

Manell-Geus Watershed Characterization Report



Steep hillsides in the Manell watershed bordering the Achang Flat Marine Preserve (Pait et al., 2019)

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FINAL

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Table of Acronyms

ACOE – Army Corps of Engineers
BSP – Guam Bureau of Statistics and Plans
CCU – Guam Consolidated Commission on Utilities
CDC – U.S. Center for Disease Control and Prevention
CRI – Guam Coral Reef Initiative
DIN – Dissolved inorganic nitrogen
DDT – Dichlorodiphenyltrichloroethane
EPA – Environmental Protection Agency
FDM – Farallon de Medinilla
GCMP – Guam Coastal Management Program
GWA – Guam Waterworks Authority
GPA – Guam Power Authority
NMFS – National Marine Fisheries Service
NPDES – National Pollutant Discharge Elimination System
NOAA – National Oceanic and Atmospheric Administration
NTU – Nephelometric turbidity unit
PCB – Polychlorinated biphenyls
SLR – Sea level rise
SPCC – Spill Prevention Control and Countermeasure Program
SSC - Suspended sediment concentration
TSS – Total suspended solids

1.0 Introduction

The Manell-Geus watershed (**Figure 1**) was identified as a priority watershed for assessment and management under Guam’s Coral Reef Initiative in 2009 and as a NOAA Habitat Blueprint Focus Area in 2014 (NMFS PIRO, 2017). The watershed is located at the southwestern edge of Guam and encompasses the village of Merizo. The Manell-Geus watershed drains into the island’s only shallow water lagoon, Cocos Lagoon, and only intact barrier reef system, the Achang Reef Flat Marine Preserve, as well as some of the island’s most substantial seagrass beds and mangrove forests. These ecosystems support cultural and subsistence harvests, as well as tourism in the region.

These important ecosystems are affected by water quality impairments that have been linked to high levels of upland and stream bank erosion from deforestation from arson, inadequate stormwater management, and the spread of invasive bamboo plants. Erosion not only results in high levels of sedimentation that affect the health of aquatic habitat, but it is also contributing to flooding in Merizo (NMFS PIRO, 2017). Many of these impacts will only be further exacerbated by climate change, which is anticipated to bring to Guam more frequent and intense precipitation events, higher temperatures that enable longer lasting wildfire conditions, and sea level rise, among other concerns (Grecni et al., 2020).

This report provides an initial characterization of watershed conditions and is intended to summarize existing information on the watershed, identify gaps in data, and provide background material for future field assessments and public engagement activities. COVID19 has delayed much of this effort. The information provided here will be incorporated into a comprehensive Watershed Management Plan to guide stewardship of this watershed for the coming decades.

2.0 Watershed Description

2.1 Location

The Manell-Geus watersheds are located at the southwestern side of Guam encompassing Merizo Village. The headwaters of the Manell-Geus watersheds are primarily public property managed by the Chamorro Land Trust Commission. However, most areas transitioning into the coastal plains are privately owned. The maximum point of elevation in the Manell watershed is approximately 1,106 feet (EA Engineering, Science, Technology, 2014). The maximum point of elevation in the Geus watershed is approximately 1,122 feet (Guam Forest Action Plan Advisory Committee, 2021). The Geus watershed is situated between the peaks of Mt. Schroeder, Mt. Finansanta, and Mt. Sasalaguan (Khosrowpanah et al., 2015). The Geus watershed has experienced substantial anthropogenic disturbance in recent history. In particular, the Geus River channel was modified in the lower reach through substantial artificial bank stabilization, as well as the addition of three major impoundments (Camacho et al., 2016).

Immediately bordering the Manell-Geus watershed is Cocos Lagoon, an atoll-like coral reef. The lagoon is separated from the open ocean by a series of fringing reefs and barriers islands, including Cocos Island. Cocos Lagoon is a popular area for tourists and locals for recreational activities including fishing, boating, and diving, in addition to subsistence fishing (Guam EPA, 2020).

Date: 6/8/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI
This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.

- Towns
- Rivers
- ▭ Subwatersheds
- ▭ Watersheds
- Roads
- ▭ Municipalities



Manell Geus
Subwatersheds.

Figure 1. Manell-Geus subwatershed delineation (Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI).

2.2 Size

The Manell and Geus watersheds are smaller in comparison to the rest of the watersheds in the country (**Table 1**). While the Geus watershed is the second smallest of the major watersheds in Guam, it has the second highest mean slope of 33% (Khosrowpanah et al., 2015).

Table 1. Manell-Geus Watershed Size and Stream Length

Watershed Characteristics	Manell Watershed	Geus Watershed
Drainage Area	4.55 sq. miles	1.73 sq. miles
Combined Total River Length	7.89 miles	2.71 miles
Total Length of Perennial Streams	12.7 miles	3.3 miles
Total Length of Intermittent Streams	3.6 miles	-

Dataset used is from EA Engineering, Science, Technology (2014) and Guam Forest Action Plan Advisory Committee (2021).

2.3 Subwatersheds

The Manell-Geus watershed contains several subwatersheds (**Table 2**).

Table 2. Manell and Geus Subwatersheds

Watershed	River	Approximate Length	Water Body Discharging To
Manell	Ajayan	2.91 miles	Ajayan Bay
Manell	Nelansa (Manell)	2.01 miles	Pacific Ocean
Manell	Laolao	0.98 miles	Pacific Ocean
Manell	Fintasa	0.77 miles	Pacific Ocean
Manell	As Liyog	0.72 miles	Pacific Ocean
Manell	Asgadao	0.5 miles	Pacific Ocean
Geus	Geus	2.71 miles	Philippine Sea

Dataset used is from EA Engineering, Science, Technology (2014) and Guam EPA (2020).

The Nelansa (Manell) subwatershed is an area of about 1.13 square miles. The subwatershed extends from Mount Sasalaguan to Achang Bay. The subwatershed slope is moderately steep at approximately 13%. This river is predominantly natural and unlined, until it moves through a concrete-lined drainage ditch that runs parallel to and under Route 4. The Manell River is joined by a tributary from the west at a point just above Route 4. A 2020 U.S. Army Corps of Engineers Flood Hazard Study developed a one-dimensional study flow model of the subwatershed. The study indicated that floodwaters enter the overbank areas and residential properties as often as the 50% AEP (2 year) event due to the narrow channel, low overbanks, and structural constrictions along the Manell River (U.S. Army Corps of Engineers, 2020b).

3.0 Land Use and Land Cover

3.1 Village of Merizo

The Manell-Geus watersheds encompass the village of Merizo. The municipality also include Cocos Island, accessible via boat off the coast of the mainland. Merizo (traditional village name Malesso'), is part of the Southern (Haya) District. The village name is derived from the word "lesso," the juvenile rabbit fish locally known as "manahak." These fish were traditionally caught at the mouth of the bay by villagers (Mayor's Council of Guam, n.d.). Today, the Village continues utilizing traditional fishing practices (NOAA et al., 2016). 2016 household surveys of Merizo residents indicated that 58% of Merizo residents engage in fishing activities (NMFS PIRO, in prep).

Access into the Geus Valley is provided via Espinosa Street, which extends about one mile inland along the Geus River. This region contains fairly limited residential development. Of the surrounding ridges, only the western ridge contains multiple developments including housing, the Pigua subdivision, Merizo Elementary School and Ball Park, and the Merizo Community Center and Mayor's Office (Khosrowpanah et al., 2015). Most villagers live in the rural valleys of the municipality. Commerce in the village is primarily limited to the Cocos Island Resort and its vendors, in addition to a few small village-based retail stores and a gas station (Chargualaf and Mansapit, 2014).

The population of Merizo is currently estimated to be 1,604 (U.S. Census Bureau, 2020). Merizo contains approximately 345 households (NOAA et al., 2016). A majority of Merizo residents identify as Chamorro (U.S. Census Bureau, 2010b). About 50% of the population in Merizo, ages 5 years and over, speak English only. Of the residents who speak a language other than English, Chamorro is the most common Pacific Island language spoken at 87%. Residents speaking Filipino make up 5% of the population and 7.3% of the population speak other Pacific languages (U.S. Census Bureau, 2010b). Merizo's population consists mainly of people ages 16 years and older, with an overall equal number of males and females, with more males in the younger age class (16 and older) and more females in the older age classes (18 and older) (U.S. Census Bureau, 2010a). Of residents ages 25-64, approximately 20% attained less than a high school education, approximately 50% attained a high school diploma, approximately 20% attained some college or associates degrees, and approximately 10% attained a bachelor's degree or higher (U.S. Census Bureau, 2010a). Median family income in Merizo in 2009 dollars was approximately \$55,833 (U.S. Census Bureau, 2010c).

3.2 Land Use

While developed land is fairly limited along the coastline of the watershed, disturbed areas, primarily from arson, are present in larger numbers in the watershed (**Figure 2**). Based on the 1994 Guam Generalized Land Use Map (**Figure 3**), parks, recreation, and open space make up the majority of the Manell-Geus watershed. Limited residential developments, farmland, and roadways cover the lower reaches of the watershed (W.B. Flores et al., 1994).

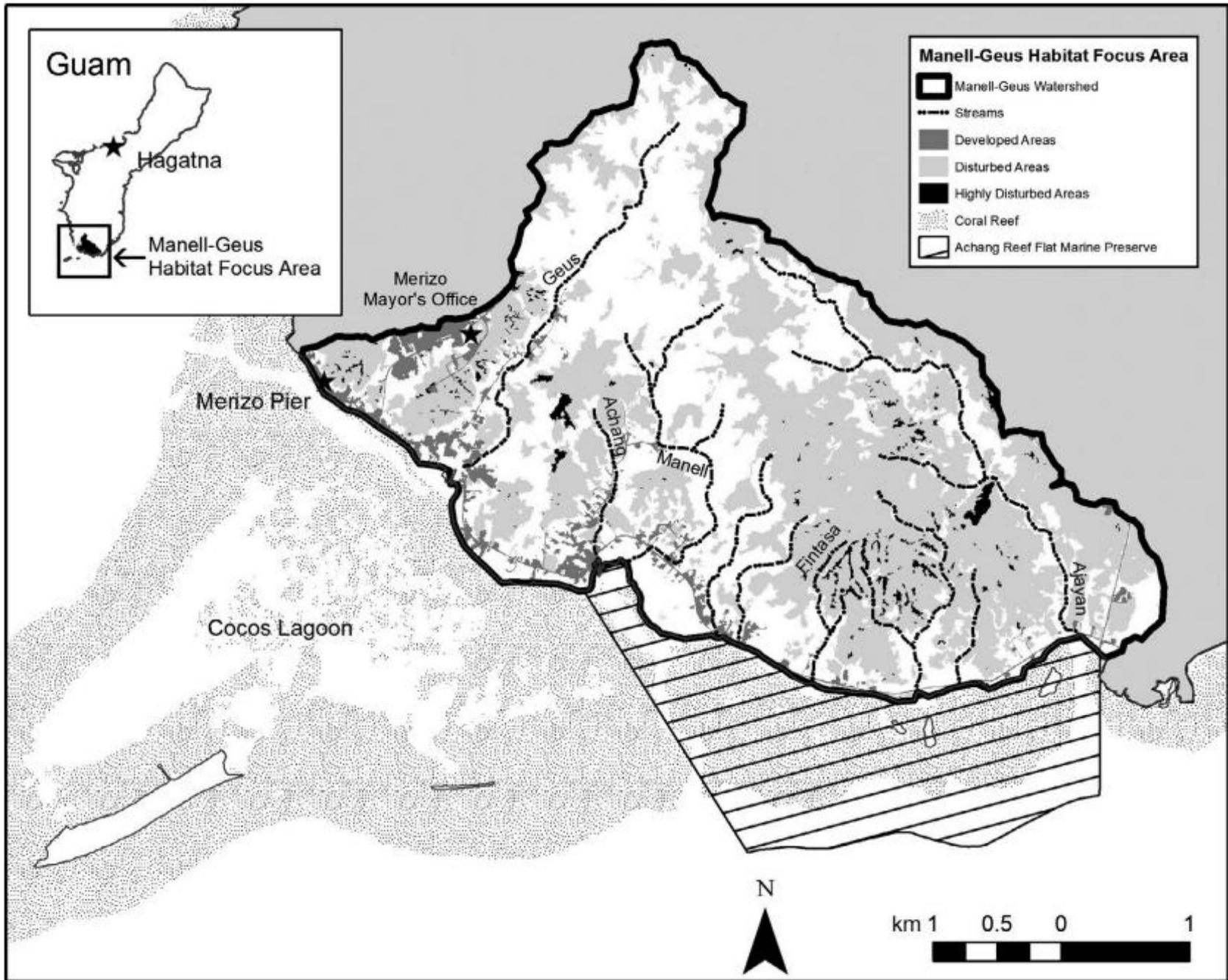
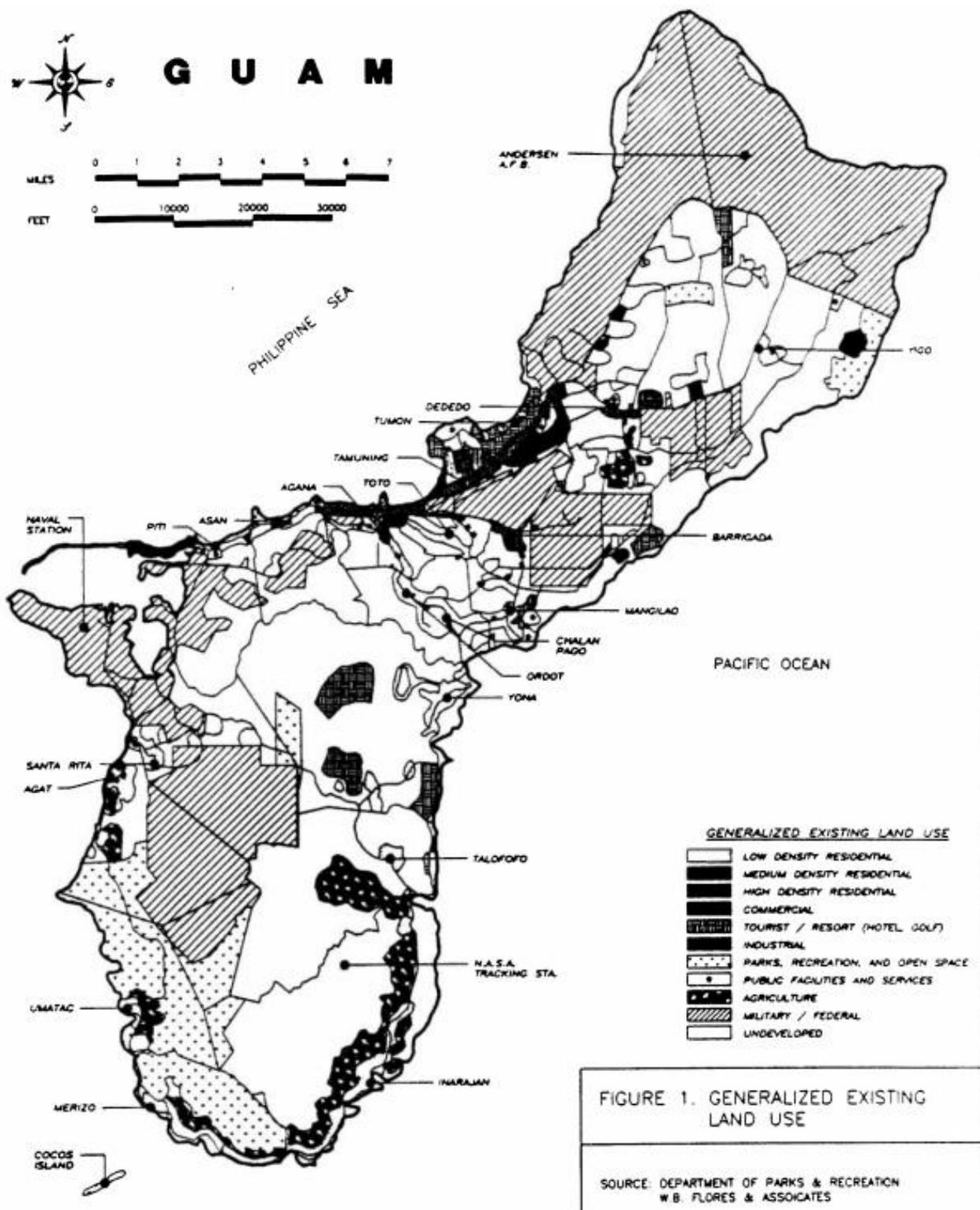


Figure 2. Manell-Geus Watershed Developed, Disturbed, and Highly Disturbed Areas (NOAA, 2012).



W.B.FLORES/STRATEGIC PLANNING GROUP JV
 PREPARED BY PATTON HARRIS RUST & ASSOCIATES

FIGURE 1. GENERALIZED EXISTING LAND USE

SOURCE: DEPARTMENT OF PARKS & RECREATION
 W.B. FLORES & ASSOCIATES

Figure 3. 1994 Guam Generalized Land Use (W.B. Flores et al., 1994).

3.3 Land Cover

Landcover in the Manell and Geus watersheds (**Figure 4**) includes the following:

Table 3. Landcover in the Geus and Manell Watersheds

Watershed	Land Cover Type	Area (acres)	Percentage
Geus	Bare Land	14.83	1%
Geus	Developed Land	101.31	9%
Geus	Forest	518.92	46%
Geus	Open Water	0	0%
Geus	Shrub/Grassland	459.62	42%
Geus	Wetlands	27.18	2%
Geus	Other	0	0%
Manell	Bare Land	49.42	2%
Manell	Developed Land	93.9	3%
Manell	Forest	1107.03	35%
Manell	Open Water	7.41	0%
Manell	Shrub/Grassland	1801.4	58%
Manell	Wetlands	27.18	1%
Manell	Other	32.12	1%

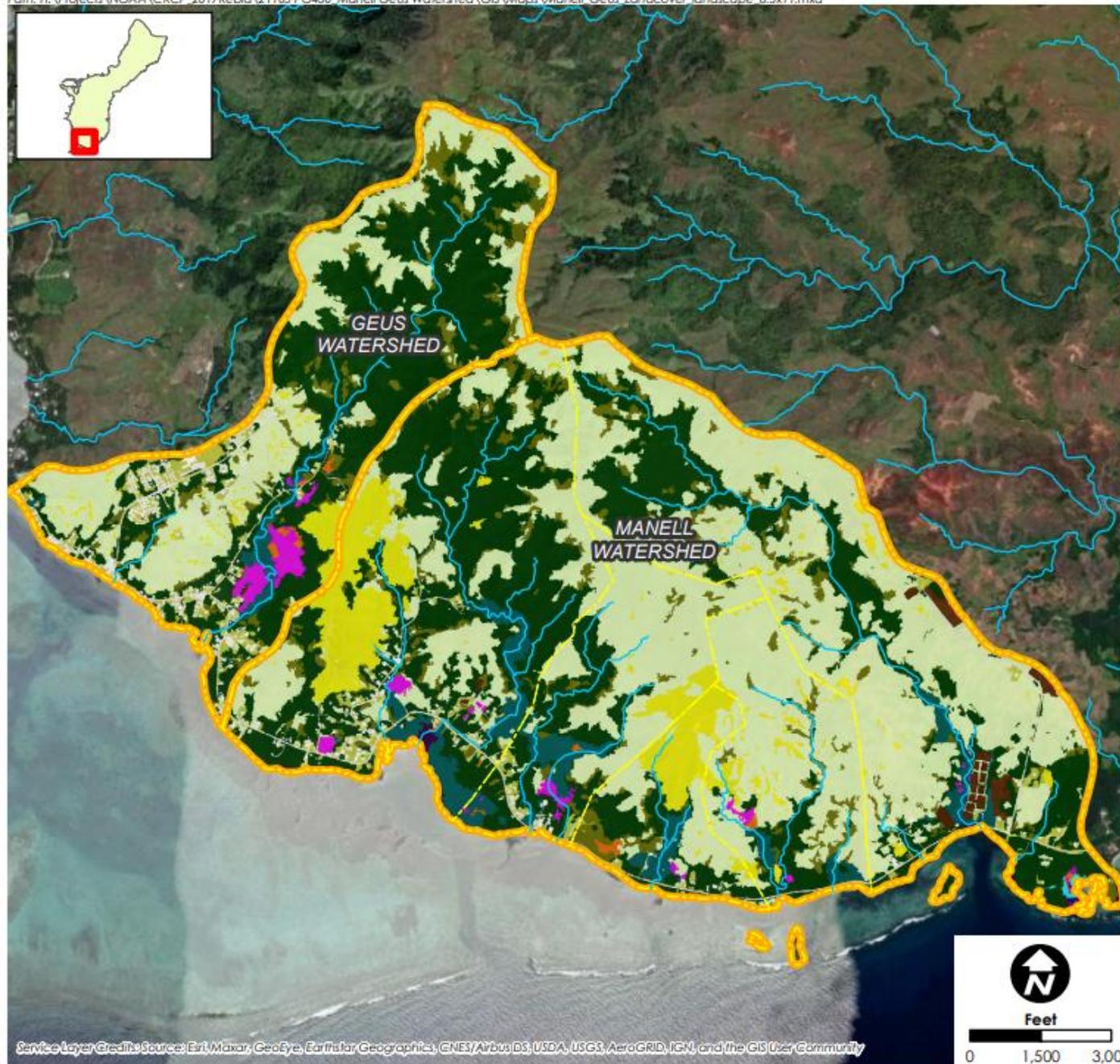
Dataset used is from Amidon et al. (2017).

3.4 Regulatory Designations

In 1997, a network of marine preserves was established in Guam in response to decreasing nearshore fish stocks (NOAA, 2007). The Achang Reef Flat Marine Preserve, located on the eastern end of Cocos Lagoon, was established by the Division of Aquatic and Wildlife Resources of the Guam Department of Agriculture (**Figure 5**) (Pait et al., 2019). The preserves are managed by the Guam Division of Aquatics and Wildlife Resources within the Guam Department of Agriculture. Covering an area of 4.85 km², fishing in the preserve is restricted except by special permit (Chargualaf and Mansapit, 2014).

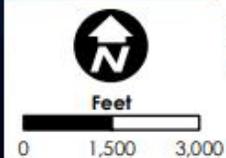
Date: 6/9/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.



- Rivers
- Subwatersheds
- Watersheds
- 2016 NOAA C-CAP Landcover**
- Impervious
- Developed, Open Space
- Cultivated Crops
- Grassland/Herbaceous
- Evergreen Forest
- Scrub/Shrub
- Palustrine Forested Wetland
- Palustrine Scrub/Shrub Wetland
- Palustrine Emergent Wetland
- Estuarine Forested Wetland
- Estuarine Scrub/Shrub Wetland
- Estuarine Emergent Wetland
- Unconsolidated Shore
- Bare Land
- Open Water

2016 NOAA C-CAP
Landcover Classes.



Service Layer Credits: Source: Earthstar, GeoEye, Earthstar, Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4. 2016 NOAA C-CAP land cover in the Manell and Geus watersheds (Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI).

Date: 6/8/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI

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Achang Reef Flat Marine Preserve.

Figure 5. Achang Reef Flat Marine Preserve (Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI).

3.5 Historic and Cultural Sites

There are several notable historic and cultural sites within the Manell and Geus watersheds (**Figure 6**):

- The San Dimas Catholic Church was dedicated in 2002 and serves an important gathering center for the community (Chargualaf and Mansapit 2014).
- The Malesso' Pier Park, *Plasan Tantalán Beteranon Mansendalon Malesso'* (Malesso Veteran Sons and Daughters Pier Park) was named in honor of the men and women from Malesso' who have served in the US Armed Forces, and in acknowledgement of all Guam Veterans. The pier faces the Mama'on Channel, the main pass into Cocos Lagoon (Chargualaf and Mansapit, 2014).
- The Malesso' Kombento is a 19th century two-story structure built using Spanish-influenced Chamorro construction. In 2000, it was restored using funds from the Guam Preservation Trust. Today, it houses the parish priest and a small museum (Plate, 2021).
- The Malesso' Belltower, or *Kampanayun Malesso*, dates to 1910 and the tenure of Father Cristobal de Canals. It is included in the National Register of Historic Places (Plate, 2021).
- The Santa Marian Kamalen Shrine and Park is located near the *Kombento* and the Belltower (Plate, 2021).
- The Malesso' Pillbox is located approximately 100 meters south of the mouth of the Guam River. The structure was built during Japanese occupation of Guam and is the only recorded Japanese fortification along the Merizo shoreline. The site is included in the National Register of Historic Places (National Archives Catalog, 2022c).
- The Merlyn G. Cook Schoolhouse was built in approximately 1931 and was deemed Guam's "largest and best school" upon its construction. The school was first occupied by Japanese soldiers when Japan invaded Guam on December 9, 1941. During the period of occupation, the school later became a refuge for Guamanians taking shelter from Japanese soldiers. Today the school serves as a center for both youth and senior citizens. The site is included in the National Register of Historic Places (National Archives Catalog, 2022d).
- The Malesso' Japanese Rice Mill is associated locally with the families of Malesso that were involved with forced Japanese rice production and labor during the Japanese occupation of the area during World War II. The building also represents a rare example of non-military Japanese architecture from a significant period of Guam's history. The site is included in the National Register of Historic Places (National Archives Catalog, 2022e).
- The Tinta Massacre Site was the site of the massacre of sixteen Merizo civilians by Japanese troops six days prior to the liberation of Guam on July 15, 1944. The site retains the same natural setting that was present at the time of the event. The site serves to represent the suffering and hardships that the Guamanian people were forced to endure during Japanese occupation of the island. The site is included in the National Register of Historic Places (National Archives Catalog, 2022a).
- The Faha Massacre Site was the site of the massacre of thirty Merizo civilians by Japanese troops five days prior to the liberation of Guam on July 16, 1944. The event is recognized as a culminating factor provoking the Guamanian rebellion against the Japanese at Atate on July 20, 1944. The site includes commemorative markers placed at the site by residents. The site serves to represent the suffering and hardships that the Guamanian people were forced to endure during Japanese occupation of the island. The site is included in the National Register of Historic Places (National Archives Catalog, 2022b).

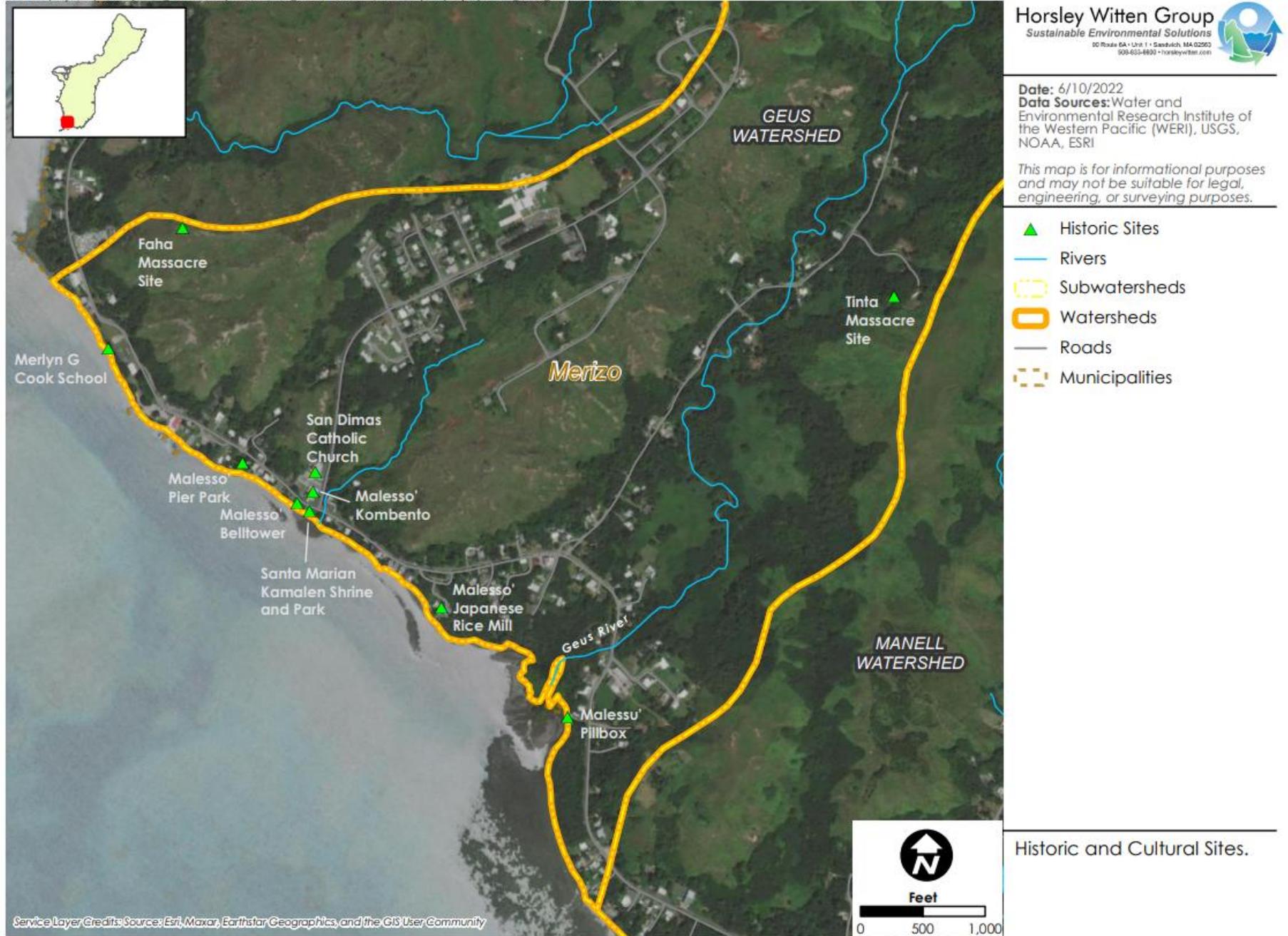


Figure 6. Merizo historic and cultural sites (Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI).

4.0 Infrastructure

4.1 Wastewater

In a 2010 survey of Merizo residents, approximately 72% of the population indicated that they dispose of their sewage via public sewer, while 25% utilized a septic tank or cesspool (King, 2010).

The below figure shows the sewer infrastructure for the Umatac-Merizo Wastewater Treatment Plant (WWTP), operated by the Guam Waterworks Authority under an issued current NPDES permit (permit no. GU0020273).

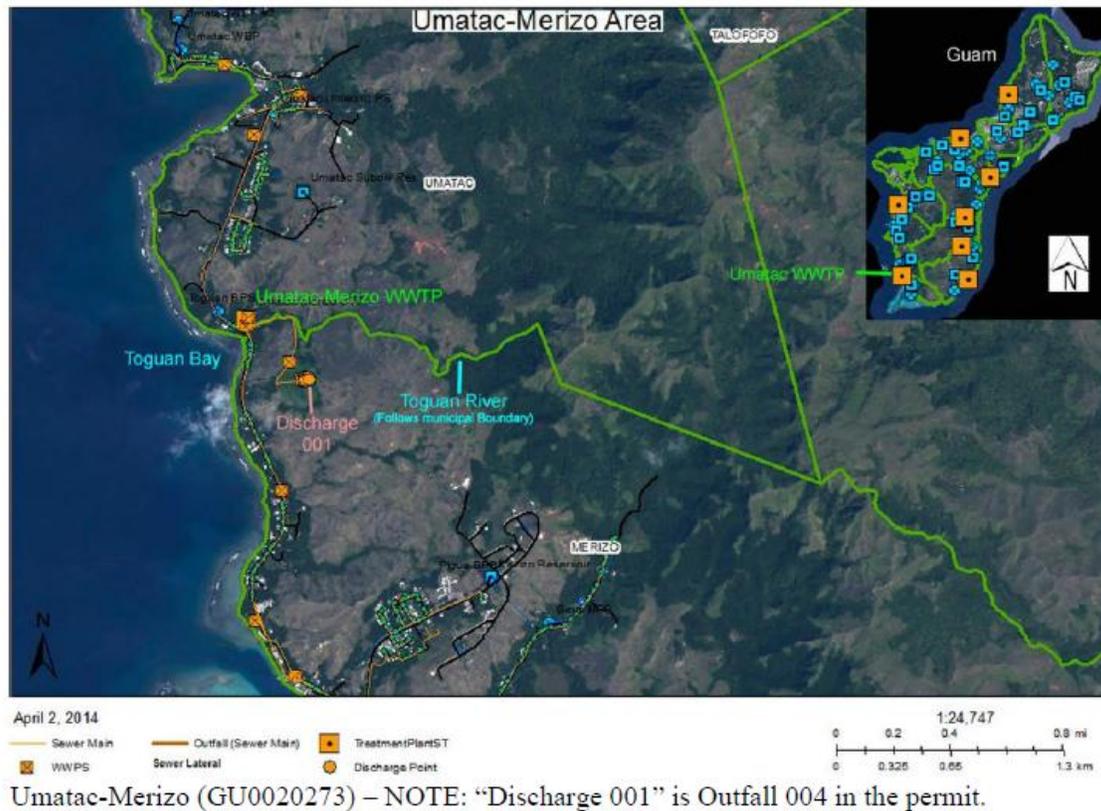


Figure 7. Map of sewer infrastructure for the Umatac-Merizo NPDES permit (NPDES Permit No. GU0020273).

4.2 Stormwater

In 2010, the Government of Guam Department of Public Works (DPW) published a Stormwater Drainage Master Plan, via Parsons Public Transportation Group, Inc., which identifies existing storm water drainage patterns and systems throughout the island of Guam and provides an assessment of potential projects that could improve drainage conditions on the island. The intent of the report is to provide a systematic approach for drainage improvement for the island of Guam. The report evaluates approximately 300 project sites and prioritizes improvement projects from both a village and routed road level of interest/benefit. The report sections include:

- Methodology of defining drainage improvements;
- Criteria used to evaluate needed drainage improvements;

- Probable costs of improvements;
- Prioritization of projects for Capital Improvement Program (CIP) inclusion; and
- Available funding.

The report provides a prioritized list of drainage improvement projects for each village based on criteria detailed in Section 3 of the report. A total of 30 potential projects were considered for the village of Merizo, covering drainage improvements for both the Manell and Geus watersheds (**Figure 8**).

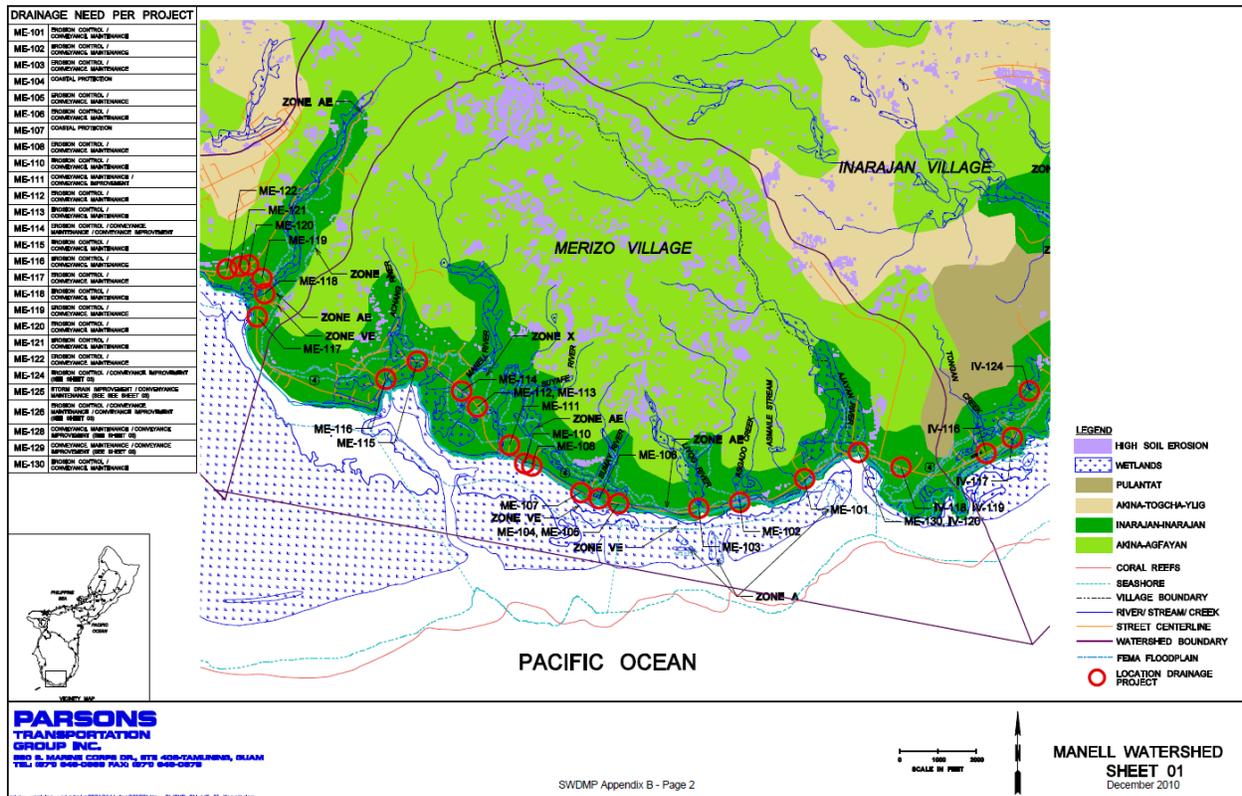


Figure 8. Drainage improvement projects list and map for the Village of Merizo (Guam DPW SW Drainage Master Plan).

The SWDMP’s projected costs to complete the drainage improvement projects for the Village of Merizo is \$13.2 million US dollars, which represents 8.8 percent of the total estimated costs for completion of all projects, island-wide (**Figure 9**).

VILLAGE	PROJECTED COST (million \$)	% OF TOTAL
TOTAL ALL VILLAGES	150	100
Agana Heights	2.76	1.9
Agat	7.92	5.3
Asan	9.38	6.3
Barrigada	4.57	3.0
Chalan Pago-Ordot	5.50	3.7
Dededo	3.79	2.5
Hagatna	12.2	8.1
Inarajan	7.62	5.1
Mangilao	7.37	4.9
Merizo	13.2	8.8
Mongmong-Toto-Maite	1.08	0.7
Piti	36.6	24.4
Santa Rita	5.50	3.7
Sinajana	0.13	0.1
Talofofo	6.31	4.2
Tamuning	16.6	11.1
Umatac	7.58	5.1
Yigo	0.60	0.4
Yona	1.01	0.7

Figure 9. Projected costs for potential drainage improvement projects for the island of Guam (Guam DPW SW Drainage Master Plan).

The report identifies high priority projects for the Village of Merizo, based on the criteria detailed in Section 3. The top five ranked projects for Merizo include ME-102, ME-103, ME-119, ME-128, and ME-129, which are summarized in Appendix C of the report (**Figure 10**). To date, none of these projects have been planned or implemented in Merizo. However, the planning process for ME-114 at Route 4 and the Manell Channel, and ME-130 at Route 4 and the Ajayan River is underway. ME-126 at Route 4 and the Pigua River was completed. This project involved the widening of a cross culvert and embankment stabilization upstream and downstream of the culvert. Additional detail on cost estimates can be found in Appendix D of the report. Appendix E provides tables that rank each village’s drainage improvement projects, with data fields that include details on site location, evaluation categories, and assessment descriptions, as well as mitigation type, effort, descriptions, and costs estimates.

VILLAGE	Priority Projects
Agana Heights	AG-103,, AG-102 AG-101, AG-104
Agat	AV-128, AV-109, AV-125, AV-121, AV-111
Asan	AS-112, AS-111, AS-109, AS-104, AS-102
Barrigada	BV-116, BV-112, BV-131, BV-110, BV-130
Chalan Pago-Ordot	CP-111, CP-112, CP-102, CP-107, CP-104
Dededo	DE-101, DE-102, DE-103, DE-106, DE-105
Hagatna	HA-109, HA-105, HA-103, HA-110,HA-119
Inarajan	IV-116, I-102, IV-124, IV-104, IV-120
Mangilao	MO-111, MO-106, MO-107, MO-108, MO-102
Merizo	ME-102, ME-119, ME-128, ME-103, ME-129,
Mongmong-Toto-Maite	MM-101
Piti	PI-107, PI-103, PI-108, PI-111, PI-102
Santa Rita	SR-107, SR-109, SR-105, SR-108, SR-102
Sinajana	SV-102, SV-101
Talofofo	TA-102, TA-108, TA-113, TA-116, TA-112
Tamuning	TV-109, TV-110, TV-103, TV-108, TV-105
Umatac	UM-101, UM-108, UM-112, UM-109, UM-106
Yigo	YI-101, YI-102, YI-103, YI-107, YI-109
Yona	YO-103, YO-107, YO-105, YO-101, YO-108

Figure 10. High priority projects listed by village (Guam DPW SW Drainage Master Plan).

In addition to using villages as the underlying focus for drainage project prioritization, the SWDMP also reviewed potential improvement projects based on those which were located along routed roads. Appendix F of the report contains additional tables similar to those found in Appendix E, but only reviewing and ranking those projects located along routed roads, which reduces the overall number of projects considered to approximately 170.

The SWDMP’s projected costs to complete the drainage improvement projects along routed roads for the Village of Merizo is \$12.5 million US dollars, which represents 11.2 percent of the total estimated costs for completion of all projects along routed roads, island-wide (**Figure 11**).

VILLAGE	PROJECTED COST (million \$)	% OF TOTAL
TOTAL ALL VILLAGES	112	100
Agana Heights	0.2	0.2
Agat	5.4	4.8
Asan	7.5	6.7
Barrigada	2.1	1.9
Chalan Pago-Ordot	0.4	0.4
Dededo	2.7	2.4
Hagatna	11.9	10.6
Inarajan	3.3	3.0
Mangilao	2.4	2.1
Merizo	12.5	11.2
Mongmong-Toto-Maite	1.1	1.0
Piti	35.3	31.5
Santa Rita	2.0	1.8
Sinajana	0.1	0.1
Talofoto	3.5	3.1
Tamuning	15.6	13.9
Umatac	5.3	4.7
Yigo	0.3	0.3
Yona	0.2	0.2

Figure 11. Projected costs for potential drainage improvement projects along routed roads for the island of Guam (Guam DPW SW Drainage Master Plan – Appendix F).

The top five ranked projects along routed roads for Merizo include ME-106, ME-110, ME-114, ME-127, and ME-129, which are summarized in Appendix C of the report (Figure 12).

VILLAGE	Priority Projects	Total Estimated Cost (million \$)
Agana Heights	AG-104	0.2
Agat	AV-128, AV-109, AV-121, AV-111, AV-120	0.9
Asan	AS-112, AS-111, AS-104, AS-102, AS-103,	7.5
Barrigada	BV-112, BV-131, BV-110, BV-130, BV-134	0.5
Chalan Pago-Ordot	CP-112, CP-107, CP-104	0.4
Dededo	DE-101, DE-102, DE-106, DE-117, DE-111	1.0
Hagatna	HA-109, HA-105, HA-103, HA-110, HA-119	5.1
Inarajan	IV-116, I-102, IV-104, IV-120, IV-118	0.6
Mangilao	MO-114, MO-113, MO-115, MO-116	2.4
Merizo	ME-129, ME-127, ME-106, ME-114, ME-110	8.3
Mongmong-Toto-Maite	MM-101	1.1
Piti	PI-107, PI-108, PI-111, PI-102, PI-112	1.0
Santa Rita	SR-107, SR-109, SR-108, SR-120, SR-116	1.0
Sinajana	SV-102	0.1
Talofoto	TA-113, TA-116, TA-112, TA-114, TA-115	3.5
Tamuning	TV-109, TV-110, TV-103, TV-108, TV-101	15.6
Umatac	UM-101, UM-112, UM-109, UM-106, UM-110	4.7
Yigo	YI-101, YI-107, YI-109, YI-106	0.3
Yona	YO-105, YO-101	0.2

Figure 12. High priority projects along routed roads, listed by village (Guam DPW SW Drainage Master Plan – Appendix F).

There are two existing/active MS4 permits with coverage in the Manell/Geus watersheds. One of the permits (NPDES Permit No. GUS040000) is issued to the Department of the Navy (DON) and the other (NPDES Permit No. GUS040001) is issued to the Guam Department of Public Works (**Figures 13 and 14**).

NPDES PERMIT NO. GUS040000 (As Modified on _____)	
In compliance with the provisions of the Clean Water Act (“CWA”) (Public Law 92-500, as amended, 33 U.S.C. 1251 et seq.), the following discharger is authorized to discharge stormwater runoff and specified non-stormwater discharges from all outfalls from the facility specified below, in accordance with the effluent limits, monitoring requirements, and other conditions set forth in this permit:	
Discharger Name	Department of the Navy (DON)
Discharger Address	Department of the Navy Naval Base Guam (NBG) PSC 455, Box 152 FPO AP, Guam 96540-1000
Facility Name	Municipal Separate Storm Sewer System (MS4)
Facility Location Address	Department of Defense Facilities on the Island of Guam
Facility Rating	Minor
Modification issued on	
Modification became effective on	
This permit was issued on:	December 20, 2018
This permit became effective on:	February 1, 2019
This permit shall expire at midnight on:	January 31, 2024

Figure 13. Department of the Navy MS4 permit details (NPDES Permit No. GUS040000).

NPDES PERMIT NO. GUS040001	
In compliance with the provisions of the Clean Water Act (“CWA”) (Public Law 92-500, as amended, 33 U.S.C. 1251 et seq.), the following discharger is authorized to discharge stormwater runoff and specified non-stormwater discharges from all outfalls from the facility specified below, in accordance with the effluent limits, monitoring requirements, and other conditions set forth in this permit:	
Discharger Name	Guam Department of Public Works
Discharger Address	Department of Public Works (DPW) 542 N. Marine Corps Drive Tamuning, Guam 96913
Facility Name	Municipal Separate Storm Sewer System (MS4)
Facility Location Address	DPW MS4 on the Island of Guam
Facility Rating	Minor
This permit was issued on:	December 20, 2018
This permit shall become effective on:	February 1, 2019
This permit shall expire at midnight on:	January 31, 2024

Figure 14. Guam DPW MS4 permit details (NPDES Permit No. GUS040001).

4.3 Drinking water

The Guam Consolidated Commission on Utilities (CCU) comprises the Guam Waterworks Authority (GWA) and the Guam Power Authority (GPA). The CCU supplies power, drinking and wastewater services for all of Guam. Sources of water supply for the GWA in the Southern Region of Guam include an intake from the Ugum River, in addition to water purchased from the US Navy Water System (**Figure 15**) (U.S. Army Corps of Engineers, 2022).

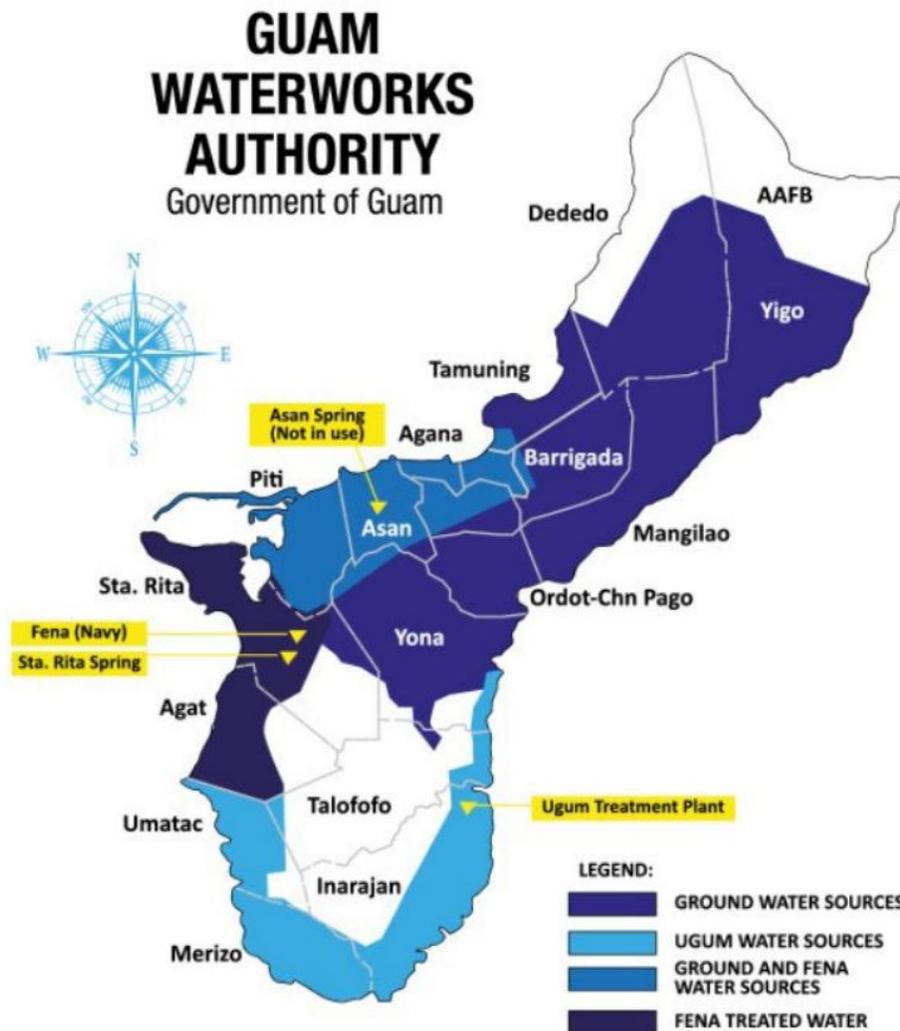


Figure 15. Guam Waterworks Authority Territory (U.S. Army Corps of Engineers, 2022).

4.4 Other

Healthcare Infrastructure:

The Guam Memorial Hospital and Guam Regional Medial City are the two main medical facilities providing health services to the civilian population of Guam. The Guam Memorial Hospital is located in Tamuning, and the Guam Regional Medical City is located Dededo. Many private medical and dental clinics are also established on the island. The military population in Guam receives medical services from the Naval Hospital Guam, which also provides voluntary services to the civilian population (ACOE, Watershed Assessment, Appendix B).

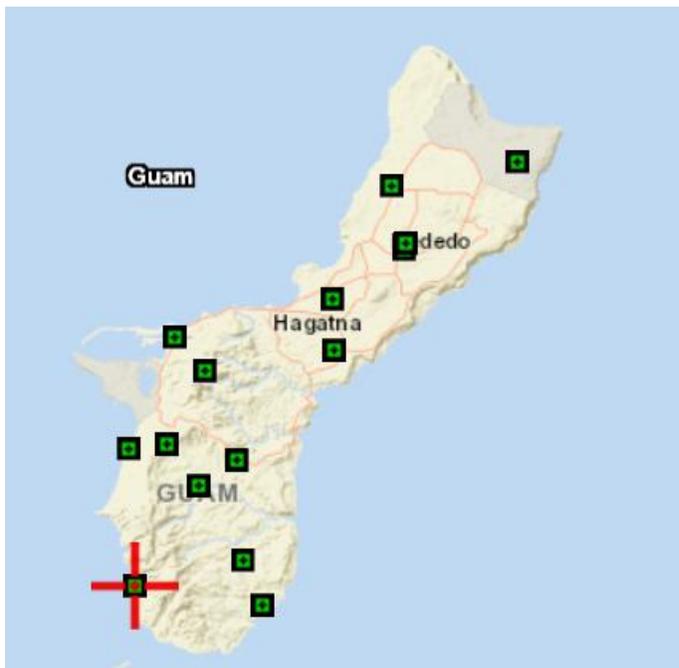
Energy:

The island of Guam meets its existing energy demands by importing petroleum products, based on information from the U.S. Energy Information Administration. The petroleum products are used as gasoline and jet fuel, as well as to produce electricity, after being received by the seaport in Apra. Power generation and delivery oversight is the responsibility of the Guam Power Authority. The Guam Power Authority provides electricity to end users that include the government, the U.S. military, residential households, private office buildings, restaurants, and hotels. The Dandan facility generates solar power, which is the island's primary source of renewable energy. Guam is considering energy generation via wind turbines; however, this type of renewable energy system needs to account for additional challenges such as earthquakes, typhoons, and environmental impacts, which necessitate additional research and development before they can be designed and implemented properly (ACOE, Watershed Assessment, Appendix B).

5.0 Hydrology & Coastal Dynamics

5.1 Mean Annual Precipitation

The climate of Guam is characterized by a dry season from January through June. The dry season provides approximately 30% of the annual total rainfall. The rainy season, from July through December, provides approximately 70% of the annual total rainfall (Khosrowpanah et al., 2015). Mean annual precipitation in the Manell watershed is 96 inches. Mean annual precipitation in the Geus watershed is 100 inches (Pait et al., 2019). Within the watersheds, high velocity runoff events of relatively short duration are frequent in the mountainous areas (Pait et al., 2019). Exceptionally dry years occur about once every four years in correlation with episodes of El Niño Southern Oscillation (ENSO) in the Pacific (Grecni et al., 2020).



Recurrence Interval (24-hour duration)	Precipitation (in) NOAA Atlas 14
1 year	4.76 (3.82-5.98)
2 year	6.32 (5.07-7.94)
5 year	8.46 (6.76-10.7)
10 year	10.1 (8.06-12.8)
25 year	12.4 (9.80-15.8)
100 year	16.1 (12.4-20.8)

Figure 16. NOAA Umatac Precipitation Station, Guam (left) and precipitation totals for 24-hour storm events (right) (NOAA Atlas 14).

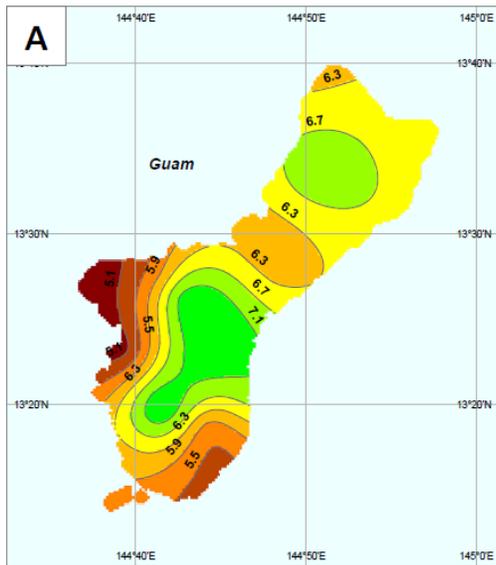


Figure 17. Isopluvial of 24-hour precipitation event with average recurrence interval of 2-years in Guam (NOAA Atlas 14).

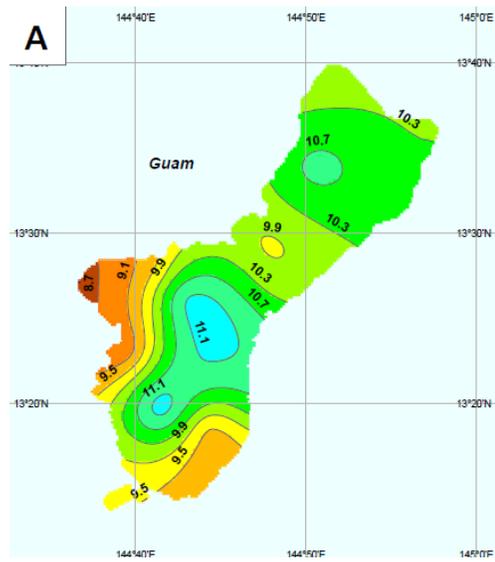


Figure 18. Isopluvial of 24-hour precipitation event with average recurrence interval of 10-years in Guam (NOAA Atlas 14).

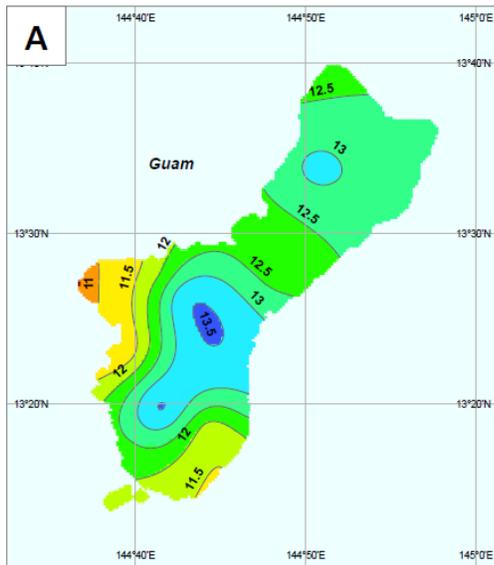


Figure 19. Isopluvial of 24-hour precipitation event with average recurrence interval of 25-years in Guam (NOAA Atlas 14).

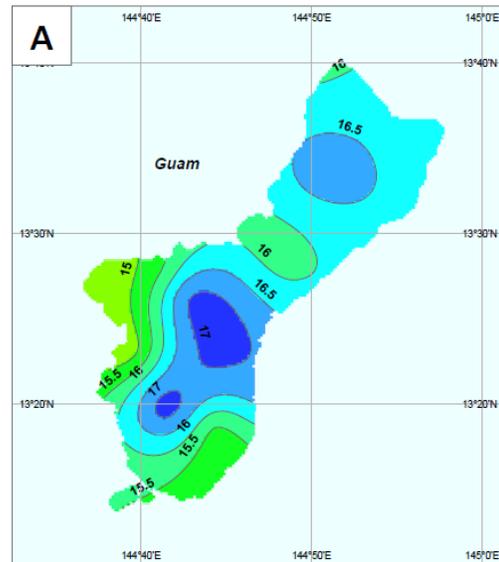


Figure 20. Isopluvial of 24-hour precipitation event with average recurrence interval of 100-years in Guam (NOAA Atlas 14).

5.2 Streamflow/Discharge

The Manell and Geus stream and river systems transition through three different valley types and several stream types. Using Rosgen's 1996 *Applied River Morphology*, the valley and stream types for the Manell and Geus watershed include the following:

- Upper elevations and the first-order stream contained within the valley are type VII. They are characterized by steep, highly dissected fluvial slopes that contain predominantly low-sinuosity A and G stream types (EA Engineering, Science, Technology, 2014).
- Lower reaches which approach the coastline and tidal influence are valley type III, alluvial fans and debris cone dominated systems. These sections have been substantially transformed by agriculture and residential development, as well as stream pattern modification to accommodate built infrastructure. This valley type is primarily G stream types and second- and third-order streams (EA Engineering, Science, Technology, 2014).
- At the coastal plain and tidal interface, the valley type transitions to type XI. These types include deltaic landforms with wave and/or tidal influence. This area has also been modified by infrastructure, agriculture and residential development. The stream types include entrenched G and F stream types and a single fourth- or higher-order stream (EA Engineering, Science, Technology, 2014).

Valley Types	Summary Description of Valley Types	Stream Types
I	Steep, confined, V-notched canyons, rejuvenated side-slopes	Aa+, A, G
II	Moderately steep, gentle-sloping side-slopes often in colluvial valleys	B, G
III	Alluvial fans and debris cones	A, B, F, G, D
IV	Canyons, gorges and confined alluvial and bedrock-controlled valleys with gentle valley slopes	C, F
V	Moderately steep, U-shaped glacial-trough valleys	C, D, F, G
VI	Moderately steep, fault-, joint- or bedrock-controlled valleys	Aa+, A, B, C, F, G
VII	Steep, fluvial dissected, high-drainage density alluvial slopes	Aa+, A, G
VIII	Alluvial valley fills either narrow or wide with moderate to gentle valley slope with well-developed floodplain adjacent to river, and river terraces, glacial terraces or colluvial slopes adjacent to the alluvial valley	C, D, E, F, G
IX	Broad, moderate to gentle slopes, associated with glacial outwash or eolian sand dunes	C, D, F
X	Very broad and gentle valley slopes associated with glacio- and nonglacio-lacustrine deposits	C, DA, D, E, F, G
XI	Deltas	C, D, DA, E

Figure 21. Rosgen Valley and Stream Types (Rosgen and Silvey, 1996).

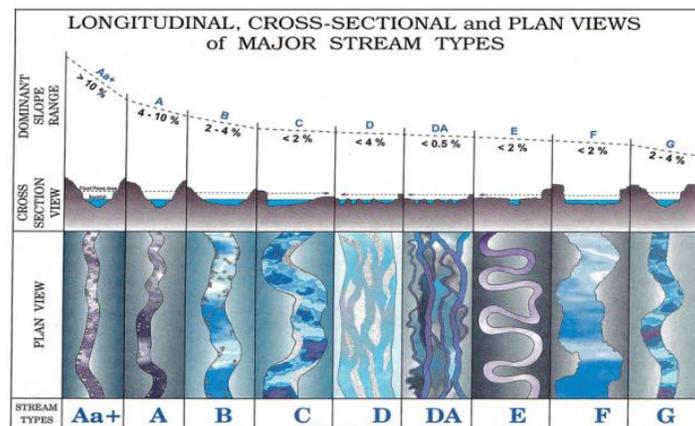


Figure 22. Rosgen Stream Types (Rosgen and Silvey, 1996).

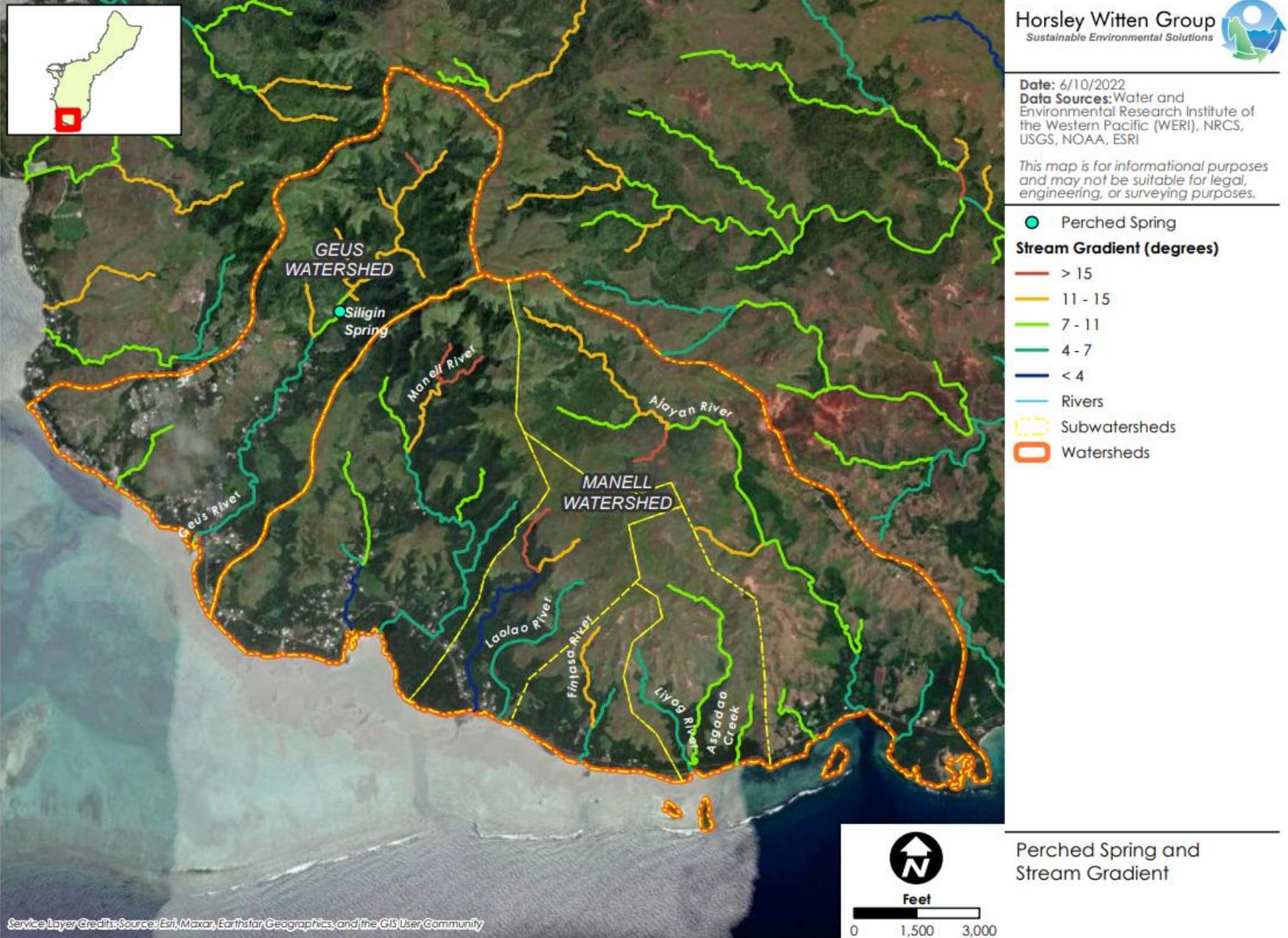


Figure 23. Perched springs and stream gradient in the Manell-Geus watershed (NRCS, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

The Geus River is characterized by three biotope regions, which included the headwater, the mid-valley, and the lower valley regions. The headwater region is a narrow section of the river where water flows rapidly around a boulder-strewn bed and through a series of riffles and pools. The headwater region stretches from the base of the mountains to a small impoundment. Downstream of the headwater region is the mid-valley region. The mid-valley region stretches from just below the impoundment to the bridge that spans route 4. The river in the mid-valley region flows relatively freely to form shallow pools and riffles in places, as the bed material transitions from the boulders in the headwater region to loose pebbles and alluvium. Beyond the route 4 bridge, the Geus River transitions to the lower valley region, which extends from the bridge to the alluvial delta located adjacent to the Mamaon Channel. The river is estuarine in this section, due to tidal influence, and becomes increasingly more saline between the upper and lower portions of this region. The bed material in the lower valley region is comprised of coarse alluvial deposits (Kami et al, 1974).

5.2a Geus Watershed

The Geus watershed is a dynamic watershed. A 2015 assessment of conditions in the Geus watershed determined that there is a strong correlation between stream level and rainfall. In addition, the assessment indicated that there was a strong correlation between turbidity and rainfall in the Geus watershed. Intensity of storms was identified as a key factor influencing erosion and runoff as indicated by turbidity levels. For example, during the largest storm event recorded during the study (Tropical Storm Halong on July 30, 2014) the maximum stream level recorded was 7.0 feet at 2:05 am. Duration at that height was a five-minute interval. During that spike, stream level was greater than 6 feet for 30 minutes, greater than 5 feet for 40 minutes, and greater than 4 feet for 70 minutes. Based on this data, the stream level doubled then came back down (from 3.5 to 7 feet) in less than an hour and a half. A similar pattern was exhibited in the turbidity data, which recorded a maximum concentration of 964.9 NTU from 2:15 am to 2:30 am. Turbidity above 900 NTUs lasted about an hour and a half, and significant increases were observed when the stream level rose to more than three feet. Based on the dimensions of the Geus Watershed, the assessment concluded that the river floods appear to last less than a couple of hours (Khosrowpanah et al., 2015).

Geus river



Figure 24. Geus River conditions before and after Tropical Storm Halong (Khosrowpanah et al., 2015).

A 2016 NOAA assessment of the Geus River evaluated stream discharge estimated rates in the lower and upper reaches of the river. The average discharge in the lower reach of the Geus River was 0.005

m·s⁻¹. The mean discharge in the lower reach of the Geus River ranged from 0.0093 ± 0.0050 m·s⁻¹ near the mouth of the river to 0.098 ± 0.05 m·s⁻¹ in upstream sections of the lower reach. The mean discharge in the upper reach of the Geus River was 0.0033 ± 0.0038 m·s⁻¹ (Camacho et al., 2016).

5.3 Groundwater

In the southern half of Guam, fresh groundwater is present in unconsolidated sediments within river drainages, weathered volcanic rock with low permeability, and along the eastern coast's fringing limestone formations. Other than a few springs, groundwater production in southern Guam is primarily restricted to the narrow fringing limestone along the eastern coast, where the water table rarely reaches elevations greater than a few feet above sea level. Brackish to saline groundwater does occur along the southern and western coasts of the southern province within artificial fill, fractured limestone, and unconsolidated marine and estuarine sediments (Guam EPA, 2020). In southern Guam, a majority of the groundwater discharges directly to stream valleys above sea level where there are intersections with the water table. Minor perched systems are found in some of the higher-altitude limestone overlying the volcanic rocks of southern Guam (Gingerich, 2003).

5.4 Hydrodynamics

The Manell Channel separates Cocos Lagoon to the west and the Achang Reef Flat Marine Preserve to the east (**Figure 25**). Cocos Lagoon and the Achang Reef Flat Marine Preserve are both relatively shallow, with an average depth of approximately 6 m – 4 m or less nearshore Merizo (**Figure 26**). Cocos Lagoon is the island's only shallow water atoll-like lagoon, spanning approximately 10km² (NOAA, 2020). The Achang Reef Flat Marine Preserve contains inner and outer reef flats, which are exposed at low tide and separated by a low-tide moat and a depressed middle-reef flat (NOAA, 2009).

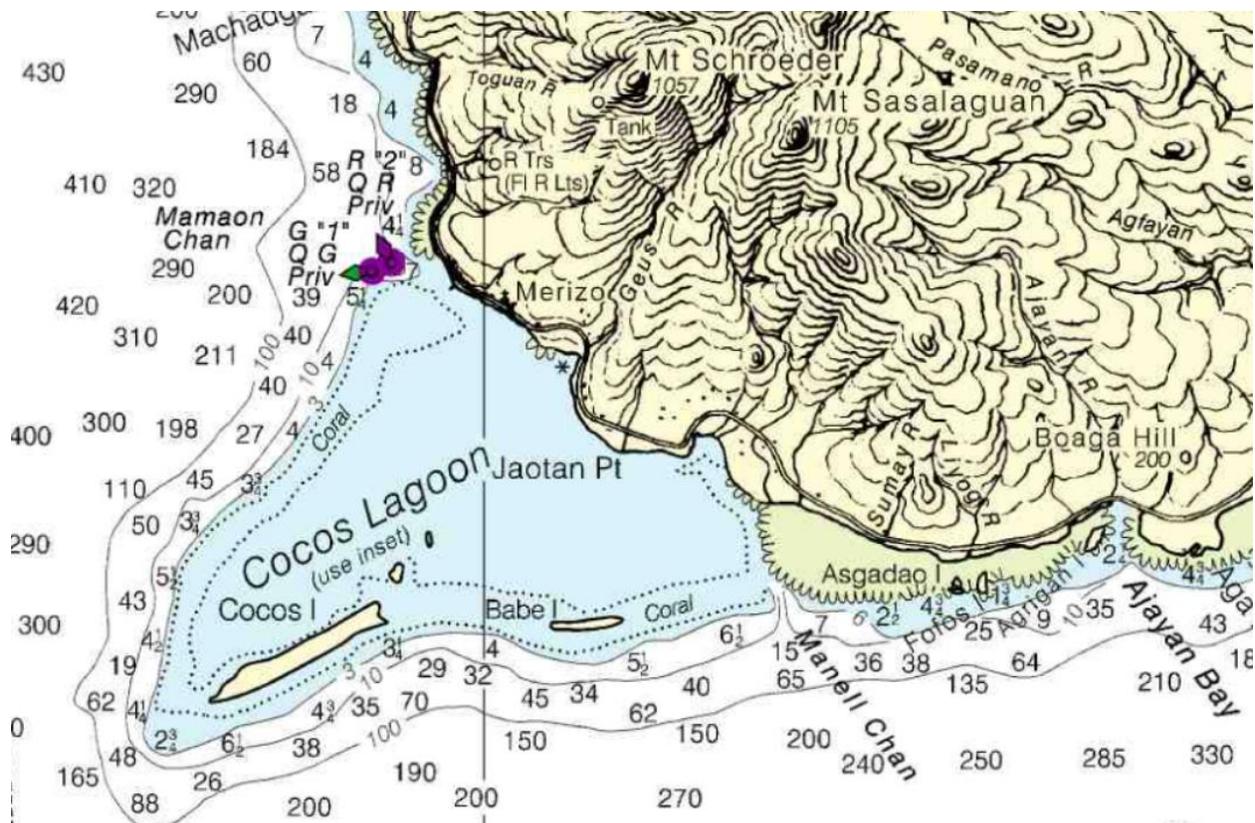


Figure 25. Cocos Lagoon and Achang Marine Preserve in Guam (NOAA, 2006).

Information regarding large-scale oceanic circulation and how the island modifies circulation is fairly limited. Large-scale oceanic circulation around Guam is controlled by the North Equatorial current flowing northwestward at about $0.1\text{--}0.2\text{ m s}^{-1}$. One 2003 assessment of eddies around Guam identified Cocos Island as one of three salient capes in Guam that could steer currents and generate eddy motions. To the south of Guam, drifter data showed a westward current at a speed of 0.1 m s^{-1} and to the southwest of Guam, the data showed energetic, cyclonic eddies with a complete rotation in 4–5 days (**Figure 27**). However, it was noted that circulation around the island of Guam is spatially and temporally variable. These eddies are significant biologically for the island because they provide a mechanism for the trapping and return of eggs and larvae of coral and fish on Guam coral reefs. In addition, they control the connectivity among various reefs along the island (Wolanski et al., 2003).

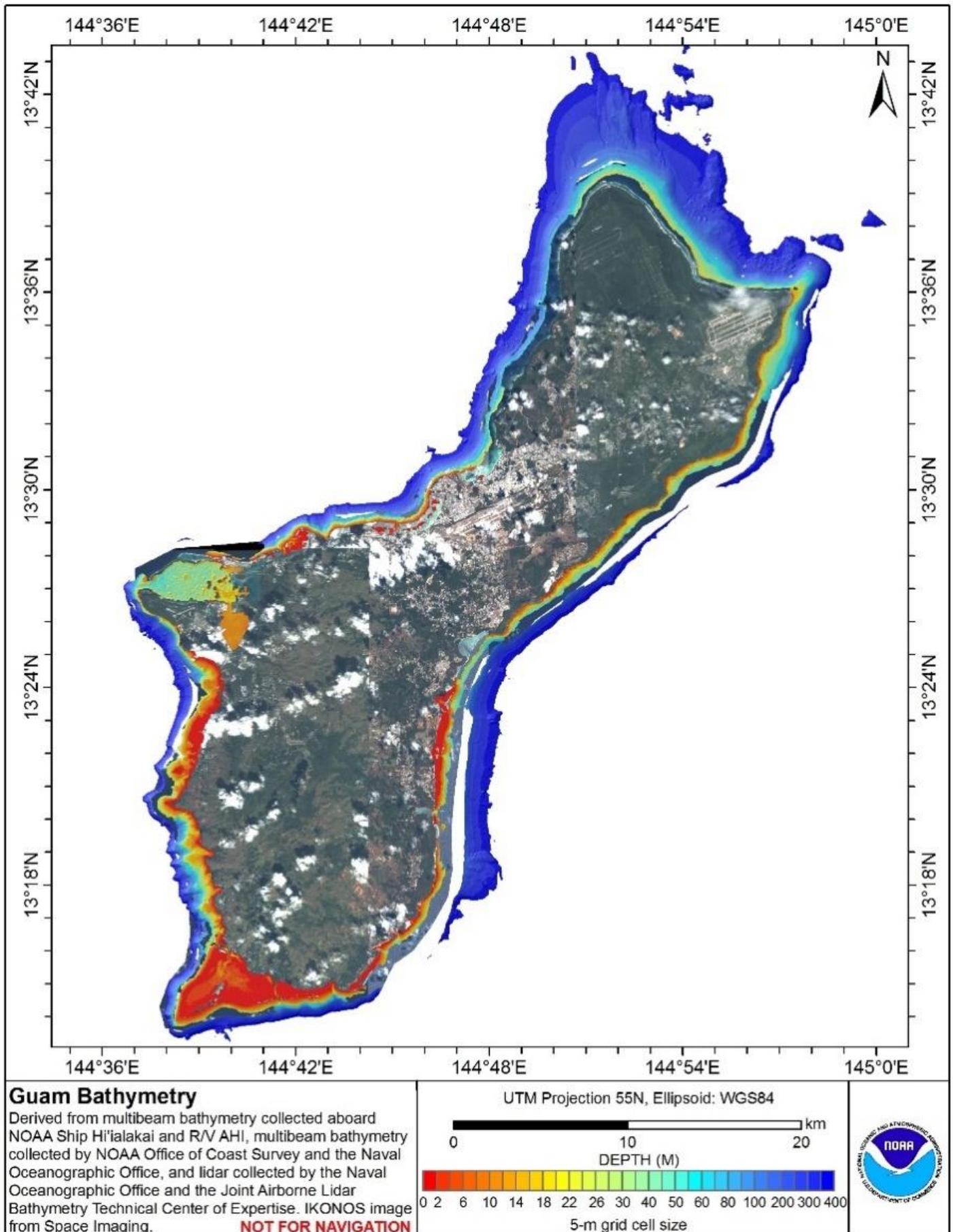


Figure 26. Multibeam and Lidar integrated bathymetry for Guam (NOAA, 2011).

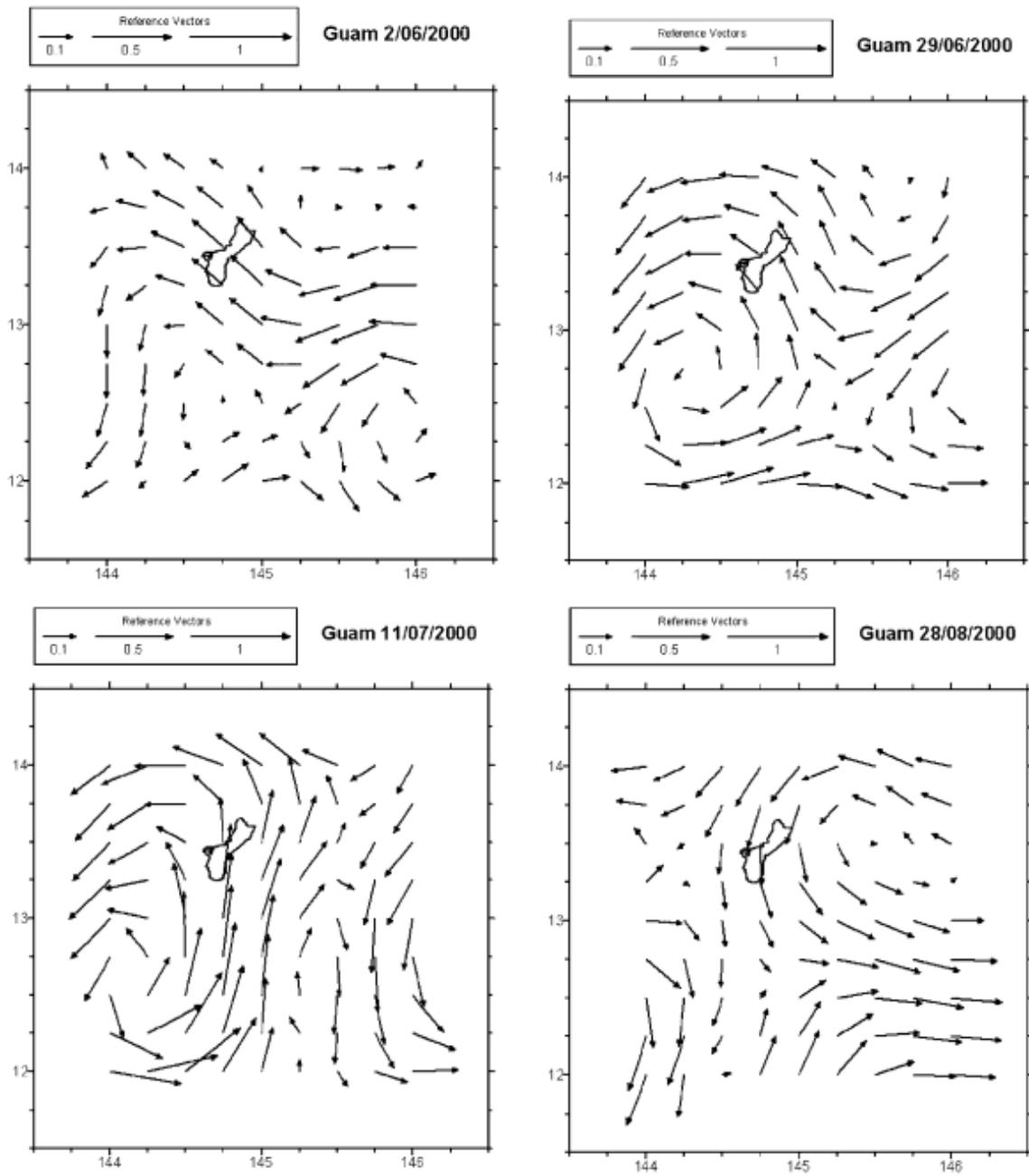
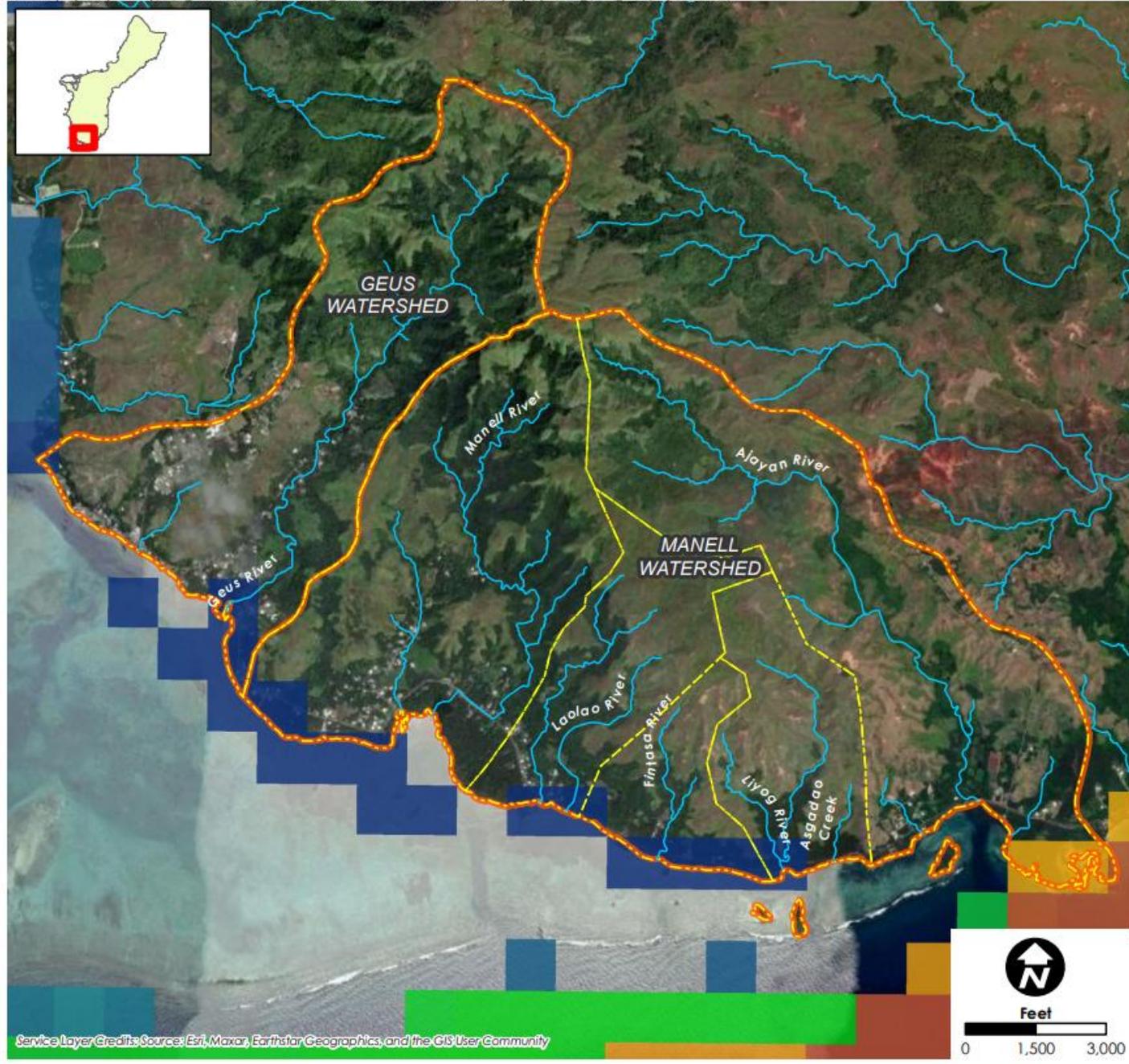


Figure 27. Synoptic distribution during 2000 of near-surface currents ($m s^{-1}$) in a $2^{\circ} \times 2^{\circ}$ domain centered around Guam, as derived from satellite altimetry data from TOPEX/Poseidon (Wolanski et al., 2003).

Date: 6/10/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), NRCS, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.

- Rivers
 - Subwatersheds
 - Watersheds
- Wave Exposure**
Energy Level (J/m³)
High : 1918.69
Low : 5.41311



Wave Exposure

Service Layer Credits: Source: Esri, Maxar, Earthstar, Geographics, and the GIS User Community

Figure 28. Wave exposure levels in the Manell-Geus watershed (NRCS, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

5.5 Climate Vulnerability

Climate change has brought and will continue to bring significant impacts to Guam. Some of the major climate impacts highlighted in the 2020 Pacific Islands Regional Climate Assessment include the following:

- Warmer ocean temperatures resulting in coral reef bleaching and loss;
- Rising sea levels resulting in damage to natural and built assets with flooding, storm surges, and coastal erosion;
- Increasing air temperatures for both daytime and nighttime resulting in an increase in heat-related illnesses, wildfires, demand for water, decreased water supplies, droughts, and transmission of disease;
- Declining total rainfall amounts with a decrease in rainy season precipitation and an increase in dry season precipitation; and
- Stronger tropical storms and typhoons delivering higher wind speeds and more rainfall (Grecni et al., 2020).

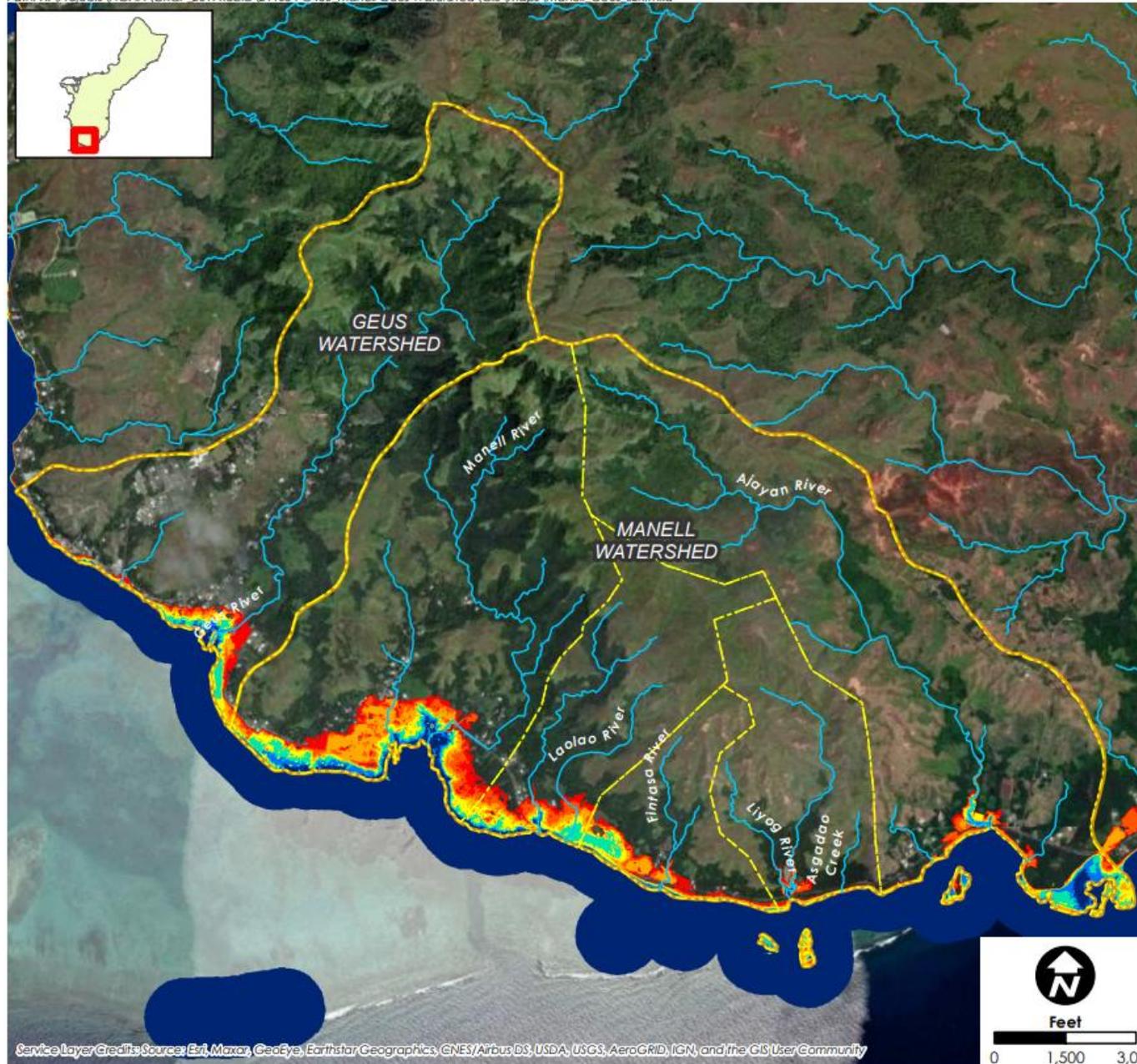
5.5a Coastal Climate Impacts

With approximately 152 miles of coastline, communities throughout Guam are highly exposed to a variety of coastal-flood related threats. Located in the region known as “Typhoon Alley,” Guam is particularly vulnerable typhoons and tropical storms. Tropical cyclones occur regularly in the region with three tropical cyclones of tropical storm intensity and higher, per year per 5-degree latitude longitude square (Amidon et al., 2017). Climate projections indicate that while there may be fewer tropical cyclones in the future, they are expected to increase in intensity (Wang, 2016).

The impacts from severe storm-related flooding will be further exacerbated by rising sea levels in Guam (**Figure 29**) and flooding (**Figure 30**). Merizo already experiences tidal flooding regularly (Grecni et al., 2020). Guam is projected to experience three feet in sea level rise by the end of the century (King et al., 2019). In a 2019 GIS spatial analysis of anticipated infrastructure impacts under different sea level rise scenarios, the southern region of Guam was anticipated to experience the greatest impacts to infrastructure overall. With a three-foot rise in sea level, 73% of infrastructure (including electricity, wastewater, roads, bridges, and buildings) in the southern villages of Guam are anticipated to experience major impacts. In Merizo, under a three-foot sea-level rise scenario, it was projected that 100% of sewage pump infrastructure, 27% of bridges, and 20% of buildings would be affected (King et al., 2019). A 2021 U.S. Army Corps of Engineers Institute of Water Resources Risk Management Center’s LifeSim 2.0.1 model estimated areas with populations at risk (PAR) due to flooding from sea level rise for Guam and identified Merizo as the village with second highest PAR in Guam. The assessment also indicated that Merizo would be likely to experience the most damages in Guam due to sea level rise (**Figure 31**) (U.S. Army Corps of Engineers, 2022).

Date: 6/8/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), NRCS, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.



- Rivers
- Subwatersheds
- Watersheds
- 0 ft
- 1 ft
- 2 ft
- 3 ft
- 4 ft
- 5 ft
- 6 ft

NOAA Coastal Services Center Sea Level Rise Data: 1-6 ft Sea Level Rise Inundation Extent.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

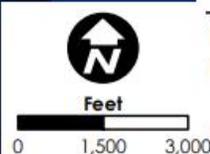
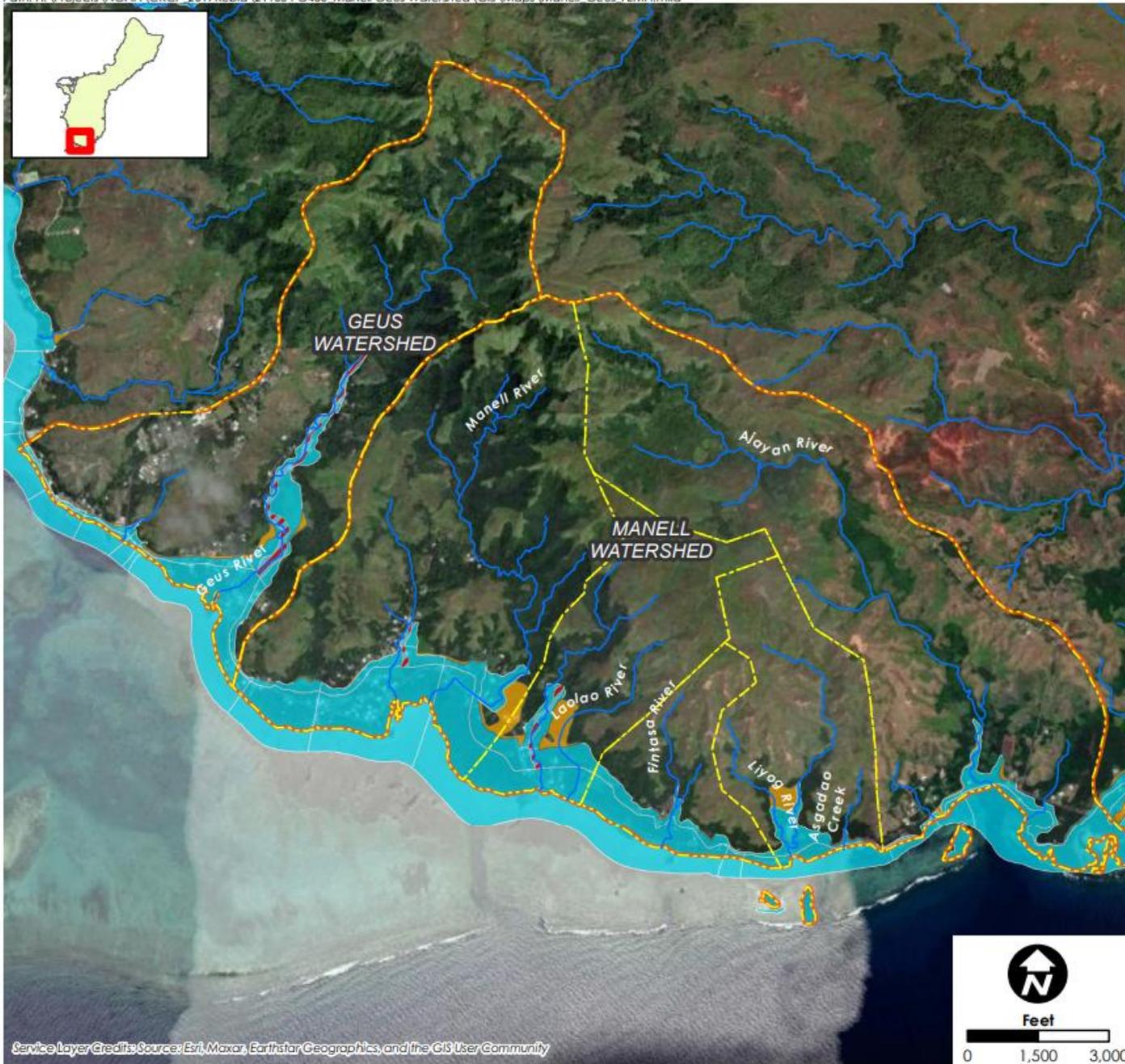


Figure 29. NOAA Coastal Services Center Sea Level Rise Projections for the Manell-Geus Watershed (Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI).

Date: 6/10/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), NRCS, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.

- Rivers
- Subwatersheds
- Watersheds
- Flood Hazard Zones**
 - Flood Hazard Area
 - Regulatory Floodway
 - 0.2% Annual Chance Flood Hazard



FEMA National Flood Hazard Layer.

Service Layer Credits: Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Figure 30. FEMA National Flood Hazards in the Manell-Geus watershed (NRCS, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

Place	Damage Existing	Damage Future ¹	Increased Damage in Future
Agat	\$2,184,163	\$7,986,350	266%
Asan	\$16,408	\$49,158	200%
Chalan Pago-Ordot	\$256,097	\$703,748	175%
Hagåtña	\$0	\$80,038	New Risk ²
Inarajan	\$941,167	\$3,033,755	222%
Merizo	\$4,510,906	\$12,210,745	171%
Piti	\$95,967	\$788,929	722%
Tamuning	\$55,696	\$373,560	571%
Umatac	\$260,262	\$800,076	207%
Yona	\$75,031	\$198,151	164%
Total	\$8,395,697	\$26,224,511	212%

¹Estimates are rough order of magnitude and should not be used beyond screening level.

²Risk only appears in future model, not existing.

Figure 31. Existing and Future Damages from Sea Level Rise (U.S. Army Corps of Engineers, 2022).

Similarly, a 2021 National Fish and Wildlife Foundation assessment of Community Exposure Index using the Coastal Resilience and Evaluation Siting Tool identified areas where community assets are potentially exposed to flood-related threats identified several locations in the Manell-Geus watershed (**Figure 32**). The low elevation of Merizo’s coastline coupled with the siting of major roads and highways along these flood prone areas leads to higher exposure potential. The Threat Index tool similarly identified several areas within the watershed with storm surge scenarios and landscape characteristics that would exacerbate flood potential (**Figure 33**) (Dobson et al., 2021).



Date: 6/8/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), NFWF, CREST, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.

- Rivers
- Subwatersheds
- Watersheds

Community Exposure Index

- 2 (low)
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 (high)



Feet



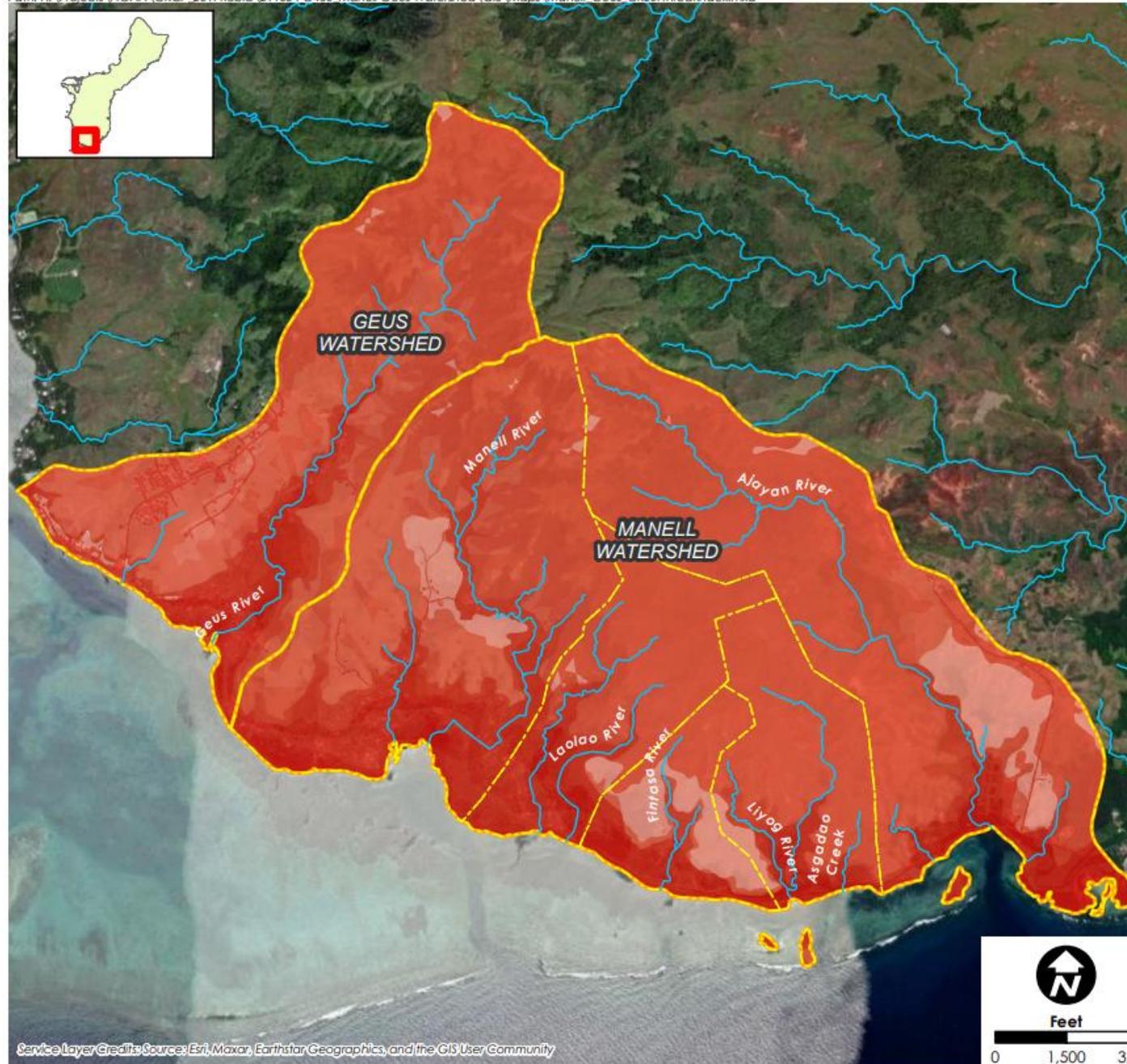
NFWF Coastal Resilience Assessment:
Community Exposure Index.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 32. NFWF Community Exposure Index for the Manell-Geus watershed (NFWF, Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI).

Date: 6/10/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), NFWF CREST, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.



Service Layer Credits: Source: Esri, Maxar, Earthstar, Geographics, and the GIS User Community

NFWF Coastal Resilience Assessment: Threat Index.

Figure 33. NFWF Threat Index for the Manell-Geus watershed (NFWF, Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI).

5.5b Social Vulnerability

Guam is at an increased risk for environmental and social challenges that will be worsened by climate change. Social vulnerability is a key factor to consider in assessing a region’s ability to recover from climate related disasters. The U.S. Centers for Disease Control and Prevention (CDC) produces social vulnerability index (SVI) maps and estimates for all states, however the SVI for Guam has not been developed. In 2021, a group of independent researchers developed calculations for SVI for Guam using data from the 2010 Guam Census, utilizing the CDC methodology to rank and identify the most vulnerable communities in Guam. A second set of adjusted SVI for Guam was also calculated using a CDC-modified method that incorporated additional Guam-specific characteristics on housing structure, communication capacity, and other relevant indicators. Separate rankings were developed for the 19 municipalities in Guam. Based on this analysis, Merizo ranked second highest in Guam for vulnerability using the CDC methodology and seventh highest in Guam using the adjusted methodology (**Figure 34**) (Paulino et al., 2021).

Social Vulnerability Index (SVI) and Percentile Rank for the 19 Municipalities in Guam Stratified by Methodology (Source: 2010 U.S. Census)

CDC Methodology			Adjusted Methodology*		
Rank	SVI	Municipality	Rank	SVI	Municipality
1	1.00	Agat	1	1.00	Agat
2	0.94	Merizo	2	0.94	Dededo
3	0.89	Hagatna	3	0.89	Yigo
4	0.83	Mongmong-Toto-Maite	4	0.83	Hagatna
5	0.78	Dededo	5	0.78	Umatac
6	0.72	Mangilao	6	0.72	Mangilao
7	0.67	Umatac	7	0.67	Merizo
8	0.61	Yigo	8	0.61	Mongmong-Toto-Maite
9	0.56	Sinajana	9	0.56	Inarajan
10	0.50	Yona	10	0.50	Chalan Pago-Ordot
11	0.44	Barrigada	11	0.44	Barrigada
12	0.39	Inarajan	12	0.39	Yona
13	0.33	Chalan Pago-Ordot	13	0.33	Sinajana
14	0.28	Agana Heights	14	0.28	Talofofo
15	0.22	Talofofo	15	0.22	Tamuning
16	0.17	Tamuning	16	0.17	Agana Heights
17	0.11	Asan-Maina	17	0.11	Asan-Maina
18	0.06	Santa Rita	18	0.06	Santa Rita
19	0.00	Piti	19	0.00	Piti

*Adjusted for Guam definition of minority (neither CHamoru nor Filipino) and additional Guam-specific variables on housing, connection, and other minority indicators.

CDC = Centers for Disease Control and Prevention

Figure 34. Social Vulnerability Index and Percentile Rank for Guam Based on Methodology (Paulino et al., 2021).

6.0 Geology & Soils

6.1 Geology

The Mariana archipelago is a series of 15 islands in the western North Pacific that is divided into two geologic subgroups. The islands between, and including, the islands of Guam and Farallon de Medinilla (FDM) are older coralline limestone islands (Amidon et al., 2017).

Guam is a volcanic island that contains a coralline limestone plateau around its entire perimeter. The southern half of the island has more topographic relief and is primarily made up of volcanic rock, with areas of highly erodible lateritic soils (Guam Forest Action Advisory Committee, 2021).

Saprolite, or weathered bedrock, is present near soil surface in riparian areas in the southern region of Guam. Many first-order stream tributaries are incised through topsoil layers and are footed upon saprolite. Many of the exposed, un-vegetated areas of the southern Guam savannah are exposed saprolite. Saprolite is difficult to vegetate but does not contribute significant sediment through rainfall events and resulting runoff. It does, however, contribute towards the increased watershed runoff observed through fire, as compared with vegetated areas. Additionally, it prevents the vertical incision of stream channels in the upper watershed by providing a significant resistance to high energy stream flows (EA Engineering, Science, Technology, 2014).

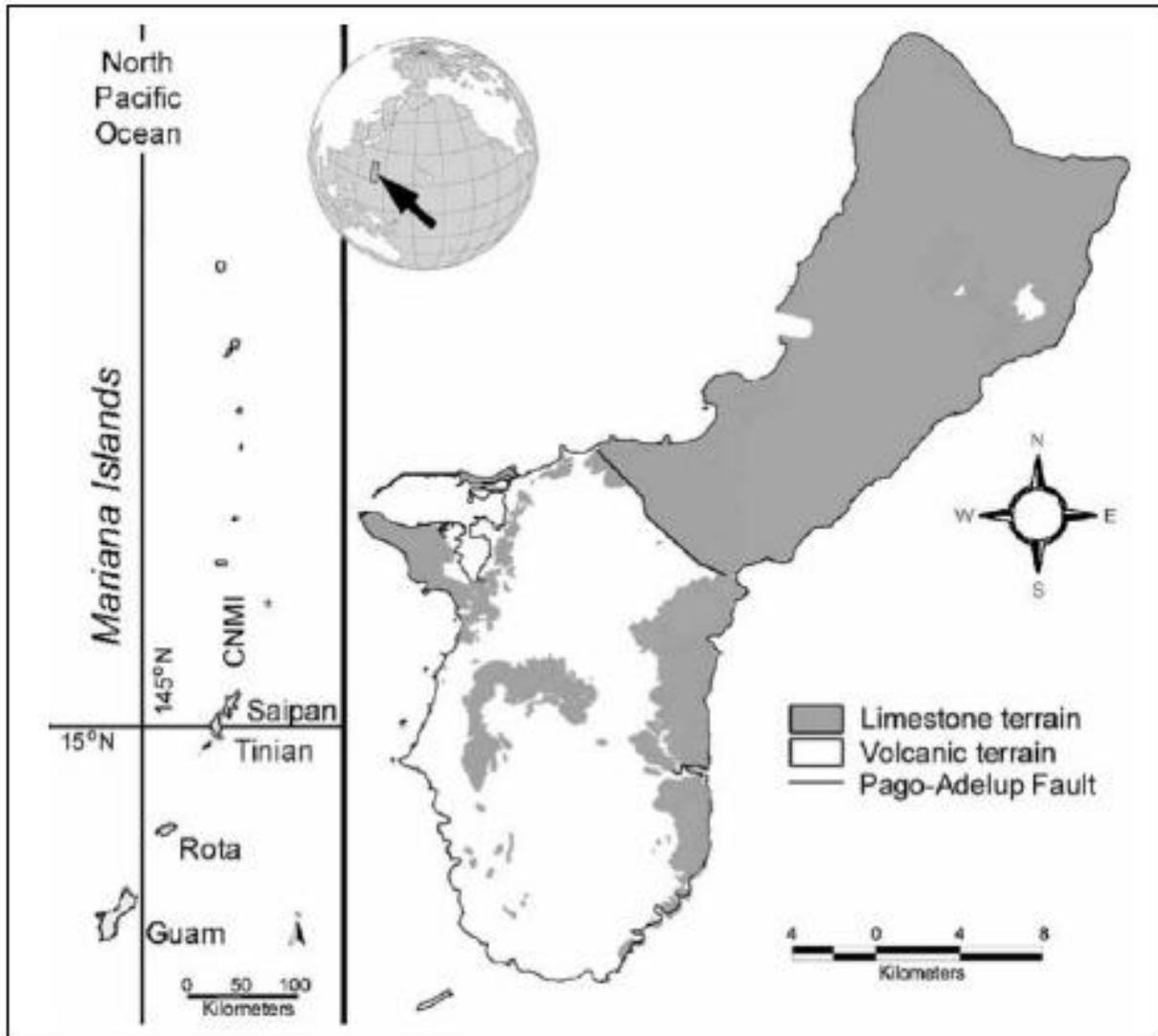


Figure 35. Mariana Islands Vicinity; Terrain of Island of Guam (Water & Environmental Research Institute of the Western Pacific University of Guam via ACOE, Watershed Assessment, Appendix C).

The Geus watershed geology is made up of rock formations that originate from the Facpi and Umatac episodes of Guam's volcanic history. These formations are relatively impermeable, resulting in a limited viable groundwater aquifer. The Facpi formation is the oldest of Guam's rock members. It makes up a short stretch of the island's surface which extends from the southwestern part of the Geus Watershed and northwest up to the coast to Facpi Point. The eastern ridge and interior highlands of the Geus

Watershed are comprised of Umatac formation rock of several flow members, including the Geus, Schroeder, and Bolanos pyroclastic members, as well as the Umatac formation undifferentiated. Alluvial clay deposits make up the surface between the Facpi and Umatac formations, along the coast and valley floor. The Facpi formation is made up of high calcium boninite basalts which formed into pillow lavas. Breccias, hyaloclastites, and sandstones of the same lithology are also present in the Facpi formation. The Umatac formation has a total estimated thickness of 2,200 feet with minor interbedded limestone and calcareous shale. The Bolanos pyroclastic member forms the mountain peaks of the back valley from Mt. Schroeder to Mt. Sasalaguan and Mt. Finansanta. It consists of tuffaceous breccias with fragments of tuffaceous sandstone, limestone, and volcanic conglomerates extending approximately 750 to 1,000 feet deep. The Schroeder flow member is older than the Bolanos type and consists of pillow basalts with interbedded sandstones in the upper layer. It has an estimated thickness of approximately 100 to 400 feet. The Geus flow member is the oldest of the Umatac formation members and includes interbedded limestones, sandy and tuffaceous limestones, sandstones, and volcanic conglomerates with an estimated thickness of 250 to 300 ft. (Khosrowpanah et al, 2015).

The Geus Watershed is part of the Umatac formation deposited during early Mocene times composed of three major geologic formations, which include volcanic conglomerates, lava flows and dikes, and alluvium (Kami et al, 1974)

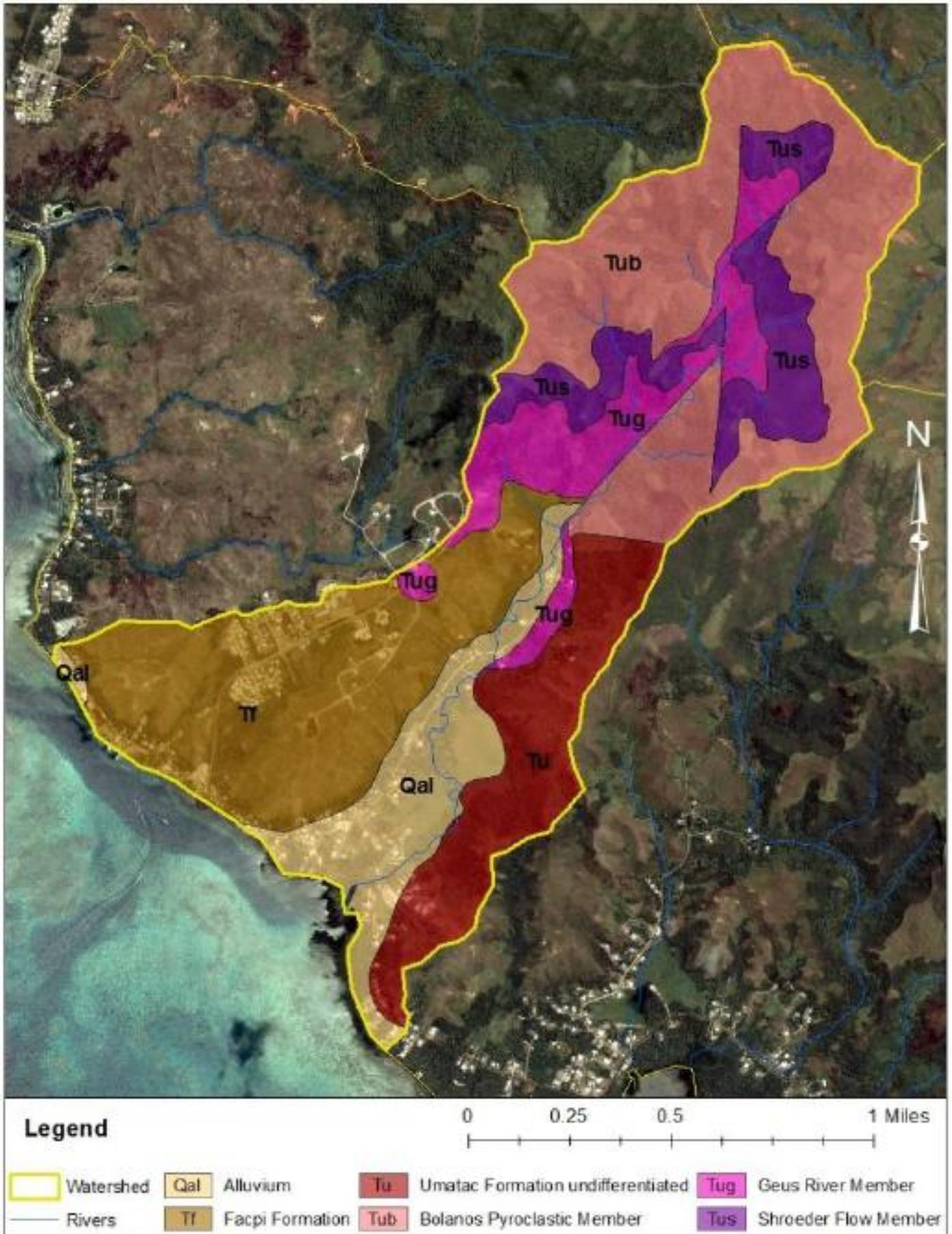


Figure 36. Geus watershed geology (Siegrist et al., 2008 via Khosrowpanah et al., 2015).

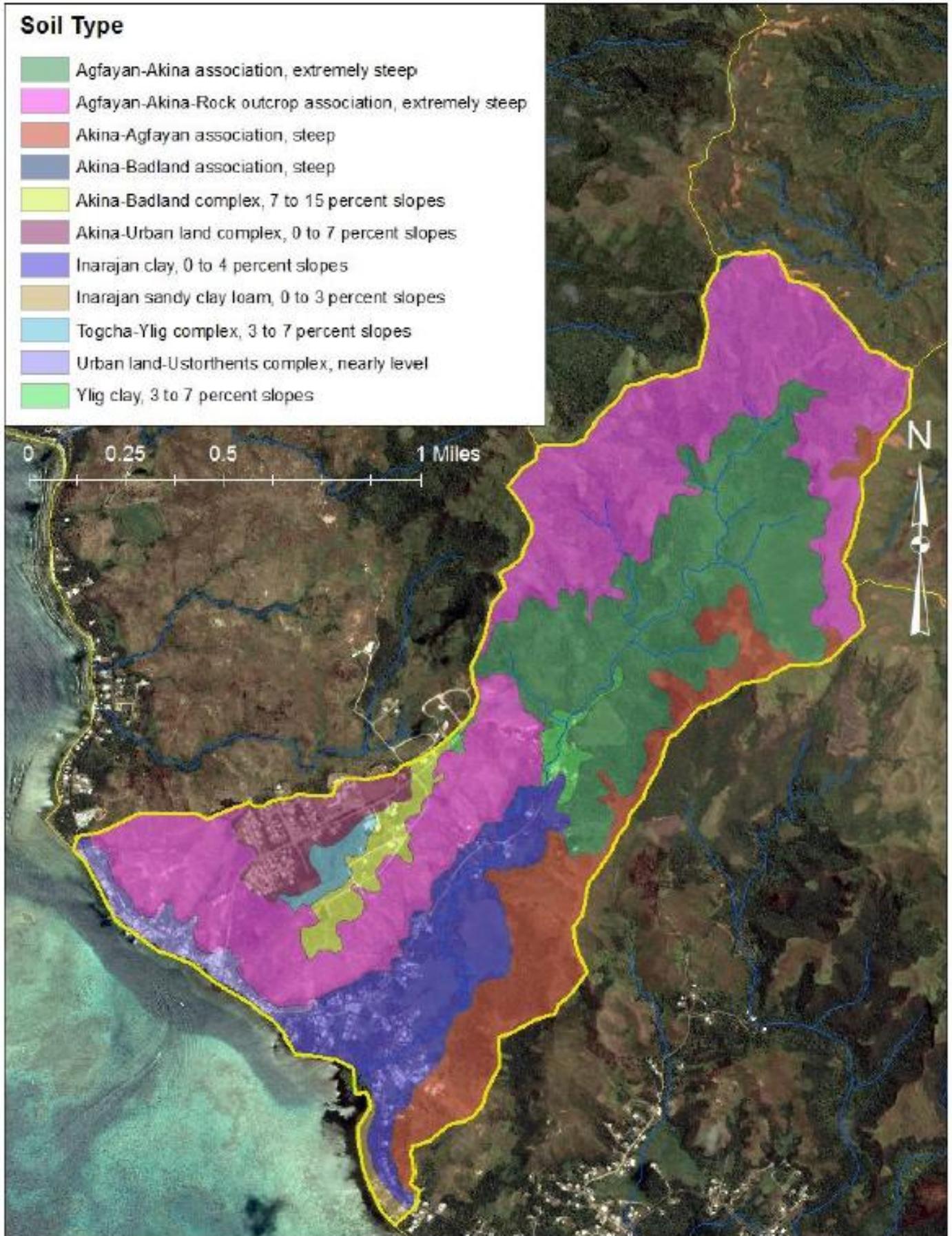


Figure 37. Soil types and location within the Geus watershed (Young, 1988 via Khosrowpanah et al., 2015).

6.2 Soils (HSG)

Table 4. Hydrologic Groups by Subwatershed

Watershed	Subwatershed	Hydrologic Group	Percent Cover
Manell	Ajayan	A	2.61
	Ajayan	B	2.49
	Ajayan	C	21.3
	Ajayan	D	73.34
	Fintasa	C	2.83
	Fintasa	D	96.98
	Laolao	C	7.75
	Laolao	D	92.24
	Liyong	B	0.04
	Liyong	C	15.61
	Liyong	D	84.35
	Manell	C	49.9
Manell	D	49.92	
Geus	Geus	A	2.07
	Geus	B	1.06
	Geus	C	17.69
	Geus	D	78.6

Dataset used is from NRCS.

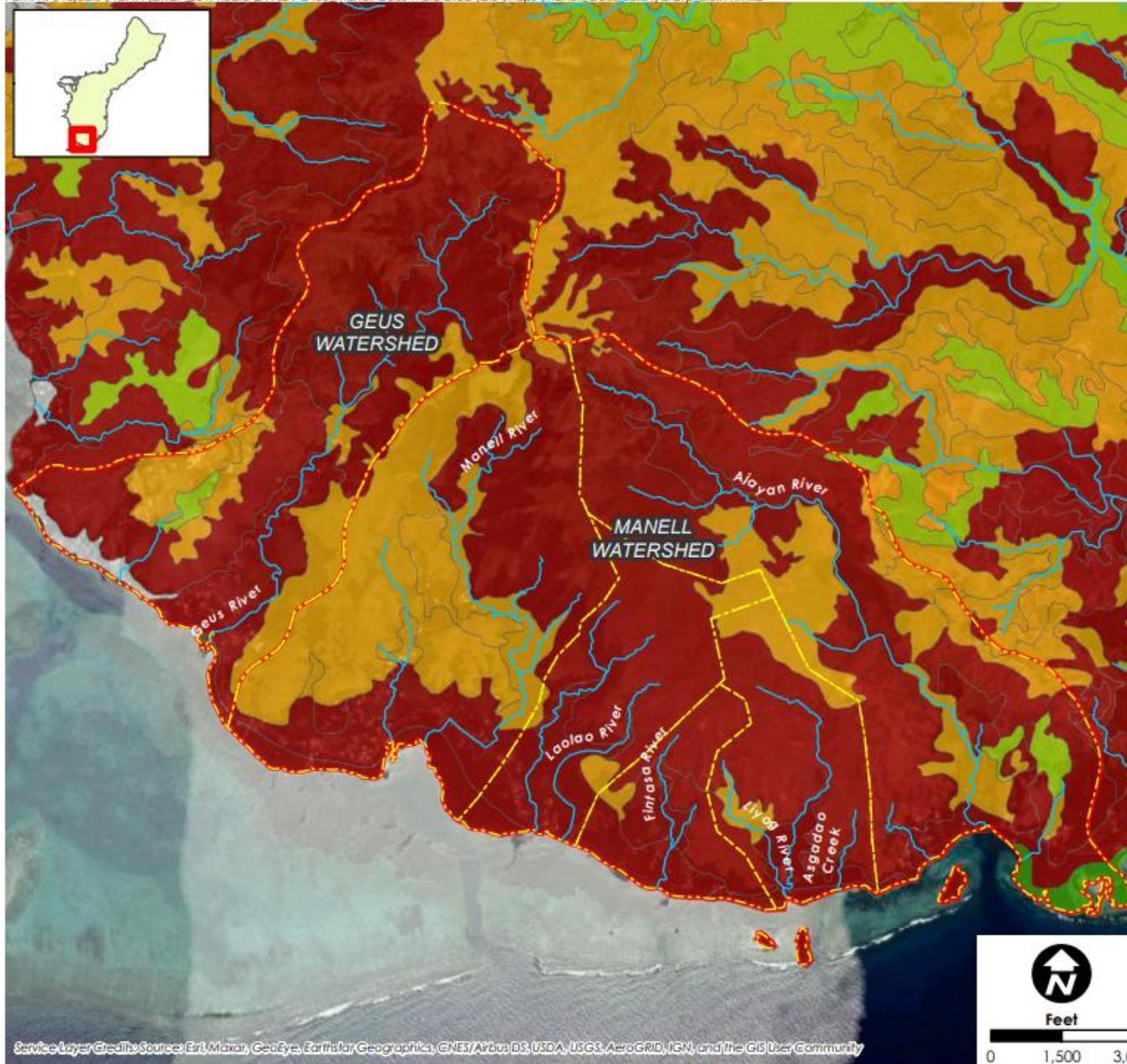
The southern portion of Guam is mountainous with steep slopes and volcanic streams. The soils in the southern region are primarily unstable clay-sand and volcanic rock (ACOE, Watershed Assessment, Appendix C).

The Manell and Geus watersheds primarily contain the Akina-Agfayan soil series. The soil ranges from very shallow to very deep, well drained, and moderately steep to extremely steep soils. Soils vary based on location, including dissected mountains, plateaus remnants, and jagged mountains. Akina soils are primarily found on the side slopes and ridgetops in these watersheds. These soils are very deep and well drained. The soils are red, acidic silty clay and clay and are underlain by saprolitic tuff at a depth of 20 to 40 inches. Agfayan soils are primarily found on side slopes and ridgetops in these watersheds. These soils are very shallow and are well drained. The soils are slightly acid to neutral clay and are underlain by weathered bedrock at a depth of 4 to 15 inches (EA Engineering, Science, Technology, 2014).

The soil types and topographic conditions of the Geus watershed are common for areas of southern Guam susceptible to badland development. Badlands occupy approximately 1.7% (18.5 acres) of the Geus watershed. Approximately half of the Geus badlands are located on Agfayan-Akina-Rock outcrop association, extremely steep soils. Akina-Agfayan association, steep make up approximately 37.2% of Geus badlands, and about 16.6% of the badlands are on Agfayan-Akina association, extremely steep. (Khosrowpanah et al, 2015).

Date: 6/8/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), NRCS, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.



- Rivers
- Subwatersheds
- Watersheds
- Hydrologic Group**
- Null
- A
- B
- C
- D

NRCS SSURGO-Certified Soils.

Figure 38. NRCS SSURGO-Certified soil groups in the Manell-Geus watersheds (NRCS, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

6.3 Erosion potential

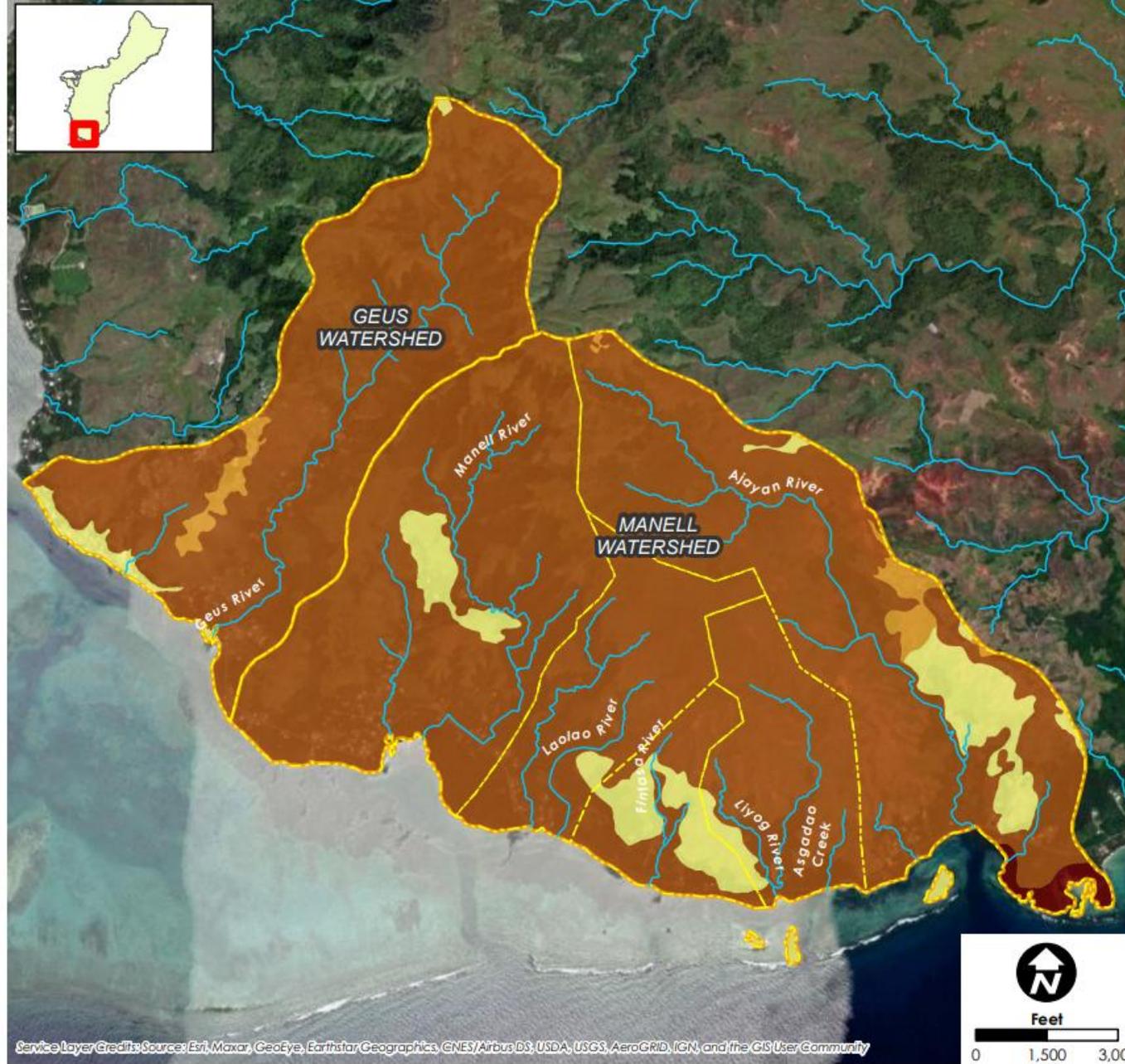
Soil erosion is a significant environmental concern for island ecosystems. As soil particles are detached, transported, and deposited by wind and/or water, the health of associated upland, freshwater, and marine ecosystems may be compromised. High velocity runoff events occurring over short periods of time, such as flash floods, are common in Guam. Erosion from events like these increases sediment loads reaching and settling out in marine environments which is one of the biggest threats to the health of Guam's coastal reef systems (Khosrowpanah et al, 2015).

Guam's terrestrial and aquatic environments are susceptible to the impacts of erosion and associated sedimentation. Reductions in vegetation coupled with intense precipitation events, steep terrain, mass wasting, narrow river cross sections, and changes in river direction can increase erosion. Human-built structures, such as shoreline protection structures, can increase the rate of coastal erosion in adjacent properties that are not armored while preventing any beach profile from accreting. Cleared areas that are subjected to winds and waves often have a higher risk of coastal erosion than highly vegetated areas where structures are set-back farther inland. Coastal erosion and associated sedimentation can harm nearby reefs, reducing sunlight necessary for growth, and depositing contaminants contained in eroded soils. Erosion can also harm existing vegetation, sea grass communities, beaches, and benthic organisms. (Guam HMP 2019) (ACOE, Watershed Assessment, Appendix C).

La Niña and El Niño events also contribute to coastal erosion, with El Niño causing lower sea levels but increased tropical cyclone activity, while La Niña causes less tropical cyclone activity, but higher background sea levels (ACOE, Watershed Assessment, Appendix C).

The steep mountains of the Manell-Geus watersheds are highly vulnerable to erosion caused by human activities, as well as natural forces. Disturbance activities and/or forces that diminish the vegetative cover and increase the extent of exposed soils leads to development of areas known as 'badlands', which are areas that continuously erode along sloping terrain, particularly during significant storm events. Soil loss rates and volumes can be significant in badland areas, due to their high potential for erosion (Khosrowpanah et al, 2015).

The problems associated with erosion and sedimentation in Guam are almost entirely focused in the southern volcanic region. Erosion runoff may contribute to non-point sources of pollution such as nutrients, pesticides, or sediment deposits, impacting the water quality of freshwater resources and ecosystems as well as near-shore marine habitats. Unlike the karst northern limestone plateau, southern Guam is mostly comprised of highly weathered soils born from impermeable volcanic rock which are very susceptible to erosion along the steep mountainous terrain (Khosrowpanah et al, 2015).



Date: 4/29/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), National Fish and Wildlife Foundation, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.

- Rivers
- Subwatersheds
- Watersheds
- Soil Erodibility Index**
 - 0
 - 2
 - 3
 - 5

CREST Resiliency Assessment - Soil Erodibility

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 39. CREST NFWF Soil Erodibility Index for the Manell-Geus watershed (NFWF, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

Watershed	Estimated Delivered Sediment Yield (average tons/yr)	Watershed Area (sq mi)	Delivered Sediment Yield (tons/acre/yr)
Agana	5,238	13.62	0.6
Agat	15,785	3.92	6.3
Apra	40,330	12.94	4.9
Asalonso-Dandan	16,082	6.54	3.8
Cetti	43,395	3.01	22.5
Fonte	4,140	2.46	2.6
Geus	8,822	1.75	7.9
Inalajan	64,601	8.69	11.6
Manell	63,147	4.86	20.3
Mangilao	12,983	13.71	1.5
Pago	55,427	10.44	8.3
Piti/Asan	13,609	3.11	6.8
Taelayag	25,376	2.56	15.5
Talofofu	103,149	23.46	6.9
Toguan	11,736	1.41	13.0
Ugum	39,076	.58	8.1
Umatac	49,771	3.82	20.3
Ylig-Togcha	81,928	15.73	8.1

Figure 40. Estimated delivered sediment yield by watershed (Guam Forest Action Advisory Committee, 2021).

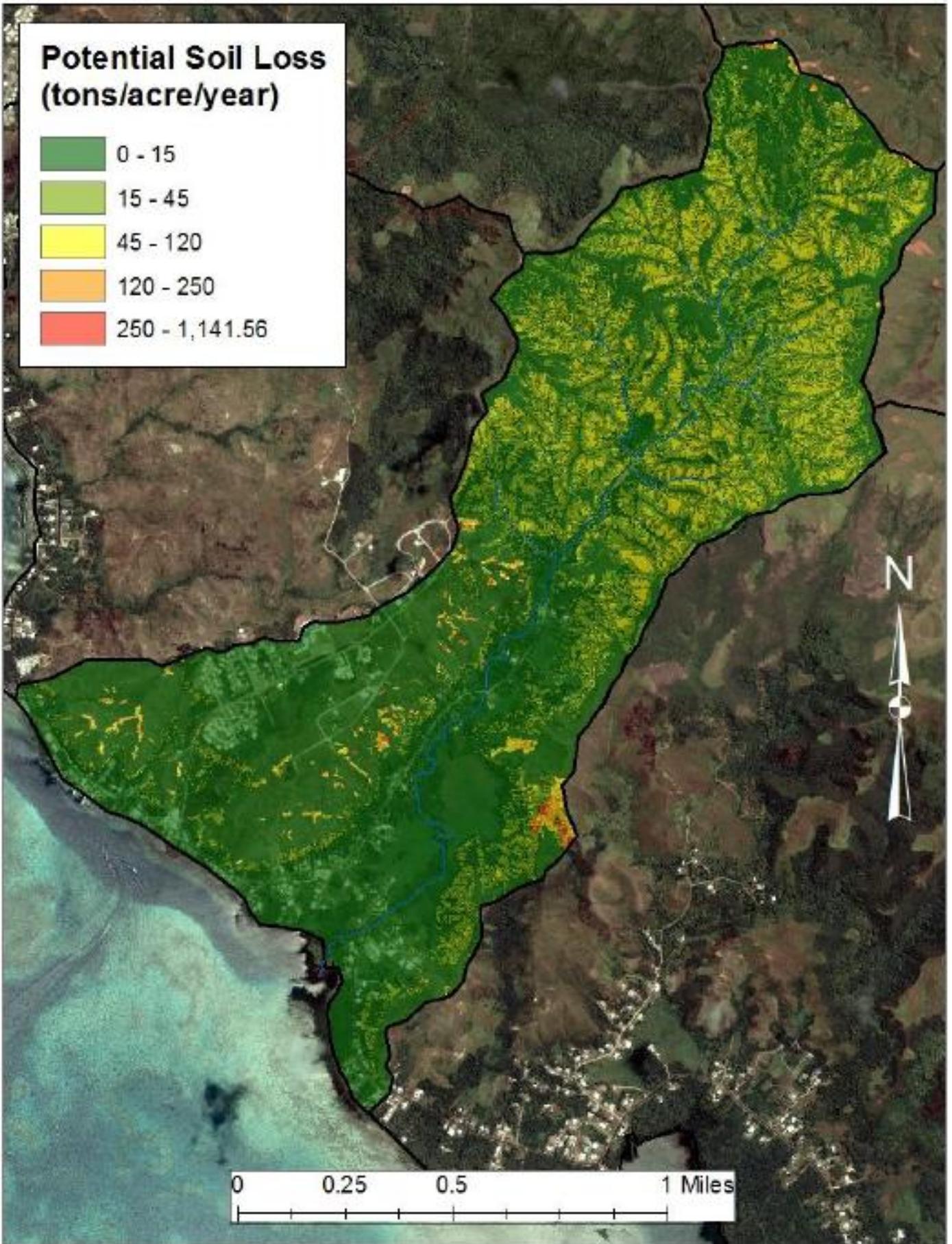


Figure 41. Erosion/soil loss potential within the Geus watershed (Khosrowpanah et al, 2015).

6.3a. Upland Erosion and Wildfires

The upland portion of the watershed experiences fires and other disturbances which can exacerbate erosion (**Figure 42**). These fires are often caused by arson for the purpose of developing fresh grassland as grazing habitat for non-native feral pig and Philippine deer. These practices do not foster the growth of native tree and shrub vegetation which has superior erosion control abilities in comparison with grassland (EA Engineering, Science, Technology, 2014). When there are precipitation events, exposed sediments are washed into nearby waterways, impacting the freshwater ecosystems and organisms, in addition to the marine ecosystems in Cocos Lagoon. Sedimentation has serious impacts on coral reef health by decreasing growth rates and increasing susceptibility to disease (NOAA, n.d.). 50% of Merizo residents confirmed that they have been impacted by wildfires in the prior five years (NMFS PIRO, in prep). According to Guam's 2016 State and Private Forestry Fact Sheet, wildfire is Guam's number one priority issue for forestry management (NMFS PIRO, 2017).

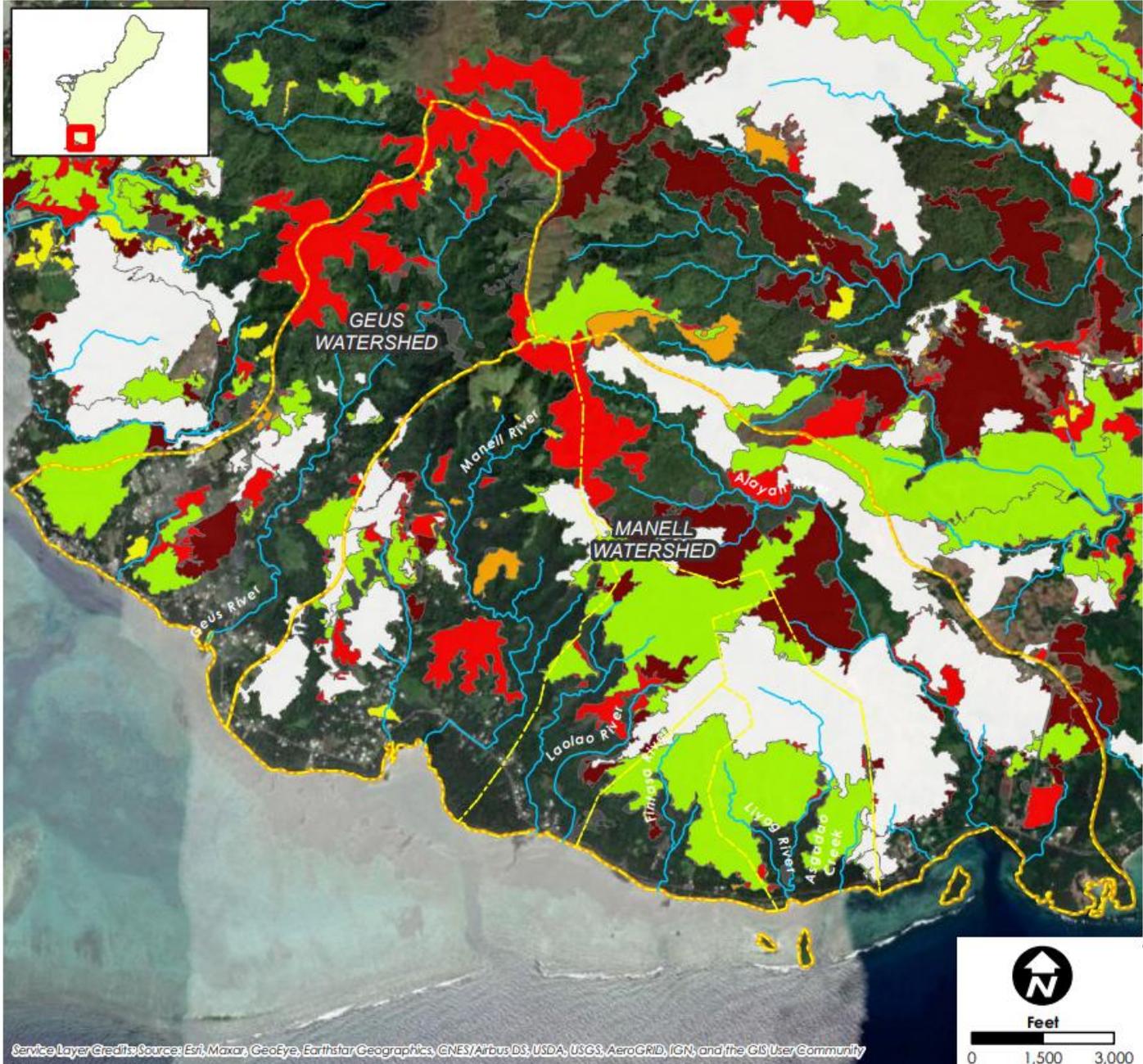
Colluvial sediment sources are a major contributor to the sediment load at the tidal outlet of the rivers in the Manell-Geus watershed. This includes sources of sediment that enter through landslides, and erosion, and runoff. The lack of vegetation and presence of shallow saprolite enhance runoff and reduce potential for groundwater recharge in the watershed. This enhances concentration of flow and increases likelihood of erosion along stream and riverbanks (EA Engineering, Science, Technology, 2014).

Estimated delivered sediment yields by watershed indicate for the Manell watershed are fairly high compared to the rest of the island at 63,147 average tons per year. Estimated delivered sediment yields by watershed indicate for the Geus watershed are 8,822 average tons per year (Guam Forest Action Plan Advisory Committee, 2021).

Date: 6/10/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), National Fish and Wildlife Foundation, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal.

- Rivers
- Subwatersheds
- Watersheds
- 2022
- 2021
- 2020
- 2019
- 2018
- 2017
- 2016



Guam Wildfires Burned Areas.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 42. Wildfires in the Manell-Geus Watershed ((NFWF, Water and Environmental Research Institute of the Western Pacific (WERI), USGS, NOAA, ESRI).

6.3b. Streambank Erosion and Flooding

Most of the rivers located in the Manell-Geus watershed have either sand or silty clay banks with lenses of gravel or cobble. Tall, vertical banks of fine erodible sediments with minimal vegetation cover are exposed in these areas (Guam Forest Action Plan Advisory Committee, 2021).

The invasive grass *Bambusa vulargis* has been identified along the Manell and Geus Rivers. Also known as bamboo, the plants increase streambank erosion and flooding in the lower reaches of the watershed. As a result, sedimentation in the river and nearshore areas is increased. In addition, during heavy storms the bamboo debris blocks stream culverts and stormwater floods the only road through the village of Merizo (NOAA, n.d.). The Merizo Mayor's Office has reported that they have to remove bamboo debris from culverts during most heavy rainfall events to prevent or reduce flooding. The Mayor's Office has reported that pilot bamboo removal and eradication efforts led by Guam Forestry and the Bureau of Statistics and Plans reduced flooding in the Manell River during subsequent rainfall events (NMFS PIRO, 2017).

It has been estimated that in the last five years, nearly 60% of the residents in the town of Merizo have been affected by flooding (Pait et al., 2019).

Date: 4/29/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), National Fish and Wildlife Foundation, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.

- Rivers
- Manell and Geus Subwatersheds
- Watersheds
- Landslide Susceptibility Index**
 - 1
 - 3
 - 4

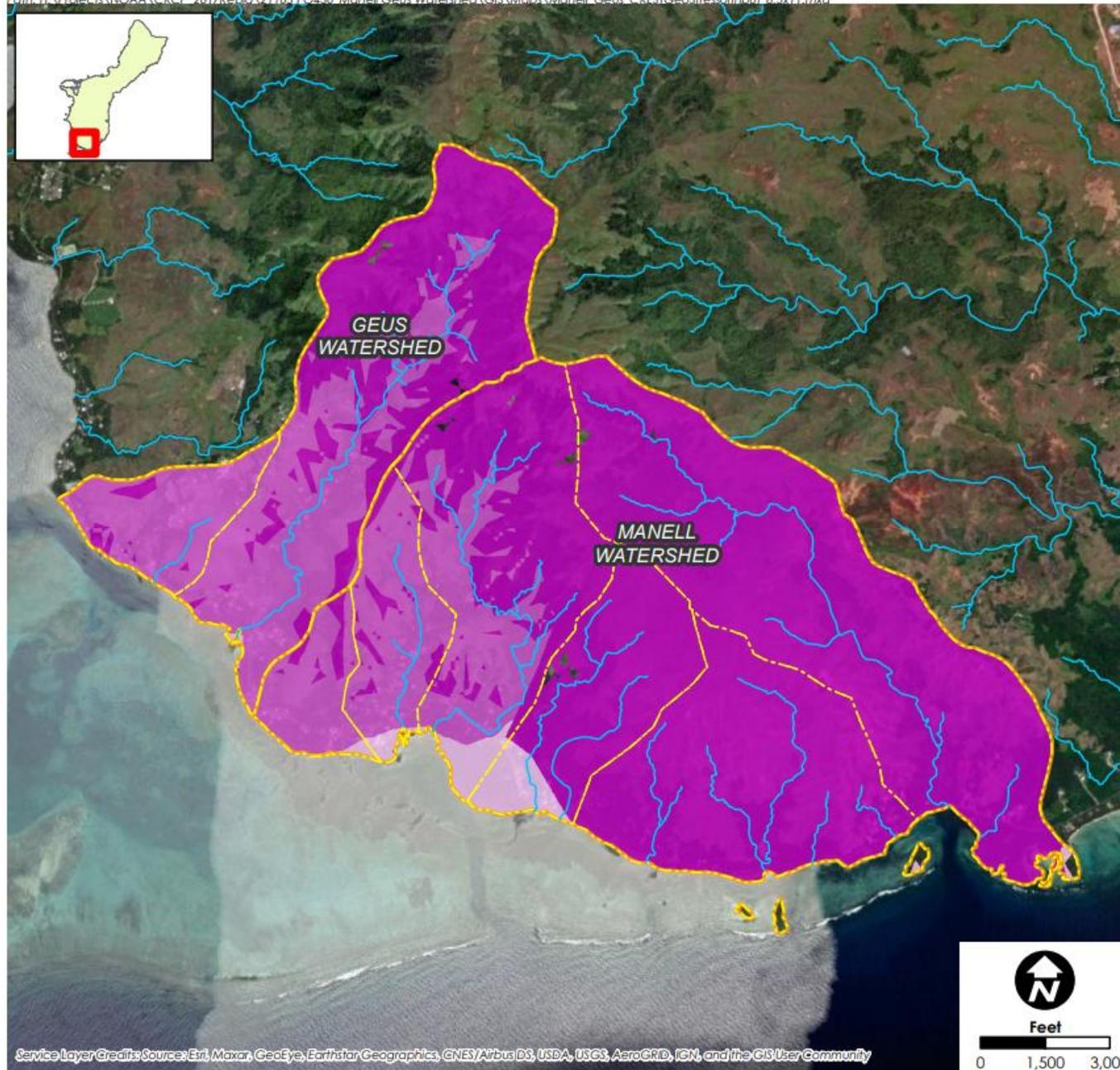


Figure 4
CREST Resiliency Assessment - Geological Stressors

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 43. CREST NFWF Landslide Susceptibility in the Manell-Geus watershed (NFWF, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

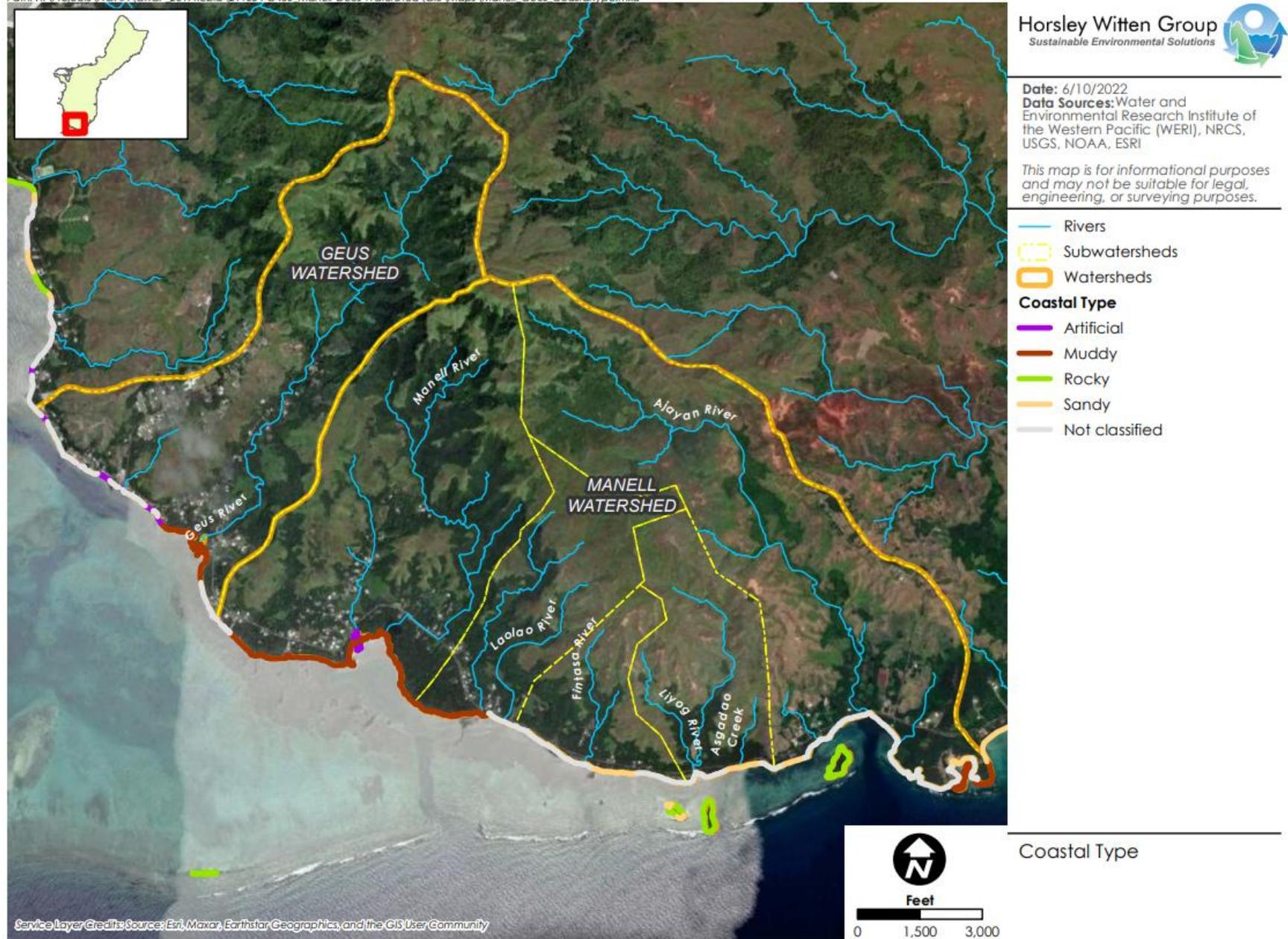


Figure 44. Coastal shoreline classification for the Manell-Geus watershed (NRCS, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

7.0 Ecology

7.1 Terrestrial

The Manell-Geus Watershed is of particular importance because of its ecological value, and its direct effect on coastal resources that are culturally significant to the traditional fishing community of Merizo. The primary forest types in the Manell-Geus watershed include limestone forest, scrub forest, ravine forest, broken forest, and strand forest (King, 2010). (Khosrowpanah et al, 2015).

Guam's tropical forests support more than 600 species of plants, including over 100 species of trees. These forests support human uses such as agroforestry, timber harvesting, medicinal plant collection, and wood carving, but also provide critical ecosystem services and habitat for native, endemic, and endangered species. Guam's forests have been affected by a combination of natural and anthropogenic factors, which include typhoons, droughts, wildfires, introduction and invasions by non-native plants and animals, as well increasing human population size and associated development. These factors have significantly impacted the native ecosystems of Guam and threaten the health and function of Guam's biodiversity and watersheds (Guam Forest Action Advisory Committee, 2021)

Data sources:
 Government of Guam; USGS; NOAA; USDA Forest Service;
 University of Guam; Pacific Marine Environmental Lab; Traoy et. al, 1984

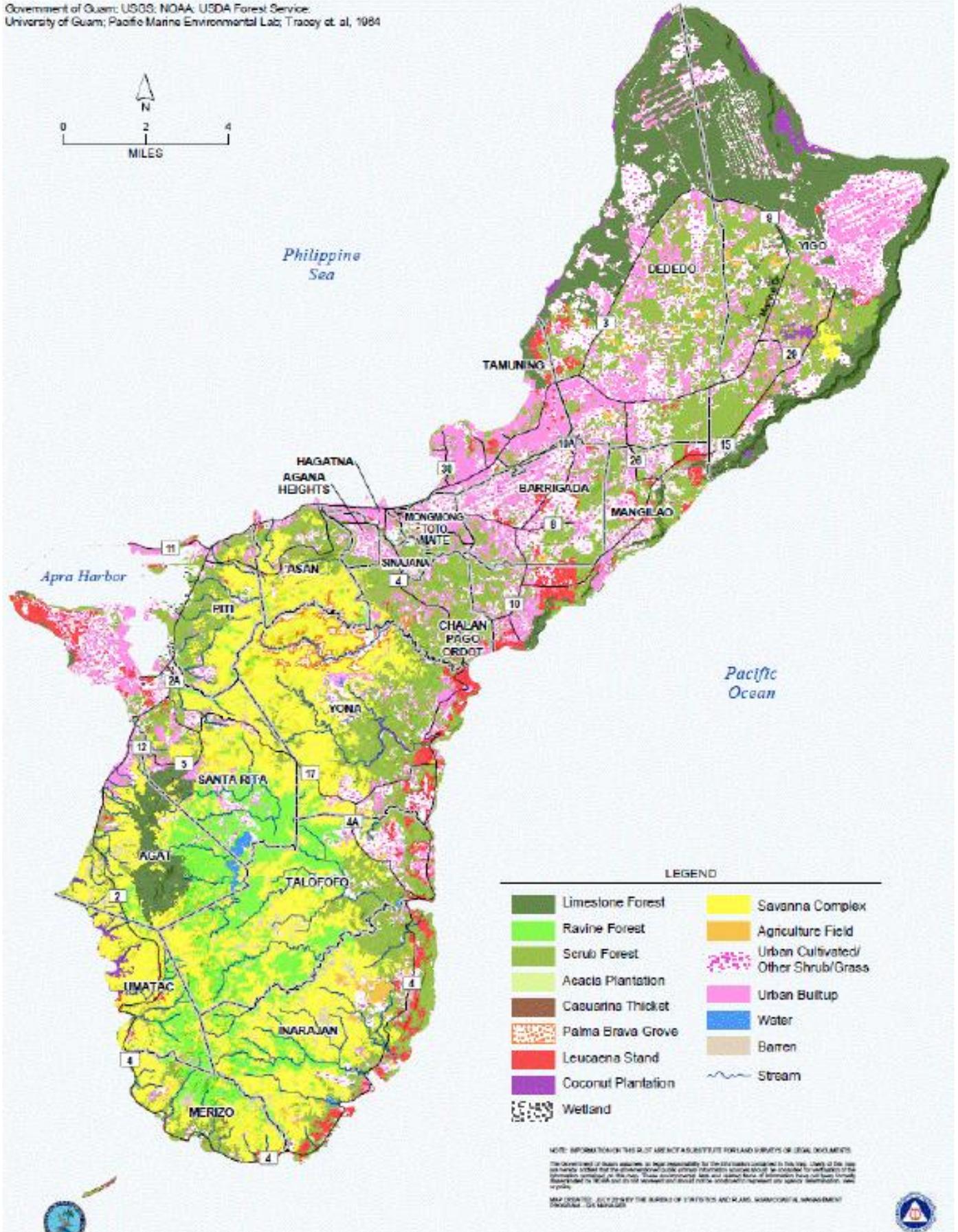
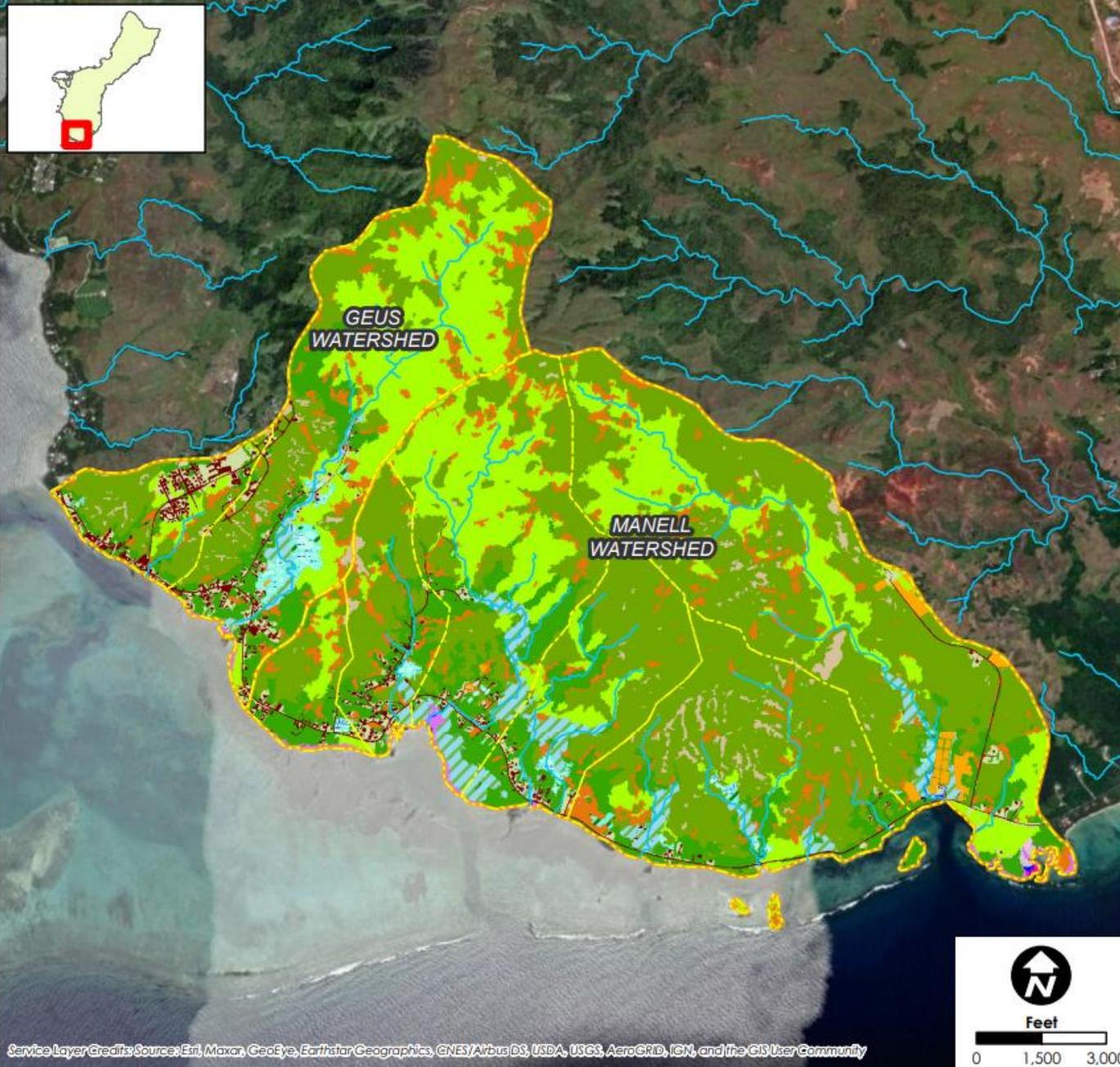


Figure 45. Vegetation types of Guam (ACOE, Watershed Assessment, Appendix C).

Tropical vegetation borders the inland areas of rivers in ravine forests in the Southern Region of Guam. The southern uplands contain some of the island's only stretches of unspoiled terrain (U.S. Army Corps of Engineers, 2020a).

Southern Guam consists primarily of non-vegetated areas or savanna grasses (swordgrass and mission grass) which are present primarily near the mountain stream beds. Southern Guam's grasslands, ravine forests, and coastal areas provide habitat for the endangered *Gallinula chloropus guami* (Mariana common moorhen), *Aerodramus bartschi* (Mariana swiftlet), *Eretmochelys imbricata* (hawksbill turtle) and threatened *Pteropus mariannus mariannus* (Mariana fruit bat) and *Chelonia mydas* (green sea turtle) (NRCS) (ACOE, Watershed Assessment, Appendix C).

The Geus Valley is characterized by three types of biotopes, which include an upland savanna, a ravine forest, and an agricultural floodplain. The upland savanna areas, located at the tops of the mountains adjacent to the Geus River, are vegetated with a combination of grasses, ferns, and some shrubs. In the ravine forest biotope, which can be found primarily along the banks of the Geus River and its tributaries, the vegetation is comprised of a combination of Betelnut, screw pine, coconut palm, bamboo, limonchina, and pago. Occasional limestone outcroppings support limestone-associated vegetation within the ravine forest biotope. The canopy height of the ravine forest typically does not exceed forty feet and intercepts a significant amount of sunlight, limiting visibility in the understory. The understory contains dense, thorny vegetation that is difficult to negotiate on foot, especially as large sections of this biotope are located on steep-sloping riverbanks. The ravine forest vegetation is indicative of a second growth forest. There are bamboo flats located within isolated locations of the upper valley floor, which are small clearings contained by steep slopes around their perimeters. These clearings are occasionally intentionally burned. Furthest down the valley is the agricultural floodplain, which is subject to the greatest level of disturbance. The agricultural floodplain has been converted from native vegetation to small farm crops and residences, and a mix of exotic tropical plants represent the dominant vegetative cover otherwise (Kami et al, 1974):



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Date: 4/29/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), USDA Forest Service, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.

- Rivers
- Manell and Geus Subwatersheds
- Watersheds
- Landcover Classes**
- Impervious
- Developed, Open Space
- Cultivated Crops
- Grassland/Herbaceous
- Scrub/Shrub
- Palustrine Forested Wetland
- Palustrine Scrub/Shrub Wetland
- Palustrine Emergent Wetland (Persistent)
- Estuarine Forested Wetland
- Estuarine Scrub/Shrub Wetland
- Estuarine Emergent Wetland
- Unconsolidated Shore
- Barren Land
- Open Water
- Ravine Forest
- Scrub Forest
- Tangantangan Thicket

Figure 2
Landcover and Vegetation.

Figure 46. Vegetation types in Guam (USDA Forest Service, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

7.2 Wetland/streams

In a study conducted by Camacho et al (2016), the Geus River was found to contain varying in-stream faunal assemblages between upper and lower reaches of the river (**Figure 47**). The study shows that the lower reaches of the river were dominated by predatory fish species of the *Kuhlia* and *Awanous* genera, while the upper reaches had a higher abundance and diversity of non-predatory gobioid fish species and palaemoinid shrimp species. The predatory fish species are limited to the lower reaches due to geomorphological barriers, such as river impoundments and waterfalls. The study also demonstrated a preference for hard-bottom substrate by the gobioid fish species, which is generally more abundant in the upper reaches. This preference for hard-bottom substrate is an important factor in maintaining sicydiine goby populations. Changes in the upper reach stream substrate should be monitored, with particular attention to losses of hard-bottom substrate due to sedimentation/sediment accumulation due to upland disturbances. This is of particular importance in the southern watersheds of Guam, where erosive potential is high, vegetative cover is low and comprised significantly of non-native/invasive species such as bamboo (*Bambusa vulgaris*), and where sedimentation rates are high.

Camacho et al (2016) also performed a vegetation survey along the riparian zone of the Geus River and found a predominance of non-native grasses and vines. The invasive bamboo is one of the most dominant grass species overall, which is of concern due to its potential to spread and contribute to river widening and bank destabilization.

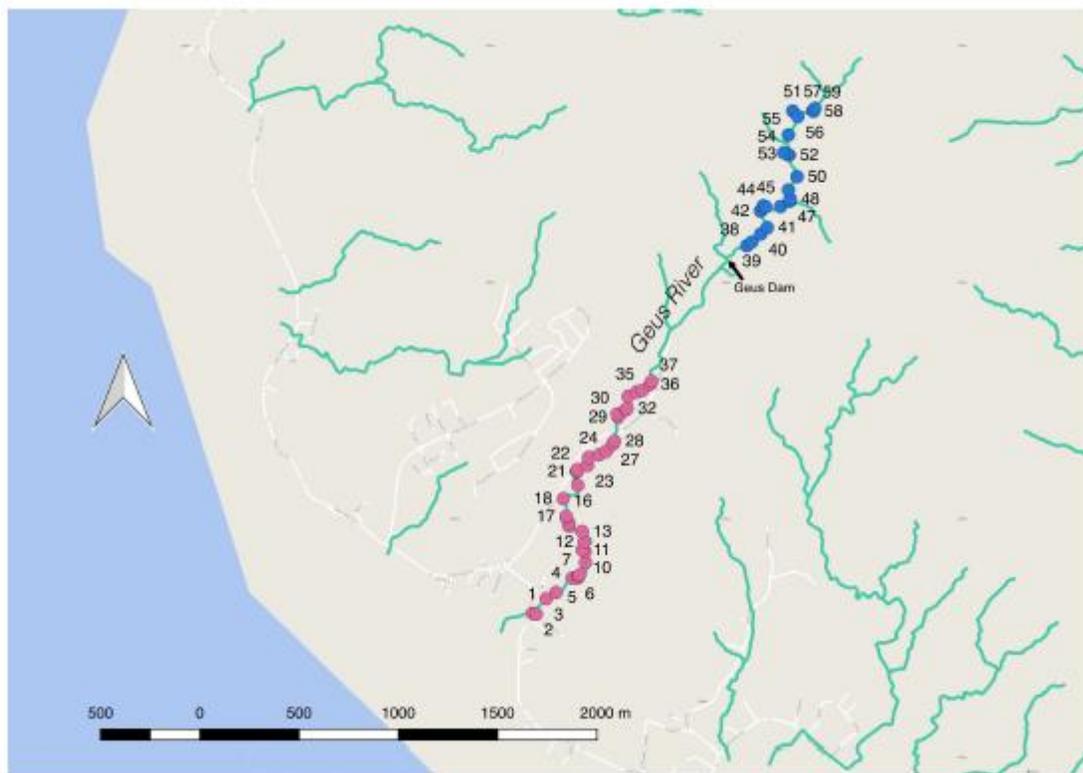


Figure 47. Survey sites for streamfish and prawn densities and physicochemical variables in the Geus River (Camacho et al, 2016).

7.3 Marine benthic

The nearshore zone along the southern edge of the Manell-Geus watersheds support three biological communities of significance, including mangrove forest, seagrass beds, and coral-dominated communities. The Manell watershed contains the full extent of the existing mangrove forests, which is present as a narrow fringe along the coast from the Achang Marine Preserve, near the mouth of the Fintasa river, to the village of Malesso, approximately 0.5 miles west of Manell Point. The seagrass beds are concentrated almost entirely at the seaward base of the Manell watershed (Raymundo et al, 2018).

Guam's coast is lined by an important reef system, which supports one of the most species-rich marine ecosystems found within any of the U.S. jurisdictions. The coastal waters of Guam are host to over 5,100 identified marine species, which includes over 1,000 nearshore fish species and more than 400 species of scleractinian coral. Guam's reef system provides resources that support many uses, including tourism, recreation, fisheries, and shoreline and infrastructure protection (Guam Forest Action Advisory Committee, 2021).

Three species of seagrasses are present in Guam: *Enhalus acoroides*, *Halophila minor*, and *Halodule uninervis*. *Enhalus acoroides* is the largest species present on the island and it inhabits the sandy-silt areas near the mouths of rivers in the southern half of Guam. *Halodule uninervis* is also abundant in Cocos Lagoon. *Halophila minor* can be found in shallow sandy reef flats and deeper lagoon environments (King, 2010).

Chaetomorpha vieillardii, also known as angel hair algae, has been identified in Cocos Lagoon. The algae blooms form dense mats which can block sunlight from reaching coral. The mats also impede fishing, tangle boat propellers, and shade out seagrasses and other benthic species (NOAA, n.d.).

Cocos Lagoon, lying offshore adjacent to the village of Merizo, is one of the Guam island's two barrier reef systems (NOAA et al., 2016). Coral reefs in Cocos Lagoon were affected by coral bleaching events in 2013, 2014, 2016, and 2017. A combination of stressors from extreme low tides and coral bleaching reduced coral cover significantly in the Lagoon (NOAA, n.d.). For example, University of Guam scientists documented 80-90% mortality in staghorn coral stands in Cocos Lagoon from 2013-2014 (Raymundo et al., 2017).

The extensive seagrass beds and patch coral reefs in Cocos Lagoon provide important forage and resting habitat for green and hawksbill sea turtles. The beds also extend eastward into the Achang Reef Flat Marine Preserve. The preserve provides critical nursery habitat for a variety of fish including the mafute (*Lethrinus harak* or the thumbprint emperor), the tiao (juvenile *Mullids* or goatfish), and the mañahak (juvenile *Siganids*) (NOAA, n.d.).

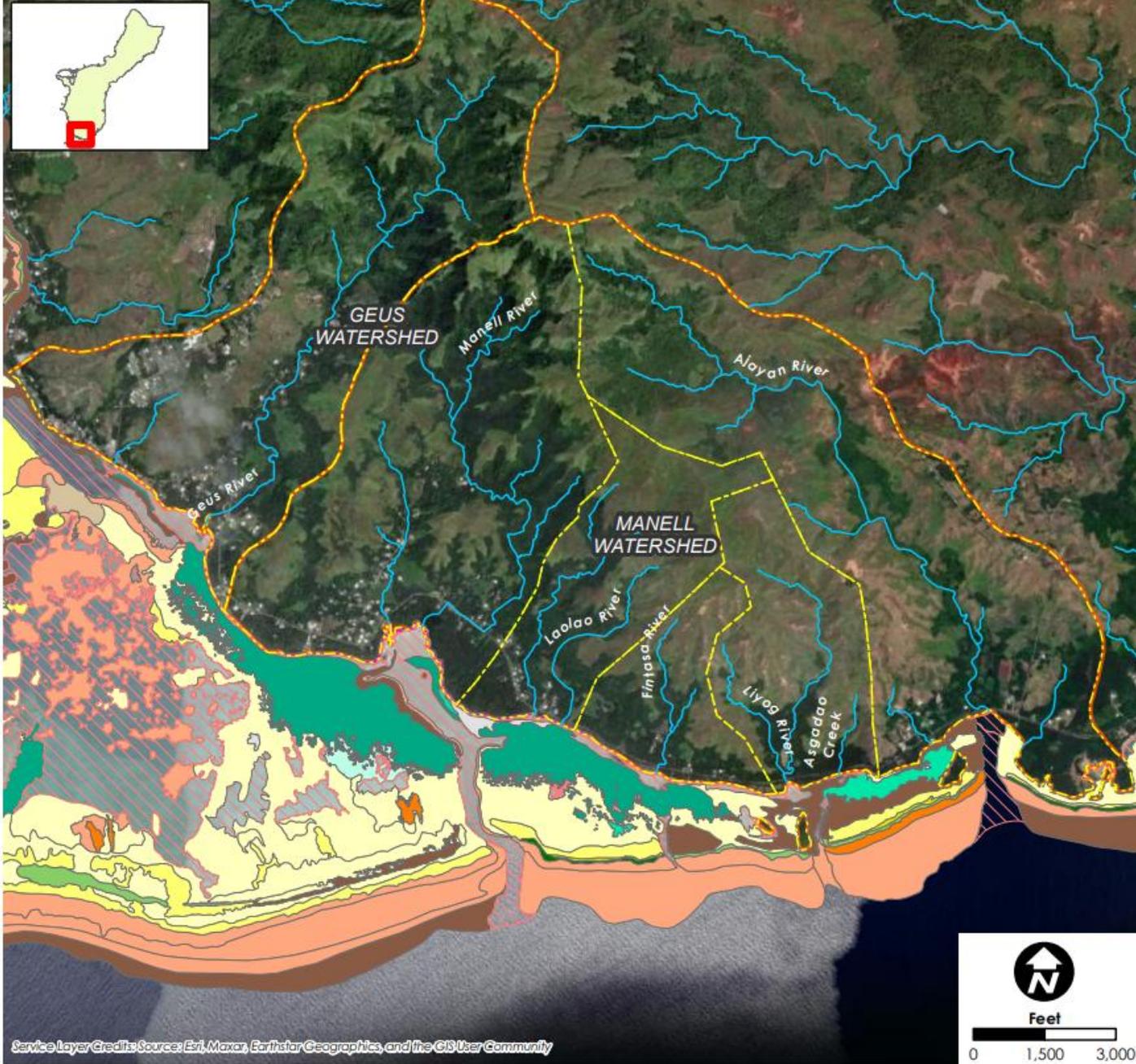
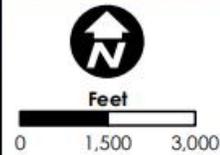


Date: 6/10/2022
Data Sources: Water and Environmental Research Institute of the Western Pacific (WERI), NRCS, USGS, NOAA, ESRI

This map is for informational purposes and may not be suitable for legal, engineering, or surveying purposes.

- Rivers
- - - Subwatersheds
- ▭ Watersheds
- Benthic Habitat Cover**
- ▭ Coral 10%-<50%
- ▭ Coral 50%-<90%
- ▭ Coralline Algae 10%-<50%
- ▭ Coralline Algae 50%-<90%
- ▭ Emergent Vegetation 90%-100%
- ▭ Macroalgae 10%-<50%
- ▭ Macroalgae 50%-<90%
- ▭ Macroalgae 90%-100%
- ▭ Seagrass 10%-<50%
- ▭ Seagrass 50%-<90%
- ▭ Seagrass 90%-100%
- ▭ Turf 10%-<50%
- ▭ Turf 50%-<90%
- ▭ Uncolonized 50%-<90%
- ▭ Uncolonized 90%-100%

Benthic Habitats.



Service Layer Credits Source: Eri Maxar, Earthstar Geographics, and the GIS User Community

Figure 48. Marine benthic habitat along the Manell-Geus watershed (NRCS, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).



Map of the Manell-Geus Habitat Focus Area, showing the location of the survey sites presented in this manual. SG = seagrass; MNG = mangroves; Sites A through O are Cocos Lagoon coral patches; TON = Tonggan Way; AJA = Ajayan River; LIY = Liyog River; LAO = Laolao River; MNS and MNN = Manell Channel South and North.

Figure 49. Map from the Atlas of the Nearshore Shallow Benthic Habitats within the Manell-Geus Habitat Focus Area (Raymundo et al, 2018).

Coral Reef Habitat Map of Detailed Biological Cover Classes

Cocos Lagoon, Guam

LEGEND

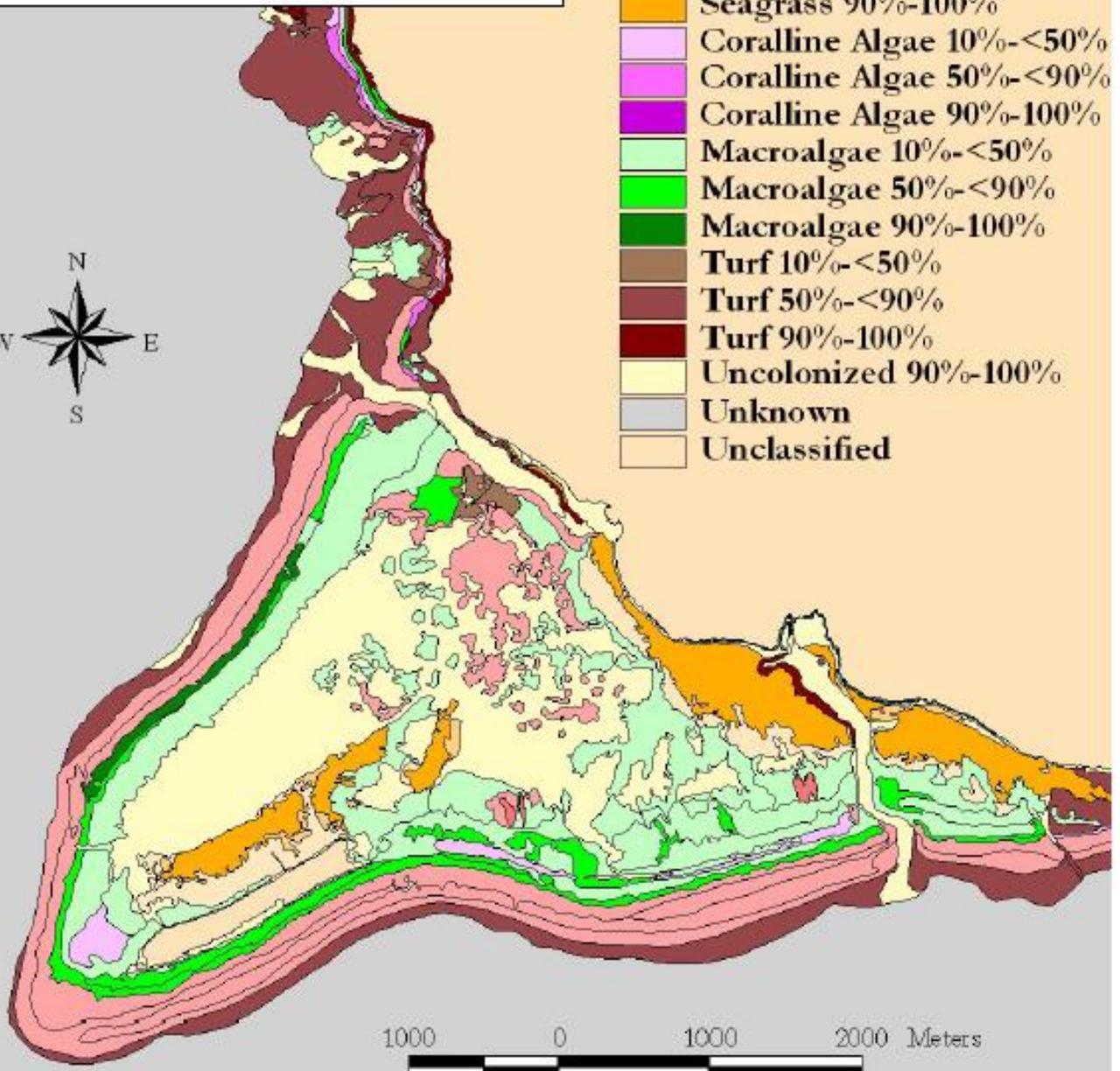


Figure 50. Coral Reef Habitat Map of Detailed Biological Cover Classes (NOAA NCCOS, 2022)

Coral Reef Habitat Map of Detailed Structure Classes

Cocos Lagoon Guam

LEGEND

- Aggregate Reef
- Aggregated Patch Reef
- Individual Patch Reef
- Land
- Mud
- Pavement
- Rubble
- Sand
- Scattered Coral/Rock
- Spur and Groove
- Rock/Boulder
- Unknown

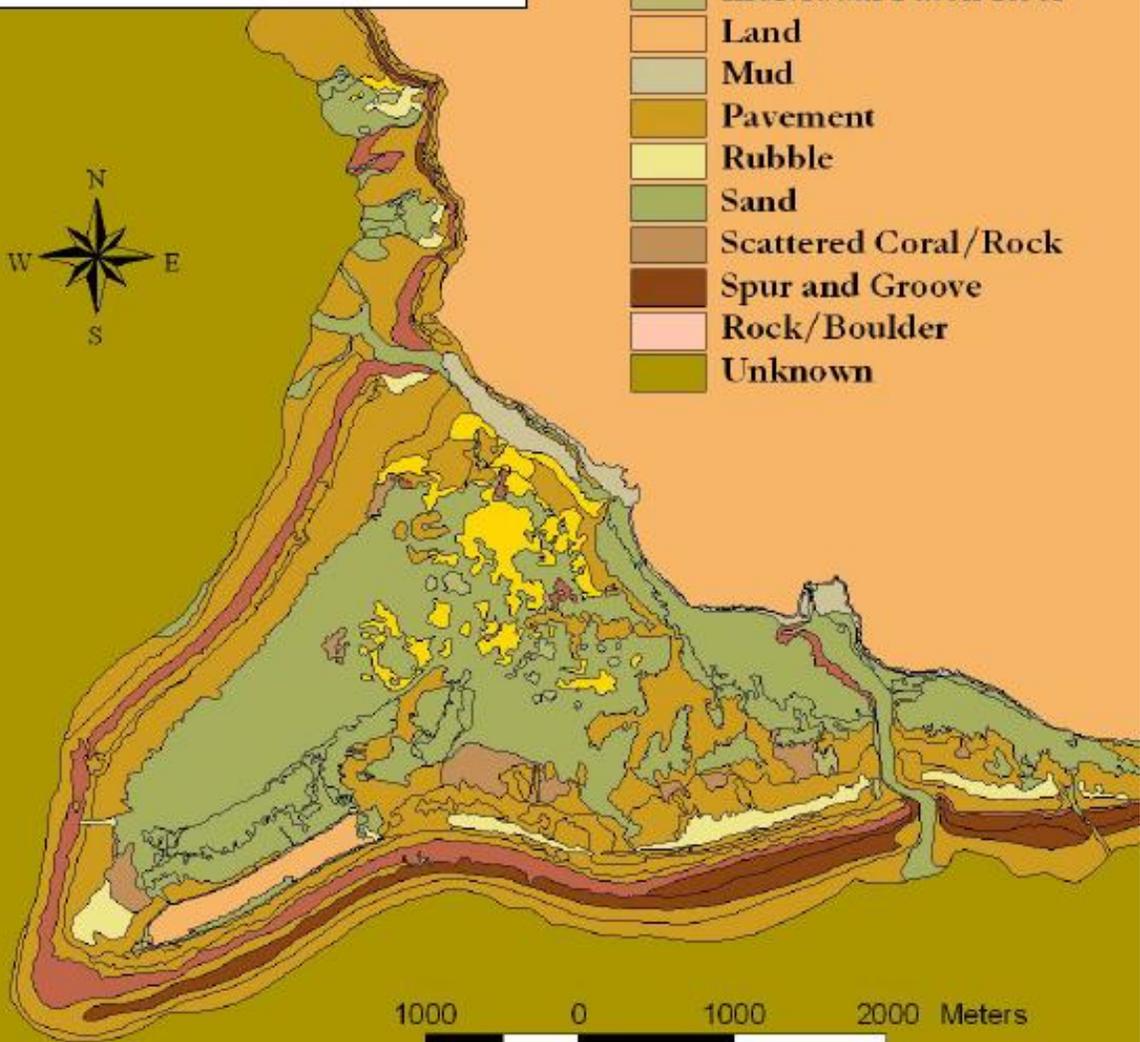


Figure 51. Coral Reef Habitat Map of Detailed Structure Classes (NOAA NCCOS, 2022).

8.0 Water Quality

8.1 Standards for Surface Water and Groundwater

Marine and surface waters in Guam are classified by the Guam EPA based on their use and desired water quality (**Figure 52**). The Geus watershed appears to be designated S3, and the Manell watershed appears to be designated S2. Cocos Lagoon and the Achang Preserve are designated as M1 (**Figure 53**) (Guam EPA, 2015).

Marine Waters		
<u>Category</u>	<u>Ranking</u>	<u>Description</u>
M1	Excellent	Suitable to protect whole body contact recreation, and also to ensure preservation of marine life
M2	Good	Allows for propagation and survival of marine organisms
M3	Fair	Suitable for general, commercial and industrial use
Surface Waters		
<u>Category</u>	<u>Ranking</u>	<u>Description</u>
S1	High	Suitable for drinking water, wilderness areas, propagation and preservation of aquatic life, whole body contact and recreational enjoyment
S2	Medium	Suitable for recreational purposes, including whole body contact recreation, and as use as potable water after adequate treatment is provided.
S3	Low	Primarily used for commercial, agricultural, and industrial activities

Figure 52. Classification of Guam Marine and Surface Waters (Guam EPA, 2015).

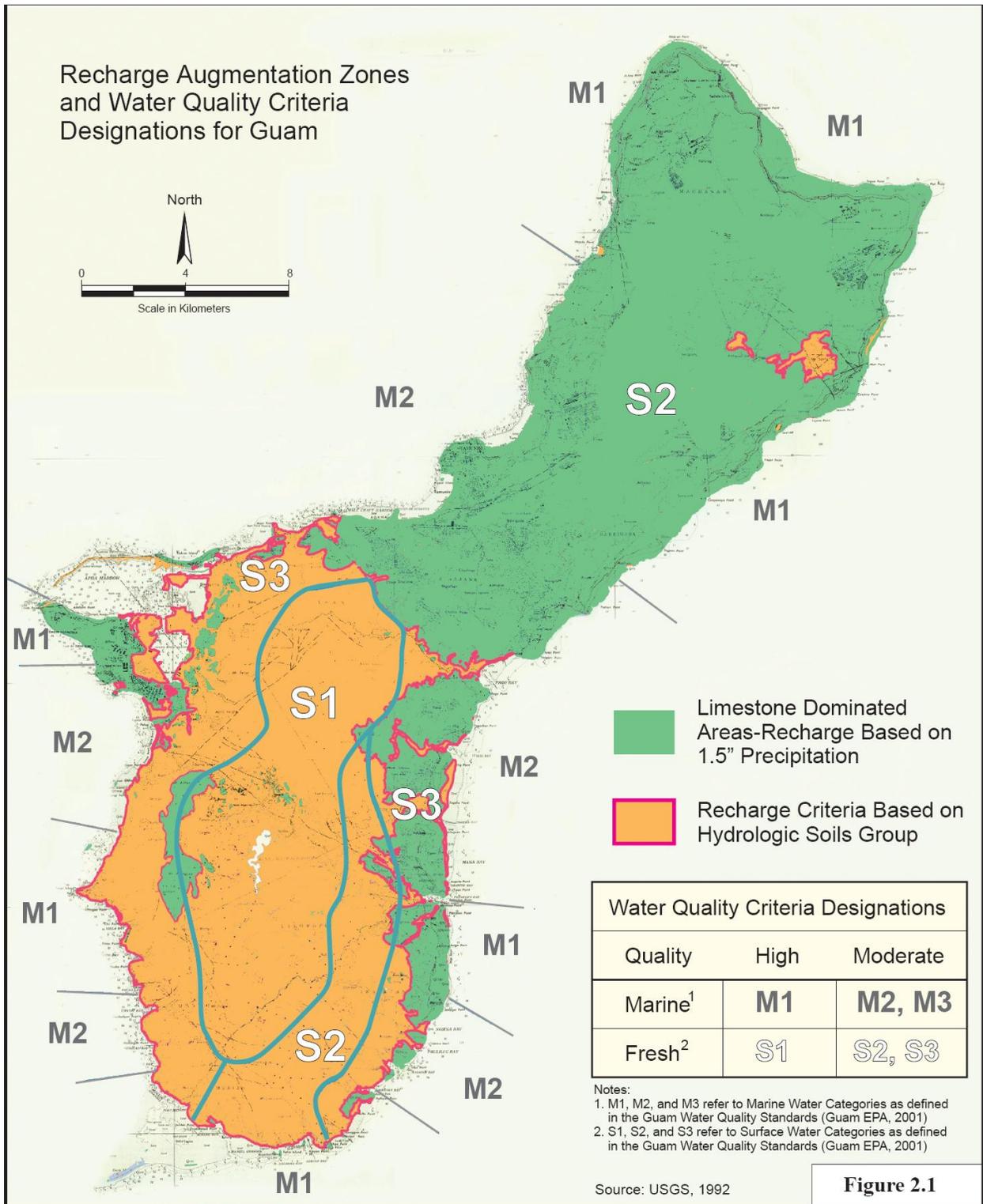


Figure 53. Resource Augmentation Zones and Water Quality Criteria Designations for Guam (USGS, 1992).

Table 2.3 Summary of Recharge Criteria for CNMI and Guam based on Surficial Geology

Surficial Geologic Classification (see Figures 2.1-2.4)	Recommended Recharge Requirement
Limestone-dominated areas	1.5 inches x total site area x % impervious area ¹
Volcanic-dominated areas and areas with deep soil profiles ²	Match natural rate based on HSG

Figure 54. Summary of recharge criteria for CNMI and Guam based on Surficial Geology (Horsley Witten Group, 2006).

The following figures indicate which numeric criteria apply for priority toxic pollutants in the categories of waters.

Compound	AQUATIC LIFE				HUMAN HEALTH	
	Freshwater (µg/l)		Saltwater (µg/l)		Consumption (µg/l)	
	Acute	Chronic	Acute	Chronic		
	(B1)	(B2)	(C1)	(C2)	(D1*)	(D2*)
Copper	18	12	4.8	3.1	1300	X
Mercury	2.4	0.012	2.1	0.025	0.050	0.051
Cyanide	22	5.2	X	X	700	200,000
Benzene	X	X	X	X	1.2	71
Thallium	X	X	X	X	1.7	6.3

*D1 = Assumes exposure due to consumption of (fresh) water plus organisms living in the water
 *D2 = Assumes exposure due to consumption of organisms only (e.g. marine water organisms)
 X = No assigned Value

Figure 55. Selected Numeric Criteria for Priority Toxic Pollutants (Guam EPA, 2020).

Water Categories	Numeric Criteria*
M-1	C1, C2, D2
M-2	C1, C2, D2
M-3	C1, C2, D2
S-1	B1, B2, D1
S-2	B1, B2, D1
S-3	B1, B2, D2
G-1	Refer to the Guam Water Quality Standards
G-2	Refer to the Guam Water Quality Standards

Figure 56. Numeric Criteria Applied to Categories of Water (Guam EPA, 2020).

8.3 Impairments and TMDLs

The draft 2020 303(d) Integrated Waters Report identifies several impairments for the Manell and Geus watersheds (Table 5 and 6) (Guam EPA, 2020). The Merizo Pier-Mamaon Channel is categorized as a Category 4b impairment with potential sources of pollutants including sewer line blockages or breaks and sewer system overflows (Guam EPA, 2020).

Table 5. 2020 Guam EPA List of Impaired Waterbodies in the Manell-Geus Watershed

Waterbody	Assessment ID	Watershed	Water Type and Classification	Waterbody Size	Unit	Assessed Units	Pollutants	Basis for Listing	Priority Ranking
Cocos Lagoon 1	GUG-020a-1	Geus	Marine Bay – M1	5.70	Square Miles	5.70	PCBs in fish tissue	Fish Advisory (2006)	Low
Cocos Lagoon 2	GUG-020a-2	Geus	Marine Bay – M2	0.34	Square Miles	0.34	PCBs in fish tissue	Fish Advisory (2006)	Low
Ajayan River	GUMZRAJ	Manell	River – S2	3.95	Miles	3.86	Dissolved oxygen, Orthophosphates, Suspended solids	Exceeds WQS > 10% of Samples	Medium
As Liyog River	GUMZRL	Manell	River – S2	1.83	Miles	1.81	Dissolved oxygen, Orthophosphates, Suspended solids	Exceeds WQS > 10% of Samples	Medium
Sumay River	GUMZRSY	Manell	River – S2	1.06	Miles	1.02	Dissolved oxygen, Orthophosphates, Suspended solids, Nitrates	Exceeds WQS > 10% of Samples	Medium

Table 6. 2020 Guam EPA 303(d) Impaired Waters in the Manell Watershed

River	Length	Pollutants	Source
Sumay River	1.02 miles	Dissolved Oxygen Orthophosphates Nitrates Suspended Solids	Runoff Agricultural activities Septic systems
As Liyog River	1.81 miles	Dissolved Oxygen Orthophosphates Suspended Solids	Runoff Agricultural activities Septic systems
Ajayan River	3.86 miles	Dissolved Oxygen Orthophosphates Suspended Solids	Runoff Agricultural activities Septic systems

Table 7. 2020 Guam EPA Assessment for Rivers and Streams in the Manell-Geus Watershed

Waterbody	Watershed	Water Type and Classification	Channel Length in Miles	Assessable Miles	Assessed Miles	Reporting Category
Achang River 1	Manell	River – S2	0.50	0.50	0.00	3
Achang River 2	Manell	River – S2	0.30	0.30	0.00	3
Ajayan River	Manell	River – S2	3.95	3.86	0.00	5
As Liyog River	Manell	River – S2	1.83	1.81	1.81	5
Geus River 1	Geus	River – S1	0.99	0.99	0.99	3
Geus River 2	Geus	River – S2	0.52	0.52	0.52	3
Geus River 3	Geus	River – S3	0.78	0.78	0.78	3
Manell River	Manell	River – S2	2.77	2.65	0.00	3
Sumay River	Manell	River – S2	1.06	1.02	1.02	5
Suyate River	Manell	River – S2	0.88	0.00	0.00	3
Asgadao Creek	Manell	River – S2	0.59	0.00	0.00	3
Asmaile River	Manell	River – S2	0.77	0.00	0.00	3

For TMDLS, the Merizo Pier – Mamoan Channel (Waterbody ID S-08) was previously under a bacteria TMDL along with 24 other beaches on this island due to exceedances of Guam’s Water Quality Standards for enterococci bacteria (**Figure 57**). The enterococci bacteria TMDL was completed in 2016 (Guam EPA, 2013).

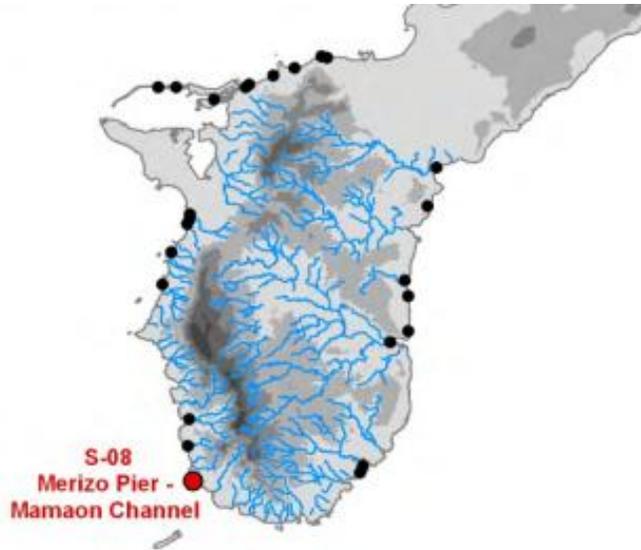


Figure 57. Location of Merizo Pier - Mamoan Channel relative to other TMDL sites (Guam EPA, 2013).

8.4 Water Quality Studies

8.4a Manell Watershed Water Quality Studies

A December 2019 NOAA study of turbidity, suspended sediments, and nutrients in three rivers (Ajayan, Sumay, and As Liyog) that drain to the Achang Preserve from the Manell watershed pointed to the need for continued restoration efforts in the watershed (**Table 8**). There was some evidence that a number of the parameters showed decreasing trends in concentration during the project. Further monitoring is needed to determine if these decreases are real, which could be an indication of the benefits of the ongoing restoration activities in the watershed, evidence of natural vegetation regrowth post-wildfires, or a combination of both (Pait et al., 2019).

Table 8. Summary of NOAA 2019 Water Quality Results for the Manell Watershed

River	Criteria	Results
Ajayan	Mean SSC	Excellent-Good
	Turbidity	Good-Fair
	Mean nitrate concentration	Excellent
	Mean orthophosphate concentration	Good-Fair
As Liyog	Mean SSC	Good-Fair
	Turbidity	Good-Fair
	Mean nitrate concentration	Excellent
	Mean orthophosphate concentration	Good-Fair
Sumay	Mean SSC	Excellent-Good
	Turbidity	Good-Fair
	Mean nitrate concentration	Excellent
	Mean orthophosphate concentration	Good-Fair

8.4b Geus Watershed Water Quality Studies

In 2015, Khosrowpanah et al. assessed turbidity in the Geus watershed and concluded that fire and disturbance are major contributors to erosion and high levels of turbidity and sedimentation in the Geus River. Relatedly, Camacho et al. (2016) concluded that substrate composition in the Geus River shifted from hard bottomed habitat in the upper reach, to soft-bottomed in the lower reach (Camacho et al., 2016). These sediment impacts have been found to extend into the adjacent marine habitats where high levels of sedimentation affect the health of corals and seagrasses in the Achang Preserve and Cocos Lagoon (NMFS PIRO, 2017).

A 2016 NOAA assessment of the Geus River determined that water chemistry was generally uniform across the stream reaches, even in the more urbanized and modified areas of the lower reaches of the river. The findings included the following:

- **Nitrates:** Nitrate concentrations were slightly enriched and ranged from 0.66 – 2.88 mg•L⁻¹ across all the sites that were assessed.
- **Phosphates:** Phosphate levels exceeded local water quality standards, ranging from 0.1 – 1.05 mg•L⁻¹.
- **pH:** pH values were slightly alkaline throughout the Geus River, suggesting some water may be percolating from carbonate springs.
- **Dissolved oxygen:** Dissolved oxygen levels were relatively high in the lower and upper reach during sampling.
- **Algae:** Filamentous algal growth was present in large quantities in the lower reach of the stream, especially in areas with low canopy cover.

These results suggest that the Geus River is a conduit for inorganic nitrogen and phosphorus that could enhance algal production in coastal receiving waters. It is possible that substantial amounts of nitrate and phosphate are entering the lower reaches of the river from anthropogenic sources of pollution, such as agricultural runoff. In the upper reaches of the Geus River, levels of nitrates and phosphates were elevated even in areas without residences or farmland present. The source of these nutrients may be from decomposition and microbial mineralization of instream organic material, as well as runoff from the surrounding watershed. This assessment further concludes that the river exports relatively low levels of nutrients to the adjacent marine community during the dry season (Camacho et al., 2016).

8.4c Manell-Geus Water Quality Studies

Human activities, such as agriculture and sewage discharge, are potential factors contributing to enrichment of the coastal waters adjacent to the Manell and Geus watersheds. Nutrient additions can contribute to increases in algal growth and certain corals diseases. In 2018, the University of Guam Marine Laboratory reported on experimental data collected using algae (*Padina sp.*) to represent nutrient enrichment from sewage sources (**Figure 58**). The highest nutrient concentrations were measured at the deeper sections of the Cocos Lagoon, as well as at the mouths of the rivers entering the coastal waters from the Manell and Geus watersheds. The lowest concentrations were in shallower waters that are subject to more coastal currents bringing nitrogen in from the open ocean (Raymundo et al, 2018).

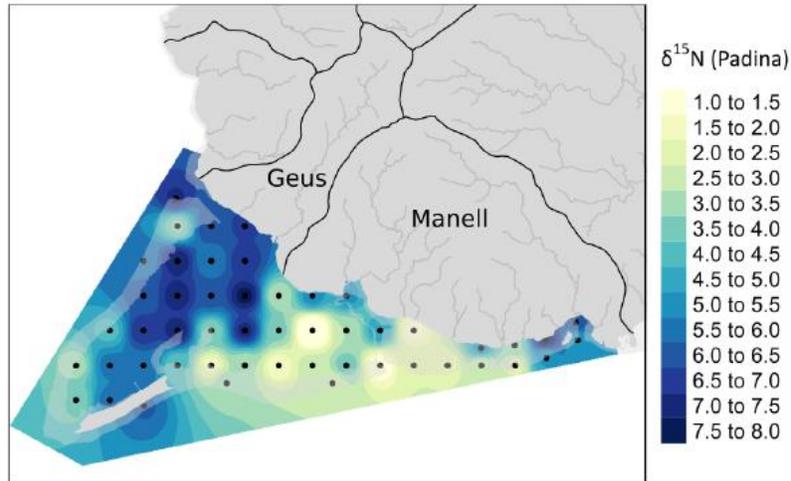


Figure 58. Nutrient enrichment experiment results (Raymundo et al, 2018).

An additional experiment was conducted by the University of Guam in January of 2017 to test for *Enterococcus* bacterium concentrations entering the coastal waters from the rivers of the Manell and Geus watersheds (Figure 59). The *Enterococcus* bacterium is found in mammalian digestive tracts, so can be used to test for fecal contamination of water. The experiment results showed that 9 out of 17 sites tested contained higher *Enterococcus* concentrations than the EPA limits (35 CFUs/100ml), with every upstream test site (i.e., landward of Highway 4) demonstrating *Enterococcus* concentrations above the EPA limit (Table 9). Potential sources were not identified in the study (Raymundo et al, 2018).



Figure 59. *Enterococcus* contamination study points (Raymundo et al, 2018).

Table 9. Enterococcus bacterial counts for tested rivers within the Manell-Geus Habitat Focus Area

Sample Sites	Site Code	ENT CFU counts/100ml
Ajayan River upstream	AJA	53.4
Ajayan River mouth	AJA	58
Liyog River upstream	LIY	38
Liyog River mouth	LIY	43.8
Site 8 beach reference site (negative control 1)	REF	24.2
Unnamed stream, upstream	Site 4	56.2
Unnamed stream, mouth	Site 4	22.6
Laolao River upstream	LAO	62
Laolao River mouth	LAO	24.2
Manell River upstream	MAN	88.4
Manell River mouth	MAN	4.4
Geus River upstream	GEU	50.2
Geus River mouth	GEU	22.4
Pugua River upstream	PUG	68.8
Pugua River mouth	PUG	113.2
Cocos Resort	CORST	0.2
Cocos Resort downstream reference site	COREF	1.4
Cocos Lagoon center, near anchor buoy (negative control 2)	LAG	0
Filtered drinking water (negative control 3)	NA	0

Dataset used is from Raymundo et al., 2018

Preliminary results from a 2022 Ridge-to-Reef Assessment of Southern Guam assessment of dissolved inorganic nitrogen (DIN) indicate that the Manell River had relatively high DIN levels with a corresponding relationship to rainfall, suggesting that the levels are driven by non-point sources. The Sumay River had relatively low DIN levels, but with a weak corresponding relationship to rainfall, suggesting that levels are driven by point sources. For the Geus River, DIN levels were relatively low, also with a corresponding relationship indicating that the levels are driven by non-point sources (Figure 60) (Houk et al., 2022).

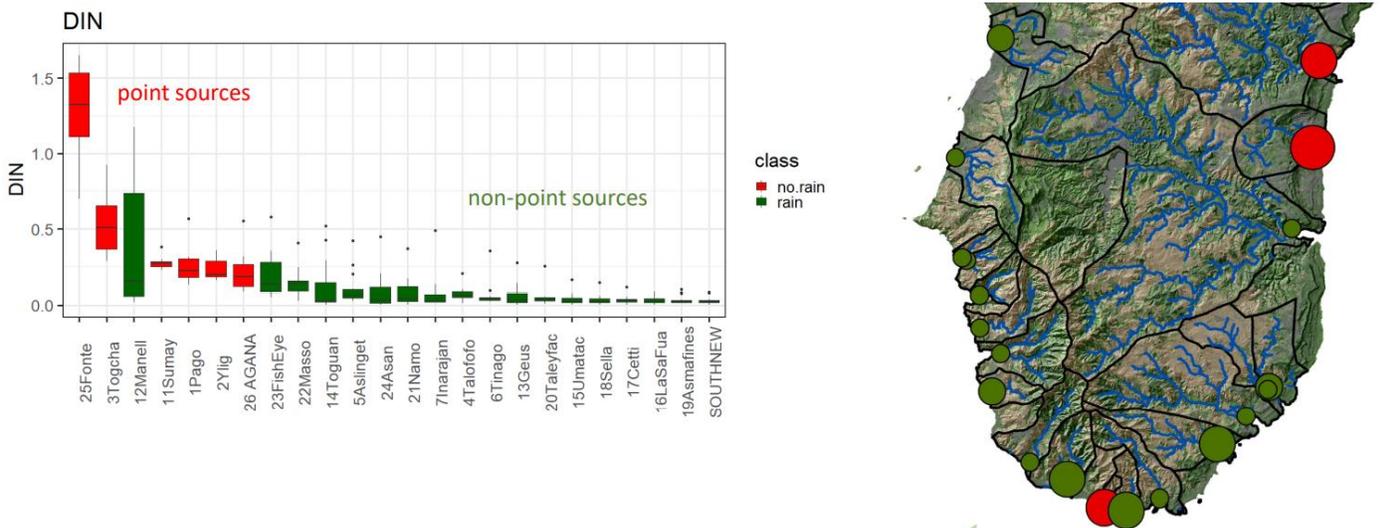


Figure 60. DIN levels and mapped survey sites in Southern Guam (Houk et al., 2022).

8.4d Cocos Lagoon Water Quality Studies

Between 1944 and 1963, the U.S. Coast Guard operated a LORAN navigation station on Cocos Islands just off of the mainland in Cocos Lagoon. It appears that improper disposal of materials from the station resulted in the contamination of soils on the island near the former LORAN site, as well as in adjacent waters. Of particular concern is the potential impacts of contaminants on fish populations. In 2006, a fish consumption advisory for PCBs was put in place for all of Cocos Lagoon, and it remains in place today. In a 2019 NOAA assessment of chemical contaminants around Cocos Island using polyethylene passive water samples, results indicated that detections of PCBs and DDT were limited to nearshore sites. PCBs and DDT were found in the highest quantities near the high-water mark of the site of the former U.S. Coast Guard LORAN station on Cocos Island. Results indicated that uptake of these contaminants directly from the water column into biota such as fish in nearshore areas is likely occurring (Pait et al., 2019).

9.0 Prior Identified Recommendations

9.1 Manell Recommendations

A 2020 U.S. Army Corps of Engineers Flood Hazard Study of the Nelansa (Manell) subwatershed developed the following recommendations to address flooding:

- Reforestation of the Manell subwatershed
 - Two reforestation scenarios in the Manell subwatershed near Route 2 should be evaluated, a 1-acre site and a 10-acre site, to address flooding concerns in the area. Both sites should be adjacent to a main road, such as Route 2 or Jose Q. Aguon St. The sites should be planted with dominant tree species found in the local ravine forest currently. These may include hibiscus tiliaceus, pandanus tectorius, pandanus dubius, ficus prolixa, glochidion marriannensis, and premna serratifolia. The estimated cost of construction to reforest a 1-acre site in 2020 was approximately \$51,400 with a 43% contingency for a total estimated construction contract cost of \$73,600 (U.S. Army Corps of Engineers, 2020b).
- Restoring the natural flow path of the Manell River
 - A historical topography map created by the U.S. Army Map Service in 1944 shows the Nelansa (Manell) River flowing directly through Route 4 toward Balang Point. Currently, the Manell River makes a nearly ninety degree turn immediately upstream of Route 4 and runs parallel to this main road before crossing beneath it. The intent of this proposed alternative is to restore the river to a somewhat natural flow path instead of forcing the water to make such a sharp turn in a developed area. While restoring it to its historical path exactly would require extensive work beyond what is necessary to reduce flood risk in the area, constructing a new culvert at the turning point and excavating through the bay front wetland to create a new outflow point would allow flood waters to drain from the area more effectively. The size of the culvert is proportionate with the size of the concrete channel upstream which has an area of approximately 86 feet². The proposed culvert has a vertical span of 6.6 feet, a horizontal span of 13 feet, and a length/deck width of 21 feet. The headwall height (deck thickness) is approximately 2.6 feet. Downstream of Route 4, a new channel would be excavated across the bay front wetland to create a new outflow point and allow flood waters to drain from the area more effectively. Regulatory and permitting actions should be limited as the proposed alternative is the *removal* of fill in the wetland rather than the *placement* of fill. The proposed channel is approximately 1,100 feet, trapezoidal shape with a base width of 20 feet, side slopes of 3H:1V, and depth of 3.3 feet. The approximate cut volume is 11,000 feet³. This alternative by itself does not mitigate for

the 1% AEP (100- year) peak discharge, which is approximately 3,410 feet³/s at this location (**Figure 61**). It was designed to be cost effective, but by doing so, only mitigates for the 20% AEP (5-year) event. It also assumes that the channel that runs parallel to Route 4 could still be utilized. The estimated cost of construction to restore the natural flow path of the channel is approximately \$387,000 with a 35% contingency for a total estimated construction contract cost of \$523,000 (U.S. Army Corps of Engineers, 2020b).



Figure 61. Current (Red), Proposed (Green), and Historic (Yellow) Path of the Nelansa River (U.S. Army Corps of Engineers, 2020b).

- Upper detention basin development in the Manell subwatershed
 Detention basins can be effective in reducing peak flow by capturing large amounts of water during a storm event and releasing it more gradually. In the Manell Watershed, there were two possible identified locations for a detention basin: upstream of Route 4 along the Manell River and between Joutan Lane and J Baza Street (**see Figure 62**). These locations are ideal to capture flow from the Manell River and overland runoff from the mountains between the Manell River and Achang Bay, respectively. These basins would contain nearly the 50% AEP (2 year) flood event and reduce the 10% AEP (10 year) peak flow in half along the Manell River. The estimated cost of construction to retrofit two detention basins is approximately \$24,800 with a 43% contingency for a total estimated construction contract cost of \$35,500 (U.S. Army Corps of Engineers, 2020b).

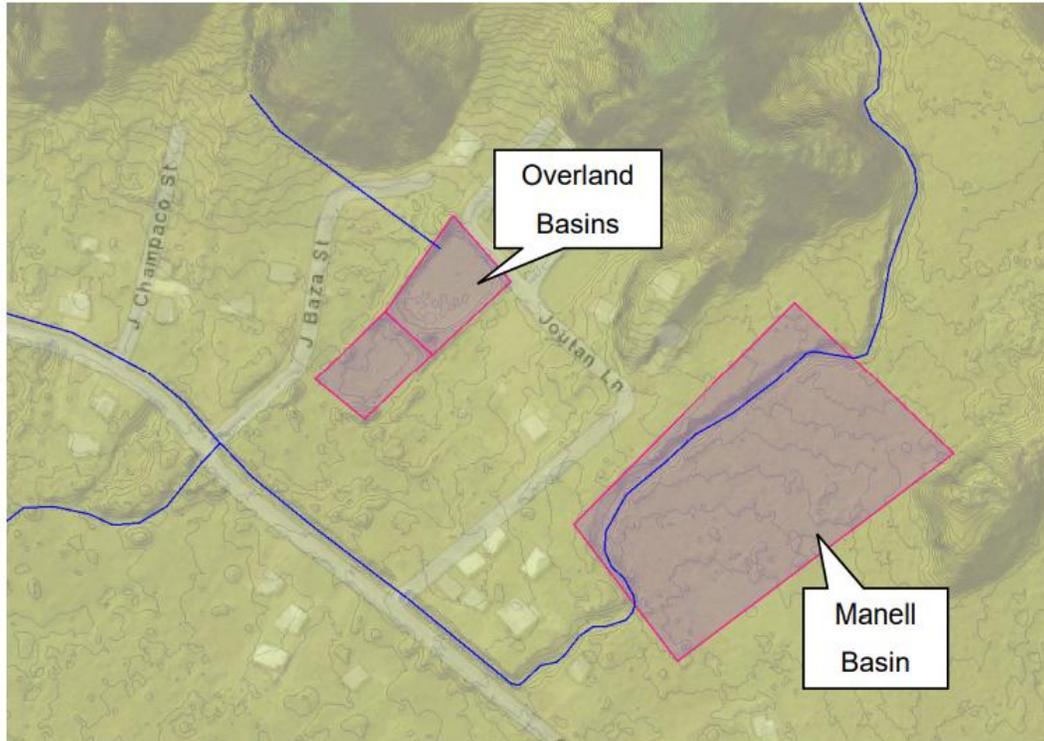


Figure 62. Potential Detention Basin Placement in the Manell Subwatershed (U.S. Army Corps of Engineers, 2020b).

9.2 Geus Recommendations

In a 1974 assessment of the Geus watershed, fire control measures and reforestation of the upland savanna were identified as top restoration priorities (Kami et al., 1974). Relatedly, Golabi et al. (2005) examined simulated runoff from a variety of surface conditions common in savanna habitats. The results showed the rate of soil loss from bare soil and controlled burn area were significantly higher than natural savanna but could be reduced further with the use of vetiver grass.

A 2015 assessment of turbidity in the Geus watershed developed the following recommendations:

- **Increase outreach to the local community and more effective enforcement of Guam’s laws against fugitive burning to minimize the threat of fire.** The study asserted that this watershed, and in particular the southern coastal area of the watershed, will not benefit from any restoration or vegetative cover improvements unless public support for minimizing fire threats is achieved.
- **Any future restoration activities be focused on disturbed portions of the watershed.** In particular, habitat restoration of the degraded savannas was identified as a top priority.
- **Further investigation of water quality in the watershed.** The study included specific areas in need of additional assessment and recommended that assessments quantify differences between the developed regions of the watershed and the undisturbed regions.
- **Placement of monitoring stations at each of the major tributaries during rainy seasons.** The study specified that upper reaches of streams should be assessed first.

- **In-depth study of sediment being discharged into the ocean from the Geus River.** The study emphasized that additional information is needed to understand that extent of the impacts erosion and sediment overload are having on Cocos Lagoon (Khosrowpanah et al., 2015).

9.3 Manell-Geus Recommendations

A 2014 report by EA Engineering, Science and Technology for NOAA’s Pacific Islands Regional Office Coral Reef Conservation Program identified the following best practices (**Table 10**) for watershed restoration projects based on selected project study sites within the Manell-Geus watershed (**Figure 63**).

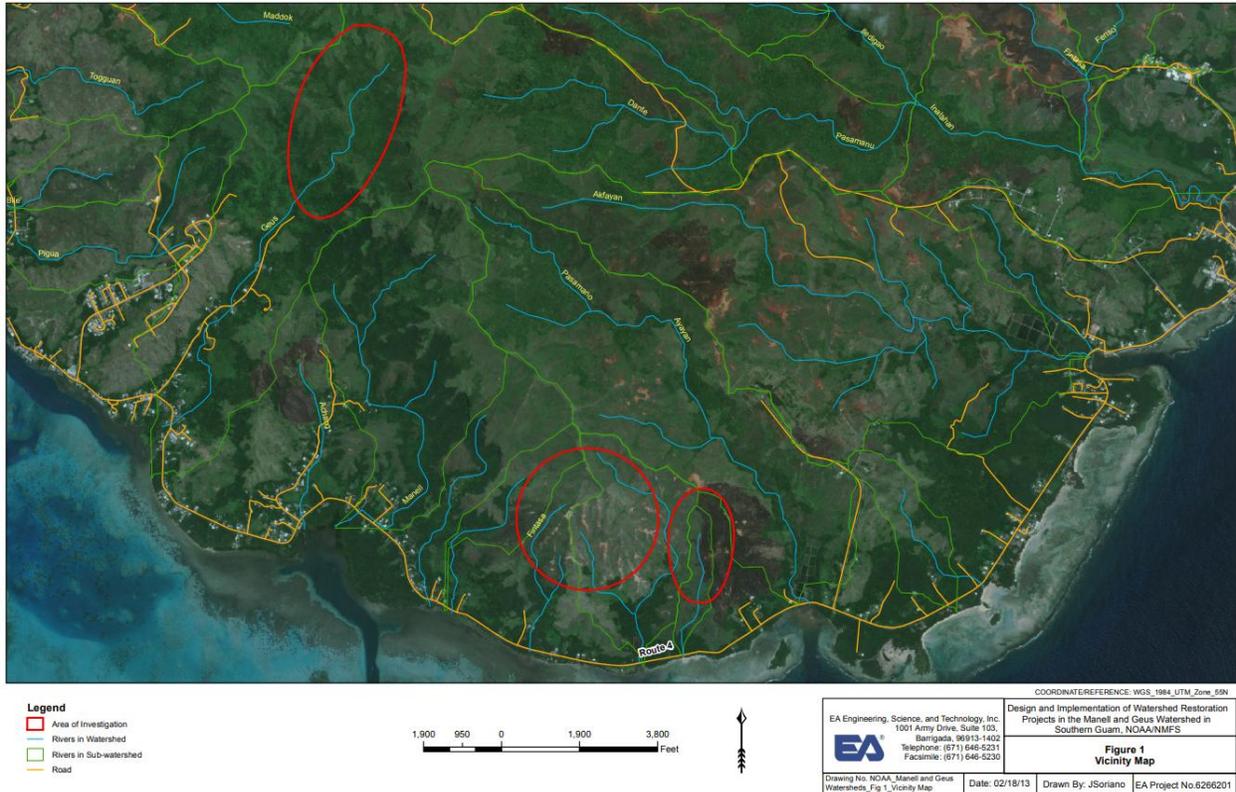


Figure 63. Project study sites for watershed restoration (EA Engineering, Science, and Technology Inc., 2014).

Table 10. 2014 EA Engineering, Science, and Technology recommended watershed restoration projects for the Manell-Geus Watershed

Strategy	Recommended Actions
Planting and Seeding	<ul style="list-style-type: none"> • Planting recommended adjacent to drainages and streams. • Planting inside of the stream banks likely to be unsuccessful due to washout from large stream flows. • Planting and seeding identified as most cost effective and implementable means of achieving erosion control.
Containerized Stock Planting	<ul style="list-style-type: none"> • Installation of larger containerized stock plants essential to establishing tree canopy and understory shrubs.

Strategy	Recommended Actions
	<ul style="list-style-type: none"> • Containerized plants are the highest cost vegetation control option, but also have the greatest survivability compared to other practices.
Live Stake Planting	<ul style="list-style-type: none"> • Live stakes of pajo are cost-effective to introduce vigorous riparian vegetation to the sites. • Pajo live stakes grow rapidly and are tolerant of wet and dry conditions, aiding in the restoration of native vegetation.
Bare Root Planting	<ul style="list-style-type: none"> • Vetiver grass provides local control for erosion with low risk of spreading to pristine habitats as an invasive species. • When coupled with tree and shrub plantings, likely to be eventually shaded and replaced by native species, once canopy is established. • Bare root specimens of vetiver grass at four stems per linear foot were selected to hold deep loose soil such as in colluvial deposits, as well as create vegetative filter strips near channels and head cuts to limit the surface transport of sediment into stream channels. • Vetiver is a non-native species from Southeast Asia but does not produce seed and spreads through rhizomatous action.
Herbaceous Plantings	<ul style="list-style-type: none"> • Establishing groundcover in planting areas determined to reduce erosive potential through sheet flow and runoff. • Native herbaceous ferns essential part of the native forest community.
Invasive Plant Species Control	<ul style="list-style-type: none"> • Control of invasive species essential to reduce erosion. • Invasive species in the forested areas of the study watersheds displaced native vegetation and were observed to reduce vegetative cover, particularly groundcover. • Initial control of invasive species was recommended as part of the maintenance of the site demonstration plots.
In-Stream Control	<ul style="list-style-type: none"> • Log revetment/rootwads recommended to form stable sills and deflect energy from banks and could be instituted in areas of moderate impairment with some stable floodplain benches. • Stone bank protection recommended for installation in areas where extensive grading and floodplain restoration could not be instituted. • Both approaches useful for protecting roads, existing trees and infrastructure. • In-channel stone vanes and step pools were also recommended for installation to reduce flow energy and uplift stream channels.
Protection of Installed Vegetation	<ul style="list-style-type: none"> • Planting immature seedlings should be protected from weeds, animals, and other organisms to ensure plant establishment. • Applying organic mulch around trees or shrubs helps conserve moisture and control weeds. • Individual tree protection or fencing can be utilized.

Strategy	Recommended Actions
Monitoring and Maintenance	<ul style="list-style-type: none"> • Following successful installation of plantings, within the first month, plantings should be inspected and monitored for proper establishment. • Any damage, distress, or infestations or diseased plants should be recorded. • Plants that are found dead within the first few months should be replaced. • Periodic maintenance of new plantings should occur. • Continue to remove bamboo and other unwanted vegetation and debris which inhibit growth. • When new bamboo growth near the plots is observed, immediately cut and/or spray glyphosate herbicide over the entire clump (may require several treatments). • Watering should occur if unexpected dry weather occurs; otherwise, the rainy season should be sufficient for watering the plant stock. • If reduced plant growth is observed, a periodic application of complete fertilizer (nitrogen, phosphorus, potassium) may be warranted to expedite plant establishment. • During maintenance activities, disturbed areas and sediment controls, including the log check dams and filter strips, should be inspected to ensure the controls are in place and adequately functioning. • If sediment inspections indicate that a control is not functioning properly, the control should be replaced or modified.

In 2010, the Guam Statewide Forest Assessment and Resource Strategy identified areas that were the likely source of sediment reaching streams in the Manell-Geus watershed (**Figure 64**). These areas were identified as the primary targets for watershed restoration. Projects have been implemented in three of the four target areas shown in the Manell watershed and one has also been implemented in the Geus watershed (Watershed Professionals Network, 2010).

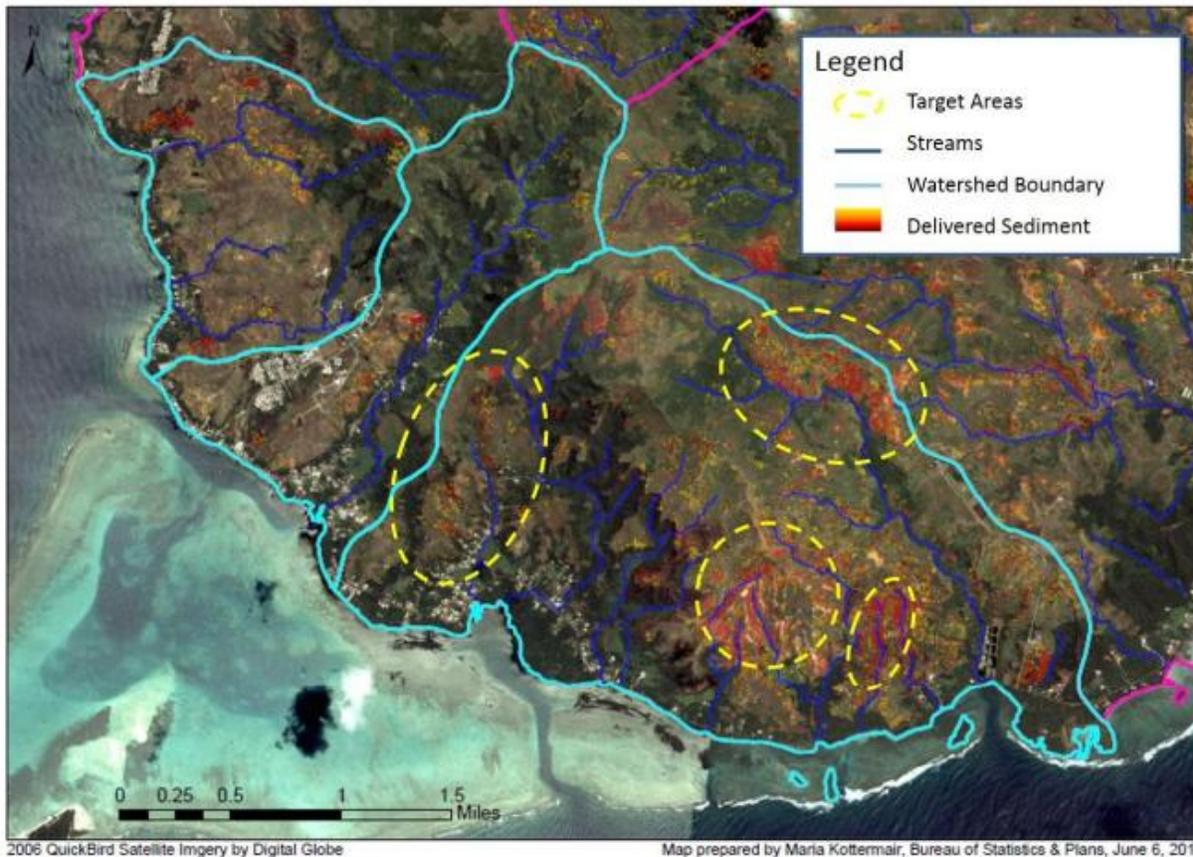


Figure 64. Map of Target Areas for Watershed Restoration Based on Delivered Sediment Estimates Created by the Guam Statewide Assessment and Resource Strategy (Bureau of Statistics and Planning, 2012).

A 2021 National Fish and Wildlife Foundation assessment of Community Resilience Hubs using the Coastal Resilience and Evaluation Siting Tool identified areas of open lands and protected space that may be suitable for resilience building efforts in Guam. The Hubs are ranked by priority given the level of exposure that nearby assets have to flood-related threats and the presence of fish and wildlife species surround the Hub. A significant portion of the coastline of Merizo and the region surrounding the Geus River ranked highly in this assessment (**Figure 65**) (Dobson et al., 2021).

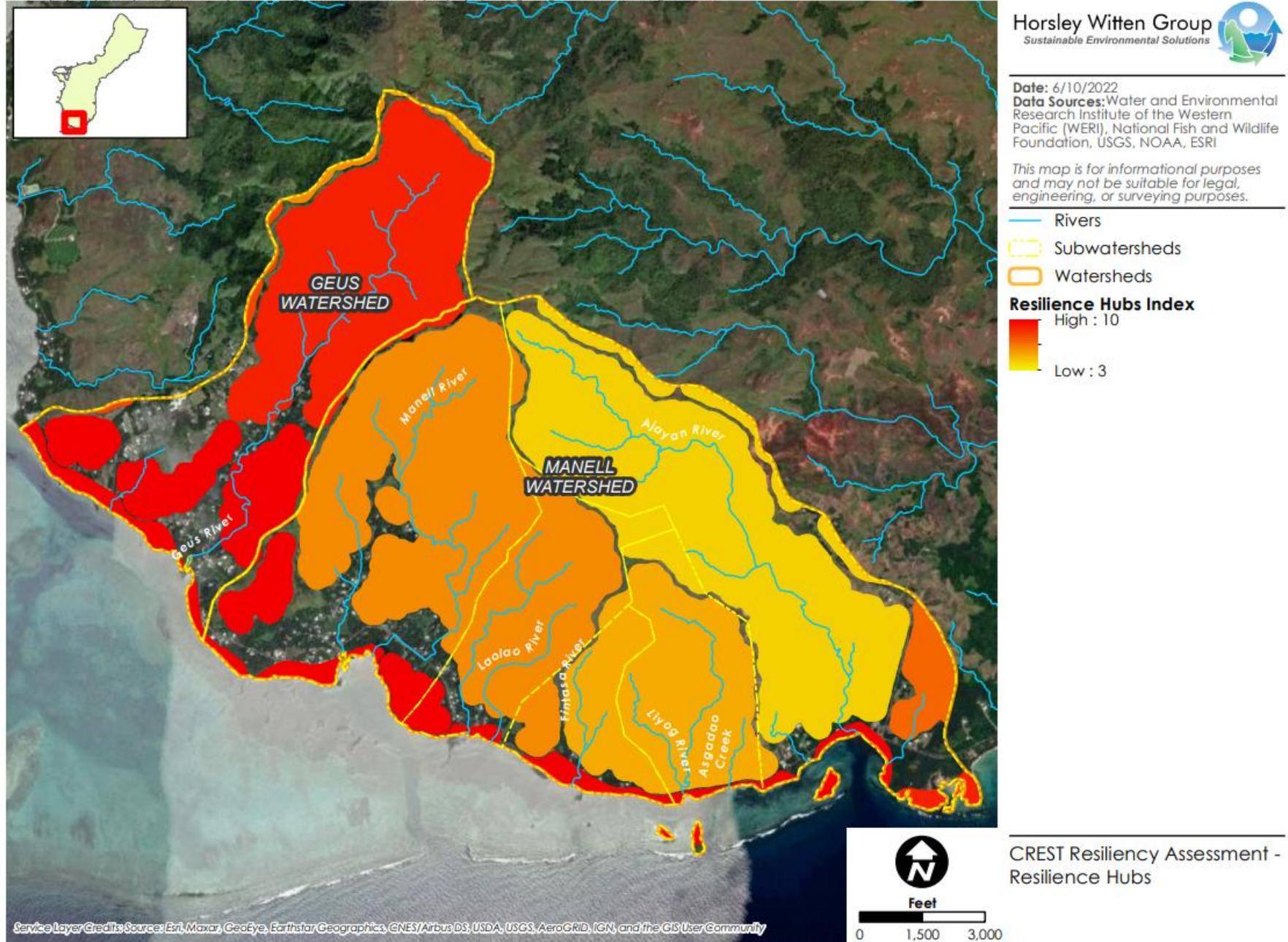


Figure 65. CREST NFWF Identified Resilience Hubs in the Manell Geus Watershed (NFWF, USGS, NOAA, Water and Environmental Research Institute of the Western Pacific (WERI), ESRI).

9.4 Cocos Lagoon Recommendations

Regarding PCB and DDT contamination on Cocos Island and Cocos Lagoon, one recommendation from NOAA and partners was the installation of piezometers around the former location of the U.S. Coast Guard LORAN station, followed by the installation of polyethylene devices to assess if the contaminants may be concentrated in one part of the former site. Additionally, NOAA recommended the placement of piezometers in an array towards the water to see if a gradient of dissolved concentrations of contaminants is present. If so, these piezometers could be used to assess if the higher concentrations of contaminants are limited to a particular area that may be related to past land use activities or groundwater and subsurface flow. This information would be useful to resource managers in deciding how to proceed with any restoration activities to reduce the levels of contaminants going into Cocos Lagoon (Pait et al., 2019).

10.0 Community Perceptions and Experiences in the Watershed

10.1 Flooding

2016 household survey results indicate that more than half of Merizo residents are affected by flooding during heavy rain events or storms, which respondents indicated impact the local economy and travel in and out of the village (**Figure 66**). In a focus group that was included as part of this study regarding flooding concerns, participants discussed how they prepare households in anticipation of flooding, such as moving household items to higher ground, using sandbags, and clearing their property from debris prior to the start of rainy season. Infrastructure changes to village roads, such as concrete culverts to channel water, and urban development were also identified by participants as both potential problems and solutions (NMFS PIRO, in prep).

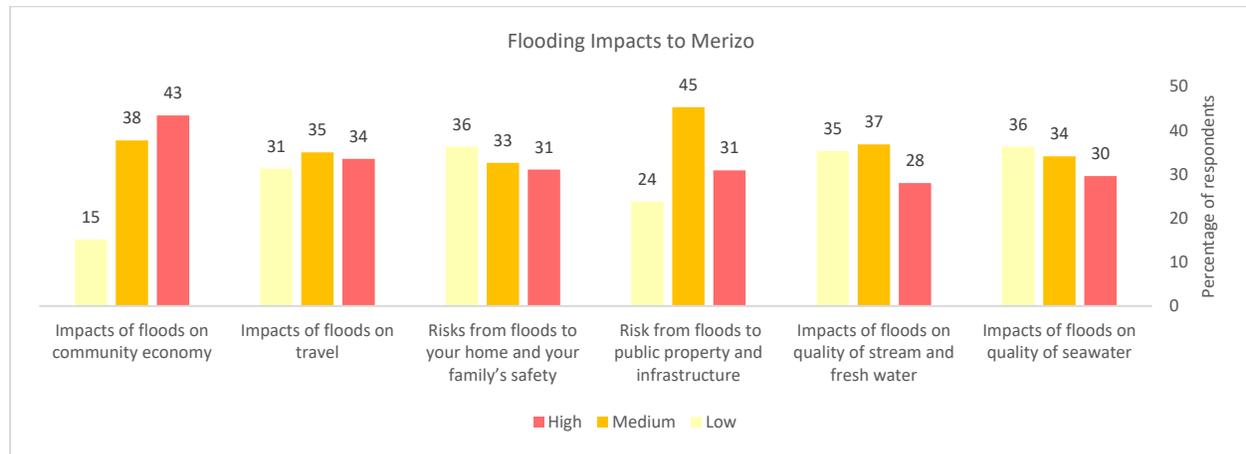


Figure 66. Flood severity risk rated by respondents affected by flooding at least once, n=121 (NMFS PIRO, in prep).

10.2 Wildfires

In 2016, household surveys of Merizo residents indicated that wildland fires in Merizo's watershed affect approximately half of Merizo households. Merizo respondents were most concerned about family and home safety, water quality, and health issues associated with these wildland fires in the watershed (**Figure 67**). In a focus group that was included in this 2016 study, residents identified respiratory issues and elderly residents that are significantly far from medical centers as top concerns related to wildfires (NMFS PIRO, in prep).

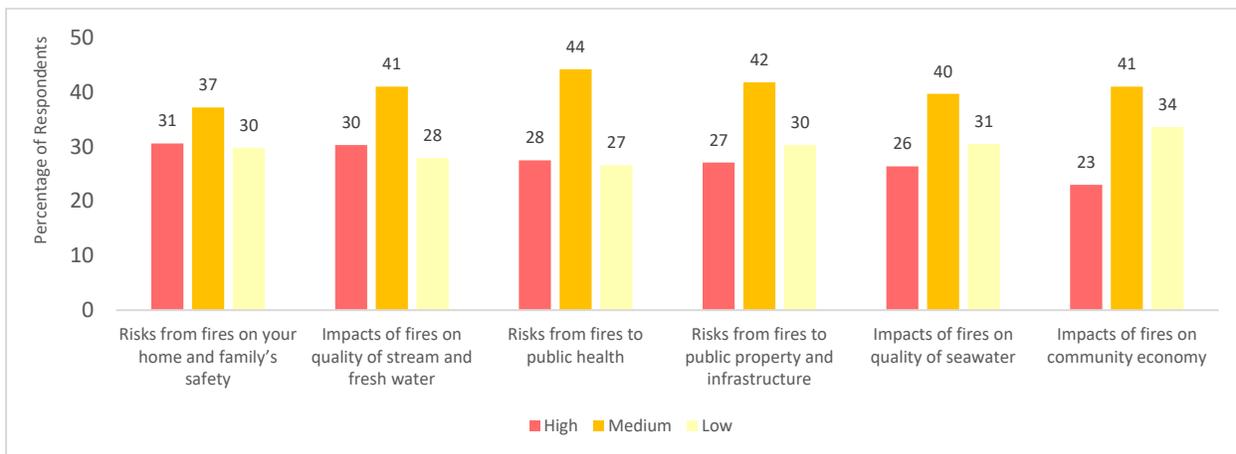


Figure 67. Fire risk severity by respondents affected by fires at least once in the last five years, n=344 (NMFS PIRO, in prep).

10.3 Watershed Health

In 2010, a community household survey was conducted in Merizo and 58% of respondents perceived threats to the Manell-Geus watershed. Of that 58%, the top threat perceived in the watershed was flooding (Figure 68) (King, 2010).

Threat Perceptions

	Strongly disagree	disagree	Don't Care	agree	Strongly agree	Don't know
Pollution	2%	1%	2%	28%	49%	18%
Development	2%	3%	3%	26%	33%	32%
Wildland fires	3%	6%	3%	30%	31%	29%
Off-roading	3%	7%	5%	29%	21%	34%
Invasive Species	2%	5%	3%	30%	24%	36%
Lack of awareness	2%	7%	2%	28%	30%	31%
Lack of rainfall	4%	19%	3%	19%	20%	36%
Overfishing	7%	12%	4%	19%	16%	41%
Land clearing	2%	4%	2%	27%	40%	25%
Coastal erosion	1%	2%	1%	25%	50%	9%
Climate change	4%	6%	3%	27%	27%	34%
Overpopulation	5%	10%	3%	27%	25%	30%
Military build-up	4%	7%	3%	22%	28%	36%
Poor infrastructure	2%	3%	2%	27%	40%	26%
Flooding	2%	0%	1%	22%	57%	19%
Other						

Figure 68. Residents' identified threats to the Manell-Geus Watershed (King, 2010).

In 2016, household surveys of Merizo residents indicated that current stream water quality is perceived as very bad or bad by 39% of residents. In addition, 38% residents believed that stream water quality has become a lot worse or somewhat worse over the last ten years in the Manell-Geus watershed. Nearly half of respondents also indicated that they believed there are no water quality problems on Merizo’s coral reefs (48%) (**Figure 69**). About 50% of respondents indicated that they believed the amount of coral and number of fish improved over the last 10 years (**Figure 70**) (NFMS PIRO, in prep).

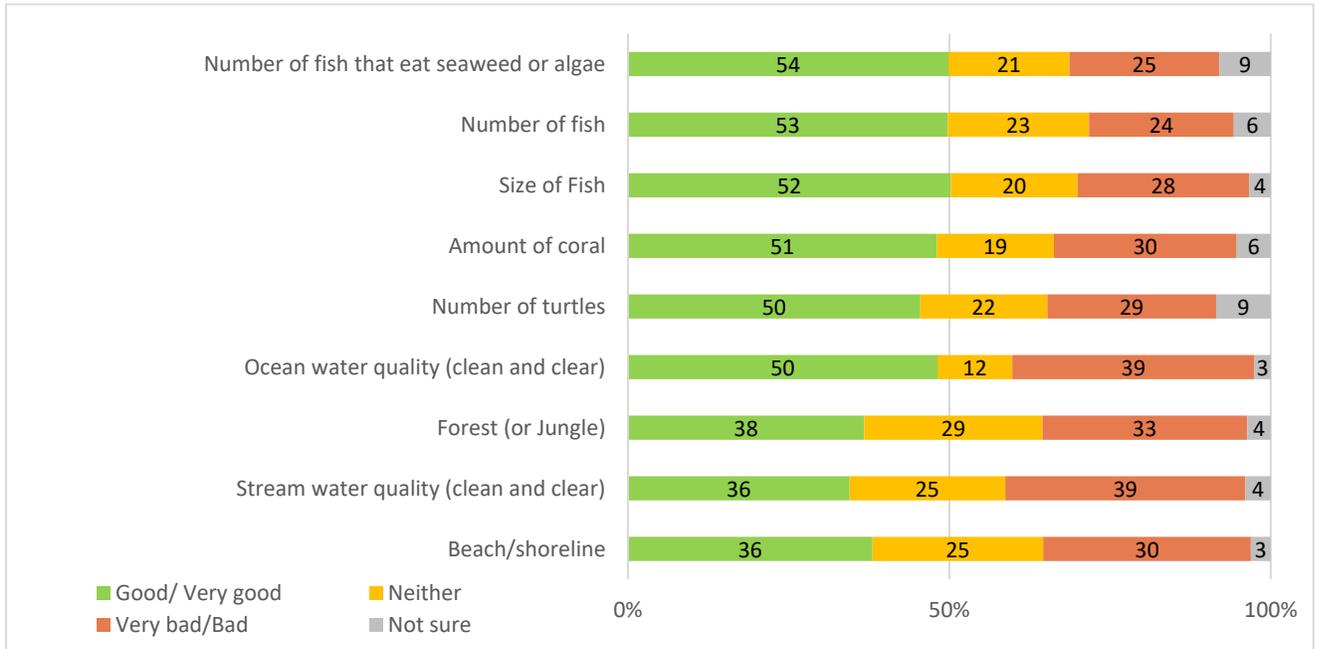


Figure 69. Perceived current conditions of Merizo’s natural resources, n=344 (NMFS PIRO, in prep).

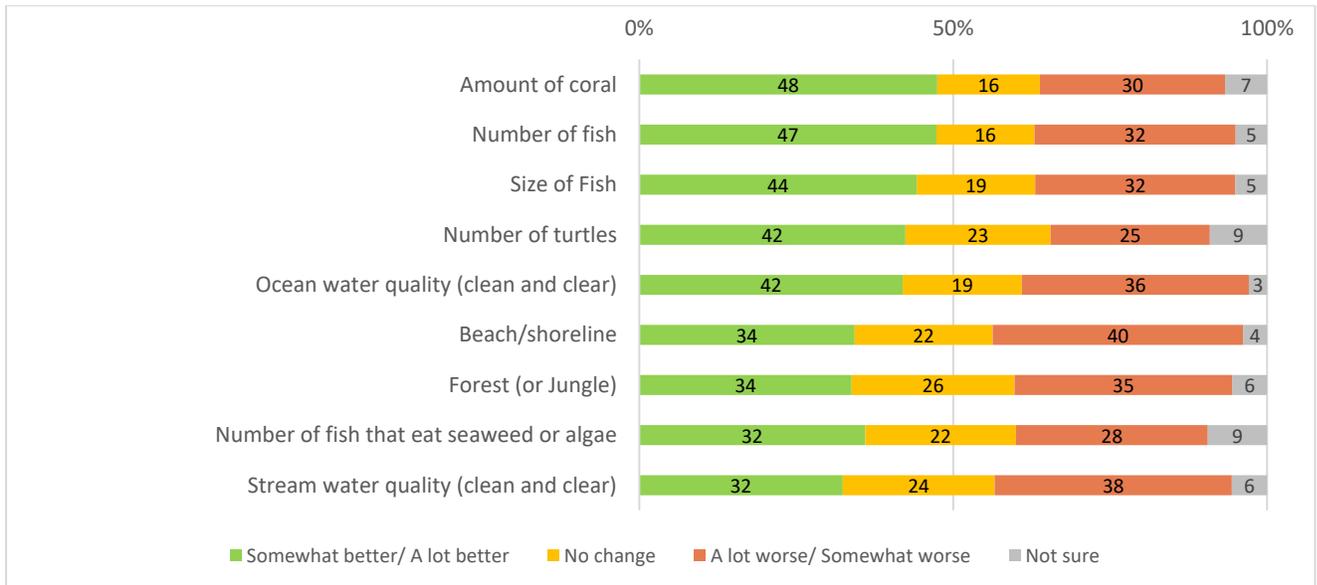


Figure 70. Perceived change in Merizo’s natural resources over the last 10 years, n=344 (NMFS PIRO, in prep).

10.4 Support for Watershed Restoration

In a 2010 household survey of Merizo residents, 20% of respondents indicated that they had participated in a watershed project in 2009 and 57% of respondents indicated that they want to participate in future watershed projects. In a 2016 household survey, a majority of Merizo households (84%) plant trees or native plants to prevent erosion at least once a year or more (**Figure 71**). Merizo residents are most interested in creating gardens on their property to slow runoff (60%) and volunteering for a community wildfire fighting team (60%) in Merizo (**Figure 72**) (NMFS PIRO, in prep).

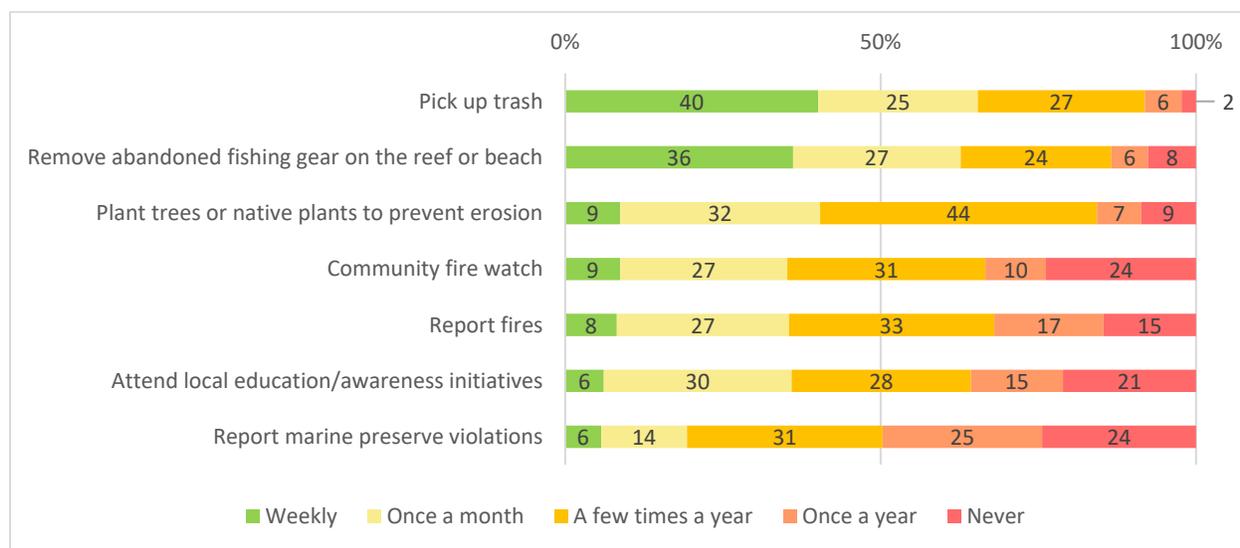


Figure 71. Percent of Merizo residents' current participation in reef protection activities, n=344 (NMFS PIRO, in prep).

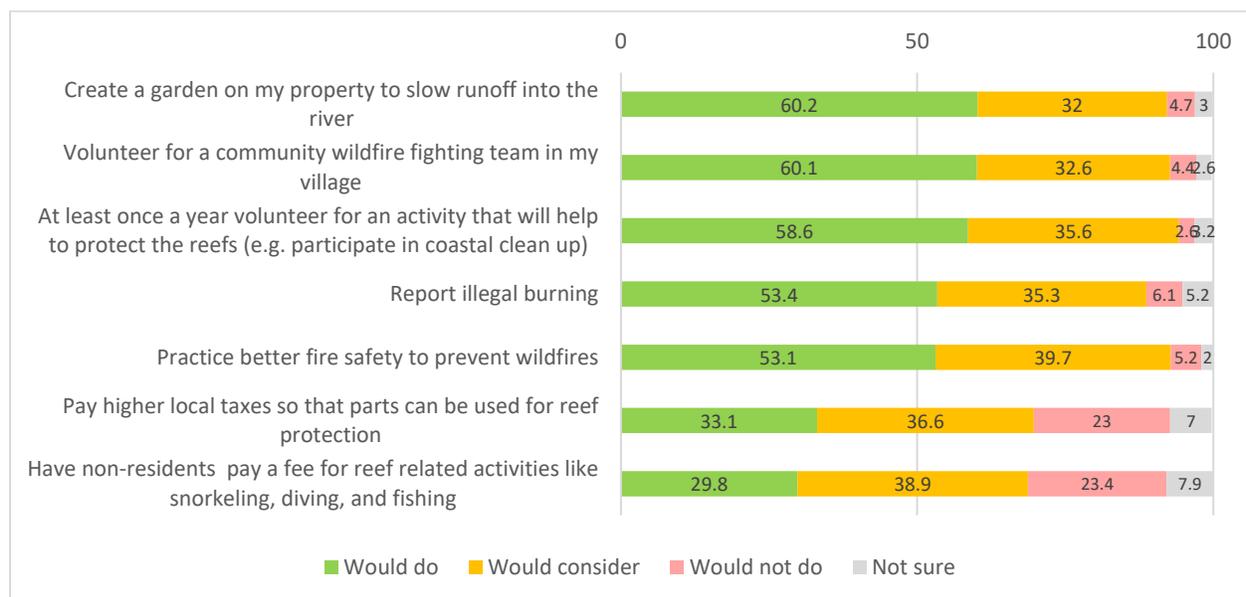


Figure 72. Percent of Merizo residents who would participate in reef protection activities, n=344 (NMFS PIRO, in prep).

11.0 Existing Regulatory Authority

11.1 Agencies

Table 11. Guam Agencies with Relevant Watershed Responsibilities

Agency	Relevant Watershed Management Responsibilities
Guam Environmental Protection Agency	<ul style="list-style-type: none"> • Houses the Water Pollution Control Program which regulates and enforces local law including the Water Pollution Control Act and the Toilet Facilities and Sewage Disposal Act; • The Program includes two sections, the Community Wastewater Program section and the Individual Wastewater Program section; • The Community Wastewater Program staff are responsible for administering provides sewage treatment programming and related facilities for Guam, while the Individual Wastewater Program staff are responsible for controlling pollution from domestic wastewater through permitting; • Guam EPA’s Water Pollution Control Program handles the administration of the Federal Sewer Construction Grants Program, the National Pollutant Discharge Elimination System (NPDES) Program, Spill Prevention Control and Countermeasure (SPCC) Program, Nonpoint Source Management Program, Individual Wastewater Program, implementation and enforcement of the Guam Water Quality Standards, Guam Soil Erosion and Sediment Control Regulations, Feedlot Waste Management Regulations, Connection to Public Sewer Regulations, and Guam Soil Erosion and Sedimentation Control Regulations (Guam EPA, 2022).
Guam Bureau of Statistics and Planning	<ul style="list-style-type: none"> • Houses the Guam Coastal Management Program which is responsible for the land-use and natural resource planning duties of the Bureau (Guam Bureau of Statistics and Plans, 2021).
Guam Department of Agriculture	<ul style="list-style-type: none"> • Responsible for conservation management of local government conservation lands; • Forestry and Soil Resources Division (Guam Forestry) in the Department is the central agency with the responsibility of protecting and restoring forest ecosystems and soil resources in Guam (Guam EPA, 2022).
Guam Department of Land Management	<ul style="list-style-type: none"> • Houses the Chamorro Land Trust Commission which is responsible for overseeing public lands by way of residential, agricultural and commercial land distribution and economic assistance programs (Guam Department of Land Management, 2017).
Guam Department of Public Works	<ul style="list-style-type: none"> • Responsible for administering the Guam MS4 permit on the island (Guam EPA, 2020).

11.2 Programs

The Guam Department of Agriculture, Guam Environmental Protection Agency, Guam Bureau of Statistics and Plans, and NOAA participate in the Guam Coral Reef Initiative (CRI). Established in 1997, CRI was developed to address threats to coastal habitats, including land-based sources of pollution, unsustainable fishing practices and repeated coral bleaching (Wongbusarakum et al., 2019).

11.3 Regulations

The following water related regulations are currently in effect in Guam:

- Guam Water Quality Standards Regulations ([Title 22, Division 1, Chapter 1](#))
- Guam Safe Drinking Water Regulations ([Guam Public Law 35-115](#))
- Guam Water Resource Development and Operating Regulations ([Title 22, Division 2, Chapter 7](#))
- Guam Sewer Connection Regulations ([Title 22, Division 2, Chapter 8](#))
- Guam Underground Injection Control Regulations ([Title 22, Division 2, Chapter 9](#))
- Guam Soil Erosion and Sediment Control Regulations ([Title 22, Division 2, Chapter 10](#))
- Guam Individual Wastewater Disposal Systems Regulations ([Title 22, Division 2, Chapter 12](#))
- Guam Pesticide Regulations ([Title 22, Division 3, Chapter 15](#))
- Guam Connection to Public Sewer Regulations ([Title 22, Division 5, Chapter 25](#))
- Guam Feedlot Waste Management Regulations ([Title 22, Division 8, Chapter 40](#))
- Guam and CNMI Stormwater Management Manuals ([Volume I](#) and [Volume II](#))
- Guam 2022 NPDES MS4 Permit ([No. GUS04001](#))

References

- Amidon, F., Metevier, M., and Miller, S. (2017). Vegetation Mapping of the Mariana Islands: Commonwealth of the Northern Mariana Islands and the Territory of Guam. *Pacific Islands Fish and Wildlife Service*. http://piccc.net/piccc/wp-content/uploads/2015/05/MI_Veg_Final_November2017.pdf
- Camacho, F., Lindstrom, D., Moots, K., and Moran, S. (2016). Baseline surveys of streamfish and macroinvertebrates in the Geus River watershed, Merizo, Guam. (Technical Report No. 1), Mangilao, Guam: Biology Program, University of Guam.
- Chargualaf, E. and Mansapit, J. (2014). Community Based Management Plan for Malesso Coastal Marine Resources. Malesso Mayor's Office, Malesso, Guam. https://issuu.com/wpcouncil/docs/malesso_cbfmp_01212015
- Dobson, J., Johnson, I., Kowal, V., Rohdes, K., Lussier, B., and Byler, K. (2021). Guam Coastal Resilience Assessment. *UNC Asheville National Environmental Modeling and Analysis Center, Asheville, NC. Prepared for the National Fish and Wildlife Foundation*. <https://www.nfwf.org/programs/national-coastal-resilience-fund/regional-coastal-resilience-assessment>
- EA Engineering, Science, Technology, Inc. (2014). Design and Implementation of Watershed Restoration Projects in the Manell and Geus Watersheds in Southern Guam. Prepared for National Oceanic and Atmospheric Administration, Pacific Islands Regional Office, Coral Reef Restoration Program. https://www.ncei.noaa.gov/data/oceans/coris/library/NOAA/CRCP/project/559/559_FY12_Manell_and_Geus_Watershed_Report.pdf
- Gingerich, S. (2003). Hydrologic Resources of Guam. U.S. Geological Survey. Water-Resources Investigation Report 03-4126. Prepared in cooperation with the Water and Environmental Research Institute. Accessed on April 20, 2022. <https://pubs.usgs.gov/wri/wri034126/htdocs/wrir03-4126.html>
- Gingerich, S. (2013). The effects of withdrawals and drought on groundwater availability in the Northern Guam Lens Aquifer, Guam: U.S. Geological Survey Investigations Report 2013-5216, 76 p. <http://dx.doi.org/10.3133/sir20135216>
- Golabi, M., Iyekar, C., and Denney, M. (2005). Challenges and Actions Regarding the Rehabilitation of Degraded Lands: Case Study from the Pacific Island of Guam. *Sociedade & Natureza*, 1(1), 87–106. <https://www.redalyc.org/articulo.oa?id=321328500007>
- Grecni, Z., Miles, W., King, R., Frazier, A., and Kenner, V. (2020). Climate Change in Guam: Indicators and Considerations for Key Sectors. Report for the Pacific Islands Regional Climate Assessment. Honolulu, HI: East-West Center. <https://www.eastwestcenter.org/PIRCA-Guam>
- Guam Bureau of Statistics and Plans (2021). The Guam Coastal Management Program Overview. Accessed on April 21, 2022. <https://bsp.guam.gov/guam-coastal-management-program/>
- Guam Department of Land Management (2017). Chamoru Land Trust Commission. Accessed on June 1, 2022. <https://dlm.guam.gov/chamoru-land-trust-commission/>

Guam EPA (2013). Bacteria TMDL's for Twenty-Five Beaches. https://ofmpub.epa.gov/waters10/attains_impaired_waters.show_tmdl_document?p_tmdl_doc_blobs_id=67942

Guam EPA (2015). Guam Water Quality Standards, 2015 Revision. <https://www.epa.gov/sites/default/files/2014-12/documents/guam-wqs.pdf>

Guam EPA (2020). 2020 Integrated Report.

Guam EPA (2022). "About the Water Pollution Control Program." Accessed on April 12, 2022. <https://epa.guam.gov/programs/water-pollution-control/>

Guam Forest Action Plan Advisory Committee (2021). Guam Forest Action Plan 2020-2030. *Guam Department of Agriculture, Forestry and Soil Resources Division*. https://www.stateforesters.org/wp-content/uploads/2021/12/GUAM-FAP_2020to2030_20210429.pdf

Houk, P., Castro, F., Hernandez-Ortiz, D., Rucinski, M., McInnis, A., Cruz, J., Starsinic, C., Salas, B., Concepcion, T., Haggans, N., Manglona, S., Sablan, L., and Naden, W. (2022). Ridge-to-Reef Assessment for Southern Guam.

Kami, H., Drahos, N., Lujan, R., and Jeffrey, J. (1974). Biological Study of the Geus River Basin. Technical Report No. 16. University of Guam Marine Laboratory. November 1974. https://www.uog.edu/resources/files/ml/technical_reports/16Kami_et_al_1974_UOGMLTechReport16.pdf

Khosrowpanah, S., Lander, M., Rouse, J., and Whitman, B. (2015). Assessment of Turbidity in the Geus River Watershed in Southern Guam. *University of Guam Water and Environmental Research Institute of the Western Pacific*. <http://www.weriguam.org/docs/reports/156.pdf>

King, R. (2010). Geus/Manell Conservation Action Planning Workshop (September 2010) Overview of Results. *Guam Coastal Management Program, Bureau of Statistics and Plans*. https://www.ncei.noaa.gov/data/oceans/coris/library/NOAA/CRCP/other/grants/NA09NOS4190173/Guam/Guam_TNC_Manell_Geus_CAP.pdf

Mayor's Council of Guam (n.d.). "Malesso'." Accessed on April 12, 2022. <https://mcog.guam.gov/villages-list?keyword=Malesso>

National Archives Catalog (2022a). Guam SP Tinta Massacre Site. Accessed on April 18, 2022. <https://catalog.archives.gov/id/131517989>

National Archives Catalog (2022b). Guam SP Faha Massacre Site. Accessed on April 18, 2022. <https://catalog.archives.gov/id/131517981>

National Archives Catalog (2022c). Guam MPS Malessu' Pillbox. Accessed on April 18, 2022. <https://catalog.archives.gov/id/131517857>

National Archives Catalog (2022d). Guam SP Cook, Merlyn G., School. Accessed on April 18, 2022. <https://catalog.archives.gov/id/131517979>

National Archives Catalog (2022e). Guam SP Malessso Japanese Rice Mill. Accessed on April 21, 2022. <https://catalog.archives.gov/id/131517983>

NMFS PIRO (in prep). Socioeconomic assessment results for the Manell-Geus habitat focus area, Merizo, Guam. Honolulu, HI: NOAA Fisheries Technical Report.

NMFS PIRO (2017). Manell-Geus habitat focus area implementation plan. Tiyan, Guam: NOAA Fisheries.

NOAA (n.d.). *Manell-Geus Habitat Focus Area (HFA)*. Retrieved April 5, 2022, from <https://noaa.maps.arcgis.com/apps/MapSeries/index.html?appid=46a0d81853bf46d5be4dc0c2e58f26af>

NOAA (2006). NOAA Nautical Chart 81048. Accessed on June 2, 2022. <https://charts.noaa.gov/OnLineViewer/81048.shtml>

NOAA (2007). Report on the Status of Marine Protected Areas in Coral Reef Ecosystems of the United States. Volume 1: Marine Protected Areas Managed by U.S. States, Territories and Commonwealths. NOAA Technical Memorandum CRCP 2.

NOAA (2009). Coral Reef Habitat Assessment for U.S. Marine Protected Areas: U.S. Territory of Guam. https://www.coris.noaa.gov/activities/habitat_assessment/guam.pdf

NOAA (2011). Mosaic of gridded multibeam and lidar bathymetry of the US Territory of Guam. Accessed on June 2, 2022. https://www.soest.hawaii.edu/pibhmc/data_all/cnmi-guam/bathymetry/Guam_5m_bathymetry_mb&lidar.jpg

NOAA (2017). "A Chemical Contaminant Characterization of Waters Surrounding Cocos Island, Guam, using Polyethylene Devices." Accessed on April 12, 2022. <https://coastalscience.noaa.gov/project/chemical-contaminant-characterization-waters-surrounding-cocos-island-guam-using-polyethylene-devices/>

NOAA (2020). 50 Years Later: Clearing Tires from Cocos Lagoon. Accessed on June 2, 2022. <https://blog.marinedebris.noaa.gov/50-years-later-clearing-tires-cocos-lagoon>

NOAA, NOAA Coral Reef Conservation Program, The Nature Conservancy, and Micronesia Islands Nature Alliance (2016). Socioeconomic Monitoring Draft Plan: Manell-Geus, Guam. https://www.ncei.noaa.gov/data/oceans/coris/library/NOAA/CRCP/NMFS/PIFSC/Projects/30091/Manell-Geus_SEM_Draft_Plan_Jan_2016.pdf

Pait, A., Mason, A., Hartwell, S., and Apeti, D. (2019). An Assessment of Chemical Contaminants in the Waters Around Cocos Island, Guam Using Polyethylene Passive Water Samplers. NOAA Technical Memorandum NOS NCCOS 261. Silver Spring, MD. <https://doi.org/10.25923/0bvz-p335>

Pait, T., Hartwell, I., Apeti, D., and Mason, A. (2019). Measurement of Turbidity, Suspended Sediments and Nutrients in Three Rivers that Drain to the Achang Preserve from the Manell Watershed, Guam. NOAA Technical Memorandum NOS NCCOS 268. Silver Spring, MD. <https://doi.org/10.25923/v587-3f08>

Paulino, Y., Badowski, G., Chennaux, J., Guerrero, M., Cruz, C., King, R., and Panapasa, S. (2021). Calculating the Social Vulnerability Index for Guam. Natural Hazards Center Public Health Grant Report Series, 12. Boulder, CO: Natural Hazards Center, University of Colorado Boulder. Accessed on April 20, 2022. <https://hazards.colorado.edu/public-health-disaster-research/calculating-the-social-vulnerability-index-for-guam>

Plate, D. (2021). “Malesso’ (Merizo).” Accessed on April 12, 2022. <https://www.guampedia.com/merizo-malesso/>

Raymundo, L., Burdick, D., Lapacek, V., Miller, R., and Brown, V. (2017). Anomalous temperatures and extreme tides: Guam staghorn *Acropora* succumb to a double threat. *Marine Ecology Progress Series*, 564, 47–55. <https://doi.org/10.3354/meps12005>

Raymundo, L., Goldstein B., Baker, D., Kim, K., McIlroy, S., Thompson, P., Lapack, V., Duprey, N., Cybulski, J., LaRoche, C., and Geeraert, N. (2018). Atlas of the Nearshore Shallow Benthic Habitats Within the Manell-Geus Habitat Focus Area. *University of Guam Marine Laboratory Technical Report No. 163*. <https://www.researchgate.net/publication/325793374> Atlas of the Nearshore Shallow Benthic Habitats within the Manell-Geus Habitat Focus Area

Rosgen, D. and Silvey, H. (1996). *Applied River Morphology*. Pagosa Springs: Wildland Hydrology Books.

U.S. Army Corps of Engineers, Honolulu District (2020a). Guam Comprehensive Flood Study – Part 1: Flood Frequency Estimates for Streams on Guam. Prepared for Government of Guam, Bureau of Statistics and Plans. <https://bsp.guam.gov/wp-bsp-content/uploads/2020/07/01-Part-1-General1.pdf>

U.S. Army Corps of Engineers, Honolulu District (2020b). Guam Comprehensive Flood Study – Part 3: Flood Hazard Study Nalansa (Manell) River. Prepared for Government of Guam, Bureau of Statistics and Plans. <https://bsp.guam.gov/wp-bsp-content/uploads/2020/07/06-Part-3-Manell1.pdf>

U.S. Army Corps of Engineers (2022). Guam Draft Watershed Plan.

U.S. Census Bureau (2010a). Educational Attainment by Employment Status for the Population 25 to 64 Years. *Decennial Census of Island Areas*. <https://data.census.gov/cedsci/table?q=Merizo%20CDP,%20Guam%20Education&tid=DECENNIALGU2010.PBG27>

U.S. Census Bureau (2010b). Ethnic Origin or Race. *Decennial Census of Island Areas*. <https://data.census.gov/cedsci/table?q=Merizo%20CDP,%20Guam%20Race%20and%20Ethnicity&tid=DECENNIALGU2010.P3>

U.S. Census Bureau (2010c). Median Family Income in 2009 (Dollars). *Decennial Census of Island Areas*. <https://data.census.gov/cedsci/table?q=Merizo%20CDP,%20Guam%20income&tid=DECENNIALGU2010.PBG72>

U.S. Census Bureau (2020). Population of Guam: 2010 and 2020. *2020 Census of Guam*. <https://www2.census.gov/programs-surveys/decennial/2020/data/island-areas/guam/population-and-housing-unit-counts/guam-phc-table01.pdf>

U.S. Environmental Protection Agency (2018). Addendum to Fact Sheet: Final NPDES Permit No. GUS040001 Municipal Separate Storm Sewer System, Guam Department of Public Works. <https://www.epa.gov/sites/default/files/2019-02/documents/gus040001-guam-dpw-ms4-final-fact-sheet-2018-12-19.pdf>

U.S. Environmental Protection Agency (2020). Table 28. 2020 Guam List of Impaired Waterbodies. *Clean Water Act, Section 303(d)*.

U.S. Environmental Protection Agency (2022a). Fact Sheet: Final Modification of NPDES Permit No. GUS040001 Municipal Separate Storm Sewer System, Guam Department of Public Works. <https://www.epa.gov/system/files/documents/2022-02/gus040001-guam-dpw-final-ms4-permit-mod-factsheet-2022-01-18.pdf>

U.S. Environmental Protection Agency (2022b). “How’s My Waterway: Guam.” Accessed on April 12, 2022. <https://mywaterway.epa.gov/community/220100000204/monitoring>

W.B. Flores et al. (1994). I Tano'-Ta: The Land Use Plan for Guam. Prepared for the Territorial Planning Council. [https://www.guamlegislature.com/Public_Laws_22nd/P.L.%2022-139%20\(9\).pdf](https://www.guamlegislature.com/Public_Laws_22nd/P.L.%2022-139%20(9).pdf)

Wang, Y. (2016). 21st Century high-resolution climate projections for Guam and American Samoa. International Pacific Research Center, University of Hawaii at Manoa. Final report to the United States Geological Survey (G12AC20501). <https://cascprojects.org/#/project/4f8c650ae4b0546c0c397b48/50118ddce4b0d78fd4e59ba3>

Water and Environmental Research Institute of the Western Pacific University of Guam (2012). “Guam Comprehensive Monitoring Program.” Accessed on April 12, 2022. <http://www.weriguam.org/locally-sponsored-research/guam-comprehensive-monitoring-program/>

Watershed Professionals Network (2010). Guam Statewide Forest Resource Assessment and Resource Strategy 2010–2015. Prepared for the Forestry and Soil Resources Division, Guam Department of Agriculture. <http://www.thewflc.org/islandforestry/guam.pdf>

Wen, Y., Khosrowpanah, S., and Heitz, L. (2009). Watershed Land Cover Change in Guam. University of Guam Water and Environmental Research Institute of the Western Pacific. <http://www.weriguam.org/docs/reports/124.pdf>

Wolanski, E., Richmond, R., Davis, G., Deleersnijder, E., and Leben, R. (2003). Eddies around Guam, an island in the Mariana Islands group. *Continental Shelf Research*, 23, 991-1003. [https://doi.org/10.1016/S0278-4343\(03\)00087-6](https://doi.org/10.1016/S0278-4343(03)00087-6)

Wongbusarakum, S., Brown, V., Loerzel, A., Gorstein, M., Kleiber, D., Quinata, M., Iwane, M., and Heenan, A. (2019). Achieving social and ecological goals of coastal management through integrated monitoring. *Journal of Applied Ecology*, 56, 2400-2409. <https://doi.org/10.1111/1365-2664.13494>