Operational Status and Estimated Flows of Village Water Systems in American Samoa

By: Chris Shuler and Valentine Vaeoso
Prepared for: The USGS Water Use Data and Reporting Program

Summary

Village water systems are deeply rooted in Samoa's cultural and geographical history, and were once the primary water sources for the people of Tutuila, American Samoa. However, due to challenges such as contamination and water shortages, since the 1970s there has been a transition toward groundwater systems. Despite this shift, many villages continue to use their traditional water systems, particularly in areas where groundwater is less reliable. This report provides a preliminary assessment of the historical and present-day use of village water systems in American Samoa and documents the status of these systems, including their operational characteristics, the challenges they face, the impacts of climate change, and future water availability.

To determine village water usage patterns and assess the status of these systems, a boots-on-the-ground data collection effort was conducted by establishing contact with 42 Pulenuu (village leaders) through phone calls, emails, and site visits. Information was gathered on the current operational status of village water systems, the number of families depending on these systems, and the historical and present uses of the water. Additionally, a geospatial analysis of watershed characteristics above village water intake locations was conducted to quantify the features of the basins supplying these systems. Surface water availability for each watershed was calculated using USGS-developed low-flow statistics, and projected changes in future availability were assessed by applying results from downscaled climate projections to assess future change from present data estimates.

Results show that village water systems remain important to many communities in Tutuila, with 64% of villages with perennial streams confirming active use of these systems for drinking, bathing, agriculture, and other purposes. However, water availability varies significantly across the island, with central and western villages benefiting from higher precipitation and larger watershed areas, while eastern villages face lower water availability due to smaller basins and less rainfall. Climate change predictions suggest increasing precipitation and groundwater recharge, which could bolster water supply reliability in some areas. However, the anticipated rise in runoff, especially under high-emission scenarios, may pose challenges such as heightened flood risks and potential water quality issues, necessitating strategic investments in water storage and stormwater management. These findings highlight the potential for village water systems to function as an important secondary water source to ensure island water resilience in the face of potential disruptions to the municipal water system or to evolving environmental conditions.

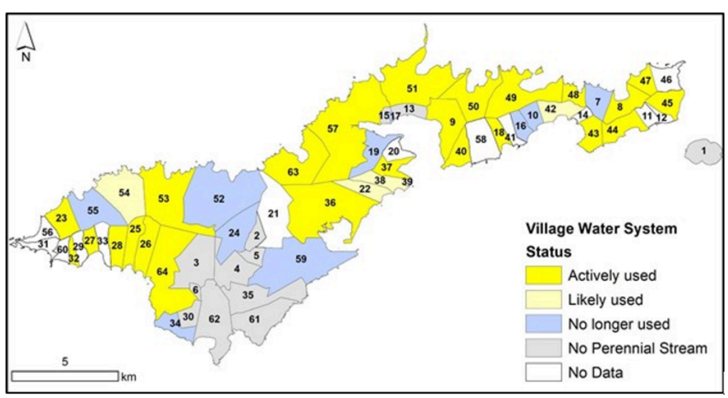

Figure: Map of known village water usage showing villages that actively use village water in yellow and where available, estimates of the number of households using village water.

1.0 Introduction and Background

1.1 Traditional Use and Design of Village Water Systems

The Samoan Islands (***Figure 1***) were settled 2000-3000 years ago by Polynesian voyagers crossing vast swaths of ocean (Green, 1991). These early sailors must have been elated to see the first signs of islands on the horizon, in much part because high islands like those of the Samoan archipelago typically offer abundant sources of freshwater. The surface water resources presumably used by these first inhabitants are the same water sources investigated in this report. The importance of natural watercourses can be seen in the human geography of the islands, whereas nearly every Samoan Nu'u, translated into English as 'village', is formed around the central feature of a freshwater stream. These streams served as the lifeblood of sustainable communities for millennia, ensuring their survival and prosperity. Traditionally, canals were dug to make water access more convenient and once available, pipes were used to transport water from a catchment or intake location, typically upstream of a village, into the developed area for consumption and use. This infrastructure, referred to as the Village Water Systems, were not only a crucial element in historical Samoan life, but in many cases are still used, though to a limited extent, even today.

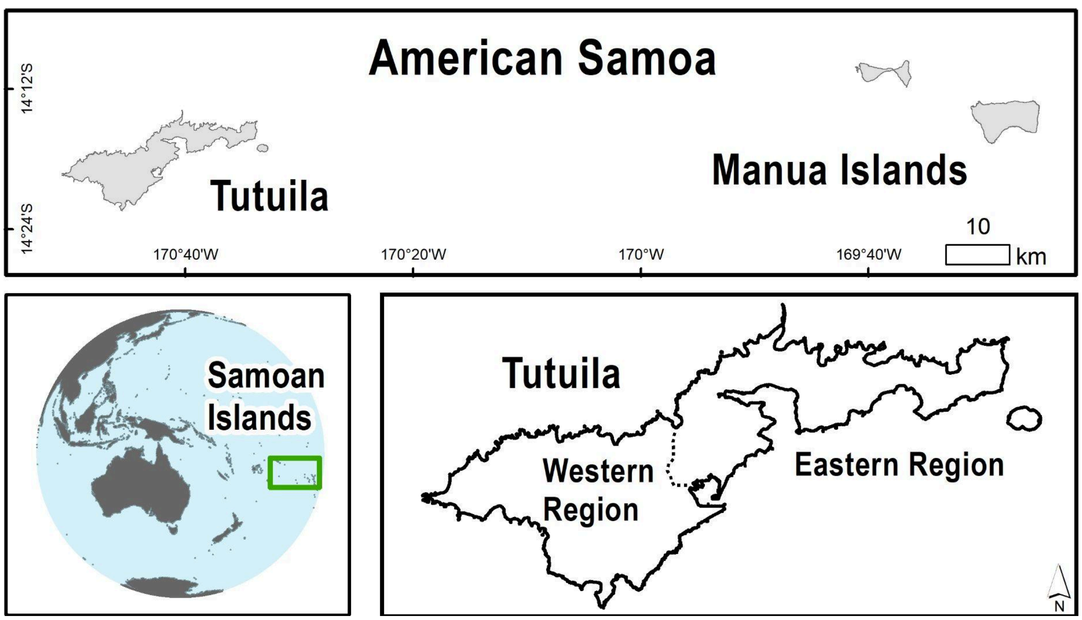

Figure 1: Map of American Samoa, showing Tutuila, and the Manua Island group which consist of the islands of Ofu-Olosega and Tau. Due to limited perennial streams and no information regarding village water use in the Manua Islands, this study focuses exclusively on Tutuila, American Samoa's political and population center.

Before the 1970s, surface water from village water systems served as the primary source of water for all villages in American Samoa (URS, 1978). These systems were and are typically constructed with a small check dam placed across a stream, and the delivery pipe that is usually embedded within the dam structure (***Figure 2***). Intake sites for these systems were chosen based on the natural channel geometry, ensuring the creation of a standing pool of water to keep the intake continuously submerged. The delivery pipe would typically lead to a communal faucet in the central area of the village, although in some instances, wealthier families or chiefs might have the village water supply directly connected to their homes (Davis, 1963). Davis further reports that in a few villages even as late as the 1960s, no infrastructure was used and water was directly collected by dipping from pools in streams; with upstream pools designated for drinking water and downstream pools allocated for washing and bathing. During this time, municipal scale water systems and a few small reservoirs were developed, but surface water treatment plants were difficult to operate and were eventually phased out.

Figure 2: Photos of typical village water systems and types. (a) Abandoned village water system valve in a streambed; (b) pipe carrying diverted stream water through Masefau village; (c) concrete dam across Maloata stream with abandoned outlet pipes visible; (d) pool created with rocks in a low-flowing stream, as an example of how simplified versions of village water systems may have been traditionally constructed prior to the advent of pipes.

1.2 Transition Away from Village Water Systems

Because village water systems in American Samoa rely on surface water sources they are susceptible to contamination from soil, debris, and pathogens. As a result, the water quality provided by these systems tends to be highly variable, posing a risk of waterborne illnesses to residents. Additionally, although the islands receive abundant annual rainfall, many short term droughts have been recorded. Due to the small size and low-natural storage capacity of the island's soils and aquifers, these events caused insufficient streamflow leading to water shortages.

By the late 1970s, recognizing the problems associated with surface water quality and availability in American Samoa, groundwater development emerged as a strategic solution. During this period, the American Samoa Public Works Department (ASDPW) embarked on a program to develop a robust network of groundwater infrastructure, encompassing both the development of the groundwater sources and the establishment of an island-wide water transmission system. This initiative, which spanned multiple decades, was managed by ASDPW until the American Samoa Power Authority (ASPA) assumed responsibility for the territory's water system operations around the year 2000. In the 1980s to the early 2000s, the American Samoa Environmental Protection Agency (ASEPA) actively promoted the transition from village water systems to the more reliable groundwater system. This shift was encouraged as the groundwater system met the Safe Drinking Water Act's standards and was generally considered a better alternative to the surface water systems. Despite the benefits, the transition was not universal. A significant portion of the population continued to rely on village water systems for traditional reasons or due to the financial implications of switching to the metered and billed groundwater system. At present, even though village water systems retain practical, cultural, and historical significance there exists very little documentation regarding their design, usage, or significance. This report is one of a very few, and possibly the only attempt to comprehensively document the status of village water systems on Tutuila. As early as the 1970's it was written that villages do not maintain any records pertaining to their water systems (URS, 1978), and we also found this to be true during the course of our study.

1.3 Present Day Use of, and Knowledge Gaps about Village Water Systems

In contemporary times, while the existence and use of village water systems are well recognized, they often remain overlooked by the public and underappreciated by regulatory and government bodies. These systems are generally viewed as inferior and problematic, with ongoing efforts to discourage their use, especially on Tutuila the Territory's capital and most populous island. However, in parts of Eastern Tutuila, the necessity of village water persists, particularly where groundwater salinity levels compel residents to revert to these traditional sources. Despite their infrequent use, village water remains a crucial alternative, especially in light of Davis's (1963) early assessment that the combined discharge of Tutuila's major streams could meet the island's domestic water needs—a situation that may no longer be true due to increased demand, but underscores the potential value of surface water in less favorable conditions or emergencies. The impact of climate change, coupled with observed supply chain disruptions from the Covid-19 pandemic, has highlighted the vulnerability of small island communities to water shortages triggered by drought, climate variability, or natural disasters. The groundwater system relies not only on availability of water but also of power, which currently is generated almost wholly by diesel generation, to pump water into the system. The storage capacity of the water distribution system's tanks in Tutuila is constrained, even under normal conditions. Additionally, several of the island's wells pump directly into the transmission systems, meaning that a power outage would swiftly lead to a water outage as well. In such times, village water sources become invaluable as emergency reserves, emphasizing the need to quantify and understand American Samoa's surface water resources to safeguard against disruptions in the groundwater supply system.

1.4 Purpose and scope of the report

The purpose of this report is to comprehensively document and assess the status of village water systems across Tutuila, underscoring their critical role in the resilience and cultural heritage of the island. Historically, village water systems have been marginalized and are poorly documented, mainly due to concerns over safety and reliability which led to a government and Navy-driven push in the 1970s to phase them out in favor of groundwater systems. However, these traditional systems remain culturally significant and serve as a vital water source that does not rely on the vulnerable supply chains necessary for powering groundwater pumps. This report aims to:

1. Document the current usage of village water systems across Tutuila.
2. Assess the availability of streamflow for village water and other surface water diversion systems.
3. Explore how potential future climate scenarios could impact these resources.

Understanding the historical and present use of village water is essential not only for future surface water development but also to ensure equity and justice in managing a resource that supports often under-represented groups within the community.

1.5 Geographical and Cultural Cultural Setting:

American Samoa consists of a group of small high-volcanic islands located in the South Pacific at about 170° west longitude and 14° south latitude. Tutuila is the main island in the chain and has an area of 55 square miles. American Samoa is located roughly 2,300 miles southwest of Hawaii, and 1,600 miles northeast of New Zealand. Tutuila, the largest island and the capital of the U.S. Territory is the center of government and business. Aunu'u, a satellite of Tutuila, lies one mile off the east coast of Tutuila.

The climate of American Samoa is tropical and characterized by a wet season lasting November through April and a dry season in May through October. The islands lie within the South Pacific Convergence Zone (SPCZ), which in the wet season is typically characterized by weak and variable winds with frequent and intense convective rainstorms. Trade wind weather is more prevalent in the dry season and results in less, but still significant amounts of rainfall.

The Samoan people share their polynesian roots with other island cultures including Hawaiians, Cook Islanders, French Polynesians, Tongans, and the Māori of New Zealand. The traditional Samoan lifestyle is focused around the aiga, which consists of both close and extended family. In this system the family and community is prioritized over the individual. Communities in American Samoa typically are organized into villages which consist of one or more aigas and are traditionally governed by a Matai or chief. The matai is responsible for the welfare of all village residents and manages communal village assets such as communal land and the village water systems. The matai system of governance is politically complex and titles and responsibilities are bestowed based on the interplay of family lineage and personal interest. (need citation) This traditional system of governance currently co-exists, interacts with, and compliments the western democratic Government of American Samoa (ASG). The territorial annexation of American Samoa was initiated in the 1870s by requests to U.S. President Grant by a group of high-ranking Matai, and was completed by 1904 with the cession of the islands as a U.S. Territory (Leibowitz, 1980). This led to the establishment of a westernized governance structure overseen by the U.S. Navy, which terminated in 1951 and subsequently evolved into the ASG. The ASG, which incorporates elements of traditional Samoan and American governance, is framed by the American Samoan Constitution, ratified in 1967 (Faleomavae, 1990).

American Samoa is organized in a hierarchy of districts, counties, and villages. Central to this structure is the Office of Samoan Affairs (OSA), which serves as a crucial bridge between the traditional village leadership, led by chiefs or Matais, and the parliamentary democratic government that oversees broader territorial affairs. At the village level, decision-making power remains predominantly with the Matais; however, the daily administrative duties are managed by appointed leaders known as village mayors, or "Pulenuu." These mayors are responsible for acting as liaisons and ensuring the seamless operation of community activities. They also play a pivotal role as intermediaries between the villages and the OSA, facilitating communication and collaboration on issues that impact the community and its residents.

It is important to note that the primary focus of this report, village water systems, fall under the jurisdiction and management of the traditional Samoan governance system, and are generally not regulated by or within the purview of ASG departments. This underscores the enduring significance of the Matai system in managing essential community resources, despite the overlay of modern governance structures.

Because the data collected for this report were provided by indigenous leaders of modern-day, functioning, traditional areas of governance, it is important to recognize that these data remain under the ownership of each of the villages and their leadership. Therefore, the authors wish to acknowledge the sovereignty that each of the American Samoan Pulenuu retain over these data and we have taken steps to ensure that none of the information shared in this report encroaches on that sovereignty or contains any identifiable information regarding individuals, families, or locations of infrastructure.

2. Methodology

2.1 Collection of Village level data

In order to determine village water usage patterns we obtained contact information for all village's Pulenuu. This was initiated with a public records search through contacting OSA leadership. The OSA reviewed our proposed methods and agreed to support the project by providing contact information for 53 village-level officials. While there are 65 villages represented in the ASG database, some villages are currently uninhabited and others have leadership structures that overlap or extend to adjacent villages. A comprehensive list of all villages is presented in ***Table 2***. It is important to note that 13 villages lack perennial streams, therefore reducing the number of villages relevant for assessing water use to 52. Throughout the course of the study, we successfully reached out to and engaged with a total of 42 Pulenuu. The other 10 did not respond, or had incorrect contact information listed in the OSA records. These data were collected through phone calls, emails, and site visits with pulenuu and chiefs.

Our initial engagement with village Pulenuu was conducted via phone. All of the Pulenuu we were able to contact expressed a willingness and interest in discussing the use of water within their respective villages. Many agreed to meet in person and allowed us to conduct a site visit to see the construction and condition of the water systems. We gathered information from each mayor concerning the current operational status of their village water sources, the number of families that continue to depend on these systems, historical and present uses of the village water, and the ongoing necessity for these water systems. Although not every Pulenuu could answer all questions comprehensively, we have synthesized the collected data into the findings presented in ***Table 2***.

2.2 Geospatial Analysis of Basin Characteristics and Future Climate Projections

To understand and quantify features of the basins supplying the village water systems, we conducted a geospatial analysis of watershed characteristics for areas above the assumed village water intake locations. The actual locations of these intake sites were not documented out of respect for community privacy and indigenous data sovereignty. Therefore, we assumed reasonable estimated locations for the intakes, defined as the point on the stream directly above the highest elevation urbanization or development in the village. This assumption is reasonable as most village water system intakes are located at or near the urban-wildland interface to avoid water quality issues from return flow and to minimize construction costs. These assumed locations are often near or coincide with historical USGS stream gauging sites reported by Wong (1996). It is important to note that village boundaries and watershed boundaries do not perfectly align, although the names are used interchangeably in this report. All geospatial analysis was conducted using hydrologically defined watershed boundaries, which in general reflects the traditional Polynesian governance structure that encompasses control of an entire watershed from the mountain ridge to the sea, known as an ahupua'a in Hawaii and nu'u in Samoa. Villages may contain multiple watersheds, while watersheds typically do not contain multiple villages. We thus selected one intake location per village, meaning some villages may have multiple systems on different streams. This approach likely results in a conservative estimate of water availability, as those villages with more than one stream have access to additional water beyond what is calculated and reported here. Once the intake location was defined for each watershed, we clipped watershed boundaries to encompass only the area above the intake, yielding the contributing basin area to the stream at that location. These areas were used to extract basin parameters from available geospatial datasets, including land cover percentage derived from an analysis by Meyer et al. (2016), average annual precipitation values (Daly et al., 2006), basin slope from a 3m DEM (NGDC, 2013), and projected changes in water budget parameters under future climate scenarios (Shuler et al., 2021). The pre-processed climate scenario rasters developed by Shuler et al. are based on projections by Wang and Zhang (2016), and are representative of the late 21st century period, under modeled future climates from RCP 4.5 and RCP 8.5 emissions scenarios. Population counts for each village were obtained from the 2020 census data provided by the American Samoa Department of Commerce in their statistical yearbook (ASDOC, 2022). The results of these analyses are presented in ***Table 5***.

2.3 Streamflow Quantification Methods: Expected Availability of Water

The availability of surface water resources for use as a village water supply was determined through analysis of low-flow statistics developed by the USGS from gauged and ungauged perennial streams. The analysis was only conducted for those streams within watersheds that also contained inhabited villages. Most villages on Tutuila are located in watersheds with perennial streams, except for those villages located in the very hydrogeologically permeable Tafuna-Leone Plain (***Figure 1***). Likewise, most watersheds with perennial streams, except for those that are located on the island's remote north shore within and adjacent to the National Park of American Samoa generally contain inhabited villages. While there are a number of possible methods for assessing a watershed's quantity of usable water, the typical construction of a village water system limits the type of water that can be used. Specifically, it is the baseflow component of the stream water that is used, as runoff in the steep hydraulically flashy mountains of Turuila usually contains such a high sediment load that it is not usable. While baseflow is variable, a conservative measure of a given stream's minimum baseflow availability can be quantified using low-flow statistics as described below.

This analysis benefits from tremendous effort expended by the USGS during the many years of work the agency spent stream gauging at streams in American Samoa. Since the 1950s up until 2008, the USGS maintained eleven continuous record stream gauges, and measured baseflow discharge at 75 low-flow monitoring sites (Wong, 1996). Through analysis of these datasets Wong developed regression equations to estimate low-flow statistics in ungauged basins based on location and watershed parameters. Wong presented two separate equations for basins in the eastern portion of the island (those located East of the villages of Malaeimi and Nuuuli) and those in the Western portion. The two equations were of similar form but used different coefficients and took the following parameters into account:

- Drainage area above the gauging point
- Gage altitude above sea level
- Basin relief, equaling the difference between the watershed's highest point and the gage elevation
- Basin Slope, equaling the product of basin relief and drainage density

2.4 Low-flow statistics as a measure of surface water availability

The 7-day average low-flow is calculated as the average streamflow over a 7-day rolling window. The magnitude of 7-day low-flow events can be described through yearly recurrence intervals in the same way flood events are described, e.g. the 100-year flood. Thus the 7-day 2-year low-flow represents the amount of flow that is expected to be exceeded in the stream for all but one week during a 'typical' 2-year period, with the word typical defined through analysis of existing streamflow records, which started in the late 1950s, and at some stations and continued through 2008. This statistic gives a reasonable indication of how much water users could expect to have available during typical years with normal amounts of seasonal variability. The 7-day 10-year low flow was also calculated for this assessment and was used to represent the amount of water users could expect to have available during exceptionally dry years. It should be noted that streamflow will nearly always be higher than the 7-day low flows, but due to the lack of storage reservoirs on nearly all of Tutuila's basins, water can not be stored for dry periods and these times are when water availability is most critical.

Wong (1996) developed regression equations for calculating the mean, median, 7-day 2-year, and 7-day 10-year streamflows of streams throughout Tutuila. Because of differences between the hydrology of Western Tutuila and Eastern Tutuila two distinct sets of equations were developed to estimate streamflow in these different regions. Note the use of the derived parameter of basin slope (β), which is calculated from basin relief (γ) and drainage density (λ), in Western Tutuila, but not Eastern Tutuila. In Western Tutuila The standard error of estimate, expressed as a percentage, for the 7-day 2-year low flow is 34.2%, for the 7-day 10-year low flow is 37.5%, for the mean flow is 36.5%, and for the median flow is 29.8%, and for eastern Tutuila, the standard errors of estimate for the same parameters are 95.2%, 110%, 62.6%, and 65.5%, respectively. These equations are presented in ***Table 1*** and take the following parameters into account:

(α): Drainage area calculated above the gauging point (in square miles)
(η): Gage altitude (in feet above sea level)
(γ): Basin relief which is the difference between the highest point and the gage elevation in a basin
(λ) Drainage Density: calculated by dividing the total length of all stream channels in a basin by the drainage area **(α)**
(β) Basin Slope: calculated by multiplying the basin relief **(γ)** by the drainage density **(λ)**

Table 1: Regression equations developed by Wong (1996) to estimate low flow characteristics of Tutuila's streams.

	Western Tutuila	**Eastern Tutuila**
7-day 2-year low flow	$0.00365 \times \alpha^{0.909} \times \eta^{0.11} \times \beta^{0.594}$	$0.0000335 \times \alpha^{0.488} \times \eta^{0.244} \times \gamma^{1.16}$
7-day 10-year low flow	$0.000925 \times \alpha^{0.922} \times \eta^{0.135} \times \beta^{0.645}$	$0.00000447 \times \alpha^{0.488} \times \eta^{0.280} \times \gamma^{1.3}$
Mean flow	$0.0862 \times \alpha^{0.972} \times \beta^{0.479}$	$0.00188 \times \alpha^{0.474} \times \gamma^{0.983}$
Median Flow	$0.0464 \times \alpha^{0.964} \times \beta^{0.510}$	$0.000619 \times \alpha^{0.478} \times \gamma^{1.04}$

3. Results:

3.1 Current Water Use in Village Systems

Among the 64 identified villages on Tutuila, only 42 of these have perennial streams. Our team targeted all villages and was able to survey 44 villages total, yielding a 69% response rate and a 31% non-response rate, primarily due to us having outdated contact information. Of the 44 villages surveyed, 27 confirmed that some residents still use village water for drinking, bathing, agriculture, or other purposes, representing approximately 64% of those villages with perennial streams. Ten villages noted that, although they once had a village water system, it is no longer in use by any residents to their knowledge, accounting for 24% of the villages with perennial streams. Four village mayors were uncertain about the status of their water systems but assumed that some residents might still be using village water. We were unable to contact the mayors of 10 villages with perennial streams, leaving us with missing data for these 10 villages, or 24% of those with streams. Among the 27 villages with perennial streams and active village water systems, village leaders provided quantified household usage estimates for 18 villages, or 67%. These estimates range from one household in Onenoa to more than 70 households in Afao. The remaining 33% of village leaders knew or assumed there was some village water usage but could, or would not estimate the number of households. ***Figure 3*** presents a map illustrating those villages with active village water systems in yellow, those where usage is assumed but uncertain in light yellow, historically inactive systems in light blue, villages without perennial streams in gray, and those with no contact information available in white. ***Table 2*** provides village water system status and individual data for each village.

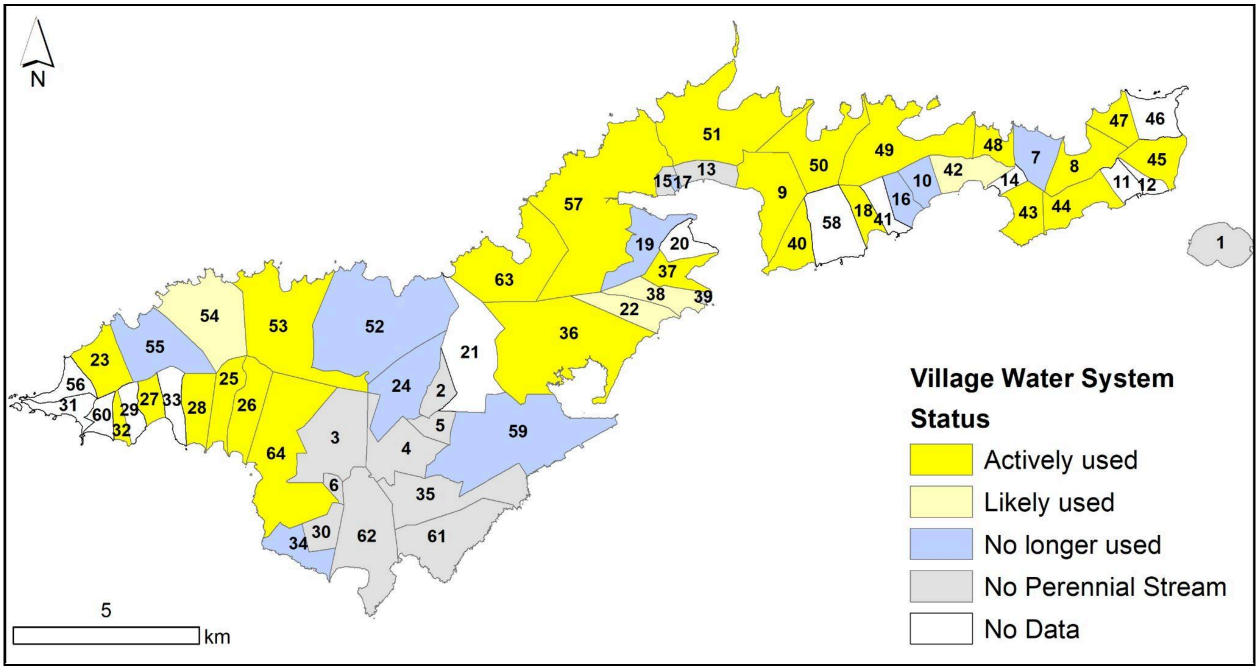

Figure 3: Map of known village water usage showing villages that actively use village water in yellow and where available, estimates of the number of households using village water.

Table 2: Generalized characteristics of villages with streams that support, or may support, village water systems on Tutuila, American Samoa. The table lists villages that were surveyed for this study, indicating whether village leaders participated in the survey, current status of village water systems, and number of households using systems. Population estimates are based on 2020 U.S. census data. Villages are categorized based on the presence or absence of perennial streams. Where villages lack perennial streams data was not collected.

Map Number	Watershed or Village Name	Village Leaders Surveyed	Village Water System Status	Number of Households using Village Water	2020 Population
1	Aunuu	Yes	No Perennial Stream	-	
2	Mesepa	Yes	No Perennial Stream	-	
3	Malaeloa Aitulagi	No	No Perennial Stream	-	
4	Pavaiai	No	No Perennial Stream	-	
5	Faleniu	No	No Perennial Stream	-	
6	Malaeloa Ituau	No	No Perennial Stream	-	
7	Sailele	Yes	No longer used	0	60
8	Aoa	Yes	Actively used	20+	344
9	Aua	Yes	Actively used	unknown	1549
10	Amaua	Yes	No longer used	0	68
11	Auasi	No	No Data	-	88
12	Utumea East	No	No Data	-	
13	Leloaloa	Yes	No Perennial Stream	-	
14	Pagai	No	No Data	-	81
15	Anua	No	No Perennial Stream	-	
16	Auto	Yes	No longer used	0	214
17	Atuu	Yes	No longer used	0	
18	Alega	Yes	Actively used	1+	29
19	Fagatogo	Yes	No longer used	0	1445
20	Utulei	No	No Data	-	479
21	Malaeimi	No	No Data	-	
22	Faganeanea	Yes	May be used	unknown	93
23	Fagalii	Yes	Actively used	30+	163
24	Mapusagafou	Yes	No longer used	0	
25	Asili	Yes	Actively used	17	157
26	Amaluia	Yes	Actively used	10	163
27	Seetaga	Yes	Actively used	10+	177
28	Afao	Yes	Actively used	70+	96
29	UtumeaWest	No	No Data	-	42
30	Taputimu	Yes	No Perennial Stream	-	
31	Amanave	No	No Data	-	246

Table 2: Continued					
Map Number	Watershed or Village Name	Village Leaders Surveyed	Village Water System Status	Number of Households using Village Water	2020 Population
32	Agugulu	Yes	Actively used	10+	42
33	Nua	Yes	No Perennial Stream	-	
34	Vailoatai	Yes	No longer used	0	
35	Iliili	No	No Perennial Stream	-	
36	Nuuuli	Yes	Actively used	unknown	4991
37	Fagaalu	Yes	Actively used	unknown	731
38	Matuu	Yes	May be used	unknown	317
39	Fatumafuti	No	No Perennial Stream	-	
40	Laulii	Yes	Actively used	60+	736
41	Avaio	No	No Data	-	34
42	Fagaitua	Yes	May be used	unknown	287
43	Alofau	Yes	Actively used	6	296
44	Amouli	Yes	Actively used	20+	261
45	Alao	Yes	Actively used	10+	275
46	Tula	No	No Data	-	308
47	Onenoa	Yes	Actively used	1	100
48	Masausi	Yes	Actively used	2	134
49	Masefau	Yes	Actively used	10	260
50	Afono	Yes	Actively used	unknown	327
51	Vatia	Yes	Actively used	30	460
52	Aasu	Yes	No longer used	0	
53	Aoloau	Yes	Actively used	unknown	
54	Fagamalo	Yes	May be used	unknown	37
55	Maloata	Yes	No longer used	0	6
56	Poloa	No	No Data	-	130
57	PagoPago	Yes	Actively used	8	3000
58	Aumi	No	No Data	-	176
59	Tafuna	Yes	No longer used	0	
60	Failolo	No	No Data	-	87
61	Vaitogi	Yes	No Perennial Stream	-	
62	Futiga	Yes	No Perennial Stream	-	
63	Fagasa	Yes	Actively used	70	577
64	Leone	Yes	Actively used	unknown	1598

3.2 Water Availability and Streamflow Estimation Results

In general, villages located in watersheds surrounding the island's highest peaks, Mount Matafao and Rainmaker Mountain (also known in Samoan as Mount Pioa) are estimated to yield the highest baseflow, and thus have the greatest potential for village water use. This is reasonable, as these areas also receive the highest precipitation and contain relatively large, steep watersheds. Villages in Eastern Tutuila generally have lower estimated water availability due to smaller basin sizes and less developed streams. Although not an explicit factor in the equations used to calculate water availability, the eastern portion of Tutuila also receives significantly less rainfall than the central part of the island, further reducing water availability. Precipitation and other basin-related factors, which indirectly influence watershed characteristics used to calculate low-flow statistics, were calculated and reported in ***Table 4***. The availability of streamflow, as indicated by the 7-day 2-year low-flow statistic, ranged from 0.03 CFS (13 GPM) in villages with the smallest streams to 0.52 CFS (233 GPM) in villages with the largest (***Figure 4***). 7-day 10-year low-flows ranged from 0.01 to 0.23 CFS (5 to 104 GPM). Mean flows ranged from 0.19 to 3.1 CFS (86 to 1379 GPM), though it should be remembered that mean flows encompass runoff events, which typically produce sediment-laden water unsuitable for human use without settling and extensive treatment. The villages with the greatest estimated 7-day 2-year low-flow, in descending order, are Nuuuli, Fagaalu, Pago Pago, Leone, and Afono. Conversely, the villages with the smallest estimated 7-day 2-year low-flow, in ascending order, are Avaio, Failolo, Utulei, Amanave, and Amouli (***Table 3***) .

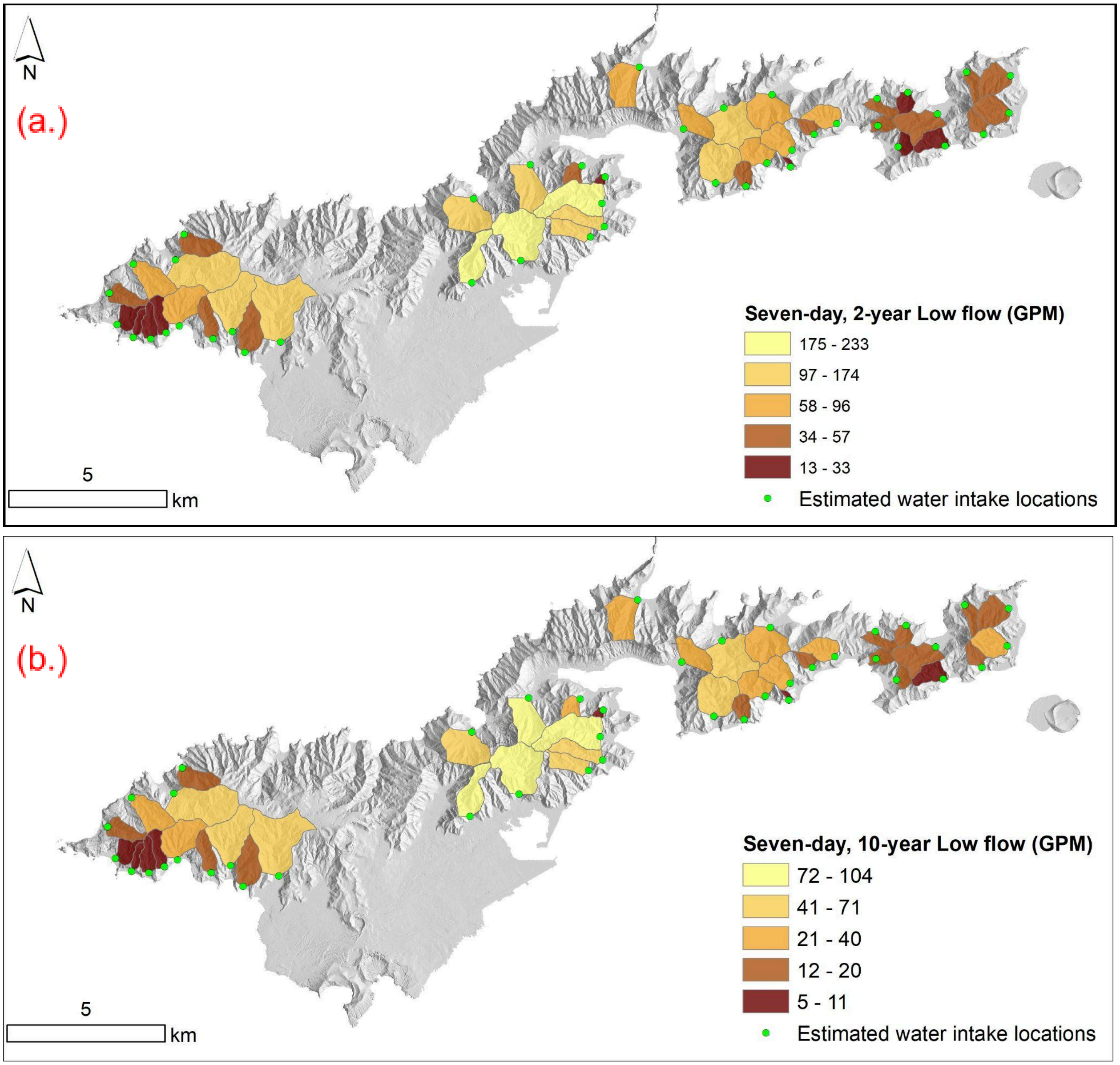

Figure 4: Maps of village water availability based on calculated low-flow estimates of streams in GPM, with panel (a.) showing the 7-day 2 year low flow estimates and panel (b.) showing the 7-day 10 year low flow estimate. Green dots represent estimated water intake locations and do not indicate actual water system infrastructure locations to protect village privacy and data sovereignty.

Table 3: Estimated Water Availability Based on calculated Low-Flow Statistics and Mean and Median Flows for Villages on Tutuila. (Units listed only in GPM for brevity, GPM can be converted to CFS by dividing by an approximate factor of 448.8.)

Map Number	Watershed or Village Name	Village Water System Status	Drainage Area (mi2)	Ave. Slope (deg)	Ave. Precip. (inches)	7-day, 2 year low flow (GPM)	7-day, 10 year low flow (GPM)	Average Flow (GPM)	Median Flow (GPM)
7	Sailele	No longer used	0.12	26	105	32	12	219	104
8	Aoa	Actively used	0.39	24	110	44	17	457	222
9	Aua	Actively used	0.30	34	176	96	40	709	355
10	Amaua	No longer used	0.10	32	147	44	18	270	131
11	Auasi	No Data	0.13	25	108	35	14	295	143
14	Pagai	No Data	0.12	29	116	40	16	252	121
16	Auto	No longer used	0.29	31	168	76	31	469	230
18	Alega	Actively used	0.27	31	177	64	26	462	226
19	Fagatogo	No longer used	0.12	30	200	54	23	306	149
20	Utulei	No Data	0.03	37	179	19	8	113	54
22	Faganeanea	May be used	0.25	37	209	139	62	796	403
23	Fagalii	Actively used	0.37	26	149	68	27	487	289
25	Asili	Actively used	0.62	26	204	112	45	837	496
26	Amaluia	Actively used	0.35	20	184	45	17	435	258
27	Seetaga	Actively used	0.46	27	178	65	24	608	361
28	Afao	Actively used	0.21	26	184	38	15	263	157
29	UtumeaWest	No Data	0.16	24	158	29	11	205	123
31	Amanave	No Data	0.17	24	136	23	8	192	114
32	Agugulu	Actively used	0.16	25	148	28	11	195	116
36	Nuuuli	Actively used	0.77	36	221	233	104	1379	701
37	Fagaalu	Actively used	0.66	36	203	185	80	1291	657
38	Matuu	May be used	0.25	37	204	131	58	745	375
40	Laulii	Actively used	0.54	34	175	126	53	937	470
41	Avaio	No Data	0.02	30	157	13	5	86	41
42	Fagaitua	May be used	0.25	27	132	64	26	402	195
43	Alofau	Actively used	0.10	30	112	33	13	199	95
44	Amouli	Actively used	0.21	26	109	26	9	273	131
45	Alao	Actively used	0.30	29	106	57	23	442	215
46	Tula	No Data	0.29	23	99	37	14	364	176
47	Onenoa	Actively used	0.13	28	101	45	18	286	138
48	Masausi	Actively used	0.14	27	111	36	14	274	132
49	Masefau	Actively used	0.47	28	153	82	33	602	295
50	Afono	Actively used	0.58	33	170	163	71	965	484
51	Vatia	Actively used	0.44	32	167	81	32	791	395
54	Fagamalo	May be used	0.28	29	155	52	20	394	235
55	Maloata	No longer used	0.85	26	184	153	62	1130	668
56	Poloa	No Data	0.21	26	134	36	14	247	147
57	PagoPago	Actively used	0.44	31	201	174	78	864	434
58	Aumi	No Data	0.14	31	172	42	17	282	136
60	Failolo	No Data	0.08	27	142	14	5	88	53
63	Fagasa	Actively used	0.54	32	186	119	50	940	471
64	Leone	Actively used	0.99	26	208	169	67	1395	825

3.3 Basin Characteristics and Land Use

Water availability is closely linked to watershed conditions and characteristics. Degraded lands often have a reduced capacity for water retention and production, and they can negatively impact water quality. Precipitation is the most direct factor influencing water availability, and there is a significant gradient across Tutuila, with central villages like Nuuuli receiving up to 221 inches of rainfall annually, while eastern villages such as Tula receive as little as 99 inches per year. Although steeper slopes typically lead to faster runoff, which can reduce groundwater recharge, this effect seems to be counterbalanced by the higher rainfall observed in the steeper central Tutuila watersheds. This increased rainfall is likely due to orographic uplift, which is influenced by the island’s central high terrain—remnants of a large caldera characterized by weathering-resistant trachyte rocks (Stearns, 1944).

Land cover classification also plays a critical role in understanding a watershed's ability to absorb water versus losing it to runoff. Forests and grasslands are generally assumed to have better water retention capabilities, whereas developed and agricultural lands are more prone to generating runoff. However, no specific studies have been conducted in American Samoa to validate this assumption. Nevertheless, examining variations in land cover classification between watersheds provides valuable insights into potential impacts on village water availability and water quality, especially during or after runoff events. ***Table 4*** presents the percentage of land under different land use categories across various watersheds and villages, offering a detailed view of how these factors may influence village water availability and quality across Tutuila’s varied landscapes.

Table 4. Percentage of land under different land use categories (developed, agriculture, forest, and scrubland) across various watersheds and villages in Tutuila, American Samoa. The land cover information is based on data from Meyer et al. (2016) and is derived from high-resolution orthoimagery and LIDAR remote sensing data.

						Percentage of land under given land use			
Map Number	Watershed or Village Name	Village Water System Status	Drainage Area (mi2)	Ave. Precip. (inches)	Ave. Slope (deg)	Developed	Agriculture	Forest	Scrub-land
7	Sailele	No longer used	0.12	105	26	0%	0%	97%	3%
8	Aoa	Actively used	0.39	110	24	1%	6%	89%	4%
9	Aua	Actively used	0.30	176	34	5%	20%	64%	12%
10	Amaua	No longer used	0.10	147	32	0%	0%	96%	4%
11	Auasi	No Data	0.13	108	25	0%	2%	95%	3%
14	Pagai	No Data	0.12	116	29	3%	10%	83%	5%
16	Auto	No longer used	0.29	168	31	0%	0%	95%	5%
18	Alega	Actively used	0.27	177	31	0%	0%	98%	3%
19	Fagatogo	No longer used	0.12	200	30	1%	1%	97%	1%
20	Utulei	No Data	0.03	179	37	0%	5%	88%	7%
22	Faganeanea	May be used	0.25	209	37	0%	0%	94%	6%
23	Fagalii	Actively used	0.37	149	26	1%	7%	91%	2%
25	Asili	Actively used	0.62	204	26	0%	4%	94%	3%
26	Amaluia	Actively used	0.35	184	20	2%	9%	75%	14%
27	Seetaga	Actively used	0.46	178	27	1%	6%	91%	2%
28	Afao	Actively used	0.21	184	26	0%	8%	91%	2%
29	UtumeaWest	No Data	0.16	158	24	0%	4%	94%	3%
31	Amanave	No Data	0.17	136	24	1%	19%	74%	6%
32	Agugulu	Actively used	0.16	148	25	0%	16%	81%	3%
36	Nuuuli	Actively used	0.77	221	36	1%	3%	88%	7%
37	Fagaalu	Actively used	0.66	203	36	3%	4%	79%	13%
38	Matuu	May be used	0.25	204	37	0%	0%	94%	6%
40	Laulii	Actively used	0.54	175	34	1%	8%	76%	16%
41	Avaio	No Data	0.02	157	30	0%	1%	95%	4%
42	Fagaitua	May be used	0.25	132	27	0%	2%	93%	6%
43	Alofau	Actively used	0.10	112	30	0%	2%	94%	4%
44	Amouli	Actively used	0.21	109	26	3%	11%	84%	2%
45	Alao	Actively used	0.30	106	29	0%	6%	90%	5%
46	Tula	No Data	0.29	99	23	0%	25%	71%	4%
47	Onenoa	Actively used	0.13	101	28	0%	0%	99%	1%
48	Masausi	Actively used	0.14	111	27	2%	13%	78%	7%
49	Masefau	Actively used	0.47	153	28	1%	7%	80%	13%
50	Afono	Actively used	0.58	170	33	1%	7%	78%	15%
51	Vatia	Actively used	0.44	167	32	1%	4%	91%	5%
54	Fagamalo	May be used	0.28	155	29	1%	4%	94%	1%
55	Maloata	No longer used	0.85	184	26	0%	0%	98%	2%
56	Poloa	No Data	0.21	134	26	2%	6%	90%	3%
57	PagoPago	Actively used	0.44	201	31	4%	20%	72%	3%
58	Aumi	No Data	0.14	172	31	0%	2%	96%	2%
60	Failolo	No Data	0.08	142	27	0%	1%	98%	2%
63	Fagasa	Actively used	0.54	186	32	2%	15%	79%	4%
64	Leone	Actively used	0.99	208	26	1%	14%	80%	5%

3.4 Results of basin characteristics analysis

The analysis of basin characteristics reveals significant variation in precipitation rates, land cover, and development across Tutuila's villages. The five villages with the highest precipitation rates are Nuuuli (221 inches), Faganeanea (209 inches), Leone (208 inches), Asili (204 inches), and Matuu (204 inches). These villages are located in central or western parts of the island, where orographic uplift contributes to higher rainfall. In contrast, the villages with the lowest precipitation rates are Tula (99 inches), Onenoa (101 inches), Sailele (105 inches), Alao (106 inches), and Auasi (108 inches), which are all situated in the eastern part of the island, which receives significantly less rainfall.

Regarding land use, the five most pristine watersheds—those with the highest percentage of forest cover and minimal development—are Onenoa (99% forest), Maloata (98% forest), Alega (98% forest), Failolo (98% forest), and Sailele (97% forest).. These areas are characterized by their natural landscapes and minimal human impact. On the other hand, the five most developed villages, with the highest percentage of developed land, are PagoPago (4% developed, 20% agriculture), Aua (5% developed, 20% agriculture), PagoPago (4% developed, 20% agriculture), Fagaalu (3% developed, 4% agriculture), Amouli (3% developed, 11% agriculture), and Pagai (3% developed, 10% agriculture). These villages have a higher degree of human activity, which may contribute to increased runoff and potential water quality issues.

3.5 Future Climate Predictions

It is clear that present conditions and historical datasets are no longer reliable indicators of the climate and hydrology of the future. To better understand future water availability for village water systems, we performed a basin-wide analysis of water budget components to assess potential changes to village water availability. The climate scenarios used in this analysis, based on projections by Wang and Zhang (2016), indicate that by the late 21st century, American Samoa may experience a significant increase in annual mean rainfall (10-25%) and a moderate rise in surface air temperature, with higher temperature increases under the high emissions scenario (RCP 8.5). The frequency of weak tropical cyclones is projected to decrease under both emissions scenarios, with a more pronounced decline under RCP 8.5. Given the uncertainty in future greenhouse gas emissions, analyzing different scenarios allows us to understand a range of potential impacts on water resources, providing critical context for planning and adaptation efforts.

Four critical water budget components were used to assess impacts to village water systems: precipitation, groundwater recharge, runoff, and evapotranspiration (ET), which can each and together provide an understanding of the hydrological dynamics in Tutuila, American Samoa. Shuler et al. (2021) calculated these components using the Soil Water-Balance-2 (SWB2) model, which provided high temporal and spatial resolution estimates for groundwater recharge on Tutuila. By running the calibrated model with dynamically downscaled climate predictions and future land-cover scenarios, the study projected potential changes in water availability under varying future conditions. ***Table 5*** presents the percentage differences in water budget component data taken from Shuler et al. (2021) delineated by each village in the present analysis, illustrating how modeled future climate conditions may impact each village differently.

The projected changes in water budget components under both RCP 4.5 and RCP 8.5 scenarios would have implications for the village water systems across Tutuila. The anticipated increases in precipitation and corresponding rise in groundwater recharge would enhance the overall availability of water resources, potentially improving water supply reliability for villages with actively used water systems. Therefore, if Wang and Zhang's (2016) projections prove to be correct the estimates of village water availability in this report would be considered to be conservative, -low-end estimates of future availability, albeit considering that these projections are for the years 2080-2100.

For villages such as Afao, Aoa, and PagoPago, which are projected to experience substantial increases in recharge, this could translate into a more resilient water supply, better able to meet the demands of growing populations or increased usage during dry periods. However, the significant increases in runoff projected for many villages, particularly under the RCP 8.5 scenario, raise concerns about flood risks and the potential for stormwater management challenges. Villages like Sailele and Tula, where runoff is expected to more than double, may face heightened risks of flooding, which could overwhelm existing infrastructure and lead to water quality issues, such as contamination from surface runoff entering water supply systems. If village water systems remain in use, they may need to invest in enhancing water storage capacities, improving stormwater management systems, and developing strategies to protect water quality in light of these anticipated hydrological shifts. The variations between the moderate (RCP 4.5) and extreme (RCP 8.5) scenarios also suggest that the degree of adaptation required will depend heavily on the future trajectory of global emissions.

Table 5: Percent change differences in water budget components between present conditions and under modeled future climate scenarios both for RCP 4.5 and RCP 8.5 emissions scenarios. Future climate scenarios are based on projections from Wang and Zhang (2016), while water budget components—precipitation (Precip.), groundwater recharge (GW Recharge), stream runoff, and evapotranspiration (ET) — data are derived from Shuler et al. (2021).

					Water budget change: Present vs. Future climate (%-Difference)							
					Scenario under RCP 4.5 Emissions				Scenario under RCP 8.5 Emissions			
Map Number	Village Name	Village Water System Status	Drain Area (mi2)	Ave. Precip. (inches)	Precip.	GW Recharge	Runoff	ET	Precip.	GW Recharge	Runoff	ET
7	Sailele	Not used	0.12	105	18%	25%	146%	0.3%	6%	9%	64%	0.3%
8	Aoa	Actively used	0.39	110	17%	26%	99%	0.4%	7%	9%	50%	0.4%
9	Aua	Actively used	0.30	176	18%	22%	66%	0.3%	12%	14%	56%	0.2%
10	Amaua	Not used	0.10	147	20%	23%	102%	0.0%	10%	11%	54%	0.0%
11	Auasi	No Data	0.13	108	16%	26%	84%	0.3%	6%	10%	47%	0.3%
14	Pagai	No Data	0.12	116	21%	31%	124%	0.2%	9%	13%	55%	0.1%
16	Auto	Not used	0.29	168	18%	18%	88%	0.0%	9%	8%	51%	0.0%
18	Alega	Actively used	0.27	177	18%	17%	89%	0.0%	9%	8%	51%	0.0%
19	Fagatogo	Not used	0.12	200	17%	14%	88%	0.0%	12%	10%	59%	0.0%
20	Utulei	No Data	0.03	179	17%	14%	114%	0.0%	10%	8%	65%	0.0%
22	Faganeanea	May be used	0.25	209	17%	13%	84%	0.0%	11%	9%	51%	0.0%
23	Fagalii	Actively used	0.37	149	13%	13%	59%	0.1%	11%	12%	34%	0.0%
25	Asili	Actively used	0.62	204	16%	15%	53%	0.0%	11%	12%	33%	0.0%
26	Amaluia	Actively used	0.35	184	16%	16%	53%	0.1%	11%	12%	37%	0.1%
27	Seetaga	Actively used	0.46	178	15%	14%	59%	0.1%	12%	12%	37%	0.1%
28	Afao	Actively used	0.21	184	16%	16%	65%	0.1%	12%	12%	46%	0.0%
29	Utumea W.	No Data	0.16	158	15%	16%	59%	0.1%	11%	13%	40%	0.0%
31	Amanave	No Data	0.17	136	15%	19%	56%	0.3%	12%	15%	50%	0.3%
32	Agugulu	Actively used	0.16	148	16%	20%	62%	0.3%	12%	14%	47%	0.3%
36	Nuuuli	Actively used	0.77	221	18%	16%	61%	0.1%	10%	9%	39%	0.0%
37	Fagaalu	Actively used	0.66	203	17%	13%	83%	0.2%	11%	10%	51%	0.1%
38	Matuu	May be used	0.25	204	17%	12%	91%	0.0%	11%	9%	50%	0.0%
40	Laulii	Actively used	0.54	175	18%	20%	86%	0.3%	9%	9%	58%	0.1%
41	Avaio	No Data	0.02	157	19%	21%	102%	0.0%	9%	9%	61%	0.0%
42	Fagaitua	May be used	0.25	132	21%	25%	101%	0.0%	10%	12%	49%	0.0%
43	Alofau	Actively used	0.10	112	18%	28%	181%	0.3%	7%	11%	97%	0.4%
44	Amouli	Actively used	0.21	109	17%	24%	125%	0.6%	7%	10%	63%	0.5%
45	Alao	Actively used	0.30	106	17%	26%	84%	0.5%	7%	9%	49%	0.4%
46	Tula	No Data	0.29	99	20%	33%	131%	1.0%	10%	13%	129%	0.8%
47	Onenoa	Actively used	0.13	101	18%	28%	99%	0.2%	8%	11%	60%	0.3%
48	Masausi	Actively used	0.14	111	21%	27%	108%	0.2%	9%	12%	46%	0.1%
49	Masefau	Actively used	0.47	153	19%	20%	106%	0.2%	11%	10%	69%	0.1%
50	Afono	Actively used	0.58	170	18%	19%	100%	0.2%	11%	10%	79%	0.1%
51	Vatia	Actively used	0.44	167	19%	21%	97%	0.1%	12%	12%	72%	0.1%
54	Fagamalo	May be used	0.28	155	16%	17%	89%	0.0%	9%	10%	40%	0.0%
55	Maloata	Not used	0.85	184	15%	14%	62%	0.0%	11%	12%	29%	0.0%
56	Poloa	No Data	0.21	134	13%	13%	55%	0.1%	11%	13%	36%	0.1%
57	PagoPago	Actively used	0.44	201	18%	15%	75%	0.4%	13%	13%	48%	0.2%
58	Aumi	No Data	0.14	172	18%	19%	81%	0.0%	9%	9%	43%	0.0%
60	Failolo	No Data	0.08	142	16%	18%	57%	0.0%	12%	13%	43%	0.0%
63	Fagasa	Actively used	0.54	186	18%	17%	78%	0.3%	12%	11%	53%	0.1%
64	Leone	Actively used	0.99	208	17%	16%	58%	0.1%	13%	13%	39%	0.1%

4. Future work and Data availability

This report represents one of the first known efforts to collect information on village water systems and usage in American Samoa. Our findings highlight the potential for village water systems to serve as a critical secondary water source, enhancing the overall resilience of Tutuila's water supply infrastructure. As climate change introduces greater variability in weather patterns and an increased likelihood of extreme events, the reliability of municipal groundwater systems has potential to be compromised by factors such as power outages, rising salinity levels, or damage from natural disasters. In such scenarios, village water systems, with their decentralized nature and reliance on local surface water sources, could provide an essential backup to the centralized municipal system, ensuring that communities have continued access to water during emergencies. Additionally, these traditional systems can be maintained at the community level, offering a greater degree of flexibility and responsiveness. By investing in the preservation and enhancement of village water systems, there is an opportunity to build a more robust, multi-layered water security strategy that mitigates the risks posed by environmental changes and infrastructure vulnerabilities. This dual system approach not only preserves cultural heritage but also creates a safeguard against the unpredictable challenges of a changing climate.

Data collection for this project took place during the COVID-19 Pandemic, and due to the limitations imposed therein, the scope of data collection was restricted, focusing only on village leadership rather than individual households. In the future, additional data collection could involve additional visits and photo documentation of village system infrastructure as well as documenting additional historical accounts of village water use. Surveying village residents, with appropriate research protocols in place, would produce better estimates of the number of households relying on village water. The data and code from this project are publicly available in this GitHub repository: https://github.com/cshuler/Am_Samoa_WUDR_ASPA/Village_Water.

Acknowledgements

We would like to acknowledge the significant contributions of the director of the Office of Samoan Affairs and all]the village pulenuu and leaders for their collaboration, support, and their willingness to share their extensive traditional knowledge, without which this project could not have been. We also must highlight the invaluable contributions of the report’s co-author, Valentine Vaeoso who performed the majority of fieldwork independently, throughout the trying times of the Covid-19 lockdown. Additionally we would like to thank Kelley Anderson-Tagarino, Meagan Curtis, and Sabrina Woofter for their assistance in helping to coordinate staffing needs during the pandemic. Finally, we remember Brian Thompson, whose expertise and fiscal assistance were instrumental in making this project possible.

References

ASDOC (2022). American Samoa Statistical Yearbook: 2022. (39th ed.). The American Samoa Department of Commerce Statistics and Analysis Division. Retrieved from https://www.doc.as.gov/resource-center (Accessed 2024-07-17)

Daly, C., Smith, J., Doggett, M., Halbleib, M., & Gibson, W. (2006). High-resolution climate maps for the Pacific Basin Islands, 1971–2000. National Park Service Pacific West Regional Office Rep. Retrieved from http://www.botany.hawaii.edu/basch/uhnpscesu/pdfs/sam/Daly2006AS.pdf. (Accessed 2020-7-18-)

Davis, D.A., (1963) Ground-water reconnaissance of American Samoa: U.S. Geological Survey Water-Supply Paper 1608-C, 21 p. Retrieved from https://pubs.usgs.gov/wsp/1608c/report.pdf (Accessed 2024-08-10)

Faleomavae, E. F. (1990). Some perspectives on American Samoa's political relationship with the United States. Pacific Studies, 13.

Green, R. C. (1991). "The Lapita Horizon and Traditions - Signature for one set of Oceanic migrations." In: The Lapita Cultural Complex in Time and Space: Expansion Routes, Chronologies and Typologies. Eds. P. V. Kirch and T. L. Hunt. pp. 41–68. Auckland: University of Auckland.

Leibowitz, A. H. (1980). American Samoa: Decline of a Culture. Cal. W. Int'l LJ, 10, 220.

Meyer, R. A., Seamon, J. O., Fa'aumu, S., & Lalogafuafua, L. Classification and Mapping of Wildlife Habitats in American Samoa: An object-based approach using high resolution orthoimagery and LIDAR remote sensing data; (2016), Report in preparation for American Samoa Department of Marine and Wildlife Resources. Available upon request to Department of Marine & Wildlife Resources, Executive Office Building, Pago Pago, AS, 96799.

NGDC (National Geophysical Data Center) (2013). American Samoa 1/3 Arc-second MWH Coastal Digital Elevation Model [dataset]. https://catalog.data.gov/dataset/pago-pago-american-samoa-coastal-digital-elevation-model34341 (Accessed 2015-12-10).

Shuler, C., Brewington, L., & El-Kadi, A. I. (2021). A participatory approach to assessing groundwater recharge under future climate and land-cover scenarios, Tutuila, American Samoa. Journal of Hydrology: Regional Studies, 34, 100785.

Stearns, H. T. (1944). Geology of the Samoan islands. Bulletin of the Geological Society of America, 55(11), 1279-1332.

URS (1978). American Samoa water resources study. U.S. Army Engineer District, Honolulu. Retrieved May 8, 2024,from https://www.govinfo.gov/content/pkg/CZIC-tc424-a44-u77-1978/html/CZIC-tc424-a44-u77-1978.htm

Wang, Y., Zhang, C., (2016). Project Final Report - 21st Century High-resolution Climate Projections for Guam and American Samoa. Retrieved from: https://www.sciencebase.gov/catalog/item/583331f6e4b046f05f211ae6. (Accessed 2020-07-18).

Wong, M. F. (1996). Analysis of streamflow characteristics for streams on the island of Tutuila, American Samoa (Vol. 95, No. 4185). US Department of the Interior, US Geological Survey. Retrieved from: https://pubs.usgs.gov/wri/1995/4185/report.pdf (Accessed 2024-08-10)