A SURVEY OF LAUFUTI STREAM, TAÚ ISLAND, NATIONAL PARK OF AMERICAN SAMOA

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Technical Report NPS/NRWRD/NRTR-2001/290

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National Park Service - Department of the Interior
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August, 2001

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United States Department of the Interior
National Park Service

ABSTRACT

Laufuti stream, on the island of Taú, American Samoa is a complex interrupted perennial stream that includes a perennial spring-fed lower section at sea level, an intermittent middle section, and a perennial upper section that percolates into permeable volcanic rock. The stream courses across the floor of a collapsed caldera, separated into sections by faulting. As a result of the geologic history and youth of the island of Taú, the pattern of physical zonation exhibited by Laufuti differs from that found in most tropical Pacific island streams.

The macro-fauna of Laufuti stream consists primarily of amphidromous species that are relatively common and widespread in the tropical Pacific. However, in comparison to stream communities on Tutuila, American Samoa's largest and best-studied island, Laufuti is unusual. Its shrimp community is diverse and abundant, dominated by <u>Macrobrachium latimanus</u>, a species that is neither widespread nor abundant on Tutuila. It also supports a relatively diverse, alien-free freshwater fish community, which includes <u>Anguilla megastoma</u>, a species of limited occurrence on Tutuila. Zonation of macrofauna occurs in Laufuti, though the absence of an estuarine connection and the severe barrier represented by the Falls Zone have produced a pattern that is uncommon.

Laufuti's watershed is dominated by native forest and shrublands, with no active plantations. Water quality is high, with no evidence of degradation from anthropogenic input of nutrients or bacteria. Laufuti is one of the most undisturbed, pristine, and unusual streams in American Samoa, supporting a biota that is one of the most diverse and abundant of any stream in American Samoa.

ACKNOWLEDGEMENTS

This work was made possible through the financial support of the National Park Service, National Park of American Samoa, Christopher Stein, Superintendent. Mino Fialua, Francis Huber, Dain Perry, David Vana-Miller and Don Tiernan provided assistance with fieldwork. Francis Huber and Sheila Weigman of the American Samoa Environmental Protection Agency provided assistance with water analyses.

Specimen identification was provided by Robert Cowie, Lucius Eldredge, and David Muir of the Bishop Museum, and by David Smith and Lynne Parenti of the Smithsonian Institution, National Museum of Natural History.

Preliminary drafts were greatly improved upon as a result of critical review by Peter Craig, Mark Flora, and John Portnoy. Critical review by David Vana-Miller and two anonymous reviewers greatly improved the final draft. Melia Lane-Kamahele and Mark Adams created the map figures.

INTRODUCTION

Although the U.S Territory of American Samoa (Figures 1 and 2) contains many freshwater streams, studies of them are few. Most work on the Territory's streams has been directed towards streamflow (Matsuoka 1978, Wong 1996), groundwater quantity and quality (Bentley 1975, Izuka 1996, 1997) or surface water quality (M&E Pacific 1979). The only known survey of American Samoan streams that includes both biological (other than bacteria) and physical/chemical data is the American Samoa Water Resources Study (Burger and Maciolek 1981, U.S. Army Corps of Engineers 1981). This survey collected, fish, macro-invertebrates, and basic stream chemistry from 37 streams on Tutuila. These studies provide an important baseline for monitoring changes over time in Tutuila streams, as well as a point of reference in evaluating streams elsewhere in American Samoa.

Laufuti Stream is a prominent feature on the southern coast of Taú Island (Figure 3). It is an interrupted perennial stream, i.e. some stream sections are perennial while others are intermittent in flow. Its presence along some of the island's more accessible coastline make it a logical destination for hikers, and hence National Park Service plans call for improving trail access along the coast to Laufuti Spring (NPS 1997). While such plans are being formulated, the ability to evaluate their potential impacts and provide a basis for monitoring future changes in stream conditions was hampered by a lack of physical, chemical or biological data on Laufuti, or any other stream on the island of Taú. Not only were data lacking, but with the exception of the relatively short portion of the stream accessible from the coast (hitherto referred to as Lower Laufuti), access to the remainder of the stream was difficult and largely unexplored by park staff.

This survey was conducted to document for the first time physical and chemical parameters and the macrofauna of Laufuti Stream, and compare it with other freshwater streams in American Samoa and other tropical Pacific islands. Since Laufuti, and the park in general receive little visitation at present, this survey documents baseline conditions prior to any significant visitation.

MATERIALS AND METHODS

Survey Sites and Dates of Sampling

Based on physiography and accessibility, the stream was divided into four sections, separated from each other by sheer cliffs/canyon walls that are also waterfalls during periods of stream flow (Figure 4). Only three sections, referred to as Lower Laufuti (LL), Middle Laufuti (ML), and Upper Laufuti (UL), were accessible. The fourth, referred to as the Falls Zone (FZ), is a series of four sheer waterfalls that begin at 121 ft (37m) elevation and rise to 862 ft (263m). The Falls Zone separates Lower Laufuti, which is accessed from the coast, from the rest of Laufuti Stream. The survey was conducted in three sampling periods; 19-21 November 1996 and 25-26 April 1997 (Lower Laufuti), and 8-12 July 1997 (Middle and Upper Laufuti). A total of nine stations (three/accessible section), ranging in elevation from 6 ft (2m) to 1532 ft (467m) were sampled (Figure 5). Elevations of sampling stations and physiographic features were determined using a Thommen Digital Altitronic altimeter, accurate to approximately 30 ft (10m). Features of sampling stations and major physiographic features of Laufuti stream are summarized in Table 1 and Appendix A, respectively.

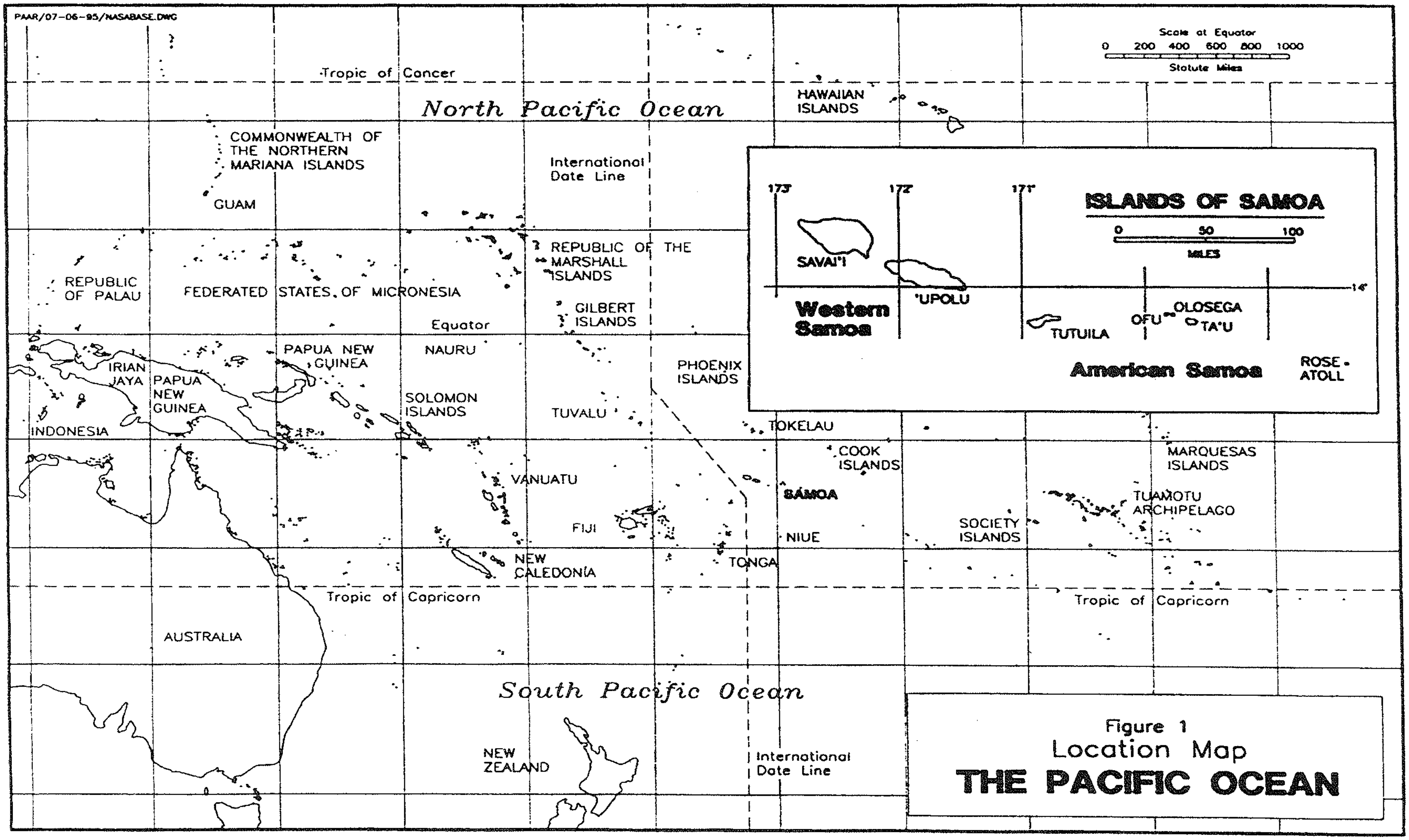
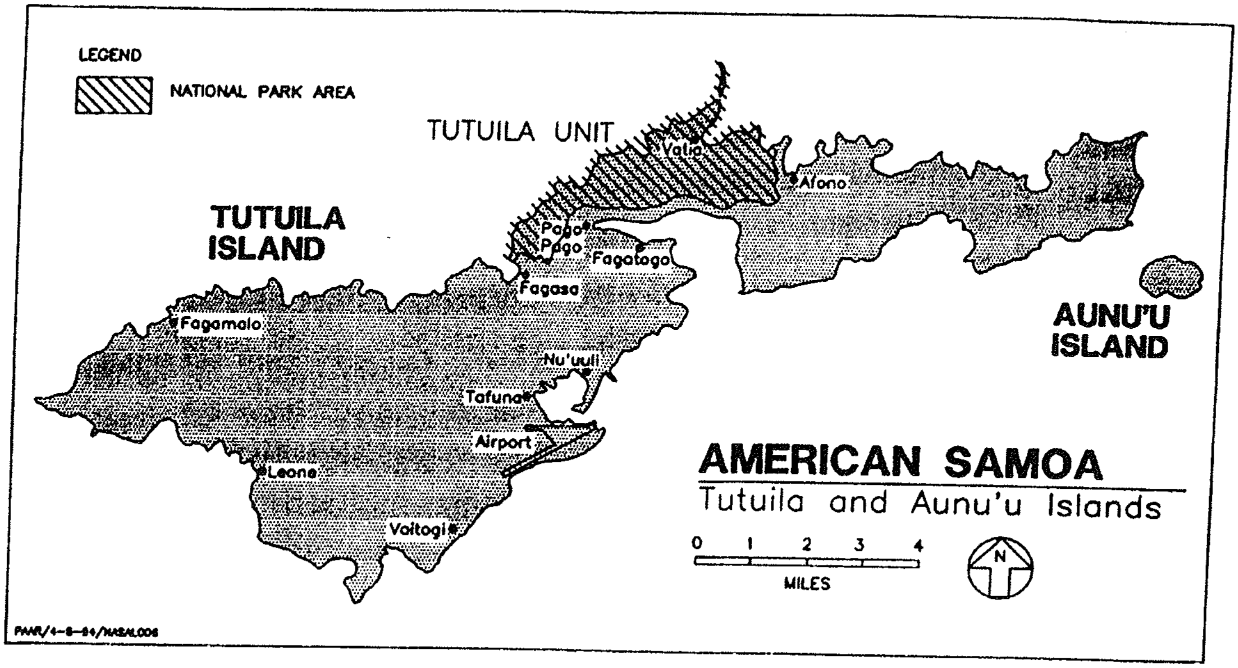


Figure 1. Location of the Samoan Archipelago.



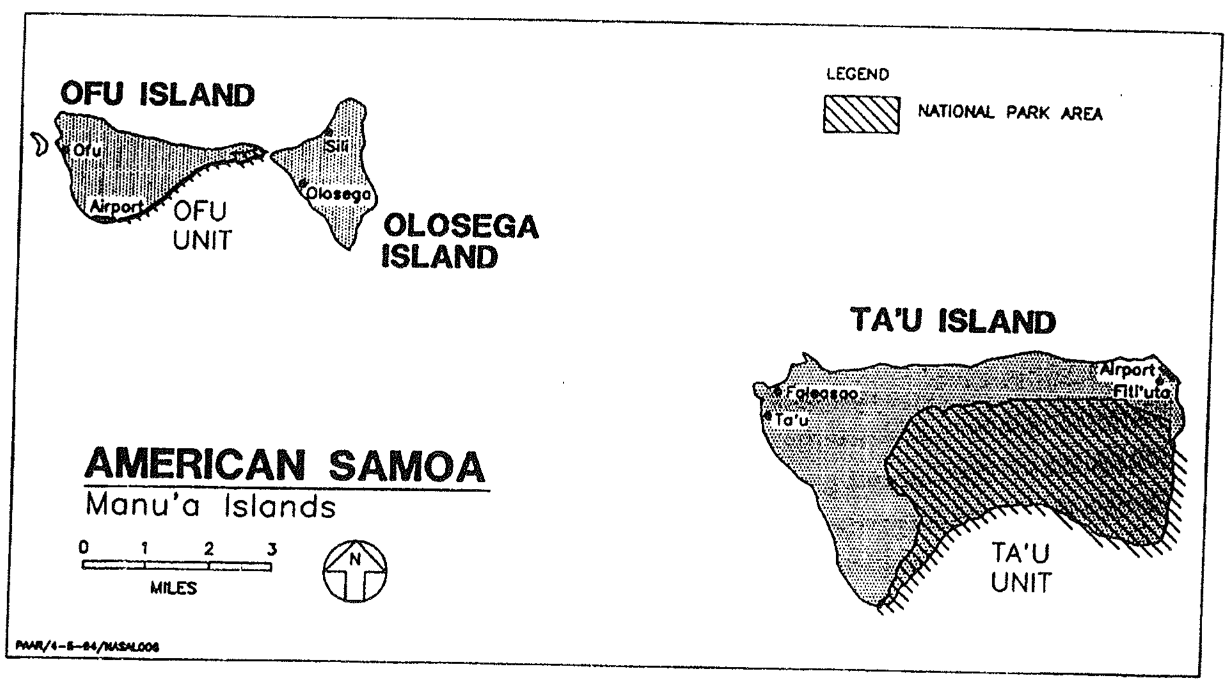


Figure 2. Major islands of American Samoa and units of the National Park of American Samoa.

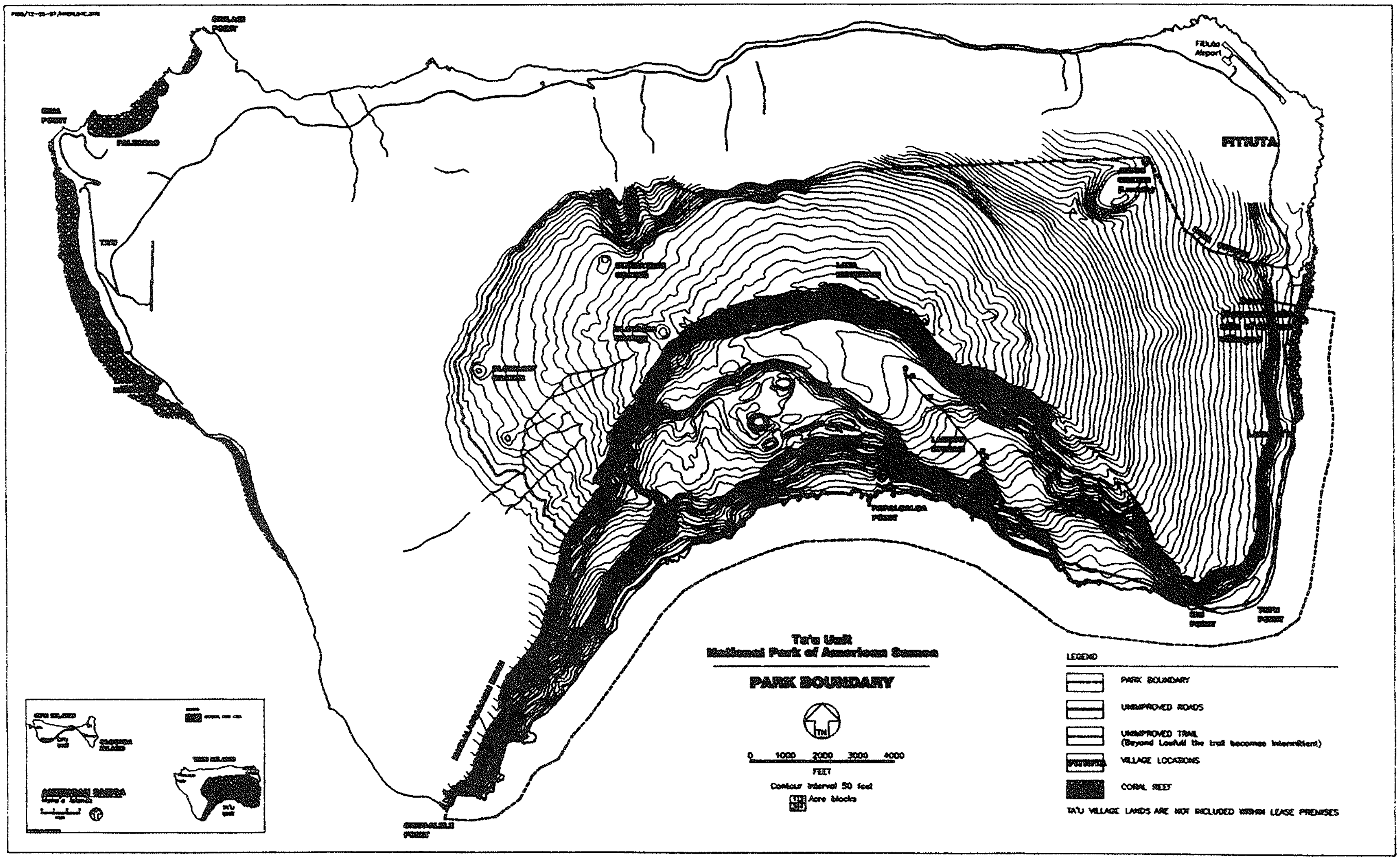


Figure 3. Taú Unit, National Park of American Samoa.

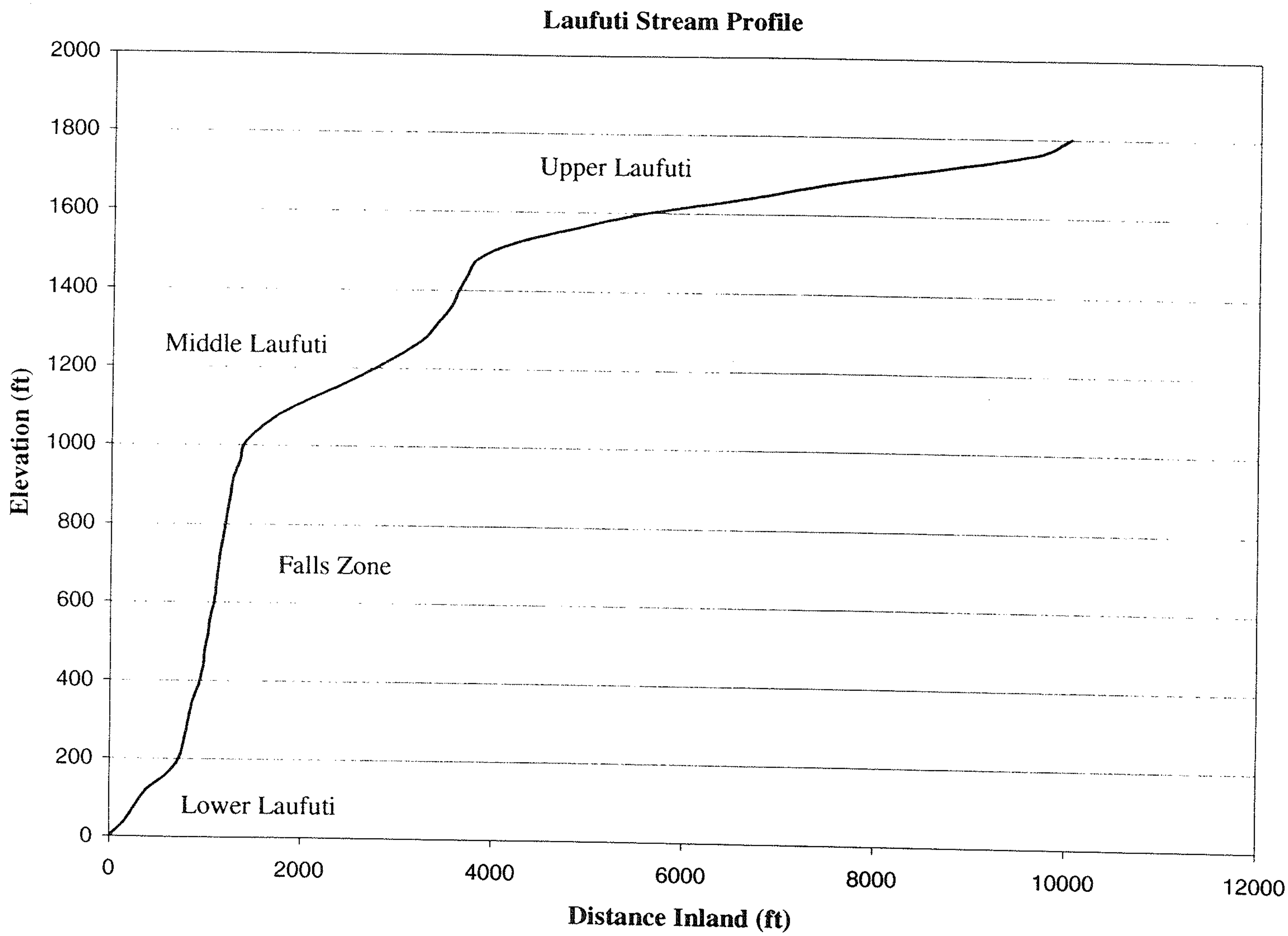


Figure 4. Profile of Laufuti Stream showing the four sections referred to in the text.

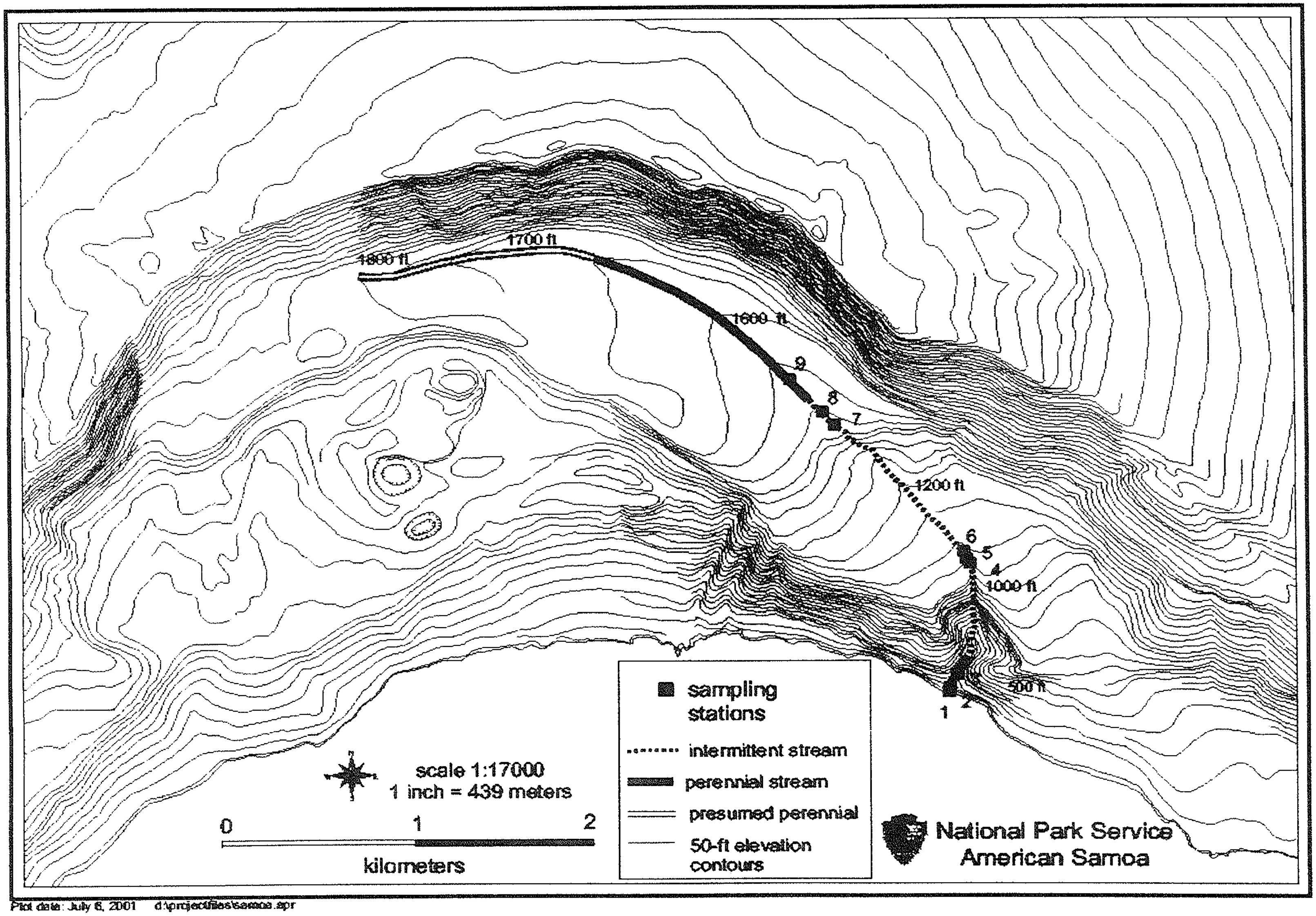


Figure 5. Laufuti Stream, Taú, showing sampling locations and sections of perennial and intermittent flow.

Physical Description

Taú is the remnant of a constructional dome that collapsed, forming a caldera on the island's south side. The caldera has only a northern rim and to the south is a valley that slopes downward, extending more than 8,000 feet below sea level. The caldera was not formed at the exact summit of Lata Mountain, the island's highest point, but was located slightly to the south (Stice and McCoy 1968).

Major faulting produced the 1,400-foot escarpment that extends up to the island's summit, Lata Mountain, forming the northern boundary of the bench or downfaulted block which Laufuti stream flows across. This bench, referred to as Afuatai by Stice and McCoy (1968) and Laufuti Terrace by Whistler (1992), is one of two benches within the collapsed caldera that represent the caldera floor. The second, referred to as Ele'elesa by Stice and McCoy (1968), is called Liu Bench on the USGS Topographic Map (USGS 1963). Residents of Taú explained to me that both benches are known locally as Liu. Stice and McCoy (1968) also noted discrepencies between locally-used versus published place names.

Laufuti Stream flows across Afuatai, a comparatively flat feature that rises up in a northwesterly direction from Aufotu Cove on the south and increases gently in elevation up to 1800+ ft. It is bounded to the north by the fault escarpment leading up to Lata Mountain, and on the south, by fault escarpments leading down to the coast and Ele'elesa or Liu Bench. Geologically, Afuatai (Laufuti Terrace) consists of lava flows of the Lata formation. Above it, on Lata Mountain are post-caldera volcanics of the Lata formation, and below, Ele'elesa or Liu Bench consists of intra-caldera volcanics (Stice and McCoy 1968).

In addition to the major faults, Stice and McCoy (1968) mapped a number of lesser faults to the southeast of the Afuatai Bench. One extends across the stream's valley at 1,400 ft elevation separating Upper from Middle Laufuti. A second extends from 200 to 800 ft elevation and angles across the stream valley. This fault, plus erosion through a complex of hundreds of dikes from sea level to 800 ft elevation at the mouth of Laufuti (Stice and McCoy 1968), have created the series of cascades referred to here as the Falls zone.

Lower Laufuti is a perennial, spring fed stream flowing through a highly dissected bedrock channel. The stream flows through a narrow, steep canyon with vertical walls up to 100 meters above the streambed. Stream habitat alternates between riffles, runs, pools, and cascades. Substrate is predominantly boulder and cobble. The upper end of Lower Laufuti is defined by the base of the "first waterfall", elevation 121 ft (37 m).

The Falls Zone consists of a series of four sheer bedrock waterfalls, ranging in height from ca. 45 ft (13.7 m) to 430 ft (131 m). There are pools of standing water at the base of the first (moving upstream from the mouth) and second waterfall (the latter is not readily accessible). Based on numerous visits between 1996 and 1998, there is always a slight flow of water over the first waterfall, but only once was water observed flowing over the second waterfalls. The third (and largest waterfall) was never observed with water flowing over it. The pool at the base of the fourth waterfall was dry on the four occasions it was observed from above.

Table 1. Physical habitat of Laufuti Stream stations. Stream flow measured on 9 July 1997.

Station	Section	Elev ft(m)	Streambed Feature	Substrate	Length (m)	Width (m)	Depth (m)	Discharge (cfs)
1	Lower	6(2)	riffle	boulder	20	2.2	0.4	2.01
2	Lower	48(15)	riffle/run	boulder-cobble	20	2.5	0.8	0.67
3	Lower	110(34)	pool-flowing	boulder-cobble	20	2.5	0.2	0.07
4	Middle	1040(317)	pool-standing	bedrock-boulder	9	5	0.5	
5	Middle	1056(322)	pool-standing	bedrock-boulder	10	5	0.5	
6	Middle	1077(328)	pool-standing	boulder-cobble	8	8	0.7	
7	Upper	1469(448)	pool-standing	bedrock	6	3	0.2	
8	Upper	1493(455)	pool-standing	bedrock	10	3	0.3	
9	Upper	1532(467)	pool-flowing	bedrock	16	0.4	0.2	0.1

Middle Laufuti is intermittent. No flow was observed on any of the survey dates. However, judging from the scouring of bedrock and dry plunge pools, it experiences periods of very heavy flow. It is a curvilinear dissected bedrock channel, where the channel depth varies from ca. 1 to 10 meters. Substrate is generally a mixture of bedrock and boulders, and occasional cobble, though in dry pools there is more cobble and gravel. From 862 ft elevation (263 m) up to 1024 ft (312 m), where the access trail enters the streambed, it is a high gradient stream, dominated by boulders and bedrock, with several large dry pools and cascades of up to 10-15 meters in height. There is little standing water here. From 1024 ft to 1134 ft (346 m) elevation, the streambed is flatter, and more uniform in its ascent (i.e. fewer and smaller dry waterfalls). The streambed is more bedrock and fewer boulders. Most of the pools with standing water in Middle Laufuti were located between 1024 ft and 1134 ft elevation. From 1134 ft to the dead end at 1257 ft (383 m) elevation, Middle Laufuti again becomes a high gradient stream, with more large boulders and deep dry pools below dry waterfalls of 5-10 meters height.

Upper Laufuti begins at the top of a waterfall/canyon at 1422 feet (433 m) elevation and is relatively flat, with very little incision into the bedrock streambed. The streambed surface of Upper Laufuti reflects more the influence of volcanic activity than of post-volcanic water flow, with features of volcanic flow readily observable. These correspond to the horizontal pahoehoe flows of Afuatai (Stice and McCoy 1968). From 1422 ft to 1510 ft (460 m) elevation, there is no flowing water. Much of the streambed consists of numerous small (usually less than 1 meter diameter), shallow (maximum 0.3 m deep) pools. From 1510 ft to 1650 ft (503 m) elevation, Laufuti becomes a slow flowing perennial stream, 1-2 meters wide, and 0.1 to 0.5 m deep. Exploration of Upper Laufuti stream was halted at 1650 ft (503 m) elevation. At this point the stream was flowing, ca. 1 m wide, 0.5 m deep, and heavily overgrown with dense shrubs. Even though the topographic map for Taú (USGS 1963) shows that water flow does not occur on Laufuti above 1200 ft, a re-interpretation of the map, in light of these observations, suggests it is ca. another kilometer to the stream's source.

Physicochemical Description

The physical characteristics of sampling sites were described based on streambed features (pools, riffles, runs, cascades, and falls) and substrate type (bedrock, boulder, cobble, gravel, sand, and silt) using the same definitions as U.S. Army Corps of Engineers (1981).

Discharge was measured at five locations on Lower and Upper Laufuti. With the exception of the first waterfall, discharge was calculated by the six-tenths-depth method (Platts et al. 1983). Wherever possible the stream channel was divided into partial sections and discharge was measured for each, then summed to obtain total discharge. Velocity was measured as average velocity over a 60 second period with a Global Water model FP-101 Flow Probe. At the first waterfall, discharge was calculated using a bucket and watch to measure the volume of water trickling down over a 1-minute period.

All measurements of water quality were taken from mid-channel or mid-pool, and ca. 10-15 cm below the surface. On 9 July 1997, the full suite of parameters described below was measured at stations 1-9. A subset of these was measured on 25 April 1997 at stations 1-3.

Temperature, salinity, and conductivity were measured using a Yellow Springs Instruments Model 33 S-C-T meter. pH was measured with a HANNA Multipurpose pH field meter, model 8314. Dissolved oxygen and percent saturation were measured with a Yellow Springs Instruments model 55 dissolved oxygen meter. Total and phenolpthalein alkalinity were determined to the nearest 4 ppm $CaCO_3$ by titration using a LaMotte model WAT-MP-DR alkalinity test kit. Turbidity was measured with a HACH model 2100P portable turbidimeter. All instruments were calibrated per manufacturer's instructions prior to use at each sampling station.

Water samples for nutrient analysis were collected and stored in clean, sterile BOD bottles in the course of fieldwork, and transported back to a freezer by day's end. All samples were held frozen and shipped by airfreight to AECOS Laboratories (Kailua, Hawaii) for analysis. Total nitrogen and total phosphorous were determined using United States Environmental Protection Agency methods 353.2 (modified for total nitrogen) and 365.1 respectively (USEPA 1979).

Levels of coliform bacteria were determined for samples of water collected at the nine sampling stations on 12 July 1997. Water samples were transported back from sampling stations in backpacks with blocks of ice, transferred to a freezer for further chilling, and then transported in a cooler by airplane to the American Samoa Environmental Protection Agency Water Quality Laboratory on Tutuila. The samples were tested in accordance with the American Samoa Environmental Protection Agency Membrane Filter coliform testing protocol, which follows those of APHA (1998).

Biological Inventory

On Lower Laufuti, biota were initially sampled with funnel traps (Gee's Minnow Trap, model G-40) baited with canned sardines. These yielded relatively few captures, in spite of the observed presence of many fish and crustaceans. Because of the low capture rates of funnel traps, but also to facilitate comparison with inventories conducted on Tutuila (U.S. Army Corps of Engineers 1981), electroshocking (Smith Root Backpack Electroshocker model 15-C) was conducted on 20 meter long sections at stations 1-3 (Figure 5). The entire length of each section was electroshocked for 159 to 229 seconds (mean=199 seconds). Two persons standing downstream with long handled dip-nets collected stunned specimens.

In electroshocking Lower Laufuti, it became apparent that capture rates were significantly influenced by stream velocity. Pools and other slow moving portions of sampling sites produced few captures, though many individuals could be seen reacting to the shocker. Rather than being carried downstream into nets, the stunned animals dropped down between rocks and went unsampled. Since Middle and Upper Laufuti contained only non-flowing and slowly flowing pools, sampling with an electroshocker was deemed inappropriate.

Sampling of Middle (stations 4-6) and Upper Laufuti (stations 7-9) was conducted with small funnel traps only (Figure 5). Sampling stations on Middle Laufuti were discrete, non-flowing, isolated pools. On Upper Laufuti, sampling stations seven and eight were in similar pools whereas station nine was located in a slowly flowing pool. Sampling effort at each station consisted of three funnel traps. Traps were initially baited with half a tin of sardines packed in oil. Traps were checked and re-baited 2 days later and all specimens collected for identification and vouchering. Traps were rechecked and removed one day later. In addition, snails and eels were hand-collected opportunistically, the latter for stomach analysis. At station 9, the density of *Melanoides* (a gastropod) was estimated with a 0.0929 m^2 quadrat placed randomly in the stream.

Biological specimens collected for identification were fixed in 10% formalin for 24 hrs, soaked in water for 48 hours, and stored in 50% ethanol. Freshwater shrimp were identified using keys developed for American Samoa (Devaney 1981). Identification was confirmed at the Bishop Museum, Honolulu (David Muir and Lucius Eldredge, pers. comm., 1998) where a representative sample of specimens was deposited. Snails were identified at the Bishop Museum, Honolulu (Robert H. Cowie, pers. comm. 1997). Fish specimens were sent to the National Museum of Natural History for identification. Anguillids were identified by David G. Smith and all other specimens by Lynne Parenti (pers. comm. 1998). David Smith and Lynne Parenti, National Museum of Natural History provided nomenclature and synonymy of fish used in this report (Parenti, pers. comm. 1998). A representative sample of each species was accessioned into the NMNH collection (accession #419049).

RESULTS

Discharge and Flow

Discharge and flow data are limited to measurements from 9 July 1997 (Table 1), plus incidental observations made on 10 dates over the course of this survey. Discharge in Lower Laufuti on July 9, 1997 increased from 0.0045 cubic feet/second (cfs) at the first waterfall (elev. 121 ft), to 2.01 cfs (902 gallons/minute) at station 1, just before Laufuti enters the Pacific. Stations 2 and 3 had discharges of 0.67 and 0.07 cfs, respectively. In Lower Laufuti, seepage of water from the base of the canyon walls into the streambed was observable at many locations, accounting for the downstream increase in flow and its perennial nature. Water flow over the second waterfall (elev. 166 ft, 51 m) was observed during only 10% of the visits, and water was never observed flowing over the third or fourth waterfall. Similarly, water was never observed seeping into or flowing through Middle Laufuti or flowing over the waterfall separating Middle and Upper Laufuti. In Upper Laufuti, flow was intermittent up to 1510 ft (460 m) elevation, then became perennial, up to at least 1650 ft (503 m), elevation. Discharge at station 9 (elev. 1532 ft, 467 m) was 0.1 cfs (Table 1). In total, these limited data and observations show Laufuti to be an interrupted, perennial stream, with spring flow appearing to provide most of the discharge in Lower Laufuti.

Water Quality Parameters

Station values and stream section mean values for water quality parameters are presented in Tables 2, 3, and 4.

Conductivity ranged from 63 to 101 *u*mhos/cm on 9 July 1997 (mean=81.7, sd=15.3). By stream section, mean conductivity was 95.6, 84.3, and 65.3 for Lower, Middle, and Upper Laufuti, respectively.

Table 2. Water quality parameters measured in Laufuti stream, 9 July 1997. CNCC=confluent, non-coliform colonies. TNTC=too numerous to count.

	Lower Laufuti			Middle Laufuti			Upper Laufuti				
Parameter	station 1	station 2	station 3	station 4	station 5	station 6	station 7	station 8	station 9	Mean	sd
Temperature (C^o)	23.5	23	23.1	22	22	22	22.6	22	22	22.5	0.6
Salinity (ppt)	0	0	0	0	0	0	0	0	0	0	0
Conductivity (umhos/cm)	91	95	101	73	80	100	64	63	69	81.7	15.3
Turbidity (NTU's)	0.25	0.25	0.25	1.25	0.85	0.75	0.5	0.73	0.49	0.59	0.34
pH	8.8	8.75	7.69	6.4	6.4	6.3	7.15	8.2	8.9	7.62	1.09
Dissolved Oxygen (mg/l)	6.15	6	6.1	2.66	1.15	1.22	8.4	5.5	7.8	5.0	2.69
Dissolved Oxygen (% saturation)	73	71	72.3	31	14	14.6	95	63.6	90	58.3	30.8
Total Alkalinity (mg/L $CaCO_3$)	48	48	40	32	28	28	24	20	28	32.9	10.2
Total Nitrogen (mg N/L)	0.171	0.174	0.235	0.566	0.2	0.332	0.189	0.124	0.442	0.27	0.15
Total Phosphorous (mg P/L)	0.096	0.094	0.096	0.05	0.02	0.038	0.018	0.11	0.035	0.06	0.04
N/P ratio (molar)	3.94	4.09	5.41	25.02	22.11	19.31	23.21	2.49	27.92	14.8	10.6
Total Coliform (colony/100 ml)	17-25	73	51	CNCC	CNCC	CNCC	26	CNCC	103		
Fecal Coliform (colony/100 ml)	23	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	98	68		

Table 3. Mean values of water quality parameters by stream section on 9 July 1997.

	Stream Section		
Parameter	Lower	Middle	Upper
Temperature (c^{o})	23.2	22	22.2
Salinity (ppt)	0	0	0
Conductivity (umhos/cm)	95.7	84.3	65.3
Turbidity (NTU's)	0.25	0.95	0.57
pH	8.4	6.4	8.1
Dissolved Oxygen (mg/l)	6.08	1.68	7.23
Dissolved Oxygen (% saturation	72.1	19.9	82.9
Total Alkalinity (mg/L $CaCO_3$)	45.3	29.3	24
Total Nitrogen (mg N/L)	0.193	0.366	0.252
Total Phosphorous (mg P/L)	0.095	0.036	0.054
N/P ratio (molar)	4.48	22.15	17.87

Table 4. Comparison of water quality parameters at stations 1-3 on Laufuti Stream on two separate dates.

Location	Station 1	Station 1	Station 2	Station 2	Station 3	Station 3
Date	25-Apr-97	09-Jul-97	25-Apr-97	09-Jul-97	25-Apr-97	09-Jul-97
Temperature (c^o)	24	23.5	23.8	23	23.5	23.1
Salinity (ppt)	0	0	0	0	0	0
Conductivity (umhos/cm)	92	91	125	95	110	101
pH	7.9	8.8	7.86	8.75	7.92	7.69
Dissolved Oxygen (mg/l)	10.7	6.15	10.6	6	10.8	6.1
Dissolved Oxygen (% saturation)	126	73	126	71	127.3	72.3

Turbidity ranged from 0.25 to 1.25 NTU's on 9 July 1997 (mean =0.59, sd=0.34). By stream section, mean turbidity was 0.25, 0.95, and 0.57 for Lower, Middle, and Upper Laufuti, respectively.

pH ranged from 6.3 to 8.9 on 9 July 1997 (mean=7.62, sd=1.09). By stream section, mean pH was 8.4, 6.4, and 8.1 for Lower, Middle, and Upper Laufuti respectively. When converted to [H+], analyzed, and then converted back to pH values, mean pH was 6.8, stream section means were 8.1, 6.4, and 7.6 for Lower, Middle, and Upper Laufuti, respectively.

Dissolved oxygen (D.O.) values ranged from 1.15 to 8.4 mg/L on 9 July 1997 (mean=5.0, sd=2.69). By stream section, mean D.O. was 6.1, 1.7, and 7.2 for Lower, Middle, and Upper Laufuti, respectively.

Dissolved oxygen % saturation values ranged from 14 to 95% on 9 July 1997 (mean=58.3, sd=30.8). By stream section, mean D.O. % saturation was 72.1%, 19.9%, and 82.9% for Lower, Middle, and Upper Laufuti, respectively.

Alkalinity values ranged from 20 to 48 mg/L $CaCO_3$ on 9 July 1997 (mean=32.9, sd=10.15). By stream section, mean alkalinity was 45.3, 29.3, and 24.0 for Lower, Middle, and Upper Laufuti, respectively.

Total nitrogen values ranged from 0.124 to 0.566 mg/L N on 9 July 1997 (mean=0.27, sd=0.147). By stream section, mean total nitrogen was 0.19, 0.37, and 0.25 for Lower, Middle, and Upper Laufuti, respectively.

Total phosphorous values ranged from 0.092 to 0.11 mg/L N on 9 July 1997 (mean=0.061, sd=0.037). By stream section, mean total phosphorous was 0.095, 0.036, and 0.054 for Lower, Middle, and Upper Laufuti, respectively.

A single matrix correlation analysis of water quality variables was performed. Positive correlation existed between alkalinity and temperature, alkalinity and conductivity, and D.O. and pH. Negative correlations existed between station and temperature, station and conductivity, station and alkalinity, turbidity and temperature, and turbidity and pH (Table 5).

Biological Inventory

Two gastropod, seven crustacean, and six fish species were collected (Table 6). For both crustaceans and fish, species richness was greatest in Lower Laufuti. Only the two freshwater shrimp *Macrobrachium lar* and *Ma. latimanus* were recorded throughout the length of the stream.

Sampling with an electroshocker in Lower Laufuti yielded seven species of freshwater shrimp representing two families and five species of fish representing three families (Table 7). The most abundant Palaemonid shrimp was *Ma. lar* and the most abundant Atyid was *Caridina weberi.* The fish fauna was dominated by members of the family Gobiidae (3 species), with the most abundant species being *Sicyopterus micrurus*. Station one had the highest species richness for

Table 5. Correlation matrix of Laufuti Stream water quality parameters. Marked (*) correlations are significant at $p<0.05$, N=9.

VARIABLE	Station	Temperature	Conductivity	Turbidity	pH	%Sat_D.O.	Alkalinity	Total N	Total P
Station	1.00	-.76*	-.69*	0.32	-0.10	0.11	-.90*	0.19	-0.45
Temperature		1.00	0.51	-.79*	0.51	0.49	.83*	-0.47	0.54
Conductivity			1.00	-0.42	-0.02	-0.28	.70*	-0.12	0.30
Turbidity				1.00	-.73*	-.68*	-0.58	0.59	-0.44
pH					1.00	.76*	0.44	-0.32	0.59
%Sat_D.O.						1.00	0.17	-0.25	0.27
Alkalinity							1.00	-0.14	0.50
Total N								1.00	-0.41
Total P									1.00

Table 6. Distribution of macrofauna in Laufuti Stream, based on all methods of data collection.

Species	Lower Laufuti	Middle Laufuti	Upper Laufuti
Gastropods			
Neritina variegata	X		
Melanoides tuberculata		X	X
Shrimp			
Macrobrachium lar	X	X	X
M. latimanus	X	X	X
M. australe	X		
M. hirtimanus	X		
Atya serrata	X		
A. spinipes	X		
Caridina weberi	X		
Bony Fish			
Anguilla marmorata [1]	X		
A. megastoma [2]		X	X
Eleotris fusca	X		
Sicyopterus pugnans	X		
S. micrurus [3]	X		
Stiphodon elegans	X		

[1,2,3]Reported by U.S. Army Corps of Engineers (1981) as *A. mauritania, A. celebensis*, and *S. taeniurus*, respectively.

Table 7. Number of individuals for each species collected by electroshocking on Lower Laufuti (stations 1-3), for the entire length of stream by trapping, and for all methods combined.

		Electroshock				
Species	Station 1	Station 2	Station 3	Total Electroshock	Total Trapping	All Methods
Shrimp						
Macrobrachium lar	27	16	9	52	7	59
M. latimanus	9	10	3	22	1071	1093
M. australe	5	4		9	1	10
M. hirtimanus	8	2		10		10
Atya serrata	116	12	0	128		128
A. spinipes	12	248	5	265		265
Caridina weberi	42	233	238	513		513
Total Inds Shrimp	219	525	255	999	1079	2078
Species Richness	7	7	4	7	3	7
Shannon Diversity Index H'_2	2.03	1.5	0.45	2.81	0.07	2.3
Bony Fish						
Anguilla marmorata	2	2		4	1	5
A. megastoma						3
Eleotris fusca	3	1	3	7	2	9
Sicyopterus pugnans	3			3		3
Si. micrurus	52	3	2	57		57
Stiphodon elegans	4			4		4
Total Inds Fish	64	6	5	75	3	81
Species Richness	5	3	2	5	2	6
Shannon Diversity Index H'_2	1.06	1.46	0.97	1.26	0.92	1.52
Electroshocker time (seconds)	159	209	229			

Table 8. Numbers of individuals by species (and catch per trapnight) collected with funnel traps in Laufuti Stream.

	Lower Laufuti	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Total
Date	11/96-4/97	7/8-11/98	7/8-11/98	7/8-11/98	7/8-11/98	7/8-11/98	7/8-11/98	
# Trap Nights	9	9	9	9	9	5	5	55
Gastropods								
Neritina variegata	observed							
Melanoides tuberculata					observed	1 (0.2)	9 (1.8)	10 (0.18)
Shrimp								
Macrobrachium lar	7 (0.78)	observed	observed	observed	observed	observed		7 (0.13)
Ma. latimanus	2 (0.22)	185 (20.6)	157 (17.4)	379 (42.11)	75 (8.3)	143 (28.6)	132 (26.4)	1071 (19.47)
Ma. australe	1 (0.11)							1 (0.02)
Bony Fish								
Anguilla marmorata	1 (0.11)							1 (0.02)
Anguilla megastoma		observed	observed	observed	observed	observed		
Eleotris fuscus	2 (0.22)							2 (0.04)

both crustaceans and fish, with all but one species recorded in the entire survey represented at this station.

Trapping yielded three species of freshwater shrimp and two species of fish in Lower Laufuti. In Middle and Upper Laufuti only the shrimp, *Ma. latimanus*, was caught, in spite of *Ma. lar* and *Anguilla megastoma* being readily observed. Based on catch per trapnight, densities of shrimp in Middle and Upper Laufuti were two orders of magnitude greater than Lower Laufuti, with *M. latimanus* dominating the shrimp community in these sections (Table 8).

The two species of gastropods recorded were the Neritid, *Neritina variegata*, found only in Lower Laufuti, and the Thiarid, *Melanoides tuberculata*. *Me. turberculata* was rare in Middle Laufuti and common to abundant in Upper Laufuti. At station 9, they were very conspicuous, reaching a density estimated at 538/square meter.

Three eels (*A. megastoma*) were hand-collected from Upper and Middle Laufuti. These three, plus one collected in upper Amalau Valley (elevation 1050 ft, 320 m), Tutuila were analyzed for food habits. Crustacean remains (identifiable as shrimp or simply as crustacean) were the most frequent item (75% occurrence, 6 items) followed by various insects (50% occurrence, 3 items), and the snail, *Me. tuberculata* (25% occurrence, 3 items) (Table 9).

Table 9. Digestive tract contents of *Anguilla megastoma* collected in Laufuti Stream and on Tutuila, American Samoa.

Ind #	Total Length	Date	Location	Stomach Contents	Large Intestine
1	760 mm	09-Jul-97	Upper Laufuti	Two unidentifiable shrimp	Set of insect wings-suggest Cicadadae
2	590 mm	11-Jul-97	Middle Laufuti	Empty	Few small crustacean fragments
3	502 mm	11-Jul-97	Middle Laufuti	Coleoptera larvae, ca. 1cm long	3 snails, 1 *Me. tuberculata*
4	685 mm	17-Jul-97	Amalau Valley, Tutuila	Two unidentifiable crustaceans	Wing cover of coleopteran

DISCUSSION

Discharge and Flow

In its discharge and flow, Laufuti both conforms to and deviates from the "typical" stream found in American Samoa and other tropical Pacific high islands. It is the only perennial stream on Taú, the result of erosion in its lower valley cutting into a complex of intrusive dikes and tapping springs fed by ground water trapped by the relatively impermeable dikes (Stice and McCoy 1968). On Tutuila, where most streams are perennial (Matsuoka 1978), spring flow is also the determinant of stream permanence (Keating 1992). While conditions observed during this survey may represent those most frequently encountered, the scoured streambed and dry plunge pools indicate that discharge is variable, and occasionally very high. Such large variability in stream discharge is typical in American Samoa, due to the variability of rainfall and the high permeability of much of the substrate (Keating 1992, Matsuoka 1978, Wong 1996).

Stice and McCoy (1968) reported on the flow and discharge of Laufuti. They partitioned Laufuti into two sections, a perennial lower section extending up to 1,000 ft elevation and an intermittent upper section, where flow only occurred after heavy rains and water remained in small pools and ponds. Many of my observations are consistent with these, but there are some distinctions. There was no evidence of perennial flow above the pool at the base of the second waterfall (elev. 166 ft, 51 m), and water flow over the second waterfall was observed during only 10% of the visits. Since Stice and McCoy (1968) were not focused solely on Laufuti stream, their comments on the distribution of perennial flow are probably generalizations. Similarly, their report of discharge "on the order of thousands of gallons per minute, even during periods of minimum rainfall" (Stice and McCoy 1968) deviates somewhat from the 902 gallons/minute measured at station 1.

The discontinuity of surface flow that occurs in Upper Laufuti appears to be unique, or at least, uncommon in American Samoa. While USGS Topographical Maps show Laufuti to be an intermittent stream originating at ca. 1230 ft (374 m) elevation, flowing water was observed from 1510 to 1650 ft (460 to 503 m) and there was nothing evident at 1650 ft to suggest that the source was nearby. Stream width, depth, and flow were fairly constant above 1600 ft (486 m) elevation and, given that topography is very flat from 1520 to 1760 ft (463 to 536 m), surface flow likely is present well above 1700 ft (517 m). Considering that high elevation springs and seeps occur on Tutuila and Taú where cliffs sit atop lava flows (Keating 1992), it suggests that flow in Upper Laufuti includes both surface and ground water. Ground water likely seeps down through the permeable post-caldera formation of Lata Mountain and emerges as springs at the base of the fault escarpment below Lata Mountain, probably at ca. 1800 ft elevation, which is where the valley formed by the stream bed meets the cliff base.

Naturally interrupted perennial streams, where surface flow is perennial in the upper reach and becomes seasonally sub-surface in the middle and the terminal reach have been described for tropical Pacific Islands, (Polhemus et al. 1992). Laufuti is also a naturally interrupted perennial stream, though, due to its geologic history, is differs in where the perennial flow occurs.

Water Quality

Limitations of Data

Water quality data for Laufuti stream are limited. The entire nine stations were sampled once. Stations 1,2, and 3 were sampled twice. Thus these data provide little to no insight into temporal variability. For stations 1-3, variability in temperature, salinity, conductivity, (and to a lesser extent pH) between the two dates are small. However, differences in D.O. and % saturation values between April (126% mean saturation) v. July 1997 (72% mean saturation), are hard to explain, particularly since temperature decreased slightly. It is impossible to know if these differences are real, or the result of equipment problems. In addition, the bacteriological data are limited by the fact that many of the samples had uncountably high or confluent colonies that additional dilution could have rectified had longer-term repeat sampling been conducted.

In spite of these limitations, the water quality data provide some insight into spatial variability in Laufuti Stream as well as its overall condition. In addition, while there are limited published data on water quality of tropical Pacific streams, some groundwater data are also available. Since Lower Laufuti is fed primarily by groundwater seeps, comparison with groundwater data may be informative.

Physical/Chemical Parameters

Measures of salinity and conductivity show Laufuti to be freshwater (Table 2), with conductivity values at the lower end of the range reported for Tutuila streams. On Tutuila, stream conductivity ranged from 20 to 800 *u*mhos/cm (average 217) (U.S. Army Corps of Engineers 1981) and groundwater ranged from 150 to 4650 (average 760) (Eyre 1994). Higher mean conductivity values for Tutuila are the result of saline input. In the case of groundwater, it is due to salt intrusion from over pumping. In streams, it is due to input from saline waters at sampling stations located at estuarine-like stream mouths. Laufuti, on the other hand, lacks estuarine-like conditions. It has a "mouth" that is above sea level and water flows down and through cobble and boulder before it enters the Pacific Ocean.

Conductivity values for Laufuti are comparable to those reported from other streams on Pacific islands formed of volcanic basalt, <50 *u*mhos/cm in headwaters and generally 100-150 in terminal reaches (Polhemus et al. 1992). Hawaiian streams measured at stations above tidal influences had conductivities of 59-71 *u*mhos/cm (Timbol et al. 1989) and 70-90 (Kido 1998), values in 27 streams in Fiji ranged from 40-510 (Sheath and Cole 1996), and in French Polynesia, values ranged from 40 to 150 (Marquet and Galzin 1991).

The spatial variation in conductivity, showing an increase from the upper to lower section (Table 3), is consistent with the general phenomenon of increasing dissolved salts from stream source to mouth (Gillers and Malmqvist 1998). This trend has been reported for Pacific islands as well (Timbol et al. 1989, Polhemus et al. 1992). Saline input through aerosols was also considered a potential explanation for the higher conductivity in Lower Laufuti, but, if this were the case, station 1 should have the highest conductivity. This was not the case (Table 2).

Values for stream and groundwater pH on Tutuila are generally slightly alkaline (pH 7.4) and rarely exceed 8.0 (M&E Pacific 1979, U.S. Army Corps of Engineers 1981, Eyre 1994), a situation also typical of Hawaiian streams (Timbol et al. 1989, Kido 1998). In Fiji, stream pH ranged from 7.2-8.6 (Sheath and Cole 1996) and in French Polynesia stream pH ranged from 7.0-8.0, closer to 8.0 (Marquet and Galzin 1991). On Taveuni, Fiji, pH of basaltic groundwater is 7.1 (Southern et al. 1986). In Laufuti, the Lower and Upper sections (mean pH 8.4 and 8.1 respectively) fall towards the higher end of this collective range and the Middle section is acidic, pH 6.4 (Table 3). Stream pH increasing from source to mouth is a general phenomenon (Gillers and Malmqvist 1998) also noted on Pacific islands (Polhemus et al. 1992). Kido (1998) describes such a pattern of spatial variation in pH in a Hawaiian stream, attributing the acidic condition at higher elevations to organic acids from decomposing plant materials. Laufuti stream also exhibits spatial variability, though it is not simply correlated with elevation/distance from source. The acidity of Middle Laufuti is likely due to the decomposing plant matter in the stagnant pools found there.

While no comparative data on total stream alkalinity were found, streams on Pacific high islands are known to be alkaline (U.S. Army Corps of Engineers 1981, Timbol et al. 1998), due to the alkaline basalt that forms the islands (Keating 1992). On Tutuila, groundwater alkalinity averaged 92.2 mg/L $CaCO_3$, with a range from 43-156 (Eyre 1994). Laufuti is less alkaline (Table 2), perhaps due to a smaller island/watershed size providing less opportunity for flowing water to dissolve salts. Within Laufuti, the higher alkalinity of Lower Laufuti (Table 3) is likely due to two factors. First, there is the general trend for alkalinity to increase from source to mouth due to increased loading of dissolved salts (Giller and Malmqvist 1998, Polhemus et al. 1992). Secondly, Middle and Upper Laufuti have higher accumulations of organic matter (e.g. leaf litter), whose decomposition creates organic acids (Kido 1998) that are neutralized by the alkalinity. This process lowers alkalinity. Thus, Lower Laufuti likely has a higher inherent alkalinity to begin with, and is subject to less neutralizing acidity than Middle or Upper Laufuti.

Turbidity values (Table 2) suggest that the waters of Laufuti stream are clear. On Tutuila, turbidity measurements in undisturbed watersheds averaged 3.22 NTU's (range 2-4) and may be as high as 65 in stressed watersheds (M&E Pacific 1979, U.S. Army Corps of Engineers 1981). Certainly, turbidity increases during freshets (U.S. Army Corps of Engineers 1981), and there was occasion to visually note differences in the turbidity of water flowing over the first waterfall. Spatial variation in turbidity (Table 3) is likely due to water velocities and the accumulation of organic detritus. Middle Laufuti contains stagnant, detritus rich pools, whereas Lower and Upper Laufuti are flowing, with intermediate amounts of organic matter.

Flowing streams on Pacific islands are generally well oxygenated (Marquet and Galzin 1991, Polhemus et al. 1992, Timbol et al. 1989), with supersaturation sometimes occurring in steep, high velocity sections (Kido 1998). On Tutuila, all but stagnant waters are at or near saturation (U.S. Army Corps of Engineers 1981), averaging 8.09 mg/L in undisturbed streams (M&E Pacific 1979). The low oxygen saturation on Lower Laufuti on 9 July 1997 (72.1% mean saturation) is hard to reconcile, particularly when supersaturation was indicated on 25 April 1997 (Table 4). The absolute values of D.O. measured on 9 July 1997 (Table 2) are likely incorrect. In streams of the Pacific Northwest United States, chronic mortality occurs at and below D.O. levels of 3 and 4 mg/L in fish and invertebrates respectively (MacDonald et al. 1991). D.O.

levels recorded in Middle Laufuti (mean value 1.68 mg/L) are well below this limit, yet the pools there supported an abundance of invertebrates, with no apparent signs of oxygen stress.

In spite of problems with the absolute values for D.O., their relative values are likely valid, and illustrate the relatively low levels of oxygen occurring in the pools of Middle Laufuti. In these pools, the lack of flow, combined with relatively high biological oxygen demand from organic detritus and abundant shrimp would reduce D.O. levels.

Natural levels of nitrogen in rivers unaffected by human activities are low, and tropical rivers generally have lower levels than temperate rivers (Allen 1995). Marquet and Galzin (1991) noted low nitrate levels in French Polynesia, but did not provide quantitative data. A survey of small to mid-sized streams in the USA found total nitrogen to average from 0.598 mg/L in watersheds >90% forested to 0.839 mg/L in watersheds >50% forested (Allen 1995). Values below 0.3 mg/L are considered safe from eutrophication (MacDonald et al. 1991). On Tutuila, total nitrogen averaged 0.327 mg/L in undisturbed streams and 0.562 mg/L streams affected by urban/agricultural activities (M&E Pacific 1979). Total nitrogen in Tutuila groundwater is greater, averaging ca. 0.86 mg/L with a range from 0.31 to 2.7 (Eyre 1994). In Laufuti, total nitrogen levels averaged 0.27 mg/L (Table 2), placing it in the range expected for tropical streams unaffected by human activities. By contrast, a lake/wetland complex in Fiji, averaged 3.3 mg/L total nitrogen (Southern et al. 1986).

Total phosphorous is also naturally low in streams, 0.025 mg/L (Allan 1995). In small forested streams in the Cascade Mountains of the United States, an average annual concentration less than 0.06 mg/L phosphorous is typical (MacDonald et al. 1991). In another survey of small, unpolluted temperate woodland streams, total phosphorous values were below 0.034 mg/L (Allan 1995). In contrast, total phosphorous on Tutuila averaged 0.106 mg/L in undisturbed streams and 0.157 mg/L in streams affected by urban/agricultural activities (M&E Pacific 1979). Groundwater total phosphorous on Tutuila was lower, averaging 0.076 mg/L (Eyre 1994). Phosphorous levels in Laufuti (0.06 mg/L mean value, Table 2) are slightly lower than what might be expected based on the Tutuila data, but are consistent with those found in small, forested streams in North America. They are well below the 0.5 mg/L median value recorded for a lake/wetland complex in Fiji (Southern et al. 1986).

Correlation analysis of water quality parameters (Table 5) is generally in accordance with established relationships. The positive relationship between alkalinity and temperature, and alkalinity and conductivity are consistent with increases in these parameters from a stream's source to its mouth (Gillers and Malmqvist 1998, Polhemus et al. 1992). The negative correlation of station with these parameters is also due to this effect. The correlation between D.O. and pH, temperature and turbidity, and turbidity and pH are likely intercorrelation, driven by the conditions present in Middle Laufuti. Here, the stream is intermittent and sampling stations were small, isolated pools with relatively high levels of plant detritus and abundant populations of *Macrobrachium* shrimp. These conditions result in low pH due to organic acids from the decomposing plant matter (Kido 1998), low D.O. from the oxygen demand of plant decomposition and *Macrobrachium* respiration, and higher turbidity than perennial sections of the stream due to organic matter accumulation in stagnant pools. Thus, spatial variation in conductivity, alkalinity and temperature likely reflect a gradient of increase from headwaters to mouth, whereas spatial variation in D.O., pH, and turbidity likely reflect Middle Laufuti's intermittent nature.

Bacteriological Analysis

Bacteriological analysis indicates that Laufuti Stream has low to moderate levels of coliform bacteria (Table 2), generally consistent with the values of fecal coliforms (mean 60 colonies/100 ml) recorded in undisturbed streams on Tutuila. In contrast, streams on Tutuila influenced by urban/agricultural activities were much higher, with a mean fecal coliform count of 3460 colonies/100 ml (M&E Pacific 1979). In Tutuila groundwater, mean fecal coliform was 25 colonies/100 ml (range >1 to >240) and total coliforms ranged from >1 to >1,600. Fecal coliforms were found in both sparsely and densely populated sites (Eyre 1994).

Values for both fecal and total coliform bacteria exceed USEPA standards for drinking water, which is zero (USEPA 1986). Several stations (Table 2) also exceed standards for recreational bathing, which are 2400 colonies/100 ml for Total and 200 colonies/100 ml for Fecal Coliform respectively (USEPA 1986). The presence of confluent non-coliform colonies and as well as coliform colonies that were too numerous to count limits the usefulness of these results. Nonetheless, the greater occurrence of samples with confluent or uncountably high colonies in Middle Laufuti (Table 2) seems consistent with its stagnant, non-flowing nature. A refinement in methodology (i.e. further dilution of water samples prior to incubation) is needed to obtain more precise measurements and better determine patterns of variation in coliform levels.

While elevated levels of coliform bacteria are often associated with human and domestic animal wastes, coliform bacteria are also associated with the digestive tracts of warm-blooded animals, i.e. birds and mammals (APHA 1998). Numerous studies suggest that coliform bacteria may be naturally occurring and free living in tropical rain forest watersheds and that high levels of coliforms are not necessarily correlated with known sources of fecal contamination, occurring even in pristine tropical streams (Hazen and Toranzos 1990). This latter point regarding occurrence in undisturbed settings seems borne out by both stream and groundwater data from Tutuila, though these data do show the expected relationship between coliform levels and contamination sources (Eyre 1994, M&E Pacific 1979).

Laufuti does not receive inputs from humans or domestic animals. Moreover, though feral pigs are present on Taú, no evidence of their presence anywhere near the Laufuti watershed was observed. On the other hand, the south coast of Taú, particularly the forests and escarpment above Laufuti supports large numbers (ca. 20,000) of colonial waterbirds (Amerson et al. 1982) and flying fox. Thus, given the ubiquity of coliforms in the tropical environment, and the data from Tutuila, the levels of coliform bacteria in Laufuti stream appear more to represent natural conditions rather than to indicate bacterial contamination.

Biological Inventory

Methodological Limitations

Though the intention was to use electroshocking throughout this survey, this was not feasible. The inefficiency experienced by electroshocking in slow moving or non-flowing water, indicated that this technique was not well suited for the pools of standing water or slow flowing water that characterize Middle and Upper Laufuti. Hence wire funnel traps were employed there.

While effective at capturing certain species, mesh and entrance size of wire traps influence the composition of their sample. Thus both electroshocking and trapping have inherent, and not necessarily similar biases, constraining data comparison between sites not sampled with identical methods. While the funnel traps were very effective at capturing *Ma. latimanus* in Middle and Upper Laufuti, their failure to capture any other species, in spite of the fact that *Ma. lar* was observed there indicates that funnel traps did not sample all shrimp species present. Reasons for the absence of *Ma. lar* in the samples collected at Middle and Upper Laufuti are uncertain. While *Ma lar* was seen, *Ma. latimanus* was observed to be the most abundant shrimp species. When checked, traps were crowded with *Ma. latimanus*. The large numbers of *Ma. latimanus* crowding the traps may have inhibited other species from entering the traps. The traps alone were not the reason for the absence of *Ma. lar*. In lower Laufuti, where shrimp were less abundant, a broader range of species, including *Ma. lar* were taken in traps.

Among the fish species recorded, only *A. megastoma* was recorded in Middle and Upper Laufuti. Since gobies were conspicuous and more readily observed than eels in Lower Laufuti, the lack of any goby sightings in Middle and Upper Laufuti is interpreted as strong evidence of their absence. The lack of any trap captures for *A. megastoma* in Middle and Upper Laufuti is problematic. While eels were observed in the pools where traps were set, all individuals in these pools were very large, perhaps too large to enter the funnel traps. All observations of eels small enough to enter the funnel traps were in pools too small and shallow to trap. While speculative, observation suggests that large eels may exclude smaller individuals from the deeper pools where traps were set.

<u>Gastropods</u>

The two species of snails found in Laufuti are widely distributed. *N. variegata* is native to Oceania and the Indo-Pacific (Cowie, in prep; Haynes 1988), its widespread distribution likely due to the amphidromous reproduction of Neritids (Cowie, in prep.; Hodges and Allendorf 1998). This survey extends its known range in Samoa to include Taú. *Me. tuberculata* is likely Asian or African in origin. Its reproduction is predominantly clonal, but it has been introduced widely in many parts of the world though human activity (Cowie, in prep.)

The distribution of these two species within Laufuti Stream corresponds closely to accounts by Cowie (in prep.). *N. variegata*, restricted to lower Laufuti, is a species found in the lower reaches of fast flowing streams, whereas *Me. tuberculata* is generally found in habitats that have sandy/muddy bottoms and rich plant materials. While its distribution can range from sea level to 500 m (Cowie in prep), typical habitat for this species occurs principally on Upper Laufuti, where *Me. tuberculata* was most abundant.

<u>Crustaceans</u>

The shrimp community of Laufuti Stream is composed of fairly common, widespread species. The seven shrimp species occur widely throughout the Indo-Pacific region (Devaney 1981). All were recently (1979-1980) recorded on Tutuila and three (*Ma. lar*, *Ma. australe* and *C. weberi*) were described as very common and widespread on Tutuila (U.S. Army Corps of Engineers 1981). Yet, while the shrimp species occurring in Laufuti are nothing unusual individually, as a community it differs from those found on Tutuila.

The shrimp community of Laufuti Stream is one of the most diverse in American Samoa. It has a greater number of species than 89% of the 37 streams surveyed on Tutuila (U.S. Army Corps of Engineers 1981). Only one stream on Tutuila surpassed Laufuti in species richness, and three equaled it (Table 10). For a single sampling station, Laufuti station 1 surpassed 95% of the 71 stations sampled on Tutuila (U.S. Army Corps of Engineers 1981).

Comparisons of diversity based on the Shannon Diversity Index (H'_2) are complicated by the fact that calculations by U.S. Army Corps of Engineers (1981) were for an entire stream. In 15 instances this was based on a single sampling station but in nine others it involved combining data from 2-4 sampling stations per stream. The highest values of H'_2 reported for stream crustaceans on Tutuila by U.S. Army Corps of Engineers (1981) was 1.86 for a single sampling station, and 1.45 for a stream that contained more than one sampling station. Of all values for crustacean H'_2 reported by U.S. Army Corps of Engineers (1981), only 10 of 24 (42%) exceeded 1.00. Comparable values obtained in this survey for Laufuti stream are 2.03 for a single electroshocked station, 2.81 for all three electroshocker stations combined, and 2.30 for all methods combined (Table 7). Thus, in spite of these comparability problems, the shrimp community of Laufuti stream ranks as one of the most diverse recorded in American Samoa.

The most unusual aspect of Laufuti's shrimp community is the prominence of *Ma. latimanus*. This species is not very widespread on Tutuila, having been recorded as occasional at 8 of 71 stations and 8 of 37 streams (U.S. Army Corps of Engineers 1981). In Laufuti *Ma. latimanus* was common at two of the three electroshock stations and abundant at the trapping stations above the Falls Zone. In spite of possible trapping bias for this species, it is clearly numerous in Middle and Upper Laufuti. The abundance and predominance of *M. latimanus* in Laufuti seems to be an unusual situation in American Samoa.

The shrimp community of Laufuti is spatially variable, with seven species recorded in Lower Laufuti and only two recorded in Middle and Upper. In addition *M. latimanus* is spatially variable in abundance. Spatial variability in *M. lar* in a Hawaiian stream was noted by Timbol et al. (1989), who only recorded it at low elevations. Conversely, in Micronesia, Nelson et al. (1995; 1997) found *Macrobrachium* sp. and Atyid shrimp to be more abundant at higher elevations, above a waterfall that acted as a barrier to a predator, Mountain Bass (*Kuhlia rupestris*). In this case, the spatial variation in abundance was attributed to presence/absence of predator effects rather than to the direct effects of physical features. In Laufuti, there were no *Kuhlia*, but eels (*A. marmorata and A. megastoma*), which feed heavily on shrimp (especially *Macrobrachium*) (Marquet and Lamarque 1986), provide predation pressure throughout. In Laufuti, it appears that some of the species occurring in Lower Laufuti may be excluded from Middle and Upper Laufuti by either dispersal barriers (i.e. Falls Zone) or lack of habitat (i.e. lack of flowing water) rather than by distribution of predators.

Table 10. Shrimp community of Laufuti compared to species rich streams on Tutuila. Data for Auvai, Papa, Vaitele, and Soonapule from U.S. Army Corps of Engineers (1981).

	ENTIRE STREAM				
SPECIES	Laufuti	Auvai	Papa	Vaitele	Soonapule
Atya serrata	x	x		x	x
A. spinipes	x	x	x	x	x
Caridina weberi	x	x	x	x	x
C. serratirostris		x	x	x	
C. nilotica			x		
Macrobrachium lar	x	x	x	x	x
M. latimanus	x		x		x
M. australe	x	x	x	x	x
M. hirtimanus	x	x	x	x	x
Species Richness	7	7	8	7	7
Species Diversity H'_2	2.81	1.45	1.39	0.87	1.28
# Sampling Stations	3	2	4	3	1

Based on trapping data (Table 8) the abundance of shrimp is much greater in Middle and Upper Laufuti than it is in Lower Laufuti. Part of this may be due to shrimp being concentrated in standing pools as opposed to the flowing stream habitat of Lower Laufuti, but even at sampling stations 8 and 9, which were more stream-like, shrimp were abundant. Differences in abundance between Lower Laufuti and Middle/Upper Laufuti are likely due to food availability. Organic matter (such as leaf detritus) is a major component of stream energy flow (U.S. Army Corps of Engineers 1981), and was observed to be much more abundant in the non-flowing pools and slow flowing stream of Middle/Upper Laufuti than in the faster moving Lower Laufuti. Middle/Upper Laufuti is more frequently under a forest canopy and presumably receives a greater organic input. This factor, plus the tendency for organic matter to collect in the standing water pools would lead to a greater food base, especially for leaf shredders like freshwater shrimp in the low gradient/intermittent flow regime of Middle/Upper Laufuti. In contrast, in Lower Laufuti, much of the organic input is apparently flushed out into the ocean. A similar relationship between shrimp abundance, leaf litter, and flow regime occurs on Guam (Ellis-Neill 1991).

Fish

Similar to the shrimp, all of the fish species recorded in Laufuti Stream are widespread throughout the Indo-Pacific region (Fowler 1928; 1931; 1934; 1949; Munro 1967). All were recently (1979-1980) recorded on Tutuila and four of the six (*A. marmorata*, *Eleotris fusca*, *Sicyopterus micrurus*, *Stiphodon elegans*) were described then as common and/or widespread on

Tutuila, occurring in over 60% of streams sampled (U.S. Army Corps of Engineers 1981). Conversely, *S. pugnans* occurred in only 19% (7/37) of steams and *A. megastoma* was recorded in only one stream. Thus the fish community of Laufuti Stream combines mostly common species with a couple that appear to be uncommon to rare in American Samoa.

Compared to the streams sampled on Tutuila, the fish community of Laufuti Stream is relatively diverse, with a species richness that equals or exceeds 78% of Tutuila streams. For a single sampling station, Laufuti Station 1, species richness exceeded 70% of the Tutuila stations (U.S. Army Corps of Engineers 1981). Based on Shannon Diversity Indices, H'_2 values for Laufuti Stream rank it as one of the most diverse stream fish communities in the Territory. The highest values of H'_2 reported for stream fish on Tutuila (U.S. Army Corps of Engineers 1981) were 1.51 and 1.21 for a single sampling station, and 1.17 for a stream that contained more than one sampling station. Of all values for fish H'_2 reported by U.S. Army Corps of Engineers (1981), only 4 of 24 (17%) exceeded 1.00. Comparable values obtained in this survey for Laufuti stream are 1.46 for a single electroshock station, 1.26 for all three electroshock stations combined, and 1.52 for all methods combined (Table 7).

In comparing the fish community of Laufuti with those of Tutuila streams, it is apparent that there are differences. First, none of the alien species reported for Tutuila are present. Second, Tutuila streams contain euryhaline species that occur at low elevations, entering streams with sandy, low-gradient, tidally influenced mouths. For example, whereas *Kuhlia* was very common and widespread on Tutuila, it was absent from Laufuti. The "mouth" of Laufuti is a combination of surface flow across and seepage through a steep boulder and cobble field beach, and is two meters above the tidal range. The absence of estuarine conditions at the mouth of Laufuti appears to act as a barrier to preclude species typical of the freshwater-marine interface.

Third, Tutuila contains a number of freshwater species not recorded from Laufuti. U.S. Army Corps of Engineers (1981) list four species of freshwater gobies (*Hypseleotris guntheri, Stenogobius genivittatus, Awaous ocellaris, Mugilgobius fontinalis*) from Tutuila that were not recorded in Laufuti. Wass (1984) noted that many gobies were very habitat specific and of limited occurrence, and this is likely a factor in the absence of these species in Laufuti.

Community Structure, Physiography, and Within-Stream Zonation

Freshwater fish communities of the Australo-Pacific region are relatively depauperate, due to the absence of the Ostarophysi, which account for almost seven-eighths of the world's primary freshwater fish (Darlington 1957, Powell and Powell 1999). Tropical Pacific islands tend to be even more depauperate, the result of insularity, island size, and distance from centers of origin (Powell and Powell 1999) coupled with the volcanic origin of most tropical Pacific islands. When young, the uneroded volcanic islands lack well-developed estuarine habitats, have low stream habitat diversity and are characterized by high velocity streams with many waterfalls. These conditions favor successful colonization by gobies, gudgeons, and eels (Gobiidae, Eleotridae, and Anguillidae respectively), noted for their ability to climb or crawl (Baker and Foster 1992, Moriarty 1978). While weathering eventually leads to greater stream habitat diversity, the already established gobies and gudgeons are better positioned to exploit the newer habitats and, through adaptation and speciation, tend to occupy the majority of freshwater niches to the general exclusion of other families (Ryan 1991). Dominance of streams by gobies, gudgeons, and eels has been documented on many tropical Pacific islands (Balon and Bruton 1994, Bright and June 1991, Nelson et al. 1997, Powell and Powell 1999, Ryan 1991, Timbol et al. 1989), including Tutuila (U.S. Army Corps of Engineers 1981). Laufuti conforms to this pattern, with its six species of fish limited to members of these three families.

The role of physiography in shaping tropical Pacific island stream fish communities is well documented (Marquet and Galzer 1991, Powell and Powell 1999, Marquet 1996, Timbol et al. 1989, Pusey and Kenard 1996, Polhemus 1992, Nelson et al. 1997). While details vary between specific streams, the "model" stream has three zones. The lower zone begins with estuarine conditions and continues inland into the coastal lowlands, there follows a middle zone where gradient increases, and then an upper zone, where the stream is even higher gradient (Marquet and Galzin 1991, Polhemus et al. 1992, Powell and Powell 1999, Pusey and Kennard 1996). As a general trend, species richness is greatest in the lower zone, due to the presence of marine euryhaline species. Members of the families Gobiidae and Eleotridae dominate the middle and upper zones (Balon and Bruton 1994; Powell and Powell 1999), though headwater reaches in Hawaii lack fish (Polhemus et al. 1992)

Physiography affects stream communities in two major ways, by influencing entry of species into streams and the extent of their upstream penetration. Older islands have comparatively better eveloped estuarine habitats. These habitats allow many estuarine and euryhaline species to occur in at least the lower stream portions, or in the case of genera such as *Kuhlia*, to penetrate inland beyond the estuary (Balon and Broton 1994; Nelson et al. 1997; Powell and Powell 1999). In contrast, geologically young, tropical Pacific islands are characterized by steep slopes, few estuaries, and a transition from fresh to seawater in a few meters, thereby limiting the ability of euryhaline species to enter freshwater streams (Ryan 1991). One million year old Taveuni in Fiji is a graphic example (Ryan 1991), and Taú, age 0.1 million years (McDougall 1985) is another. The absence of estuarine conditions at the mouth of Laufuti has prevented the entry of euryhaline estuarine species.

In many tropical Pacific streams, waterfalls play a significant role in zonation, often serving to delineate stream sections and determine species distributions. Waterfalls limit the upstream penetration of many species and allow, through the attenuation of predation and/or competition, for the increased dominance and biomass in those species occurring above the waterfall (Balon and Bruton 1994, Marquet and Galzin 1991, Nelson et al. 1997, Pusey and Kennard 1996).

On Bouganville Island, Papua New Guinea, where no mention is made of waterfalls, species such as *A. marmorata* and *Kuhlia* occur throughout the three river zones (Powell and Powell 1991). In Pohnepei and Palau, *Kuhlia* are restricted to waters below major waterfalls, whereas species of *Stiphodon* and *Sicyopus* (including *St. elegans*) occur above the falls and into the headwaters, and *A. marmorata* occurs above the waterfalls but does not penetrate into the headwaters (Nelson et al. 1995, 1997). In the case of the Ngermeskang Waterfall on Palau, photos in Nelson et al. (1995) suggest it to be ca. 10 m high and ca. 45 degrees in slope, making it considerably smaller and less sheer than the series of falls on Laufuti. On the Tatinga River of Anjouan, in the Comoro Archipelago, there are two waterfalls, each 15 m high. *Kuhlia* and *E. fusca* are limited to below the first fall, *A. marmorata* occurs up to the second waterfall, but only *S. lagocephalus* is able to ascend the high velocity waters of the upper waterfall (Balon and Bruton 1994).

While eels are generally thought of as highly capable of surmounting barriers such as waterfalls (Moriarty 1978), the observations on Anjouan (Balon and Bruton 1994) suggest that, at least for An. marmorata, these abilities are limited. In French Polynesia *A. marmorata* is widespread among archipelagos and islands, and within many streams, occurs from lower to upper zones. However, they are excluded from the upper zone "when the waterfall that separates it from the middle zone is too high" (Marguet and Galzin 1991). *A. megastoma* is neither as widely distributed geographically nor within stream zones. It occurs in the middle and upper zones of rivers, sometimes sympatrically with *A. marmorata*, but it also occurs at high elevations, above waterfalls where *A. marmorata* does not occur (Marquet and Lamarque 1986). A similar pattern of altitudinal zonation between these two species occurs in New Caledonia (Marquet 1996). The distribution of these two species in Laufuti stream corresponds closely to this pattern, with *A. marmorata* restricted by the Falls Zone to Lower Laufuti and *A. megastoma* occurring above, in Middle and Upper Laufuti.

A synthesis of the above patterns of distribution suggests that among freshwater fishes inhabiting tropical Pacific island streams, there is a continuum in ability to surmount dispersal barriers. Among the species discussed, ability to surmount barriers appears to increase as follows; *Kuhlia* sp., *Stenogobius* sp., *E. fusca*, *A. marmorata*, *Stiphodon* sp., *Sicyopus* sp., *Sicyopterus* sp., *A. megastoma*. How this influences species' distribution and community structure in a stream depends on the type, location, and severity of barriers. For example, the influence of a waterfall will vary as a result of a waterfall's location, size, sheerness, and stream velocity, and the species available to be influenced, itself determined by presence/absence of estuarine conditions. Thus, while stream fish communities exhibit zonation, details vary between streams and are not as pre-determined as models suggest.

Diet of *Anguilla megastoma*

Diet of eels on tropical Pacific islands is opportunistic, with variation between species a function of prey availability. In addition, given the inter-stream variation in macrofauna distribution that occurs due to physiography, intra-specific variation in diet would also be expected. In Tahiti, crustaceans (primarily *Macrobrachium*), gobies, and mollusks dominated the diet of *A. megastoma* (Marquet and Lamarque 1991). Though a limited sample, the diet of *A. megastoma* in American Samoa shows a similar opportunism (Table 10). It too is dominated by crustaceans. However, since *A. megastoma* occurred in the absence of other fish species, its diet was devoid of fish, included comparable amounts of mollusks, and also included insects, a taxa not recorded in the diet of Tahitian *A. megastoma* (Marquet and Lamarque 1991).

Life Histories and Evolution

With the exception of the alien gastropod *Me. tuberculata* the macrofauna recorded in Laufuti stream still utilize the marine environment to complete their life cycles. The eels are catadromous, breeding in ocean waters and returning to streams as young known as elvers. The gobies, guddgeons, and shrimp are amphidromous. They breed and oviposit in freshwater and pass through a marine larval stage that returns to freshwater (Devaney 1981, U.S. Army Corps of Engineers 1981). These strategies favor a wide rather than restricted distribution, which is exactly the case for the species occurring in Laufuti. Whereas endemic species of amphidromous gastropods, shrimp and fish have evolved in Hawaii (Baker and Foster 1992, Hodges and Allendorf 1998), Taú is geologically young (0.1 million years, McDougall 1985) and the Samoan archipelago far less isolated than Hawaii. Thus lack of sufficient time and inadequate isolation minimize the likelihood of endemic species presently occurring in Laufuti stream.

THREATS

Laufuti Stream and its watershed are contained entirely within the National Park. The vegetation is essentially native forest and scrubland, with no active plantations. While feral pigs are present in some forest areas of Taú, extensive reconnaissance over the past 2 years has failed to find any evidence of pigs in the Laufuti watershed or anywhere else on the island's south side. Given these present conditions and the stable to declining, low-density human population of Taú (NPS 1997), human demographic-based threats are unlikely to develop in the near future. This contrasts with general Territorial population trends, in which the estimated population (95% of which is on Tutuila) has risen from 33,000 to 59,600 since the 1981 U.S. Army Corps of Engineers stream survey (Craig 1993, ASG Dept. of Commerce 1997). Thus, whereas the quality of stream habitats on Tutuila may decline in the future, the inclusion of Laufuti in the National Park of American Samoa offers a unique opportunity for its preservation. Visitation, if not properly managed, poses a potential threat, though present levels are not a problem. Also, any resumption of agricultural activity, though unlikely, could degrade water quality in Laufuti Stream.

RECOMMENDATIONS

To ensure Laufuti Stream's continued preservation the following are recommended:

1. Feral pigs need to be prevented from getting into the watershed.

2. Visitor impacts need to be minimized through education and monitored. Monitoring should focus initially on impacts to vegetation and litter in Lower Laufuti.

3. Water quality on Lower Laufuti should be monitored.

4. Agricultural activities should be directed away from the Laufuti watershed.

LITERATURE CITED

Allan, J.D. 1995. Stream ecology: structure and function of running waters. Chapman and Hall, London. 388 pp.

American Samoa Dept. of Commerce. 1997. American Samoa Population: 1997. AS Department of Commerce, Statistics Divison, Pago Pago. 1 pp.

Amerson, A.B., W.A. Whistler and T.D. Schwaner. 1982. Wildlife and wildlife habitat of American Samoa. U.S. Fish and Wildlife Service, Honolulu.

APHA. 1998. Standard methods for the examination of water and wastewater. 20th ed. American Public Health Association, Washington, DC.

Baker, J.A. and Foster, S.A. 1992. Estimating density and abundance of endemic fishes in Hawaiian streams. Hawaii department of Land and Natural Resources, Division of Aquatic Resources. 49 pp.

Balon E.K, and Bruton, M.N. 1994. Fishes of the Tatinga River, Comoros, with comments on freshwater amphidromy in the goby *Sicyopterus lagocephalus*. Ichthyol. Explor. Freshwat. 5(1):25-40.

Bentley, C. B. 1975. Ground-water resources of American Samoa with emphasis on the Tafuna-Leone Plain, Tutuila Island. U.S. Geological Survey. Water Resources Investigation 29-75. viii+45 pp.

Bright, G.R., and June, J.A. 1981. Freshwater fishes of Palua, Caroline Islands. Micronesica 17:107-111.

Burger, I.L. and Maciolek, J.A. 1981. Map inventory of nonmarine aquatic resources of American Samoa with on-site biological annotations. Review Draft. U.S. Fish and Wildlife Service, National Fishery Research Center. Seattle, Washington. 182 pp.

Cowie, R. H. (in preparation). *Samoan snails and slugs: a field identification guide.*

Craig, P. 1993. How many people can American Samoa support? American Samoa Department of Marine and Wildlife Resources. Biological Report Series 42:4-5.

Darlington, P.J. Jr. 1957. Zoogeography: The geographical distribution of animals. Wiley and Sons, NY.

Devaney, D.M. 1981. American Samoa Freshwater Crustacean Identification Project. Bishop Museum, Honolulu. Unpublished report prepared for U.S. Army, Corps of Engineers, Honolulu. 24 pp.

Ellis-Neill, L. 1991. Distribution and production dynamics of benthic invertebrates in a tropical stream on Guam. Micronesica 24 (2):295.

Eyre, P.R. 1994. Groundwater quality reconnaissance, Tutuila, American Samoa, 1989. U.S. Geological Survey Water-Resources Investigations Report 94-4142. 15 pp.

Fowler, H.W. 1928. The fishes of Oceania. Memoirs Bernice P. Bishop Museum, Honolulu. Volume X:540 pp.

Fowler, H.W. 1931. The fishes of Oceania. Supplement 1. Memoirs Bernice P. Bishop Museum, Honolulu. Volume XI, 5:313-381.

Fowler, H.W. 1934. The fishes of Oceania. Supplement 2. Memoirs Bernice P. Bishop Museum, Honolulu. Volume XI, 6:385-460.

Fowler, H.W. 1949. The fishes of Oceania. Supplement 3. Memoirs Bernice P. Bishop Museum, Honolulu. Volume XII, 2:37-186.

Giller, P.S. and B. Malmqvist. 1998. The biology of streams and rivers. Oxford Univ. Press. 296 pp.

Haynes, A. 1988. Notes on the stream Neritids (Gastropoda; Prosobranchia) of Oceania. Micronesica 21:93-102.

Hazen, T.C. and Toranzos, G.A. 1990. Tropical source water. Pages 32-53 *in* McFeters, G.A. editor, Drinking water microbiology: Progress and recent developments. Springer-Verlag, New York, 502 pp.

Hodges, M.H., and Allendorf, F.W. 1998. Population genetics and pattern of larval dispersal of the endemic Hawaiian freshwater amphidromous Gastropod *Neritina granosa* (Prosobranchia: Neritidae). Pacific Science 52(3):237-249.

Izuka, S.K. 1996. Summary of ground-water and rainfall data for Tutuila and Aunuu islands, American Samoa, for July 1984 through September 1995. U.S. Geological Survey. Open File Report 96-116. iv+44 pp.

Izuka, S.K. 1997. Summary of ground-water and rainfall data for Tutuila and Aunuu islands, American Samoa, for July 1985, through September, 1996. U.S. Geological Survey. Open-File Report 97-654. iv+44 pp.

Keating, B.H. 1992. The geology of the Samoan islands. Pp 127-178 in Keating, B.H. and B.R. Bolton, eds., Geology and offshore mineral resources of the central Pacific basin. Springer-Verlag, New York, 296 pp.

Kido, M.H. 1998. Baseline and monitoring studies of Alakahi and Onomea streams, Hamakua Coast, Hawaii. Hawaii Stream Research Center, Univ. of Hawaii. 15 pp. < http://www2.hawaii.edu/hsrc/home/onomea1.htm >

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific northwest and Alaska. U.S. Environmental Protection Agency, Water Division Report EPA/910/9-91-001. 166 pp.

Marquet, G. 1996. The freshwater eels (Anguillidae) of New Caledonia: Taxonomy and distribution. Vie Milieu 46(1):65-71.

Marquet, G. and R. Galzin. 1991. The eels of French Polynesia: Taxonomy, distribution and biomass. La mer 29:8-17.

Marquet, G. and P. Lamarque. 1986. Acquisitions recentes sur la biologie des anguilles de Tahiti et de Moorea (Polynesie Francaise): *A. marmorata, A. megastoma, A. obscura.* Vie Milieu 36 (4):311-315.

Matsuoka, I. 1978. Flow characteristics of streams in Tutuila, American Samoa. U.S. Geological Survey. Water Resources Investigation 78-103. vi+35 pp.

McDougall, I. 1985. Age and evolution of the volcanoes of Tutila, American Samoa. Pacific Science 39(4):311-317).

Moriarty, C. 1978. Eels; A natural and unnatural history. Universe Books, New York. 192 pp.

Munro, I.S.R. 1967. The fishes of New Guinea. Department of Agriculture, Stock, and Fisheries, Port Moresby, New Guinea. xxxvii+651 pp, 78 plates.

M&E Pacific, Inc. 1979. Baseline Water Quality Survey, American Samoa. Contract report prepared for U.S. Army Corps of Engineers, Pacific Ocean Division, Honolulu.

National Park Service. 1997. General Management Plan/Environmental Impact Statement. National Park of American Samoa. National Park Service, Pago Pago, American Samoa. 301 pp.

Nelson, S.G., Smith, B.D., Parham, J.E., Tibbatts, B., and F.A. Camacho. 1995. A survey of the streamfishes of the upper reaches of the Ngermeskang River, Palau, with recommendations for conservation and monitoring. University of Guam Marine Laboratory, Tech. Rep. 100. 31 pp.

Nelson, S.G., Parham, J.E., Tibbatts, R.B, Camacho, F.A, Leberer, T., and B.D. Smith. 1997.Distributions and microhabitats of the amphidromous gobies in streams of Micronesia. Micronesica 30(1):83-91.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Department of Agriculture, Forest Service, Washington, DC.

Polhemus, D.A., Maciolek, D., and J. Ford. 1992. An ecosystem classification of inland waters for the tropical Pacific islands. Micronesica 25(2):155-173.

Powell, J.H. and Powell, R.E. 1999. The freshwater ichthyofauna of Bouganville Island, Papua New Guinea. Pacific Science 53 (4):346-356.

Pusey, B.J. and Kennard, M.J. 1996. Species richness and geographical variation in assemblage structure of the freshwater fish fauna of the wet tropics region of northern Queensland. Marine and Freshwater Research. 47:563-573.

Ryan, P.A. 1991. The success of the Gobiidae in tropical Pacific insular streams. New Zealand Journal of Zoology. 18:25-30.

Sheath, R.G. and Cole, K.M. 1996. Stream macroalgae of the Fiji Islands: A preliminary study. Pacific Science 50(1):46-54.

Southern, W., J. Ash, J. Brodie, and P. Ryan. 1986. The flora, fauna, and water chemistry of Tagimaucia Crater, a tropical highland lake and swamp in Fiji. Freshwater Biology 16:509-520.

Stice, G. and F. McCoy. 1968. The geology of the Manua Islands, Samoa. Pacific Science 22:427-457.

Timbol, A.S., M.H. Kido, and D.E. Heacock. 1989. A descriptive study of selected biological and physicochemical characteristics of Limahuli stream, Kauai. Hawaii. Hawaii Stream Research Center, Univ. of Hawaii. 25 pp. www2.hawaii.edu/hsrc/home/timbolsv.htm

United States Army Corps of Engineers 1981. American Samoa Stream Inventory, Island of Tutuila, American Samoa Water Resources Study. U.S. Army Corps of Engineers, Honolulu District. Honolulu, Hawaii. v+122 pp.

United States Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes. EPA-600/4-79-020, National Environmental Research Center, Cincinnati, Ohio.

United States Environmental Protection Agency. 1986. Ambient water quality criteria for bacteria-1986. EPA-440/5-84-002. U.S. Environmental Protection Agency. Washington, DC.

United States Geological Survey. 1963. Topographic Map. Manua Islands-American Samoa.

Wass, R.C. 1984. An annotated checklist of the fishes of Samoa. NOAA Technical Report NMFS SSRF-781. U.S. Dept. Of Commerce, NOAA, National Marine Fisheries Service. 43 pp.

Whistler, W.A. 1992. Botanical Inventory of the proposed Taú Unit of the National Park of American Samoa. University of Hawaii, Cooperative National Park Resources Study Unit, Tech. Rep. #83. 100 pp

Wong, M.F. 1996. Analysis of streamflow characteristics for streams on the island of Tutuila, American Samoa. U.S. Geological Survey. Water Resources Investigation 96-4185. v+168 pp.

Appendix A. Summary of habitat features and locations referenced during the survey of Laufuti stream. Linear measurements are in meters.

Section	Feature	Elev. ft(m)	Length/Diameter	Width	Depth
LL	station 1 (lower end)	6(2)			
LL	station 2 (lower end)	48(15)			
LL	"Flume"	55(17)			
LL	station 3 (lower end)	110(34)			
LL	pool at base of lowest waterfall	121(37)	9.5		3.2
FZ	pool at base of second waterfall*	166(51)			
FZ	base of third waterfall*	346(105)			
FZ	base of fourth waterfall	776(237)			
ML	low end of Middle Laufuti	862(263)			
ML	trail reaches top of stream canyon	936(285)			
ML	upper end of rope into stream bed	962(293)			
ML	trail enters stream bed	1024(312)			
ML	First eel pool-station 4	1040(317)	9	5	0.5
ML	long pool-station 5	1056(322)	10	5	0.5
ML	deep round pool-station 6	1077(328)	8		0.7
ML	long thin pool	1079(329)	9	2	0.3
ML	series of five pools				
ML	1	1085(331)	6	4	0.4
ML	2		7	5	0.5
ML	3		4	5	0.3
ML	4		9	4	0.5
ML	5	1090(332)	3		0.2
ML	small round pool	1092(333)	3		0.25
ML	small round pool	1134(346)	2		0.4
ML	shallow lava tube cave (25ft deep)	1194(364)			
ML	dead end canyon at base of waterfall	1257(383)			
UL	top of waterfall-beginning of UL	1422(433)			
UL	Large Eel Pool-station 7	1469(448)			
UL	Long Narrow Pool-station 8	1493(455)	10	3	0.3
UL	lower limit of stream flow	1510(460)			
UL	Long Flowing Pool-station 9	1532(467)			
UL	upper limit of exploration	1650(503)			

* height of waterfall is a visual estimate

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS 126-D14, August 2001