University of Hawaiʻi Water Resources Research Center
UNIVERSITY OF HAWAIʻI AT MĀNOA
Honolulu, Hawaiʻi 96822

The Known Water Quality Impacts of Agriculture in American Samoa

A review of existing water quality studies and data as they relate to agricultural impacts on coastal and inland waters

Christopher K. Shuler* and Michael Mezzacapo
Corresponding author: cshuler@hawaii.edu

This policy brief compiles and summarizes relevant findings on the impact of nutrients and agricultural chemicals to the territory's inland aquatic habitats and reefs.

Summary of Findings

THE STUDIES REVIEWED HERE SUGGEST SYNTHETIC FERTILIZERS ARE NOT A PREDOMINANT OR CONCERNING SOURCE OF NUTRIENTS TO THE ENVIRONMENT.

A majority of the studies reviewed in this policy brief found instances of moderately elevated levels of nutrient discharge (relative to control sites) to Tutuila's streams and coastal waters in inhabited areas. Nitrogen (N) levels in streams and groundwater **sometimes** exceed American Samoa's fresh surface water quality standards, and **infrequently** exceed the American Samoa coastal water quality standards (ASEPA, 2013). However, results from studies that applied source tracing methods clearly indicate **human wastewater from cesspools and poorly located septic tanks is the major source of nitrogen** to environmental waters. Manure from piggeries is often found to be the second most important source, whereas the impact from imported synthetic fertilizers has been found to be fairly low, on the same order of magnitude as natural levels of nitrogen discharge to pristine coastlines.

Other relevant findings:

- Glyphosate (Roundup®) has been detected in stream and groundwater samples in Fagaalu ,though in very small quantities, well below EPA Drinking Water Limits of 0.7 MCLG (mg/L).
- Other compounds and metals have been detected in stream waters, such as lead, mercury, cadmium, chromium, copper, nickel, chlordane, DDT, PCBs, and zinc. Some contaminants were found at elevated levels and may elicit cause for concern, though overall pollution is generally low.
- Relatively high-levels of phosphorus (P) in groundwater and streams discharging to the coast is likely from natural sources such as bird guano or weathering of basalt.
- A single fertilizer related algal bloom has been documented in the territory. This event was related to "aggressive" fertilization at the soccer field directly on the harbor, with fast draining soils and no runoff control.

About the Water Resources Research Center

The Water Resources Research Center (WRRC) is a research institute at the University of Hawai'i at Mānoa dedicated to promote understanding of critical state and regional (including the U.S. Affiliated Pacific Islands) water resource management and policy issues through applied research, community outreach, and public education.

WRRC has worked with agencies in American Samoa since 2013 to develop an integrated water resources research program to address territorial concerns. Multiple WRRC studies examining nutrient impacts have resulted in peer-reviewed journal articles and reports relating to the effects of nutrients in coastal and inland waters.

Indicators of Impact

Nitrogen Concentrations and Nitrogen Isotopes ($\delta^{15}N$) in Water and Biotic Samples are Key for Assessing the Sources of Nutrient Pollution and their Impacts on the Environment.

Nitrogen Concentrations: The amount of nitrogen contained in land-based and coastal waters directly affects the health of sensitive reef ecosystems. Excess nitrogen concentrations can cause reef smothering or toxic algal blooms. Nitrogen can come in different forms, typically waters are tested for total nitrogen (TN) or inorganic nitrogen, with the most common form being nitrate (NO_3^-). Water quality standards set by regulatory agencies provide baseline and comparative values for water quality tests. **The 2013 AS WQ standards have a TN limit for fresh surface waters of 0.3 mg/L** (median value) and for coastal waters in bays the limit is 0.15 mg/L TN (median). Hawai'i State Water Quality Standards (HAR Chapter 11-54) set limits in streamwater for TN at 0.25 mg/L and for NO_3^- at 0.07 mg/L. The U.S. EPA drinking water standard for NO_3^- is 10.0 mg/L.

Table 1: Concentrations of NO_3^- in coastal-draining streams and springs from studies conducted in American Samoa and in Hawaii, for context. Note: see concentration limits set in American Samoa and Hawaii Water Quality Standards are described at left. Note that in AS streams and groundwater, NO_3^- is often the main form of N in TN.

Data Source	Median NO_3^- (mg/L)	Average NO_3^- (mg/L)	Max NO_3^- (mg/L)	Number of samples	Type(s) of samples
Comeros-Raynal et al. (2020) (Tutuila)	0.05	0.09	1.33	466	Streams and coastal springs, islandwide
Shuler et al. (2019a) (Tutuila)	0.16	0.23	1.1	23	Streams, coastal springs, 4 sites
Shuler et al. (2019b) (Tutuila)	0.11	0.22	0.93	11	Streams and coastal springs, Fagaalu
Shuler et al. (2017) (Tutuila)	0.86	0.90	1.81	35	Wells, Tafuna-Leone
ASPA groundwater monitoring data (Nov 2008 to Oct 2019)					
Wells in Western Tutuila	0.65	0.65	1.50	19	Production Wells
Wells in Central Tutuila	0.15	0.16	0.61	91	Production Wells
Wells in Eastern Tutuila	0.17	0.17	0.36	80	Production Wells
Wells in Tafuna Leone Plain Region	0.90	0.91	2.10	292	Production Wells
Comparison to Hawaii studies					
*Bishop et al. (2016) (Maui, HI)**	-	*1.52*	*5.3*	*50*	*Coastal Springs, 6 different locations*
*Wiegner and Mead (2009), (Hilo, HI)**	-	*0.37*	*0.52*	*12*	*Wailoa river, Hilo Bay*

Nitrogen Isotopes: ^{15}N is a rare isotope of nitrogen (N), most of which is in the form of ^{14}N. The ratio between these two isotopes relates to the $\delta^{15}N$ value, and this value changes when N is produced by different sources. Specifically, manure and wastewater produce elevated $\delta^{15}N$ values between 5‰ and 25‰ and synthetic fertilizers produce $\delta^{15}N$ values centered around 0‰ (Figure 1). Natural processes in soils produce N with $\delta^{15}N$ values between 4‰ and 6‰. Therefore when water or biologic samples show high $\delta^{15}N$ values (greater than 7‰ - 10‰) this indicates the N found in the sample likely came from a wastewater source. When samples show low $\delta^{15}N$ values (near 0‰) it suggests the N came from synthetic agricultural fertilizers.

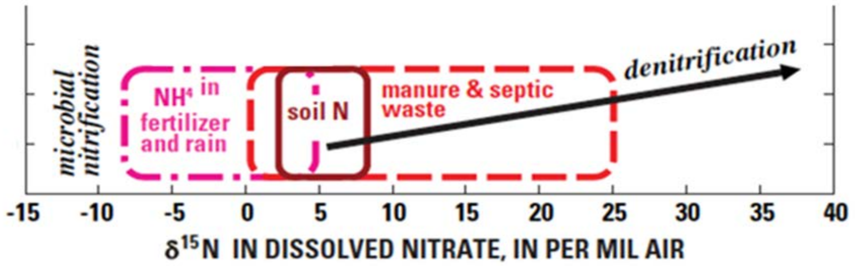

Figure 1: Graph showing classification of nitrogen sources based on nitrogen isotope compositions of dissolved nitrate (modified from Kendall and McDonnell, 1998).

Summaries of Relevant Studies

SHULER ET AL. (2017). SOURCE PARTITIONING OF ANTHROPOGENIC GROUNDWATER NITROGEN IN A MIXED-USE LANDSCAPE, TUTUILA, AMERICAN SAMOA

Key Finding: On the Tafuna-Leone Plain, only 9% of nitrogen in groundwater was estimated to come from synthetic fertilizers, however, 60% came from cesspools or septic tanks.

Water samples were collected from drinking water wells across Tutuila and combined the water quality data with a groundwater model to determine which land use activities contribute the most nitrogen to the groundwater. The model accounted for nitrogen contributions from cesspools, piggeries, agriculture, and natural sources, and found that on the Tafuna-Leone Plain, 60 ± 7% of the nitrogen in groundwater was from cesspools, 20 ± 6% was from piggeries, 12 ± 1% was from natural sources, and only 9 ± 4% was sourced from agricultural application of synthetic fertilizers. The model results were independently validated with $\delta^{15}N$ values, which are a source-dependent tracer that can identify the difference between nitrogen from synthetic fertilizers and nitrogen from wastewater or manure.

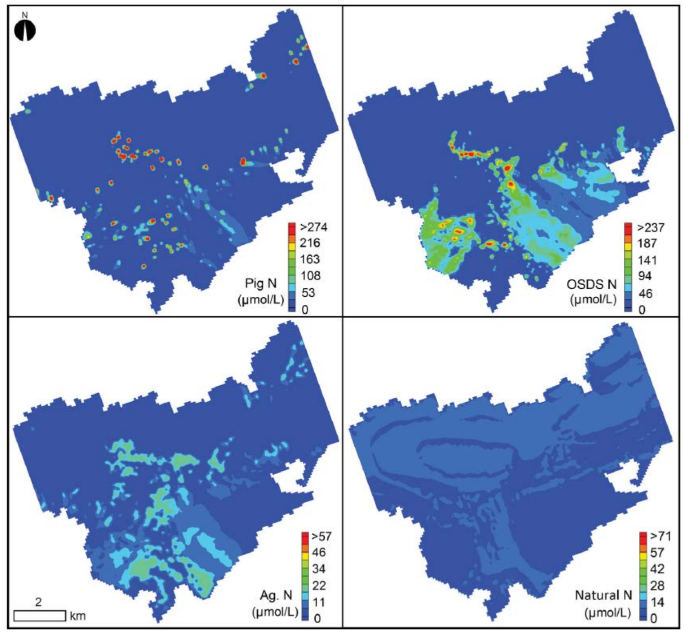

Figure 2: The spatial distribution of TN release from each of the modeled sources, which includes cespools (OSDS), piggeries (Pig), agriculture (Ag.), and natural sources on the Tafuna-Leone Plain. Note the different concentration scales for each source, and also note that even the highest modeled TN concentrations are well below 10 mg/L, the USEPA drinking water limit for NO_3^-.

WELCH ET AL. (2019). SUBMARINE GROUNDWATER DISCHARGE AND STREAM BASEFLOW SUSTAIN PESTICIDE AND NUTRIENT FLUXES IN FAGA'ALU BAY, AMERICAN SAMOA

Key Finding: Glyphosate (Roundup®) was detected in all water samples at 13 sites, at concentrations around 3,000 times lower than the EPA drinking water limit.

Groundwater and surface water samples were taken at 13 sites throughout Fagaalu Watershed, and analyzed for nutrients (N and P), glyphosate (Roundup®), and 3 pesticides (DDT, imidacloprid, and azoxystrobin). Results showed all samples had detectable levels of glyphosate, averaging 160 ± 80 ng/L. This concentration is nearly 3,000 times below the EPA drinking water limit for glyphosate of 700,000 ng/L. The legacy pesticide DDT was detected at most sites, while the other two pesticides were not detected at any sites. A groundwater model was also used to estimate that 90% of the dissolved nitrogen entering coastal waters come from cesspools and septic tanks.

SHULER ET AL. (2019B). UNDERSTANDING SURFACE WATER–GROUNDWATER INTERACTION, SUBMARINE GROUNDWATER DISCHARGE, AND ASSOCIATED NUTRIENT LOADING IN A SMALL TROPICAL ISLAND WATERSHED

Key Finding: Isotope analysis of water in Fagaalu Stream suggests excess nitrogen originates from wastewater sources.

Surface water samples were collected during a survey through Fagaalu Stream, and also took coastal water samples on the reef flat. Samples were analyzed for nutrients and $\delta^{15}N$ values of dissolved inorganic nitrogen. Results showed $\delta^{15}N$ values increased downstream. This corresponded to an increase in human impact on the stream, suggesting that as the stream flows through the village, delivery of excess nitrogen is primarily due to either wastewater or manure, and not agricultural inputs.

SHULER ET AL. (2019A). ASSESSMENT OF TERRIGENOUS NUTRIENT LOADING TO COASTAL ECOSYSTEMS ALONG A HUMAN LAND-USE GRADIENT, TUTUILA, AMERICAN SAMOA

Key Finding: Nitrogen isotopes in water and algae show excess nitrogen in stream and spring water is from a wastewater source rather than an agricultural source.

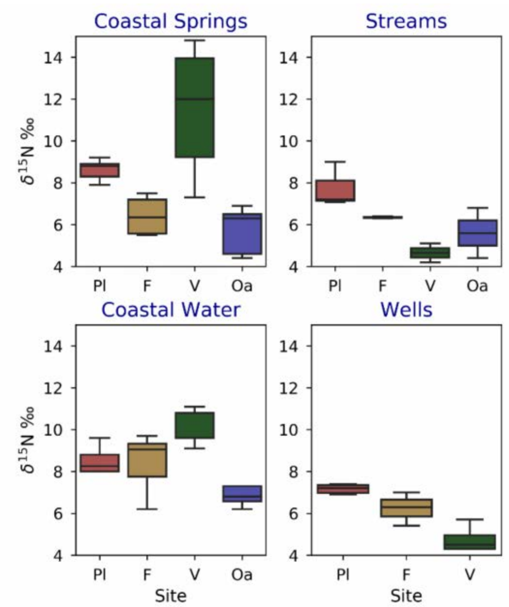

Figure 3: Results of water quality samples analyzed for $\delta^{15}N$ from four bays across Tutuila. Box center lines represent median, edges represent interquartile range, and whiskers represent range. Site names are coded as, Pala Lagoon: Pl, Faga'alu: F, Vatia: V, and Oa: Oa. The PL site is heavily impacted by human land-use, the F and V sites are moderately impacted, and the Oa site is pristine.

Coastal water quality was examined in four of Tutuila's watersheds and reef flats. Water samples were taken from coastal groundwater, streams, and nearshore surface water. Samples were analyzed for nutrient concentrations and $\delta^{15}N$ values of dissolved inorganic nitrogen. Tissue samples of macroalgae (seaweed) were also taken from reef flats to test for the origin of their N using $\delta^{15}N$ values. The $\delta^{15}N$ values of dissolved inorganic nitrogen can 'fingerprint' the sources of N in water and algae samples. In all human impacted study sites, both water and algae samples showed elevated $\delta^{15}N$ values (relative to the pristine site) indicating excess nitrogen found in stream and spring water can be traced to a wastewater source rather than an agricultural source. Additionally, phosphate concentrations in Tutuila's coastal waters were found to be unusually high, even at the pristine site. This indicated natural sources of phosphorus such as dissolution from basalt or perhaps seabird guano create a naturally high P environment in Tutuila's coastal waters, which is not surprising considering similar results from other basaltic islands.

Summaries of Relevant Studies (continued)

MORTON ET AL. (2011). **COASTAL EUTROPHICATION, LAND USE CHANGES AND *CERATIUM FURCA* (DINOPHYCEAE) BLOOMS IN PAGO PAGO HARBOR, AMERICAN SAMOA 2007–2009**

Key Finding: Excessive fertilization of the Pago Soccer Field caused a red-tide algal bloom in the harbor. This event was isolated and quickly mitigated.

This study covers the only scientifically documented example of an algal bloom in Pago Pago Harbor. The first stage of the red-tide algal bloom (composed of dinoflagellates) was thought to have been caused by application of 1,000 kg of fertilizer over 6 months at a site directly adjacent to the most enclosed part of Pago Pago Harbor with no natural buffer or effective run-off management practices. An algal bloom of this scope had not been observed before this event and has not been observed since. This work describbes the only known instance of environmental impacts caused by fertilizer on Tutuila, and this was an isolated event which was rapidly mitigated through better runoff management and best practices.

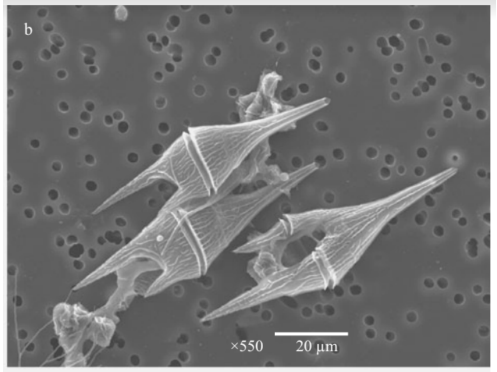

Figure 4: Scanning electron micrograph of *Ceratium furca*. Adapted from Morton et al. 2011.

WHITALL AND HOLST (2015). **POLLUTION IN SURFACE SEDIMENTS IN FAGA'ALU BAY, TUTUILA, AMERICAN SAMOA**

Key Finding: Contamination in Fagaalu from organics and heavy metals was generally low with a few exceptions. Levels of N & P in coastal waters were within AS water quality standards.

Sediments sampled in Fagaalu Stream and Bay were tested for polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, and heavy metals. 'Snapshot' measurements of dissolved nitrogen and phosphorus were also taken from coastal water in Fagaalu Bay, and levels were found to be within AS and Hawaii water quality standards. In general, pollution in Faga'alu Bay sediments and watershed streams was low. Some contaminants were found at elevated or potentially concerning levels including: arsenic, chromium, nickel, silver, zinc, chlordane, DDT, and PCBs. Contaminants like nickel, silver, and zinc may be elevated due to natural geologic erosion or exacerbated by mining activities at a nearby quarry. It was also hypothesized that a legacy landfill beneath the elementary school may be a potential source of pollution, though future research is needed.

COMEROS-RAYNAL ET AL. (2020). **IMPROVING WATERSHED AND ISLAND SCALE RESILIENCE THROUGH A QUANTITATIVE PRIORITY-SETTING MANAGEMENT FRAMEWORK**

Key Finding: Island-wide, monthly water sampling data and a nitrogen loading model was used to determine that only 3-5% of coastal nitrogen discharge comes from agriculture.

Dissolved inorganic nitrogen (DIN) concentrations were measured monthly in streams and reefs for a year at 20 sites across the island. Statistical analysis of the 466 stream and spring samples showed moderately elevated concentrations of DIN in some villages (Table 1). These data were used to develop a whole island nitrogen loading model which was able to link and quantify coastal DIN discharge from human and natural sources. The model indicated the vast majority of DIN being discharged to reefs comes from cesspools, with piggeries being a secondary source. Agricultural fertilizers were estimated to be responsible for 3% to 5% of the DIN discharged to coastal waters. This work was conducted collaboratively by AS-EPA, CRAG, Marine Sanctuaries, and UH-WRRC.

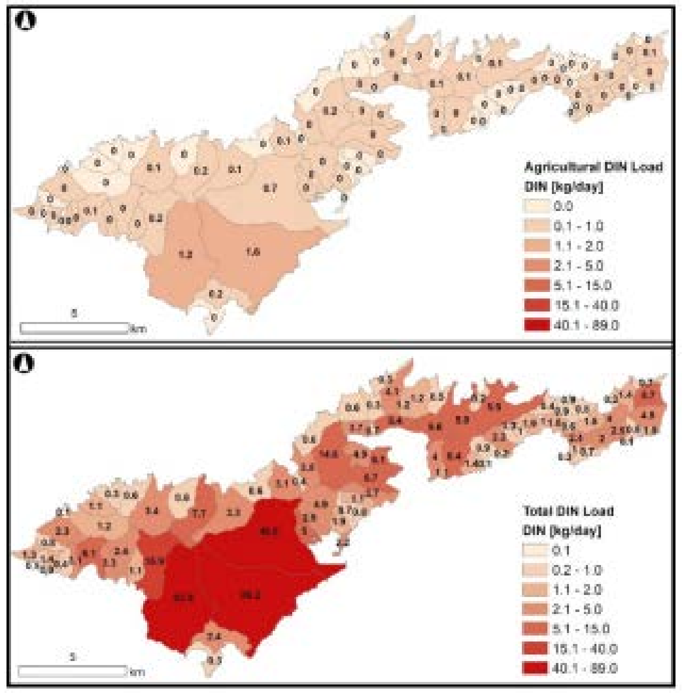

Figure 5: Comparison between modeled DIN loading from agriculture vs. DIN loading from all sources including cesspools and piggeries.

WHITALL ET AL. (2019). **EXCESS NUTRIENTS IN VATIA BAY, AMERICAN SAMOA: SPATIOTEMPORAL VARIABILITY, SOURCE IDENTIFICATION AND IMPACT ON CORAL REEF ECOSYSTEMS**

Key Finding: Nitrogen pollution is a problem in Vatia Bay. Most N is likely from wastewater, as there is only limited agriculture in the watershed, and wastewater indicators were found.

Table 2. Estimated nitrogen budget for Vatia Bay. Adapted from Whitall et al. (2019).

Nitrogen Source	Total N Load to Bay (kg)	% of Load from Source
Wastewater	3,200	43%
Pigs	3,016	40%
Dogs	600	8%
Agriculture	200	3%
Forest	486	6%
Total	6,118	100%

Coastal water was sampled at 17 sites in Vatia Bay for nutrients and wastewater indicators (sucralose, and caffeine). Results indicate nutrient pollution, especially nitrogen, is a problem in Vatia Bay. The presence of sucralose and caffeine tracers also show that human waste is reaching the bay. The authors note that crop agriculture is not prevalent in the watershed. Therefore, fertilizer input is unlikely to be a significant source of nitrogen pollution.

Summaries of Relevant Studies (continued)

POLIDORO ET AL. (2017). LAND-BASED SOURCES OF MARINE POLLUTION: PESTICIDES, PAHS AND PHTHALATES IN COASTAL STREAM WATER, AND HEAVY METALS IN COASTAL STREAM SEDIMENTS IN AMERICAN SAMOA

Key Finding: Elevated levels of heavy metals and organic pesticides were found in Pago Pago, Nuuuli, and Futiga during a "snapshot" screening study.

Coastal stream and sediment samples were taken at 7 sites in Pago Pago, Nuuuli, and near Futiga landfill in June 2015. Samples were analyzed for the presence and concentration of selected organic contaminants (pesticides, PAHs, and phthalates) and toxic metals. Sediment samples were taken at each surface water site. All stream sites in Pago Pago and Nuuuili showed high concentrations of lead in sediments, several had high levels of mercury. Several metals (Cadmium, Chromium, Copper, Nickel and Zinc) exceeded marine sediment screening concentrations and several streams had concentrations of pesticides above chronic toxicity values to fish and other aquatic organisms, some contain restrictions or bans in the US.

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