APPENDIX C. POLLUTANT LOAD MODELING

One element of EPA's watershed planning criteria is to estimate existing and future watershed pollutant loads to help prioritize management actions. To this end, we used the Watershed Treatment Model (WTM), Version 3.0 (Caraco, 2013)--a public-domain, Microsoft Excel-based spreadsheet model used to estimate annual watershed pollutant loads. The WTM was used to broadly evaluate sediment and nutrient loads in the Geus and the Manell watersheds and load reductions from potential restoration efforts.

The model relies principally on annual rainfall and land use-based pollutant runoff concentrations to estimate annual loads and runoff volumes. Secondary pollutant sources, such as wastewater systems, marinas, channel erosion, and livestock, can be added. In addition, the WTM can estimate future loads based on land use changes and structural and non-structural treatment measures (i.e., stormwater management practices, stream buffers, regulatory and educational programs, wastewater improvements, street sweeping). Readily available GIS data are used to generate much of the input data. Field observations on pollutant sources, stream characteristics, and other watershed conditions can be used to adjust model input variables. Unless the user inputs watershed-specific data, the WTM uses default values derived from US national averages. The WTM offers a lot of flexibility to accommodate better data as it becomes available, but also provides a comprehensive framework that is best suited for big picture watershed planning purposes.

INPUTS AND ASSUMPTIONS

Table 1 summarizes primary and secondary input data used for the model, including land cover, rainfall, soils, and other parameters. These can (and should) be adjusted as more information is collected, particularly if more accurate numerical loads are desired. The model inputs are based on a combination of available mapping information, literature values, and our observations of watershed conditions. It should be noted that:

- The Geus watershed model includes both the Pigua and Geus subwatersheds. The Manell watershed model includes the Quinene, Nelansa-Manell, Suyafe, Sumay, Liyog, Asgado, Tainatongo, Ajayan, and several direct drainage subwatersheds.

- The values for pollutant concentrations in runoff and loading rates by land cover type are summarized in **Table 2**. Sediment loss/yield and erosion rates from badlands and grasslands were derived from previous modeling and empirical studies from southern Guam (**Table 3**) and range by orders of magnitude depending on the watershed and methods of each study (4,200 to 486,000 lbs/acre/yr for bare lands, for example).

- Not all input parameters were fully vetted during field investigations and some of the GIS data used may not reflect current conditions (e.g., active construction, burned areas). No inputs were included for channel erosion, wild pigs and livestock, illicit discharge (i.e., wastewater hookups to storm drains), or erosion control programs for construction sites, for example.

- No model calibration or validation was conducted against water quality data, although TSS loads were compared to other modeling studies (i.e., N-SPECT, RUSLE) for the Geus watershed.

- Stream erosion is not well accounted for in the model, and it was assumed that 25% of the sediment load comes from stream erosion.

- The model does not account for routing, attenuation, or subsurface flows in the watershed, but loads to groundwater from infiltration BMPs and septic systems are reported separately from surface waters.

- Restoration scenarios are summarized in **Table 4** and include hooking up remaining onsite septic systems to sewer (pumped to Umatac-Merizo Wastewater Treatment Plant), implementation of stormwater retrofits (mostly concentrated in the Pigua and Geus subwatersheds, see **Table 5**), and widespread revegetation of badlands.

Table 1. Input Data Used to Estimate Existing Loads

Input Parameter	WTM Input Values		Description
	Geus	**Manell**	
Avg annual rainfall (inches)	100	96	Ranges from 80 on coast to 110 in headwaters. Used values in Table 10 from Forest Action Plan (2021)
Watershed Area (acres)	1102	2973	HW update to WERI-provided boundary
Land Use & impervious cover	See **Table 2.**		Derived from NOAA CCAP 2016 data, where developed area is a combination of residential, commercial, roads, etc. and is broken into impervious and developed open spaces.
Pollutant Event Mean Concentrations (EMCs) and Loading Rates	See **Table 3.**		TN and TSS only. Used average nutrient and sediment event mean concentrations across urban land in the WTM from NSQD. Sediment loading data for non-urban areas are based on erosion and sediment yield studies from southern Guam.
Hydrologic Soil Groups (% of watershed)	1% HSG B; 20% HSG C; 77% HSG D 2% null	1% HSG A; 1% HSG B; 26% HSG C; 72% HSG D	Based on NRCS mapping. The HSGs are used to estimate surface conditions for infiltration potential, with A soils generally having a high permeability rate (e.g., sandy soils) and D soils having a low permeability rate (e.g., clay soils).
Depth to Groundwater (% of watershed)	12% <3 ft; 4% 3-5f; 84% >5 ft	20% <3 ft; 6% 3-5ft; 74% >5 ft	Based on NRCS soil mapping (depth to groundwater estimates) plus an adjustment of 4% for transition zone.
Stream length (miles)	4.2	15.7	NHD
# of buildings (dwellings)	204	220	From buildings layer (WERI 2021)
Sanitary Sewer Overflows (pipe network miles and #overflows)	4.74	2.53	Some of the watershed is sewered. Length of sewer lines are from GWA dataset.
	# SSOs: 0.14 per mile		WTM default assume 140 sewer overflows per 1,000 miles.
Onsite Disposal Systems	57	150	OSDS counts are estimated from # of parcels with buildings that did not have a lateral connections (GWA).
	30% within 100' of stream		We assumed <u>all</u> OSDS are conventional design (i.e., not enhanced for nutrient removal) with default influent/effluent concentrations, removal efficiencies, and failure rates from WTM
	30% failure rate		
Stream Channel Erosion	Low. 25% of total sediment load		Not based on any field data. Selected default method 1 in the model that back calculates a % for channel erosion based on total sediment load and miles of stream.
Structural stormwater BMPs (post-construction)	none	none	No existing BMPs identified
Riparian Buffers (50 ft)	4.1 out of 4.2 miles	15.5 out of 15.7 miles	NHD Rivers, 50-ft Buffer intersected with NOAA C-CAP 2016 (reclassified as developed vs undeveloped)

Does not include illicit discharges, livestock, or erosion control for construction sites

Table 2. Applied pollutant values for each land cover category

Category	Acres*		Event Mean Concentration or Annual Load		
	Geus	Manell	TN*	TSS	Data Source
Developed	98.9 (52% IC)	93.2 (51% IC)	1.9 mg/L	58 mg/L	National Stormwater Quality Database (v 1.0) overall value average across urban land use categories.
Agricultural	0.3	18.9	4.6 lbs/ac	100 lbs/ac	WTM default TN and TSS
Forest	508.3	953.5	2.5 lbs/ac	100 lbs/ac	WTM default TN and TSS
Scrub/Shrub	93.9	185.5	2.5 lbs/ac	600 lbs/ac	WTM default for TN; 1/3 grassland TSS from Scheman 2002
Grassland	304.5	1,311.3	2.5 lbs/ac	1840 lbs/ac	WTM default for TN; TSS from Scheman 2002
Barren	37.5	216.7	2.5 lbs/ac	33,560 lbs/ac	WTM default for TN; TSS from Khosrowpanah et al., 2015
Wetland	58.5	193.5	12.8 lbs/ac	155 lbs/ac	WTM default TN and TSS
Total	1101.8	2972.7			

*Land cover derived from NOAA CCAP 2016 data

Table 3. Modeled and empirical erosion rates estimated from various Guam watershed studies

Source	Location	Sedimentation Data	Badland erosion annual rates (lbs/acre/yr)
NRCS 1996	Ugum watershed	243 tons/acre/year in sediment yield. Results from the assessment were determined using the Universal Soil Loss Equation.	486,000 lbs/acre
Lewis, 1997	Taelayag River watershed	Completed during a single wet season, the total rainfall accumulation for the period of the study was only 52.9 in (134.4 cm). The results estimated approximate sediment yield for badland erosion at 2.1 to 9.5 tons/acre/year, 96% less than the results published by the NRCS for both the Ugum and Fena watershed reports.	4,200-19,000 lbs/acre
Scheman 2002*	Umatac, La Sa Fua watershed	Determined by the RUSLE model and empirically derived LS averages. Badlands across the steepest slopes contribute an average of 65.90 tons/acre/year in soil yield, as opposed to the 225.92 tons/acre/year calculated from the Revised Universal Soil Loss Equation (RUSLE). Badlands from the lower lying, less steep areas averaged 13.70 tons/acre/year. Grasslands 1.49 tons/acre/year from RUSLE, but applying the measured LS-factors averaged between 0.16 and 0.92 tons/acre/year.	Badlands: 27,400-133,800 lbs/acre (451,800 lbs/acre from RUSLE) Grasslands: 320-1,840 lbs/acre (2,980 lbs/acre RUSLE)
Golabi 2005*	Southern Guam	Natural savanna (5.22 tons/hectare/year); vetiver plot (1.47 tons/hectare/year); controlled burn (14.13 tons/hectare/year); bare soil (104.75 tons/hectare/year)	4,200 lbs/acre savannah 1,200 lbs/acre vetiver 28,260 lbs/acre burned 84,800 lbs/acre bare soil
FSRD 2010	Geus annual erosion and delivery	7.9 tons/acre/year using N-SPECT. The result is an estimate of average annual sediment erosion and delivery to streams from surface and rill erosion,	158,000 lbs/acre

Source	Location	Sedimentation Data	Badland erosion annual rates (lbs/acre/yr)
		but not mass wasting, gully, or stream bank erosion.	
Manibusan 2012, Khosrowpanah et al 2012, FSRD, 2010, Minton 2006*	Piti-Asan watersheds	GIS-based erosion model estimated 8.05 tons/acres/year in the Asan Watershed, and 5.15 tons/acre/year from the Piti Watershed (combined average of 6.6 tons/acre/year). Actual sediment accumulation measured on the Piti-Asan reef, estimated watershed contribution of 6.7 tons/acre/year. An N-SPECT model, estimated 6.8 tons/acre/year of sediment is yield.	13,200 lbs/acre combined average
Khosrowpanah et al., 2015	Geus	The mean annual rate of soil loss for the entire watershed is an estimated 16.78 tons/acre/year, with a standard deviation of 26.77 tons/acre/year. The range of estimated annual soil erosion potential (maximum of 1,141.56 tons/acre/year) is	Mean 33,560 lbs/acre Max 2,283,120 lbs/acre
Guam Forest Action Plan 2021	Watershed Sediment yields	Manell: 63,147 average tons/year. Geus: 8,822 average tons/yr (based on 225.92 tons/acre/yr from RUSLE)	(based on 451,800 lbs/ac) 130,000,000 lbs/yr 18,000,000 lbs/yr

*Empirical studies; Shaded values were selected for the WTM

Table 4. Future management measures applied

Input Parameter	Geus	Manell
Expanded sewer	• 100% hook up to WWTP • 0.2 miles of additional sewer line	• 100% hook up to WWTP • 3 miles of additional sewer line
Badland Restoration	Revegetation 100% of badlands (37.4 acres): convert 10 acres to forest, 17.4 acres to shrub/scrub, and 10 acres to grassland	Revegetation 25% of badlands (54 acres): convert 18 acres to forest, 18 acres to shrub/scrub, and 18 acres to grassland.
Stormwater retrofits (See **Table 6**)	• 14.5 additional acres managed (6.27 impervious acres) assumed 100% capture rate for target volume (0.80 inch). The Pigua subwatershed has 13% of its drainage area managed with retrofits. • low maintenance	0.3 additional acres managed (60% impervious)

Stream restoration, buffer enhancement, septic system upgrades, or educational or regulatory programs were not included in restoration scenarios.

Table 5. Future stormwater management practices (retrofits) modeled

Stormwater BMP		Watershed	Acres		Removal Rates*	
			DA	Impervious	Nitrogen	Sediment
R-8	Road Stabilization/Permeable Pavers	Geus	0.18	0.18	60%	80%
R-9	Road Stabilization//Permeable Pavers	Geus	0.14	0.14		
R-11	Bioretention	Manell	0.3	0.18	65%	85%
R-13	Bioretention	Geus	1.24	0.36		
R-18	Bioretention	Geus	0.17	0.15		
R-19	Bioretention	Geus	1.88	0.34		
R-20	Bioretention	Geus	2.4	0.9		
R-21	Bioretention	Geus	0.95	0.58		
R-14	Constructed Wetland	Geus	7.67	1.82	25%	75%

*Standard pollutant removal rates in WTM

RESULTS

While the WTM can be used to generate qualitative pollutant loads, it is better for comparing relative contributions between watersheds and management scenarios. A preliminary estimate of existing and future pollutant loads was run based on an initial assessment of conditions and restoration opportunities. For the purposes of this report, it is the relative change in value between existing and future conditions, all data input assumptions being equal, that is the most relevant. Determining the full, optimal extent of management actions required to meet a reduction target is an iterative process; however, we modeled only one set of potential future management activities: aggressive badland restoration, sewer hookup in all areas currently relying on onsite wastewater systems, and implementation of stormwater retrofits. Stream restoration, wetland and floodplain enhancements, and non-structural measures (resident education, street sweeping, construction oversight, etc.) were not accounted for in the restoration scenarios.

Under the restoration scenario, the model predicted 6% and 4% reductions in total nitrogen and 47% and 14% reductions in total suspended solids in the Geus and Manell watersheds, respectively. Nitrogen was identified as a water quality issue by (Houk et al., 2022), reporting that the Manell subwatershed had high dissolved inorganic nitrogen levels corresponding with rainfall. The Sumay subwatershed also had high levels, but was found not to be related to rainfall, suggesting some kind of point source (or perhaps groundwater discharge). The Geus subwatershed had relatively low levels of DIN. The WTM model showed that the removal of conventional septic systems via sewer hookup and revegetation of badlands had the most significant impact on potential nitrogen reduction, but these restoration measures don't target atmospheric deposition or nitrogen derived from forested areas. While some reductions are achieved, stormwater practices are not as effective in removing soluble nitrogen as they are with other pollutants.

Sediment loads are primarily influenced by the rate of sediment loss (lbs/ac/yr) assigned to forested, grassed, and baren lands. The loading rates used in the WTM were selected from Scheman 2002 and Khosrowpanah et al., 2015, which resulted in total watershed yields for Geus and Manell at 2.6 million lbs/year (1303 tons/yr) and 12.9 million lbs/yr (6491 tons/yr), respectively. These total loads are significantly less than 8,822 and 63,147 average tons/year reported in the Guam Forest Action Plan (2021) for Geus and Manell, respectively, which were derived from much higher erosion rates.

The WTM model predicted a combined reduction of over 3 million lbs/yr in the Manell-Geus watershed-- primarily as a result of extensive badland restoration. A greater percentage of badlands in the Geus watershed was part of the restoration scenario than in Manell. Stream restoration, wetland and floodplain enhancements, and non-structural measures were not accounted for in the restoration scenarios. As such, stream channel erosion and surface erosion from forests and grasslands remain large contributors to watershed sediment loads.

To more accurately quantify loads, additional information would be needed on local concentrations of nitrogen from each land cover types, an estimate of nitrogen reserves in streams, and how groundwater contributions of soluble nitrogen impact the lagoon. Better input data on stream erosion rates and loads from vegetated slopes in these watersheds could be used to refine modeling in the future.

Table 6 summarizes model results for existing conditions and future restoration in Geus and Manell. Quantification of the numeric annual load, while useful, is highly dependent on specific data inputs. We don't recommend putting much stock in these numbers unless more refined input data can be obtained

and the model is calibrated with measurements from the water quality monitoring program. **Figure 1** shows the sources of watershed contributors of annual nitrogen and sediment in the Geus and Manell. **Tables 7** and **8** show how pollutant loads and potential load reductions are allocated across sources in each watershed.

Table 6. Summary of Potential Load Reductions to Surface Waters

Watershed	Scenario	Total Nitrogen (lbs/yr)	Total Suspended Solids (lbs/yr)	Runoff Volume (acre-feet/year)
Geus	existing	5,383	2,606,299	1,033
	w future restoration	5,082	1,375,932	1,024
	% reduction	**6%**	**47%**	**1%**
Manell	existing	11,474	12,982,576	2,593
	w future restoration	10,980	11,212,730	2,592
	% reduction	**4%**	**14%**	**0%**

Table 7. Loads to Surface Waters in the Geus Watershed

Source	Existing Loads		% Potential Load Reduction	
	TN (lbs/yr)	TSS (lbs/yr)	TN (%)	TSS (%)
Urban Land	2,064	67,233	4%	5%
Sewer System Overflows	30	199	100%	100%
Channel Erosion	-	605,980	--	0%
Forest	2,267	667,450	-4%	-4%
Rural Land	95	1,255,174	99%	100%
Septic Systems	179	1,196	100%	100%
Open Water	749	9,068	0%	0%
Total Storm Load	4,008	2,412,741	3%	46%
Total Non-Storm Load	1,375	193,557	14%	64%
Total Load to Surface Waters	**5,383**	**2,606,299**	**6%**	**47%**

Table 8. Loads to Surface Waters in the Manell Watershed

Source	Existing Loads		% Potential Load Reduction	
	TN lbs/year	TSS lbs/year	TN %	TSS %
Urban Land	1,757	56,456	1%	0
SSOs	16	106	100%	100%
Channel Erosion		2,999,107	0%	0%
Forest	6,126	2,619,442	-2%	-2%
Rural Land	629	7,274,342	21%	25%
Septic Systems	470	3,131	100%	100%
Open Water	2,477	29,993	0%	0%
Total Storm Load	7,619	11,990,013	0%	13%
Total Non-Storm Load	3,855	992,563	12%	18%
Total Load to Surface Waters	**11,474**	**12,982,576**	**4%**	**14%**

Geus Existing TSS Load Allocation

Open Water 0.3%
Urban Land 2.6%
Channel Erosion 23.3%
Rural Land 48.2%
Forest 25.6%

Geus Existing TN Load Allocation

Septic Systems 3.3%
Rural Land 1.8%
Open Water 13.9%
Urban Land 38.3%
Forest 42.1%
SSOs 0.6%
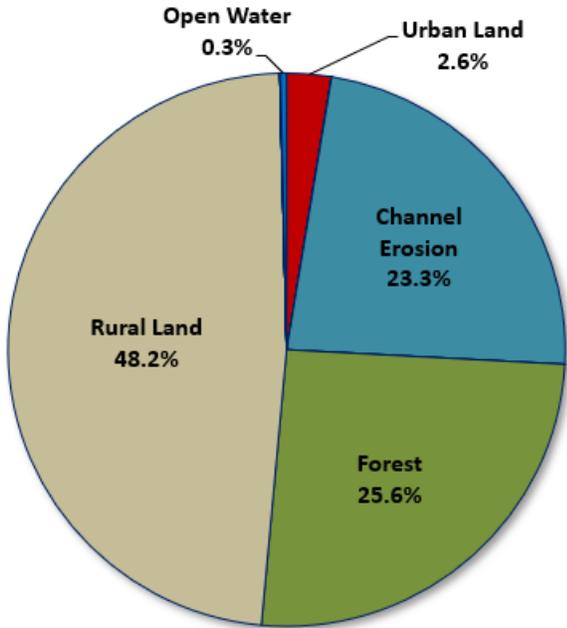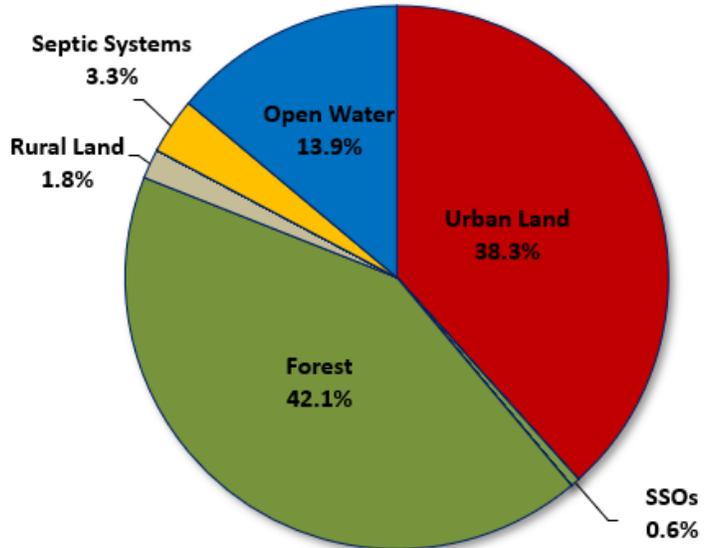
Manell Existing TSS Load Allocation

Open Water 0.2%
Urban Land 0.4%
Channel Erosion 23.1%
Rural Land 56.0%
Forest 20.2%
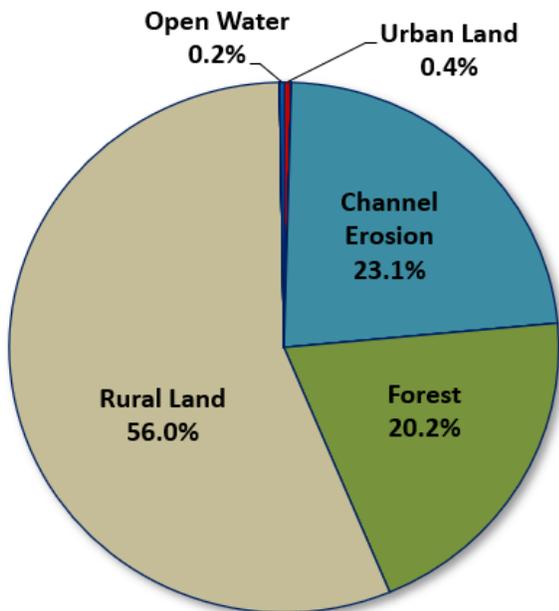
Manell Existing TN Load Allocation

Septic Systems 4.1%
Open Water 21.6%
Urban Land 15.3%
SSOs, 0.1%
Rural Land 5.5%
Forest 53.4%
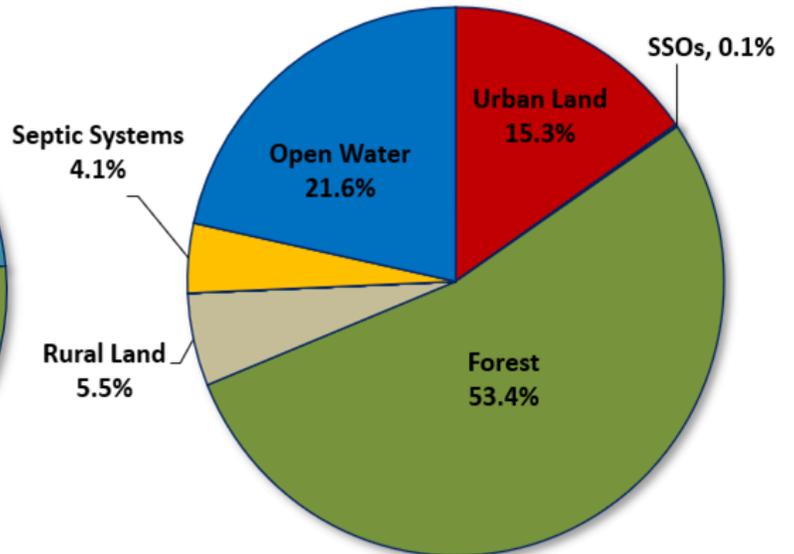
Figure 1. Sources of existing nitrogen and sediment loads to surface waters in the Geus and Manell watersheds