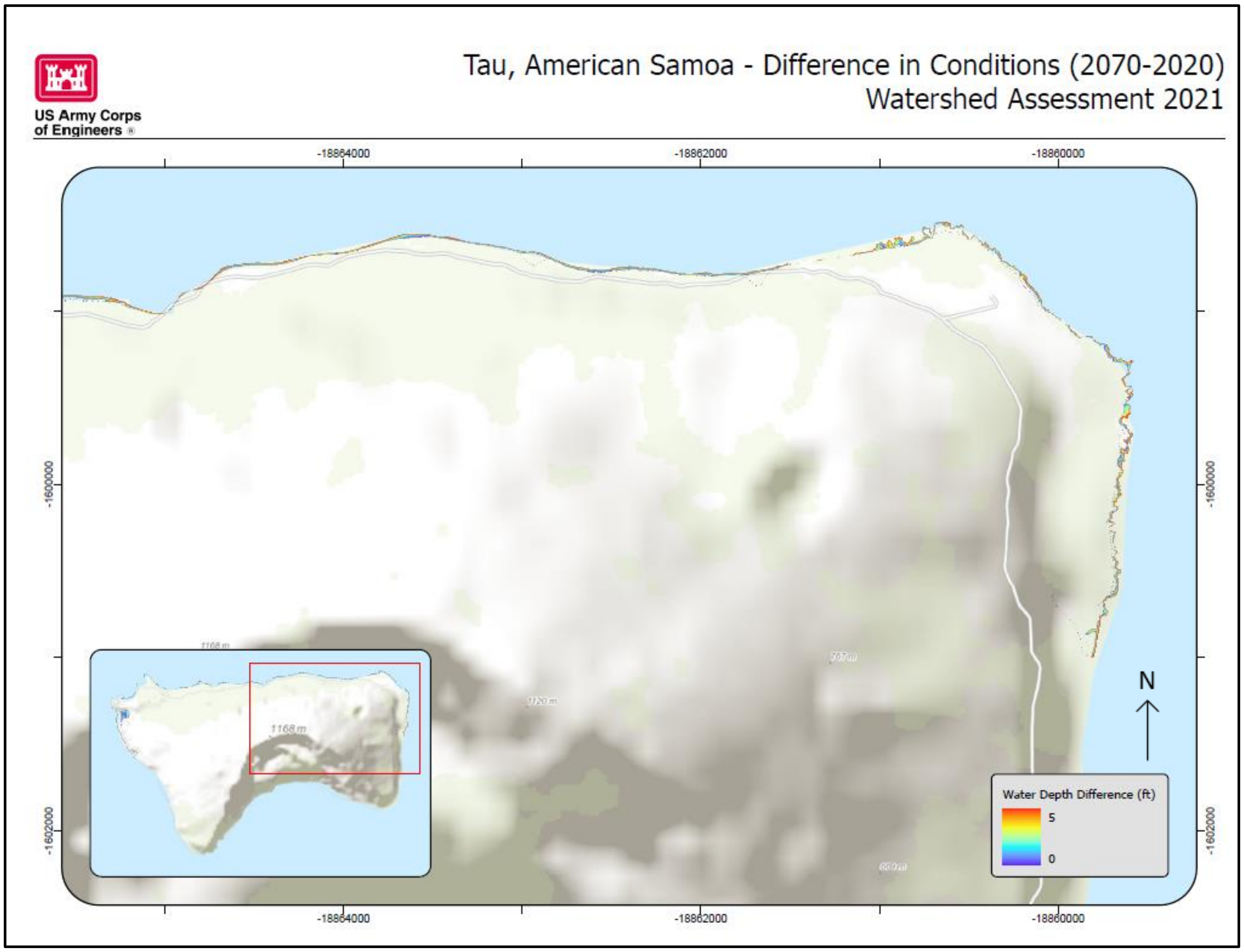


Figure 35. Figure 2.6.2.9. Northeast Tau, FEMA 1% AEP Flood Depths, Future Conditions

A comparison between existing and future (RSLC) conditions were analyzed by adding NOAA SLC depth rasters to the FEMA 1% AEP flood hazard data. Like the HURREVAC future conditions, NOAA SLC rasters for a five-foot rise were incorporated to represent the 4.6-foot RSLC for the territory based on the USACE high curve, which includes subsidence. The future condition of 5-foot versus 4.6-foot rise is closer to a 2075 project horizon versus a 2070 horizon but is appropriate for use in watershed assessment planning.

2.7.5 Riverine and Urban Flooding and Riverine Erosion, Future Conditions

ENSO effects in the central south Pacific vary by the strength of the specific anomaly. During strong and weak El Nino events the South Pacific Convergent Zone, the equatorial low-pressure system (SPCZ), is pulled to the east-northeast of the region or west of the region, respectively. Conditions are drier than average with a lessor potential for cyclone activity. With moderate ENSO events, cyclonic development is more likely, and the wet season begins sooner and ends later. El Nino-like conditions are projected to increase based on expected weakening of the Walker Circulation and temperature gradients over the equator. Because of the proximity of the region to the equator and complex climate teleconnections, American Samoa may see more extremes of drought as well as heavier and longer rainfall episodes (NOAA, 2013). Globally, rainfall intensity is expected to increase while changes to rainfall frequency hold less confidence (NOAA, 2013). This supports projections of greater extreme weather. Longer periods of droughts will dry soils and impact food security and increased rainfall intensity from tropical storms will lead to greater riverine and flash flooding and accentuated erosion and landslides. Storm systems are taxed when runoff volumes exceed capacity.

One third of the emergency shelters (DHS, National Shelter Facilities) in Tutuila are within the FEMA 1% AEP flood plain (coastal and riverine) or adjacent to it. Table 7 lists the shelters and village locations. The 2070 future condition Maximum of Maximum (MOM) hurricane inundation was also analyzed and reflected similar inundation.

Table 7. Shelter Locations within the FEMA Hazard Zones

National Shelter Facility Name	Village	Generator Power
CATHOLIC SHELTER- AASU VILLAGE	AASU VILLAGE	
LMS / ASILI- AFAO VILLAGE	AFAO VILLAGE	
ASSEMBLY- AFONO VILLAGE	AFONO VILLAGE	
METHODIST - AGUGULU VILLAGE	AGUGULU VILLAGE	
CATHOLIC SHELTER- ALAO VILLAGE	ALAO VILLAGE	
ALATAUA-ALUA ELEMENTARY SCHOOL	ALATAUA-ALUA ELEMENTARY SCHOOL	NO
METHODIST -ALOFAU VILLAGE	ALOFAU VILLAGE	
LMS -AMALUIA VILLAGE	AMALUIA VILLAGE	
CATHOLIC SHELTER- AMANAVE VILLAGE	AMANAVE VILLAGE	
LMS -AMAUA VILLAGE	AMAUA VILLAGE	
LMS -AMOULI VILLAGE	AMOULI VILLAGE	
LMS -AOA VILLAGE	AOA VILLAGE	
CATHOLIC SHELTER- ASILI VILLAGE	ASILI VILLAGE	
LMS -ATUU VILLAGE	ATUU VILLAGE	
AUA ELEMENTARY SCHOOL	AUA VILLAGE	
LDS -AUTO VILLAGE	AUTO VILLAGE	
FAGA'ITUA ECE	FAGA'ITUA ECE	NO
LMS -FAGALII VILLAGE	FAGALII VILLAGE	
FAGALI'I ELEMENTARY SCHOOL	FAGALI'I VILLAGE	

National Shelter Facility Name	Village	Generator Power
LMS -FAGASA VILLAGE	FAGASA VILLAGE	
LMS - FAGATOGO VILLAGE	FAGATOGO VILLAGE	
METHODIST -FAILOLO VILLAGE	FAILOLO VILLAGE	
FALENIU MORMON STAKE	FALENIU VILLAGE	
CATHOLIC SHELTER- LAULII VILLAGE	LAULII VILLAGE	
MARIST HALL-LELOALOA VILLAGE	LELOALOA VILLAGE	
CATHOLIC SHELTER- LEONE TAI VILLAGE	LEONE TAI VILLAGE	
GURR RESIDE- MALOTA VILLAGE	MALOTA VILLAGE	
LMS -MASAUSI VILLAGE	MASAUSI VILLAGE	
CATHOLIC SHELTER- NUU'ULI TAI VILLAGE	NUU'ULI TAI VILLAGE	
LMS -ONENOA VILLAGE	ONENOA VILLAGE	
LMS -SAILELE VILLAGE	SAILELE VILLAGE	
MANULELE JRH SHELTER- TAFUNA MAAMAA VILLAGE	TAFUNA MAAMAA VILLAGE	
ASSEMBLY- TULA VILLAGE	TULA VILLAGE	
LMS -UTUMEA VILLAGE	UTUMEA VILLAGE	
FAGAITUA HIGH SCHOOL-UTUSIA VILLAGE	UTUSIA VILLAGE	
LDS -VATIA VILLAGE	VATIA VILLAGE	

Compound flooding refers to a phenomenon in which two or more flooding sources occur simultaneously or subsequently within a short period of time. In terms of coastal flooding, a compound flooding event is flooding caused by the interaction of the open ocean, atmosphere, and watersheds. As American Samoa is made up from a portion of a submerged mountain range and has very steep terrain and the alluvial fans are very short, we believe there are insignificant areas where the phenomenon of compound flooding exists.

3 References

ASEPA (2020), Integrated Water Quality Monitoring and Assessment Report.

ASEPA (2020), American Samoa Watershed Protection Plan Vol 2

Bureau of Environmental and Coastal Quality Division of Coastal Resources Management (BECQ-DCRM), (2015). 2016-2020 Section 309 Assessment and Strategy Report, May 2016.

Bureau of Environmental and Coastal Quality Division of Coastal Resources Management (BECQ-DCRM), (2020). 305(b) and 303(d) Water Quality Assessment Integrated Report.

CRAG American Samoa's Healthy Coral Reef Local Action Strategy 2020-2025.

Department of Homeland Security (DHS), HURREVAC – National Hurricane Program, https://hvx.hurrevac.com

Intergovernmental Panel on Climate Change, IPCC-AR5 (2014), Fifth Assessment Report of the Assessment of the U.S. Tsunami Program and the Nation's Preparedness Efforts

Intergovernmental Panel on Climate Change, [IPCC] (2007), Evidence for Changes in Tropical Storms, AR4 Chapter 3.8.3. Retrieved April 2021 from https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch3s3-8-3.html

NOAA and Princeton University (2018), Projected Response of Tropical Cyclone Intensity and Intensification in a Global Climate Model

Intergovernmental Panel on Climate Change, Climate Change 2014 Synthesis Report

International Pacific Research Center [IPRC] (2014), The Sea Level Seesaw of El Nino Taimasa, Vol 14 No.1. Retrieved April 2021 from: http://iprc.soest.hawaii.edu/newsletters/iprc_climate_vol14_no1.pdf

Maynard, J. A., McKagan, S., Raymundo, L., Johnson, S., Ahmadia, G. N., Johnston, L., Houk, P., Williams, G. J., Kendall, M., Heron, S. F., van Hooidonk, R., Mcleod, E., Tracey, D., & Planes, S. (2015). Assessing relative resilience potential of coral reefs to inform management. *Biological Conservation*, *192*, 109 119. https://doi.org/10.1016/j.biocon.2015.09.001.

Mitchell, J.N., Presley, T.K., and Carruth, R.L., (2021). Groundwater conditions and trends, 2009–19, Saipan, Commonwealth of the Northern Mariana Islands: U.S. Geological Survey Scientific Investigations Report 2020–5129,51 p. Retrieved from https://doi.org/10.3133/sir20205129.

National Ocean and Atmospheric Administration (NOAA) NHC (2021), National Storm Surge Hazards Maps version2. HURREVAC data retrieved from https://hvx.hurrevac.com/hvx/home.html

National Ocean and Atmospheric Administration (NOAA) (2013), NOAA Technical Report NESDIS 142-8 Regional Climate Trends and Scenarios of the US National Climate Assessment-Part 8 Climate of the Pacific Islands.

National Ocean and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI) and Weather Forecast Office (WFO) Pago Pago. Retrieved from https://w2.weather.gov/climate/xmacis.php?wfo=samoa

National Ocean and Atmospheric Administration (NOAA), NCEI[a], National Hazards Viewer (online), retrieved from https://maps.ngdc.noaa.gov/viewers/hazards/?layers=0

National Ocean and Atmospheric Administration (NOAA), NCEI[b], Storm Events Database (online). Retrieved from https://www.ncdc.noaa.gov/stormevents/

National Ocean and Atmospheric Administration (NOAA), (2013), NOAA Technical Report NESDIS 142-8 Regional Climate Trends and Scenarios of the US National Climate Assessment-Part 8 Climate of the Pacific Islands.

National Ocean and Atmospheric Administration (NOAA). (2018). Projected Response of Tropical Cyclone Intensity and Intensification in a Global Climate Model

National Ocean and Atmospheric Administration (NOAA). NOAA Coral Reef Conservation Program. Status Reports. (2018). Data retrieved from: https://www.coris.noaa.gov/monitoring/status_report/

National Ocean and Atmospheric Administration (NOAA). (2021), El Niño/Southern Oscillation (ENSO) Technical Discussion

Natural Resources Conservation Service (NRCS), (2018) Extension University of Nebraska Department of Agriculture, Soil Notebook. Retrieved May 2021 from https://extension.unl.edu/statewide/enre/2018%20Soils%20Notebook-FINAL.pdf

Office of Planning and Development Advisory Council (PDAC) (2020) Resources Report Planning for Sustainability in the Commonwealth of the Northern Mariana Islands – Draft

R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. Retrieved from http://dx.doi.org/10.7930/J0R49NQX

Rupic, M., Wetzell, L., Marra, J., Balwani, S. (2018, February). 2014-2016 El Nino assessment report; an overview of the impacts of the 2014-16 El Nino on the US affiliated Pacific Islands (USAPI) [PDF]. Retrieved June 2019 from https://www.ncdc.noaa.gov/sites/default/files/attachments/ENSOTT_Report_02.26.2018%20FINAL%20draft.pdf

U.S. Department of Agriculture (USDA) (1984) Soil Survey of American Samoa. Retrieved May 2021 from: https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/pacific_basin/PB630/0/american_samoa.pdf

USACE1 (2022). Climate Preparedness and Resilience CoP Applications Portal. https://www.usace.army.mil/corpsclimate/Public_Tools_Dev_by_USACE/

USACE ECB 2018-14 Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, And Projects. (2020).

USACE (2020), American Samoa Climate Related Vulnerability Assessment

USACE. (2017). Engineer Technical Letter (ETL) 1100-2-3 Guidance for Detection Nonstationarities in Annual Maximum Discharges. Washington, DC: USACE.

USACE (2015). CWTS 2015-21: Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions- Water Resources Region 20, DC: U.S. Army Corps of Engineers

USACE (2019), Sea-Level Change Curve Calculator (Version 2021.12). Retrieved April 2021 from https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

USACE (March 2012), American Samoa Tsunami Study – Final Report

USACE (1980), Tsunami Elevation Predictions for American Samoa. Retrieved April 2021 from https://apps.dtic.mil/dtic/tr/fulltext/u2/a090275.pdf

U.S. Global Change Research Program (USGCRP), (2016). The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen,

Willsey, Tyler, Kwon, J.A., Amidon.F, Miller, S.E. and M.K. Reeves, US Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, Honolulu, HI 2019

University (2018), Projected Response of Tropical Cyclone Intensity and Intensification in a Global Climate Model

U.S. Geological Survey (USGS)[a] (Wood N.J. et al., 2019), Population Vulnerability to Tsunami Hazards Informed by Previous and Projected Disasters: A Case Study of American Samoa

U.S. Geological Survey (USGS)[b] (Wood N.J. et al., 2019), Tsunami Warning and Preparedness: An

U.S. Geological Survey (USGS) (Jones J.M., Wood N.J., 2018) Tsunami Evacuation Time Map for American Samoa. GIS retrieved April 2021 from https://link.springer.com/article/10.1007/s11069-018-3493-7

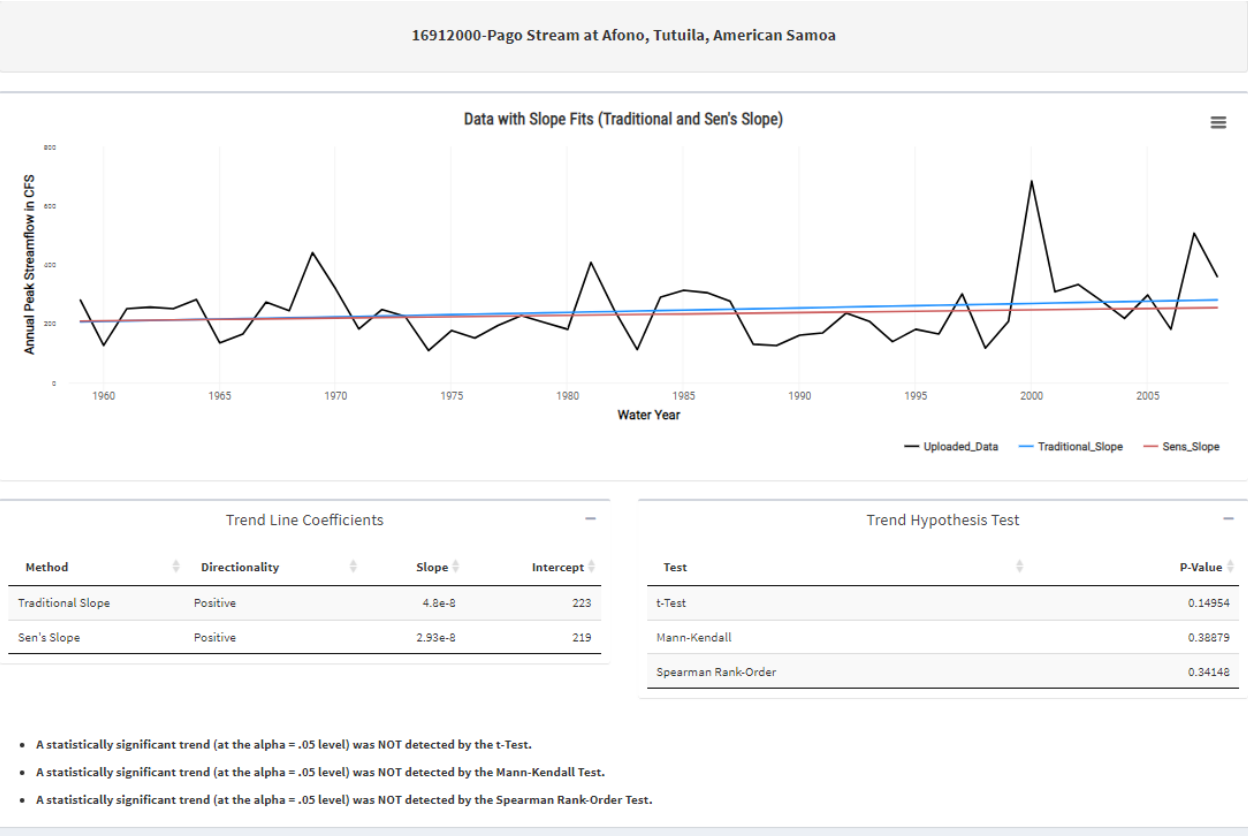
The World Bank (June 2020), The Global Landslide Hazard Map Final Project Report

4 Plates

16912000-Pago Stream at Afono, Tutuila, American Samoa

No nonstationarities detected!

Plate 1. Nonstationarity Analysis of Maximum Annual Flow, Pago Stream at Afon, Tutilla, American Samoa, (1959-2008)



16912000-Pago Stream at Afono, Tutuila, American Samoa

Trend Line Coefficients

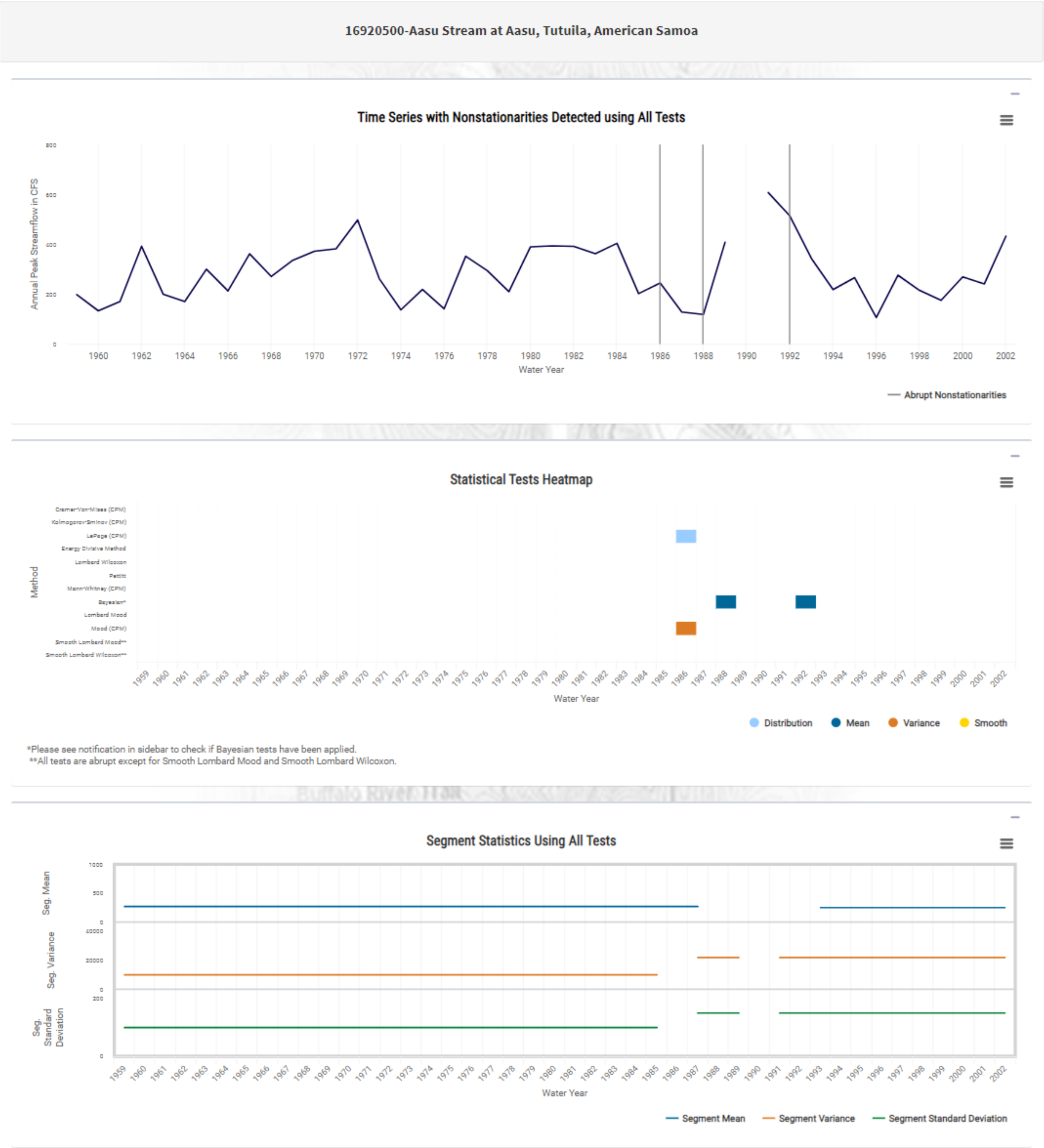
Method	Directionality	Slope	Intercept
Traditional Slope	Positive	4.8e-8	223
Sen's Slope	Positive	2.93e-8	219

Trend Hypothesis Test

Test	P-Value
t-Test	0.14954
Mann-Kendall	0.38879
Spearman Rank-Order	0.34148

- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.**

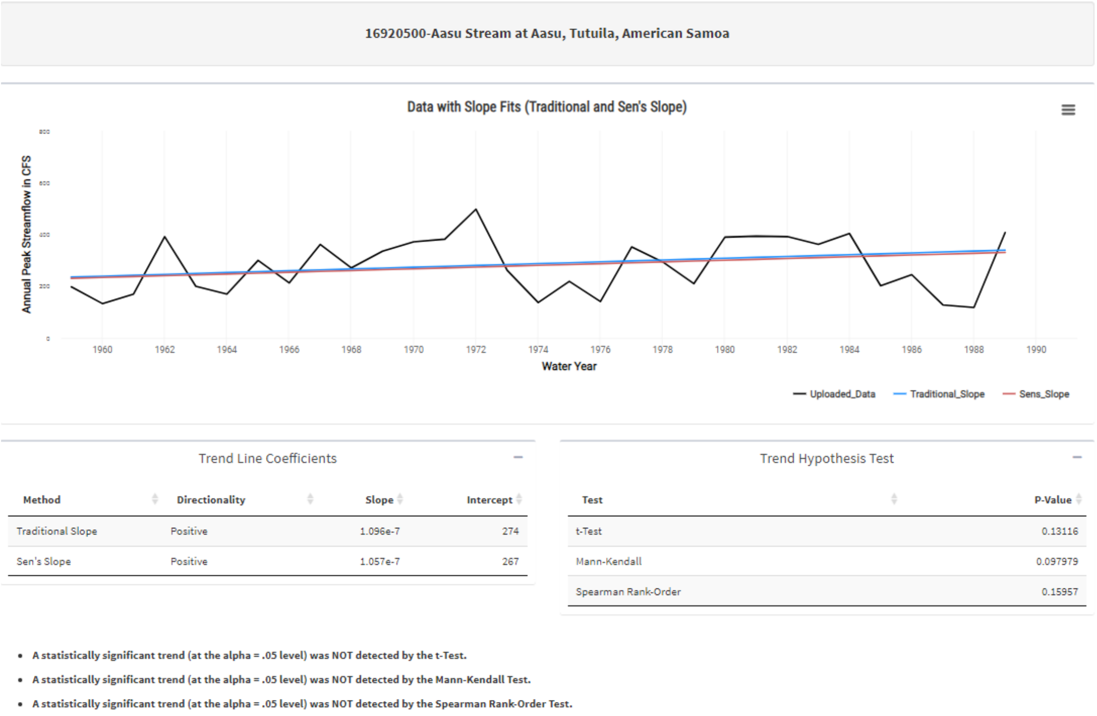
Plate 2. Trend Analysis of Maximum Annual Flow, Pago Stream at Afon, Tutilla, American Samoa, (1959-2008)



16920500-Aasu Stream at Aasu, Tutuila, American Samoa

*Please see notification in sidebar to check if Bayesian tests have been applied.
**All tests are abrupt except for Smooth Lombard Mood and Smooth Lombard Wilcoxon.

Plate 3. Nonstationarity Analysis of Maximum Annual Flow, Aasu Stream at Aasu, Tutilla, American Samoa, (1959-2002)



16920500-Aasu Stream at Aasu, Tutuila, American Samoa

Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	1.096e-7	274
Sen's Slope	Positive	1.057e-7	267

Trend Hypothesis Test

Test	P-Value
t-Test	0.13116
Mann-Kendall	0.097979
Spearman Rank-Order	0.15957

- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.**

Plate 4. Trend Analysis of Maximum Annual Flow, Pago Stream at Afon, Tutilla, American Samoa, (1959-1989)

16920500-Aasu Stream at Aasu, Tutuila, American Samoa

Trend Line Coefficients

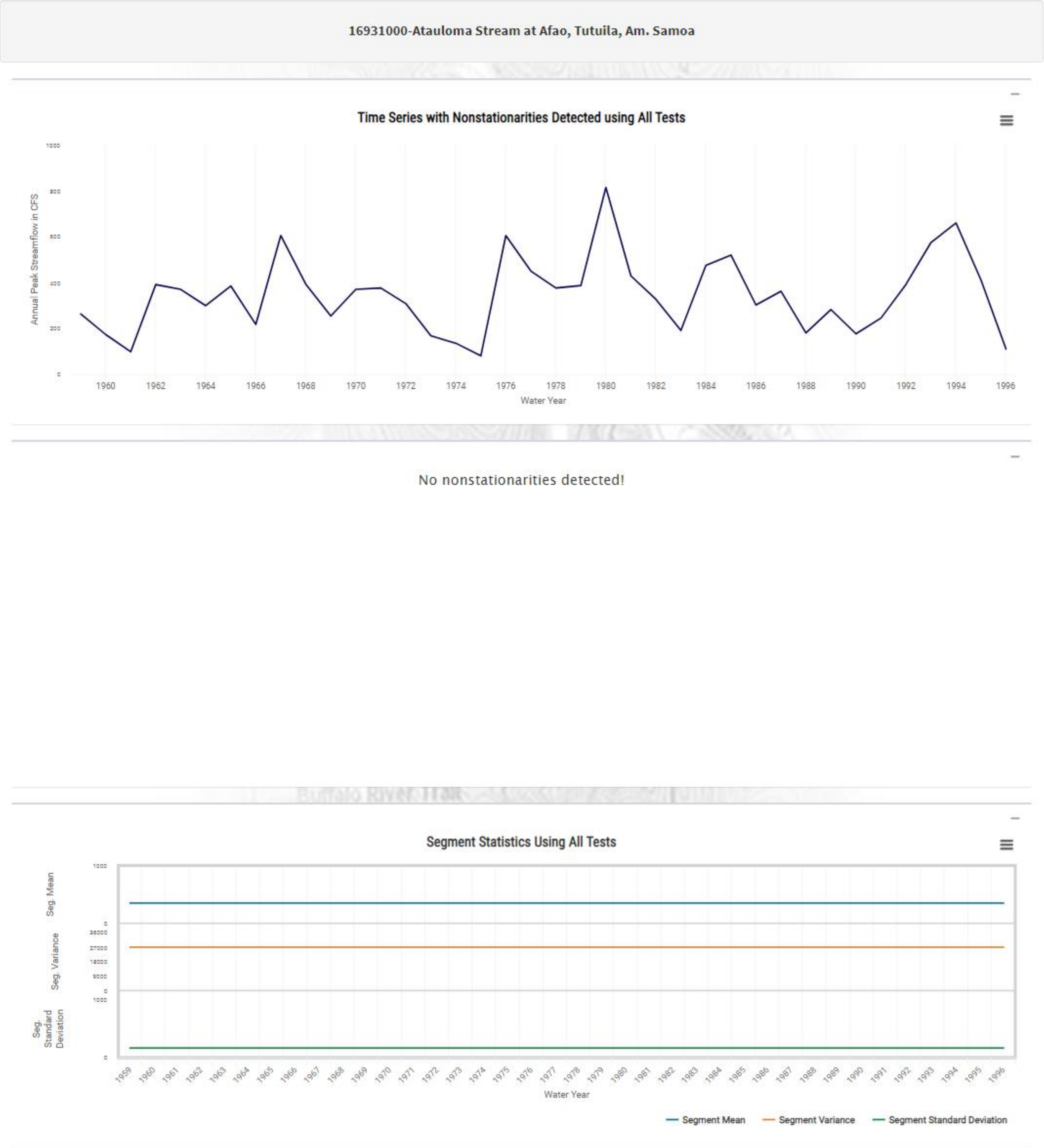
Method	Directionality	Slope	Intercept
Traditional Slope	Negative	-5.648e-7	778
Sen's Slope	Negative	-5.174e-7	700

Trend Hypothesis Test

Test	P-Value
t-Test	0.1509
Mann-Kendall	0.24372
Spearman Rank-Order	0.25514

- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.**

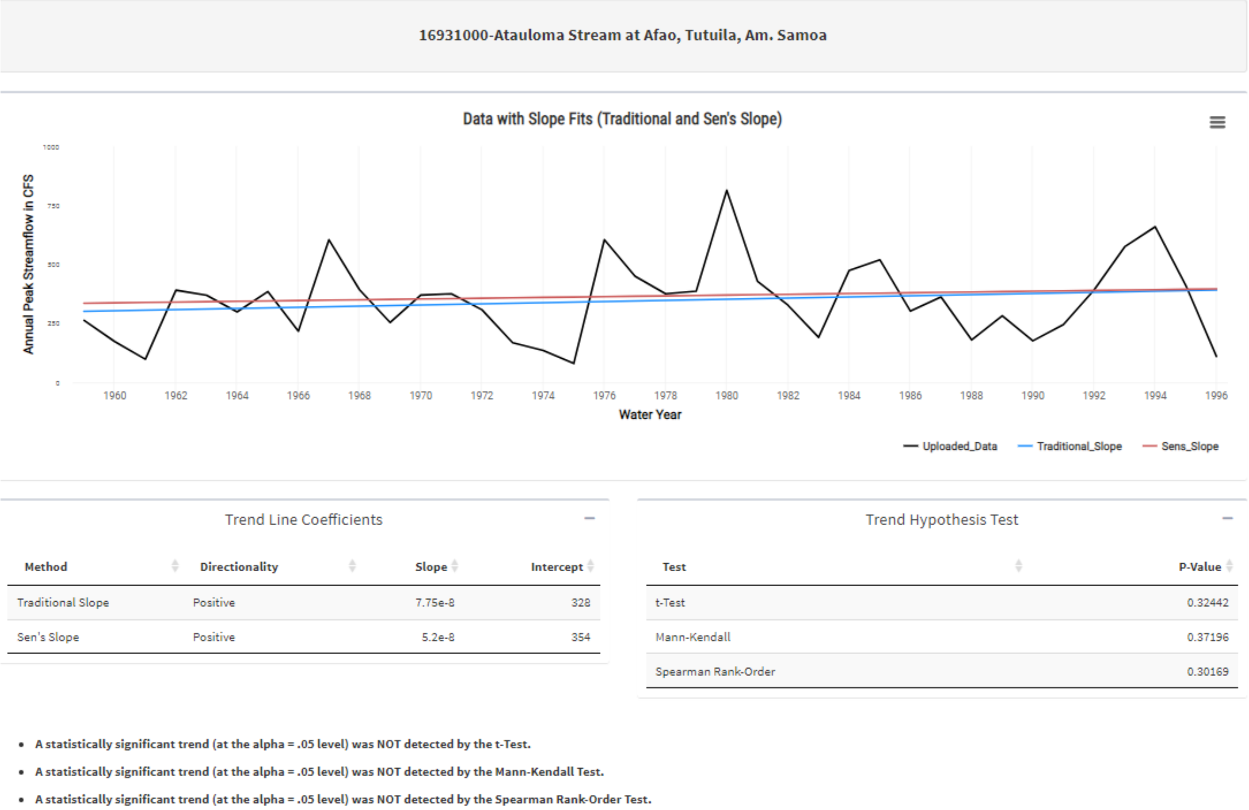
Plate 5. Trend Analysis of Maximum Annual Flow, Pago Stream at Afon, Tutilla, American Samoa, (1991-2002)



16931000-Atauloma Stream at Afao, Tutuila, Am. Samoa

No nonstationarities detected!

Plate 6. Nonstationarity Analysis of Maximum Annual Flow, Atauloma Stream at Afao, Tutilla, American Samoa, (1959-1996)



16931000-Atauloma Stream at Afao, Tutuila, Am. Samoa

Data with Slope Fits (Traditional and Sen's Slope)

Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	7.75e-8	328
Sen's Slope	Positive	5.2e-8	354

Trend Hypothesis Test

Test	P-Value
t-Test	0.32442
Mann-Kendall	0.37196
Spearman Rank-Order	0.30169

- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.**

Plate 7. Trend Analysis of Maximum Annual Flow, Annual Flow, Atauloma Stream at Afao, Tutilla, American Samoa, (1959-1996)

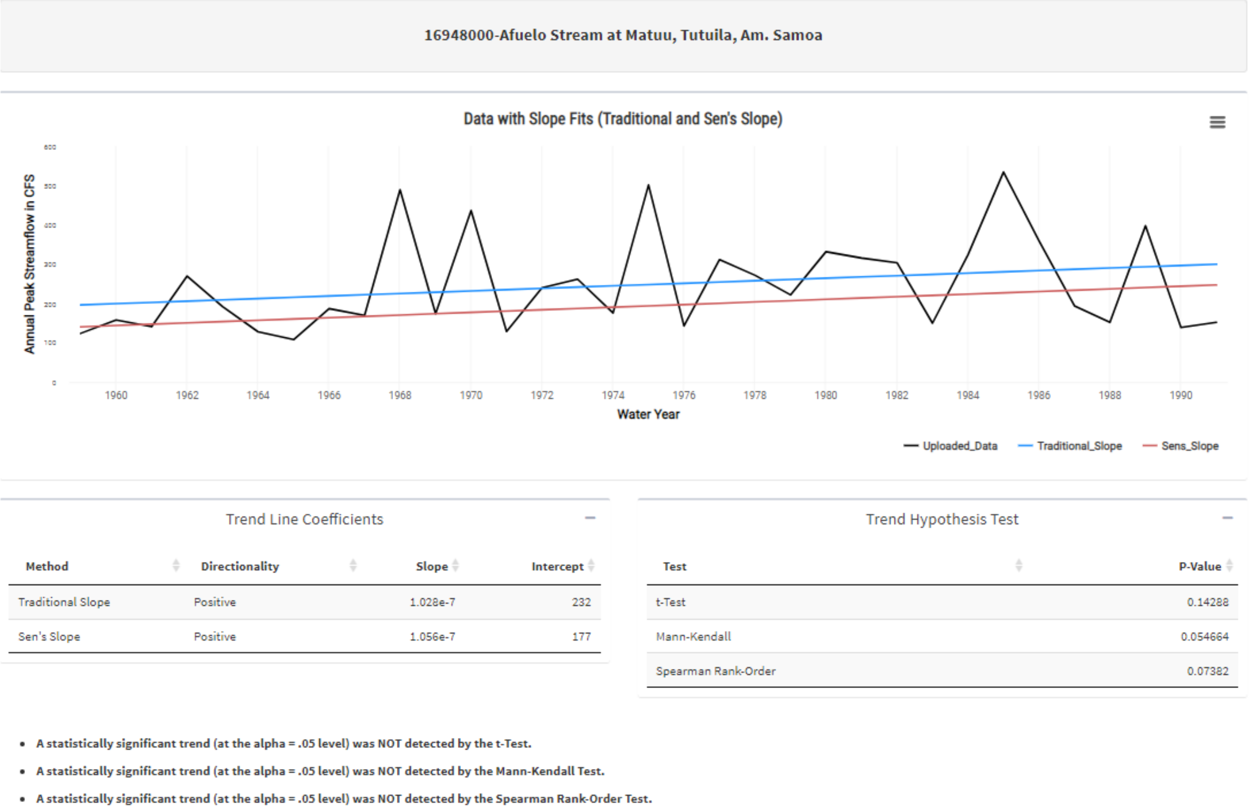
16948000-Afuelo Stream at Matuu, Tutuila, Am. Samoa

Time Series with Nonstationarities Detected using All Tests

No nonstationarities detected!

Segment Statistics Using All Tests

Plate 8. Nonstationarity Analysis of Maximum Annual Flow, Afuelo Stream at Matuu, Tutilla, American Samoa, (1959-1996)



16948000-Afuelo Stream at Matuu, Tutuila, Am. Samoa

Trend Line Coefficients

Method	Directionality	Slope	Intercept
Traditional Slope	Positive	1.028e-7	232
Sen's Slope	Positive	1.056e-7	177

Trend Hypothesis Test

Test	P-Value
t-Test	0.14288
Mann-Kendall	0.054664
Spearman Rank-Order	0.07382

- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was NOT detected by the Spearman Rank-Order Test.**

Plate 9. Nonstationarity Analysis of Maximum Annual Flow, Afuelo Stream at Matuu, Tutilla, American Samoa, (1959-1991)