GUAM ENVIRONMENTAL PROTECTION AGENCY

CHLORDANE AND DIELDRIN TMDLs FOR TUMON BAY

PREPARED BY
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TODO Y NILALA Y TANO MAN UNO
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Abbreviations

AFB	Air Force Base
ATSDR	Agency for Toxic Substances and Disease Registry
CGP	Construction general permit
CWA	Clean Water Act
DON	Department of Navy
DPW	Department of Public Works
EPA	U.S. Environmental Protection Agency
GEPA	Guam Environmental Protection Agency
GWA	Guam Waterworks Authority
ICIS	Integrated Compliance Information System
LA	Load allocation
MCL	Maximum contaminant level
MOS	Margin of safety
MS4	Municipal separate storm sewer system
NCEI	National Centers for Environmental Information
NGLA	Northern Guam Lens Aquifer
NOAA	National Oceanic & Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OEHHA	Office of Environmental Health Hazard Assessment
PCE	Tetrachloroethylene
STP	Sewage treatment plant
SWPPP	Storm Water Pollution Prevention Plan
TCE	Trichloroethylene
TMDL	Total maximum daily load
WERI	Water and Environmental Research Institute
WLA	Wasteload allocations
WQC	Water quality criteria
WQS	Water quality standards
WWTP	Wastewater treatment plant

1 Introduction

The Clean Water Act (CWA) requires jurisdictions to include all impaired waterbodies on the Section 303(d) list during a biennial update to their Integrated Report. The CWA also requires states to establish a priority ranking for impaired waters and to develop and implement a Total Maximum Daily Load (TMDL) for each §303(d)-listed impairment. The purpose of a TMDL is to attain water quality standards (WQS), thereby supporting designated uses of the waterbody. A TMDL is defined as the sum of the individual waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background, such that the capacity of the waterbody to assimilate pollutant loading (i.e., the loading capacity) is not exceeded (40 CFR §130.2).

Several of Guam's waterways were listed in the 2020 Integrated Report as category 5, indicating that they require TMDL development (Guam Environmental Protection Agency [GEPA], 2020). These waterbodies include coastal waters, marine bays, wetlands, and rivers and streams. Tumon Bay, classified as an M-2 water, is included on the 303(d) list of impaired waters for not attaining its designated uses due to dieldrin and total chlordane levels[1]. Tumon Bay, which has been identified as impaired for over two decades, is listed as a high priority ranking for TMDL development (GEPA, 2020).

This TMDL report is organized with the following sections, addressing all required components of a TMDL:

- **Problem Statement** describing the impairment to be addressed by these TMDLs (Section 2);
- **Setting** presents the physical conditions in and around Tumon Bay that influence pollutant loading conditions (Section 3);
- **Water Quality Standards and Numeric Targets** identify the applicable designated uses and criteria that are used for data assessment and TMDL calculation (Section 4);
- **Data Evaluation** presents a review of available water quality and fish tissue data, including a comparison to applicable criteria (Section 5);
- **Source Assessment** identifies potential sources of the pollutants of concern (Section 6);
- **Technical Approach and Linkage Analysis** presents the range of approaches and the selected approach for TMDL development, and describes the methodology and analyses conducted to calculate the relationship between pollutant sources and receiving water conditions (Section 7);
- **TMDL Development** presents the loading capacity and allocations, the identified margin of safety (MOS), and seasonality and critical conditions (Section 8).

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[1] Tumon Bay is also listed for tetrachloroethylene (PCE), trichloroethylene (TCE), antimony, and arsenic. However, current monitoring data for Tumon Bay indicates the applicable water quality standards for these pollutants have been attained, and GEPA is undertaking to delist Tumon Bay for these pollutants.

2 Problem Statement

Guam's marine waters are characterized as "good" overall; however, Tumon Bay has been listed as impaired due to dieldrin and total chlordane levels for over two decades (GEPA, 2020). The 2016 Waterbody Quality Assessment Report by the U.S. Environmental Protection Agency (EPA) identifies the designated use impairments by pollutant (Table 2-1). Dieldrin and total chlordane fail to attain the consumption designated use and contribute to impairment of the aquatic life use (Table 2-1).

Table 2-1. Tumon Bay Causes of Impairment

Pollutant	Pollutant Group	Designated Use(s)	Designated Use Group
Chlordane	Pesticides	Consumption	Aquatic Life Harvesting
		Aquatic Life	Fish, Shellfish, and Wildlife Protection and Propagation
Dieldrin	Pesticides	Consumption	Aquatic Life Harvesting
		Aquatic Life	Fish, Shellfish, and Wildlife Protection and Propagation

The 2020 Integrated Report does not specify sources that may be causing impairment; however, common uses and sources of these contaminants are identified below with links to details from the Agency for Toxic Substances and Disease Registry (ATSDR):

- **Chlordane**: pesticides, termite control, agricultural pest control (commercial use cancelled in 1988);
- **Dieldrin**: pesticides, termite control, agricultural pest control, treatment for lumber (manufacturer voluntarily cancelled use in 1987).

The remainder of this report presents physical conditions and potential sources in the Tumon Bay watershed (Sections 3 and 6, respectively) as well as water quality criteria (WQC) and guidelines applicable to these waterbodies (Section 4). In addition, the available fish tissue, sediment, and water quality data to support these TMDLs were compiled and reviewed (Section 5). Sampling over the years has been conducted by PCR Environmental, Inc., the University of Guam Water Environmental Research Institute (WERI) in collaboration with Guam Waterworks Authority (GWA), and the military, among others. These studies have typically evaluated inputs to the Bay, in particular groundwater wells in the Northern Guam Lens Aquifer (NGLA) and the freshwater springs that discharge at several locations at or near Tumon Bay beaches. A recent study for GEPA and EPA Region 9 sampled springs discharging into the Bay as well as many marine locations, seven sediment locations, and four fish species (PG, 2020). Analysis of these data indicate that the chlordane and dieldrin impairments persist in the Bay (Table 5-1); however, inputs of the pollutants of concern into the Bay from the springs have decreased (Table 5-2). TMDLs are developed for dieldrin and total chlordane because the latest sampling study supported the continued impairment status for the parameters of concern.

Tumon Bay is located in the heart of Guam's tourist area and is, therefore, important to the economy. In 1999, the Bay was designated as a Marine Preserve, limiting the types of boating and fishing activities; however, it is possible that fish from Tumon Bay are part of the diet of subsistence fishers in the area and are also consumed by recreational fishers. Due to the ecological, economical, and recreational importance of Tumon Bay, its health and condition are a priority for the island.

3 Setting

Guam is an unincorporated territory of the United States located in the tropical western Pacific Ocean, approximately 1,600 miles due east of the Philippines (Figure 3-1). At 30 miles long and 9 miles wide (on average), it is the largest and southernmost island in the Mariana Island chain.

Figure 3-1. Guam location map

The nearly 120-mile coastline of Guam includes rocky cliffs, mangroves, and sandy beaches. Parts of the island are surrounded by coral reefs with deep water channels. Coral reef habitat is located within lagoons and coastal waters along each coast of the island, particularly the tip of the southern coast. Two large barrier reef systems have been identified at Cocos Island Lagoon and Apra Harbor. There are approximately 14.2 square miles of coral reefs located in coastal and inland areas of the island (GEPA, 2020). These reef systems provide popular recreational and fishing activities in Tumon, Hagåtña, Agat, and Asan bays and on the shore side of Cocos Island Lagoon. They also provide valuable marine habitat and protection from erosion caused by storm events and tides. Given the value of these reef systems, the Government of Guam established five marine preserves in 1997, located in Tumon Bay, Piti Bomb Holes, Sasa Bay, Achang Reef Flat, and Pati Point.

These TMDLs focus on Tumon Bay, which is a 1.98 square mile crescent-shaped bay on the west coast of the northern portion of Guam (Figure 3-1). Tumon Bay is a popular tourist location on the island and is home to a significant commercial sector including numerous hotels and restaurants, which are dependent on maintaining the ecological condition and natural beauty of the Bay (Guam Water Resources Research Center, 2000). Given the area's important economic and ecological value, both interests must be actively managed to accommodate the tourists that visit each year while protecting the coastal environment (Figure 3-2). The remainder of this section describes the physical conditions that may influence the water quality and aquatic health in and around Tumon Bay.

Photos courtesy of Bobby Jacobsen, PG

Figure 3-2. Images near Tumon Bay

3.1 Geology and Topography

Guam has two distinct geological formations. The Adelup Fault separates the northern limestone plateau of Guam from the southern region of the island with eroded volcanic mountain formations.

The northern region of the island is a relatively flat area with steep cliffs that drop down to the narrow coastal shelf. It has porous soils, high percolation rates, and very limited runoff since water that reaches the land surface quickly drains into the aquifer below. Southern Guam includes volcanic hills rising to over 1,300 feet (approximately 400 meters) above sea level. The variable topography in the south forms numerous streams that are typically short in length (GEPA, 2020). Figure 3-3 illustrates the differences in topography and surface drainage between the northern and southern regions.

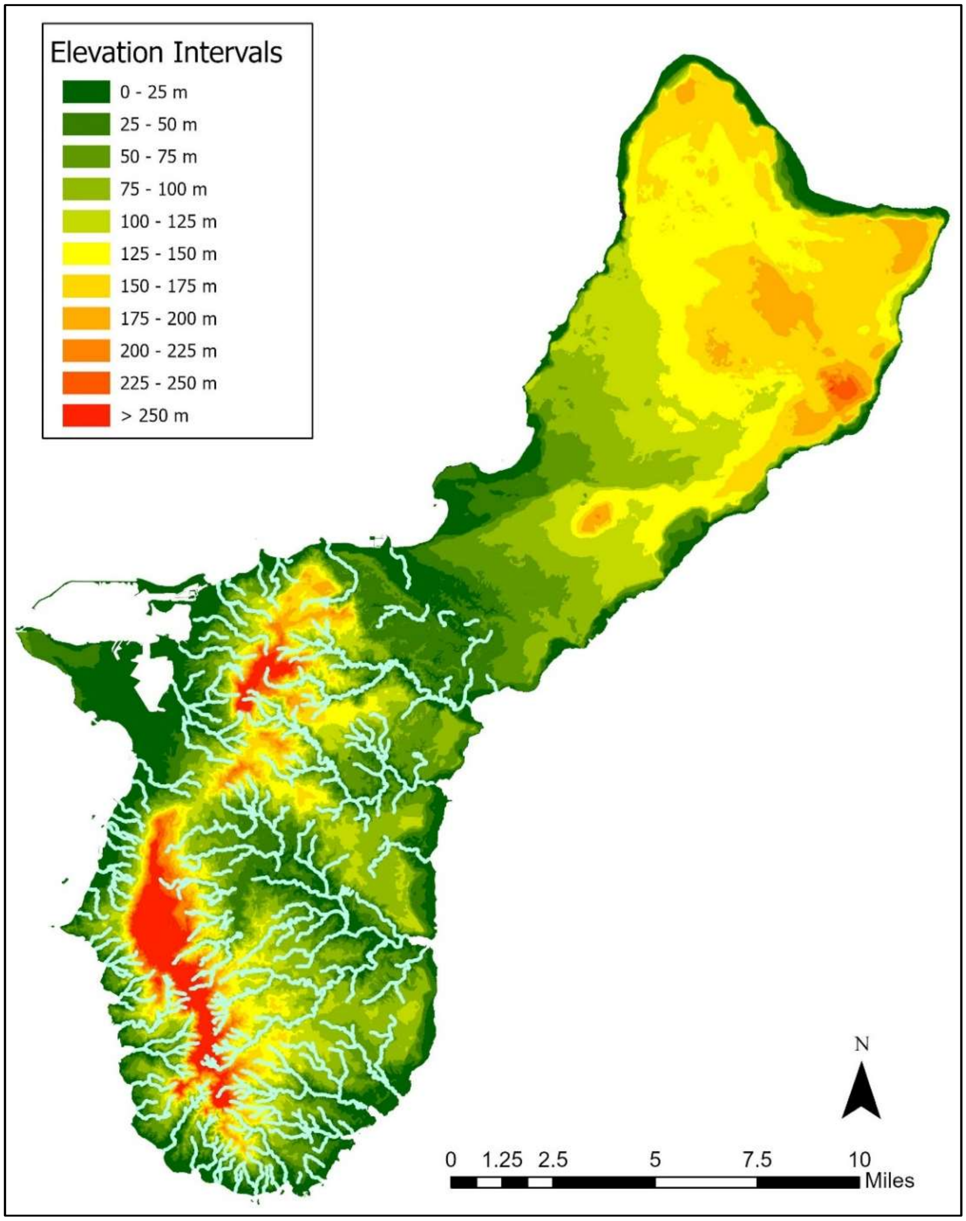

Figure 3-3. Topography of Guam

3.2 Surface and Subsurface Drainage Areas

The geology and topography described in Section 3.1 influence all aspects of surface and sub-surface water flow on the island. As noted above, Tumon Bay is located in the northern half of Guam, falling exclusively in the Northern watershed that encompasses the entire northern third of the island (shown with a black outline in Figure 3-4). Because of the underlying geology, drainage in northern Guam is subterranean, forming several sub-surface (or "basement drainage") basins. Sub-surface flow to Tumon Bay occurs largely through the Yigo-Tumon basin (30 square miles; 19,369 acres), with the Hagåtña basin influencing the southernmost portion of the Bay (23 square miles; 14,514 acres) (basement drainages are shown as color coded basins in Figure 3-4).

The limestone bedrock in this region contains the NGLA, which discharges freshwater at its perimeter through springs located on the coastline (represented by circles along the western coast in Figure 3-4). Freshwater is less dense than saltwater, so it floats on the surface in coastal areas, which is particularly evident during low tide. The NGLA is replenished by rain seeping down through the limestone from the land surface and, in addition to its natural coastal discharge, water is pumped through production wells for use as potable water to island residents. Rainfall amounts and intensity as well as the saturation of the vadose zone determine the aquifer recharge rates. In some cases, surface water that may contain pollutants can flow through quickly to the aquifer rather than percolating slowly, which can remove pollutants (Jocson et al., 2002).

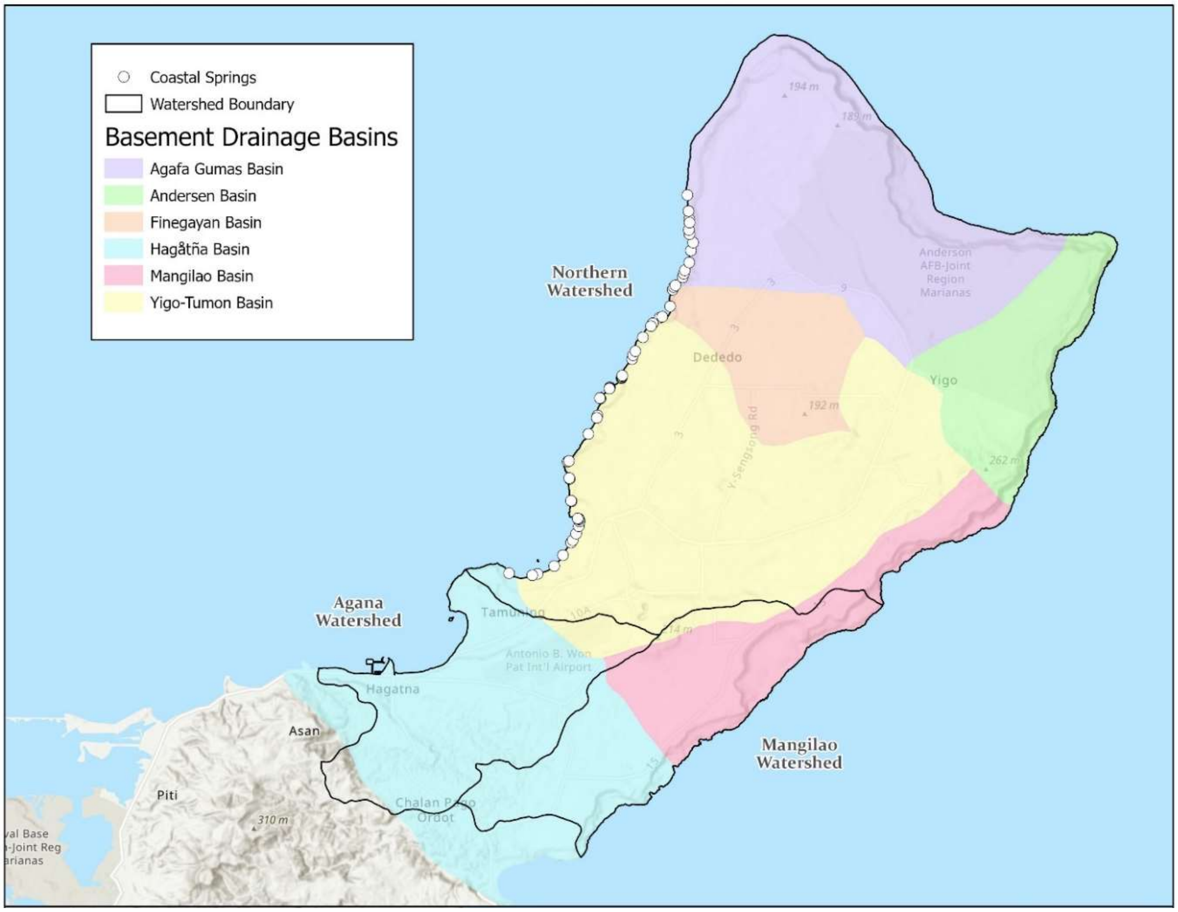

Figure 3-4. Northern region surface and sub-surface drainage basins

3.3 Climate

Guam's climate is generally warm and humid year-round. Daily temperatures typically range from the low seventies to mid-eighties (GEPA, 2020). The island is impacted by trade winds, with prevailing winds from the east-northeast causing surface waters to move downwind, south along the eastern coast (windward) of the island. The west (or leeward) coast of the island receives an upwelling.

The average annual rainfall is 99 inches, with a range from 58 to 136 inches, at the Guam International Airport, which has an elevation of 254 feet (based on 1958-2020 data; National Oceanic & Atmospheric Administration [NOAA] National Centers for Environmental Information [NCEI], 2021). Rainfall also varies geographically, with more precipitation in the higher areas compared to the coast (GEPA, 2020).

There are clear seasonal patterns to rainfall, with a dry season from January to May and a wet season from July to November (Figure 3-5). March is the driest month, followed closely by April and February, while August through October are the wettest months with over a dozen inches on average each month (Figure 3-5). Guam International Airport has slightly higher recorded precipitation than Andersen Air Force Base (AFB) on the north end of the island (note: Andersen AFB data only had a full period of record from 1958 to 2002). On six occasions since 1958, over 10 inches of rain has fallen in one day.

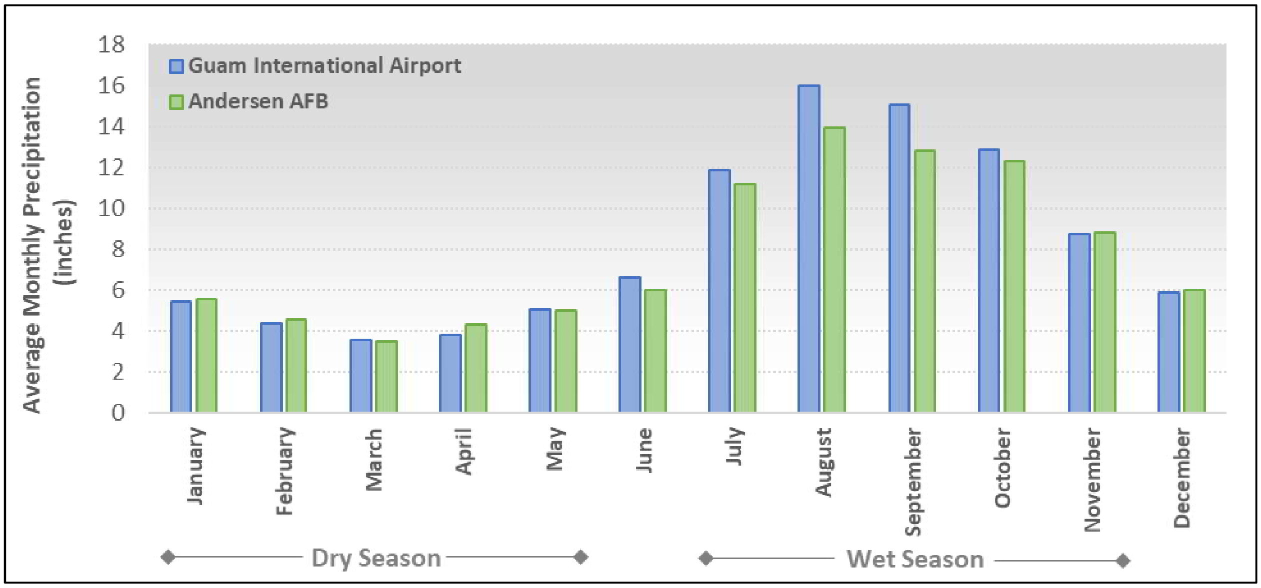

Figure 3-5. Average monthly precipitation at Guam Airport and Andersen AFB

3.4 Land Cover

Land cover in northern Guam is over one-half evergreen forest and an additional one-third is impervious or developed open space (Table 3-1; Figure 3-6). Larger parcels of scrub/shrub and grasslands are spread throughout the area with small pockets of bare land, cultivated land (agriculture), wetlands, pasture, and shoreland or water making up the remaining area. The northernmost and northwestern portion of the island is home to United States Air Force installations and the airport is located just to the south-southeast of Tumon Bay.

Table 3-1. Northern Guam Land Use Areas

Land Use Category	Northern Guam (acres)	Yigo-Tumon Basin		Hagåtña Basin	
		acres	percent	acres	percent
Bare Land	938	337	1.7%	185	1.3%
Cultivated	347	149	0.8%	38	0.3%
Developed Open Space	10,731	3,172	16.4%	2,704	18.6%
Evergreen Forest	34,276	9,511	49.1%	6,531	45.0%
Grassland	3,052	1,151	5.9%	342	2.4%
Impervious Surface	9,825	3,547	18.3%	3,254	22.4%
Palustrine Aquatic Bed	1	–	–	1	0.0%
Palustrine Emergent Wetland	172	2	0.0%	165	1.1%
Palustrine Forested Wetland	220	8	0.0%	211	1.5%
Palustrine Scrub/Shrub Wetland	128	8	0.0%	118	0.8%
Pasture/Hay	21	–	–	–	–
Scrub/Shrub	5,020	1,459	7.5%	925	6.4%
Unconsolidated Shore	18	5	0.0%	8	0.1%
Water	121	19	0.1%	32	0.2%
Total	**64,868**	**19,369**	**100.0%**	**14,514**	**100.0%**

Notes: "–" indicates no land in this category.

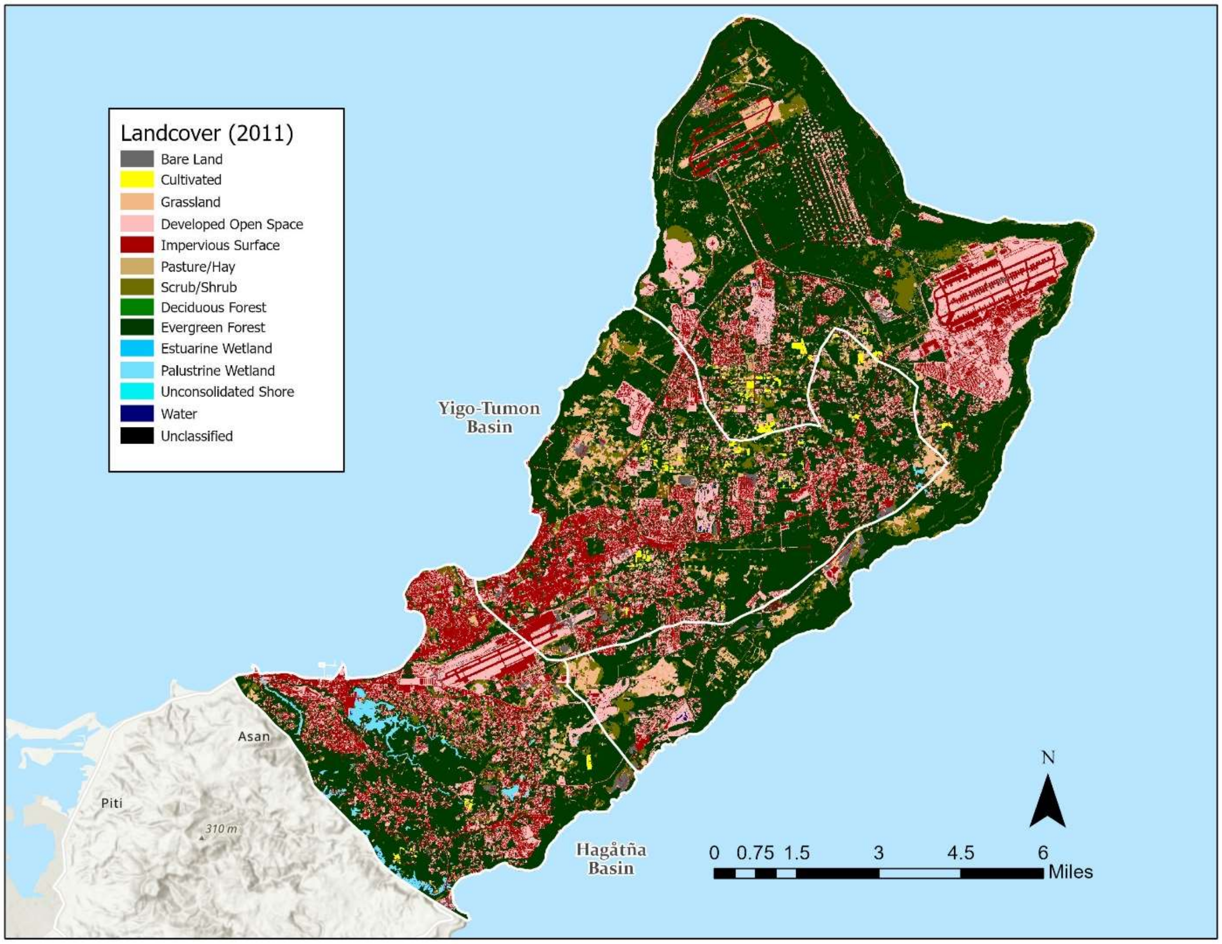

Figure 3-6. Land cover distribution of Northern Guam

The Yigo-Tumon basin is the most important area to consider for this TMDL since water draining from this land connects directly to Tumon Bay either through overland flow or sub-surface drainage. This area is nearly 50 percent evergreen forest, largely located to the north of Tumon Bay and in the east and northeast portions of the drainage area. Impervious land (consisting of buildings, paved surfaces, etc.) and developed open space are immediately surrounding Tumon Bay and along a northeastern transect across the basin, making up 35 percent of the land area. A portion of the airport area also resides in the Yigo-Tumon sub-surface basin. The remaining land is comprised largely of undeveloped-type areas, including scrub/shrub, grasslands, and bare land, with just a small portion (less than one percent) of cultivated land (Table 3-1; Figure 3-6). The portions of the Hagåtña basin that are adjacent to Tumon Bay are largely impervious or developed open space with some scrub/shrubland interspersed (Figure 3-6); this includes the airport, which is not adjacent to Tumon Bay, but is hydrologically connected (Moran and Jenson, 2004).

4 Water Quality Standards and Numeric Targets

WQS consist of three elements: 1) designated uses; 2) narrative and/or numeric WQC; and 3) an antidegradation policy. WQS are used to identify numeric targets for TMDL development. Applicable WQS and numeric targets for Tumon Bay are described below.

4.1 Water Quality Standards

Tumon Bay is listed as impaired because its water quality does not support the associated designated uses as defined in the Guam WQSs for M-2 waters (good quality marine waters; GEPA, 2015).

4.1.1 Designated Uses

The Guam WQS define designated uses based on water categories. M-2 waters have the following designated uses:

> “Water in this category must be of sufficient quality to allow for the propagation and survival of marine organisms, particularly shellfish and other similarly harvested aquatic organisms, corals and other reef-related resources, and whole body contact recreation. Other important and intended uses include mariculture activities, aesthetic enjoyment and related activities.” (GEPA, 2015)

As noted in Table 2-1 above, the consumption of organisms designated use is not attained. Consumption of organisms is not attained for chlordane and dieldrin.

4.1.2 Water Quality Criteria

For toxic pollutants, M-2 waters are subject to criteria presented in columns C1, C2, and D2 in Appendix A of Guam’s WQS (GEPA, 2015). Columns C1 and C2 represent the acute and chronic criteria, respectively, for aquatic life protection in saltwater, while column D2 represents protection of human health for consumption of organisms only. The M-2 WQC for the pollutants of concern are identified in Table 4-1.

Table 4-1. Guam Marine WQC for Tumon Bay Pollutants of Concern by Designated Use

Pollutant	Aquatic Life Saltwater Acute WQC (C1) (µg/L)	Aquatic Life Saltwater Chronic WQC (C2) (µg/L)	Human Health Consumption of Organisms Only (D2) (µg/L)
Chlordane	0.09	0.004	0.0022
Dieldrin	0.71	0.0019	0.00014

4.1.3 Antidegradation Policy

The anti-degradation policy in Guam’s WQS state:

> “(1) Existing in-stream water uses, and the level of water quality necessary to protect these uses, shall be maintained and protected. No further water quality degradation which would interfere with or become injurious to existing designated uses is allowable.
>
> (2) Water quality for those waters not attaining their uses due to impacts from pollution shall be improved so uses are attained. Where the natural conditions are of lower quality than criteria assigned, the natural conditions shall constitute the water quality criteria.” (GEPA, 2015)

These provisions effectively prohibit any water quality degradation which would interfere with or become injurious to existing designated uses.

4.2 TMDL Numeric Targets

Numeric targets are a required component of a TMDL. A numeric target is the quantitative value used to calculate the loading capacity and evaluate whether the applicable designated uses are attained. The numeric targets for the Tumon Bay TMDLs were set equal to the lowest value from Table 4-1 for each pollutant. These values are identified in Table 4-2. The numeric targets are associated with the WQC for consumption of organisms.

Table 4-2. Tumon Bay TMDL Numeric Targets

Pollutant	TMDL Numeric Target (µg/L)
Chlordane	0.0022
Dieldrin	0.00014

4.3 Supplemental Criteria and Screening Values

In addition to marine water samples that are subject to the targets in Table 4-2, available data to support TMDL development include groundwater, sediment and fish tissue samples. The WQC and screening values for data evaluation are presented in Table 4-3. The groundwater WQC are from the Guam WQS for G-1 and G-2 groundwater uses (GEPA, 2015), except where noted. The sediment screening values are from Guam's Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater (see Table D, "Soil and Groundwater Screening Levels, Deep Soils (>3m bgs)"; Brewer, 2013). The fish tissue screening values are associated with a carcinogenic risk for both recreational and subsistence fishers (EPA, 2000).

Table 4-3. Guam WQC and Screening Values for Groundwater, Sediment and Fish Tissue

Pollutant	Groundwater (µg/L)	Sediment* (mg/kg)	Fish Tissue Screening Value – Recreational Fishers (µg/kg)	Fish Tissue Screening Value – Subsistence Fishers (µg/kg)
Chlordane	2	29	114	14
Dieldrin	0.056**	30	2.5	0.307

* Sediment criteria is based on "unlithified material in the vadose zone that is situated above the capillary fringe of the shallowest saturated unit" (Brewer, 2013). While not directly related to the soils sampled, the application of this criteria has been deemed the most applicable.

** Guam WQS do not have a groundwater level for this parameter. This value is based on the freshwater chronic concentration for priority toxic pollutants (Appendix A, column B2 of Guam's WQS [GEPA, 2015]).

5 Data Evaluation

An important step in the TMDL development process is the review of existing water quality monitoring data. Examination of these data assists in defining the impairment that the TMDL will address and provides a basis for future implementation efforts by identifying potential sources through pattern analysis. This section provides a review of the available water quality, sediment quality, and fish tissue data in and around Tumon Bay.

The available monitoring data are associated with four studies, identified below, which are referenced throughout the remainder of this section using the study names in bold below:

- **PCR 2000-01 Sampling:** PCR Environmental, Inc. conducted sampling for the springs that naturally occur on the beaches of Tumon Bay. A total of eight spring sites were sampled, and the samples were evaluated for the two pollutants of concern, among other pollutants. Sampling was conducted from August 30, 2000 through August 20, 2001 (PCR, 2002).
- **PG 2020-22 Sampling:** PG Environmental contracted with PCR in 2020 to perform sampling to essentially repeat much of their 2000-01 sampling; for clarity, this is referred to as the PG 2020-22 sampling throughout this document. This study also collected samples of marine water, fresh/spring water, sediment, and fish tissue from the Bay. The Tumon-Maui Well was sampled in both 2021 and 2022. A total of sixteen spring sites, seven sediment sites, twelve marine water sites, and four fish tissue sites were sampled between July 30, 2020 and June 28, 2022 and associated raw data are presented in this report (PG, 2020).
- **Air Force Groundwater Sampling:** The United States Air Force conducted sampling at groundwater sites within the Tumon Bay area. The Air Force sampled for many contaminants, including dieldrin, but not for chlordane (U.S. Air Force, 2004). The referenced report includes raw data for this study which are summarized below.
- **GWA Groundwater Sampling:** GWA conducted groundwater sampling at well sites near Tumon Bay over two periods of time (Denton and Sian-Denton, 2010). The first set of samples were collected between 1997 and 2001 and the second set of samples were collected between 2002 and 2007. The samples were analyzed for concentrations of chlordane and dieldrin; however, available data summaries were more limited for dieldrin. For both parameters, the report summarized data and provided the range of concentrations measured and the median concentration, while for chlordane, summary information also included the number of samples that exceeded the maximum contaminant level (MCL) and 50 percent of the MCL (EPA, 2010). Raw data were not provided in the study.

5.1 Water Quality Data – Marine Stations

The marine water quality data represent the conditions within Tumon Bay and are the most directly applicable to support TMDL development and confirmation of impairments. No historical data were available in the Bay itself, so changes prior to the 2020-2022 sampling period are unknown. The stations illustrated in Figure 5-1 (blue triangles) and summarized below in Table 5-1 are from the PG 2020-22 study. Twelve marine stations were sampled, and the Gun Beach and Central South Tumon Bay location were sampled twice; with an attempt to cover a range of areas along the reef.

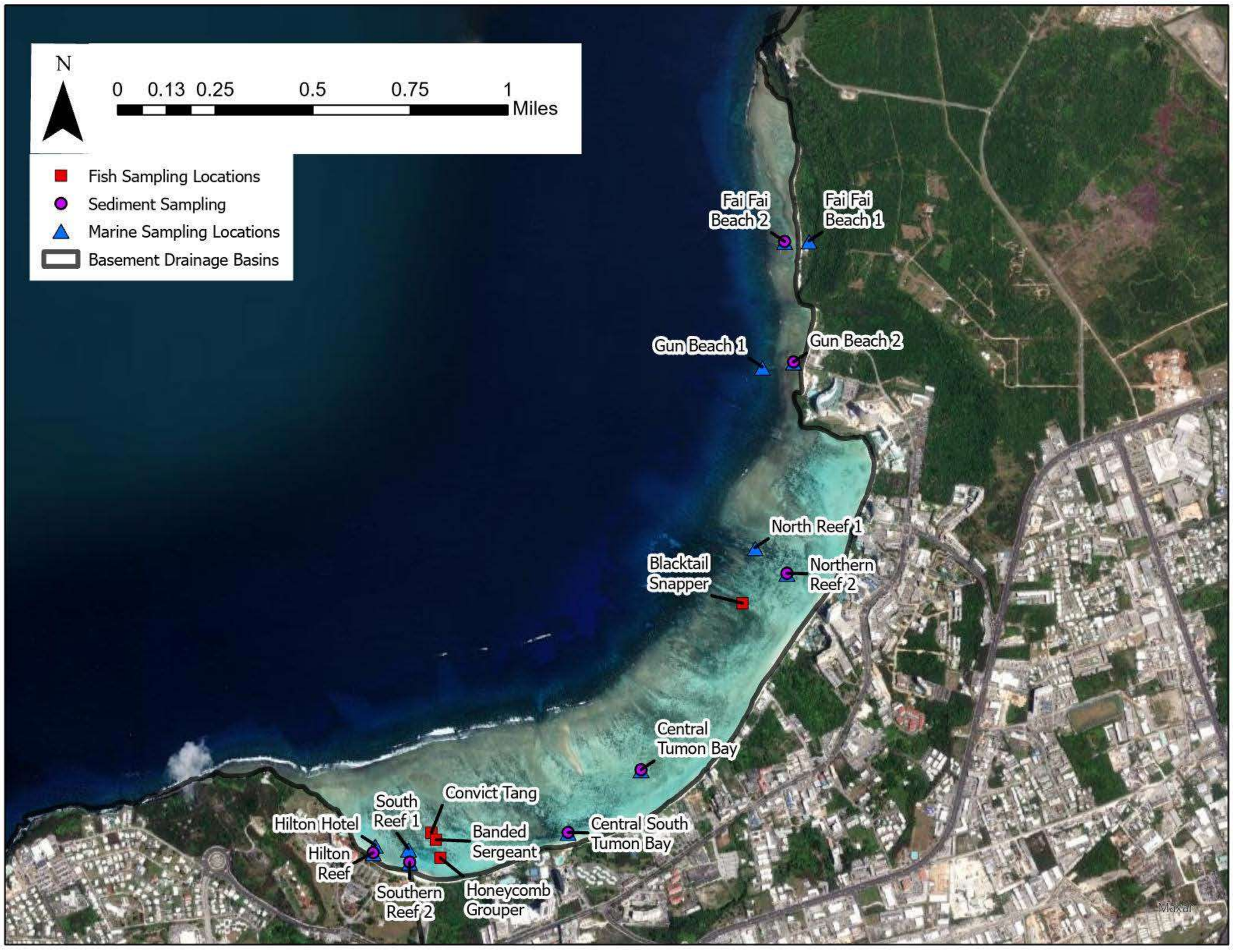

Figure 5-1. Location of marine water quality and fish tissue sampling locations

Table 5-1. Marine Water Quality Concentrations

Station Name	Sample Date	Chlordane (µg/L)	Dieldrin (µg/L)
WQC	**--**	**0.0022**	**0.00014**
Gun Beach 1	7/30/2020	<0.0069	**0.0016**
Gun Beach 1	9/17/2020	**0.053**	**0.0039**
Fai Fai Beach 1	1/11/2021	<0.007	<0.00027
Hilton Hotel	1/11/2021	<0.007	**0.00044**
North Reef 1	1/11/2021	<0.007	**0.0013**
South Reef 1	1/11/2021	<0.007	<0.00027
Central Tumon Bay	5/3/2022	<0.0069	<0.00026
North Reef 2	5/3/2022	<0.007	**0.00062**
Central South Tumon Bay	5/4/2022	<0.0069	**0.00045**
Central South Tumon Bay	5/4/2022	<0.0069	<0.00026
Fai Fai Beach 2	5/4/2022	<0.0069	**0.00048**

Station Name	Sample Date	Chlordane (µg/L)	Dieldrin (µg/L)
Gun Beach	5/4/2022	<0.0069	<0.00026
Hilton Reef	5/4/2022	<0.0069	**0.0017**
South Reef 2	5/4/2022	<0.007	**0.0017**

Notes: Sample results in red are above the applicable WQC.

Exceedances of the lowest WQC were observed for chlordane and dieldrin. Specifically, as shown in Table 5-1, the sample collected at Gun Beach on 9/17/2020 had a chlordane concentration of 0.053 µg/L, which exceeds the Aquatic Life Saltwater Chronic WQC concentration of 0.004 µg/L and the criterion to protect Human Health for the Consumption of Organisms Only (0.0022 µg/L). The other thirteen chlordane samples were below all WQCs.

Nine of the fourteen marine water samples had dieldrin concentrations that exceeded the WQC (64 percent). The maximum observed concentration was 0.0039 µg/L, collected at Gun Beach on 9/17/2020. This location and date coincide with the chlordane exceedance and these samples were collected after a significant rainfall event. This sample was above two of the WQC, while the eight additional exceedances were above the criterion to protect Human Health for the Consumption of Organisms Only (0.00014 µg/L). The remaining five dieldrin samples were non-detects, but the detection limit was above the WQC, so an exceedance evaluation could not be determined.

5.2 Water Quality Data – Groundwater and Springs

The locations and monitoring results that were collected from both 2001-02 by PCR and 2020-22 by PG are shown in Figure 5-2 (labeled locations represent stations for the 2020-22 study) and Table 5-2. The monitoring results from these two studies were compared to identify changes in the pollutant concentrations over time. The sections below describe the spring results as well as additional data from groundwater wells by pollutant (the groundwater wells are largely the unlabeled locations in Figure 5-2, which were sampled by the Air Force).

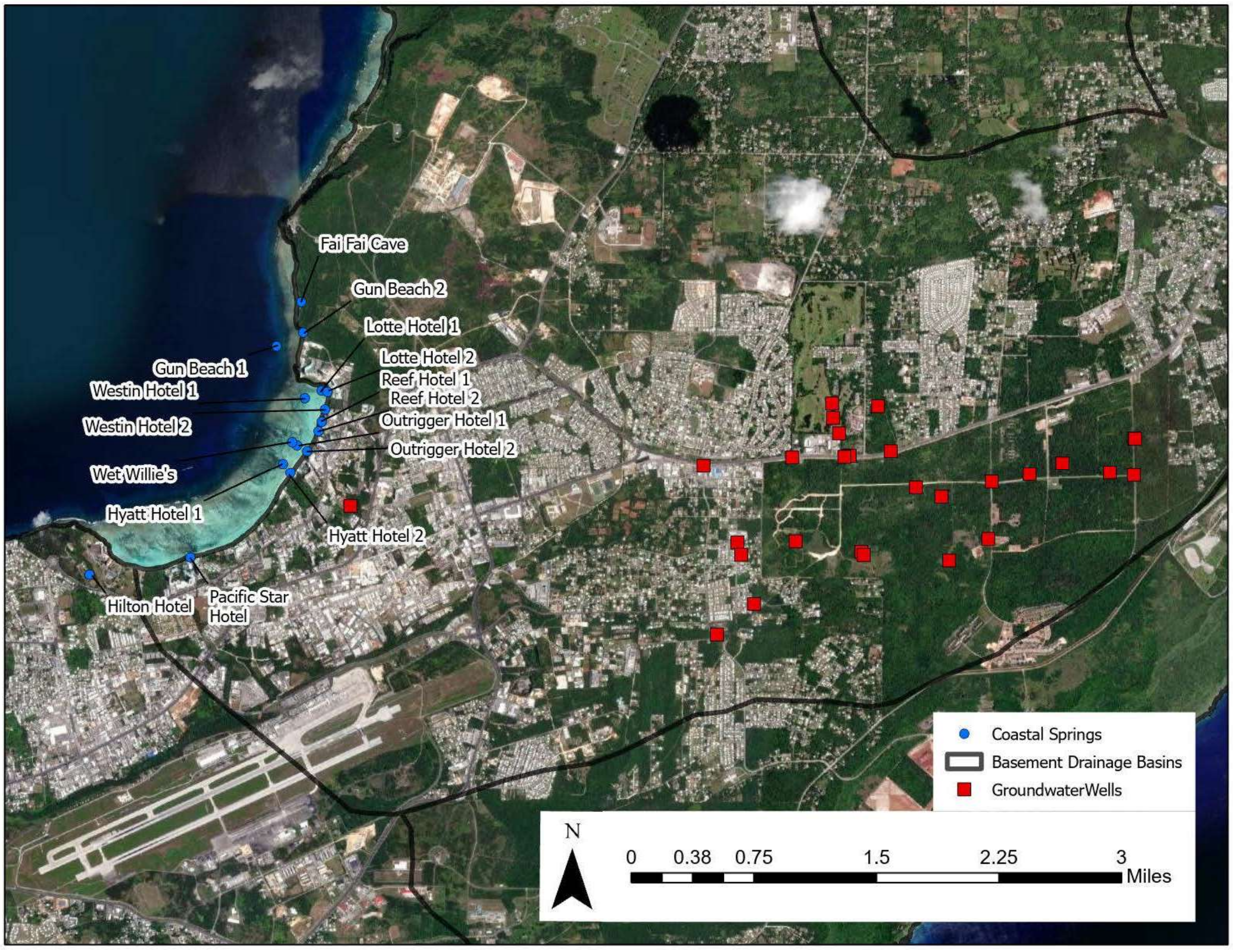

Figure 5-2. Location of coastal spring and groundwater well sampling locations

Table 5-2. Spring Sampling Data Over Time

Spring Location	Sample Dates							
	8/30/00	2/27/01	6/6/01	8/20/01	7/30/20	9/17/20	1/11/21	6/28/22
Chlordane (total) (Groundwater WQC = 2 μg/L)								
Fai Fai Cave	–	–	–	–	–	–	0.078	–
Gun Beach 1	<0.1	<0.338	<0.2	<0.2	0.13	0.048	–	–
Hilton Hotel	<0.1011	<0.338	0.2	<0.2	–	–	–	–
Hyatt Hotel 1	<0.1	<0.338	<0.2	<0.2	0.059	0.032	–	–
Lotte Hotel 1	–	–	–	–	0.069	0.17	–	–
Outrigger Hotel 1	<0.1	<0.338	<0.2	<0.2	<0.0069	0.055	–	–
Pacific Star Hotel	<0.1	<0.338	<0.2	<0.2	0.0755	0.0425	–	–
Reef Hotel 1	<0.1	<0.338	<0.2	<0.2	0.19	0.015	–	–
Westin Hotel 1	<0.1	<0.338	<0.2	<0.2	0.23	0.2	–	–
Wet Willie's	<0.1	<0.338	<0.2	<0.2	–	–	–	–
Gun Beach 2	–	–	–	–	–	–	–	0.078
Hyatt Hotel 2	–	–	–	–	–	–	–	0.043

Spring Location	Sample Dates							
	8/30/00	2/27/01	6/6/01	8/20/01	7/30/20	9/17/20	1/11/21	6/28/22
Lotte Hotel 2	–	–	–	–	–	–	–	0.26
Outrigger Hotel 2	–	–	–	–	–	–	–	0.074
Reef Hotel 2	–	–	–	–	–	–	–	0.051
Reef Hotel 2	–	–	–	–	–	–	–	0.064
Reef Hotel 2	–	–	–	–	–	–	–	0.048
Westin Hotel 2	–	–	–	–	–	–	–	0.24
Dieldrin (WQC = 0.056 μg/L*)								
Fai Fai Cave	–	–	–	–	–	–	0.017	–
Gun Beach 1	<0.1	<0.1	**0.16**	<0.1	0.014	0.008	–	–
Hilton Hotel	**0.169**	**0.23**	**0.26**	<0.1	–	–	–	–
Hyatt Hotel 1	<0.1	**0.15**	<0.1	<0.1	0.022	0.018	–	–
Lotte Hotel 1	–	–	–	–	0.032	0.016	–	–
Outrigger Hotel 1	<0.1	**0.15**	**0.14**	<0.1	0.016	0.028	–	–
Pacific Star Hotel	<0.1	**0.23**	**0.16**	<0.1	0.008	0.007	–	–
Reef Hotel 1	<0.1	**0.14**	<0.1	<0.1	0.025	0.0085	–	–
Westin Hotel 1	<0.1	**0.18**	**0.15**	<0.1	0.038	0.024	–	–
Wet Willie's	<0.1	**0.15**	**0.14**	<0.1	–	–	–	–
Gun Beach 2	–	–	–	–	–	–	–	0.0098
Hyatt Hotel 2	–	–	–	–	–	–	–	0.018
Lotte Hotel 2	–	–	–	–	–	–	–	0.034
Outrigger Hotel 2	–	–	–	–	–	–	–	**0.069**
Reef Hotel 2	–	–	–	–	–	–	–	0.023 / 0.027 / 0.0049
Westin Hotel 2	–	–	–	–	–	–	–	0.04

Notes: The Pacific Star Hotel location includes the Marriott Spring location in the PCR study (2002). Sample results in red are above the applicable groundwater WQC. "–" indicates no data available.

* A groundwater WQC has not been adopted for dieldrin, therefore the freshwater chronic aquatic life surface water criterion has included as an alternative.

5.2.1 Chlordane

The springs chlordane data from the PCR 2000-01 and the PG 2020-22 sampling events are shown in Table 5-2. The samples collected in 2000-01 and 2020-22 were similar and showed the least change over time compared to other parameters. All concentrations were below the groundwater WQC of 2 μg/L (Table 4-3). These results are also illustrated in Figure 5-3. Data collection in the 2020-22 study also sampled the Tumon-Maui groundwater well managed by GWA and measured a concentration of 0.11 μg/L and 0.028 μg/L respectively, which is illustrated by blue diamonds in Figure 5-3.

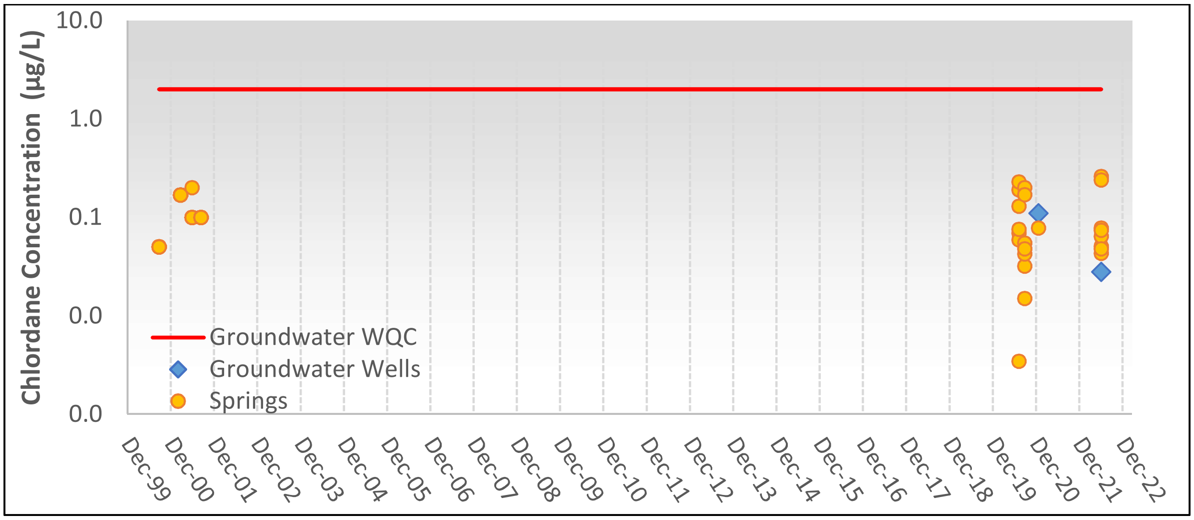

Figure 5-3. Spring and groundwater well chlordane concentrations over time

Notes: Non-detect values are illustrated at one-half the detection or reporting limit. These values were only used in exceedance calculations if the known limit is below the WQC.

While the Air Force study did not include chlordane data, groundwater wells were sampled by Denton and Sian-Denton during two different time intervals and summary statistics were published (Denton and Sian-Denton, 2010) along with the 2021 and 2022 sampling of the Tumon-Maui well (Table 5-3). The first GWA interval was between 1996-2001, which measured chlordane concentrations in 283 samples from 30 wells. The second sampling effort was conducted from 2002 to 2007, evaluating 316 samples in 58 wells (including 34 new wells compared to the first interval). These results are summarized in Table 5-3 and found that chlordane concentrations exceeded the WQC during the latter time interval (less than 1 percent), with exceedances noted in a single well. The concentration from the 2020-22 Tumon-Maui Well sampling event was below the WQC.

Table 5-3. Summary of Chlordane Sampling in Groundwater Wells

Parameter	GWA Sampling – First Interval	GWA Sampling – Second Interval	PG 2020-22 Sampling – Tumon-Maui Well	
Sampling Interval	1996-2001	2002-2007	2021	2022
Number of Wells	30	58 (34 additional wells)	1	1
Number of Samples	283	316	1	1
Chlordane Concentration Range (µg/L)	0.07 - 1.9	0.02 - 3.4	0.11	0.028
Median Concentration (µg/L)	0.24	0.23	0.11	0.028
Groundwater WQC (µg/L)	2.0	2.0	2.0	2.0
Number of Samples that Exceeded the WQC	0	3 (Samples from 1 well)	0	0

5.2.2 Dieldrin

The spring water dieldrin data are presented in Table 5-2 above. The PCR 2000-01 spring sampling events collected a total of 32 samples. Fourteen of the samples measured dieldrin concentrations between 0.14 and 0.26 µg/L, which were above the WQC for freshwater chronic conditions of 0.056 µg/L (Table 4-3; note a groundwater WQC is not available, so a freshwater criterion is used as an alternative). The remaining 18 samples from 2000-01 measured dieldrin concentrations less than 0.1 µg/L, a value above the available WQC, so exceedance could not be determined. The spring samples collected in 2020-22 had lower dieldrin concentrations than 2000-01, ranging from 0.008 – 0.040 µg/L, except for a sample of 0.069 µg/L at the Outrigger Spring, above the WQC.

The Air Force, GWA, and PG evaluated dieldrin concentrations of groundwater samples collected at wells in the Tumon Bay area. Dieldrin concentrations were measured at over 90 unique sites between 1997 and 2022 (Table 5-4). The dieldrin concentrations identified four Air Force samples exceeding the WQC (15 percent), at least one GWA sample exceeding the WQC (exact number is unknown since only summary statistics were available), and an exceedance in 2021 at the Tumon-Maui Well.

Table 5-4. Summary of Dieldrin Sampling in Groundwater Wells

Parameter	Air Force Groundwater Sampling	GWA Sampling	PG 2020-22 Sampling – Tumon-Maui Well	
Sampling Interval	1997-2002	1997-2007	2021	2022
Number of Wells	4	88	1	1
Number of Samples	27	875	1	1
Dieldrin Concentration Range (µg/L)	<0.02 - 0.11	0.01 - 1.6	0.08	0.027
Median Concentration (µg/L)	<0.02	0.05	0.08	0.027
Groundwater WQC (µg/L)	0.056	0.056	0.056	0.056
Number of Samples that Exceeded the WQC	4	>1	1	0

All available raw data are presented over time in Figure 5-4. This figure illustrates that dieldrin concentrations in springs are generally lower over time; however, the Tumon-Maui Well station sampled in 2021 was above the WQC, with a concentration of 0.08 µg/L. Other groundwater samples initially exceeded the criterion and then fell below in subsequent years (1998 to 2002).

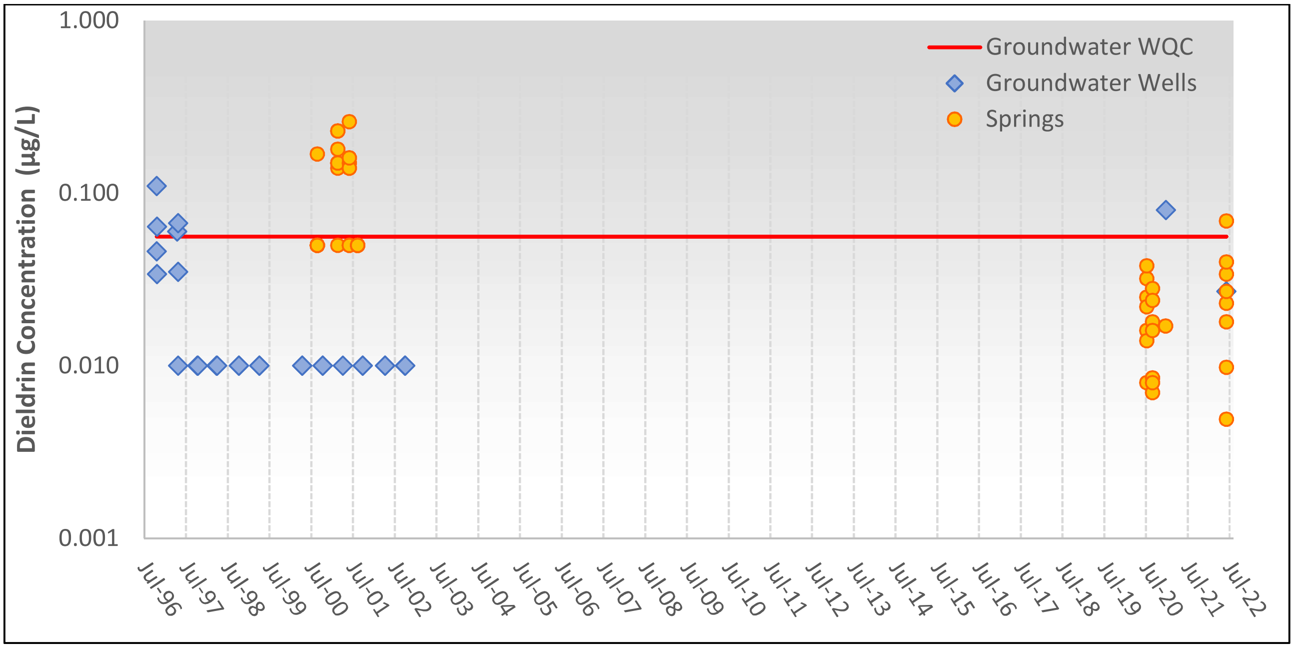

Figure 5-4. Spring and groundwater well dieldrin concentrations over time

Notes: Non-detect values are illustrated at one-half the detection or reporting limit. These values were only used in exceedance calculations if the known limit is below the WQC.

5.3 Fish Tissue Data

Fish tissue samples were analyzed as part of the PG 2020-22 sampling efforts. Samples of convict tang (*Acanthurus triostegus*), banded sergeant (*Abudefduf septemfasciatus*), honeycomb grouper (*Epinephelus merra*), and blacktail snapper (*Lutjanus fulvus*) were collected from four nearshore marine locations in Tumon Bay, shown in Figure 5-1 above. The whole fish samples were analyzed for chlordane and dieldrin. The concentrations that were measured in each sample are shown in Table 5-5. Where screening values are available (Table 4-3), all measured concentrations exceeded the values for subsistence fishers, regardless of fish type, and the dieldrin concentrations also exceeded the thresholds for recreational fishers. There is no pattern in concentrations between herbivore and carnivore species, which is not surprising given the limited sample sizes.

Table 5-5. Fish Tissue Concentrations

Species	Sample ID	Date of Collection	Herbivore or Carnivore	Chlordane (µg/kg)	Dieldrin (µg/kg)
Convict Tang	HCT-1	8/4/2020	Herbivore	**53**	**14**
Banded Sergeant	HBS-1	8/4/2020	Herbivore	**54**	**13**
Honeycomb Grouper	CHG-1	8/6/2020	Carnivore	**55**	**6.6**
Blacktail Snapper	CBS-1	8/6/2020	Carnivore	**21**	**15**

Notes: Sample results in red font are above the applicable subsistence fishing screening value and cells shaded in pink are above the recreational fishing screening value.

5.4 Sediment Data

Sediment samples were analyzed as part of the PG 2020-22 sampling efforts. Sediment samples were analyzed for chlordane and dieldrin. The stations illustrated in Figure 5-1 (purple circles) and summarized below in Table 5-7 are from the PG 2020-22 study. Seven sediment stations were sampled. There were no instances of exceedance of sediment screening values for any pollutants at any of the sample locations.

Table 5-6. Sediment Concentrations

Station Name	Sample Date	Chlordane (µg/kg)	Dieldrin (µg/kg)
Central Tumon Bay	5/3/2022	<0.27	<0.016
North Reef 2	5/3/2022	<0.38	0.047
Central South Tumon Bay	5/4/2022	<0.26	0.018
Fai Fai Beach 2	5/4/2022	<0.24	<0.014
Gun Beach	5/4/2022	<0.33	<0.019
Hilton Reef	5/4/2022	0.99	0.088
South Reef 2	5/4/2022	<0.26	<0.016

Notes: The sediment screening values are based off terrestrial soils rather than marine. However, these screening values were determined to be the most applicable to this analysis.

5.5 Data Summary

The PG 2020-22 samples from each media are summarized in **Error! Reference source not found.**8, with the percent of samples exceeding their applicable criteria in Table 4-2 and Table 4-3. Sampling demonstrated that nine of the fourteen marine water samples, one of the groundwater samples (Tumon-Maui Well), and all four fish samples had dieldrin concentrations that exceeded the WQC or screening value. Exceedances measured in multiple matrices suggests that dieldrin is likely causing impairment in Tumon Bay. The groundwater that flows into the bay was identified as a potential source of impairment in previous studies. Previous ground and spring water sampling from the Air Force, PCR, and GWA all collected samples that exceeded the dieldrin groundwater WQC.

Table 5-7. Percent of Samples That Exceed Criteria or Screening Values

Parameter	Marine Water (n=14)	Sediment (n=7)	Spring Water and Groundwater (n=25)	Fish Tissue (n=4)
Chlordane	7% (1 Sample)	0%	0%	100% (4 Samples)
Dieldrin	64% (9 Sample)	0%	6% (1 Sample)	100% (4 Samples)

Notes: “n/a” = not applicable.

One of the fourteen marine water samples and all four of the fish tissue samples had chlordane concentrations that exceeded the applicable WQC or screening values. The high chlordane concentrations measured in the fish tissue samples suggest that bioaccumulation may be causing persistent issues in the Bay or that legacy sediment or other sources (represented by the single marine sample exceedance) are causing ongoing contamination. None of the spring water or sediment samples demonstrated chlordane exceedances.

6 Source Assessment

Source assessments are an important component of water quality management and TMDL development. These analyses are generally used to evaluate the type, magnitude, timing, and location of pollutant loading to a waterbody (EPA, 1999). Source assessment methods vary widely with respect to their applicability, the ease of use, and acceptability. This section presents potential sources of pollutants throughout northern Guam that may contribute loads of the pollutants of concern, as well as the mechanisms by which pollutants can reach the Bay, both of which can be useful in determining applicable implementation efforts.

Pollutant sources are separated into two categories. Point source discharges are regulated through National Pollutant Discharge Elimination System (NPDES) permits. Point sources include stormwater and urban runoff (municipal separate storm sewer system [MS4]) and other NPDES discharges, including treatment plants. Nonpoint sources, by definition, include pollutants that reach the receiving water from a number of diffuse land uses and are not regulated through NPDES permits.

The 2020 Integrated Report identified suspected pollution source categories for marine waters as municipal point sources, combined sewer overflows, agriculture, urban runoff/storm sewers, contaminant sediments, and groundwater seeps and springs (GEPA, 2020). While this source information is not specific to Tumon Bay, some of these source categories, among others, were identified as possibly impacting the area.

Tumon Bay is a marine waterbody, but it is highly influenced by freshwater seeps and springs that flow from the NGLA. This unique transport process is described below in Section 6.1 and is important to consider when evaluating potential loadings to the Bay. While the NGLA is not identified as impaired, the 2020 Integrated Report includes general sources of groundwater pollution as agricultural activities, underground storage tanks, disposal activities (landfills and septic systems), hazardous waste generators, pipelines and sewer lines, saltwater intrusion, and urban runoff (GEPA, 2020). Some of these sources could be or have historically contributed pollutants to the aquifer, ultimately reaching Tumon Bay.

The point and nonpoint sources potentially contributing to the Tumon Bay impairments are described below in Sections 6.2 and 6.3, respectively. These are also summarized by pollutant in Table 6-1 and a range of sources is illustrated in Figure 6-1.

Table 6-1. Potential Sources by TMDL Pollutant

Pollutant Source	Pollutant	
	Chlordane	Dieldrin
Point sources		
Sewage Treatment Plants (GWA)		
Stormwater permits	●	●
Minor NPDES: construction general permit	●	●
Nonpoint sources		
Agriculture	●	●
Stormwater runoff (non-permitted)	●	●
Military	●	●
Landfills and Dumps	●	●
Legacy sediment	●	●
Ocean Natural Background		
Atmospheric Deposition		

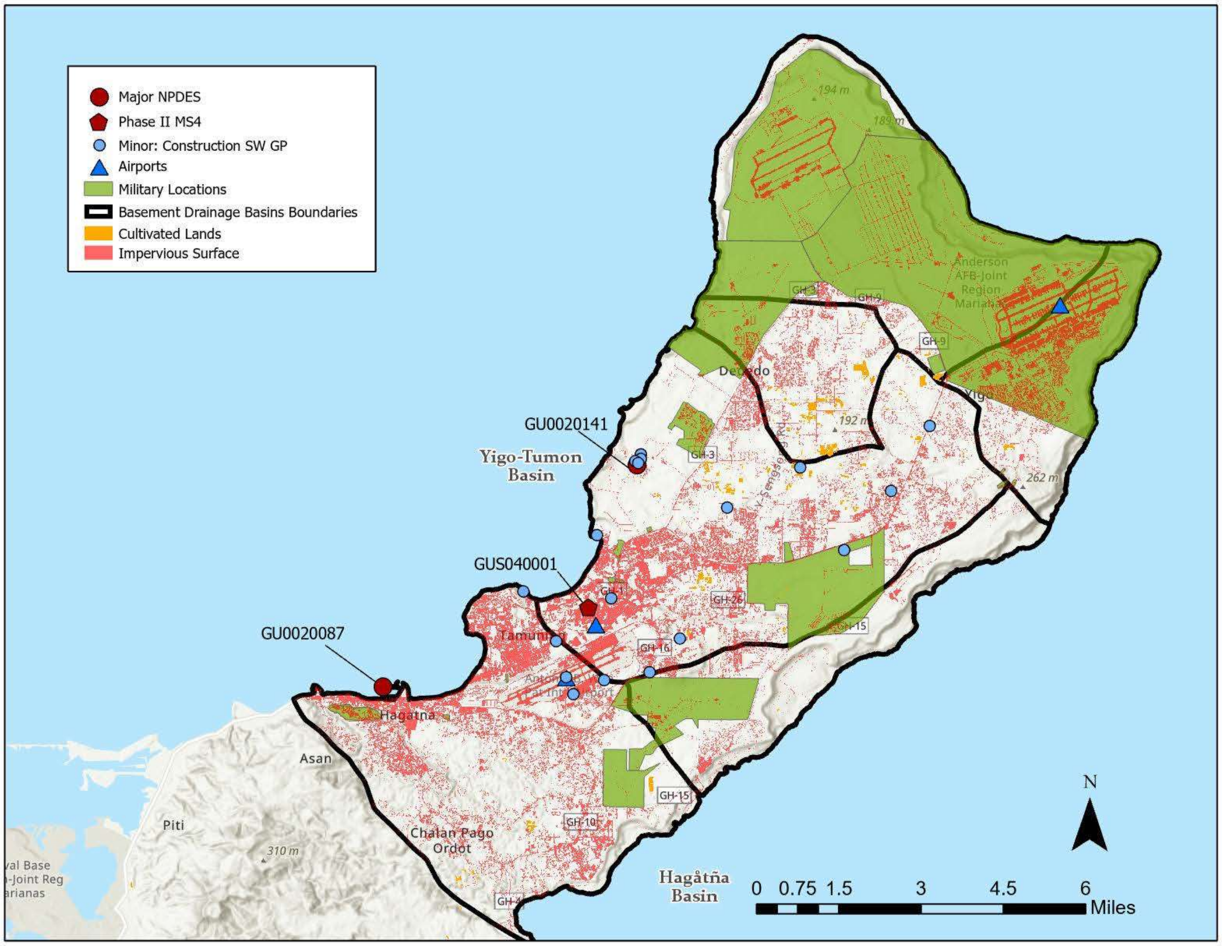

Figure 6-1. Summary of potential sources

6.1 Pollutant Transport Mechanisms

Pollutant transport mechanisms can have a significant impact on the technical approach (or linkage analysis) used in TMDL development. As noted previously, the inputs and delivery mechanisms to Tumon Bay are somewhat unique due to the porous geology of the northern portion of the island (Section 3.1). Transport of pollutants are likely similar throughout the drainage because, in order to reach the Bay, pollutants must percolate into the aquifer and ultimately discharge through seeps and springs in the Bay or reach the Bay through surface runoff following significant precipitation events. Source evaluation is difficult in this situation since there are natural mixing mechanisms within the aquifer and surface runoff can have many origins.

As water flows across the land and paved surfaces, debris and pollutants are collected. Pollutants subsequently flow with the water into storm drains and small waterways that lead to local coastal waters or into infiltration basins or ponding areas where water infiltrates to the groundwater. Water percolating through the porous soils in northern Guam reach the aquifer and are then transported to surface waters through coastal springs at the edge of the NGLA. A dye study of the Harmon Sink, which is located south-southeast of Tumon Bay and collects stormwater from the surrounding industrial park, airport, and occasionally sewage from failing lift stations, found that it takes 17 days for water to move from the sink to the coastal springs (with 8 days of transport between the airport and the springs). Transport throughout the aquifer is controlled by gradient-driven flow, with secondary pathways following the same direction (Moran and Jenson, 2004).

Water that begins as surface water may ultimately transport pollutants as groundwater once it reaches the aquifer. Natural attenuation and filtration within soils helps to remove pollutants from infiltrated water; however, this water may still contribute pollutants to the NGLA. Given the relatively fast transport of water from the surface to Tumon Bay via coastal springs, natural filtration is likely limited except for constituents with a strong affinity to bind with sediment; therefore, Tumon Bay itself may be the final sink for some pollutants of concern unless tidal processes sufficiently move the water out to the Philippine Sea.

As an alternative to the aquifer-driven process, water that reaches a storm drain or small waterway connected directly to the Bay can be transported as stormwater. Higher density of impervious area, if not properly managed, results in greater surface runoff due to the reduced ability of water to infiltrate into the ground during rain events and may increase the transport of pollutants to receiving waters. If stormwater is within a permitted MS4 area, it is considered point source pollution (Section 6.2); however, stormwater in a non-permitted area falls into the nonpoint source category (Section 6.3).

The unique regional geology in northern Guam impacts water transport and this condition, along with rainfall intensity and frequency, affects the amount of runoff during rain events. Because of the largely distributed sources and limited datasets, quantifying pollutant loads associated with upstream sources is not possible.

6.2 Point Sources

Several point sources with NPDES permits discharge in areas that may affect water quality in Tumon Bay (Table 6-2; obtained from an EPA Integrated Compliance Information System [ICIS] data search). These are described in further detail below and are illustrated in Figure 6-1. Permitted facilities identified in Table 6-2 will receive WLAs in the TMDL.

Table 6-2. Point Sources with NPDES Permits

NDPES ID	Discharger	Facility Name	Permit Expiration
Major: GU0020141	Guam Waterworks Authority	Northern District Sewage Treatment Plant	12/31/2024
Major: GU0020087	Guam Waterworks Authority	Agaña/Hagåtña Sewage Treatment Plant	12/31/2024
Phase II MS4: GUS040001	Guam Department of Public Works	Guam Department of Public Works Municipal Separate Storm Sewer System	1/31/2024
Minor CGP: GUR10003D	Doosan Ukudu Power, LLC	198MW Ukudu Combined Cycle Power Plant	2/16/2027
Minor CGP: GUR053002	Guam State Government	A.B. Won Pat International Airport, Guam	2/28/2026
Minor CGP: GUR053009	Guam State Government	A.B. Won Pat International Airport, Guam (Light Aircraft Facility)	2/28/2026

NDPES ID	Discharger	Facility Name	Permit Expiration
Minor CGP: GUR10004C	Environmental Chemical Corporation	AFSPC Radome Expansion Project	2/16/2027
Minor CGP: GUR10002B	CADDELL-NAN JV	Marine Corps Base, Camp Blaz	2/16/2027
Minor CGP: GUR10003N	Hawaiian Rock Products	Clear and Grade Lot 5035-R8 Ukudu	2/16/2027
Minor CGP: GUR100052	Pacific Rim Constructors, Inc.	Clearing and Temporary Stockpiling at Lot 5316-R3new-3, Route 3 Dededo Guam	2/16/2027
Minor CGP: GUR10004E	Join Corporation	Coast 360 FCU Upper Tumon Branch	2/16/2027
Minor CGP: GUR10003O	Core Tech – HDCC – Kajima, LLC	Contract N62742-21-D-1325, J-008 Fires Station, Marine Corps Base, Guam	2/16/2027
Minor CGP: GUR10001L	Pan Pacific Retail Management (Guam) Co. LTD	Dondondonki Guam	2/16/2027
Minor CGP: GUR10004K	Pan Pacific Retail Management (Guam) Co., Ltd.	Donki Car Park	2/16/2027
Minor CGP: GUR10002C	Pan Pacific Retail Management (Guam) Co., Ltd.	Donki Staff Housing	2/16/2027
Minor CGP: GUR10003Z	CADDELL-NAN JV	FY 21 Milcon Project P-802 Base Warehouse, Camp Blaz, Guam	2/16/2027
Minor CGP: GUR10004D	GSE, LLC	FY19 P270 Ace Gym and Dining Facility	2/16/2027
Minor CGP: GUR10002G	Caddell-Nan JV	FY20 MCON P-459 BEQ H	2/16/2027
Minor CGP: GUR10002Z	Granite-Obayashi	FY21 MCAF P-3001/AJJY203001 APSI – Standoff Weapons Complex	2/16/2027
Minor CGP: GUR100041	Chugach Consolidated Solutions, LLC	FY21 MCON Project P-803 – Individual Combat Skills Training	2/16/2027
Minor CGP: GUR10003L	Hensel Phelps Construction Co.	FY21 P-311 Central Fuel Station	2/16/2027
Minor CGP: GUR10004B	Environmental Chemical Corporation	P103 Water Well Field	2/16/2027
Minor CGP: GUR10004Z	Hansel Phelps Construction Co.	FY22 MCON P-326 Principal End Item Warehouse	2/16/2027
Minor CGP: GUR10003V	Guam Advance Enterprises, Inc.	GPA Fuel Pipeline Installation for the Ukudu 198MW Power Plant, Guam	2/16/2027
Minor CGP: GUR10004F	HDCC Guam, LLC	GTA Alupang HDD Duct Installation	2/16/2027
Minor CGP: GUR10001S	Black Construction Corporation	H-279, H-280 & H-282 Replace Andersen Housing Phase I, II, & III, AAFD, Guam	2/16/2027
Minor CGP: GUR10002Y	Hensel Phelps Shimizu Joint Venture	J-011 Base Administrative Building	2/16/2027
Minor CGP: GUR10003F	Pacific Rim Constructors, Inc.	J-017 Phase II Site Utilities and Improvement	2/16/2027
Minor CGP: GUR10002O	Reliable Builders, Inc.	J-017 Utilities and Site Improvements (U & SI), Phase II	2/16/2027

NDPES ID	Discharger	Facility Name	Permit Expiration
Minor CGP: GUR10003B	Core Tech – HDCC – Kajima, LLC	J-025 Medical/Dental Clinic	2/16/2027
Minor CGP: GUR10003R	Core Tech – HDCC – Kajima, LLC	J-032 BEQ E J-036 BEQ C J-038 BEQ J J-039 BEQ K and J-037 BEQ G	2/16/2027
Minor CGP: GUR10004J	Black Construction Corporation	J-034 Bachelor Officer Quarters-B	2/16/2027
Minor CGP: GUR10001K	CHK LLC	J-755 Urban Combat Training	2/16/2027
Minor CGP: GUR10003K	Black Construction Corporation	JFY20 J-023 Bachelor Officer Quarters-A	2/16/2027
Minor CGP: GUR10003Y	Black Construction Corporation	JFY21 J-015 Enlisted Dining Facility	2/16/2027
Minor CGP: GUR10004H	APTIM Construction JV, LLC	JFY21 J-018 Police Station	2/16/2027
Minor CGP: GUR100010	Samsung E&C America, Inc.	Kepco Mangilao Solar Project	2/16/2027
Minor CGP: GUR10002I	JMC Equipment Rental	Lot No. 2491	2/16/2027
Minor CGP: GUR100048	Hensel Phelps Construction Co.	P-290 Earth Covered Magazines, Andersen Air Force Base Guam	2/16/2027
Minor CGP: GUR100051	Black Construction Corporation	P-305 4th Marine Regiment Facilities, Marine Corps Base Camp Blaz, Guam	2/16/2027
Minor CGP: GUR10004X	Gilbane SMCC ECC (GSE) LLC	P-310 Infantry Battalion HQ	2/16/2027
Minor CGP: GUR10003M	Hensel Phelps Construction Co.	P-317 Combined EOD Compound	2/16/2027
Minor CGP: GUR100032	Core Tech – HDCC – Kajima, LLC	P296 – Ordinance Operations Admin. Building	2/16/2027
Minor CGP: GUR10004Y	Gilbane SMCC ECC (GSE) LLC	P306 Combat Logistics Battalion – 4 Facilities	2/16/2027
Minor CGP: GUR10004W	Gilbane SMCC ECC (GSE) LLC	P307 Consolidated Armory	2/16/2027
Minor CGP: GUR10002N	Core Tech – Hawaiian Dredging, LLC	P3105 APSI Munition Storage Igloos (Phase 3)	2/16/2027
Minor CGP: GUR10003A	Core Tech – HDCC – Kajima, LLC	P312 Distribution Warehouse, P804 Central Issue Facility	2/16/2027
Minor CGP: GUR10004V	Gilbane SMCC ECC (GSE) LLC	P314 MEB Enablers, Naval Support Activities	2/16/2027
Minor CGP: GUR100057	BRPH Construction Services	Pacific Deep Merriam Antenna System	2/16/2027
Minor CGP: GUR100053	VIASAT, Inc.	Project Snorkel	2/16/2027
Minor CGP: GUR10004G	Mark Zhao	Proposed 12 Lot Subdivision	2/16/2027
Minor CGP: GUR10003J	Guam Advance Enterprises, Inc.	Removal/Disposal of Above Ground Portion of Existing GPA Pipeline	2/16/2027
Minor CGP: GUR100055	InfraTech International, LLC	Route 15B Reconstruction and Widening	2/16/2027
Minor CGP:GUR10003G	Construction Management Services	Songsong Hills Subdivision Increment 1	2/16/2027

NDPES ID	Discharger	Facility Name	Permit Expiration
Minor CGP: GUR10004A	Tutujan Hill Group, Ltd. William D. Beery	Tasi Vista Subdivision (The Palisades)	2/16/2027
Minor CGP: GUR100047	Hawaiian Rock Products	Tsubaki Overflow Parking Improvement	2/16/2027
Minor CGP: GUR053008	United Airlines, Inc.	United Airlines (Formerly Continental Micronesia)	2/28/2026

6.2.1 GWA Northern District STP, Harmon Annex

GWA owns and operates one wastewater treatment plant (WWTP) (also called sewage treatment plants [STPs]) located to the north of Tumon Bay. This is operated under NPDES Permit No. GU0020141. According to the permit:

> "The facility collects and treats wastewater from the regions of Dededo, Latte Heights, Perez Acres, Ypaopao, and Marianas Terrace, the Yigo Collector System, and other unincorporated subdivisions throughout Yigo and Dededo municipalities. The service area also includes U.S. military facilities (Air Force and Navy) within the areas of Dedeo and Harmon Annex, and Anderson Air Force Base. The Northern District WWTP currently provides Chemically Enhanced Primary Treatment (CEPT) for a population of approximately 76,000 people."

This permit includes limits for nutrients, copper, zinc, and toxicity. It could be a source of some pollutants of concern for this TMDL that are typically found in municipal wastewater (Table 6-1) all of which must be monitored as part of the Priority Pollutant Scan. The STP discharges to the south of Tanguisson Point, which is located along the coast north of Tumon Bay. Under certain conditions ocean currents could carry STP effluent toward Tumon Bay; however, this would be an atypical pattern for the western side of the island, suggesting that this is a potential, but infrequent source of pollutants to the Bay.

6.2.2 GWA Agaña/Hagåtña Sewage Treatment Plant

GWA owns and operates one WWTP or STP located to the south of Tumon Bay. The plant is operated under NPDES Permit No. GU0020087. According to the permit:

> "The facility collects and treats wastewater from the central region of Guam which includes the villages of Hagåtña, Agaña Heights, Asan Piti, Tamuning, Mongmong-Toto, Sinajana, Chalan Pago-Ordot, Yona, Mangilao, portion of Barrigada, and Tumon. The service area also includes federal government installations (Naval Hospital facilities and personnel residences). Agaña WWTP currently provides Chemically Enhanced Primary treatment (CEPT) for a population of approximately 82,645 people."

This permit includes limits for nutrients, copper, silver, and toxicity. It could be a source of some pollutants of concern for this TMDL that are typically found in municipal wastewater (Table 6-1) all of which must be monitored as part of the Priority Pollutant Scan. The STP discharges into Agaña Bay, south of Tumon Bay. A study done in 2014 shows particle transport pathways entering Tumon Bay from Agaña Bay, suggesting that the STP discharge has the potential to influence water quality within the TMDL area (Storlazzi, 2014).

6.2.3 Guam Department of Public Works Municipal Separate Storm Sewer System

Effective February 2019, the MS4 operated by Guam Department of Public Works (DPW) is subject to NPDES Permit No. GUS040001. This permit manages sources of pollution that are transported through the storm drain system. As part of permit implementation, Guam DPW is required to develop maps of the stormwater drainage system and outfalls within two years of the permit effectiveness date.

This effort will distinguish areas within the Tumon Bay drainage that are subject to the MS4 permit. The other areas not discharging via the storm drain system are addressed in Section 6.3 for nonpoint sources. These maps have not yet been developed, so the exact distribution of stormwater sources between point and nonpoint sources is currently undetermined.

Urban areas are generally characterized by higher percentages of impervious land due to the conversion of natural, pervious surfaces to pavement, concrete, and buildings. These areas generate pollutants and facilitate transport over hard surfaces where surface water cannot infiltrate. In the absence of the MS4 area map required by the permit, Figure 6-2 illustrates the impervious areas and roads, which is expected to have reasonable overlap with the MS4 drainage. The area surrounding Tumon Bay is among the most developed on the island.

Although stormwater sampling for the pollutants of concern was not identified in the vicinity of the Bay, it is reasonable to assume that during wet weather events the storm drain system could convey pollutants to the Bay. The beachfront of Tumon Bay is home to numerous hotels and commercial development. Runoff from hotel areas was identified as a potential source of nutrient pollution to Tumon Bay (Denton et al., 1998); therefore, it is possible that other constituents of interest could reach the Bay by similar processes. In particular, dieldrin and chlordane are in pesticides and herbicides, which may be used in property maintenance or landscaping activities and result in localized runoff during precipitation events. These loadings could also infiltrate to the aquifer through retention ponds.

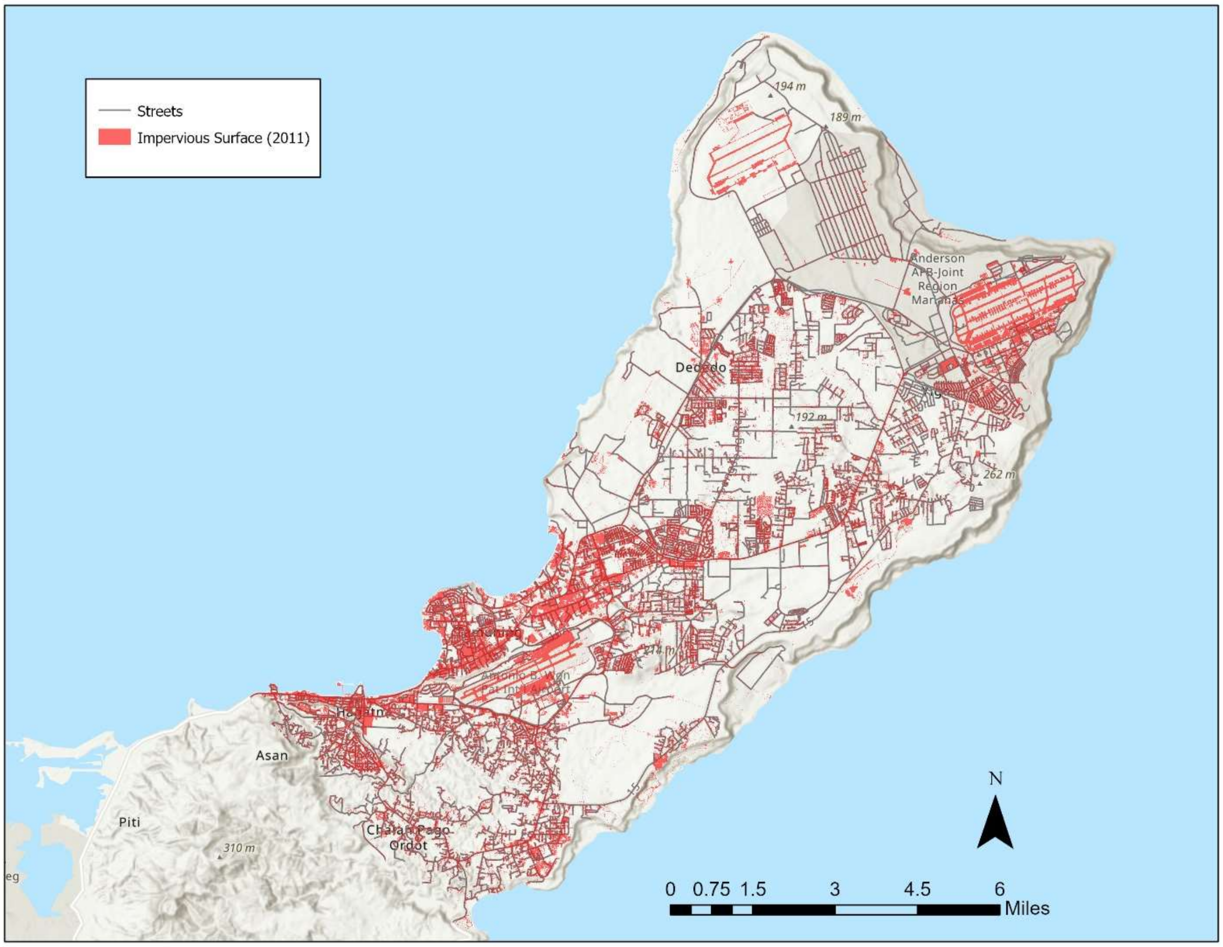

Figure 6-2. Impervious surfaces in the Tumon Bay drainage area

Other constituents of interest may also be transported by stormwater; however, their sources in the vicinity of Tumon Bay are not fully understood. In addition, other activities that may contribute to stormwater pollution from permitted sources are illicit discharges, construction activities, and industrial activities.

6.2.4 Naval Base Guam Municipal Separate Storm Sewer System

Guam is home to several large military installations. Effective February 2019, the MS4 areas owned or operated by the Department of Navy (DON) are subject to NPDES Permit No. GUS040000. The area currently subject to the permit does not fall within the Tumon Bay drainage; however, the permit requirements also apply to additional DON MS4s that are constructed in the future. Military sources and activities that may be subject to the MS4 permit in the future are described in Section 6.3.3. The exact location of these sources will ultimately determine their designation as point or nonpoint sources.

6.2.5 Minor NPDES Permits

The EPA construction general permit (CGP) is implemented in Guam as Permit No. GUR100000 for projects with disturbance of one or more acres. While these projects are intermittent, there are currently 54 construction projects that could influence water quality in Tumon Bay (Table 6-2) because they disturb soil that could be contaminated with the pollutants of concern. The exact list of active construction sites will change over time; however, it is important to note that any active site is a potential source of pollutant-laden sediment and must adhere to its facility-specific Storm Water Pollution Prevention Plan (SWPP).

6.3 Nonpoint Sources

Nonpoint sources of pollution apply to non-permitted areas that may reach Tumon Bay either through groundwater or stormwater runoff. Many nonpoint sources are intermittent and/or difficult to quantify; however, potential sources are identified below.

6.3.1 Agricultural Sources

Agricultural sources may influence Tumon Bay through stormwater and groundwater. As shown in Figure 3-6, limited cultivated farmland is present in the northern watershed, only 149 acres in the Yigo-Tumon basin based on the 2011 land use layer, less than half of the 386 acres present in 2004.

Chlordane and dieldrin are the two parameters of concern that may be associated with agricultural lands and activities. Chlordane and dieldrin are both chlorinated cyclodienes that were used as insecticides. Both are persistent, bind to sediment, and bioaccumulate in the food chain, often in fish tissue (OEHHA, 2008). Notably, concentrations of both pollutants exceed the fish tissue screening levels in Tumon Bay samples (Table 5-5). Both chemicals were also used as a termiticide; however, it is unclear if the chemicals were applied for this use in agricultural areas or in more developed areas associated with construction activities.

Although dieldrin and chlordane were historically used as pesticides, their use was banned in the late 1980's. Due to the persistence of these chemicals, they are still commonly identified in the environment, specifically in soil, sediment, and animal fat (ATSDR, 2002). It is possible that these chemicals were historically applied in the watershed and are continuing to slowly leech into the aquifer due to their persistent characteristics and affinity to bind with sediment; however, data to support this potential source are not available.

Chlordane detections continue to be observed in groundwater wells over time and are distributed across the aquifer, potentially posing an ongoing threat to water quality, even if the overall exceedance rate is low (Denton and Sian-Denton, 2010). The recent spring data did not identify any exceedances of either parameter; however, the Tumon-Maui well sample did exceed the dieldrin WQC (Table 5-4) and marine samples demonstrated exceedances for both parameters (Table 5-1).

6.3.2 Stormwater Nonpoint Sources

Stormwater transporting pollutants from un-permitted areas are nonpoint sources of pollution. The activities and fate and transport mechanisms for these sources are identical to those identified in Section 6.2.3 above and can be associated with chlordane and dieldrin.

6.3.3 Military Activities

As noted above, Guam is home to several large military installations (Figure 6-1), many of which are potential nonpoint sources of pollution to Tumon Bay due to their proximity to the NGLA and their historical activities. Military installations host a variety of activities, services, and disposal areas. Up until the late 1980's some military installations were reported having difficulty properly disposing of hazardous materials. Specifically, Andersen AFB was reported to improperly discharge pollutants into storm drains or the ground (GAO, 1987) and elevated levels of all the constituents of concern were observed in dumping grounds in and around Marbo Annex (U.S. Air Force, 2004). Elevated levels of PCE were also observed in the Tumon-Maui Well from 1990 to 1997 while the well was active (U.S. Air Force, 2004).

Numerous disposal sites are associated with these installations and may provide sources of pollution. As previously stated, the transport mechanism to Tumon Bay from these facilities is primarily through groundwater since the porous geology allows water to quickly permeate to the water table.

Military installations utilize or historically applied numerous contaminants that may be introduced to the environment. Chlordane and dieldrin are now banned but could have been used in prior landscaping or maintenance activities as pesticides.

Because of the proximity between military operations and the NGLA as well as the known improper disposal (GAO, 1987), military activities are a likely source of pollution to Tumon Bay. While many of these sources may no longer be active or may have been remediated, legacy contamination may persist in the NGLA and/or Tumon Bay itself. The groundwater well data presented throughout Section 5.2 include stations that could represent disparate military sources. Most of the observed concentrations from the late 1990s to early 2000s were below the WQC and other well stations in similar areas demonstrated limited exceedances (Denton and Sian-Denton, 2010). The recent spring sampling did not show persistent loading to the Bay; however, marine water quality and fish tissue concentrations demonstrated exceedances for many pollutants of concern, likely associated with historical loadings.

6.3.4 Landfills and Dumps

Landfills and dumps can threaten water supplies when water percolates through the waste and picks up pollutants in the process. These pollutants can cover a range of substances, including chlordane and dieldrin. The produced leachate can be a significant source of contaminated water, especially since the water is highly concentrated. Landfills are typically managed and designed to minimize discharge so these sites may not be a significant source of contamination; however, disparate unregulated dumps are a potential concern. In the northern portion of Guam, the underlying geology can facilitate the transport of leachate from landfills or dumping sites to the NGLA, where it can ultimately reach the Bay.

6.3.5 Legacy Sediment

Legacy contaminated sediment associated with military, agricultural, or other activities may be present within or in the vicinity of Tumon Bay. Previous studies detected chlordane and dieldrin at concentrations in springs typically higher than more recent sampling (Section 5.1). While recent spring concentrations are all below WQC, both marine water quality and fish tissue concentrations show elevated levels. It is possible that these observed receiving water and fish tissue conditions are associated with legacy sediment source contamination. In this situation, the sediment is releasing pollutants into the water column that can be redistributed during storms and through tidal processes, or legacy sediment on land is a source of local groundwater contamination as water infiltrates into the NGLA.

The sediment monitoring data available to date from within Tumon Bay (see Section 5.4) indicates that the pollutants of concern are present at low levels. Concentrations for chlordane and dieldrin suggest contamination at levels unlikely to result in net transport from the sediment to the water column (see Appendix A). However, sampling of Tumon Bay sediments have not been comprehensive and it is possible that future monitoring will identify heretofore unknown sources of contamination within the sediment.

6.3.6 Natural Background of Ocean Water

Chlordane and dieldrin are not naturally occurring within marine waterbodies and do not contribute to a natural background loading.

6.3.7 Atmospheric Deposition

Pollutants that are entrained in the atmosphere may be deposited in the waterbody during precipitation events (wet deposition) or as aerosol particles as bodies of air come into contact with the water surface (dry deposition). Chlordane and dieldrin are generally not present in the atmosphere and atmospheric deposition of these pollutants is not considered a likely source for this waterbody.

7 Technical Approach and Linkage Analysis

The loading capacity to Tumon Bay is the amount of pollutant loading that can be assimilated in the Bay without it exceeding the applicable WQC. Several options were identified that can be implemented given the unique geology in the northern portion of the island (i.e., all surface runoff percolates to the subsurface and discharges from the aquifer at coastal springs) limits many traditional loading analysis approaches. Additional factors that influence the selection of a technical approach include the following:

- Ability to adequately assess the loading capacity.
- Availability of adequate data to apply to the method.
- Ability to account for seasonal variation.
- Degree of uncertainty associated with the method.

These options which were considered in the development of this analysis are presented below, from lower level of effort to higher level of effort.

7.1 Technical Approaches Considered

The loading capacity of Tumon Bay for chlordane and dieldrin is the amount of each pollutant that can be assimilated in the waterbody without exceeding the WQC. Based on EPA protocols for TMDL development established in other marine water bodies, several options were identified. These included:

1. Concentration-based method
2. Mass-balance method
3. Receiving water modeling method

7.1.1 Concentration-Based Method

TMDLs with legacy sources are often challenging to model since historical loadings can be difficult to quantify, especially how they relate to current conditions. Therefore, a concentration-based method could be applied using the currently available data to address Tumon Bay impairments where the loading capacity is defined in terms of maximum allowable concentrations. TMDLs using this method would be based on simply attaining the applicable WQC. Because the loading capacity is equivalent to the numeric criteria, evaluating compliance with the TMDLs is straightforward. Although seasonal variation is accounted for implicitly, a concentration-based approach adds only limited value to relating TMDL targets to those conditions of greatest concern (e.g., wet- weather versus dry-weather). Assigning allocations is relatively simple as these would be concentration-based as well; however, this approach is limited in its ability to characterize the relative importance of various sources to support implementation efforts. For these reasons, it is often difficult to connect concentration-based TMDLs with implementation programs needed to solve water quality problems. An additional limitation of concentration-based approaches is they do not allow for the characterization of daily loads which is a typical characteristic of TMDLs.

7.1.2 Tidal Prism Mass-Balance Method

A mass balance or tidal prism approach was used to develop TMDLs for recreational beaches in the U.S. Virgin Islands and metals TMDLs for Newport Bay. The mass balance method is based on the volume of water moved in and out of an impaired segment between ebb and flood tides as well as incorporating freshwater inflows. This estimate of volume per unit time enables a loading calculation. Then, based on available data, loads would be estimated from land-based sources to develop components of the TMDLs (e.g., loading capacities and allocations). For Tumon Bay, these would likely incorporate previous modeling and analysis of groundwater well levels to estimate volumes to the Bay under different conditions, connected to precipitation, where possible. Overall, the mass balance method estimates the volume in the waterbody and adjusts for tidal flushing, freshwater inflow, and pollutant loads to the waterbody through time.

This method has an advantage over the concentration-based approach above because it would calculate a loading capacity, consistent with the strict definition of a TMDL. This approach is limited by the available data to characterize loads to the Bay from the land, which would ultimately limit the division of allocations among sources. This approach would have uncertainty because of the limited data available for inputs and the uncertainty associated with pollutant transport through the aquifer.

7.1.3 Receiving Water Modeling Method

The third approach considered was the development of a receiving water model. A hydrodynamic and sediment/contaminant transport model would represent the movement of water and contaminants within the Bay as well as the interactions between sediment contamination and Bay waters. Receiving water models, particularly linked watershed-receiving water models, have been developed to calculate many different TMDLs, including Hanalei Bay, Los Angeles/Long Beach Harbors, and San Diego Bay in EPA Region 9. A receiving water model can be developed with or without a linked watershed model; however, in the absence of a watershed model, available data are needed to represent the inflows to the Bay and create the link between source contribution and receiving water response. For Tumon Bay, these would likely incorporate previous modeling and analysis of groundwater well levels to estimate volumes to the Bay under different conditions, where possible.

A receiving water model can be developed at different spatial scales and complexities. The level of detail is typically dependent on the complexity of the environmental problem being addressed and data availability to support model configuration, calibration, and validation. For Tumon Bay, data in the Bay are limited, so model application, particularly a fine-scale or three-dimensional model, would require significant data collection. However, given sufficient data to perform proper calibration, a receiving water model would provide detailed predictions of water and sediment contamination throughout the Bay and could be used to define specific sources or areas for focused implementation efforts. Loads could be determined at varying time scales and in different areas; however, calculation of TMDL allocations would be dependent on the level of detail provided by the input data.

One significant benefit of a receiving water model is the ability to design and run different implementation scenarios to predict conditions that would attain the TMDL numeric targets. This could involve scenarios to modify the model inputs to determine the inflow conditions necessary to achieve the targets. Sediment cleanup scenarios can also be simulated where sediment hot-spots within the Bay are cleaned up or covered and then the model is run over time to ensure ongoing inflow conditions will not lead to future contamination. This approach is highly data intensive and without significant data collection, would result in a highly uncertain model based largely on assumptions.

7.2 Linkage Analysis

The linkage analysis connects patterns of pollutant source loading with water quality response within the listed waterbody. This allows for the calculation of a loading capacity within the waterbody which is consistent with attainment of TMDL numeric targets and restoration of associated designated uses.

The approach chosen to develop the TMDLs for the pollutants of concern was the tidal prism mass-balance method (see section 7.1.2 above). The framework was chosen due to the hydrologic complexity of Tumon Bay. Tumon Bay receives fluctuating amounts of freshwater from a multitude of groundwater seeps. The volume of freshwater entering the bay results from precipitation falling within the watershed, percolating into the subsurface, and traveling downgradient to the coast where it is discharged via seeps and springs to the waterbody. Tidal patterns drive the movement of ocean water into the waterbody during flood tides, and mixed bay water out on ebb tides. The mass-balance method accounts for the changing distributions of freshwater and sea water within the Bay. Therefore, this method minimizes the amount of uncertainty by focusing on the largest agent of variability. Further, this method permits the calculation of a loading capacity and development of daily allocations.

7.2.1 Tidal Prism Model Development Summary

Tumon Bay was modeled using a tidal prism modeling approach described in the previous section. Sources of flow into Tumon Bay are composed of freshwater flows from coastal seeps and springs and ocean water from the Philippine Sea entering on flood tides. Mixed water within the waterbody exits during ebb tides. Loading enters the bay from the freshwater seeps and springs, from atmospheric deposition, from “background” pollutant concentrations in the ocean, and from drifting effluent plumes from WWTPs upcoast and downcoast of Tumon Bay. A detailed description of the modeling approach is presented in Appendices A and B.

Model development began with defining the extents of Tumon Bay using the boundary for the Tumon Bay assessment unit (ATTAINS, 2022). Coastal elevation data (NOAA, 2020) and Tumon Bay bathymetry data (PIBHMC, 2022) were merged and used to compute the volume of the waterbody. Salinity measurement data associated with flood tides and ebb tides (Denton, *et al.*, 2005) were used to estimate the tidal exchange ratio for the waterbody (i.e., the ratio seawater inflow relative to total flood tide flow into the tidal prism). Freshwater inflows to Tumon Bay from coastal seeps and springs were estimated using previous groundwater modeling results (Gingerich, 2013; see Appendix A discussion).

The mass balance on Tumon Bay is characterized by the following equation:

$$\frac{dVC}{dT} = \left(Q_0C_0 - Q_bC + L_f + L_{atm} + L_s\right) \qquad (1)$$

Where,

C_0 = Concentration of pollutant that enters the bay on the flood tide through the ocean boundary (mg/L)

C = Dissolved pollutant concentration within the bay water quality segment after mixing (mg/L)

Q_0 = Amount of water entering the bay on the flood tide that did not enter on the previous ebb tide (m^3/T)

Q_b = Amount of water leaving the bay on the ebb tide that did not enter the bay on the previous flood tide (m^3/T)

L_f = Loading from freshwater seeps (g/T)

L_{atm} = Loading from atmospheric deposition (g/T).

L_s = Net loading/losses from the sediment compartment due to adsorption to settling particulate matter containing sorbed pollutant materials, precipitation of pollutants, or direct sorption to sediments (g/T).

T = Average tidal period of the waterbody (T/day)

At steady-state the mass balance equation can be simplified to Equation 2.

$$\boldsymbol{C} = \frac{Q_0 C_0 + L_f + L_{atm}}{Q_b} \qquad (2)$$

And Q_o can be estimated from the total flow into Tumon Bay on the flood tide multiplied by the tidal exchange ratio (β)

7.2.2 Seasonal Patterns

As discussed in Section 3.3, Guam's climate is tropical wet-dry, with the dry season running from January-May and the wet season running from July-November. The temporal precipitation variability paired with the porous geology of the island result in differing amounts of freshwater entering the Bay during the year. Depending on the saturation of the vadose zone, large precipitation events will either reach the coast or remain in the soil. Dry season precipitation events largely result in less freshwater entering the Bay. At the beginning of the wet season this remains true; however, once the vadose zone has been saturated, the soil cannot contain the excess and this precipitation discharges into the interior wells and out into the coastal waters. (Jocson et al, 1999).

NOAA tidal elevation data was not available for Tumon Bay, so data for a nearby location—Apra Harbor—was used to evaluate tidal patterns. Apra Harbor is on the west coast of Guam against the Philippine Sea. Tides are created by the earth's rotational force coupled with the moon's gravitational pull. Tidal data was downloaded for 2000-2022 water years[2] to determine sea elevation patterns (NOAA, 2022). The lowest tidal depth recorded was -1.24 feet occurring on Jan. 11th, 2005. The greatest tidal depth recorded was 2.89 feet, occurring on July 23rd, 2009. Apra Harbor experiences two high and two low tides per 24 hours. Apra Harbor's tidal cycle is considered semidiurnal, where the two high tides have similar heights and the two low tides have similar heights as well.

The linkage analysis used for this analysis employed long-term (i.e., multiyear) annual averages, rather than a seasonally based critical condition, as this critical condition is more applicable to the human health-based impairments identified in Tumon Bay. The TMDL numeric targets for the pollutants of concern are based on impairments for human health WQC (chlordane and dieldrin). Human health WQC have multidecadal averaging periods intended to protect a human from adverse effects over a lifetime exposure periods. And, as discussed in Section 5, Tumon Bay fish tissue samples in the waterbody exceed recreational and subsistence level tissue risk thresholds.

7.2.3 Spatial Patterns

Monitoring data for marine water samples and coastal spring sources did not suggest a particular pollutant concentration spatial gradient or the presence of hot spots within Tumon Bay (Figures 7-1 through 7-2). Nor were pollutant-specific concentration distributions readily apparent in the available monitoring data. Marine water concentrations do not display a strong gradient between the shoreline and the open ocean, which is likely due to the presence of coastal springs throughout the Bay and the influence of tidal mixing patterns. The Tidal Prism receiving water model assumes the waterbody is well-mixed over a given tidal cycle which appears to be a reasonable assumption given the available data.

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[2] A water year runs through Oct. 1 - Sept. 30.

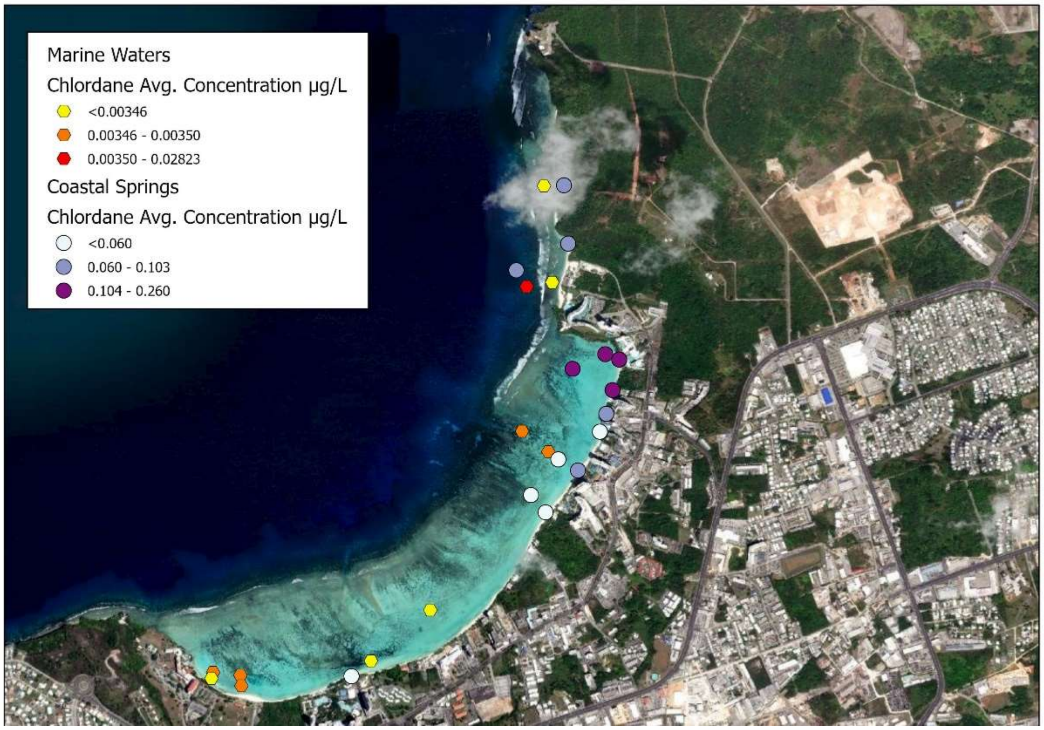

Figure 7-1. Average chlordane concentrations at marine water and coastal spring sampling stations within Tumon Bay

Figure 7-2. Average dieldrin concentrations at marine water and coastal spring sampling stations within Tumon Bay

Groundwater monitoring data was reviewed for the presence of potential hot spots which could point to potential pollutant sources (Figures 7-4 through 7-5). In general, the number of sites with monitoring data for the pollutants of concern was limited which rendered it infeasible to draw strong conclusions about the spatial distribution of the pollutants of concern within the subsurface. Dieldrin displayed a potential high-to-low gradient from south-to-north (Figure 7-4) but too few monitoring sites were available to draw more specific conclusions.

Figure 7-3. Average chlordane concentrations at groundwater sampling stations

Figure 7-4. Average dieldrin concentrations at groundwater sampling stations

8 TMDL Development

The TMDLs addressed in this report are designed to address impairments within Tumon Bay due to chlordane and dieldrin. Section 303(d)(1)(C) of the Federal Clean Water Act requires TMDL to be established at a level necessary to implement the applicable water quality standards and to account seasonal variations and a margin of safety (MOS).

A TMDL is defined as the sum of the WLAs for point sources, plus the sum of the LAs for nonpoint and natural background sources, plus a MOS. This loading budget, with an appropriate MOS, will result in a pattern of loading that the waterbody can process with its available assimilative loading capacity without exceeding water quality standards, as shown in the following equation:

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS}$$

Where,

$\sum$WLA = The sum of all individual point source WLAs

$\sum$LA = The sum of all nonpoint source and natural background LAs

MOS = Margin of Safety

The TMDLs for chlordane and dieldrin address the impairment for consumption of organisms designated use applicable to Tumon Bay. It identifies allowable loadings for point and nonpoint sources which are contributing to the impairment within Tumon Bay.

8.1 Establishment of the TMDL

The linkage analysis provides the quantitative basis for determining the loading capacities for chlordane and dieldrin for Tumon Bay. As discussed in Section 4.1, the TMDL numeric targets used in this analysis were based on the designated uses of the waterbody and associated water quality standards. Therefore, attainment of the TMDL numeric targets will result in attainment of water quality standards and associated designated uses.

As discussed in Section 7, a mass balance approach was used to establish the loading capacity of the waterbody for the pollutants of concern. Because the numeric targets for the TMDL are intended to attain fish consumption designated uses over long exposure periods, it accounts for seasonality by using long-term annual average conditions. The linkage analysis model treats the Bay as a singular control volume which is well-mixed over the course of a given tidal cycle. Pollutant loading to the waterbody occurs from the ocean-side boundary when the tide flows into the Bay, and from coastal springs which discharge contaminated groundwater directly to Tumon Bay. No active sources of chlordane or dieldrin in the watershed have been identified and it is likely that legacy contamination of groundwater is the cause of the impairment.

8.2 Loading Capacity and Allocations

The loading capacity of the waterbody is defined as the quantity of a pollutant or other waterbody constituent which can be absorbed without exceeding applicable water quality standards. The Tidal Prism model was used to compute a maximum daily loading capacity for the pollutants of concern (Table 8-1, refer to Appendix B for a discussion of the Tidal Prism model and loading capacity calculations).

Table 8-1. Tumon Bay Loading Capacity, Existing Load, and Required Load Reduction

Parameter	Chlordane	Dieldrin
TMDL Numeric Target (µg/L)	0.0022	0.00014
Loading Capacity	12 g/day	0.77 g/day
Existing Load	15 g/day	3.4 g/day
Required Load Reduction	3 g/day	2.6 g/day
Percent Reduction Needed	20%	77%

8.2.1 Chlordane and Dieldrin

At this time no active sources of chlordane or dieldrin loading from point or nonpoint sources have been identified. It is likely that loading from the coastal springs to Tumon Bay is due to historical contamination of the groundwater. Provided that there are no active sources of these pollutants within the watershed, contamination within the aquifer will undergo natural attenuation, resulting in decreased loading over time until the legacy contamination is exhausted.

The available data reviewed in this study (see Section 5) suggests that dieldrin levels in groundwater and spring water feeding Tumon Bay may have peaked in the early 2000's and are declining (Figure 8-1) over time. Similarly, chlordane measurements show limited evidence of declining groundwater and spring water concentrations over the time, though this may be masked by the gap in the monitoring record between 2001-2020. Discussing chlordane in groundwater well samples, Denton and Sian-Denton (2010) observed that the compound was "popularly used as a termiticide in the construction business on Guam until it was banned by USEPA in 1983." They further noted that the available data suggested chlordane was slowly migrating through the aquifer with detections increasing throughout the first decade of the 21st century. So long as no new sources of these compounds are introduced from point sources or nonpoint sources, these concentrations will eventually decline to levels that are below water quality standards, and Tumon Bay is expected to return to attainment with applicable water quality standards.

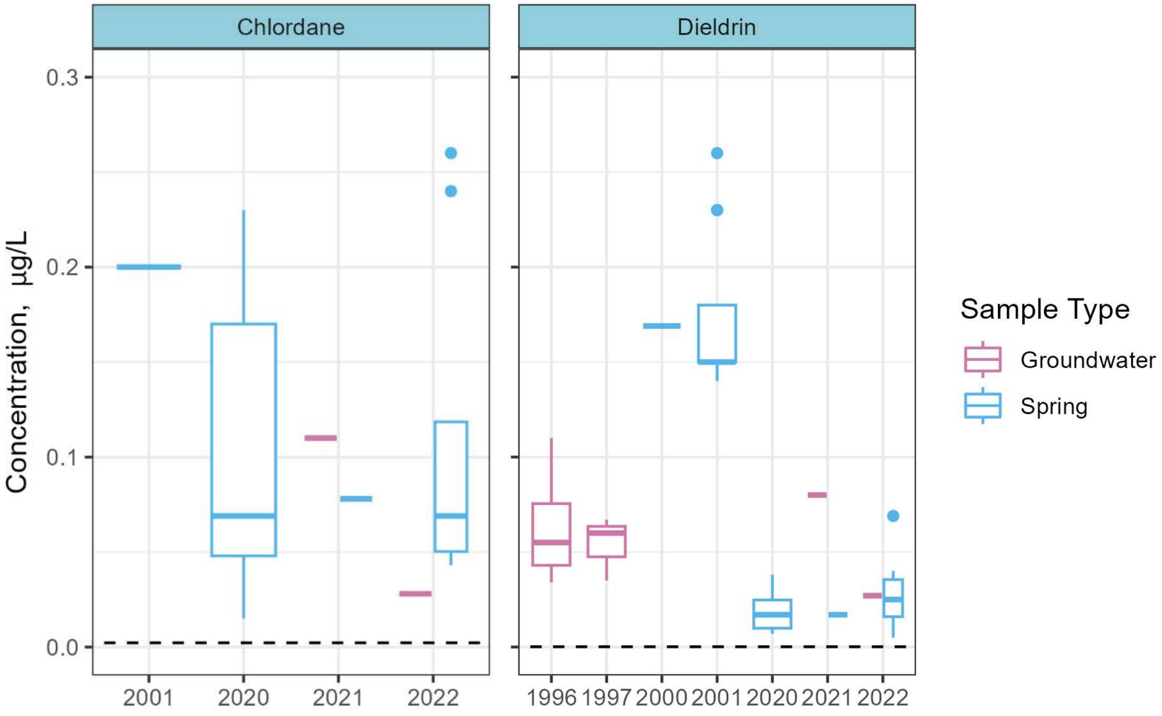

Figure 8-1. Time series boxplots of chlordane and dieldrin concentrations in groundwater and coastal springs to Tumon Bay, between 1996 – 2022

Note: Dashed line indicates concentration of TMDL numeric target. The horizontal axis is compressed and not to scale. Non-detect results with MDLs above the WQC were not plotted. Groundwater values are from Tumon-Maui Well location.

Since chlordane and dieldrin are substances whose manufacture and commercial use were prohibited since the late 1980s (ASTDR, 2002 and 2018), this TMDL establishes WLAs and LA consistent with the elimination of all sources of discharge for these two pollutants (Table 8-5)

Table 8-2. Tumon Bay Chlordane and Dieldrin Allocations

Parameter	TMDL	=	WLA	+	LA	+	MOS
Chlordane:	12 g/day	=	0 g/day	+	0 g/day	+	12 g/day
Dieldrin:	0.77 g/day	=	0 g/day	+	0 g/day	+	0.77 g/day

Table 8-6 lists WLAs assigned to point sources with the potential to contribute loading to Tumon Bay. These sources are assigned a narrative WLA which prohibits the discharge of chlordane or dieldrin.

Table 8-3. Chlordane and Dieldrin WLAs

NPDES ID	Facility Name	Existing Load	WLA	Percent Reduction Required
GU0020141	Northern District Sewage Treatment Plant	0	No discharge of pollutant[1]	0
GU0020087	Agaña/Hagåtña Sewage Treatment Plant	0	No discharge of pollutant[1]	0

NPDES ID	Facility Name	Existing Load	WLA	Percent Reduction Required
GUS040001	Guam Department of Public Works Municipal Separate Storm Sewer System	0	No discharge of pollutant[1]	0
GUR100000	Sites within the Tumon Bay watershed covered under the Construction General Permit	0	No discharge of pollutant [1, 2]	0

1. Applicable to both discharges of chlordane and discharges of dieldrin.
2. This WLA will be met through adherence to a site- or project-specific SWPP.

Similarly, an overall LA of 0 g/day is applicable to all nonpoint sources within the watershed. As discussed above, there are no known active sources of these pollutants within the watershed and the assigned allocations are designed to assure the elimination of loading of chlordane and dieldrin to the aquifer which ultimately discharges to Tumon Bay. Attainment of applicable chlordane and dieldrin WQS is reliant on the throttling of all active sources of loading, prevention of new sources of loading, and the eventual natural attenuation of legacy contamination within the groundwater aquifer.

8.3 Seasonality and Critical Conditions

The Tidal Prism model was used to simulate long-term average annual water quality conditions within Tumon Bay using loading and monitoring data available from 2013-2022, and waterbody turnover rates due to tidal action were estimated based on monitoring of diurnal tidal patterns from 2000-2022. As discussed in Section 7.2.2, a long-term annual average critical condition—as opposed to a seasonal or shorter duration critical condition—is the most reasonable averaging duration to apply to the human health-based impairments identified for Tumon Bay.

The TMDL numeric targets for the pollutants of concern are based on impairments for human health WQC (chlordane and dieldrin). Human health WQC have multidecadal averaging periods intended to protect a human from adverse effects over lifetime exposure periods. And, as discussed in Section 5, Tumon Bay fish tissue samples in the waterbody exceed recreational and subsistence level tissue risk thresholds.

8.4 Margin of Safety

The MOS is included in the TMDL to account for uncertainty regarding the relationship between pollutant loads and the water quality response of Tumon Bay, and uncertainties inherent in the modeling process. The MOS may be formulated implicitly, using conservative assumptions or analytical techniques, or explicitly by reserving a portion of the loading capacity as unallocated load. This TMDL utilizes an explicit MOS and reserves a minimum of 10 percent of the loading capacity as an unallocated load for each pollutant parameter. For chlordane and dieldrin, the TMDL goal is to reduce all sources to a "no discharge" condition and the entirety of the load is placed in the MOS in order for the TMDL equation to balance.

8.5 Reasonable Assurances and Implementation Planning

GEPA is committed to protecting Guam's waterbodies and restoring Tumon Bay to attainment with waters quality standards. GEPA anticipates the WLAs established in this TMDL Report will be implemented in the NPDES program and provide adequate control of these sources at a sufficient level to achieve the TMDL. Should future effluent monitoring indicate sources of chlordane or dieldrin in

WWTP or MS4 effluent in the future at levels exceeding the WLA, the permittees respective NPDES permits shall require the design and implementation of source investigation reduction studies. Potential source reduction measures would include public outreach campaigns to inform residents of their options for safely disposing of hazardous substances and publicizing information on these compounds' harmful effects on drinking water sources and surface waters.

GEPA is also committed to assuring achievement of the TMDL for nonpoint sources. Chlordane and dieldrin have not been commercially available for several decades and it is likely that sources of these pollutants are no longer active. In order to prevent new releases of these pollutants, local governments in Guam promote disposal of hazardous household waste at facilities maintained by the Guam Solid Waste Authority, including any legacy stores of pesticides which may contain these substances. Local governments are also closely monitoring chlordane and dieldrin levels in groundwater sources. Provided no new sources of these pollutants are introduced, GEPA anticipates the levels of these contaminants in the groundwater will eventually fall to low levels and natural attenuation processes in Tumon Bay will return the waterbody to attainment with water quality standards.

GEPA plans to continue monitoring the waterbody and groundwater sources contributing loading to Tumon Bay, and relevant data in other media to track levels of the pollutant of concern. During the National Aquatic Resources Survey for reef flats, planned for 2025 and every 5 years thereafter, GEPA will include monitoring of Tumon Bay for the pollutants of concern to provide information on progress towards attainment of applicable WQS. In the event that it is infeasible to include Tumon Bay monitoring in the National Aquatic Resources Survey, GEPA will initiate waterbody specific monitoring in Tumon Bay for the pollutants of concern on a frequency of no less than once every five years. Further, GEPA anticipates coordinating with local stakeholders to continue to monitor groundwater for chlordane and dieldrin, and to identify any legacy contaminated soils or sites which might be unknown but active sources of loading to the groundwater.

8.6 Public Participation

GEPA made the TMDL available for public comment for 30 days from March 15, 2024 to April 15, 2024 on GEPA's website and social media platforms.

9 References

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Appendix A: Source Loading Model

As discussed in Section 3, the underlying geology of Guam's Northern watershed is largely composed of highly porous limestone. Drainage of precipitation falling on the northern half of the island occurs almost entirely through the subsurface. Sub-surface flow to Tumon Bay occurs primarily through the Yigo-Tumon basin (30 square miles; 19,369 acres), with the Hagåtña basin influencing the southernmost portion of Tumon Bay (23 square miles; 14,514 acres). Basement drainages are shown as color coded basins in Figure A-1.

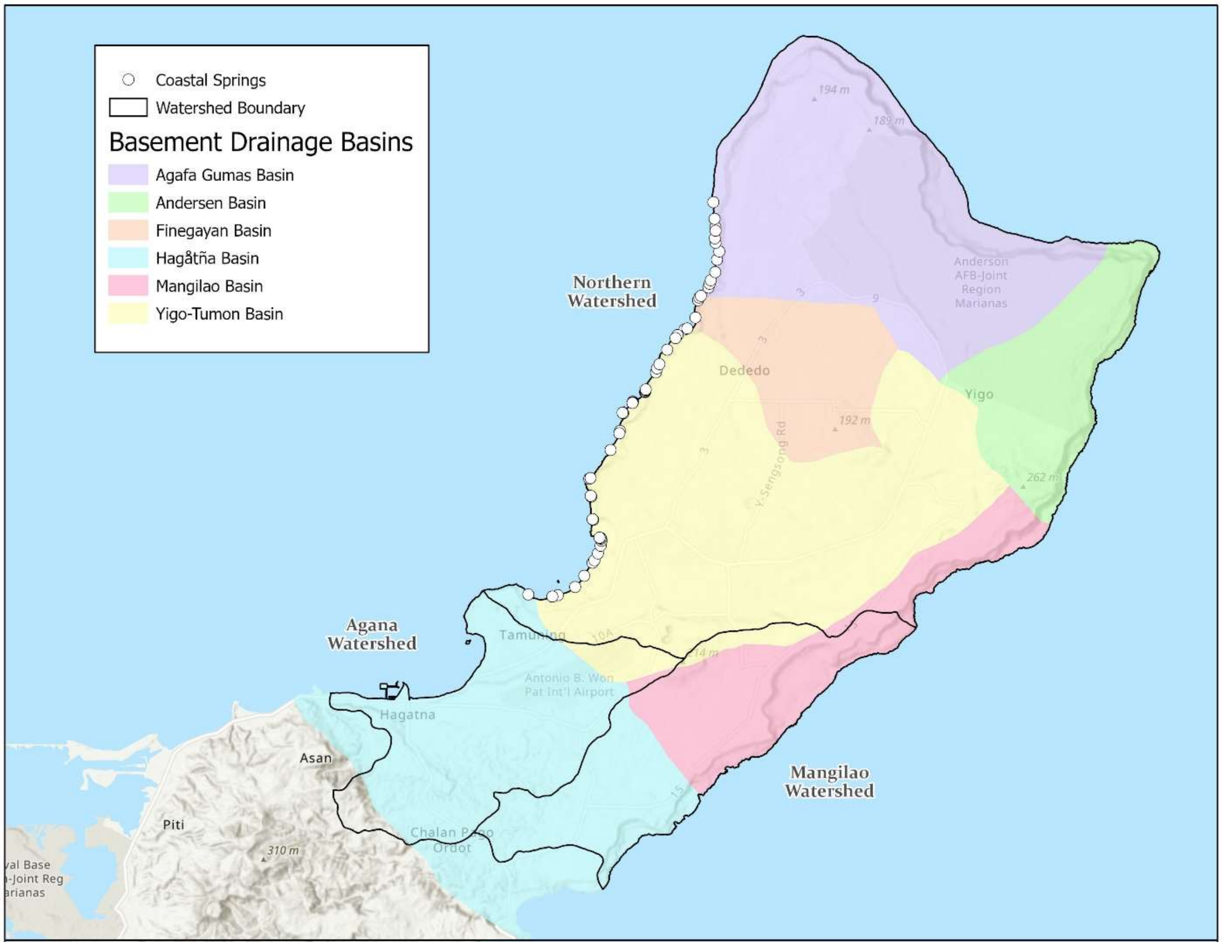

Figure A-1. Northern region surface and sub-surface drainage basins.

Pollutant loading in Tumon Bay is driven by the infiltration of pollutants in stormwater to the subsurface. Polluted stormwater travels through the NGLA subsurface, the Yigo-Tumon and Hagåtña Basement drainage systems specifically, and discharges via seeps and springs to the waterbody.

Watershed Flow Model

The watershed flow model is based on quantifying the flows and loading attributable to precipitation that falls on land within the watershed, percolates into the underlying aquifer, and migrates downgradient before being emitted from the seeps at Tumon Bay. Several researchers have attempted to quantify the rate of coastal seep and spring discharge in northern Guam using (1) mass balance models, and (2) field measurements. In general, the mass balance approaches take the form of treating the NGLA as a control volume. Equation A-1 describes the mass balance on the NGLA control volume.

$$Precipitation\ + Incidental\ Inflow - Evapotranspiration = Recharge \qquad \text{(A-1)}$$

Where,

Precipitation =	Volume of water falling within the watershed due to precipitation.
Evapotranspiration =	Volume of water lost to the atmosphere due to evapotranspiration.
Incidental Inflow =	Volume of inflow to NGLA arising from non-precipitation sources, like pipe leakage and septic systems.
Recharge =	Volume of water which is withdrawn from the system for drinking water and irrigation, plus discharges to the ocean from coastal springs and seeps.

Equation A-2 states that NGLA Recharge is composed of withdrawals for drinking water and irrigation, and discharge to the ocean from coastal springs and seeps.

$$Recharge = Withdrawals + Coastal\ Discharges \qquad \text{(A-2)}$$

Gingerich (2013) estimated that total water withdrawals from the NGLA were approximately 42 million gallons per day (MGD) in 2010. PG utilized this value when estimating coastal discharge rates at Tumon Bay.

While the volume of coastal discharges is difficult to measure directly (though, see below for a review of the best available field measurements), researchers have modeled estimates based on directly measuring all other quantities (i.e., precipitation, evapotranspiration, incidental inflows, and freshwater withdrawals) and assuming the remainder was discharged to coastal waters. This approach is valid for long averaging periods (i.e., at the scale of years or longer) when the size of the NGLA is approximately at steady state. Dougher, et al. (2019), when researching recharge rates for the Yigo-Tumon basin observed that the fraction of precipitation which went to recharge reached the water table quickly (i.e., on the order of months) and the rate of recharge could be related to seasonal rainfall patterns on an annual average timescale as shown in Equation A-3.

$$R_R = Recharge/Precipitation \qquad \text{(A-3)}$$

Where,

R_R = Recharge Ratio

Table A-1 summarizes a variety of estimates of recharge as a fraction of precipitation which have been made since the late 1970s. The available estimates of the recharge ratio varied from 45%-65%.

Table A-1. Estimates of Annual Average Groundwater Recharge as a Fraction of Rainfall

Annual Recharge (Percent of Annual Rainfall)	Source	Comment
45% (Yigo-Tumon Basin)	[1]	Empirical recharge ratio estimates derived from monitoring sites located in the Yigo-Tumon basin using data from 2008-2012.
50.6% (Northern Aquifer)	[2]	Average baseline modeled estimate using precipitation data for 1961-2005, and 2004 land cover data. Differs from other estimates in that it incorporates canopy evaporation. The author also estimated recharge during the 5 years of record with the lowest rainfall totals. Also estimated a drought condition recharge ratio value (44%).
55% (Vicinity of Guam Int'l Airport)	[2]	Empirical estimate derived from chlorine mass balance using weather station and well samples for 2010 in the vicinity of the airport.
57% (Most of Northern Guam)	[3]	Most probable estimate of recharge using 1957-1970 rainfall data.
63% (Northern Aquifer)	[4]	Modeled estimate.
60% (Northern Aquifer)	[5]	Most probable value estimate derived from simulation using precipitation and well head data dating to 1984-1988.
65% (Yigo-Tumon and Finegayan basins)	[6]	Average value based on 14-year simulation period (1982-1995). The authors further developed a regression model of recharge (R, in cm/month) as a function of total monthly precipitation (P, in cm/month) following the relationship: $R = \max(0, -4.24 + 0.87P)$
58% (Yigo-Tumon and Mangilao basins)	[7]	Average estimate based on 14-year simulation period (1982-1995). This model is updated version of the model described in [6].

1. Spellman, et al. (2022).
2. Johnson (2012)
3. Mink (1976)
4. Camp, Dresser, and McKee (1982)
5. Mink (1991)
6. Jockson, et al. (2002)
7. Habana, et al. (2009)

PG selected the 50.6% recharge estimate from Johnson (2012) in this analysis since this modeled estimate fell within the range of the two empirical estimates (see Spellman, et al., 2022; and Johnson,

2012) and this modeled result incorporated more complete estimates of evapotranspiration. In addition, it incorporated inflows from minor sources like septic systems resulting in a more complete water budget than in other modeled estimates. Finally, this model was constructed on an annual timestep whereas other modeling efforts were developed on shorter averaging timesteps (daily or monthly) which are less suited to characterizing long term average loadings to Tumon Bay.

Combining Equations A-2 and A-3 allows one to estimate the volumetric rate of aquifer water reaching the ocean:

$$Coastal\ Discharge = 0.506 \times Precipitation - \ Withdrawals \qquad \text{(A-4)}$$

Typically, precipitation data are reported as depth rates, which can be converted to a volumetric rate by multiplying the annual precipitation total by the watershed area over which the precipitation fell.

Several researchers have attempted to estimate the coastal discharge rate to Tumon Bay via either modeled estimates or by direct measurement. Jocson, et al. (1999) developed empirical estimates of the Tumon Bay coastal discharge rate and reported values ranging from 5-9 MGD/mile of coastline. Gingerich (2013) used a groundwater transport model, based partially on Johnson (2012), to estimate a 1961-2005 coastal average discharge rate of 163 MGD for the total NGLA, or 2.98 MGD/mile of coast. Gingerich's normalized discharge rate for portions of Tumon Bay ranged from 7.2 – 8.5 MGD/mile of coastline which generally agrees with Jocson's 1999 estimate.

As can be seen from Gingerich's estimate (2013), coastal discharges to Tumon Bay are higher than for the rest of the northern portion of Guam. Gingerich reported that Tumon Bay and Haputo Bay coast account for 37 percent of the coastal discharge volume, but only 14 percent of the coastline. Consistent, with this finding, PG assumed as an initial value that the Tumon Bay coastal discharge rate was approximately 2.6 times greater than the average coastline normalized rate for the NGLA. However, this parameter was used to calibrate model results to reproduce the 2010 Tumon Bay discharge range reported by Gingerich (i.e., 7.2-8.5 MGD/mile). The selected multiplier after watershed flow model calibration was a ratio of 3.0, resulting in a modeled 2010 Tumon Bay discharge rate of 8.0 MGD/mile. The 2010 discharge rate was used for calibration because it was the year with the most recent available estimate withdrawals from the aquifer and was the year for which Gingerich (2013) estimated coastal discharge rates.

The Tumon Bay coastal discharge rate is estimated by multiplying the result of Equation A-4 by the ratio of the Tumon Bay coastline (6,020 meters) to the northern Guam coastline (approximately 87,900 meters) and dividing by 365 days per year, and applying the 3.0 multiplier:

$$Discharge\ (Tumon\ Bay) = Discharge\ (Northern\ Guam)\frac{6{,}020 \times 3.0}{87{,}912\ \times 365}$$

Using calendar year annual total precipitation data collected at the Guam International Airport from 1980-2021, PG estimated the mean coastal discharge to Tumon Bay for the period was 41.9 MGD (95% confidence interval of 39.0 – 44.7 MGD). Normalized to unit of coastline, this is an average of 11.2 MGD/mile of coastline. The 2013-2022 average was 42 MGD. The estimate for the entire NGLA was a coastal discharge rate of 74,000 MGD, or 3.7 MGD/mile of coastline. Figure A-2 displays the annual time series of estimated Tumon Bay coastal discharge rates.

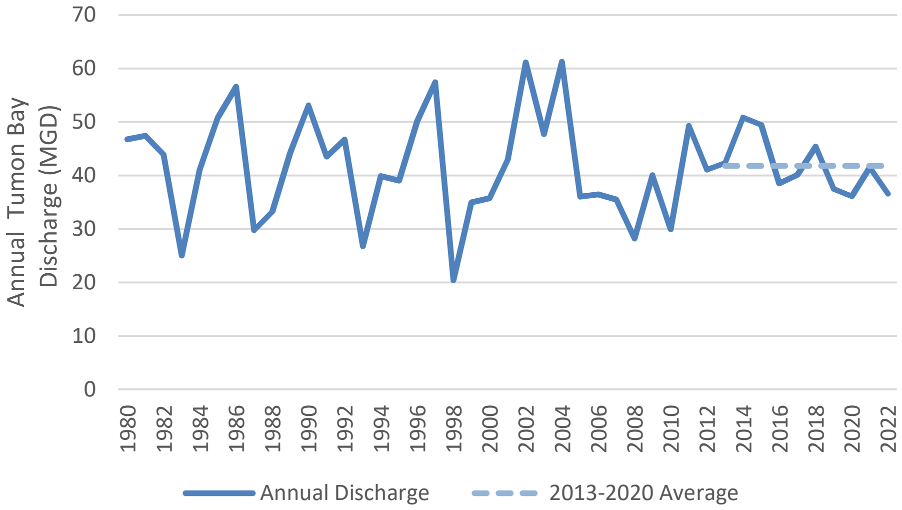

Figure A-2. Modeled Annual Tumon Bay Discharge Rate (1980-2021).

Watershed Pollutant Loading

Chlordane and Dieldrin

Chlordane and dieldrin have been banned for all commercial uses by EPA for several decades. While these pollutants have been observed in drinking water wells in Northern Guam for over a decade (Denton and Sian-Denton, 2010), there are no currently known sources of the pollutants to control or regulate. It is possible homeowners within the watershed possess and continue to use legacy stocks of pesticides containing chlordane or dieldrin; however, this use is likely to be limited and dwindling since these products are no longer being manufactured in the United States.

The sources of chlordane and dieldrin detected in coastal spring discharges are most likely to be legacy sources that are slowly migrating through the subsurface. Denton and Sian-Denton (2010) report that chlordane was detected in 30 drinking water wells in northern Guam prior to 2001 and in an additional 34 wells (58 total) between 2002-2007. Provided no new sources are introduced to the watershed, the sources of chlordane and dieldrin will migrate out of the subsurface over time and be removed from surface waters through marine sediment burial (i.e., natural attenuation processes). As these sediments are buried, the pollutants will become inaccessible to organisms and prevented from entering the local food web.

As there are no known active sources of chlordane or dieldrin within the watershed, PG modeled freshwater coastal discharge loading of chlordane and dieldrin using observed annual average coastal spring concentration measurements. PG computed loads using modeled coastal discharge rates for Tumon Bay, and the 2020-2022 average chlordane (0.095 µg/L) and dieldrin (0.021 µg/L) concentrations from freshwater springs discharging to the waterbody.

Watershed Pollutant Loading Summary

PG estimated loading average annual loadings for chlordane and dieldrin as shown in Table A-3.

Table A-3. Loading from Watershed Sources to Tumon Bay

Parameter	Average Discharge Rate to Tumon Bay[1]	Existing Pollutant Loading Rate[1]
Chlordane	42 MGD	15 g/day
Dieldrin		3.9 g/day

1. Average annual value based on the period 2013-2022.

NPDES Wastewater Treatment Plant Pollutant Loading

As discussed in Section 6.2, two NPDES permitted WWTPs discharging to the Philippines Sea are believed to be potential sources due to potential for coastal current patterns to drive discharge plumes from the WWTPs' ocean outfalls into Tumon Bay. PG reviewed discharge monitoring and reporting (DMR) data for the period 2020-2022 for the two WWTPs (Table A-4). Chlordane and dieldrin were non-detects.

Table A-4. Loading from Watershed Sources to Tumon Bay

Wastewater Treatment Plant	Design Flow Rate (MGD)	Average Observed Flow Rate (MGD)	Pollutant	Max Effluent Concentration (µg/L)[1]	Average Load[2] (g/day)
Northern District WWTP, GU0020141	12	5.16	Chlordane	Non-Detect	0
			Dieldrin	Non-Detect	0
Agaña/Hagåtña WWTP, GU0020087	12	4.65	Chlordane	Non-Detect	0
			Dieldrin	Non-Detect	0

1. Three sampling events for the 2020-2022 reporting period. Method detection limits/reporting limits were not reported for non-detect samples.
2. Computed from average flow rate and max effluent concentration.

Since chlordane and dieldrin were not detected in the discharge from either plant and not expected to be present otherwise, PG assumed neither plant is a potential source for these pollutants.

Atmospheric Deposition Pollutant Loading

PG assumed atmospheric deposition was not a source for chlordane and dieldrin.

Loading from Marine Sediments

PG utilized sediment quality data from Tumon Bay marine sediments (see Section 5.4) to determine if marine sediments were likely sources of loading to the water column. Table A-54 summarizes sediment concentrations for chlordane and dieldrin.

Table A-5. Tumon Bay Sediment Quality Data

Parameter	Units	2022 Mean Concentration
Chlordane	µg/kg	0.266
Dieldrin	µg/kg	0.0675

Chlordane and dieldrin are both very hydrophobic and desorb from sediments very slowly. These parameters are typically ingested by organisms or sorbed onto organic material and are deposited in the sediment through elimination or death of the organism. The pollutant is then partitioned between sediment-bound organic material and pore water within the sediments (EPA, 2003). PG estimated equilibrium partitioning behavior between sediment and water column compartments based on the following equation:

$$C_w = \frac{C_s}{f_{oc}K_{oc}}$$

Where,

C_w = Water column pollutant concentration (µg/L)

C_s = Sediment pollutant concentration (µg/kg)

f_{oc} = Fractional organic carbon content of the sediment (unitless)

K_{oc} = Organic carbon water partitioning coefficient.

Table A-6 describes the equilibrium water column concentrations predicted by the model.

Table A-6. Equilibrium Sediment-Water Column Partitioning

Value	Chlordane	Dieldrin
f_{oc}	0.6%[1]	
Log K_{oc} (L/kg)	4.64[2]	5.28[3]
Sediment Conc. (µg/kg)	0.266	0.0675
Equilibrium Water Conc. (µg/L)	0.0010	0.000059
WQC (µg/L)	0.0022	0.00014
2020-2022 Water Conc. (µg/L)	0.053	0.00275

1. Derived from values reported in Denton, *et al.*, 1997.
2. ASTDR, 2018
3. EPA, 2003

Predicted water column concentrations at equilibrium are well below both the applicable WQC and existing observed data for the waterbody. This suggests that marine sediments in Tumon Bay are unlikely to be net exporting chlordane and dieldrin into the water column. Therefore, PG has conservatively assumed no net transport of chlordane and dieldrin loads between the water column and marine sediments.

Appendix B: Water Quality Model

Tidal Prism Model Background and Setup

In this analysis, Tumon Bay's water quality response to pollutant loading is modeled using a tidal prism approach. Tumon Bay acts as a "bathtub" for marine water entering the waterbody from the Philippine Sea and fresh water entering Tumon Bay via coastal springs. The concept behind the tidal prism model is to determine the volume of water in Tumon Bay between the average high and low tides. Determining how much water routinely remains in the Bay allows for pollutant concentrations and their residence time to be determined via a mass balance approach.

The basic equation for the tidal prism model is the flow balance below:

$$\frac{dV}{dT} = (Q_0 - Q_b + Q_f)$$

Q_0 = Amount of water entering the bay on the flood tide that did not enter on the previous ebb tide (m^3/T)

Q_b = Amount of water leaving the bay on the ebb tide that did not enter the bay on the previous flood tide (m^3/T)

Q_f = Amount freshwater input during the tidal cycle (m^3/T)

V = Volume of the bay (m^3)

T = Average tidal period (T)

The flow balance is reformulated as a mass balance through the inclusion of pollutant concentrations entering the bay (Equation B-1). The amount of water entering the bay from the ocean is multiplied by the concentration of pollutant entering the bay from the ocean boundary, C_0. The amount of water leaving the bay is multiplied by the total dissolved pollutant concentration in the bay after mixing, C. Finally, the freshwater input is replaced by pollutant loading from the coastal freshwater seeps, L_f,, atmospheric deposition, L_{atm}, and loading from marine sediments. Outflowing sources of mass include tidal outflow from the bay.

$$\frac{dVC}{dT} = \left(Q_0C_0 - Q_bC + L_f + L_{atm} + L_s\right) \tag{B-1}$$

Where,

C_0 = Concentration of pollutant that enters the bay on the flood tide through the ocean boundary (mg/L)

C = Dissolved pollutant concentration within the bay water quality segment after mixing (mg/L)

L_f = Loading from freshwater seeps (g/T)

L_{atm} = Loading from atmospheric deposition (g/T).

L_s = Net loading/losses from the sediment compartment due to adsorption to settling particulate matter containing sorbed pollutant materials, precipitation of polllutant, or direct sorption to sediments (g/T).

T = Average tidal period of the waterbody (T/day)

At steady-state the mass balance equation can be simplified to Equation B-2.

$$Q_b C = Q_0 C_0 + L_f + L_{atm} + L_s \qquad \text{(B-2)}$$

As discussed in Appendix A, marine sediments are likely to serve as sinks for the parameters of interest rather than sources. Therefore, PG assumes conservatively assumes no loading to or from the sediment compartment ($L_s = 0$).

To solve for concentration of the pollutants, the equation is rearranged into the following:

$$C = \frac{Q_0 C_0 + L_f + L_{atm}}{Q_b} \qquad \text{(B-3)}$$

The average tidal period for the semidiurnal tidal pattern of Tumon Bay was determined to be 12.25 hours. Tidal period data was not available for Tumon Bay, therefore PG used tidal period collected at Apra Harbor (NOAA, 2022) to approximate the tidal period for Tumon Bay. To convert the daily (24 hour) pollutant load to the tidal averaging period, the daily load values were multiplied by the ratio of the average tidal time periods.

$$\mathrm{L}_f = Load_{daily} * \frac{12.25\ hour/tidal\ period}{24\ hours/day} \qquad \text{(B-4)}$$

Depending on the sea floor elevation and the bay's geometry, the amount of water entering the bay per tidal period varies. Salinity data can be used as conservative tracer to calculate the exchange ratio (β), or the ratio seawater inflow to total flood tide flow into the tidal prism. The salinity of the ocean water entering the bay on the flood tide is expressed as S_f. The salinity of the bay water exiting the bay on the ebb tide is S_e. Finally, the salinity at ocean side is S_0:

$$\beta = \frac{S_f - S_e}{S_0 - S_e} \qquad \text{(B-5)}$$

The average salinity of seawater at ocean side, S_o, is approximately 34.4 parts per thousand (ppt) based on measurements from 2011-2022 extracted from NASA's Aquarius/SMAP sea surface salinity data set (Melnichenko, *et al.*, 2016). Sea surface salinity measurements were extracted from global raster data sets for the nearest (but not overlapping) ocean side pixel to Tumon Bay.

Values for S_f and S_e are typically challenging to measure, but Denton, et al. (2005) reported a body of salinity measurements at multiple locations 50 meters out into the surf on a daily basis at specified times. Using reported dates and times, PG was able to assign each set of measurements to either a flood tide or ebb tide. The resulting S_f and S_e values were 31.6 ppt and 30.7 ppt. This is a best available estimate but may be inaccurate since salinity measurements were taken relatively close to shore. Therefore, PG used the resulting exchange ratio (β = 0.239) as an initial estimate and adjusted the parameter during model calibration.

The exchange ratio is multiplied by Q_T, the volume of ocean water entering on the flood tide, to find Q_0, volume of ocean water entering the bay on the flood tide that did not enter on the previous ebb tide.

$$Q_0 = \beta Q_T \tag{B-6}$$

The flushing or residence time of Tumon Bay, T_L, may be calculated by the ratio of the volume of water entering and exiting the bay on the flood and ebb tides.

$$T_L = \frac{V}{Q_b} \tag{B-7}$$

The volume of Tumon Bay was estimated using coastal elevation data which extended into the bay (NOAA, 2020) and bathymetry data from the Pacific Island Benthic Habitat Mapping Center (2022). These two surface rasters were combined and then clipped to the extents of the water quality segment. This data covered the majority of the Bay, but a small portion was missing (approximately 2% of the total bay). Sea floor depths were estimated for this missing portion by interpolation of the surrounding areas. A volume was then derived from the data set using ArcGIS Pro 3D analyst tools. In addition, this dataset was combined with the Apra Harbor title measurements (NOAA, 2022) to estimate the total average flood tide flow (Q_T) to the waterbody.

The hydrologic parameters of the Tidal Prism Model are reported in the following table.

Table B-1. Tidal Prism Hydrologic Model Parameters

Parameter	Name	Unit	Value
V	Volume of Bay	m^3	3.39×10^8
A	Area of the Bay	m^2	5.13×10^6
T	Tidal Period	Day/T	0.51
β	Exchange Ratio	Unitless	0.239 (initial) 0.130 (after calibration)
Q_T	Total Flood Tide Flow	m^3/tide-period	1.93×10^7
Q_o	"New" Flood Tide Flow	m^3/day	2.51×10^6
Q_b	Ebb Tide Flow	m^3/day	2.82×10^6
Q_f	Freshwater Discharge from Coastal Springs	m^3/day	3.10×10^5

Model Calibration

The water quality model was calibrated using water column monitoring data collected from 2020-2022 for the parameters of interest. The tidal exchange capacity (β) was initialized at the value calculated based on Tumon Bay salinity data (i.e., 0.239) and then adjusted. Model fit was evaluated based on the percent difference between observed and predicted annual water column concentrations for dieldrin. Chlordane was not used for calibration as only one detected measurement was available for the period of interest—all other values were non-detects with method detection limits which exceeded the applicable WQC.

Level of fit was evaluated through an examination of plots and by calculation of percent difference between observed and predicted annual concentrations. Model fit for dieldrin was poor (Figure B-1) with a relative percent difference of -83% (2020), -44% (2021), and -28% (2022). However, this may be due to characteristics of the observed dieldrin data—roughly one-third of the data points collected over the period of interest were non-detect results with method detection limits above the applicable WQC and therefore not used in model development. These non-detect values were not included in observed annual average calculations and this may result in an overestimate of water quality concentrations. When comparing the predicted concentrations to the range (minimum to maximum) of measurements for each year, the predicted concentrations overlap the observed range of dieldrin measurements. Given the limited nature and quantity of dieldrin data available for calibration, this indicates that model predictions are reasonably approximating water quality.

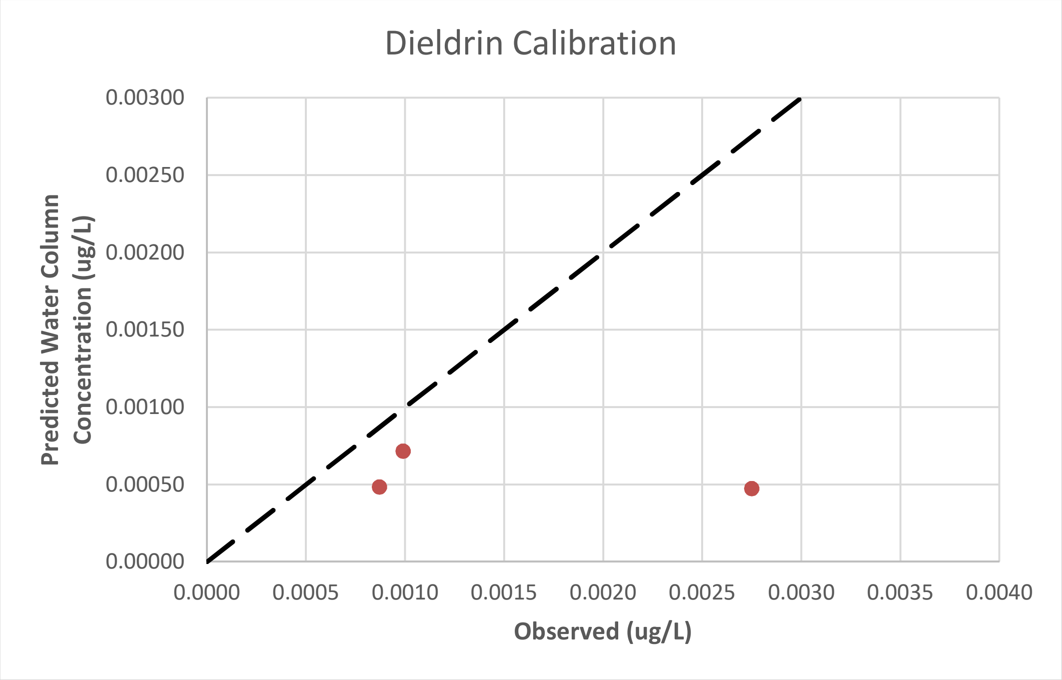

Figure B-1. Dieldrin Calibration Results. Dashed line indicates 1:1 fit between observations and predictions.

Model Loading Capacity Results

From Equation B-3, and letting C_c reflect the WQC for each parameter, the loading capacity of the waterbody may be estimated based on the following.

$$Load = C_c Q_b - Q_o C_o \quad \text{(B-8)}$$

Table B-2 summarizes the loading capacity results for the waterbody and the total existing loads to the waterbody from all sources.

Table B-2. Tumon Bay Loading Capacity

Parameter	Chlordane	Dieldrin
C_c (µg/L)	0.0022	0.00014
C_o (µg/L)	0	0
Loading Capacity	12 g/day	0.77 g/day
Existing Load	15 g/day	3.4 g/day