'ERRATA" LIST

p6, 3 lines from the bottom. Germany was **banished** not **absconded**

p16, paragraph 2, line 2. The brackets should read: (where water is less than **5 meter** deep) not **50** meter deep.

p77, 2 lines from the bottom. It should read: Samoans have always lived **in a state of "subsistence affluence"**.

p255, paragraph 2, line 2. "lay peremptory blame" should read "**inevitably lead**"

THE ROLE OF CONTAMINANTS IN ALTERING THE COASTAL ENVIRONMENT OF SAMOA

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by

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A thesis submitted in partial fulfillment of the degree of
Doctor of Philosophy in Geography

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DEDICATION

This thesis is dedicated to

the memory of my late mother, Saiaulama

and for my wife Rosa:

the two women who provided the encouragement and inspiration to succeed,

when it mattered

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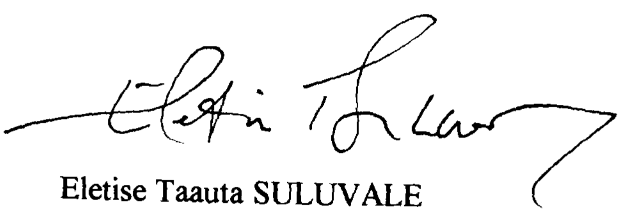
ABSTRACT

Samoa is a small island nation in the South Pacific which supports a population of 161 000 people. Most people in Samoa live a largely traditional lifestyle, dependent on terrestrial and marine resources for subsistence, but a growing number of people are being attracted to the westernized lifestyle developing in the urban centre of Apia. To date, there has been limited attention paid to the environmental concern ssociated with the island's development. In particular, the nature and magnitude of changes to the coastal zone due to anthropogenic or natural causes has remained an unexplored topic. This study addresses some of these concerns. The spatial distribution of water quality in Samoa was examined to determine terrestrial contaminant inputs to the coastal zone. It was found that the streams of Samoa were not contaminated with sulphate and total nitrogen, although substantial amounts of suspended solids, iron, total phosphorus and zinc occurred particularly close to settled areas, and especially near Apia. An intensive water sampling regime of the urban catchments for ten months revealed that the periods of greatest contaminant input into the coastal zone were either during storm events or at times of low flows, when contaminants were discharged from industrial enterprises in Apia. Analysis of sediment material adjacent to selected stream mouths showed that iron and total phosphorus are contaminants of note in the coastal sediments of Samoa, and that zinc was an important indicator of anthropogenic activities. The impact of terrestrial contamination on one coastal vegetation community was examined. Biogeographic and e thnohistorical evidence demonstrated that changes to mangrove ecosystems due to anthropogenic causes had produced pronounced effects on both the economy and lifestyle of the people living near and using the coastal zone. To ensure the protection and management of the coastal environment of Samoa, the dual legal system operating in the country was addressed, and the participation of village councils in management plans was discussed. Suggestions were made as to appropriate ways to manage environmental concerns within the framework of faa-Samoa (the Samoan way).

DECLARATION

I hereby declare that none of the material contained in this thesis has been accepted for the award of any other degree or diploma in any institution and that, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference has been made in the text of this thesis. I consent to this thesis being made available for photocopying and loan, if applicable, and if it is accepted for the award of the degree



Eletise Taauta SULUVALE

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My very special thanks goes to my lovely wife Rosa and my children, for the moral support and prayers in all the time we were separated. It was difficult living apart, and trying to make ends meet. Our understanding and patience was tested at times, but we have remained true to the love that binds our family together. Indeed, our family has gone through many ordeals, and we have sacrificed so much, in order for the subsequent chapters to be written. Although Sa lost the battle with death before this work was completed, she will never lose her place in our hearts. We thank God for her, and for the successful completion of this research.

Malo le tapuai faafetai tatalo

CHAPTER ONE

INTRODUCTION

And God said: "Let the water under the sky be gathered to one place....
the gathered water he called Seas"
Genesis1::v 9-10

Samoa is a small island nation in the South Pacific. The region usually referred to as the South Pacific is in the center of the vast expanse of ocean between Asia and the two Americas (Figure 1.1). The term South Pacific is rather misleading as it usually refers to the islands of both Polynesia and Melanesia (from Pitcairn to Papua New Guinea) and also the Micronesian island states which extend well north of the Equator (Dahl 1984a). Hawaii is usually exempt from the South Pacific region, due mainly to the political affiliation of Hawaii with the United States of America. In some documents, the South Pacific refers to the island nations south of the Equator. Some authors prefer the term Oceania to refer to all islands of the Pacific (Dahl 1984a). In this paper, the South Pacific will be taken to mean the twenty-two island nations that make up the members of the South Pacific Regional Environment Programme (SPREP).

On most maps of the world, the island areas have to be exaggerated in order to be visible at all (Mackensen & Hinrichsen 1984). With so many small island states bordered by vast expanses of ocean, the countries are remarkable in their diversity. As Thistlethwait and Votaw (1992:7) commented:

> Some of these countries consist of one or few islands; others are comprised of hundreds of islands and cover tens of thousands of square kilometers. For a few countries, all their land lies at most a few meters above mean sea level, and the vegetation is sparse; others have towering mountains and dense forest. Populations vary from barely 2 000 to over 3 million, and their peoples may speak a single language or hundreds.

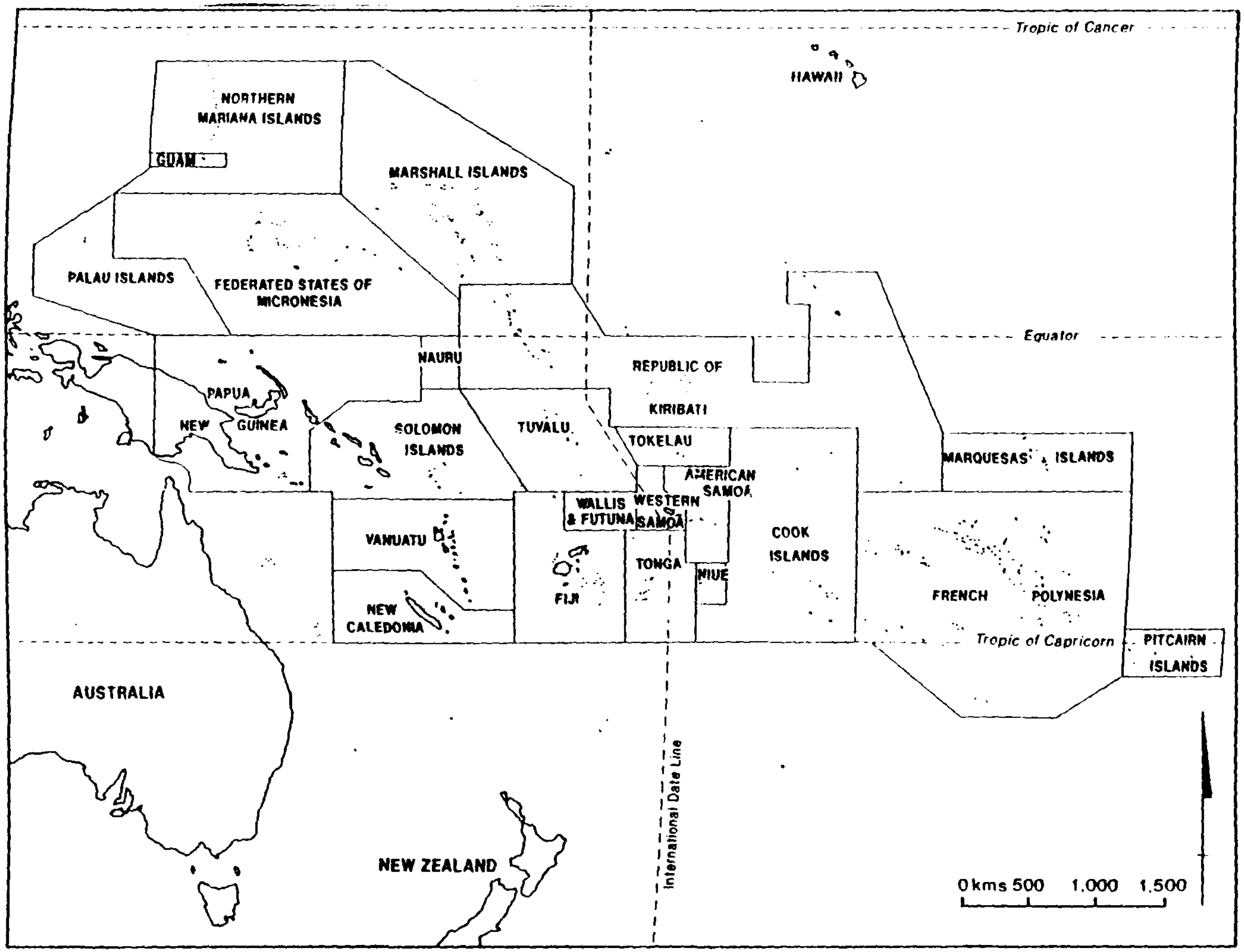

FIGURE 1.1: The Location of Samoa and the States of the South Pacific.
Source: Adapted from the South Pacific Commission - SPC (1982)

Some geographic data on these island states illustrate this point further (Table 1.1). Four countries have land areas of less than 100 km^2 eleven have land areas between 100 km^2 and 1 000 km^2; six have land areas between 1 000 km^2 and 30 000 km^2 and Papua New Guinea alone has over 460 000 km^2 or 84% of the total land mass of the region (Table 1.1).

TABLE 1.1: Some Geographic Data on Pacific Island Countries.
Source: Adapted from South Pacific Commission - SPC (1982)

COUNTRY	LAND AREA (km^2)	POPULATION*	POPULATION DENSITY (persons/km^2)	EXCLUSIVE ECONOMIC ZONE (km^2)
Fiji	18 272	771 000	42	1 290 000
New Caledonia	19 103	178 000	9	1 740 000
Papua New Guinea	462 243	4 205 000	9	3 120 000
Solomon Islands	27 556	366 000	13	1 340 000
Vanuatu	11 880	165 000	14	680 000
Guam	541	147 000	272	220 000
Kiribati	690	77 000	111	3 550 000
Marshall Islands	180	52 000	288	206 000
Federated States of Micronesia	710	121 000	170	3 050 000
Nauru	21	11 000	524	320 000
Northern Marianas	471	47 000	100	1 870 000
Palau	460	17 000	37	616 000
American Samoa	197	53 000	269	2 390 000
Cook Islands	240	19 000	79	1 830 000
French Polynesia	3 265	215 000	66	5 030 000
Niue	259	2 000	8	390 000
Pitcairn Island	5	100	20	800 000
Samoa	2 935	162 000	55	120 000
Tokelau	10	2 000	200	290 000
Tonga	699	98 000	140	700 000
Tuvalu	26	9 000	346	900 000
Wallis and Futuna	255	14 000	55	300 000

* Updated figures from United Nations Department for Economic and Social Information and Policy Analysis (1994)

There are almost 6.8 million people in the region; 62% of these live in Papua New Guinea (Table 1.1). As can be seen, if Papua New Guinea is excluded, both the land area and the population of the South Pacific region are decreased dramatically. Population densities are also quite varied (Table 1.1), ranging from 8 people per square kilometer in Niue to over 500 people per square kilometer in Nauru. The islands also show diversities in their geological origins, reflecting the differences in their resource endowments (Table 1.2). The native vegetation of the region is an extension of that of Malaya (Buxton 1927). Lowland rainforests were originally one of the principal vegetation of the regions high islands (Tourism Council of the Pacific - TCSP 1987). Mangrove forests are common coastal ecosystems in the South Pacific and are important for breeding habitat and food source for many marine species (TCSP 1987).

TABLE 1.2: Geological Origins of the Islands of the South Pacific. Source: Compiled from Thistlethwait and Votaw (1992)

ISLAND STATES	GEOLOGICAL ORIGIN	RESOURCE ENDOWMENT
Papua New Guinea, Solomon Islands, Fiji, New Caledonia, Vanuatu.	Extensions of undersea mountain ranges.	Rich in natural resources, with mineral deposits. Extensive forests and agricultural lands. Abundant marine resources.
Federated States of Micronesia, Cook Islands, Tonga, Samoa, American Samoa, French-Polynesia.	Volcanic island, peaks of dormant or active undersea volcanoes, often surrounded by fringing reefs.	Abundant forest cover, and no mineral deposits.
Niue, Wallis and Futuna, Palau, Nauru.	Raised limestone islands composed of coralline limestone.	Poor natural resources, little diversity in topography, soils or terrestrial fauna and flora.
Kiribati, Tokelau, Marshall Islands, Tuvalu.	Low lying coralline limestone atolls, generally enclose a lagoon.	Poor natural resources, little diversity in topography, soils or terrestrial fauna and flora.

There are also similarities noted in all these island states. Thistlethwait and Votaw (1992:7) noted one of these as:

> All confront threats of environmental degradation resulting from growing populations, increasing urbanization, changing patterns of economic activity and weakening customary systems of social and environmental management.

Environmental concerns affect the islands themselves and their immediate coastal areas, where the balance of population and resources is critical for the future (Dahl 1984b). This chapter introduces the reader to the people and history of the South Pacific, and the environmental problems that have recently arisen in the South Pacific due to overuse of the marine and terrestrial resources of the island states.

1.1 THE SOUTH PACIFIC : PEOPLE AND HISTORY

1.1.1 The South Pacific People

Early historians termed the region now known as the South Pacific 'Polynesia'. They identified three distinct races of people within Polynesia: Papuans, Tarapons and Sawaioris (Stonehewer Cooper 1888). The Papuans are now known as Melanesians, and include people living in Fiji, New Caledonia, Papua New Guinea, Solomon Islands and Vanuatu, and account for 84% of the regional population. The Tarapons are now the Micronesians, and include the inhabitants of Guam, Kiribati, Marshall Islands, the Federated States of Micronesia, Nauru, Northern Marianas and Palau, and account for 7% of the total population. The Sawaioris are now the Polynesians, and include occupants of American Samoa, Cook Islands, French Polynesia, Niue, Pitcairn Island, Tokelau, Tonga, Tuvalu, Wallis and Futuna and Samoa; constituting 9% of the regional population. The three ethnic groups have diverse cultural differences including varying systems of authority and land tenure systems (Pernetta and Hill 1984; Thistlethwait and Votaw 1992). The Melanesians display enormous ethnic and cultural diversities, which is illustrated by the 700 or more languages spoken in Papua New Guinea and over 100 languages spoken in the Solomon Islands (Pernetta and Hill 1984; Thistlethwait and Votaw 1992). The Micronesians and the Polynesians are linguistically more homogeneous.

1.1.2 History

The Melanesians were the earliest occupants of the region, moving in from New Guinea and parts of South East Asia some 20 000 years ago (Bellwood 1978). They were mainly migratory hunter-gatherers from Asia and Indonesia (Mackensen and Hinrichsen 1984). The Polynesians came next, moving in from Indonesia and the Philippines about 4000 years BP

(Bellwood 1978; Mackensen and Hinrichsen 1984). Finding the islands in the west already occupied by the Papuan race, they sailed on and settled the Tongan islands then moved into the Samoas some 300 years later. From here they initiated Polynesian voyages that settled the remainder of the Polynesian region, including New Zealand, in a time span of almost 2 000 years (Douglas and Douglas 1989). The mixed-race nature of the Micronesians is evidenced from the differences in colour and sizes of people from one island to another (Stonehewer Cooper 1888). They moved in and settled the north west part of the region about 10 000 years ago (Ballendorf 1984).

The South Pacific region was completely transformed in the nineteenth century at first by traders, beachcombers and castaways, and then finally by the missionaries who not only brought Western religion, but a host of Western diseases as well. Mackensen and Hinrichsen (1984:291) commented that:

> 'Power politics' and economic rivalry among Britain, France, Spain and Germany transformed the region into colonies, as it was fashionable to have a colony or two in the Pacific. It confirmed world power status.

On some of the islands, the colonial administrations exploited their agricultural potential by setting up huge plantations to produce exports to 'home' markets. This necessitated the importation of large numbers of labourers to work these plantations: Indians on the sugarcane plantations in Fiji; Chinese and Solomon Islanders on coconut plantations in Samoa; and Javanese and Tonkinese in New Caledonia. The Spanish lost their colonies in the war with America in 1898, and Germany was absconded from the region after World War I (Mackensen and Hinrichsen 1984). Today, only France and the United States of America still have territories in the South Pacific.

Progress towards island state independence was very rapid after World War II (Thistlethwait and Votaw 1992). Most Pacific islands are now independent: Samoa gained independence in 1962, Nauru in 1968, Fiji in 1970, Papua New Guinea in 1975, Solomon Islands in 1978, Tuvalu in 1978 and Kiribati in 1979. Today, the independence of many of these states rests on an unstable and very slender economic basis (Mackensen and Hinrichsen 1984)

1.2 THE DEPENDENCE OF PEOPLE ON THE TERRESTRIAL AND MARINE RESOURCES

While large differences in size, population and wealth between the islands make generalizations difficult (Brodie and Morrison 1984a), it is evident that the majority of Pacific islanders dwell along the coasts, living off both land and sea resources (Siwatibau 1984). Fish from the reef and the lagoons is the primary source of subsistence protein for the small islands and the coastal people of the South Pacific (Thistlethwait and Votaw 1992). Shellfish and seaweed are also harvested from exposed reefs (Siwatibau 1984). According to Holthus (1992), Pacific islands economies rely heavily on the values and resources of coastal lowlands and nearshore waters.

1.2.1 The Terrestrial Resources

The majority of land in the South Pacific region comprises low-lying small islands without any appreciable terrestrial resources. Food crops are limited to breadfruit, bananas and coconuts. The coconut palm is the dominant local tree and some copra is produced for export. Only in the high islands of Melanesia and some islands of Polynesia and Micronesia are terrestrial resources economically important at a global scale. Indeed, only Papua New Guinea, the Solomons, New Caledonia, Vanuatu and Fiji have rich natural resources including fertile land, timber and minerals (Thistlethwait and Votaw 1992). These countries have a variety of agricultural exports like sugar, coffee, cocoa, palm oil, rice, copra and timber. Mining enterprises for gold, copper and other minerals are a feature of the economies of Papua New Guinea, Fiji and New Caledonia. Exports from the Cook Islands, Tonga and Samoa are confined to cocoa, bananas, copra and coconut products.

1.2.2 The Marine Resources

The marine resources play a vital part in the subsistence of all the people of the region. With limited land areas and soils of low natural fertility, the foreshores and lagoon areas are the focus of their lifestyles. Thistlethwait and Votaw (1992) gave the following examples of the importance of the marine environment to a number of lowlying atolls in the region. The lagoon, reef and deep-sea fisheries are Tokelau's greatest natural asset; marine resource opportunities for economic development through commercial fisheries, mariculture operations and tourism are reported from the Marshall Islands; marine resources now represent the sole opportunity for substantial commercial economic development in the Republic of Kiribati through industrial fishing; and fish and fishing are central to life in Tuvalu with marine resources representing the sole opportunities for substantial economic development.

The high islands of the region also rely on the coastal areas for a significant portion of their protein needs. Lal (1984) noted that over 90% of the subsistence fish catch in Fiji originated from coastal areas. In Papua New Guinea coastal villagers harvested a total of 13 600 metric tonnes of reef fish per year (Kearney nd). While artisanal coastal fishing is aimed at subsistence requirements for the Solomon Islanders, that country owns the tenth largest fleet of fishing vessels in the world, and commercial fishing is a major source of the country's export earnings

(Thistlethwait and Votaw 1992). Tonga and Samoa both have long standing histories of using marine resources for protein requirements. All the South Pacific island states have experienced stress on their marine resources as the populations expand and detrimental fishing techniques are used (Dahl 1984b). However, most countries of the region, which are rich in fish species like marlin and tuna, have income potential if the exclusive economic zones are utilized.

Other important sources of foreign exchange earnings to South Pacific Island nations are tourism and remittances from nationals residing overseas (SPC 1994). Most national governments in the South Pacific region have realized that integrating tourism and nature conservation will be for the benefit of both the environment and the tourist industry (TCSP 1987).

The islands and coastal waters of the South Pacific are endangered ecosystems. The characteristics that set them apart also make them vulnerable to a wide range of environmental threats (Dahl 1984b).

1.3 THE ENVIRONMENTAL PROBLEMS IN THE SOUTH PACIFIC

The most critical issue facing the islands of the South Pacific is the sustainable use and management of the limited island resources (Dahl 1984b). According to Dahl (1984b), all the problems found in the region contribute in one way or another to this sensitive issue. Table 1.3 lists the environmental problems found in the South Pacific region as documented by SPREP (1982), Dahl and Baumgart (1983), Dahl (1984b) and Thistlethwait and Votaw (1992).

TABLE 1.3: Environmental Problems in the South Pacific.
Source: SPREP (1982), Dahl and Baumgart (1983), Dahl (1984b), Thistlethwait and Votaw (1992)

ENVIRONMENTAL PROBLEM	COUNTRY AFFECTED	EFFECT ON ENVIRONMENT
1. Widespread Problems		
* Domestic liquid waste disposal.	100% of the countries of the region	Coastal water pollution
* Forest-cover reduction.	70% of the region.	Soil loss, siltation, loss of habitat etc.
* Urbanization.	90% of the region.	Reclamation, pollution and sanitation.
* Land-use tenure.	over 50% of the region.	Land mismanagement.
2. Common Problems		
* Soil erosion.	60% of the countries.	Coastal zone degradation, pollution.
* Water shortage.	Over 60% of the region especially in low islands like Tuvalu, Tokelau etc.	Sanitation, pollution.
* Solid waste disposal.	100% of the region.	Pollution and sanitation problems.
* Endangered species.	All the high islands, Cook Islands, French Polynesia, Tonga.	Disappearance of species.
* Coastal erosion.	Over 50% of the region.	Destruction to fishery resources.
3. Localized Problems		
* Mining Effluents.	Papua New Guinea, Fiji, New Caledonia, Solomon Islands.	Water and coastal pollution.
* Industrial wastes.	Fiji, American Samoa, Papua New Guinea, Cook Islands, Samoa, New Caledonia.	Water and coastal pollution.

1.3.1 Widespread Problems

The problem affecting all the countries of the region is the safe disposal of liquid domestic wastes, particularly human wastes and urban sewage (Table 1.3). The result of present practices are serious water pollution of both freshwater supplies (rivers, groundwater and even rainwater) and coastal waters around beaches, reefs and lagoons that are important for tourism, recreation and fishing.

Another major environmental concern is the steady reduction in forest cover in more than 70% of the countries of the region. New Caledonia and Samoa, in particular, are reportedly approaching the limits of their harvestable timber resources. Forests are logged for export and cleared for agriculture. Uncontrolled fires destroy forest margins in Papua New Guinea, French Polynesia and New Caledonia (SPREP 1982). The loss of trees contributes to subsidiary problems like water shortages, soil erosion and loss of habitat for many faunal species. The removal of trees in water catchment areas increases the risk of both river sources drying up in the dry season and soil erosion in the wet season. The removal of trees may also lead to extinction of many bird and insect species as most of these use trees for homes and shelter.

Conventional systems of land and resource tenure have limited comprehensive planning and careful allocation of land for the most appropriate uses (Dahl 1984b). Some land is left undeveloped, while indigenous land tenure made agricultural modernization difficult due to fragmented land holdings (Dahl and Baumgart 1983).

Urbanization is a widespread problem in the South Pacific. Connell (1984) noted that 'throughout the South Pacific, towns are growing faster than villages, especially so in the islands of Micronesia, Fiji, Cook Islands, New Caledonia and French Polynesia'. The problem is noticeable in the Marshall Islands where population densities of 6 500/km^2 and 25 000/km^2 are reported in Majuro and Ebeye centers respectively (Heine 1984). In Papua New Guinea, Fiji and New Caledonia, urbanization has created 'squatter settlements' in the cities (Lal 1984) and have resulted in health problems from overcrowding, unsanitary conditions and a host of many other related discomforts (Thistlethwait and Votaw 1992).

1.3.2 Common Environmental Concerns

Soil erosion and loss of fertility problems are more acute in the region because the resource is often limited. As noted in Table 1.3, over 60% of the countries report soil erosion problems generally associated with agriculture on steep slopes, timber extraction in forests or other land, clearing, and construction activities. Many islands have poor soils and irregular topography to begin with, and heavy rainfall and cleared land increases the susceptibility to erosion. Importantly, these losses represent permanent reduction in productive capacity.

Water shortage is a problem. There is limited water storage capacity in many islands due to porous rock and small watersheds (Dahl 1984b). Although water quality is acceptable by World Health Organization standards in high islands, some countries like Fiji, Solomon Islands and Samoa report poorly managed catchments where water quality has become degraded by suspended sediment from erosion (Thistlethwait and Votaw 1992). The destruction of forest cover has added to this problem with some perennial streams drying up in the dry season (Taulealo 1993). Saltwater contamination of freshwater lenses in both atolls and groundwater supplies of high islands are often irreversible.

Solid waste disposal problems are common in the islands (Dahl 1984b). Disposal sites often ruin coastal mangroves or take land from other important uses (Johannes 1982; Lal 1984). Most of the time, these wastes are not collected or the sites are improperly managed resulting in health and pollution problems (Dahl 1984b; Taylor 1991).

There are seven times more endangered bird species *per capita* in the South Pacific than in the Caribbean, fifty times more than in South America and a hundred times more than in North America or Africa (Dahl 1984b). The isolation of the islands has permitted the evolution of unique flora and fauna with large numbers of endemic species. Conservation of the flora and fauna critical as the area of undisturbed land is diminishing in the region.

Removal of sand from beaches has led to coastal erosion and loss of beaches in many Pacific Island countries. Dredging of coral sand from coastal waters damages productive fisheries resources. On the land, mining affects the areas available for agriculture and leaves useless pits and quarries behind. These degrading activities are observed in over 50% of the countries and are particularly noticeable in French Polynesia, American Samoa, Kiribati, Fiji, Tonga, Tuvalu and Samoa (SPREP 1982).

1.3.3 Significant Localized Problems

In the larger islands (like New Guinea, Fiji and New Caledonia) with mining activities, and those where industrial activities are established, environmental problems such as the disposal of mine wastes, river pollution, loss of natural habitat and erosion are reported (Dahl 1984b). Food and mineral processing plants cause marine pollution through waste discharged to the lagoon areas. Examples of this include the juice processing plant in the Cook Islands, the fish cannery in American Samoa (SPREP 1982) and the Vailima brewery in Samoa (Klinckhamers 1992).

1.4 THE ENVIRONMENTAL DEGRADATION OF THE COAST

The destruction of productive coastal resources and fisheries is nearly a universal problem. Fuavao and Morrison (1992) noted that sewage-related pollutants are major contributors to the coastal pollution problem, as well as the use of agricultural chemicals, the increased sedimentation rate, the overexploitation of living resources, and the destructive fishing practices. These issues contradict the underlying philosophy of sustainable development and resource management.

Construction, dredging, pollution, siltation, and dynamiting or poisoning for fish destroys coral reefs. The highly destructive practice of fishing with dynamites continues in American Samoa, Fiji, Marshall Islands, Micronesia and Samoa (SPREP 1982; Thistlethwait and Votaw 1992). Mangrove areas are diminishing due to reclamation, dredging or by changing essential patterns of water circulation and salinity (SPREP 1982; Dahl and Baumgart 1983; Lal 1984; Zann 1991). Modern boats and fishing techniques have driven coastal species such as giant clams, dugongs and turtles to extinction in local areas (Dahl 1984b). Fish poisoning is very common in coral reefs, and over 100 serious cases of ciguatera fish poisoning were reported each month during 1983 (Dahl and Baugmart 1983; Dahl 1984a). Overfishing is a problem near most of the larger urban centers (Thistlethwait and Votaw 1992) where the lagoon is heavily fished and families glean the intertidal flats on a daily basis for food, shells and other materials for handicraft manufacture.

Natural events also contribute to environmental changes observed in the South Pacific islands. Cyclones and the less frequent volcanic eruptions and earthquakes have had catastrophic consequences on the South Pacific environment (Thistlethwait and Votaw 1992). Climatic changes associated with seal level rise result in changes to lagoon and coastal processes and sediment mobility (Nunn *et al.* 1994). The long-term meteorological influence on the region is the El-Nino Southern Oscillation (ENSO) phenomenon, where marine currents and their heat content undergo marked seasonal and inter-annual variations (Thistlethwait and Votaw 1992). This is accompanied by an eastward propagation of warm waters, variation in sea level, displacement of low atmospheric pressure zones, drought in the western areas and the disappearance of equatorial upwelling which is usually rich in plankton that supports marine life. Consequently, fish catches decline.

1.5 ISSUES ADDRESSED IN THIS THESIS

In this thesis, three of the marine environmental problems commonly found in the South Pacific countries will be examined in detail for Samoa. These problems are particular environmental concerns for Samoa (Thistlethwaite and Votaw 1992). The sedimentation problem reported by Johannes (1982) and Taylor (1991) will be addressed; the amount of sediment carried to the coastal zone by the streams and rivers of the country will be quantified. The effect of urbanization on the water quality of streams flowing through the capital Apia will also be examined. The mangrove degradation issue will be addressed and the health of selected mangrove communities from around Samoa will be assessed. The country, people and history of Samoa will be discussed in the next chapter, preparatory to examining these environmental issues.

CHAPTER TWO

THE ENVIRONMENT AND PEOPLE OF SAMOA

..the land you are about to enter is a land of mountains and valleys
a land watered by rain
Deutronomy 11:11

Samoa is located between latitudes 14°10' and 13°20' South and longitudes 171°20' and 172°50' West (Figure 2.1). The capital city of Apia is approximately 4 500 kilometres north-east of Sydney, Australia, 4 235 kilometres south-west of Hawaii, and 2 500 kilometres north-east of Auckland, New Zealand (GWS 1966). The total land area of 2 935 km^2 consists mainly of the two larger islands Savaii and Upolu with land areas of 1 825 km^2 and 1 100 km^2 respectively (Taulealo 1993). Two other inhabited smaller islands Manono and Apolima and several smaller uninhabited islands make up the remaining land area (Pearsall and Whistler 1991).

Samoa has an Exclusive Economic Zone (EEZ) of 120 000 km^2 (SPC 1982), and a total reef and lagoonal area (where water is less than 50 metre deep) of 23 100 ha (Johannes 1982). In the most recent census of population carried out by the Government of Samoa in 1991, there were 161 300 people living in over 300 villages in the country, with a population density of 55 people per square kilometre. The rural agricultural economy of the country is based predominantly on the tree crops copra and cocoa (GWS 1966; Thistlethwaite & Votaw 1992). The cyclones of 1990 and 1991 annihilated plantations of these tree crops. Now, the economy is increasingly dependent on aid, remittances from overseas and tourism (GWS 1992a; Taulealo 1993).

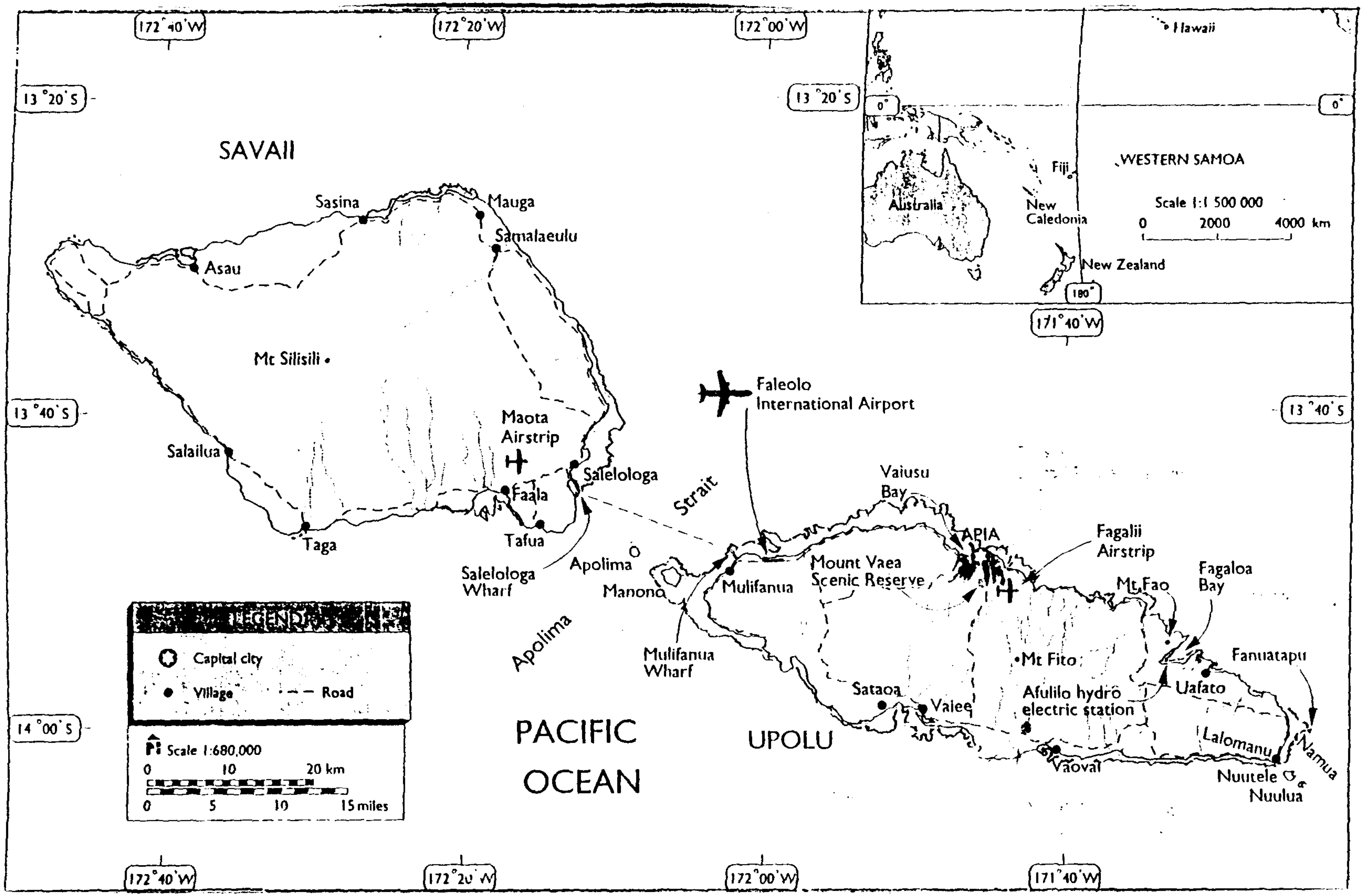

FIGURE 2.1: The Location of Samoa. Source: Taulealo (1993)

2.1 GEOLOGY, GEOMORPHOLOGY AND SOILS

2.1.1 Geological Investigations

Samoa is the larger and more westerly segment of the Samoan Archipelago (Richmond 1991). The Samoan Islands are part of a 1 200 km linear volcanic chain extending 550 km from Rose Atoll in the east to Savaii in the west. Hawkins and Natland (1974) noted that the islands were developed through a stage of shield building and caldera collapse followed by post-caldera eruptive phases and eruption of highly differentiated lava.

German publications on the geology of Samoa in the early 1900s were not accessible to this author. Jensen (1907) reported on the volcanic eruptions of 1905 to 1911 in Savaii and attributed the initial formation of the islands to a gigantic volcanic activity from the ocean floors, forming olivine bearing basaltic lava. This idea has been supported by later geological investigations. Jensen (1907:642) also noted that:

> The abundant volcanic cones lying very close to one another seemed to fuse into mountain chains that make up the backbone of the two islands. From these numerous craters, long ridges of lava flows descend gently to the sea.

Petrological descriptions of seven lava from around the country were included in Jensen's (1907) work. Thomson (1921) reviewed the geological literature extensively and presented observations previously recorded only in German administrative reports and in particular, the existence of lava tunnels in many parts of Savaii as observed by Friedlander (1910). Thomson (1921) described coral reefs, the modern volcanoes and the geology of Savaii, Western Upolu, Manono and Apolima Islands. Although the work of Stearns (1944) focussed mainly on American Samoa, he subdivided the volcanics of Upolu into three age groups based on weathering and erosion.

The most extensive work on the geology of Samoa was that of Kear and Wood (1959, 1962). They prepared a geological bulletin, produced 1:100 000 maps of the islands and identified six geological formations, according to the extent of rock weathering and in relation to offshore reef development (Figure 2.2). Kear *et al.* (1979) updated the work of Kear and Wood (1959), and included amendments resulting from drilling investigations during the 1969 to 1977 period. The islands are still volcanically active, with the last eruptions in Savaii of Mauga Afi in 1760, Mauga Mu in 1902 and Matavanu from 1905 to 1911 (Thomson 1921). These eruptions resulted in the formation of steep-sided volcanic cones composed of basaltic rock fragments ranging in sizes from blocks to cinders (Kear and Wood 1962).

2.1.2 The Rock Formations

The Samoan islands are composed almost wholly of the products of subaerial volcanic activity, mostly of either blocky structure (*aa*) or having a ropy appearance (*pahoehoe*) or pyroclastics (Thomson 1921; Kear and Wood 1959; Richmond 1991; Nunn 1998). The oldest extrusive rocks on both islands were formed in Pliocene-Pleistocene times between 2.69 Ma and 1.54 Ma (Kear and Wood 1959; Natland and Turner 1985). Kear and Wood (1959) named these the Fagaloa Volcanics. Natland and Turner (1985) however argued that the rocks on Savaii were older and petrologically distinct from those on Upolu, and named these the Vanu Volcanics. Keating (1992) regarded the Vanu Volcanics as having erupted more than 2.5 Ma, based on their paleomagnetic character.

The most detailed account of the characteristics of the six geological formations of Samoa is that by Kear and Wood (1959) and updated by Kear *et al.* (1979). This is given in Table 2.1.

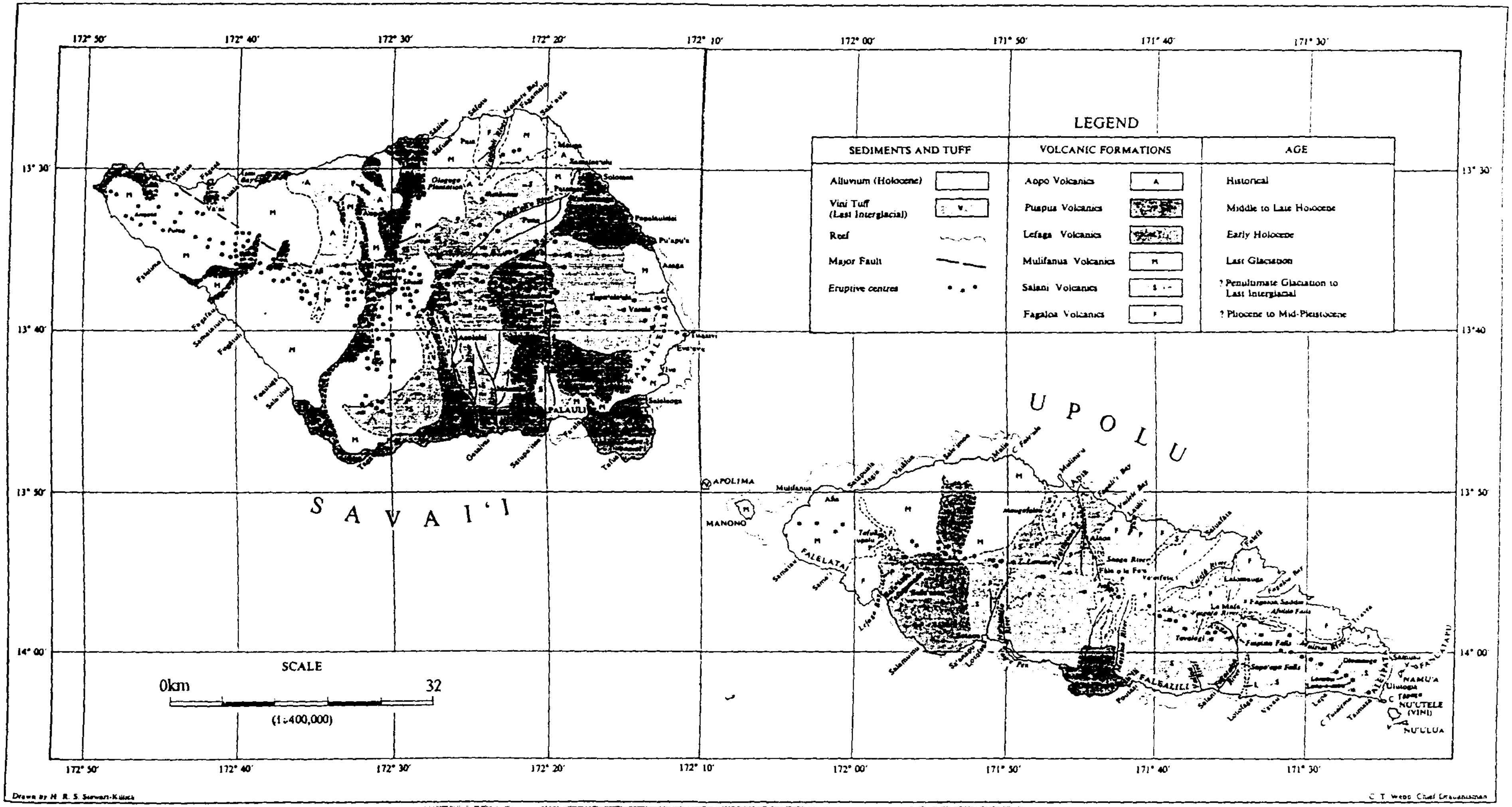

FIGURE 2.2: The Geological Formations of Samoa. Source: Kear & Wood (1959)

TABLE 2.1: The Characteristics of Rock Formations in Samoa. Adapted from Kear and Wood (1959) and Kear *et al.* (1979)

FORMATION	AGE	CHARACTERISTICS
Fagaloa Volcanics.	Late Pliocene to Mid Pleistocene.	Thick soils and rare boulders on uneven land. Surface water always present and fringing reef lies offshore. Deeply weathered (to 75 meters) and strongly eroded olivine basalt and basaltic andesites. Dykes present and cavities and vesicles almost completely coated with zeolite.
Vini Tuff.	Last interglacial (probably early Salani).	Eruptions occur outside lagoon areas. Formation of all small islands except Manono.
Salani Volcanics.	Last Glacial and older (Late Pleistocene?).	Deeply weathered olivine basalt with few boulders on ground surface. Soil depths more than 500 mm thick. Permanent stream flows cut deep gorges exposing volcanic dykes. Barrier reef present at considerable distances offshore.
Mulifanua Volcanics.	Last Glacial (Late Pleistocene).	Soil depths up to 500 mm. Common angular boulders, rare surface water, barrier reef present, moderately weathered olivine basalt.
Lefaga Volcanics.	Early Holocene.	Now includes Falealupo Peninsula. Usually no surface water, flow surfaces show thin erosion (300 - 500 mm), a fringing reef close inshore, moderately weathered olivine basalt littered with many non-weathered boulders.
Puapua Volcanics.	Middle to late Holocene. Older than 100 AD and younger than 1200 AD.	Fresh with thin soil cover without cavity fillings, boulders on uneven land, usually no surface water and no reef present, slightly weathered olivine basalt.
Tafagamanu Sand, Nuutele and, Lalomauga Alluvium.	Post glacial, high sea levels, Post Mulifanua.	Sedimentary formations, approximately contemporaneous with Puapua Volcanics.
Aopo Volcanics.	Historical. Eruptions of 1760, 1902 and 1905-11.	Poor vegetation, virtually without soil, no reef present and no surface water, very slightly weathered olivine basalt.

Drainage patterns closely follow the geological formations, with the older Fagaloa and Salani Volcanics exhibiting numerous permanent surface streams, while the historic rock formations are without any permanent streams. Extensive deposits of coral sand in the form of raised beaches and beach ridges surround most of the two islands (Kear and Wood 1959). Alluvium is common along the mouths of rivers and streams and other low-lying areas (Richmond 1991). Marine marsh vegetation or mangrove forest usually grows on alluvial deposits.

2.1.3 Rock Petrogenesis

Kear and Wood (1959) have documented pre-1960 literature on Samoan rock petrology. Again, most of these publications were by German authors and were not accessible to this author. The papers by Hedge *et al.* (1972), Hawkins and Natland (1974) and Ishii (1984) presented chemical analyses of some rocks from the islands. Table 2 2 lists the general findings observed by these Author's. Although there appears to be a difference of opinion between Ishii (1984) and the other Author's as to the abundance of aluminium oxide and silica in the rocks, there is a consensus on the type of minerals present in the rocks.

TABLE 2.2: General Petrogenesis of Rocks in Samoa.
Source: Compiled by Author

GENERAL ROCK PETROGENESIS	SOURCE
High Sr^{86}/Sr^{87} ratio, Low Al_2O_3, High Fe, Mg, K	Hedge *et al* (1972)
Low Al_2O_3, SiO_2, High CaO, TiO_2, Abundance of transition metals	Hawkins and Natland (1974)
High SiO_2 (40-49%), High Al_2O_3, High FeO, MgO and MnO	Ishii (1984)

Hedge *et al.* (1972) analyzed thirteen volcanic rock samples from Samoa from each of the geological formations listed in Table 2.1 except the Lefaga Volcanics. They found very high Sr^{86}/Sr^{87} ratios in the rocks, suggesting a less depleted mantle from which the rocks were derived. Relative to most oceanic basalt, the rocks analyzed from Samoa were low in Al_2O_3 and high in iron, magnesium, potassium and titanium (Hedge *et al.* 1972). Hawkins and Natland (1974) restricted their discussion to basanites and nephelinites, noting that the rocks are strongly undersaturated in silica, and have low Al_2O_3, high CaO and TiO_2 contents as compared to other alkalic mafic rocks. Their trace element analysis showed rocks with higher in incompatible first transition elements like strontium (Sr), chromium (Cr), nickel (Ni), barium (Ba), vanadium (V) and zinc (Zn) in decreasing order of abundance. According to Ishii (1984) there is an abundance of silica (SiO_2) in the rocks and substantial amounts of alumina (Al_2O_3), ferrous oxide (FeO), magnesium oxide (MgO) and calcium oxide (CaO) in decreasing order of abundance, as seen in Table 2.3.

TABLE 2.3: Analyses of some Basalt Rocks from Samoa.
Source: Adapted from Ishii (1984:77)

	olivine basalt from Nofoalii, NW Upolu	olivine basalt from Falealili, S.Upolu	olivine basalt from Fagaloa Bay
sample number	WSG-T182082904B4	WSI-T182083102A	WSJ-T182090409H
	(%)	(%)	(%)
SiO_2	40.42	46.66	44.75
TiO_2	5.08	3.67	4.58
Al_2O_3	13.10	15.47	15.06
Fe_2O_3	0.0	0.0	0.0
FeO	13.74	10.98	12.16
MnO	0.16	0.19	0.19
MgO	13.19	6.23	6.19
CaO	8.51	10.32	9.04
Na_2O	1.31	2.83	2.82
K_2O	0.68	0.89	1.18
P_2O_5	0.67	0.49	0.77
TOTAL	96.86	97.73	96.74

2.1.4 Geomorphology

An axial range of volcanic cones extends ESE to WNW through the interior of both islands of Samoa (Curry 1955). The landscape of Samoa is mainly the result of subaerial erosion of a long and narrow dome in the case of Upolu and a broad and elliptical dome in the case of Savaii (Wright 1963). Physical features are significant in the geography of Samoa (Curry 1955) and none is more prominent than the central ridge which forms the backbone of the islands (Plate 2.1). Taulealo (1993:1) noted that:

> The topography of the land in both islands is rugged and mountainous, characterized by steep slopes. The interior of both islands contain volcanic peaks with crestal ridges rising 1 100m and 1 848m in Upolu and Savaii respectively.

Richmond (1991) recognized three coastal types of coastline in Upolu, the most common are fringing reefs. Barrier reefs and patch reefs exist but to a lesser extent. Nunn *et al.* (1994) noted two types of coastline on Savaii namely: ironbound coasts (where reefs are absent and the area plunges steeply into deep water) and low-lying coasts (sandy embayments made largely of superficial materials). Land slopes vary from one to two degrees in the coastal flat areas to fifteen to twenty five degrees in the upland regions. Wright (1963) produced a land slope map for the two islands (Figure 2.3) on an altitudinal basis. The lowland region from sea level to 250 meters, the foothill region between 250 meters and 600 meters, the upland plateau from 600 meters to 1 200 meters, and the upland region above 1 200 meters. Approximately 40% of Upolu and 50% of Savaii are characterised by steep and moderately steep slopes (Taulealo 1993).

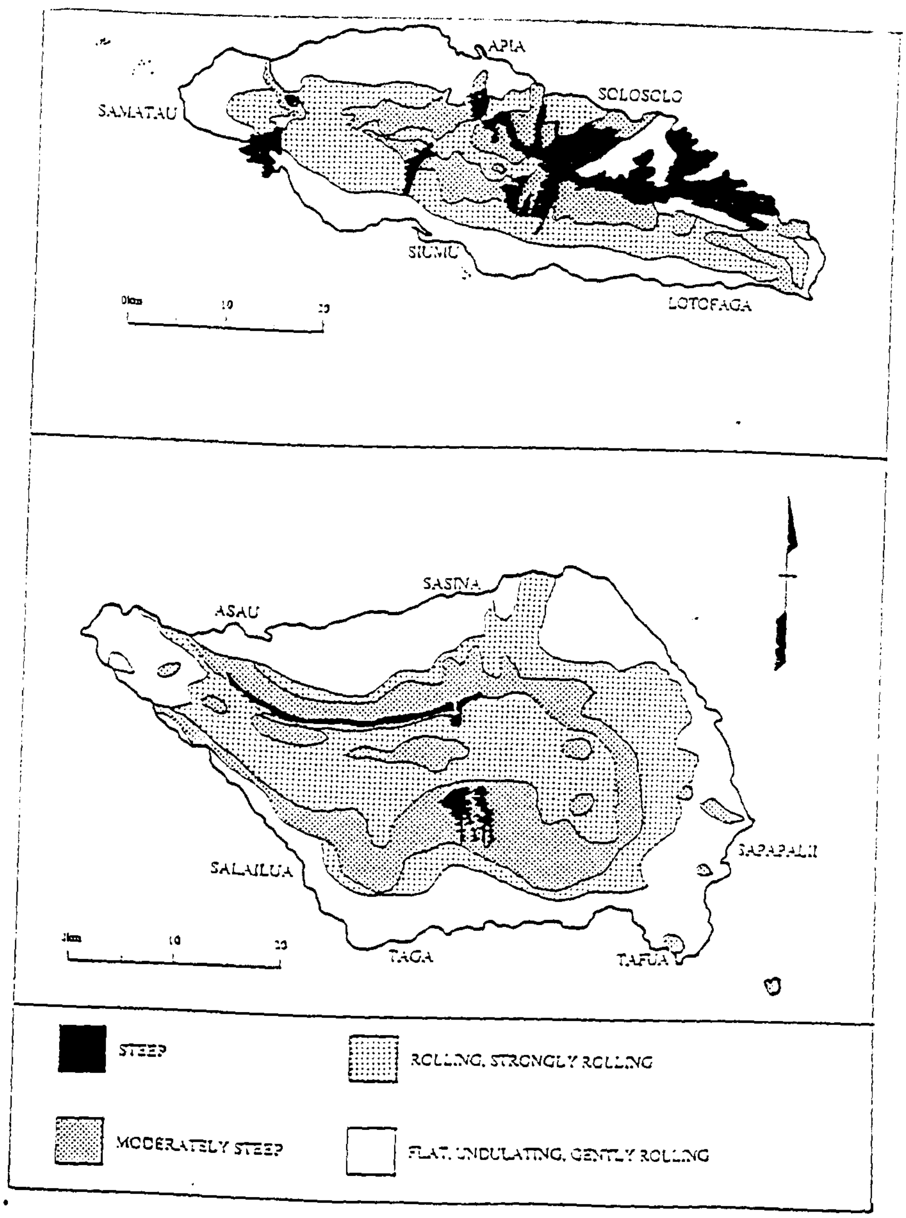

FIGURE 2.3: Landform Regions of Samoa. Source: Wright (1963)

PLATE 2.1: The physical characteristics of the islands of Samoa. Note the rugged interior, the general vegetation and the rock outcrops in the stream channel. Photograph by R. Lawrence

2.1.5 Past Sea Levels

Samoa is an area where several conflicting models of Holocene sea level changes have been applied over the years (Nunn 1995). One of the earliest observations relating to land/sea level changes on Upolu was that of Jensen (1907:646) who found despite finding "no indication of raised beaches" believed they (had) existed and emphasized the absence of evidence for submergence. Thomson (1921) argued that coastal plains covered by coral sand in parts of Upolu may have been uplifted since no parts of the old reef were exposed. Yet Stearns (1944) observed emerged reef flat at Fagalii Bay, and corresponded, he believed, to the 1.5 m emergence that affected American Samoa. Mayor (1924) took a contrary view, reporting that Upolu did not exhibit the emerged shore platform, and speculated that this was due to a slight relative submergence of Upolu. Kear and Wood (1959) found sedimentary evidence of emergence at 1.5 to 2.4 m (Tafagamanu Sand), 4.6 m (Nuutele Sand) and 9 m (Vini Tuff). Kear and Wood (1959) regarded these as the result of a sea level fall rather than uplift. Contrary to the interpretation by Kear and Wood (1959), Green and Davidson (1974:223) concluded that "varying degrees of uplift of the land" had been responsible for associated emergence. The discovery of the Ferry Berth site at Mulifanua, widely cited as evidence of recent subsidence of Upolu brought a different argument to the topic (Nunn 1995). Although Lapita pottery found at Mulifanua indicated a sea level 2.7 meters lower around 3 000 years ago, the implication that Lapita people may have lived in stilt-houses (Kirch 1988) meant that the pottery level at Mulifanua may have no relation on the contemporary shoreline level (Nunn 1995; Nunn 1998). With the addition of new dates from both American and Western Samoa, Nunn (1998) gave the most recent Holocene sea-level envelope for Samoa. Nunn (1998:190) noted that:

> The maximum Holocene sea level culminated in the formation of the Tafagamanu Sand about 2000 BP. Contemporary sea level may have slightly

> exceeded 2 m above its present mean level. This interpretation involves sea level rising during the middle Holocene at a rate of 1 m per 1000 years, then falling in the late Holocene at a rate perhaps as high as 2 m per 1000 years

Land subsidence and sea level rise in Samoa points to a submerged coastline. This may be one of the reasons of environmental changes observed in Samoa in the recent past. On a regional level, Ravuvu (1993) noted that the sea level stood at one to two meters above present level in most parts of the south west Pacific, and that sea levels have been rising throughout the Pacific region at varying rates.

2.1.6 The Soils

The first record of a systematic soil survey in the country was that of Hamilton and Grange (1938) who established that the soils of Samoa were mainly 'lateritic' in character, unusually rich in titanium oxide, and showed a leaching sequence dependent mainly on the age of the parent lava. Their conclusions and recommendations were fully endorsed by Wright (1963). The soil survey work by Wright (1963) mapped the soils of Samoa into 90 soil series. ANZDEC (1990) simplified Wright's (1963) classification to 86 soil series. On the parent material and soil type, Wright (1962:78) wrote that:

> The chief soil forming parent material is olivine basalt [both *aa* and *pahoehoe*], scoria or volcanic ash. The youngest soils are those from alluvium deposits during river valley floodings, and the coral sands accumulating in various sheltered positions in the coastline. Other young soils are those associated with recent lava flows in 1905 and 1902. These are mostly barren rock with only a very thin soil cover. The majority of the soils are Latosols [from basalt, basic andersites, basic tuffs and basic ash] and Lithosols [from basalt and basic ash].

Curry (1962) argued that the warmth and wetness of the soil throughout the year and the amount of water percolating through make the soils progressively lose their bases and become acidic. Four major soil groups, which coincided with Kear and Woods' six geological formations, were recognized and are listed in Table 2.4. The table illustrates that the soils of the older rock formations are the most suitable for agriculture, as they have deeper soil profiles, adequate water resources and workable surface characteristics. The fact that only 21% of the total land area contain soils of moderate to high fertility means that in the course of time, many soils around the country are expected to become poorer in supporting the rapidly expanding population (Taulealo 1993). As far back as the 1960s, the readily available agricultural soils in most districts showed signs of increasing exhaustion (Wright 1963). Villages with restricted agricultural lands have started to clear the forest and elevated areas adding to the problem of (accelerated) soil erosion (Wright 1962).

TABLE 2.4: Geology, Surface Configuration, Soil Structure and Agricultural Suitability of Samoan Soils. Source: Wright (1962)

GEOLOGICAL FORMATION	SURFACE CONFIGURATION	SOIL DEPTH AND TEXTURE	SUITABILITY FOR AGRICULTURE
Fagaloa Volcanics	Hilly and mountainous, few boulders on the soil surface landscape strongly dissected.	Plastic and sticky clays more than 100cm thick.	Mainly too steep for permanent agriculture, although there are many perennial streams and springs.
Salani Volcanics	More weathered rocks, terrain deeply dissected by valleys where streams flow continuously.	Clay soils between 50cm and 100cm deep.	Suitable for agriculture. Subsistence farming mainly on valley sides.
Mulifanua and Lefaga Volcanics	Slightly dissected surface water from occasional springs near tide level.	Bouldery clay loams to stony loams from 10cm to 50cm deep.	Suitable for agriculture if lasting water supply is available.
Puapua Volcanics	Very slight dissection of the surface, abundant boulders and rocks.	Very shallow bouldery loams.	Not suitable for permanent agriculture, poor water supply and subsistence farming hindered by many rock outcrops.

Approximately 200 soil samples from around the country were analyzed as part of Wright's (1962, 1963) soil survey. Chemical analysis of some soils from Samoa is given in Table 2.5. In general, the soils contained a high proportion of organic compounds, low cation exchange capacities and moderate concentrations of calcium and magnesium. Phosphorus appeared to be the only one of the chief nutrients likely to be in short supply.

TABLE 2.5 : Chemical Analyses of Some Soils from Samoa. Source: Wright (1963)

Soil	Depth (cm)	pH	P (as mg %P)	ORGANIC MATTER total N (%)	C/N	exch. cap (me%)	tot. bases (me%)	base sat (%)	CATION-EXCHANGE PROPERTIES exchange cations (me%) Ca	Mg	K	Na	VEGETATION, ALTITUDE OF SAMPLE AND TOPOGRAPHY
Namoa clay loam	0-12	6.7	4	0.24	14	31.1	32	100	8.2	16.1	2	4.1	lowland swamp forest near coast, 2.7m,
	12-30	6.5	5	0.12	9	29.3	28	96	5.2	13.9	1.7	4.9	flat terrain, water table at 50cm
Lefaga stony clay	0-5	5.6	9	1.75	10	64.4	46.6	73	34.4	10.2	0.5	0.2	tall lowland forest, 150m, very
	5-45	5.8	5	0.66	7	27	5	19	4.7	2.8	0.1	0.1	stony undualting land
Afiamalu silt loam	0-2.5	4.3	6	1.37	15	41.1	5.4	13	3.3	2.2	0.6	0.6	upland forest, 650m, gently
	2.5-30	4.7	3	0.43	14	11.2	0.1	1	0.3	0	0.05	0.1	undulating terrain
	30-65	5.5	1	0.09	21	3.1	0	0	0.2	0	0.05	0	

2.2 CLIMATE AND WATER RESOURCES

2.2.1 Climate

The climate of Samoa is tropical (Johnston 1953; Streten and Zillman 1984) typified by high humidity and heavy precipitation occasionally accentuated by severe cyclonic storms during the wet season from November to April (Douglas and Douglas 1994). The South Pacific Convergence Zone (SPCZ) which extends north-west to south-east across the region (Giambelluca *et al.* 1988) dominates the climate of Samoa. According to Steiner (1980), Samoa lies just south of the SPCZ during the months of May to October, during which times the south-east trade winds predominate. Most rainfall at this time of the year is orographic and the islands experience a dry season (Falkland and Brunel 1993; Nunn 1994). In the months of November to April, Samoa lies north of the SPCZ and winds are mostly the divergent easterlies. During these months, the SPCZ is more active and persistent, with small cyclonic disturbances common, which often develop into tropical storms or hurricanes (Giambelluca *et al.* 1988). This is the wet season in Samoa.

The predominant winds affecting Samoa are the south-east trade winds, which blow for over 80% of the time in the wet season, and about 50% in the dry season (Wright 1963; Taulealo 1993). Average wind velocities are around 20 km/hr, with gusts above 48 km/hr occurring less than 0.5% of the time (Solomon 1994). Although the country does not lie on the cyclone belt, it was hit by two severe cyclones recently: Cyclone Ofa in 1990 and Cyclone Val in 1991. Wind speeds of up to 180 km/hr were measured during the cyclones which devastated most of the roads, buildings, plantations, forests, coastal areas and reefs of the country (Chase and Veitayaki 1992).

Annual rainfall data from Mulinuu for the years 1941 to 1994 are given in Figure 2.4. Although rainfall data were recorded in other stations from around the country, most were destroyed in the cyclones of 1990 and 1991. The average annual precipitation for Mulinuu calculated for the 53 years of record is 2 900 mm (Appendix 1.1). The highest annual value of 4 190 mm occurred in 1950, and 1977 was the driest year with only 1 900 mm of rain falling. Both years coincided with El-Nino conditions (Nunn 1994).

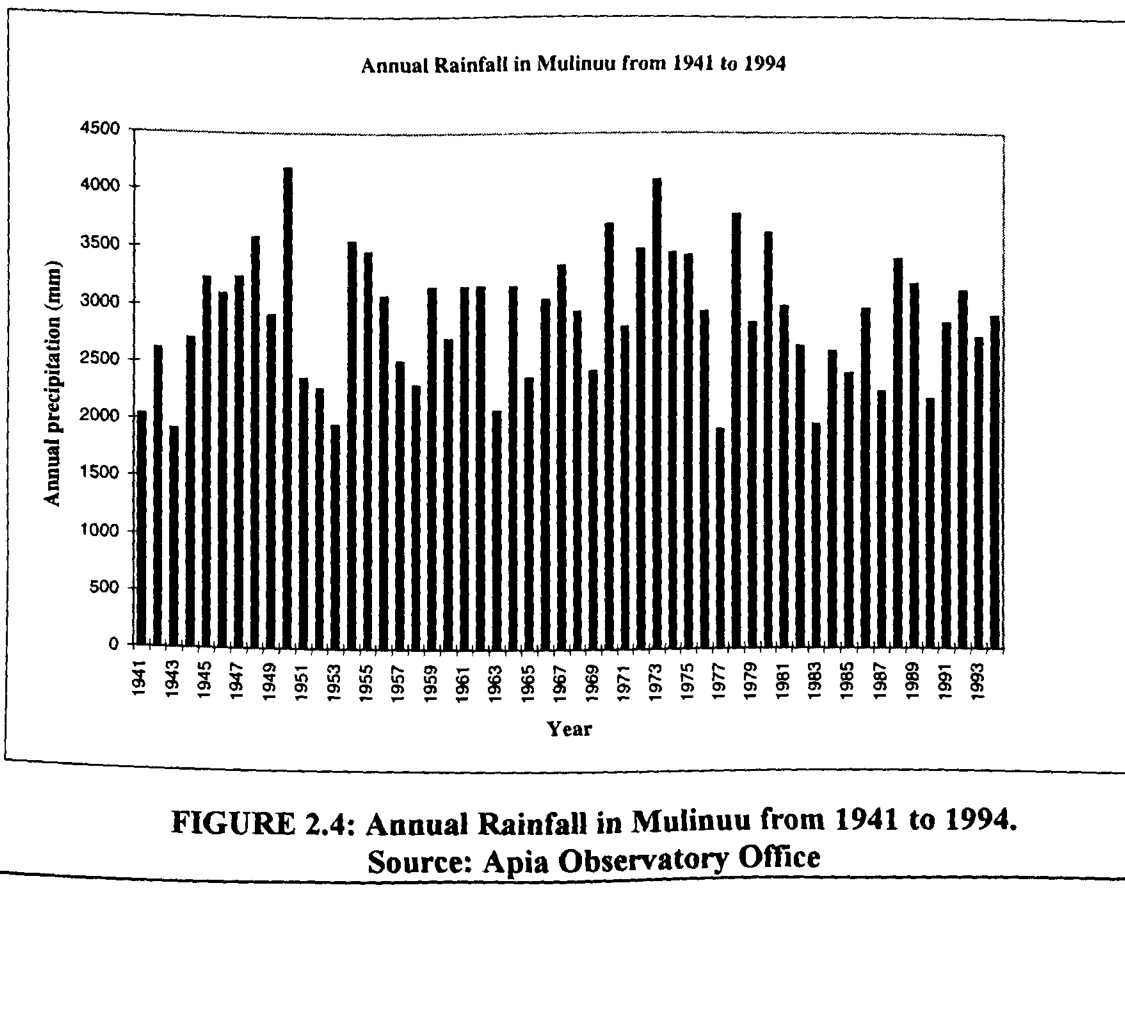

FIGURE 2.4: Annual Rainfall in Mulinuu from 1941 to 1994.
Source: Apia Observatory Office

In general, annual rainfall is variable according to location and altitude (Chase and Veitayaki 1992), with the southern lowlands receiving approximately 3 000 to 5 200 mm/yr, and the northern shores averaging as little as 2 100 mm/yr (GWS 1995). Seasonal variation in rainfall for Mulinuu (Figure 2.5) shows that peak rainfall months are December, January and February while the minimum rainfall months are June, July and August.

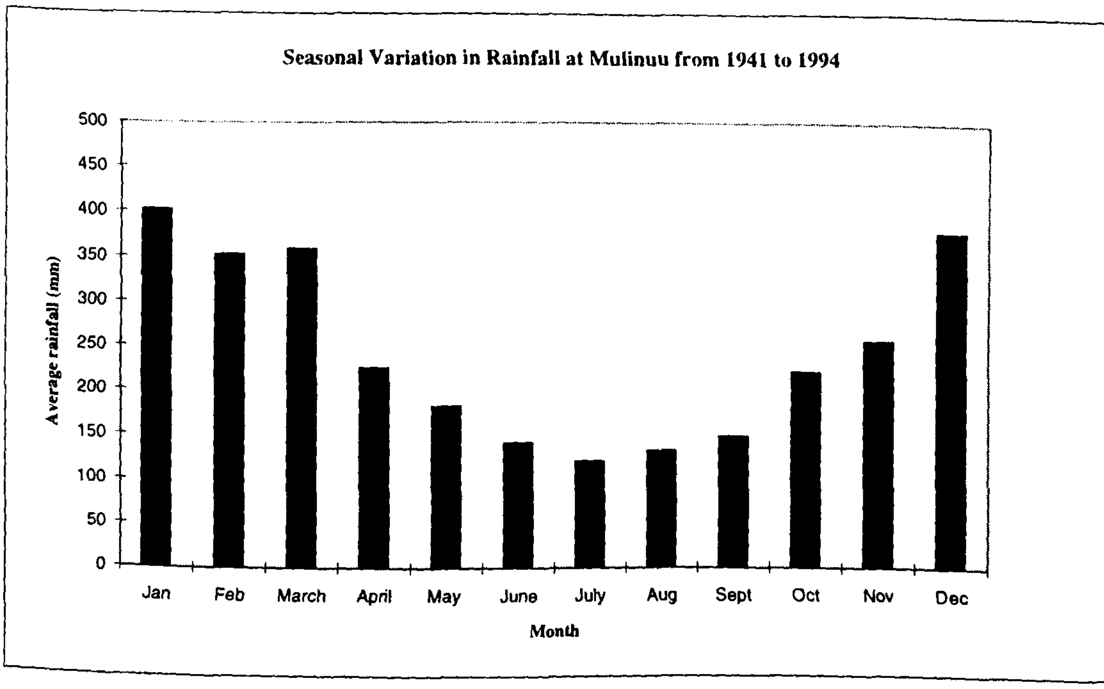

FIGURE 2.5: Seasonal Variation in Rainfall for Mulinuu from 1941 to 1994. Source: Apia Observatory Office

There is a difference in opinion on the existence of a rain shadow area in the country. Curry (1955) noted that the north western sectors of both islands are the rain shadow areas, and receive the lowest rainfall in all months. By contrast, Kear *et al.* (1979:9) wrote that:

> No 'particular' rainshadow areas are found in the country, as the winds strike the eastern tip and travel along the length of both islands bringing rain to both sides. Only certain parts of the two islands will experience 'dry' spells when the wind patterns change accordingly.

Wright (1963) who attested that there is no true lee shore, as the driest regions in Samoa are quite wet by comparison to other islands, supports this latter view.

To determine the existence of temporal trends in rainfall, an eleven-year moving average analysis was conducted (Figure 2.6).

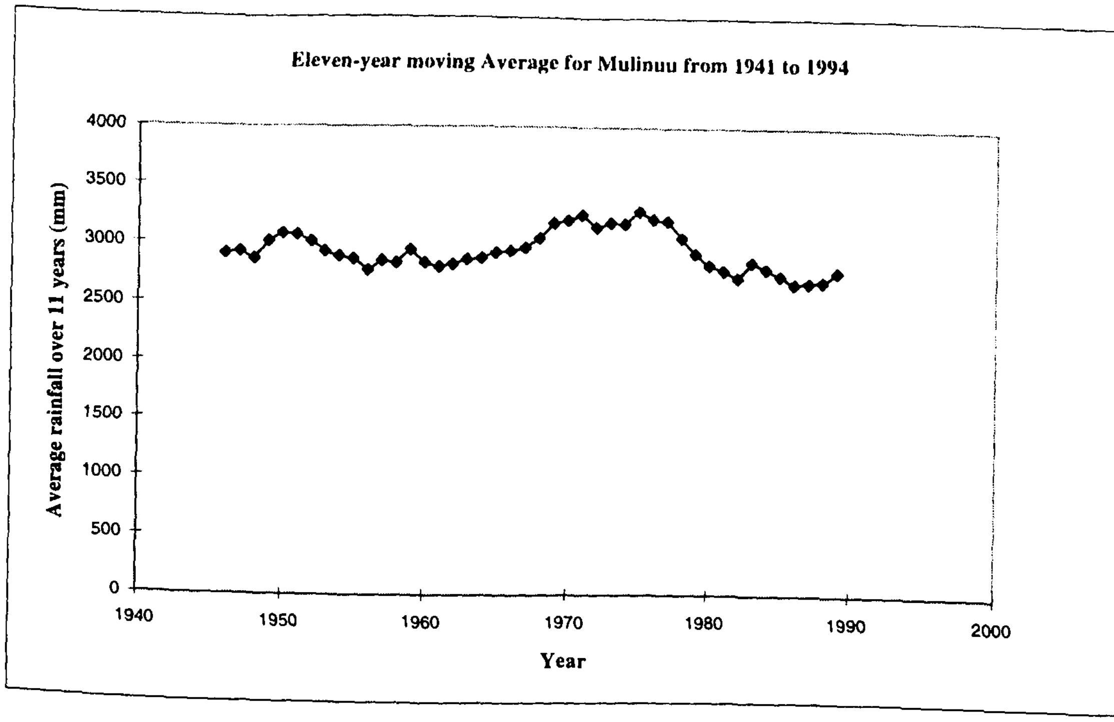

FIGURE 2.6: The Eleven-Year Moving Average Graph for Mulinuu for the past 53 years. Source: Drawn by author from Apia Observatory data

The trendline indicates that the annual rainfall has not yet recovered from below average conditions established after 1983 (Nunn 1994). Also, this period of below average conditions since 1983 is the longest lasting period of below average rainfall in the 53 years of rainfall records at Mulinuu. According to Gupta and Pitts (1992), various reasons can be given for such a pronounced and prolonged decrease in average rainfall. These are: rapid urbanization near this station may have caused a general reduction in annual rainfall when calculated over a decade; the reduced annual rainfall may be associated with a global or regional climatic change; or a combination of the above suggestions. It is uncertain which scenario is the most relevant one as far as Samoa is concerned. However, it is a fact that the capital Apia has seen a massive growth in urbanization during this time (GWS 1993b) and similar below average conditions in rainfall are reported in Fiji and Singapore (Nunn 1994; Gupta and Pitts 1992).

Samoa experiences warm temperatures of 26°C to 27°C at sea level. Dry bulb temperature records from Mulinuu for the past 53 years revealed that the average monthly temperature never exceeded 30°C (Appendix 1.2). A mean annual value of 27.5°C was obtained. The mean monthly temperature never dropped below 27°C or above 30°C in the 53 years of recording (Appendix 1.2). The highest monthly temperature of 29.1°C occurred twice in February 1983 and November 1987 and a lowest temperature of 25.8°C occurred once on July 1951. The seasonal variation in temperature is very small, but follows that of the rainfall distribution pattern, with the higher temperatures in the wet months of November to March and lower temperatures in June to September (Figure 2.7).

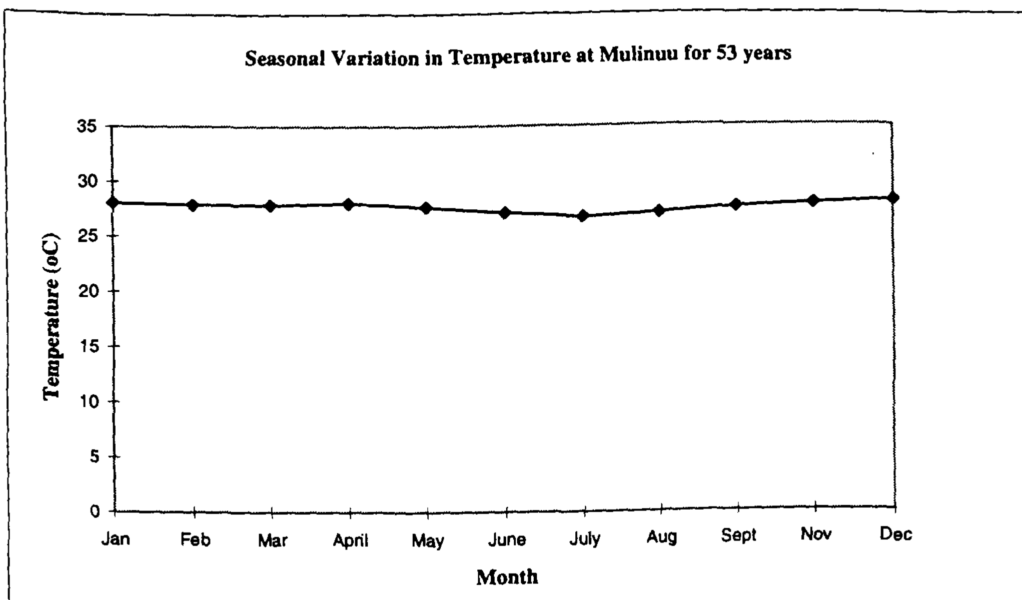

FIGURE 2.7 : Seasonal Variation in Temperature at Mulinuu for 53 years.
Source : Adapted from Apia Observatory Office data

A mean daily range of 6.8°C in January and 7.9°C in July is experienced in Samoa (Burgess nd; Chase and Veitayaki 1992). Further, there is a decline of temperature with increase in altitude, where a long term annual mean of 26°C at the coast would become 21°C on the highest point of Upolu, and 15°C on the Savaii highlands.

2.2.2 The Surface Hydrology of Samoa

Its geology, climate and topography principally determine the surface hydrology of Samoa (Kear *et al.* 1979:). In spite of heavy rainfall, perennial streams exist only in the north east and central parts of Upolu, and in the central northern and southern portions of Savaii as seen from the water resources distribution map of Samoa given in Figure 2.8.

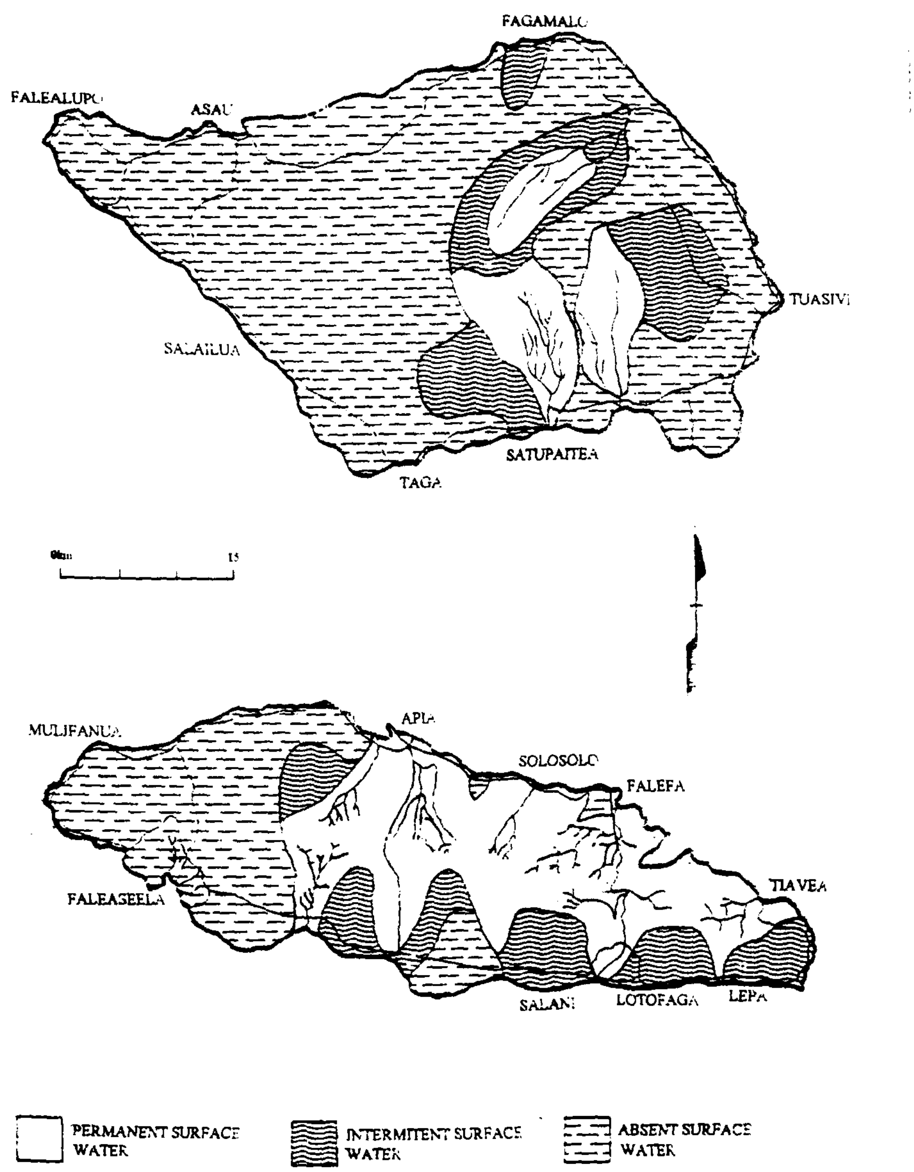

FIGURE 2.8: The Water Resources of Samoa.
Source: United Nations (1983)

In the western parts of both islands that are covered with permeable young basaltic rocks, surface streams do not exist at all or only for a few hours after torrential rain (Economic and Social Commission for Asia and Pacific - ESCAP 1989). However, groundwater is abundant in these rocks. Permanent rivers and streams are common in Upolu, but are restricted to areas of the older Fagaloa and Salani Volcanics in the central and eastern parts of the islands. Most of the country derives its water from the abundant rainfall occurring in all parts of the islands (Section 2.2.1). Of the rain that falls, Stednick (1990) estimated that 29% infiltrates into the ground water while 48% enters the stream system.

Surface water supply is a problem in many parts of Savaii (Kear *et al.* 1979). Many villages rely on groundwater supplies through wells and springs for their everyday water needs. Fortunately, not all of the country has these water deficient characteristics. Villages in northern and western coastal Upolu are relatively well supplied with water, with pipelines running westwards from Apia and northwards from Falelatai. Coastal springs of good water quality are utilized at southern and eastern Upolu. Streams are often on steep slopes and require a lot of infrastructure before the water can be gravity fed to the adjourning villages (Wright 1963). A scheme for both water supply and hydro electric power generation has been established for Apia, utilizing the waters of the Vaisigano River. The water quality of the Apia urban area is declining because of greater runoff from cleared catchment areas (Taulealo 1993).

2.2.3 Groundwater

According to Foster and Chilton (1993), small tropical islands have a shallow groundwater table in the lower-lying areas of coastal plains (Figure 2.9). Aquifers in the largely impermeable volcanic rocks are filled rapidly in the wet season. As a result, excess rainfall is rejected, resulting in extensive overland flow.

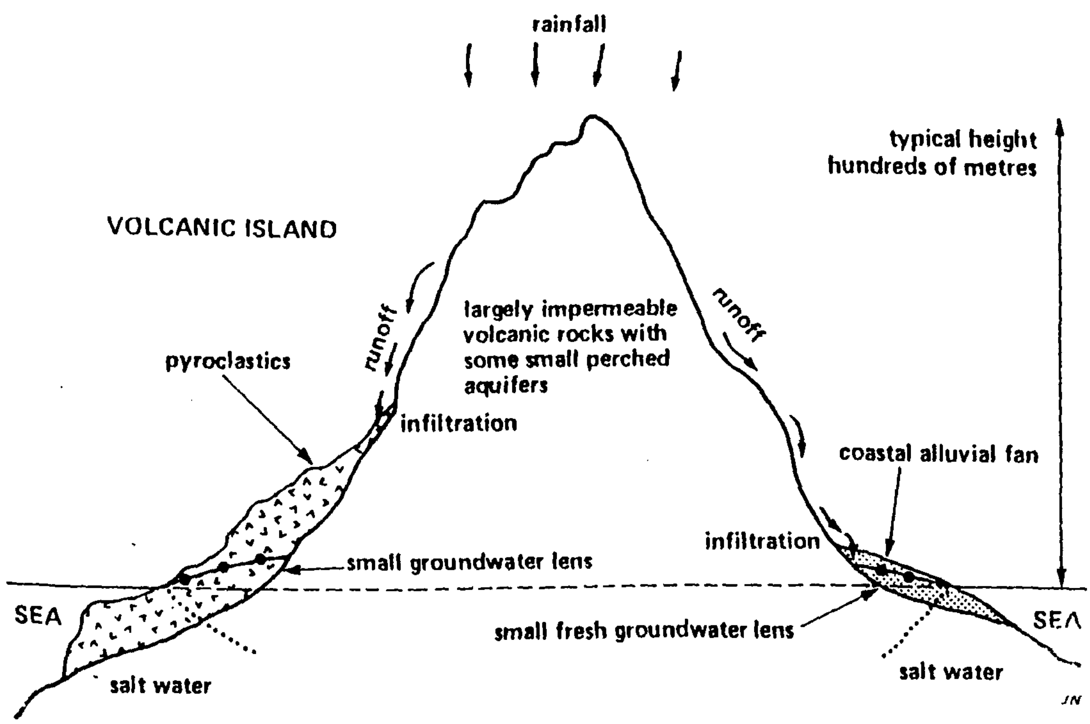

Figure 2.9: Generalized Section through a Typical Volcanic Island.
Source: Foster and Chilton (1993)

Runoff infiltration into the groundwater occurs in the coastal alluvial plains or into the pyroclastic deposits interbedded with the viscous lava (Foster and Chilton 1993). The United Nations (1983) noted that the Ghyben-Herzberg principle of a freshwater lens floating on salt water beneath the islands has been found relevant to Samoa and that saline intrusion is a general problem where wells are located close to the coastline. ESCAP (1989:34) noted that:

> The majority of wells are located from 500 meters to 3 000 meters inland, with a maximum site altitude of 80 meters above sea level. Water tables above mean sea level range from 0.1 meters in the coastal areas to 6.0 meters inland. Shallow wells near the coast yield large quantities of water, but the salinity values may exceed the World Health Organization maximum of 600 parts per million [ppm] chloride.

Meredith and Associates (1981) found salinity of the waters from seven boreholes in Savaii to exceed the maximum permissible World Health Organization (WHO) limit. These consultants also found water from intakes at Paia and Vaipouli villages to be serious health hazards, showing E-coli counts of 13 000 to 12 000 per 100 ml. However in an analysis of 56 coastal springs and wells in the Faasaleleaga district in Savaii, Cox (1960) found that the water from these was astonishingly good, considering their shoreline location. The chloride content in some of the springs was very low indeed. Groundwater is the only source of water for most villages in the western and northern parts of Savaii (Kear *et al.* 1979). Boreholes are expensive to develop, costing about $1000 WST ($600 AUD) per meter to drill, and 20 to 40 sene (22 cents) per cubic meter to operate depending on bore depth (Taulealo 1993). The drilling exercise by Kear *et al.* (1979) for groundwater in various regions of Samoa found that salinity is the major problem in the groundwater of the country.

2.3 NATIVE FLORA AND FAUNA

2.3.1 The Natural Flora

Little is known concerning the impacts of the early Polynesian inhabitants on the original plant cover of the country (Wright 1963). However, it is the commonly held belief that most of the islands were covered with forests, and that the early Polynesians burned these extensively, and introduced many of the plant species now well established in the forests of Samoa (McGlone 1984; Taulealo 1993; Nunn 1994).

Whistler (1978, 1980 and 1983) who started his pioneering work in the early 1970s (Tauiliili 1986) has done extensive studies of Samoan botany. In his ecological studies in certain regions of the country, Whistler (1978, 1983) noted that the natural vegetation consisted of cloud forests along the mountain ranges, smaller amounts of lava flow scrub, distinctive vegetation of cinder and ash deposits, and montane meadows. Many species were found to be endemic to Savaii (Whistler 1978). Park *et al.* (1992) noted that Samoa has the most diverse flora in tropical Polynesia. According to Whistler (1992a) the native flora of Samoa comprises 96 families, 298 genera and nearly 500 species. The largest families are *Orchidaceae* [Orchid family: about 100 native species] and *Rubiaceae* [Coffee family: 45 species].The largest genera are *Psychotria* [*Rubiaceae*. 20 species] and *Cytandra* [*Gesneriaceae*. 20 species].

Pearsall and Whistler (1991) classified the terrestrial ecosystems of Samoa into nineteen different types which Whistler (1992b) synthesized into a regional study of the vegetation of the country. Five broad categories are given in Table 2.6 and their altitudinal distribution is depicted in Figure 2.10.

TABLE 2.6: Vegetation Communities in Samoa.
Source: Adapted from Whistler (1992b)

VEGETATION COMMUNITY	CHARACTERISTICS
1. Littoral Vegetation	Area above the high water mark. Four plant communities are found all on the seashore: herbaceous strand or beach; littoral shrubland; *Pandanus* scrub; and littoral forest. Low in species diversity but important for birds and coastal protection.
2. Wetland Vegetation	Five communities are recognized: coastal marsh; montane or mountain marsh; mangrove scrub dominated by *Rhizophora mangle* (small sized trees); mangrove forest dominated by *Bruguiera gymnorrhiza* (large trees forming closed canopies); swamp forest.
3. Rainforest Vegetation	Five communities observed: coastal forests restricted to coastal areas; lowland forest; ridge forest; montane forest and cloud forest. Lowland forests cover most of the islands from sea level to 400 to 600 m elevation. These were extensively damaged in the recent cyclones.
4. Volcanic Vegetation	Two communities are seen: lowland volcanic scrub below 650 m and upland volcanic scrub above 1 200 m elevation.
5. Disturbed Vegetation	Four communities are recognized: managed land for human activity (plantations, roads); secondary forest dominated by weeds and vines; secondary forest and fernlands.

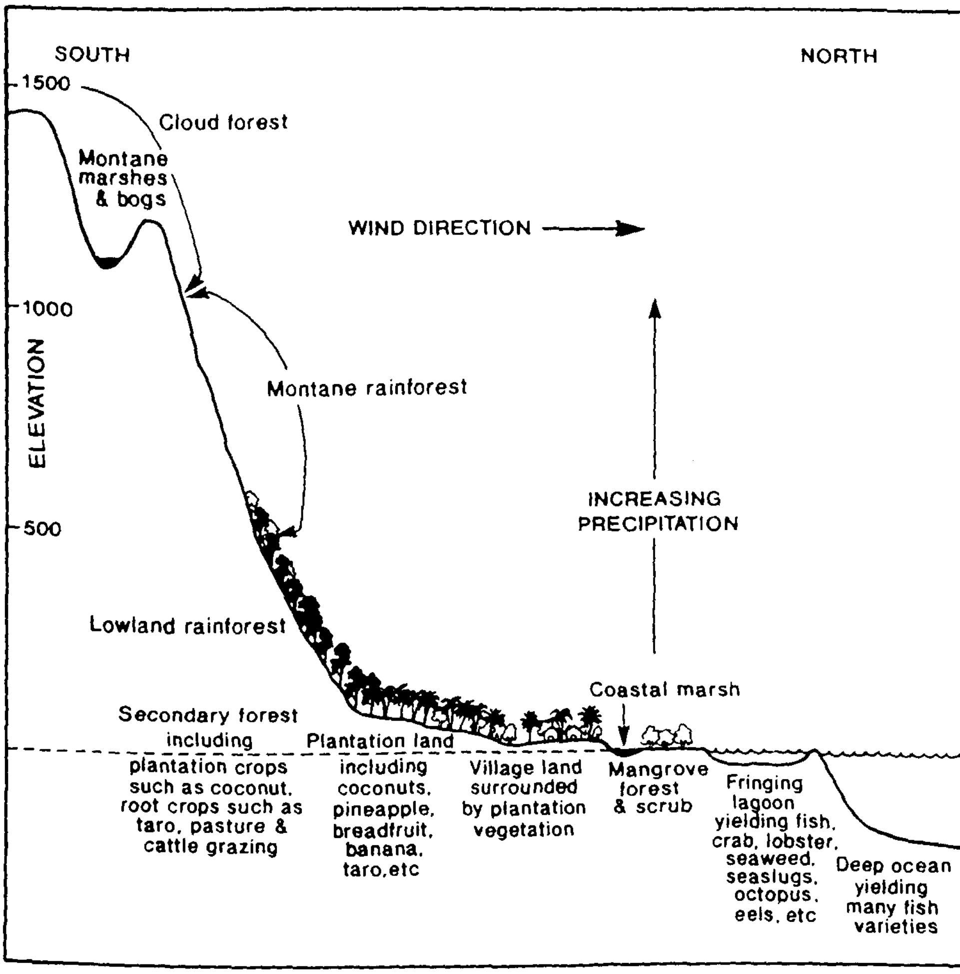

FIGURE 2.10: Generalized Spatial Distribution of the Vegetation Communities of Samoa. Source: Adapted from Amerson *et al.* (1982)

The mangrove scrubs and mangrove forests are of particular interest and importance. The biogeographical regionalisation of the tropical Pacific by Stoddart (1992) based on habitats and biotas of islands and reefs saw the Samoan islands as the easternmost limit of the *Rhizophora* genera distribution. The islands have the largest stand of mangroves in eastern Polynesia (Schuster 1993a; Thollot 1993) and provide a major fish breeding and nursery site (Park *et al.* 1992; Thollot 1993). Unfortunately, they are not valued accordingly and have been extensively damaged or degraded (Zann 1991).

The lowland ecosystems are currently under immense pressure from disturbance and development, as the majority of the population lives in lowland areas (Atherton 1994). Volcanic vegetation is confined to certain areas of Savaii while disturbed vegetation is a consequence of human activities or climatic factors. Rainforest vegetation, found between 400 and 600 meters elevation (Whistler 1992b), contains the majority of the merchantable timber resources of the country. The most important timber tree in Samoa is tava (*Pometia pinnata*) and is found in lowland forests (Ollier *et al.*1979). According to Whistler (1992b), other common canopy and subcanopy species are the mamalava (*Planchonella torricellensis*), maota malava (*Dysoxylum samoense*), maota (*Dysoxylum maota*) and malili (*Terminalia* richii). The poumuli (*Securinega samoana*) has a long history of being used for posts of the traditional Samoan houses (fales) while the sweet fragrance of the mosooi (*Canaga odorata*) flower makes it an important ingredient of traditional coconut oil production.

At least 150 species of Samoan plants are used for traditional medicine and other uses (Uhe 1974). Whistler (1992c) listed over 90 medicinal uses of Samoan plants. Recently, the extract of one of Samoa's native species has been tested as a treatment for cancer (Taulealo 1993) while another (an endangered vine) is related to the vine whose extracts have shown promise in AIDS treatment (Park *et al.* 1992).

The current rate of forest depletion in the country is about 1 500 hectares per year (GWS 1993a). In addition to this clearance, vast amounts of trees were uprooted and felled during Cyclones Ofa and Val. Whistler (1992b) commented that cloud forests are the best preserved types of rainforest remaining in Samoa due to their high elevation. There are no 'designated' endangered or threatened plant species in Samoa (Taulealo 1993), although Dahl

(1980) listed twelve rare species and Whistler (1992a) listed 136 potentially threatened species.

2.3.2 Fauna

The state of knowledge on this topic is well documented by Taulealo (1993:20) where he noted that:

> A large amount of collection and taxonomic study was carried out in the late 1800s and early 1900s on the insects of Samoa. Dahl [1986] identified twenty-one butterfly species in Samoa of which the *Hypolimnus thompsoni* is found nowhere else. Pratt *et al.* [1987] recorded thirty-five resident land birds, ten of which are found nowhere else. Samoa has one species of freshwater shrimp [*Macrobrachium lar*]. There are thirteen species of terrestrial mammals, three of which are native: the Samoan flying fox [*Pteropus samoensis*], the Tongan flying fox [*P. tonganus*] and the sheath-tailed bat [*Emballonura semicuadata*]. Eight skinks, five geckos and one snake [the Pacific boa: *Candoia bibroni*] have been recorded. One lizard [the Samoan skink: *Emoia samoensis*] is endemic to the Samoan Archipelago.

Taulealo (1993) further noted that of the thirty-five species of land birds recorded in Samoa ten are endemic at the species or sub-species level. One native species punae (*Pareudiastes pacificus*) is probably extinct.

The increased demand for land and forest resources is putting tremendous pressure on natural ecosystems, and threatening the survival of existing terrestrial fauna (Taulealo 1993). Local declines in many bird species have been observed following Cyclone Ofa in 1990 (Park *et al.* 1992) and Cyclone Val in 1991 (Lovegrove *et al.* 1992). It is not known what effect this will have on forest regeneration (Atherton 1994). In 1993, the *Protection and Conservation of Wild Animals Regulations* (1993) was instituted whereby thirty one bird species were declared protected.

Little is known about the freshwater fish of the country (Atherton 1994), but the information available points to a sparse native fauna (Waugh *et al.* 1991). On the marine fish fauna, Wass (1984) recorded 991 species including 890 inhabiting shallow waters or reefs, 56 living in deeper waters and 45 pelagic species. Various marine invertebrates have long been part of the traditional Samoan diet: species of the giant clam (faisua: *Tridacna squamosa*) and the palolo worm (*Eunice viridis*) are delicacies among the local population (Taulealo 1993). The annual spawning of the palolo worm in October and November is an important event in the cultural calendar (Buxton 1928; Zann 1991; Atherton 1994). Other sought-after invertebrates are the sea cucumbers (loli: *Halodeima atra*) and (sea: *Stichopus horridus*).

2.4 THE COASTAL ZONE

2.4.1 Reefs and Lagoons

Compared to other Pacific islands, Samoa is not well endowed with coral reefs, partly because the islands consist of steep-sided volcanic cones set in deep waters (Taulealo 1993), and partly because recent volcanic flows covered previous reef areas (Section 2.1.1). Coral reefs ring the islands of Samoa but not continuous (Solomon 1994) being mainly fringing types or barrier reefs. Subsequently, the lagoon areas are determined by the location of the reefs in relation to the shore. Little has been documented on the reefs and lagoons of the country (Zann 1991), apart from their geology and the effects of volcanism on reef formation (Kear and Wood 1959; Richmond 1991), and the intertidal zonation of shore and reefs (Morton *et al.* 1988).

Long residence times are a feature of lagoon waters in Samoa (Zann and Sua 1991). Zann (1991) further noted that the lagoons are typically shallow, ranging from 0.5 meters at low water to 15 meters in areas where blue holes are found. They are not excessively wide (0.5 to 5 kilometers). The lagoon areas are therefore easily accessible to the locals for fishing activities. Most lagoons are sandy, with coral rubble dominated by patches of seagrasses *Halophila* and *Syringodium* (Zann 1991). Interestingly, the Samoan islands are not included in the Pacific limits of these seagrass genera according to the biogeographical regionalization by Stoddart (1992).

Zann's (1991) work found that the majority of reefs around Samoa were inhabited by the coral species *Porites* (microatolls and *P. cylindrica*), and the branching and tabulate *Acropora, Pocillopora, Millepora, Montipora, Hydnopora* and *Pavona* species. He observed the presence of the unique blue coral (*Heliopora coerulea*) offshore from the Lefaga coast. Dahl and Lambert (1977) recorded a further four coral species in the reefs of Pago Pago harbour in neighbouring American Samoa. Morton *et al.* (1988) has produced an incomplete checklist of corals.

Numerous studies have shown that the utilization of lagoons is an integral part of the life cycle of numerous fishes, and juveniles and young adults mainly utilize the lagoon environment (Yanez-Arancibia *et al.* 1994). In the tropics, twenty fish families reportedly occupy the lagoon (Pauly 1982; Lowe-McConnell 1987). Thollot (1993) noted the presence of seven of these families and fourteen others in the lagoons of Samoa. In the same study, Thollot (1993) found the mullets (*Liza melinoptera* and *Valamugil engeli*) were the most dominant species numerically. A good many invertebrates, which constitute a large portion of the Samoan diet, occupy the lagoons. Some of the commonly caught fish species in fishermen hauls and organisms gleaned from the lagoons are given in Table 2.7.

TABLE 2.7: Common Fish Species and Invertebrates found in the Lagoon and Reef Areas of Samoa. Source: Zann (1991)

ENGLISH NAME	SCIENTIFIC NAME	SAMOAN NAME
mullet	*Mugilidae*	anae, aua
scad	*Selar crumeropthalmus*	Atule
emperor fish	*Lethrinidae*	filoa, mataeleele
trevally	*Carangidae*	malauli, lupo
parrotfish	*Scaridae*	Fuga
grouper	*Serranidae*	Gatala
squirrelfish	*Holocantridae*	Malau
unicornfish	*Naso unicornis*	Ume
dogtail goatfish	*Parupeneus indicus*	Tauleia
surgeon fish	*Acanthuridae*	poge, alogo
octopus	*Octopus spp*	Fee
giant clam	*Tridacna squamosa*	Faisua
sea cucumber	*Stichopus horridus*	Sea
turban shells	*Turbo spp*	Alili, aliao
crab	*Decpoda*	Paa
sea worm	*Eunice viridis*	Palolo
sea urchin	*Echinometra matheae*	Tuitui

Zann and Sua (1991) found that the lagoon and reef areas of Samoa are seriously degraded. The planning and implementation of coastal management strategies in coastal lagoons, requires an understanding of physical, chemical, geological and ecological dynamics of lagoons (Kjerfve 1994). This thesis is intended to contribute to this understanding.

2.4.2 Other Coastal Environments

According to Whistler (1992b) and Amerson *et al.* (1982), the littoral vegetation, the mangrove scrubs, mangrove forests and village land are found adjacent to the lagoon and reef areas. While the importance of the littoral vegetation lies mainly with the coastal protection it is the latter two communities that contribute largely to the physical and ecological dynamics of the lagoon and reef areas (Whistler 1992b).

The global importance of mangroves as a nutrient cycling medium has been recognized (Clough 1982). Mangroves contribute highly to the fisheries production of the adjacent waters (Dixon 1990) and are significant in shoreline stability and maintaining water quality (Chapman 1977; Fox 1974). Mangroves encourage sedimentation primarily by decreasing water velocities by as much as 50% (Bird and Barson 1982). The destruction of mangroves results in shoreline erosion as well as the liberation and mobilization of sediment that was previously trapped. While the presence of mangroves in the coastal areas promotes lagoon and reef life, the villagers mostly don't recognize this.

Recent studies by Zann (1991) and Zann and Sua (1991) have raised serious concerns about damage to the lagoons and reef areas in Samoa. They categorized the lagoons and reefs of the country as being one of the most degraded in the region. The marine environmental problems of the Samoan coast have been reported by many authors (Johannes 1982; Bell 1989; Taylor 1991) and are dealt with at length in Section 2.7.1.

2.5 THE SAMOAN CULTURE

2.5.1 Old Samoa

The Samoans are Polynesians and as such, they are speakers of an Austronesian language, belonging to the Mongoloid division of mankind (Bellwood 1978). "The Polynesian origin can be traced back to the eastern islands of South East Asia (Indonesia and the Philippines) about 4 000 yrs BP. They first settled the Tongan islands about 3 200 years ago, then moved into the Samoas 300 years later" (160).

The earliest settlement so far found in Samoa dates back to approximately 3 000 years from Lapita pottery found at Mulifanua (Green and Richards 1975). These authors favoured the interpretation of the site at 2.7 meters below present sea level. Leach and Green (1989) argued that the pottery level bears no relation to the contemporary shoreline and that Lapita people may have lived in stilt-houses (Kirch 1988).

The Samoans are a tall light copper coloured people, with fairly straight hair. Stonehewer Cooper (1888) described the island people as docile, hospitable, very lively and exceedingly courteous. According to Turner (1884), the original Samoans believed in a soul or embodied spirit called agaga, which upon death, goes to a region under the ocean called Pulotu. Turner (1884) further noted that at birth, a child is taken under the care of some god or aitu. These gods were supposed to appear in some 'visible incarnation', and the particular thing in which the god appears became an object of veneration. The forty three general village gods and twenty two household gods worshipped by the Samoan people before the missionaries arrived (Turner 1884) were all relinquished for the Christian religion.

The population in the old days was distributed three to four kilometers inland from the coast, according to archaeological discoveries in the islands (Meleisea 1987). Although there is only fragmentary evidence of this, unexplained changes in forest composition and the wide persistence of species belonging to the secondary growth communities give some hints to the extent of these inland settlements in ancient times (Wright 1963). Although the population of Samoa before the missionaries came was based upon guesses (Meleisea 1987) the estimate by John Williams of 45 000 people is the most widely accepted value. This value remained stable before 1830 due to warfare, and was probably associated with the destruction of trees and food plantations of opposing people.

Breadfruit (ulu: *Atocarpus altilis*), taro (talo: *Colocasia esculenta*), yams (ufi: *Dioscorea* spp.), bananas (fai: *Musa* spp.) and coconuts (niu: *Cocos nucifera*) formed the staple food of original Samoans (Turner 1884). The lagoons and reefs furnished a large supply of fish and shell-fish for the people, and occasionally pigs, fowls and turtles were eaten. The women continually waded about on the reef picking up sea urchins (tuitui: *Echinometra matheae*), sea slugs (gau: *Dolabella auricularia*) and octopus (fee: *Sepia* spp.) - [Plate 2.2]. The annual swarming of the palolo worm (*Eunis viridis*) is still observed today (Taulealo 1993). In the very early hours of the morning on those two specific days, the locals waded out into the reef area and scoop the worm into containers. The worm liquifies when the sun comes up. The Samoans cook their food in an oven (umu) of hot stones, by laying all the raw food on the hot stones and covering it with banana leaves (Plate 2.3).

PLATE 2.2: The octopus about to be cooked, displayed by an untitled man with a tattoo. Photograph: R. Lawrence

The Samoans were able fishermen, and they used the lagoon inside the fringing reef as fishing grounds and as a highway to travel from village to village (Buxton 1928). Pursuit of bonito (atu) took the men far out into the open sea, and outrigger canoes were used for these trips.

PLATE 2.3: The umu for cooking food - Samoan style. Photograph: R. Lawrence

The Samoan society in the past (as today) was dependent on village councils for decision-making. Membership of the village council was (and is) restricted to titled chiefs (matais), whose rank is reflected by the seating arrangement in the meeting houses and the recital of the village pedigree (faalupega) in all village meetings or special occasions. Two categories of chiefs are differentiated in the community (Meleisea 1987; Nunn 1994b): paramount chiefs (alii) who made final decisions, and talking chiefs (tulafale) who carry out special duties. Each extended family (aiga) elects their own matai, who looks after the family affairs, represents the family in village council meetings (fonos), and literally owns the family lands. The village council selects one matai among their numbers to be the village mayor (pulenuu), who is the liaison officer between the village council and the government. To complete the hierarchical structure of the village councils are the untitled men and boys who do most of the manual jobs in the village [Figure 2.11(a)].

Paramount & High Chiefs
(Alii Sao)
Talking Chiefs
(Tulafale)
Untitled Men & Boys
(Taulelea)

(a)

Head of State
Council of Deputies
Prime Minister & Cabinet
Legislative Assembly
Department Heads
Public Servants

(b)

Wives of Paramount & High Chiefs
(Faletua)
Wives of Talking Chiefs
(Tausi)
Wives of Untitled Men & Village Girls
(Ava Taulelea & Aualuma)

(c)

Church Minister
Lay Preachers
Deacons
Communionists
The Congregation
Youth Group & Sunday School

(d)

Figure 2.11: The Hierarchical Structure of (a) the Village Council, (b) Government (c) Women and (d) the Church in Samoa. Source: Author's research

Turner (1884) described many of the old Samoan customs. He noted the exchanges of goods between the husband and wife's families during their wedding. The ceremonial drinking of kava marked most events of significance - a drink made from the dried root of a cultivated species of pepper (*Piper methysticum*). This ritual is performed at every fono, when entertaining visitors or during ceremonial occasions. Chiefs were allowed to have many wives, often at the urging of orators (talking chiefs) who benefited materially from such marriages (Meleisea 1987; Aiavao 1984). Cannibalism was practiced in old Samoa (Turner 1884) although the eating of human flesh was more of a ritual than for nutrition. Tattooing (Plate 2.2) was of enormous importance in the social life of the men.

Clothing is confined to ti leaves (*Dracaena terminalis*) covering mens loins. Women used the cloth from the inner bark of the mulberry paper (ua: *Morus papyrifera*) for their wrap-arounds (lavalava) and walked around bare-breasted. The arrival of the missionaries initiated the "covering-up" period (Aiavao 1984) and women started wearing aprons from ti leaves (Turner 1884). Mats finely woven from leaves of the Pandanus shrub were also worn by women but only on ceremonial occasions.

The Samoan house (fale) is made entirely of wood, built on a platform of rock, and has no walls but use blinds made from coconut leaves to keep out the rain. Traditionally, no nails were used, but instead, the afa (sinnet processed from the fibre of coconut husks) was used to tie all the parts of the house together. The roof was covered with thatch (Plate 2.4) woven from the leaves of the sugarcane plant (tolo: *Saccharum officinarum*). No furniture was kept in the house and people sat cross-legged on the floor. People slept on mats woven from the pandanus leaves spread out on the rock floor, and bamboo supports (ali) were used as pillows.

Amusements in the form of dancing, fencing, boxing, wrestling, spear throwing, fishing matches and pigeon-catching were common in old Samoa (Turner 1884). Before the Europeans came, the Samoans traded, visited and intermarried with people from Tonga and

Fiji (Meleisea 1987). Civil wars over chiefly titles and lands were common, right up to the arrival of the missionaries. Although a number of old Samoan customs is still practiced today, many have been amended and refined since the arrival of the white man (palagi).

PLATE 2.4: Contrasting architectural styles at Taga village, Savaii. Samoan houses with tinned-roofing (left), a traditional thatched roof (middle) and with open sides in the foreground. Photograph by R. Lawrence

2.5.2 A Short Political History

Many authors have documented the history of Samoa in detail (Masterman 1934; Davidson 1948; Lewthwaite 1962; Meleisea 1987), and a brief time line of such is given in Appendix 2. This section highlights notable historical events that have impacted on the people and environment of Samoa.

Before the arrival of the Europeans, the village council (fono) regulated everyday life in Samoa. Without a central government, these individual village councils maintained law and order. Several villages comprised a district and each district possessed a kingly title (Tama a Aiga). To be indubitable king, a man had to assume five of the titles (Stevenson 1892), but local jealousy forbade its occurrence. The rivalry between the kingly factions for dominance in Samoa was the main reason for the instability that existed before and soon after the arrival of the Europeans.

European contact began in 1722 with the sighting of the Samoan Islands by the Dutchman Roggeveen (Douglas and Douglas 1989). Contacts intensified with the arrival of British missionaries: the London Missionary Society (LMS) in 1830, the Wesleyan or Methodists in 1835, and the Roman Catholics in 1845. The ideals and teachings of the missionaries were embraced by the Samoans as their presence was seen as a fulfillment of an ancient Samoan legend. This resulted in the rapid mass conversion of the people to Christianity (Lewthwaite 1962). The LMS in particular consolidated its advantage by founding a teachers' seminary at Malua in 1844, and translated the Bible into Samoan. This was the missionaries' greatest influence: the introduction of literacy to the island peoples (Thomas 1971). The missionaries' work initiated British interests in the country.

The Americans were also interested in Samoa, but mainly from a strategic viewpoint. They saw Pago Pago harbour as a safe and excellent port of call in the Pacific (Davidson 1948).

The German influence followed the extensive interests of her enterprising merchants, especially the Hamburg firm of Godeffroy and Son. This firm utilized the abundant coconut trees that grow well in the islands. It expanded and prospered rapidly when coconut oil became 'high commodity produce' in Europe for the manufacturing of candles and soap (Masterman 1934). From 1864, land purchase by the Germans was extensive. From this 'outburst' of land buying, the Germans established large coconut plantations between 1865 and 1882 (Lewthwaite 1962). Such developments naturally required extensive use of labour, which the Samoans were not interested in, so that by 1867 importation of Micronesian and later Chinese labourers occurred. The next two decades saw a period of unrest, which intensified insecurity in Samoa. Internal and bitter strivings for kingship, interference by Consuls of the three powers and their continued disputes reached a climax in 1889 (GWS 1966). In the civil war that followed, warships of the three powers ominously gathered at Apia harbour when the hurricane of March 1889 struck, sinking all the ships except the *HMS Calliope* (Lewthwaite 1962:140). This gave birth to the *Final Act of the Berlin Conference on Samoan Affairs* in April 1889, which established Samoa as a 'neutral and independent' power, under King Malietoa Laupepa (Masterman 1934; Lewthwaite 1962; Holmes 1971). But divided Samoans and biased consuls bred constant wrangling, and further turmoil was the result. Again a conference was called. The ensuing talks saw the British withdraw, the United States taking Tutuila and neighbouring islands and forming American Samoa, and Germany taking over Upolu and Savaii which is now Samoa in 1900 (Lewthwaite 1962; Holmes 1971).

Throughout their rule the Germans attempted to increase agricultural production, and promote economic development among the Samoans (Thomas 1984). Eugen Brandois introduced cocoa cultivation and Kramer began writing perhaps the most painstaking and authoritative work about Samoa and its people in 1902 (*Samoa Bulletin* 29 Dec. 1961). The German administration also set up an advisory body (Fono-a-Faipule) in 1905 to provide a link between the government and the people in the villages (Luke 1962).

German rule continued until 30 August 1914 when New Zealand troops landed during the outset of World War I. When the war ended, Samoa became a 'mandate' of Great Britain to be administered by New Zealand (Nayacakalou 1960). The *Samoan Amendment Act* of 1947 (reformed in 1957[1] and 1959) paved the way for the country's political autonomy. It provided for the election of a Legislative Assembly by matais only, the establishment of a three-member Council of State, and the appointment of a Prime Minister and Cabinet (chosen by the Assembly) to control the affairs of the government (Luke 1962). The political structure in Samoa is given in Figure 2.11(b).

Samoa gained independence on 1 January 1962 under the leadership of the late Fiame Mataafa Faumuina M. II as its first Prime Minister. Since then, four other paramount chiefs have led the country as Prime Ministers. Notable national events since 1962 have been as follows. The building of new wharves at Asau and Apia with accompanying extensive reclamation of reefs and mangrove areas in the late 1960's and early 1970's. Three severe cyclones devastated the islands in 1966, 1990 and 1991. The introduction of universal suffrage to the election system in 1991 and the complete annihilation of the taro plantations of the country by the taro leaf blight disease (*Phytopthera colocasiae*) in 1993.

2.5.3 Faa-Samoa: The Samoan Way

Many authors have discussed Samoan culture and customs since the arrival of the missionaries (Turner 1884; Watson 1891; Stevenson 1892; Kramer 1902; Gratton 1948). The term papalagi (meaning 'heaven-breakers') for Europeans originated from the arrival of the missionaries. The Samoans envisaged the universe to be a dome, ending at the horizon, so that

[1] Before 1957, Fono-a-Faipule chooses members of the Legislative Assembly with the High Commissioner as president

when the missionaries arrived, they were like gods of a supernatural being (Meleisea 1987). Without any central government at the time, these white people were looked up to as people with all power and knowledge. To the Samoans, the papalagis beliefs, customs and habits were the ideal ones. The Samoans tapa cloths and ti leaves were exchanged for cotton dresses and blouses, and even underpants, brassieres and shoes were worn (Aiavao 1984). The church building designs were almost always European, and 'white' became the accepted colour for clothing to church on Sundays (Plate 2.5).

PLATE 2.5: Sunday morning at the village of Moataa. Since the arrival of the Europeans, the Church has become a focal point for everyday life in Samoa. Note the church building design, and the clothes worn by the people.
Photograph: R. Lawrence

Life in Samoa today is governed by faa-Samoa - the Samoan way, which places greater emphasis on group activities and achievements rather than those of individual members (GWS

1983). European concepts of central government, property ownership and individual wealth do not have a place in traditional Samoan culture, where all wealth and property is owned communally by the extended family and its matai. As explained in Section 2.5.1 the aigas still elect their matai, who speaks for them in the village council and looks after the family lands and other affairs. The family, in turn, go out of their way to ensure that their matai is looked after well, and give him or her the best of all the material wealth the family may have, in return for taking care of the family's responsibilities. Each extended family lives in a cluster of nearby dwellings (fale), and each village is comprised of a number of these autonomous land-holding aigas (Bellwood 1978). Separate councils of matais wives (faletua and tausi), untitled men (aumaga) and village girls (aualuma) also exist in each village [Figure 2.11(c)]. Each council is responsible for particular tasks in village life. For example, it is the task of the women's committees to maintain cleanliness around the village and to oversee the use of water resources for drinking and washing purposes (Schoeffel 1980; Thomas and Simi 1983).

The Samoan perspectives of many material things remain different from that of the papalagi. As Aiavao (1984:8) pointed out "Samoans do things differently from the white man or the missionaries who brought Christianity to our shores. We look at things differently; and we believe differently". For example, the death of a person (a sad occasion) and a wedding (a happy occasion) are two completely separate happenings to an outsider. Yet the Samoans termed these two events as both faalavelave (which literally means an obstacle to normal everyday living). Traditional values and customs are practiced in these activities, where oratory speeches are exchanged between families, as well as food, fine mats and money. The faalavelave is the combined contribution of all family members to a wedding, funeral or other notable event in the village. It is this communal sharing and exchanges that makes the Samoan culture unique.

The early missionaries effectively converted the Samoans to Christianity. They gradually and orderly blended the Samoan culture with Christian principles. The church in Samoa has since became the focal point of each village, and over recent years the church ministers have been promoted beyond the rank of chief. The church ministers are treated like chiefs, given the best portion of the pig at feasts, and the best house in the village (Aiavao 1984). Often they are the only ones in the community with a motor vehicle. They have become the most influential people in a village community even though they have no status in the respective village councils. A different ranking is also observed in the church hierarchy [Figure 2.11(d)]. As Wendt (1977:4) wrote:

> Nearly all my relatives who all have numerous children and other dependents contribute generously to the church. Even when they have no money to contribute, they will borrow the money. My relatives continue to contribute and contribute and contribute. In short, many of my relatives neglect basic needs of their dependents in order to contribute to God's work [as interpreted by God's servants and his well-paid hired help!]

Without realizing it, the Samoans have made the church an unreasonable burden, or a force for oppression (Wendt 1977). Despite the pronounced influence of the missionaries on the Samoan people, the traditional Samoan social system has remained very strong. Indeed, tradition dies hard in Samoa. According to Aiavao (1984), Samoan culture has to be learnt, or it dies.

2.5.4 Population Trends

From the 1991 Census of Population and Housing, the population of Samoa was found to be 161 298 (GWS 1993b). Table 2.8 shows that the population grew by 90 percent during the 1951 to 1991 period with most growth occurring up until the early1970s. Of note is the continuing low population growth that recorded since 1976 (Table 2.8).

TABLE 2.8: Population Growth for Samoa from 1951 to 1991.
Source: GWS (1973) and GWS (1993b)

YEAR	TOTAL POPULATION	AVERAGE ANNUAL GROWTH (%)
1951	84 909	3.7
1956	97 327	2.8
1961	114 427	3.3
1966	131 377	2.8
1971	146 627	2.2
1976	151 983	0.7
1981	156 342	0.6
1986	157 158	0.1
1991	161 298	0.5

The observed decline is attributed mainly to both the fall in the fertility rate and the high rate of overseas migration (GWS 1993b; Taulealo 1993). While the rate did increase between 1986 and 1991, the average annual increase of about 0.5 percent is still quite low (GWS 1993b). Taulealo (1993) noted that this small increase in the last intercensal period perhaps reflects either the lessened international migration (tougher entry conditions to international destinations) or more migrants returning home due to economic recession affecting overseas employment. The population of Samoa is relatively mobile as reflected in shifts in population within the country and continuing international migration (GWS 1993b).

The population in Samoa remains largely rural, with people scattered throughout the main islands of Savaii and Upolu (Table 2.9).

TABLE 2.9: Population Distribution of Samoa by Region.
Source: GWS (1993b)

	1986		1991	
REGION	Number	%	number	%
Apia Urban Area	32 196	20.5	34 126	21.2
North West Upolu	39 383	25.1	40 409	25.0
Rest of Upolu	40 649	25.9	41 723	25.9
Savaii	44 930	28.5	45 050	27.9
Samoa	157 158	100.0	161 298	100.0

From Table 2.9 it is seen that the Apia Urban area has continued to draw people from Savaii in search for work, education and better living conditions. In addition, some movement of people away from the coastline to the interior was detected in the 1991 census, encouraged by the improvement of roads, electricity, water supplies and schools (GWS 1993b).

The general improvement in health conditions in Samoa over recent years has resulted in decreased mortality rate and increased longevity (Taulealo 1993). As shown in Table 2.10, a fall in fertility rate resulted in a decline in children between 0 and 14 years. Correspondingly, a higher life expectancy has also occurred, resulting in an increase in adults over 60 years during the last ten years. The working population those aged 15 to 59 years increased until 1986 where it remained steady at about 53% of the total population.

TABLE 2.10: The Population Structure of Samoa, 1981 to 1991. Source: GWS (1993b)

AGE GROUP	1981 (%)	1986 (%)	1991 (%)
0 - 14 years	44	44	41
15 - 59 years	51	53	53
over 60 years	5	6	6

As mentioned in Section 2.5.3, religion in Samoa exerts a tremendous influence on the customs and social life of the people. Churches abound and religious ceremony is integrated into daily life. The population is predominantly Christian with the adherents of the Congregationalist, Catholics and Methodist making up over 80% of the population.

In 1991, about 60% of the population in Samoa worked to earn money. Seventy percent of employed workers were engaged in agriculture, hunting, forestry or fishing. It was of interest to note that of all the employees working in agriculture forestry and fishing, almost 60% were between 15 and 34 years old. This is a positive sign for rural development if indeed the younger generation is turning to working the land in the absence of unlimited jobs available in Apia.

2.6 LAND USE

2.6.1 Land Tenure

Land tenure in Samoa has been discussed in many papers (GWS 1966; Holmes 1971; Seumanutafa 1984; Thomas 1984; Sesega and Burgess 1984; O'Meara 1987; Schmidt 1994). All noted that the land ownership distribution in Samoa is 81% customary land, 4% private freehold land, 11% government land, and 4% Samoa Trust Estates Corporation (WESTEC) land (Figure 2.12).

The existence of the four categories of land ownership was formalized in the *Constitution of Samoa* (Article 101) on the achievement of Independence in 1962 (Thomas 1984; Seumanutafa 1984; Schmidt 1994). Although Article 102 allows for the leasing of customary lands and taking of lands for public purposes, there is no other constitutional provision for changing land tenure except through referendum and constitutional changes (Thomas 1984). The *Taking of Lands Act* (1964) was liberally and extensively defined to include aerodomes, public health facilities, educational institutions, roads, and all lawful purposes and functions of government (Seumanutafa 1984). The *Alienation of Customary Act* (1965) made it unlawful for untitled men (<u>taulealea</u>) to lease customary land for agricultural or pastoral purposes (GWS 1966; Seumanutafa 1984): only <u>matais</u> and foreigners have this right. Schoeffel (1994) believed this is a disincentive to young men who want to obtain money through farming activities, but is consistent with faa-Samoa.

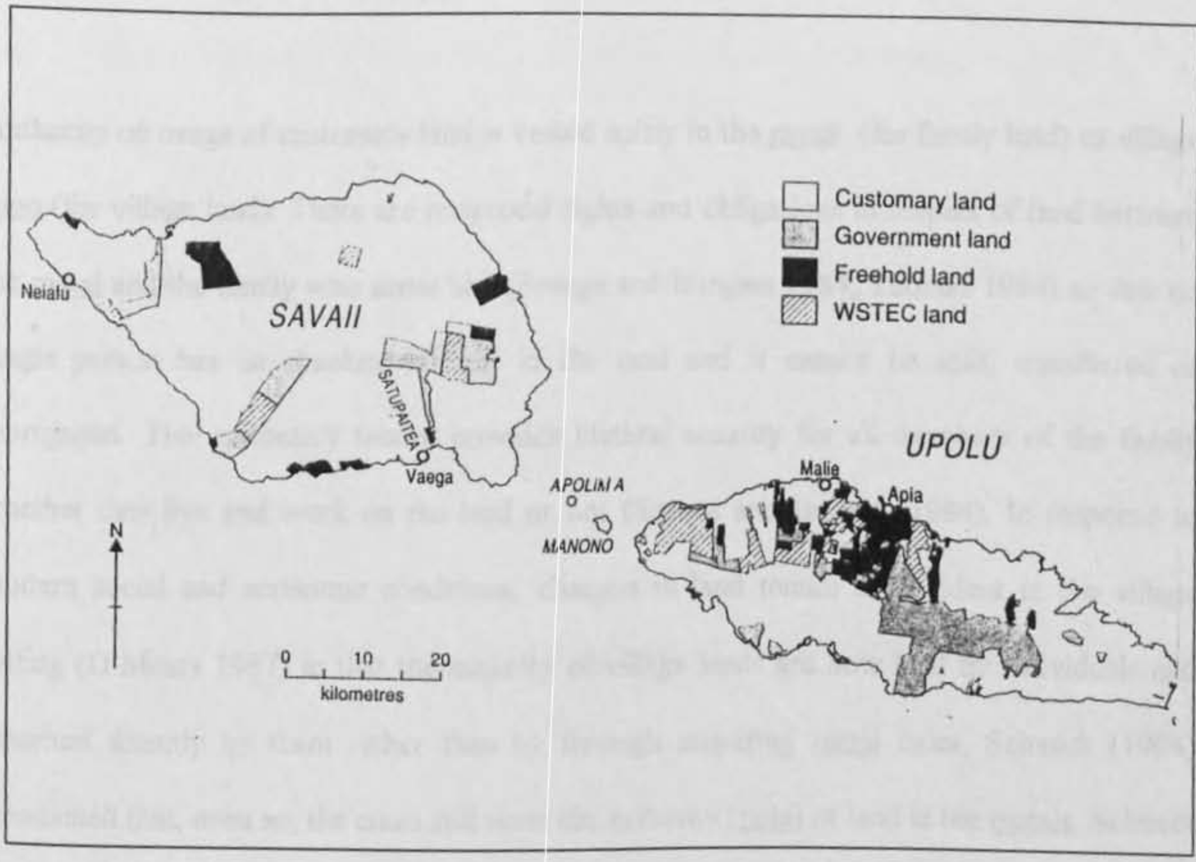

FIGURE 2.12: Land Ownership Distribution in Samoa.
Source: O'Meara (1995)

WSTEC is a government owned public trust holding corporation (Seumanutafa 1984) which operated land taken over from German owners in 1914 (GWS 1966). These confiscated lands were mainly coconut plantations. Today some of these coconut plantations, such as those at the Vailele and Vaitele subdivisions, have been divided up and sold as freehold land. Government land is being utilized for plantation farming, national reserves, public buildings and infrastructure (Taulealo 1993). Freehold land is mainly privately owned land that has been received by inheritance, or as a gift from a third party, or acquired using personal means where the payment consists of mats, pigs, knives, guns and lately also money (Shultz 1911). Most of the freehold land is concentrated in the Apia area and along the commercial plantation belt of northwest Upolu (O'Meara 1995).

Authority on usage of customary land is vested solely in the matai (for family land) or village fono (for village land). There are reciprocal rights and obligations in respect of land between the matai and the family who serve him (Sesega and Burgess 1984; Thomas 1984) so that no single person has an absolute interest in the land and it cannot be sold, transferred or mortgaged. The customary tenure provides lifetime security for all members of the family whether they live and work on the land or not (Sesega and Burgess 1984). In response to modern social and economic conditions, changes in land tenure are evident in the village setting (O'Meara 1987) in that the majority of village lands are now held by individuals and inherited directly by them rather than by through acquiring matai titles. Schmidt (1994) maintained that, even so, the court still vests the authority (pule) of land in the matais. Schmidt (1994) further recognized that Samoan custom does not vest authority over land in matais who are persons but rather in a particular matai title which is an office and owned by the aiga. O'Meara (1995) argued, however, that the distinction cannot be glossed over today as many matai titles have been split and shared by many individuals, confusing the customary tenure into a hopeless situation. This customary land tenure arrangement has been recognized as one of the major constraints to increased agricultural production in Samoa (Thomas 1984; O'Meara 1986) although Luteru (1994) insisted that this is part of the social fibre upon which the strength of society is founded.

There is little information on marine tenure in Samoa (Atherton 1994). According to von Bulow (1902) either the highest ranking chief, the village fono or the principal fisherman regulated the use of the village fishing grounds and were thus responsible for the marine tenure. National law states that all land below the high tide mark is vested in the state and therefore public land (Peteru 1993). While individual villages hold customary ownership of fishing rights (Fairbairn 1992) the power to regulate and enforce fishing activities on the fishing grounds is held by the village fono. Part 5 of the *Village Fono Act* (1990) has provided some legal basis to these actions. Although national law makes the reef and lagoon areas state-owned, the villages and village fono see this otherwise. So that the existing status of marine tenure in Samoa is that given by Fairbairn (1992).

2.6.2 Rural Land Use

The pattern of land use observed by the early Europeans is essentially the same as that of today in rural areas (Wright 1963). Wild yams (ufi: *Dioscorea spp*), taro (*Colocasia esculenta*), banana (fai: *Musa spp*) and taamu (*Alocasia macrorhiza*) are occasionally found in the interior. However, cropped land in the immediate vicinity of the village was not noted in the old days, and little indication was given of burning the forests for plantation gardens. Kramer (1902) noted that bananas were not extensively planted before 1840, but other plants grown were pawpaw, sugarcane (tolo: *Saccharum officinarium*) for roof thatches, paper mulberry (ua: *Broussonetia papyrifera*) for garments (*siapo*), and ti plants (*Cordyline terminalis*) for skirts. Pigs and fowls were quite common in the days of the missionaries (Turner 1884; Wright 1963).

The rural land uses in both islands of Samoa is shown in Table 2.11. Although 56% of the land use in Samoa is under indigenous forest, the terrestrial livelihood of most people is agriculture. It is the availability of land and the desire for certain crops that currently determines the pattern of land use, rather than the suitability of land for the purpose (Taulealo 1993). In general, village land consists of: coconut plantations along the coastal zone; the mixed cropping of cocoa, bananas and some coconuts inland from this; and taro and taamu further inland (Taulealo 1993). Figure 2.10 shows the typical pattern of crops with elevation and slopes. Agriculture is confined to areas up to 200 meters in elevation. Only in areas where the slopes are gentler is agriculture cultivation extended up to 300 meters in elevation.

TABLE 2.11: Land Cover in Samoa. Source: Government of Samoa (1991)

TYPE	UPOLU		SAVAII		TOTAL	
	ha	%	ha	%	ha	%
Indigenous forest	49 407	17	109 304	39	158 711	56
Plantation forest	34	(a)	5 345	2	5 379	2
Livestock	7 267	2	2 644	1	9 911	3
Cropping (b)	56 515	20	53 173	19	109 688	39

(a) Insignificant
(b) Includes cultivated land, land left fallow, land now overgrown, Apia district and other residential land areas

According to the GWS (1990), 48% of the country's cultivated land is under coconuts, 15% under cocoa, 26% under taro, 6% under taamu and 4% under banana. The increasing contribution of taro and cocoa on the land use pattern of the country over the last 30 years is seen in Table 2.12, where both crops increased in importance three fold and five fold respectively over this time period.

TABLE 2.12: Single Crop Cultivation as a Percentage of the Total Cultivated Land of Samoa for the last 30 years. Source: Compiled by author

YEAR	COCONUT	COCOA	BANANA	TARO	SOURCE
1963	44%	6%	5%	5%	Wright (1963)
1989	48%	15%	4%	26%	GWS (1990)

The increasing importance of the taro as a cash crop to the Samoan farmers came to an abrupt end in the beginning of 1993 when the taro leaf blight disease (*Phytopthera colocasiae*) struck and annihilated all the taro plantations of the country (Semisi 1994). The taamu and the bananas have now taken over as the main cash crops for most village plantation owners.

As seen from Table 2.11, forests occupy most of the country. It is estimated that of the remaining indigenous forests only five percent is merchantable (GWS 1992b). This GWS (1992b) report also noted that 20% of clearing is due to logging with the remaining 80% a result of agricultural expansion and other activities. The current rate of clearing will see all remaining merchantable timber of the country gone by the year 2000. Most of the coastal and littoral forests on most islands have been replaced by gardens, plantations, and settlement and, in Apia, urban development (Cameron 1962; Taulealo 1993). As many as half the plants in the country have been introduced, but there are no extensive plantations of these introduced species (GWS 1993a). The Germans, mostly for shade and windbreaks planted the banyan (*Ficus spp*), teak (*Tectona grandis*), *Albizzia spp* and Norfolk pine (*Araucaria excelsa*) (Cameron 1962).

2.6.3 Urban Land Use

The capital city of Samoa, Apia, is located on the north-western shores of Upolu. It is the point of exchange between western culture and the traditional Samoan way of life, and acts as a service center for the entire country where shops, markets, small businesses, light industries and the wharf are located (Plate 2.6). The good harbour facility at the site was the primary reason it became the focus of commercial activity at the onset of European contact. It was during the 1850s that a foreign settlement sprang up around the Apia harbour and, together with Papeete in Tahiti and Levuka in Fiji, became one of the main ports in the South Pacific (Meleisea 1987). Today, Apia is the commercial center and the only city in the country. Its boundaries are difficult to define as it extends well beyond the boundaries of the traditional village called Apia. Although the municipality planning for Apia in 1954 was confined to the area between the village of Vaimoso in the west and Moataa in the east (*Samoa Bulletin* 25 June 1954), the GWS (1954) defined urban Apia as an area roughly 7.2 km by 4.8 km. Today, this zone includes the traditional villages of Vaigaga, Vaiusu, Vailoa, Lepea, Vaimoso, Apia, Tanugamanono, Matautu, Magiagi, Vaiala, Moataa and Fagalii as well as the areas of Fugalei, Taufusi, Togafuafua, Tufuiopa, Alamagoto and Lalovaea (Figure 2.13). The latter are settlements comprising people originally from the rural villages who have been lured to Apia by better living standards and educational facilities. The inclusion of this social unit in the Apia urban area has created friction and misunderstanding between the Samoan law (especially the police force) and village rule. At present, there is a great deal of uncertainty over the respective roles of the village councils and the government in maintaining law and order in these settlements within Apia. This uncertainty extends to issues of land management.

About five years ago, the Samoan Government appointed several mayors to represent these people in government negotiations, but their responsibility is not as extensive as that of the village chiefs, and does not make the residents responsible to them.

Many people commute to Apia each day from other villages outside the designated urban area. In fact, the commuting range for Apia is the entire island of Upolu. This is a relatively new phenomena which has become apparent in the last five years. Following the 1990 and 1991 cyclones road access around and across Upolu was upgraded and this has paved the way for greater bus and car mobility.

PLATE 2.6: The capital city, Apia. Looking eastwards from the Mulinuu Peninsula.
Photograph: R. E. Lawrence

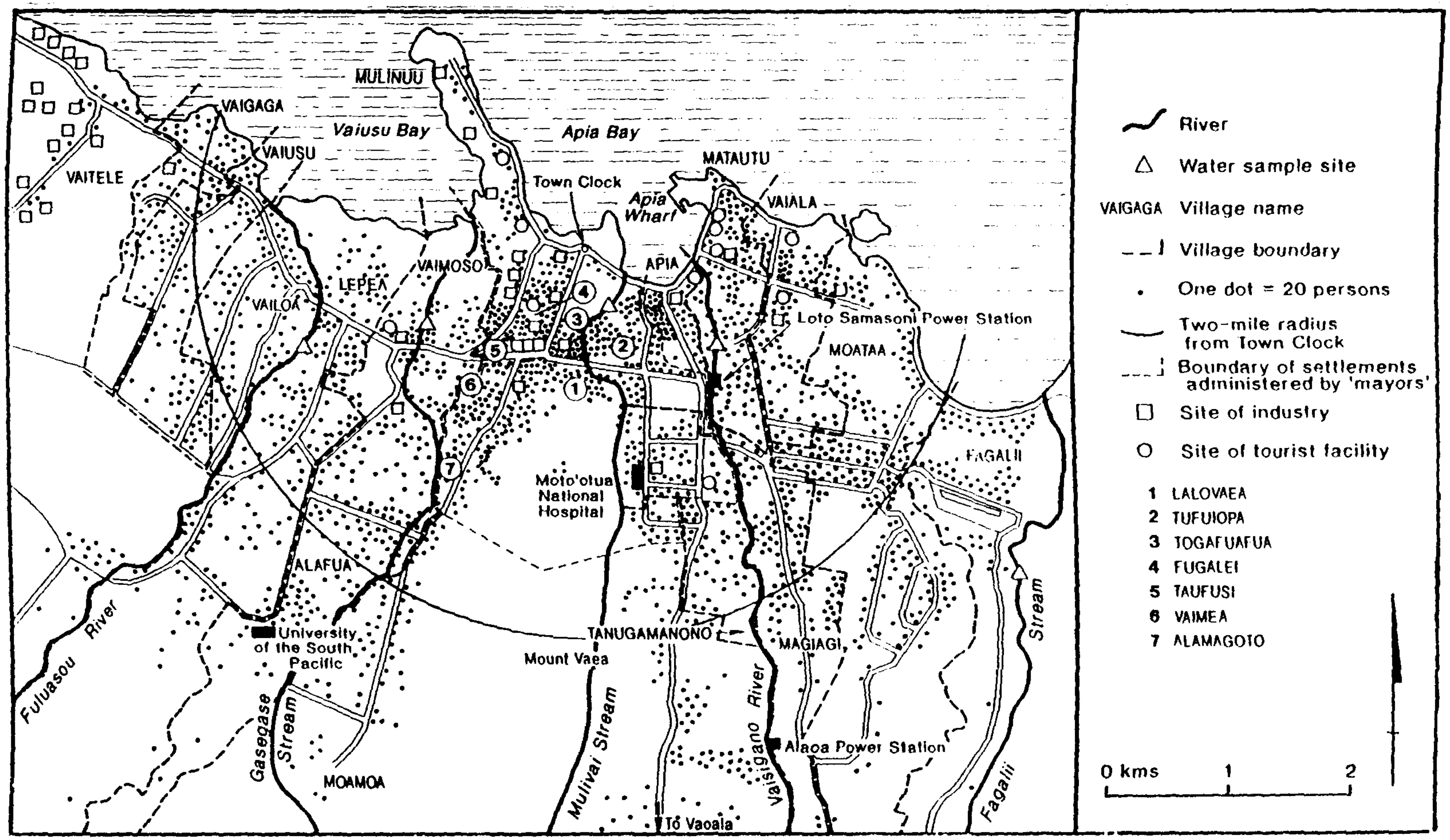

FIGURE 2.13 : The Apia Urban Area. Source : Adapted from GWS (1993b)

Politically, Apia comprises the Vaimauga West and Faleata East constituencies. In 1921, these two constituencies were home to 4 091 people, representing 12.5% of the total Samoan population (Kessing 1934). In 1991, 34 126 people lived in the two constituencies, or 21% of the total population (GWS 1993b). Over that seventy-year period, there was a 834% increase in the urban population at an average growth rate of 1.4% per annum. In addition to natural increase, this data reflects the movement of people from Savaii and outer Upolu villages to the urban Apia area. In 1991, the population density of the urban Apia area was 565 people per square kilometer, which is ten times the average population density for the entire country (GWS 1993b).

In order to encourage industrial development in a country where primary production has traditionally been the main occupation for the people, the Samoan Government established the Vaitele industrial zone about twenty years ago (Figure 2.13). In the 1970s, there were sixtyseven industries in Samoa at this time (GWS 1973), but in January 1992, the Trade, Industries and Commerce Department listed 118 registered enterprises in Samoa, depicting a 76% increase in enterprises over two decades. The majority of these industries are located in the Apia urban area, and some are located at Vaitele (Klinckhamers 1992). Table 2.13 lists the type of industries, tourist facilities and laboratories located in the Apia urban area. The bigger industries comprise mainly breweries, oil storages, wire harnessing and a concrete factory, and the largest industry is a Japanese-owned company Yasaki (Australia) which employs about 2 000 people to produce per week 15 000 wiring looms for cars. The Samoan Government is encouraging companies to utilise the low cost of labour in order to bring in foreign currency needed for the development of the country. The tourist facilities are mainly the hotels and motels scattered around the Apia town centre (Figure 2.13).

TABLE 2.13: Industrial Sites in the Apia Urban Area and Surround. Source: Adapted from Klinckhamers (1992)

TYPE OF INDUSTRY	NAME OF INDUSTRY	LOCATION
Industrial - Food and beverage	Alexander Coolstore	Vaitele
	Apia Bottling - fruit juices	Taufusi
	Hellaby	Vaitele
	Island Styles	Vaoala
	Manuia Breweries	Vaimea
	Samoa Coconut Products	Vaitele
	Samoa Tropical Products	Taufusi
	Talofa Wines	Vaoala
	Vailima Breweries	Vaitele
Industrial - Oil storage	British Petroleum	Sogi
	Mobil	Sogi
Industrial - Mechanical shops	Air Cool and General Refrigeration	Leififi
	H.J. Keil and Co.	Taufusi
	Public Works Mechanical Shop	Vaitele
	Rees Refrigeration Services	Lotopa
Industrial - Photo processing	Apia Studio	Beach Road
	Pacific Printers and Publishers	Saleufi
	Photo Mart	Vaisigano
Industrial - Saw mills	New Samoa Industries	Vaitele
Industrial – Manufacturing	Apia Concrete Products	Vaitele
	Samoa Iron and Steel Fabrication	Fugalei
	Samoa Upholstery	Saleufi
	Pacific Aluminium	Vaitele
	Yazaki	Vaitele
Industrial - Chemical manufacture	South Pacific Industries	Vaitele
	Samoa Paints	Savalalo
Industrial - Power Plants	EPC Plant – Upolu	Tanugamanono
Industrial - Dredging operations	Ulberg Brothers	Vaiusu Bay
Industrial – Other	MacKenzie's Wholesale	Saleufi
	Pepa Industries	Savalalo
	Rothmans	Vaitele
	Samoa Industrial Gases	Vaitele
Tourist facilities	Aggie Greys Hotel	Vaisigano
	Ah Kam's Motel	Saleufi
	Motel Insel Fehmarn	Moto'otua
	Tusitala Hotel	Sogi
	Temple View Lodge	Pesega
	Vaiala Beach Cottages	Vaiala
	Valentine Parker's Accommodation	Fugalei
Laboratories	Moto'otua National Hospital	Moto'otua
	University of the South Pacific	Alafua

2.6.4 Coastal Land Use

Fishing has always been an integral part of Samoan life, and even in these rapidly changing times the Samoans have found it hard to part from this activity. The missionaries found the lagoons and reefs to be a good source of fish and shellfish for the people in the early 1880s (Turner 1884). Fishing was such a common activity that it became one of the amusement sports in the old days (Turner 1884). Group fishing for skipjack tuna and turtle hunting outside the reef using traditional outrigger canoes (vaa-alo) involved a whole village. This activity is no longer practiced.

Today, 59% of agriculturally active households in Samoa are engaged in fishing and reef gleaning activities (GWS 1990). But while fishing in Samoa has remained a major source of food (Table 2.14), it has also gained importance as a source of supplementary income for the fishermen. As seen from Table 2.14, there is a ten to fifteen percent margin between fishermen consuming all their fish catch and those who sell half their catch. Money from these sales is used to buy necessities like soap, sugar, tea and lunch money or bus fares for their school children. On average, approximately 70% of the fishing population consumed all their fish catches.

TABLE 2.14: Proportion of Fish Sold in Different Areas of Samoa. Source: Adapted from Government of Samoa (1990)

AREA LOCATION	PROPORTION OF FISH CATCH SOLD	
	none i.e. all the catch is consumed	less than half the catch is sold
Apia urban area	69%	79%
Rest of Upolu	64%	76%
Savaii	70%	85%
Samoa	67%	80%

In addition to fishing, some coastal lands are used for tourism. The Samoan coastline has many beautiful sandy beaches that are ideal for picnics and relaxation. With the importance of the tourist industry as a major source of government revenue, many of these beaches have been made into tourist facilities. Small beach fales have been constructed along the beach front and tourists pay fees for the usage of these. Local families benefit financially from this otherwise unused piece of land.

2.7 SUBSISTANCE AND THE SAMOAN DIET

Prior to European influences becoming widespread over the last few decades, the Samoan people had a very homogeneous diet. Little variation in diet occurred within any given village and throughout the country. However, over recent years, there has emerged a distinct difference in the diet of those people living in and around Apia and those people living in the traditional Samoan village setting. Thus it is necessary to distinguish between the lifestyle and diet of traditional and urbanised Samoan people.

Traditional Samoans seldom eat either breakfast or lunch, except in the event that there are left-overs from the previous evenings meal. Dinner is the main and often the only meal eaten. The evening meal consists of the staple foods of cooked root crops supplemented by fish or meat. The four most common staple foods are taro (*Colocasia esculenta*) which is a highly digestible carbohydrate with a high mineral content, taamu (*Alocasia macrorhiza*) which is also known as the giant taro, breadfruit (ulu: *Artocarpus altilis*) and bananas (fai: *Musa* spp.) which are both important carbohydrates (GWS 1989). Unfortunately, taro production has declined markedly since July 1993 (Semisi 1994). The breadfruit (ulu: *Artocarpus altilis*) is eaten when this fruit is in season.

Fish is the main source of protein for traditional Samoans. It is readily available to the majority of the population who live in villages along the coastline, and is consumed four or five times per week. Popular fish varieties include squirrelfish (malau: *Holocentridae*), surgeonfish (pone: *Acanthuridae*), mullet (anae: *Liza melinoptera*), unicornfish (ume: *Naso unicornis*) and emperor fish (mataeleele: *Lethrinidae*). Shellfish and other seafoods such as the curryfish (sea: pronounced 'seeah': *Holothuriau* spp.), the sea urchin (tuitui: *Echinometra* spp.), giant clam (faisua: *Tridacna maxima*) and seaweed (limu: various species) are regarded as delicacies to traditional Samoans, and are usually eaten once a week, especially by the elderly.

Meat is eaten on an infrequent basis, such as on ceremonious occasions or when visitors arrive. Most families keep a number of pigs, which may be killed and eaten about once a month, and chicken, which is eaten once a week on average. These are usually reserved for visitors and ceremonial occasions. The 1989 Census of Agriculture showed 91% of all households keep some form of livestock: 42 percent have cattle; 83% have pigs; and 86% keeps chickens (GWS 1990).

Coconuts (niu: *Cocus nucifera*) are the most important snack food consumed by traditional Samoans. The juice of the coconut constitutes a refreshing drink, while the flesh is scraped out and eaten at any time of the day. Figure 2.14 depicts the proportion of each food type eaten by the traditional Samoan in any given week. Clearly, fish is second only to the staple foods of taro and cocoa as the most often consumed commodity of the traditional Samoan diet.

That the foods eaten by Samoans living in a traditional manner in the 1990s is representative of that of historical Samoans is verified in documents such as that of Turner (1884: 105):

> Breadfruit, taro, yams, bananas, and coconuts formed the staff of life in Samoa. The lagoons and reefs furnish a large supply of fish and shellfish, of which the natives are very fond; and occasionally all, but especially persons of rank, regaled themselves on pigs, fowls, and turtle.

Austin also agreed (1870:92):

> Fish formed one of the principal articles of diet, and were obtained in large quantities by the natives. We used to long for beef and mutton sometimes, but fowls and fish - which were always obtainable, and pigeons in the season - were not bad substitute. The natives esteemed pork above everything else, except, perhaps palolo [sea worm]. The vegetable portion of our food was taro, yam, and breadfruit.

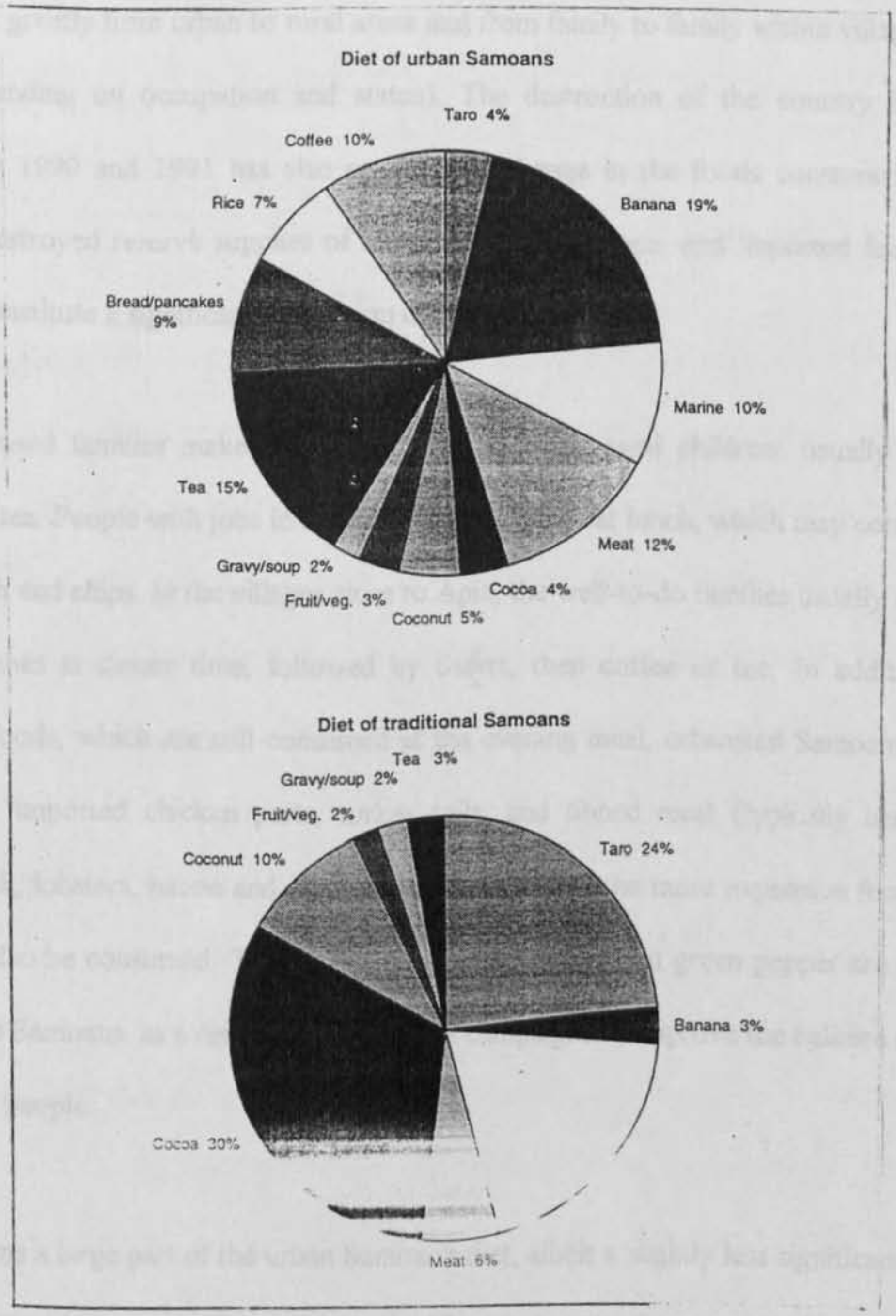

FIGURE 2.14: Foods Consumed by Traditional and Urbanised Samoans. Source: Compiled by author based on observations over decades of Samoan eating habits

Over the last few decades, western influences have played a major role in shaping the eating habits of some Samoans. The most affected people are those who have access to non-traditional foods because they live in close proximity to Apia. The food consumed by Samoans now varies greatly from urban to rural areas and from family to family within villages close to Apia (depending on occupation and status). The destruction of the country by the two cyclones in 1990 and 1991 has also produced a change in the foods consumed, since the cyclones destroyed reserve supplies of many staple food crops, and imported food, such as rice now constitute a significant proportion of some diets.

Most urbanised families make breakfast for their school-aged children: usually bread and butter with tea. People with jobs in Apia are also likely to eat lunch, which may comprise such foods as fish and chips. In the villages close to Apia, the well-to-do families usually serve three separate dishes at dinner time, followed by dessert, then coffee or tea. In addition to the traditional foods, which are still consumed at the evening meal, urbanised Samoans may also eat mutton, imported chicken parts, turkey tails, and tinned meat (typically herrings) for dinner. Steak, lobsters, bacon and eggs, which are some of the more expensive food items in Apia, may also be consumed. Tomatoes, carrots, cucumbers and green pepper are also eaten by urbanised Samoans, as a result of promotional campaigns to improve the balance of the diet of the urban people.

Fish still forms a large part of the urban Samoan's diet, albeit a slightly less significant one than for the traditional Samoan. Zann (1991) also found that the frequency and amount of fish eaten by urban Samoans was less than that for traditional Samoans (Table 2.15). The fish catches and quantities of edible marine organisms gleaned from the lagoonal and reef areas have declined markedly over the last two decades (Helm 1988; Zann 1991). Fish still remain a sought-after commodity by urbanised Samoans, but is restricted to those who can afford the prices in the fish market, since prices have soared over recent years (Helm 1988).

TABLE 2.15: Fish Consumption by Traditional and Urban Samoans.
Source: Zann (1991)

	Traditional Samoans	Urban Samoans
Days per week in which fresh fish is eaten	2.6	1.8
Average fish eaten in each fish meal (gm / capita)	300	200
Average annual fish consumption (kg / capita)	36	19

The proportion of each food type eaten by urban Samoans in any given week is also given in Figure 2.14. In comparison to the diet of traditional Samoans, it is evident that taro is no longer consumed everyday as it used to be, and has been largely replaced by bread, pancakes and rice. Bread and bananas are the most common food items in urban areas. Fish consumption has been halved and there has been a corresponding doubling of the amount of chicken, turkey tails and mutton flaps consumed. Tea and coffee have also largely replaced the traditional drink of hot Samoan cocoa. This data illustrates the disparity between the diet of traditional and urban Samoans.

Given the dependence of the majority of Samoans on plantation crops and marine organisms, it is vitally important that farming and fishing activities be maintained at a sustainable level. However, some activities have been degrading both the terrestrial and coastal environments over recent years. This has resulted from the dual factors of increased population numbers and increased westernization within Samoa.

2.8 ENVIRONMENTAL PROBLEMS IN SAMOA

Due to the abundance of both terrestrial and marine resources that are readily available to the people, Samoans have always lived a hand-to-mouth existence. Fish have always been caught and staple crops picked when the need arose. However, resources were never stretched to their limits as there was always a need to have food available for special occasions such as faalavelaves. In the past, the Samoans probably maintained a sustainable food economy. Any refuse was either burned, thrown into the river, or thrown into the shrubs behind the houses. Because all food resources were of organic origin, this practice did not produce a litter or pollution problem. However, since the introduction of Western goods such as plastic bags and paper cups, Samoans still throw those items into the river or bushes. Even industrial effluent is subject to the 'out of sight, out of mind' mentality. The majority of Samoans do not comprehend the relationship between declining marine productivity and unwise land-based activities. By nature, Samoans are a people with a care free attitude, and an expectation of living each day as it comes. This attitude has been partly responsible for the following environmental problems that now exist in Samoa.

2.8.1 The Terrestrial Environment

Almost all the environmental problems found in the South Pacific Region as noted in Table 1.3 are also found in Samoa. Particular to the terrestrial environment are the problems of forest cover reduction, soil erosion, urbanisation and pollution through liquid waste disposal.

The islands of Samoa are geologically young (Section 2.1) and mineral deposits are largely absent. The land and offshore waters are the main resources available to the people. Although the Samoan rural economy is dominated by village-based agriculture, only 83 800 hectares (29.4%) of the total land area of the country is used for this purpose (Thomas 1971). Problems of land degradation in Samoa are mostly associated with village-based agriculture, and have arisen as higher production has been sought to cater for the population which is increasing at 0.5% per annum (United Nations Development Programme 1994). Over recent years, fallow periods have decreased and new forested areas have been cleared higher up the slopes as old lands have been exhausted (Wright 1963). The results are predictably unfavourable. The natural regeneration of soil fertility has declined, instigating the heavy use of fertilisers, herbicides and pesticides (GWS 1989; GWS 1991) and erosion has increased.

There is 71 225 ha of forest in the country which represents 25% of the total land area (Mackensen and Hinrichsen 1984:325). Although the montane forests of the islands are less disturbed than the coastal zone (Schuster 1992a), extensive deforestation for commercial timber has occurred, especially on the island of Savaii (Cameron 1962; Taulealo 1993). Recently, clearing has been proceeding at the rate of 2 000 ha per year (Chase and Veitayaki 1992). This clearing rate together with the effects of cyclones will put pressure on the forest resources of Samoa. A lot of important trees are becoming scarce and facing the possibility of complete disappearance (Bell 1989). These include the ifilele (*Instia bijays*), tamanu (*Calophyllum samoensis*) and lagaali (*Agaia samoensis*) to name only three.

Soil erosion has been reported in Samoa and is largely due to human activities in an effort to develop the land, especially those lands near the riverbanks. Although there is an existing law forbidding the clearing of riverbanks, most lands are customary owned and upholding that law is virtually impossible (Section 2.8.3). Coastal erosion has been accelerated by coastal vegetation removal, reclamation and road construction. Flooding has caused agricultural loss particularly in vegetable gardens. Periods of prolonged dry weather have had detrimental effects on the environment. Streams that were normally perennial are now starting to dry up in the dry season, and forest fires in certain areas of Savaii were reported (Bell 1989).

Due to extensive land clearance for agriculture and logging for timber, flora and fauna extinction is likely (Atherton 1994). Specific habitats of many native birds have been destroyed and most birds are now facing difficulties in surviving (Park *et al.* 1992). Shooting of certain bird species has also contributed to this trend.

The damage to agriculture by the 1990 and 1991 cyclones was so severe that Chase and Veitayaki (1992) estimated that it would require nine months to five years to recover. Many buildings collapsed or lost their roofs, and all the main roads were disfigured and undermined by waves.

Urbanisation around Apia is set to continue, as more people are lured to better living facilities and modern life styles in the capital city. The conservation of adjoining vegetation communities, such as mangrove ecosystems, is critical as these ecosystems of the are particularly vulnerable to clearance. At present, no planning or conservation activities are undertaken

Associated with the development of the urban Apia area, problems of terrestrial and marine pollution have appeared, which are due in part to a lack of suitable infrastructure development and the uncontrolled disposal of waste materials. Rapid urban development has proceeded without the adequate provisions of services such as sewerage facilities (Klinckhamers 1992). Taulealo (1993) reported that private homes use either septic tanks with soakage facilities, pour-flush toilets, pit latrines, primitive toilets on drains or primitive toilets over the sea without pits. In 1972, an official solid disposal dump was established at Vaitoloa in the middle of a mangrove marsh (McQuitty 1972). Domestic waste was collected and dumped without sorting, meaning that dangerous goods such as car batteries were given no special treatment. The mangroves were filled and then rolled over by a bulldozer (Taylor 1991). In 1993, the dump was moved to Tafaigata, but the rubbish, which has accumulated over 26 years at the Vaitoloa site, remained (Plate 2.7).

PLATE 2.7: The unsorted domestic waste at the Vaitoloa dump site. Photograph by author (July 1993)

Watershed degradation and related hazards have been reported in Samoa (Baisyet 1989). The Vaisigano River has been a source of drinking water and hydropower generation for most people around Apia for many years. Ten years ago the water in the river was clear (Johannes 1982) but is now very turbid and carries a lot of silt into the Apia harbour during heavy rains. The Vaisigano and Fuluasou rivers have been supplying the Apia urban area with hydro electric power since 1930 (Aiavao 1982). As a result, the lower sectors of the rivers do not carry water for the majority of the time in the dry season. In creating the storage reservoir for the Afulilo power project in 1993, the Punataemoo swamp forest ecosystem was completely destroyed, even though Pearsall and Whistler (1991) identified the protection of this area as the number one conservation priority for the country (Waugh *et al.* 1991). Associated with the development of the hydro schemes has been an alteration of the hydrological properties of the rivers, changes due to the use of heavy machinery on the land, vegetation clearance for power lines and tunnels, and an alteration of the water quality and water quantity of the rivers.

2.8.2 Marine and Coastal Environment

The offshore waters have always been important to the Samoan people as most reside adjacent to the coastal zone. Fresh fish provides a high quality source of protein and a staple food of the Samoans. However, in obtaining fish for consumption, destructive fishing practices have sometimes been employed (Bell 1989; Zann 1991), which have contributed to environmental problems in the coastal zone.

One symptom of declining marine environmental quality is the diminishing coral reefs in Samoa. In one traditional method of fishing, the coral is crushed by a group of people with wooden poles, driving the fish into a set net. The targeted fish is the genus *chromis* known locally as tuuu (Bell 1989). However, this fishing practice has declined over the years, probably due to both the disappearance of the species population and the habitat. In some parts of Samoa, coral has been seriously affected by outbreaks of crown-of-thorn starfish (*Acanthaster planci*). The abundance of the coral species *Acropora* in the southern parts of Upolu (Zann 1991) suggests that in these areas, siltation is not a problem and clean water discharges to the lagoon have prevailed - the two conditions required for the growth of this coral species (Dahl and Lambert 1977). In other parts of Samoa, the coral reefs are completely dead: for example in the Apia harbour (Zann 1991). In the late 1960s, dynamite was used to blast the coral reefs in the wharf development of Asau and Apia harbours.

Fish poisoning is another detrimental fishing practice carried out by people not only on the lagoon and reef areas but also in rivers and streams. The poison is derived from both the root of the plant *Derris elliptica* (locally called ava niu kini because it was introduced from Papua New Guinea), which thrives in the tropical environment of Samoa, and the fruit from the *Barringtonia* plant. They are pounded into powder, wrapped into small balls and emptied into fish habitats along the reef. This process kills the juvenile fish as well as the larger fish. Even shellfish and corals are affected when the poison is delivered in high concentrations (Bell 1989). Although the use of the *Derris* roots have declined, household bleach and even some agricultural chemicals are reported to have been used as substitutes.

The dynamiting problem has been known in Samoa for the last 80 years (Johannes 1982) and is still evident today. This activity not only kills the larger fish and makes them easy to catch but also destroys the coral habitats and kills the smaller fish as well. *The Fish Dynamiting Act* (1972) was enacted three decades ago to prohibit the use of dynamite to catch fish but the practice is still observed today. Bell (1989) recorded three cases in 1988 and 1989 of fishermen being blown up by dynamite intended for the fish.

Erosion is now well recognised as a serious problem on land in Samoa, and its effect on inshore reefs is also becoming apparent (Zann 1991). As sedimentation levels increase, the corals are stressed by smothering and light inhibition (Zann 1991). High sedimentation in the marine environment is due to either the high deforestation rates in the catchment areas, and the subsequent use of land for agriculture (Taylor 1991), or the young geological age of the islands.

Major dredging operations for sand for construction materials off the coasts of Mulinuu and Mulifanua have been in operation over the last two decades. This dredging practice has resulted in increased turbidity, an alteration of water circulation and even the destruction of some reef systems (Holthus 1991). Silt may kill fish by damaging their gills, and may kill coral by smothering it (Bell 1985). The disappearance of the sea slug (gau: *Dollabela spp*) within the Vaiusu Bay is suspected to be due to high siltation from dredging operations in the bay (Bell 1985). Siltation from the Vaisigano River caused the shoaling of the harbour by about 1.7 metres between 1975 and 1981 (Gauss 1981).

Coastal lagoons are also increasingly being subjected to industrial and domestic pollution, causing the collapse of the inshore fisheries and reef systems around Apia (Taylor 1991). The shallowness of the lagoons has limited the water exchange and minimised the capacity of the lagoonal waters to dilute waste. Industrial waste discharged into Vaiusu Bay from the Vaitele Industrial Zone has been reported to be of a sub-standard level, and most of the raw wastewater effluent is pumped directly into the marine environment (Klinckhamers 1992). Zann (1991:1) noted that:

> All the wastes of modern urban life [industrial discharges, petrocarbons, detergents, pesticides, heavy metals, untreated sewage] discharge directly via stormwater drains [or indirectly via the water table] into the shallow coastal lagoon off Apia, are carried slowly westwards by the current. This problem of eutrophication and pollution increases coral die-back and seagrass expansion.

The widespread uncontrolled use of pesticides together with increased rates of runoff from the land indicates potential pesticide pollution in the lagoons (Bell 1989).

However, human activity is not the only cause of environmental changes observed in Samoa. Zann and Sua (1991) had documented the effects of recent cyclones on the lagoonal and reef areas of the country. The reef slopes were scoured of almost all live corals. In addition, about ninety cyclone banks and storm beaches were formed by the cyclones. These banks greatly affect lagoonal circulation and are likely to increase nutrient pollution to the lagoonal areas

(Zann and Sua 1991). The rise in sea level in Samoa since 1900 (Nunn *et al.* 1994) together with the irregularity in weather patterns due to ENSO conditions both play a part in environmental changes observed in Samoa today. Evidence has shown that recent climatic changes have had noticeable effects on the landscape, most notably in soil erosion and vegetation change on the Pacific islands (Nunn 1990). The ENSO effects lead to a decline in fish catches due to the alteration of the equatorial upwelling, which is rich in plankton (Thistlethwait and Votaw 1992).

The amount of flat coastal land for settlement is limited, and one solution to this land shortage has been to reclaim coastal areas (Taylor 1991). The areas most affected by these practices are within the Apia urban area (Zann 1991; Schuster 1992a). Zann (1991:5) recorded that:

> Half of the Moataa mangroves [the third largest in Samoa] have been entirely reclaimed and the estuary had been diverted through a drain. Much of the Vaipuna shore has been reclaimed for housing. The northern shore of Mulinuu Peninsula and Beach Road was once coral sand, but has now been entirely reclaimed for buildings and seawalls. The fringing reef in the Apia harbour has been almost entirely reclaimed from material dredged from the harbour.

The total extent of mangrove communities in all of Samoa is only 1 270 hectares (Zann 1991), and this area is decreasing with the high reclamation rate. The country is losing habitats for juvenile fish, natural breakwaters for storms and effective sediment traps as these swamps are reclaimed and entrances to mangrove stands are blocked.

2.8.3 Legal and Customary Land Tenure Issues

An overarching environmental problem in Samoa arises from the issue of land tenure, which has important ramifications for management. There has been a legal basis for interest in the environment of Samoa since before Independence. For example, in the contents of the *Agriculture, Forests and Fisheries Ordinance* in 1959, Section 4(b) states that one of the principal functions of the department is to promote the "conservation, production and development of the natural resources of the country". Bell (1989) claimed that up to this point in time, these aims have not been realised. For example: the forests and mangrove areas of Samoa have been logged and reclaimed respectively (GWS 1991); the lagoonal areas have been dredged for construction materials (Solomon 1994); and there has been a decrease in fish catches from around the country (Zann 1991). *The Fish Dynamiting Act* (1972) was enacted three decades ago to prohibit the use of dynamites to catch fish. *The Fisheries Act* (1988) provided for the conservation, management and development of the fisheries in waters of Samoa. *The Lands and Environment Act* (1989) provided for the conservation and protection of the environment of Samoa. In particular, Sections 119, 120 and 123 of the *Act* deal with the protection of the foreshore, coastal waters and pollution of Samoan waters respectively. While these Acts seemed quite sound, carrying them out and enforcing them is another matter altogether in Samoa. As Peteru (1993) pointed out, there is no known incidence of legislation having being applied to individuals or companies found polluting Samoan waters.

Part of the problem is the fact that Samoa has a dual legal system - one based on custom and the other on introduced legal concepts and practices (Fingleton 1991). This has resulted in a large gap between events that occur in the parliament at Mulinuu and their effect on village affairs (Taylor 1991). Table 2.16 summarises the principle differences between the two systems. The root of the problem lies more in the interpretation of the law than anything. According to Table 2.16, the *Constitution* is the supreme law of the country yet; the *Constitution* does not recognize custom and usage as a species of law (Peteru 1993). Custom and usage therefore has a subordinate ranking in relation to the *Constitution* or *Acts* of Parliament. Out in the villages, however, the village council is the law.

TABLE 2.16: Comparison between the Dual Legal System Operating in Samoa. Source: Compiled by author

	CUSTOMARY SYSTEM	LEGAL SYSTEM
Origin	The chiefly system has been with the Samoan people long before the Europeans arrived, although its origin is unknown (Bellwood 1978). The respective families elect the family matais, and the chiefs represent each family in the village council.	Established in the 1860s when land disputes between the Samoans and Europeans could not be settled by the village councils. The decisions were therefore made by officers of naval vessels or by the respective counsels of the three powers that were in the country at the time: Great Britain, United States and Germany.
Operations	The village council makes laws, exercise legislative, executive and judicial functions (Peteru 1993). They can pass measures which run contrary to the law and sometimes the *Constitution*: imposing curfews, regulating the length of women's dresses and men's hair and beard, compelling church attendances or placing rocks on the road to get cars to slow down. Often, the police are loath to interfere, but will do so in more serious breaches of the law like kidnap or murder (Peteru 1993).	The *Constitution* is the supreme law of Samoa. Parliament passes laws. The Supreme Court deals with breaches of the law relating to civil and criminal matters, while the Land and Titles Court hears land disputes and title claims, applying customs and usage (Schmidt 1994). A President and at least two Samoan judges exercise the Court's jurisdiction.
Philosophy	To strengthen the traditional authority of the matai, maintain the Samoan culture and values and minimize outside influences, which disrupt the Samoan society (O'Meara 1995). The customary land tenure system provides life-time security for all members of a family living and working on the land (Sesega and Burgess 1984).	To uphold the law according to the *Constitution* of Samoa.

While the Land and Titles Court deal with land disputes, there are times when the Court's decision cannot be enforced. In one incident, a Court decision favouring an individual was quashed by the will of the chiefs of a certain village. As Schmidt (1994:178) wrote:

> In the case of *The Alii and Faipule of Salelologa versus Pauli Koki Wong Kee*, an "interim order" to stop the village from obstructing a timber milling business set up by a firm on what Wong Kee believed to be his land was ignored and instead provoked the village chiefs and orators to exercise their own justice by setting fire to the properties of Wong Kee. Everything on the land was burnt to the ground while policemen were watching.

Compliance with written legislation is indeed a major problem if it is contrary to the faa-Samoa. Nevertheless, village authority can be used to beneficial purposes and enforced in a way not possible through government; if village councils pass laws banning the dynamiting of fish, prohibiting commercial logging, or banning the slaughtering of turtles.

2.9 OBJECTIVES OF THIS STUDY

Sections 1.3 and 2.8 have highlighted the environmental problems faced by small island nations in the South Pacific in general and Samoa in particular. To date, there has been limited attention paid to the environmental concerns faced by such small islands. Has the adoption of the European lifestyle had a greater impact on the island environment than the traditional lifestyle of the Polynesians? Are current land management practices environmentally sustainable? What has been the nature and magnitude of changes to the biota of the coastal zone due to anthropogenic and natural causes? To date, these questions have been largely unanswerable due to a lack of quantitative environmental data.

Numerous authors have noted the void of information regarding environmental concerns in Samoa. Bell (1989:7) noted that "rapid development and efforts to increase the standard of living [in Samoa] have never taken into account their impacts on the environment". There is no systematic data available on stream flow and sediment loads brought down by the rivers (Baisyet 1989), and there has been no comprehensive water resources survey in Samoa (GWS 1991). The amount of sediment delivered to the coast by streams is unknown (Richmond 1991). With regards to marine pollution, Samoa is almost void of information on water quality (Taylor 1991), and little has been documented on the reefs and lagoons of Samoa (Zann 1991). Taulealo (1993:5) wrote that "groundwater harvesting has been on the increase and no management plan is in place for groundwater utilization. Little is known about the patterns and nature of waste generation nationwide". Solomon (1994:15) noted that no information is available for the discharges into Vaiusu Bay.

This thesis addresses some of these concerns by examining the nature, rates and causes of environmental change in Samoa. In addressing these changes, a number of methodologies are proposed.

Firstly, the terrestrial inputs to the coastal zone for every river in Samoa during both the wet and dry seasons will be examined. The collected data will provide information on the existing water quality status of the streams and groundwater of Samoa. It is expected that the conditions prevailing in the rural areas of Samoa will produce good quality water since they have been little affected by human activity. Areas with anomalous readings will be identified. Chapter Three reports on the spatial distribution of water quality of Samoa.

Secondly, an intensive sampling of the urban catchments will be made to identify periods of greatest contaminant input to the coastal zone. The physical water quality parameters and nutrient levels of selected urban streams will be compared to those of a rural stream. The results are discussed in Chapter Four.

Thirdly, the contaminants carried by the streams, which will ultimately be deposited in the sediments along the coastal area, will be examined. Sediment analysis should give an indication of both the type of contaminants and their distribution patterns along the shore areas. Chapter Five is devoted to the analysis and interpretation of the sediment cores collected.

How do fluvial contaminants of terrestrial origin affect the coastal vegetation? The sixth chapter of this thesis seeks to address the role of alterations of water quality on a selected vegetation community. The effect of anthropogenic changes to the mangrove ecosystems of Samoa is discussed at length in Chapter Six along with other factors contributing to mangrove health decline.

Fifthly, the way in which changes to coastal vegetation have impacted on the people is examined. In Chapter Seven, the results of interviews with people from selected villages are documented, and the social effect of altered coastal environments is addressed.

This thesis represents an interdisciplinary approach to environmental research by combining hydrochemistry, sedimentology, plant ecology and social inquiry. Although the social response to environmental degradation has been examined, no known studies of this kind have yet been carried out in any Pacific island nation. Some water quality and sediment studies have been limited to Papua New Guinea and Fiji as documented by Maunsell and Partners 1982; Gangaiya *et al* 1986; Naidu and Brodie 1986; Naidu *et al.* 1989a and 1989b). A recent publication by Asquith *et al.* (1994) gave estimated sediment loads for some selected South Pacific island states. Although many authors have reported the changes to mangroves ecosystem in the region (Nakamura 1992; Lal *et al* 1983; Schuster 1992b) none has looked into mangrove health in detail.

Following the presentation of the results of the data collected in this project, best management strategies for the environment of Samoa will be discussed. The collected data not only provides a unique baseline to assess future environmental changes in the country, but also provides a basis for sound management proposals. The thesis concludes with a discussion of the most appropriate way in which to address the environmental problems identified at both a national and village level. If these recommendations are adopted, it is hoped that sustainable development in Samoa will indeed be achieved.

CHAPTER THREE

SPATIAL VARIATION IN THE HYDROLOGY OF SAMOA

...And the water I give.... will become a spring.
parts of John 4:v13

While poor water quality is recognised as a worldwide problem, water quality monitoring in the Asia and Pacific region has been sadly lacking, as shown in Table 3.1. The lack of funding is the principal reason cited as to why water quality analysis is almost non-existent in the small island nations of the South Pacific.

TABLE 3.1: Water Quality Monitoring Coverage in the Aisa & Pacific Region. Source: Adapted from - ESCAP (1990).

Countries/areas	Number of rivers: major/minor	Number of rivers with water quality monitoring facilities	Number of lakes & reservoirs	Number of lakes & reservoirs with monitoring facilities	Frequency of water sampling
Northern Mariannas	none	none	1	1	not given
Fiji	110/4000	1	2	1	Monthly
Guam	16	7	1	None	Monthly
Papua New Guinea	20/many	none	5	None	not given
Marshall Islands	none	none	none	None	not given
Palau	none/3	none	1	1	not given
Samoa	4/many	none	3	None	not given
Solomon Islands	2749	none	2	None	not given
Tonga	none	none	none	None	None
Vanuatu	none	none	none	None	None

The widespread reliance of the Pacific Islanders on groundwater, especially in the low-lying atoll islands, has prompted work on the distribution and properties of those waters. Detailed groundwater studies were initiated in Guam in 1979 to evaluate limestone aquifers in the northern part of the island (Guam Environment Protection Authority 1982), and the groundwater was found to be free of measurable contamination in all except one case. Downes (1981) analysed the quality of the water in wells in Tonga, Niue and the Cook Islands and found that all the waters were hard, and that the Niue Island samples had a high iron content.

Considerable work on groundwater resources of Tarawa in Kiribati was conducted by Mather (1973) and the Department of Housing & Construction (1981), who reported high hardness values, high bacteriological contamination, and unsustainable water extraction from some parts of the fresh water lens. Lee and Brodie (1981) sampled the groundwaters of Tuvalu and Tongatapu and found that saltwater intrusion has become a problem in those waters. The Ammax Exploration Mining Company (1977, 1978) examined four groundwater sites and eleven surface water stations in Fiji, and found that not only did the bore waters have higher hardness and alkalinity values than the surface waters, but also all waters contained low values of copper and zinc concentrations.

Surface hydrological studies in the Pacific region have mostly focused on the runoff volumes required for hydroelectric power and water supply schemes (Brodie & Morrison 1984b). Ongoing monitoring of the Wailoa River and Monasavu Reservoir in Fiji as reported by Gangaiya (1986), Naidu and Brodie (1986), Naidu (1988) and Naidu *et al.* (1989a) found that water quality has been maintained over the years. In an assessment of the impact of a proposed sawmill in the Lautoka area of Fiji, Gangaiya *et al.* (1986) provided baseline values for the Vitogo River water quality parameters, and found that they were comparable to the cleaner waters of the rest of the country. A grab sample from the Tipitaru Stream in the Cook Islands by Downes (1981) was found to be of good quality.

There has been no comprehensive water resources survey in Samoa (GWS 1991). Monitoring of water systems is done on a 'spot check' basis and, very infrequently, samples are sent to the University of the South Pacific for laboratory analysis (ESCAP 1990). Grab samples for the Vaisigano River and the Motootua well were documented by Zavala (1985) while Downes (1981) analysed the water quality of piped water believed to be from streams in Samoa. Cox

(1960) examined the groundwater of basalt host rocks in Samoa, where the salinities of fifty-six coastal springs and wells were recorded. Kear *et al.* (1979) also reported characteristics of coastal springs and wells in two separate groundwater-drilling programs, where they found 65% of the drilled holes contained water of sufficient quality for human consumption. A summary of the water quality parameters for surface streams that appear in the above-mentioned papers is given in Table 3.2.

The scarcity of documented information regarding water quality in the Pacific means that this thesis is one of the first studies of its kind. As noted in the objectives of this thesis (Section 2.9), this chapter focuses on the terrestrial inputs into the coastal zone. As a guide to the discussion, some hypotheses are formulated as to the present status of the surface hydrology of Samoa. Firstly, it is hypothesized that the water quality of Samoan perennial streams is equivalent for both islands of the country. Secondly, it is assumed that the background levels of pollution in these streams are minimal, although extreme values are expected at sites of human-induced activities. Thirdly, it is hypothesized that the water quality of the perennial streams of Samoa is comparable in the wet and dry seasons. Fourthly, the rivers and streams of Samoa are assumed to be comparable to streams from other Pacific islands of similar sizes that are exposed to similar environmental conditions. These hypotheses are tested by investigation. Water samples collected from all streams and freshwater springs from Savaii and Upolu islands in both the dry and wet seasons, are analysed for contaminants. The results will be compared in the following ways: firstly the wet and dry seasons will be compared; secondly, the water quality of the two islands will be contrasted; and thirdly, the water quality of Samoa will be checked against parameters recorded from neighbouring Pacific islands.

TABLE 3.2: Summary of Surface Water Quality Data from Selected Areas in the South Pacific. Source: Compiled by author

Country	River	Land uses in the catchment	Number of samples	Water quality parameters measured	Source
Cook Islands	Tipitaru Stream	Not given	1	pH = 7.4, C = 1260 TN < 0.05, $SO_4^{=}$ = 6 Fe^{++} = 0.05,	Downes (1981)
Fiji	Qarani-ni-ki River, Tailevu Province	Cultivation and vegetable farming	7	5.2< pH <7.1, 5.6< T.N. <14.4 0.05 < T.P. < 0.216 0< C <5000	Naidu *et al.* (1989)
Fiji	Vitogo River, Lautoka	Pine forest	3	5.8< pH <9.1, 60< C <25900 1< T <24, 0 < S <20 000 0.2< Fe^{++} <20, 1< $SO_4^{=}$ <3740 2.1< T.N. <11.1 0.03< T.P. <0.45	Gangaiya *et al.* (1986)
Fiji	Waidina River	Not given	5	0.01< TP <0.04, 6.4< pH <8.1 0.001< Zn < 0.005	Ammax Exploration (1978)
Fiji	Waivuni Creek, Navua	Not given	Unknown	1.6 < T.N. < 10	Gangaiya & Brodie (1987)
Fiji	Wailoa River	Power generation	3	7.0< pH <7.9, 1.5< T.N. <2.2 0.01< T.P. <0.048 0.1< Fe^{++} <0.37	Naidu *et al.* (1989)
Samoa	Vaisigano River	Power generation	1	C=72, T=1.2, $SO_4^{=}$ = 10, TP=1.8	Zavala (1985)
Samoa	Falelatai, Upolu and Siufaga, Savaii	Not given	2	7.2 < pH < 7.7, 1.0 < T < 1.5 55< T.D.S. <1470 0.05< Fe^{++} <1.4, 1< $SO_4^{=}$ <54 0.05< Zn^{++} <0.07	Downes (1981)

C = Conductivity (uS/cm), Fe^{++} = Total iron (mg/l), S = Salinity (mg/l), $SO_4^{=}$ = Sulphate (mg/l), T = Turbidity (NTU), T.D.S. = Total dissolved solids (mg/l), T.N. = Total nitrogen (mg/l), T.P. = Total phosphorus (mg/l), Zn^{++} = Zinc (mg/l)

3.1 DATA COLLECTION

Two major water sampling exercises were carried out in both Savaii and Upolu islands; one in the dry season and one in the wet season. Freshwater pools commonly found along the coast of both islands were incorporated into the sampling regime. Setbacks encountered during the fieldwork were restricted to: loss or accidental spillage of water samples, meter malfunction, and the inaccessibility of some remote areas like Fagaloa Bay, Faleseela and Tiavea. Local resistance to the sampling exercise was confined to one instance in Savaii, where the local women's committee requested payment for the sampling of pool water. In all, 1 610 analyses were carried out 287 analyses for Savaii and 1 323 analyses for Upolu.

3.1.1 Site Selection and Description

The criteria used for the collection of water samples were as follows. The sampled rivers and streams had to flow all the way to the sea so that contaminants carried by the surface runoff reached the lagoonal areas. Further, the sites were sampled at least fifty meters upstream from the coastline so as to minimize the influence of seawater intrusion. The main road around both islands proved a vantagepoint for sampling. A straight, uniform and representative section of each stream was selected, to incorporate the natural characteristics of the streamflow into the sampling procedure as much as possible (Plate 3.1).

The locations of the twenty-one sampling sites for Savaii are given in Figure 3.1. An isolated area of Fagaloa Volcanic (Figure 2.2) underlies the Avao stream in northern Savaii.

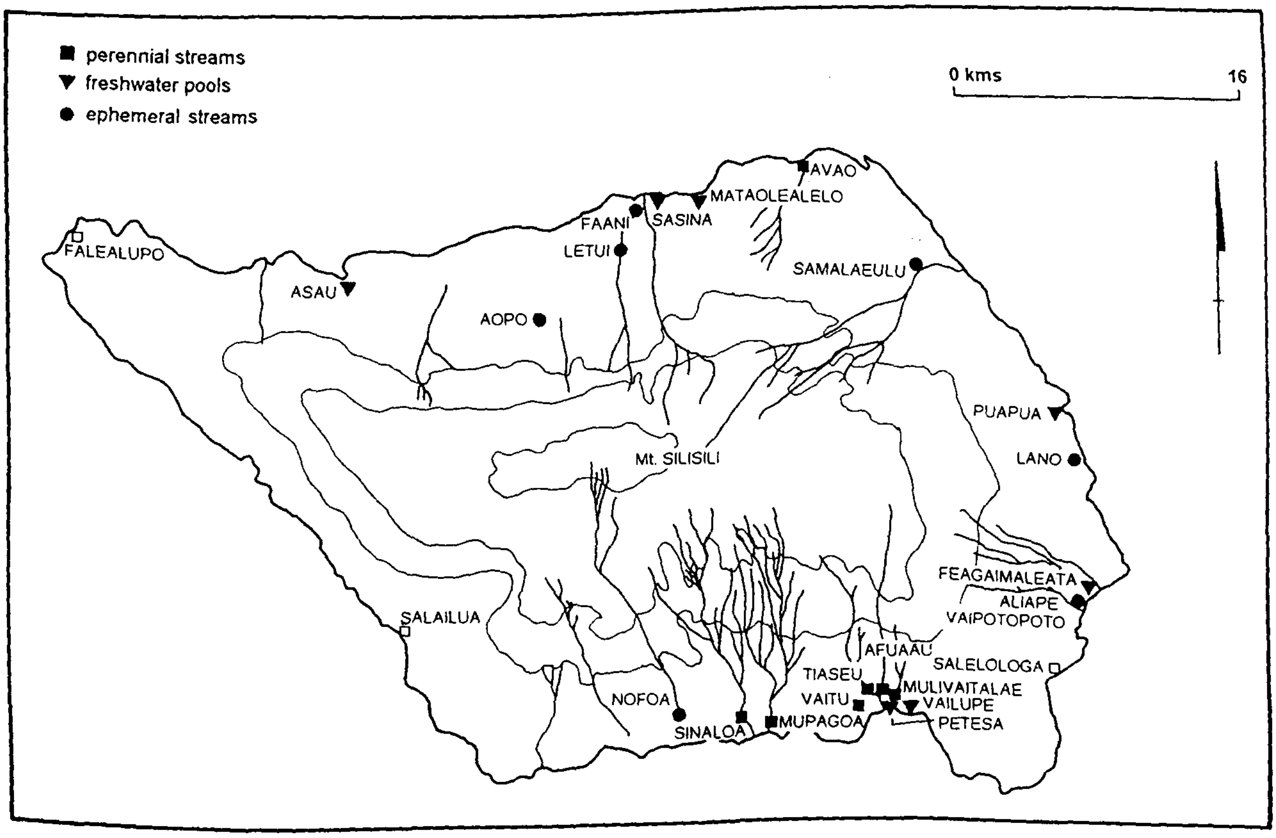

FIGURE 3.1: The Location of the Sampling Sites for Savaii Island.
Source: Author's research

PLATE 3.1: A typical water sampling site, showing the fairly straight portion of the stream, about 50 meters from the sea. Photograph by author

Land infilling for a family store some fifty meters from the sampling site had contracted the Avao Stream mouth substantially. Typical vegetation surrounding the stream was mangrove (*Rhizophora* spp) trees and swamp fern (saako: *Acrostichum auveum*). In the southern part of Savaii, between Palauli and Taga villages, six fast flowing perennial streams were sampled (Figure 3.1). This area of Savaii is underlain by older Salani and Fagaloa formations in the inland areas and by the younger Puapua Volcanic along the coast (Figure 2.2). Adjacent to the sampling sites on these rivers were coconut plantations interspersed with coastal forest trees, which were dominated by the fau (*Pariti tiliaceus*), and fuafua (*Kleinhoria hospita*) species. Areas of deeper waters in the stream channels are used for washing clothes, swimming and bathing by the local villagers. These activities were in progress fifty meters upstream at Sinaloa

River when sampling occurred here. The Mupagoa River is over twenty meters wide and is the widest river in Savaii, and one of the widest in the whole of Samoa. The Vaitu Stream seemed more like a man-made channel, which allowed the water to cross the road. Figure 3.1 also shows that perennial streams are absent in almost all the western half of Savaii. This is attributed to the dominant weather patterns existing in Samoa. The moisture-laden southeast winds, which blow for over 80% of the time impact mostly the eastern and southern sectors of both islands (Wright 1963). This means that the northwestern districts of both islands are the driest regions and surface waters are often absent (Figure 2.8). The presence of ephemeral streams at Aopo, Letui, Faani and Samalaeulu in northern Savaii not only attests to this but also reflects the young geology of these parts of Savaii. The ephemeral streams typically have dry riverbed of rocks and pebbles (Plate 3.2).

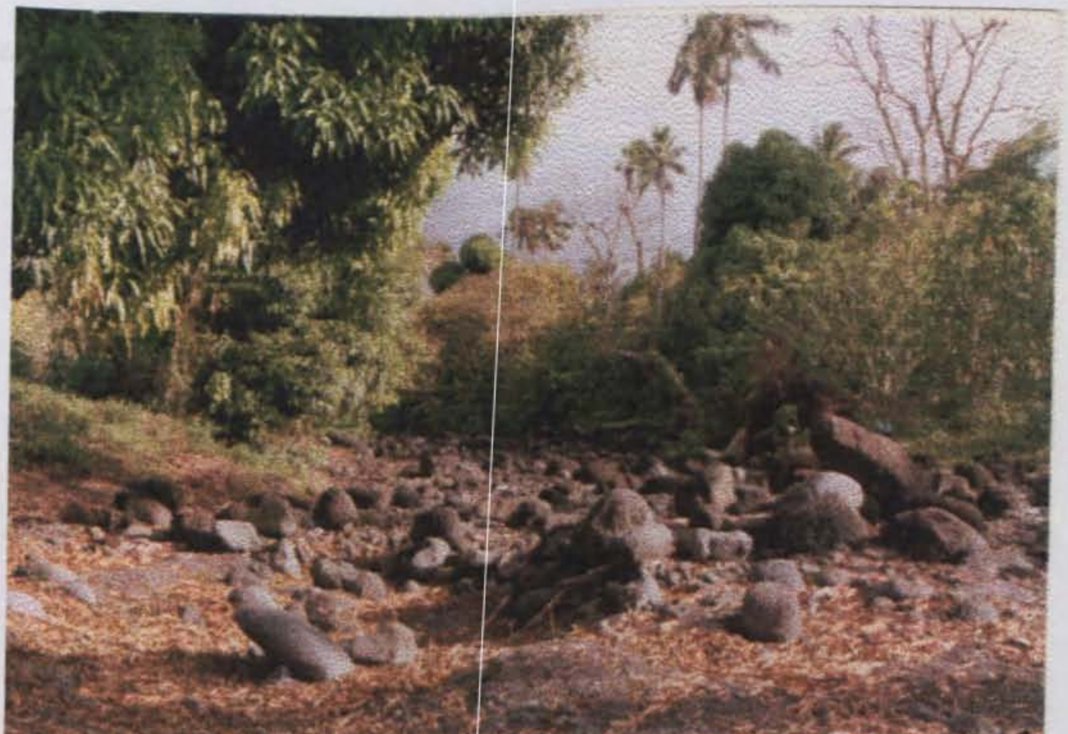

PLATE 3.2: Faani ephemeral stream near Sasina village, Savaii. Note the dryness of the area and the surrounding vegetation. Photograph by author

The surrounding vegetation is again shrubs with coconuts. The locals reported that the Mali'oli'o ephemeral stream at Samalaeulu was filled to such high levels that it was accessible only by canoes during the heavy rains of December 1989 and January 1990. The ephemeral streams at Aliape and Nofoa showed signs of recent flooding at the time of the sampling exercise, with the grasses in the water channels sloping in the direction of the water flow. Water levels reached one metre during these floods.

Eight freshwater springs were sampled in Savaii and all were found close to the sea (Figure 3.1). The villages remote from surface water supplies rely solely on these coastal water springs for their water needs, so that water cartage has become a characteristic feature of their lifestyle (United Nations 1983). The villagers value these water resources tremendously and have erected cement walls around all these freshwater pools for preservation and protection (Plate 3.3).

PLATE 3.3: Sasina freshwater pool, Savaii. The cemented wall protects the water pools, and signs of the watercartage life style are still present in these areas.

Photograph by author

A separate cement structure usually divides the strong bubbling part of the spring, which is set aside for drinking from the washing and swimming area closer to the sea. The bubbling part of each freshwater pool was sampled. Mataolealelo and Feagaimaleata pools are used for swimming only, but the rest of the pools sampled served the dual purpose.

Many more perennial streams were found in Upolu, and were distributed irregularly throughout the island (Figure 3.2). The abundance of rivers and streams in Upolu as compared to Savaii relates to the differences in geologies of the two islands where most of Upolu is underlain by the older Fagaloa and Salani rock formations (Figure 2.2). Prolonged exposure of these rocks to weathering elements has reduced the volcanic material to impermeable clay, which impedes rainwater absorption and increases surface runoff (Waterhouse 1984). Savaii is underlain by young volcanic rock and most of the precipitation percolates directly into the ground.

The observation at Savaii, where few streams were found in the west and northwestern parts of the island (Figure 2.8 and Figure 3.1) due to the dominant weather patterns of Samoa, was again evident in Upolu. Here, over 80% of the perennial streams are located in the northern shores of the island between the capital Apia and the Aleipata district (Figure 3.2). The Fagaloa Bay area alone accounted for over 50% of perennial streams in Upolu (Table 3.3).

TABLE 3.3: The Regional Distribution of Sampling Sites in Upolu.
Source: Author's research

REGION	Perennial Rivers	Ephemeral Streams	Fresh Water Pools	Drains
NE UPOLU	13	1	3	2
Aleipata district	10	0	3	0
Fagaloa Bay	38	0	1	0
NW UPOLU	1	0	4	1
SOUTH UPOLU	13	4	0	0
TOTAL	75	5	11	3

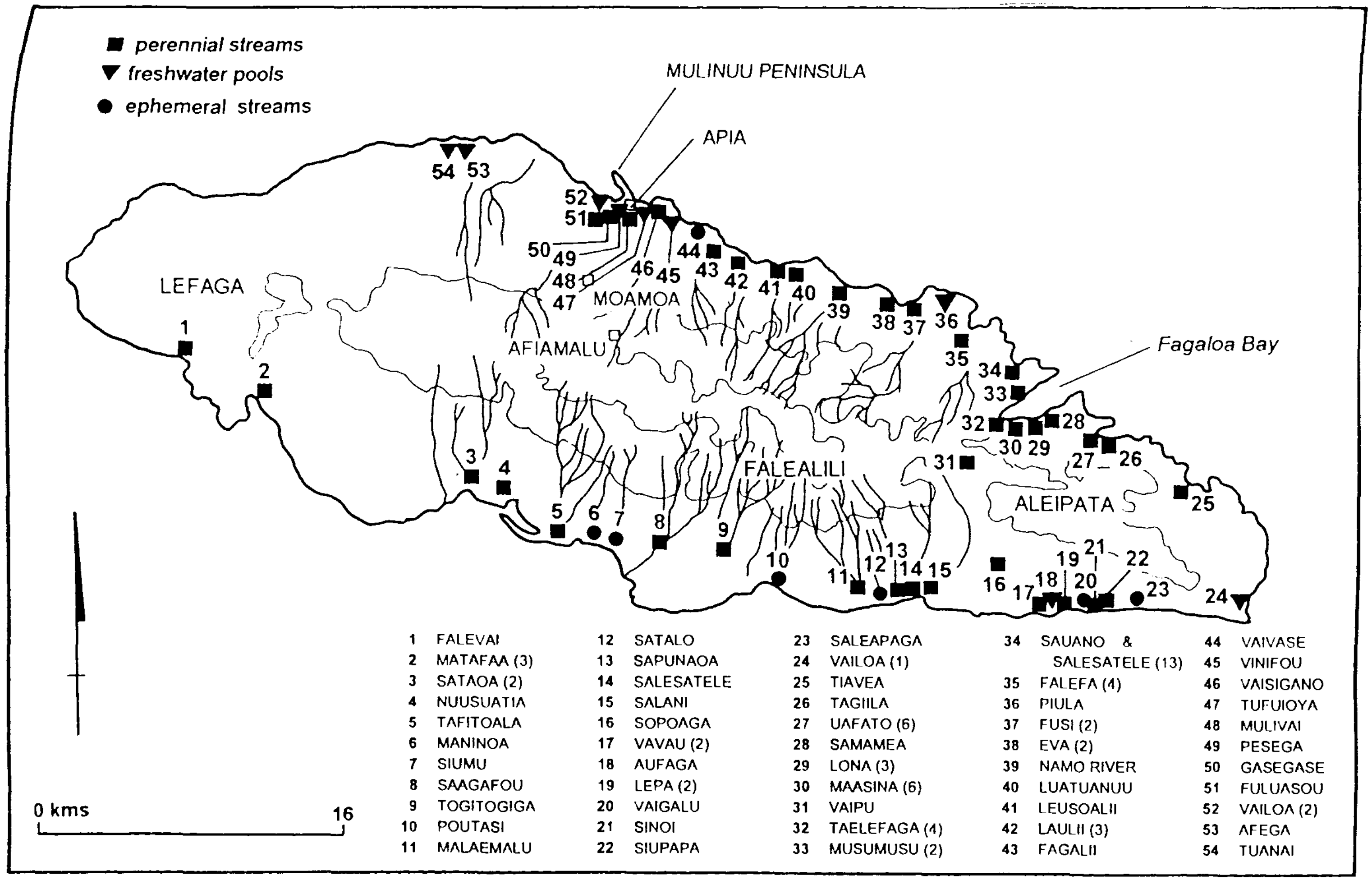

FIGURE 3.2: The Location of the Sampling Sites in Upolu. The numbers in parenthesis indicates the number of samples within that village. Source: Author's research

In the Fagaloa Bay area, ministreams that were often only two to four meters wide and ankle deep occurred almost every fifty meters along the coast. In contrast, only three streams occurred between the capital city Apia, and the western end of the island (Figure 3.2). Two of these streams were tidally influenced and were subsequently deleted from the data set. Thirteen streams were sampled in the Lefaga, Safata and Falealili districts in southern Upolu.While Namo, Falefa and Tiavea rivers were all in excess of twenty meters wide, streams as small as half a metre wide were found in the Fagaloa Bay area. For the most part, the sampling sites were close to family dwellings, and household rubbish was often seen dumped directly into the water channels. Rivers such as Namo, Vaipu, Tagaila, Sopoaga, Sapunaoa, Salesatele and Togitogiga were sampled in areas of tropical rain forests where the tree species poumuli (*Securinega samoana*) was dominant. The presence of the palm grass (vao palagi: *Setaria palmifolia*) along the riverbanks was conspicuous, while coconuts, bananas and littoral trees occupied the river valleys. Washing and swimming were common activities seen in most streams of Upolu.

Most of the freshwater pools of Upolu were found along the coast (Plate 3.4). The freshwater pools in the Apia area were located inland from the sea: Tufuiopa Pool is located about 200 meters from the centre of the capital Apia, and Vini Pool is situated approximately two kilometres inland from the sea. All the sampled freshwater pools were bounded by cement walls for protection, and maintained and policed by the women's committees of the villages concerned.

In addition to natural watercourses and springs, three drains were sampled. The drains at Eva and Salelesi were narrow waterways draining close to the village homesteads. Fugalei drain runs through one of the densely populated parts of Apia.

PLATE 3.4: Piula Pool located along the east coast of Upolu. Photograph: R. Lawrence

3.1.2 Data Collection Time

Figure 2.5 shows the seasonal distribution of rainfall in Samoa, where the wet months are from November to April, and the dry months are from May to October. The dry season sampling for Savaii took place on 24 and 25 August 1994, starting from the western end of the island at Palauli travelling clockwise. The weather at that time was overcast, but dry. Personal communication with people met along the roadside revealed that heavy rains had occurred in Savaii the previous week.

Precipitation records from some Savaii stations during the sampling period showed that indeed Palauli Station recorded heavy rains prior to the week of the sampling regime (Figure 3.3).

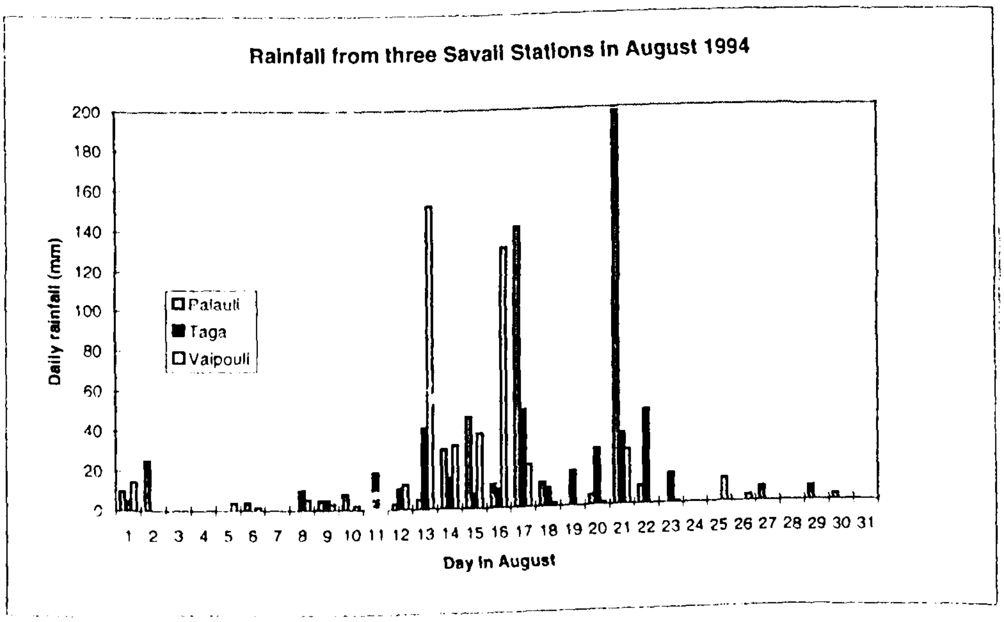

FIGURE 3.3: Precipitation Records from some Savaii Stations for August 1994. Source: Apia Observatory Office

Total precipitation at Palauli and Taga stations for August 1994 was 530 millimetres and 324 millimetres respectively. The average August precipitation for Apia for fifty years from 1941 to 1991 was only 128 millimetres (Appendix 1.1). At Taga Station, it rained incessantly for about two weeks before the sampling exercise commenced. In fact, almost 94% of the total monthly precipitation at Taga fell just before the sampling commenced. This probably explains why Afuaau, Tiaseu, Vaitu, Mupagoa and Sinaloa rivers showed overflow levels at the time of sampling.

The wet season sampling for Savaii took place on 8 and 9 March 1995, following the same route taken in the dry season sampling. The weather at this time ranged from being slightly overcast, to continuing light drizzle throughout the day, to fine and hot. Precipitation values from the same Savaii rainfall stations for March 1995 are given in Figure 3.4. Palauli Station recorded no rain for the entire month of March 1995 and Taga Station showed no rain the week before the sampling exercise (Figure 3.4). The low precipitation recorded at both these stations contributed to the drying up of Sinaloa River and the low water levels witnessed in the perennial streams in southern Savaii.

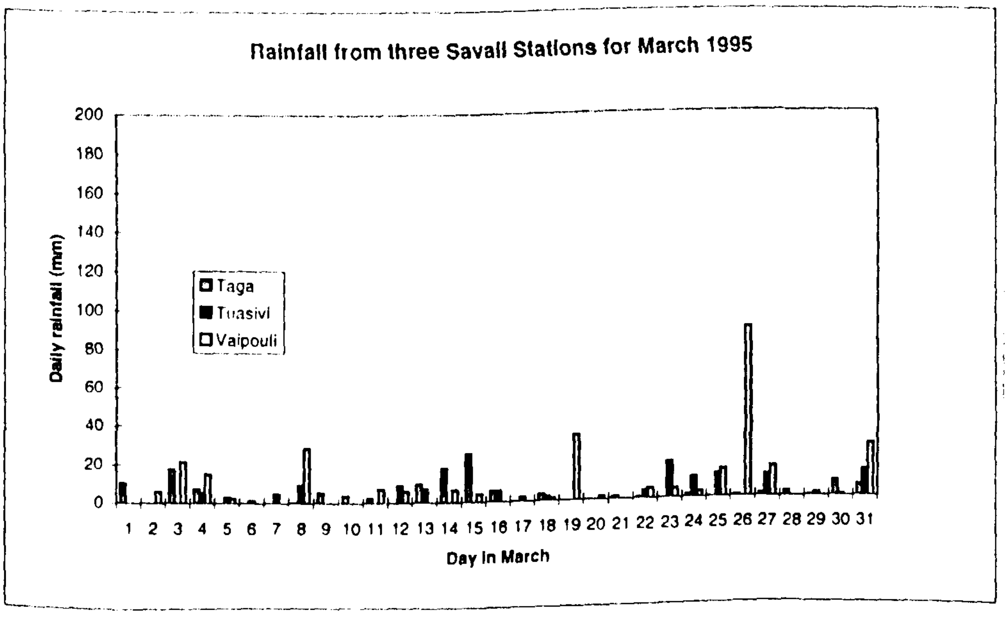

FIGURE 3.4: Rainfall Records from some Savaii Stations in March 1995.
Source: Apia Observatory Office, Mulinuu

The presence of lava tunnels occupied by underground streams that carry off a great deal of water (Thomson 1921) may also contribute to the absence of surface waters in certain parts of Savaii. It is evident from the data given in Figures 3.3 and 3.4 that the sampling times did not fit in with the normal conditions for wet and dry seasons.

The dry season sampling for Upolu occurred on 14 September 1994 for NorthEast Upolu and Aleipata districts, 15 September 1994 for NorthWest Upolu, Safata and Falealili districts, and 17 September 1994 for the Fagaloa Bay area. The weather was unsettled during the sampling days, with cloudy mornings followed by afternoon and evening rains. The precipitation records for three Upolu stations in September 1994 are given in Figure 3.5. Although Mulinuu records showed no rain the week before sampling,

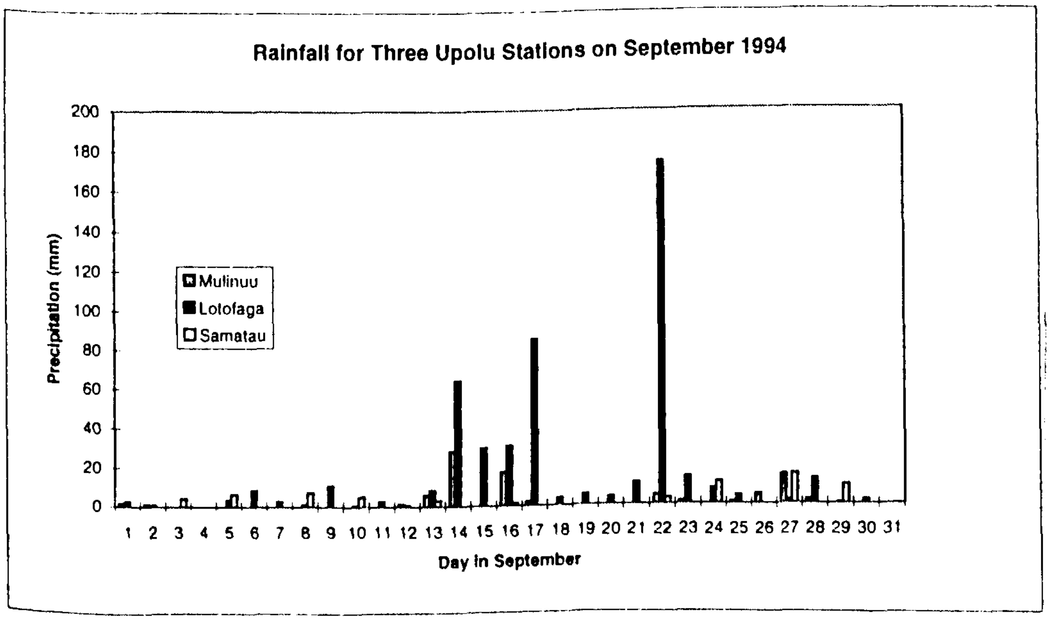

FIGURE 3.5: Rainfall Records from Three Upolu Stations for September 1994. Source: Apia Observatory Office

Lotofaga Station recorded a lot more precipitation during this period. This accounts for the fact that many streams at Aleipata were filling up at the time of sampling. The rainfall distribution showed a rainy spell in the middle of the month during the sampling exercise (Figure 3.5).

The wet season sampling regime for Upolu occurred in the North East Upolu and Aleipata districts on 18 March 1995, the North West Upolu, Lefaga, Safata and Falealili districts on23 March 1995, and the Fagaloa Bay area on 31 March 1995. The weather during these days was mainly fine and hot, although some light showers fell in the late afternoons. The precipitation records from the three Upolu stations for March 1995 showed a somewhat erratic rainfall pattern for Upolu during this month (Figure 3.6). The abnormality of the weather noted in Savaii at the times of sampling was also observed from the Upolu rainfall records, where the heavier precipitation falling at the usually drier end of Upolu at Samatau in the wet season was apparent.

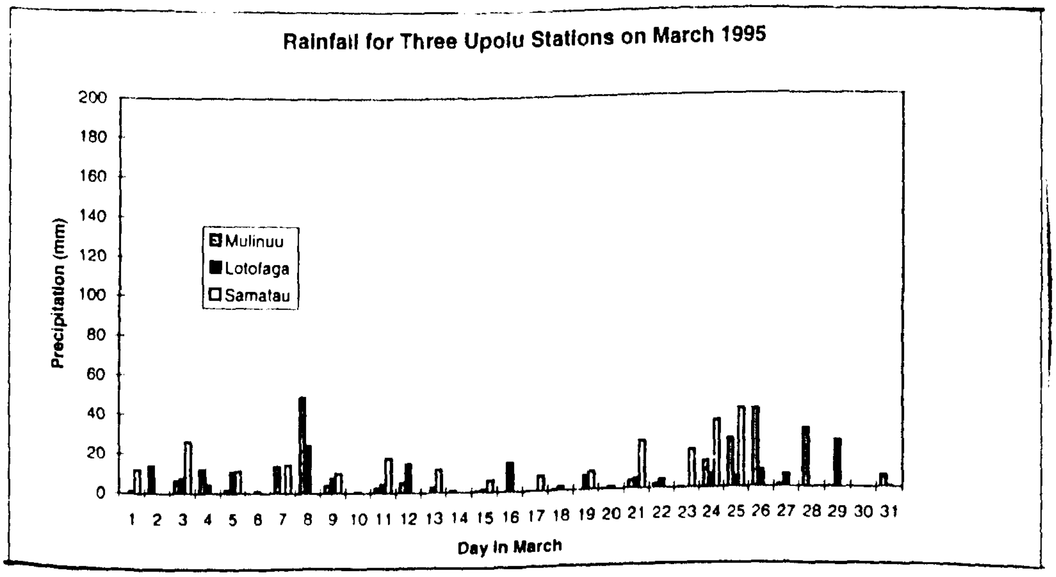

FIGURE 3.6: Rainfall Records from Three Upolu Stations for March 1995.
Source: Apia Observatory Office

Thus, it is emphasized that the dry season sampling period was undertaken during wet conditions, and the wet season sampling period occurred in the drier than normal conditions. This may affect the representativeness of the samples, and their analysis. The cause of this abnormality is not clear. However, McGregor (1990) noted that global warming and the influence of the northern hemisphere high-pressure circulation in the SouthWest Pacific might affect the climate of the Pacific islands. Further, extended shifts in weather patterns due to ENSO events are affecting the South Pacific (Richmond 1991). According to Nunn *et al.* (1994) seasonal rainfall decreases significantly in Samoa during ENSO events.

3.1.3 Parameters Measured

Equipment availability was the main determinant of the water quality parameters measured during this research. The availability of water quality monitoring devices in Samoa was investigated and none were found to be available. The lone HACH DR/2000 Spectrophotometer that was used for chemical analysis at the Apia Observatory laboratory was missing, and most HACH chemicals were out of date. Stream gauge recorders installed in twelve catchments around Samoa were reportedly destroyed by the cyclones of 1990 and 1991. Thus, the author had to arrange for the provision of recording equipment from Australia, and undertook all the water sampling, independent of government authorities. The cost and transportation of equipment and chemicals from the University of Adelaide restricted the number and type of analyses performed.

The physical water parameters measured were discharge, temperature, total dissolved solids (TDS), salinity, electrical conductivity, pH, suspended solids and turbidity. The temperature, TDS, salinity and conductivity were measured on site with battery operated portable meters.

The pH was measured with a power operated pH meter at the Alafua Laboratories. At each stream site, 750 cm^3 of water was collected in clean plastic bottles. These were refrigerated until analyzed for suspended solids, turbidity, total phosphorus, sulphate, total nitrogen, iron and zinc contents. The suspended solids and turbidity measurements were made on a portable HACH dr-el/2 Spectrophotometer from the Geography Department, University of Adelaide. Chemical analyses for the sulphate, ferrous and zinc ions were also performed on the HACH spectrophotometer, as well as the determination of total nitrogen and total phosphorus in the water samples. Details of the instruments used and procedures followed for all the water quality parameters measured are given in Appendix 3. The cost of both the chemicals required and freight charges from Australia to Samoa precluded the analysis of duplicate samples.

3.2 SAVAII PERENNIAL STREAMS

All the water quality data results for the entire sampling regime for Savaii and Upolu waters in the dry and wet seasons are given in Appendix 4.1. This section discusses the results obtained from the samples analyzed.

3.2.1 The Dry Season Samples

Table 3.4 lists the water quality parameter values of the Savaii perennial streams in the dry season. The average discharge value was calculated at 2.52 m^3/s, with Mupagoa River registering over 7.0 m^3/s. These values suggest that the streams were probably still displaying the after-effects of the heavy rains that fell the week before sampling occurred. All the streams had waters with an average temperature value of 24.6°C, low salinity values and near neutral pH readings.

The average conductivity of the waters was 90 uS/cm, and mean TDS and suspended solids values were 35 mg/l and 9.7 mg/l respectively. All the streams recorded turbidity values higher than the permissible value of 5 NTU set down for drinking water by the World Health Organisation (1993).

TABLE 3.4: Average Water Quality Parameters for Savaii Perennial Streams in the Dry Season. Source: Author's research

	STREAM NAME									
WATER QUALITY PARAMETER	Mulivai -talae	Afuau	Tiaseu	Vaitu	Mu-pagoa	Sina-loa	Avao	Mean	WHO (1)	World Average (2)
Discharge (m^3/s)	0.33	2.08	1.97	1.35	7.08	4.64	0.22	2.52		
Temperature (°C)	25	25	25	25	24	24	24	25		
PH	6.7	6.8	6.8	6.7	6.6	6.9	6.7	6.7	<8.0	6.9
Salinity (mg/l)	0.05	0.04	0.03	0.04	0.02	0.02	0.04	0.04		
Cond (uS/cm)	110	102	110	102	56	59	91	90		
TDS (mg/l)	50	50	50	50	20	20	50	35	1000	500
S.solids (mg/l)	18	10	10	15	4	6	5	10		
Turbidity (NTU)	5	6	8	10	10	8	10	8	5	5
Iron (mg/l)	0.03	0.04	0.04	0.04	0.02	0.03	0.04	0.03	3	0.67
Sulphate (mg/l)	7	7	7	8	7	8	11	8	250	11.2
TN (mg/l)	0.3	0.2	0.4	0.3	0.2	0.4	0.3	0.3	50	0-10
TP (mg/l)	0.03	0.03	0.04	0.06	0.06	0.5	0.03	0.10		< 0.05
Zinc (mg/l)	0.07	0.08	0.09	0.16	0.18	0.20	0.14	0.13	3	0.01

Notes : (1) WHO Guidelines for drinking water quality (1993)
(2) Taken from Wetzel (1975)

The waters by the roadside of some ephemeral streams showed warmer temperatures than the perennial streams of Savaii (Appendix 4.1). Since these are static water systems, heat has accumulated within a smaller water volume, resulting in higher temperatures. The elevated values for salinity and conductivity found at Letui is probably due to evaporation, where ions have concentrated into a smaller volume of water after exposure to the sun for a long period of time (Wetzel 1975). These ephemeral water pools had near neutral pH values ranging from 6.4 to 6.9 and very turbid waters.

The chemical analysis data for the Savaii perennial streams, given in Table 3.4 noted that the perennial streams of Savaii were not contaminated with $SO_4^{=}$ or Fe^{++} ions, when compared to the average values of both these parameters for unpolluted waters of the world (Wetzel 1975). Although the average zinc concentration for the Savaii perennial streams was greater than the world average, all the streams recorded much lower zinc concentrations than the maximum value of 3.0 mg/l set down for drinking water standards by WHO (1993). Total phosphorus concentrations in all the perennial streams were low, except for the elevated reading of 0.5 mg/l recorded at Sinaloa River, which was probably due to detergent from local washing and bathing upstream at the time of sampling (Section 3.1.1). This explanation also accounts for the occurrence of a higher Zn^{2+} value in the same river. All the perennial streams of Savaii recorded average total nitrogen values less than 1.0 mg/l.

The relationships between selected water parameters of the perennial streams of Savaii were determined and are given in Figure 3.7. Hownslow (1995) noted that conductivity is a good estimator of TDS values and the direct relationship between these two parameters in the perennial streams of Savaii is apparent in Figure 3.7(a). The inverse relationship between discharge and conductivity was also evident [Figure 3.7(b)]. The correlation between discharge and turbidity was obscured by the anomalous readings at Avao and Vaitu [Figure 3.7(c)], as both these sites experienced human influences of land infilling and water channel widening respectively (Section 3.1.1). There was no correlation between discharge and suspended solid as depicted in Figure 3.7(d). Figure 3.7(e), Figure 3.7(f) and Figure 3.7(g) respectively showed that concentrations of iron, total phophorus, zinc, sulphate and total nitrogen appeared to act independently of discharge in the Savaii perennial streams. Furthermore, there was no apparent correlation between iron, total phosphorus and zinc in the streams of Savaii as seen in Figure 3.7(h). Elevated concentrations of total nitrogen and total phosphorus occurred independently of each other in the perennial streams of Savaii as shown in Figure 3.7(i).

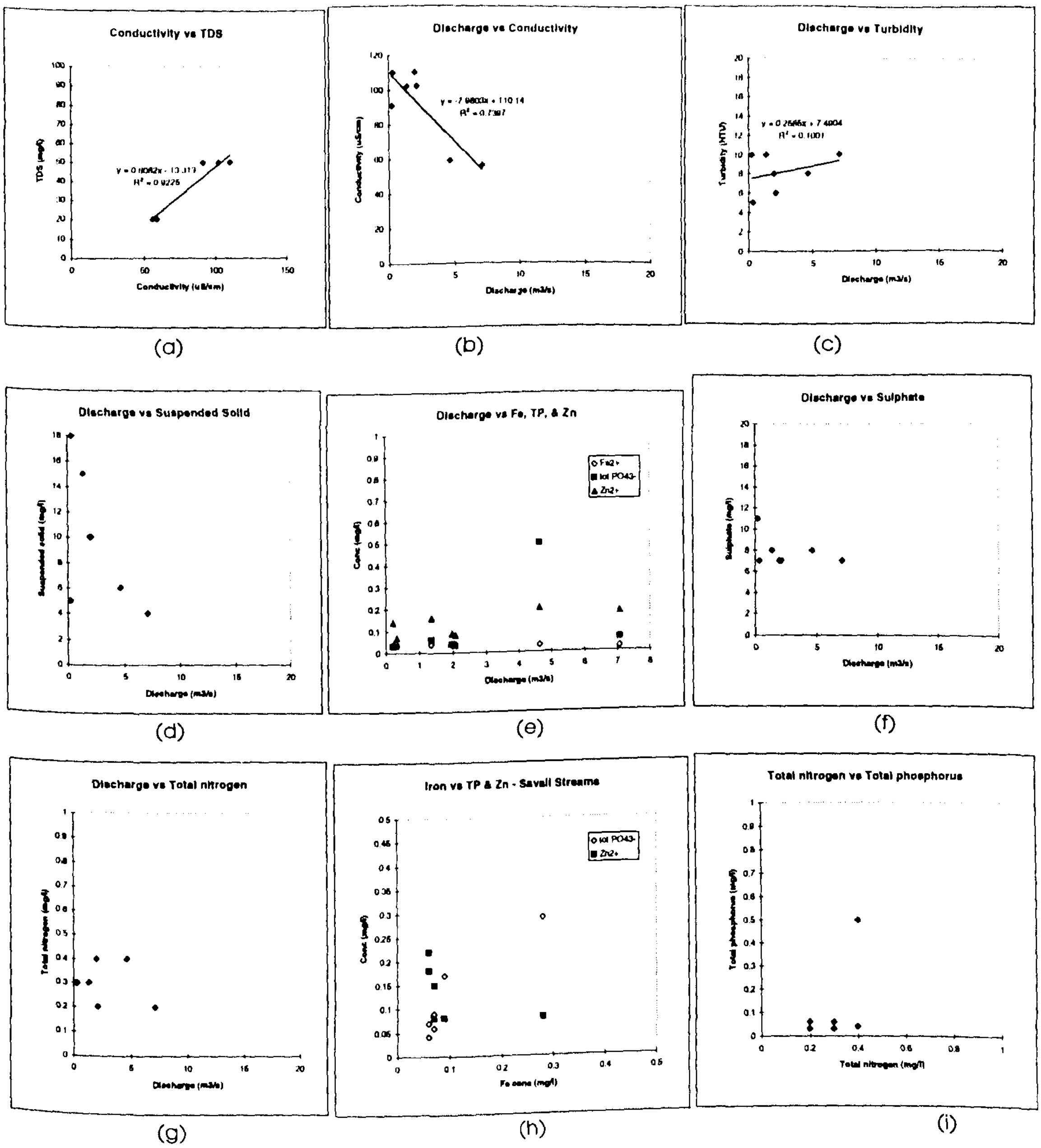

FIGURE 3.7: Correlations between the Water Quality Parameters of Savaii Perennial Streams in the Dry Season. Source: Author's research

The ephemeral water pool at Letui gave elevated levels of both total phosphorus and Fe^{2+} contents (Appendix 4.1). Given the comparatively high levels of turbidity and suspended solids recorded in this water sample, the release of both the phosphorus and Fe^{2+} from the sediment seems to be a possible explanation for the higher concentrations observed.

3.2.2 The Wet Season Samples

The water quality parameters for the Savaii perennial streams in the wet season are given in Table 3.5.

TABLE 3.5: Average Water Quality Parameters for Savaii Perennial Streams in the Wet Season. Source: Author's research

	STREAM NAME									
WATER QUALITY PARAMETER	Mulivai -talae	Afuau	Tiaseu	Vaitu	Mu- pgoa	Sina- loa	Avao	Mean	WHO (1)	World Mean (2)
Discharge (m^3/s)	dry	0.57	0.44	0.2	1.2	dry	0.76	0.63		
Temp (°C)		25	25	25	24		27	25		
PH		6.8	6.7	7.1	7.1		6.8	6.9	<8.0	6.9
Salinity (mg/l)		0.05	0.04	0.04	0.02		0.03	0.03		
Cond (uS/cm)		112	104	95	56		69	87		
TDS (mg/l)		30	30	30	20		20	26	1000	500
S. solids (mg/l)		2	1	0	8		4	3		
Turb (NTU)		1	1	0	4		4	2	5	5
Iron (mg/l)		0	0	0	0		0	0	3	0.67
Sulphate (mg/l)		0	0	0	0		2	n/a	250	11.2
TN (mg/l)		0	0	0	0		0.2	n/a	50	0-10
TP (mg/l)		0.03	0.04	0.08	0.05		0.04	0.04		<0.05
Zinc (mg/l)		0.01	0.03	0.05	0.01		0.05	0.03	3	0.01

Notes: (1) WHO Guidelines for drinking water quality (1993) (2) Taken from Wetzel (1975)

In the wet season sampling, the perennial streams in southern Savaii recorded both lower water levels and slower water discharges than in the dry season. The Sinaloa River had become ephemeral, and the Mulivaitalae Stream was also drying up. The average water temperature of the Savaii perennial streams in March 1995 was around 26°C. The pH values were all near the neutral mark. Average salinity, conductivity, TDS and suspended solids concentrations were low (Table 3.5). Turbidity readings were also low, reflecting the slower water discharges observed. Correlations between certain water quality parameters in the wet season were still evident. While conductivity decreased with discharge, turbidity values increased with discharge. The direct relationship between conductivity and TDS was also apparent.

The chemical analysis results for the Savaii perennial streams in the wet season are also given in Table 3.5. While iron was not detected in any of the stream waters, sulphate and total nitrogen readings were present in some of the streams. With the exception of the reading at Vaitu, the other streams recorded total phosphorus concentrations less than 0.05 mg/l, classifying them as unpolluted waters according to world standards (Wetzel 1975). Zinc concentrations were minimal, where an average value of 0.03 mg/l was calculated.

The ephemeral stream Aliape recorded comparatively high salinity and conductivity values while the one at Letui continued to give a turbid water sample (Appendix 4.1). Chemical analysis of the ephemeral water pools showed comparable results with those of the perennial streams of Savaii (Appendix 4.1).

3.2.3 Comparison Between Savaii Perennial Streams in the Dry and Wet Seasons

In order to compare the water quality of Savaii perennial streams for the two seasons, the mean value for each water quality parameter was examined (Table 3.6).

TABLE 3.6: The Average Water Quality Parameters for Savaii Perennial Streams in the Dry and Wet Seasons. Source: Author's research

WATER QUALITY PARAMETER	DRY SEASON	WET SEASON
Discharge (m^3/s)	2.52	0.63
Temperature (°C)	24.6	25.4
PH	6.7	6.9
Salinity (mg/l)	0.04	0.04
Conductivity (uS/cm)	90	87
Total dissolved solids (mg/l)	35	26
Suspended solids (mg/l)	9.7	3
Turbidity (NTU)	8.1	2
Iron (mg/l)	0.03	0.0
Sulphate (mg/l)	7.8	0.4
Total nitrogen (mg/l)	0.3	0.04
Total phosphorus) (mg/l)	0.10	0.04
Zinc (mg/l)	0.13	0.03

In Table 3.6, it can be seen that the average stream discharge was about four times lower in the wet season than in the dry season, which can be accounted for by the weather at the times of sampling (Section 3.1.2). The pH, salinity, conductivity, TDS and iron concentrations were comparable in both seasons, while suspended solid, turbidity, sulphate, total nitrogen, total phosphorus and zinc displayed lower concentrations in the wet season.

According to UNESCO/WHO (1978), trends in water quality maybe determined by comparing cumulative frequency curves, and the use of the Q-Q plot technique may be used to compare the two sets of data. The cumulative distribution curve is a graph of the percentage by which a parameter exceeds a certain value. The Q-Q plot is the percentile values of one set of data plotted against the percentile values of another set of data. Cumulative distribution curves for suspended solids and total phosphorus for Savaii perennial streams in the dry and wet seasons are given in Figure 3.8.

Figure 3.8 shows that there was a clear shift to lower suspended solids values in the wet season. The total phosphorus curves showed almost identical distributions in the two seasons, except for an elevated point in the dry season. This anomalous reading at the Sinaloa River has already been attributed to anthropogenic origin (Section 3.2.1).

The same trends in the distribution of the two water quality parameters are indicated in the Q-Q plots given in Figure 3.9, where the suspended solid distribution shifted to lower values in the wet season. The total phosphorus distribution points lie along the straight line except for one anomalous reading. These results showed that suspended solids concentrations had lower values in the wet season, while total phosphorus concentrations were comparable in both seasons if the anomalous reading of anthropogenic origin is ignored.

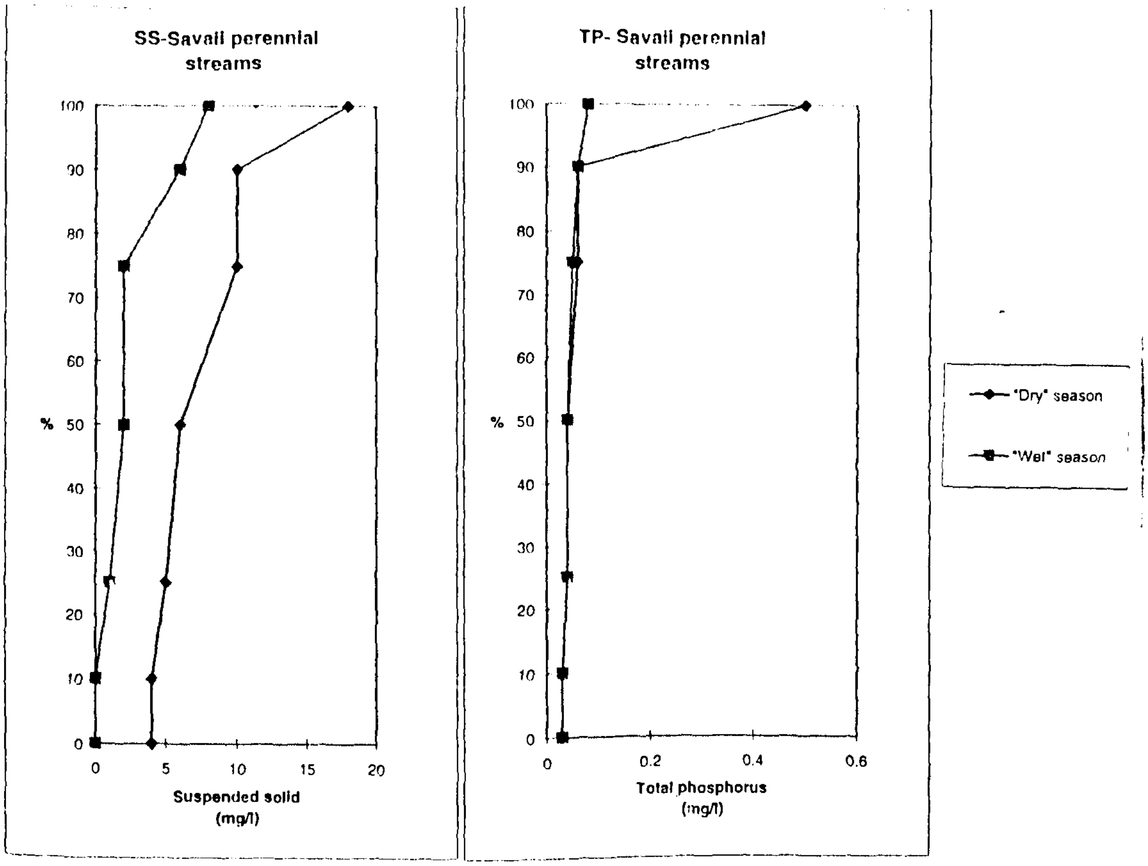

FIGURE 3.8: Cumulative Frequency Curves of Suspended Solid and Total Phosphorus of Savaii Perennial Streams in the Dry & Wet Seasons.
Source: Author's research

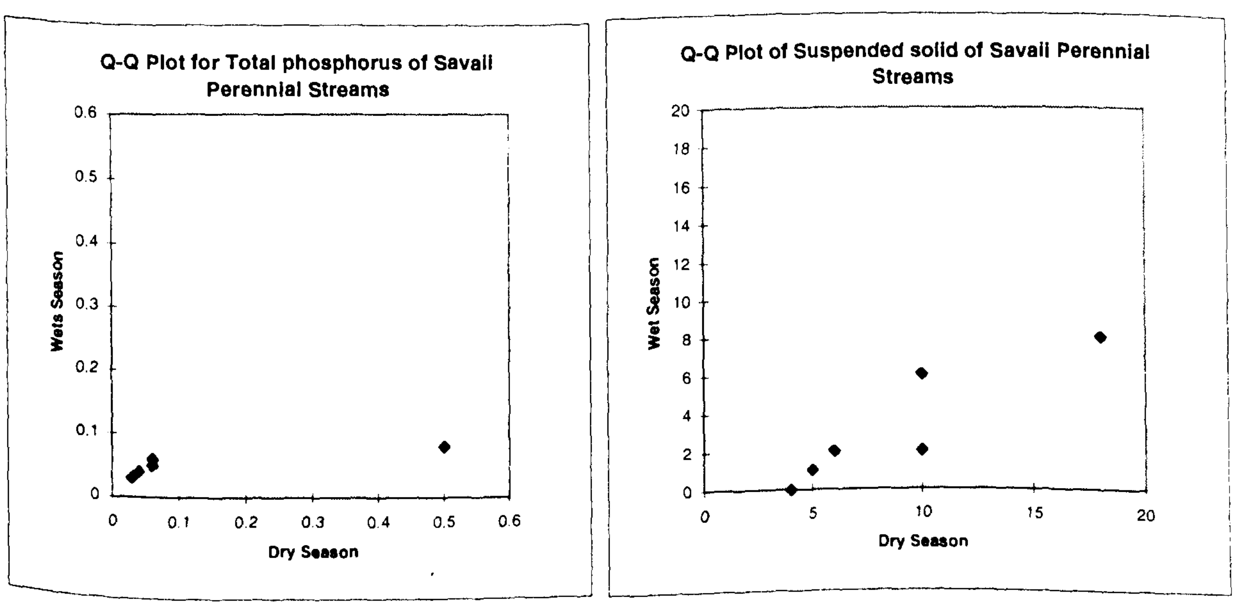

FIGURE 3.9: Q-Q Plots of Suspended Solids and Total Phosphorus of Savaii Perennial Streams in the dry & wet Seasons. Source: Author's research

Iron concentrations remained low in both seasons. Similarly, the average sulphate concentrations in both seasons gave lower values than the 10 mg/l set down for unpolluted waters of the world (Wetzel 1975). No perennial stream in Savaii recorded a total nitrogen value more than 1.0 mg/l. While the influence of climate on the water quality of Savaii perennial streams is evident from the results, there was no apparent spatial variation due to geological or land use factors.

From Table 3.6, general characteristics of the water quality of the Savaii perennial streams can be outlined. The perennial streams of Savaii have average water temperatures between 24°C and 25°C, near neutral pH values and salinity levels varying between 0.03 mg/l and 0.04 mg/l. Conductivity average values are less than 100 uS/cm. Suspended solids and turbidity values vary according to stream discharges. Average total phophorus concentrations are around 0.048 mg/l, and total nitrogen values average around 0.3 mg/l. Sulphate contents rarely reach 10 mg/l. Iron and zinc concentrations are also low at around 0.03 mg/l. The perennial streams of Savaii displayed good quality waters free of contaminants, except when exposed to human induced activities such as their use for local washing.

3.3 SAVAII FRESHWATER SPRINGS

The physical water parameters of the freshwater springs sampled in Savaii in the dry and wet seasons are given in Appendix 4.1. Table 3.7 gives average water quality parameter values for both the dry and wet seasons. It is immediately obvious from a comparison between Table 3.6 and 3.7 that the salinity, conductivity, TDS, sulphate, total nitrogen and total phosphorus values of the freshwater springs are considerably higher than for the surface perennial streams: sometimes two orders of magnitude higher.

TABLE 3.7: Average Water Quality Parameters of the Freshwater Springs of Savaii in the Dry and Wet Seasons. Source: Author's research

WATER QUALITY PARAMETER	dry SEASON	wet SEASON
Temperature (°C)	24.5	24.7
pH	6.7	6.9
Salinity (mg/l)	0.76	0.65
Conductivity (uS/cm)	1544	2096
Total dissolved solids (mg/l)	653	375
Suspended solids (mg/l)	6	0.3
Turbidity (NTU)	3	0.6
Iron (mg/l)	0.03	0
Sulphate (mg/l)	49	37
Total nitrogen (mg/l)	1	1.5
Total phosphorus) (mg/l)	0.15	0.17
Zinc (mg/l)	0.14	0.03

To determine whether these apparent differences were statistically significant or not, a non-parametric test was performed on the two populations. The advantages of non-parametric tests is that they do not assume that a sample is drawn from a population which is normally distributed, and still give rise to exact probability statements (Siegel 1956). The specific test used was the Mann-Whitney U test, which is one of the most powerful non-parametric tests, and tests the null hypothesis that two samples come from the same population with the same distribution. The null hypothesis tested was that the water samples from the streams and springs were drawn from the same population. The results of the Mann-Whitney U tests are given in Appendix 5.1. For all the water quality parameters examined, the null hypothesis was rejected at the 99% confidence level in all cases. This meant that the freshwater springs of Savaii indeed had higher concentrations of salinity, conductivity, TDS, sulphate, total nitrogen and total phosphorus than the perennial streams in both the dry and wet seasons.

According to Morrison *et al.* (1984) high conductivity values and high amounts of total dissolved solid material usually indicate the contamination of groundwater by seawater. Further, it is noted that salinity levels increase due to seawater intrusion as a result of overpumping of fresh water lenses (Falkland and Brunel 1993). This, together with the coastal location of the springs are probably the reasons for the higher levels of salinity, conductivity and TDS observed in the freshwater springs of Savaii. While the higher levels of nutrients observed in the freshwater springs than the perennial streams of Savaii is not known exactly, chemical pollution of groundwater is known to be asssociated with population density (Thomson and Foster 1986). The freshwater springs were all located within the confines of a village, and were used by all the local people. In contrast, the perennial streams were found in isolated areas, away from the villages.

Based on the standards given by Wetzel (1975) and WHO (1993), the average values of sulphate, total nitrogen, zinc and iron for the freshwater springs of Savaii in the dry season given in Table 3.7 were all considered low.

Correlation between some water quality parameters of Savaii freshwater springs in the dry season is given in Figure 3.10. The direct correlation between conductivity and TDS was again noted in Figure 3.10(a), and sulphate concentrations were again found to increase with salinity [Figure 3.10(b)]. There was no apparent relationship between the variation of suspended solid and total phosphorus or iron [Figure 3.10(c)]. Furthermore, Figure 3.10(d) showed that total nitrogen and total phosphorus occurred independently of one another in the freshwater springs of Savaii in the dry season.

In the wet season, it was observed that the water temperature, pH, salinity, iron, sulphate, total nitrogen and total phosphorus values of the Savaii freshwater springs were comparable to those recorded in the dry season. It is apparent from Table 3.7 that the conductivity levels of the freshwater springs of Savaii increased in the wet season, and there was a definite decrease in TDS, suspended solids, turbidity and zinc concentrations from the dry to wet season.

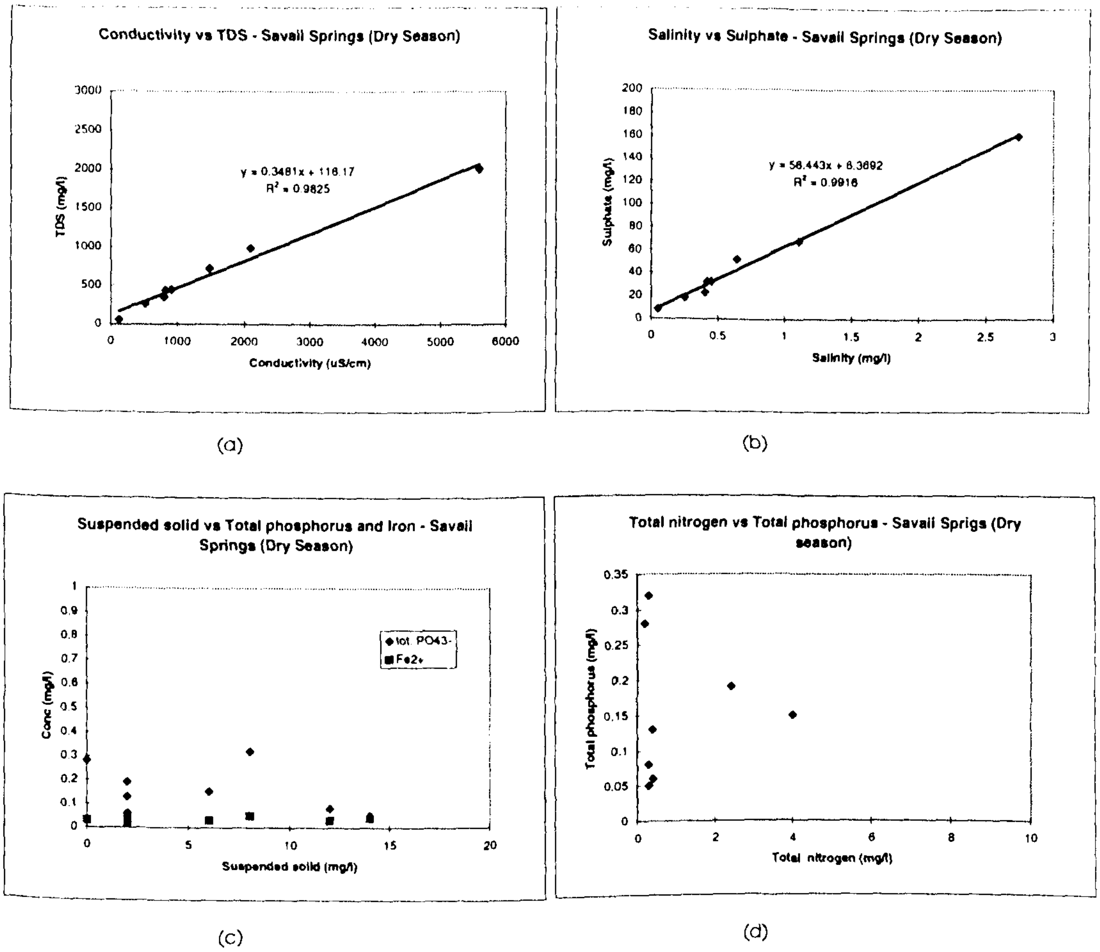

FIGURE 3.10: Correlation between some Water Quality parameters of Savaii Freshwater Springs in the Dry Season. Source: Author's research

Cumulative distribution curves given in Figure 3.11 showed that indeed all these parameters exhibited lower values in the wet season. This is most probably due to the effect of groundwater recharge from rainfall and surface runoff during the wet season (United Nations 1983). It is notable that in both seasons, the total phosphorus concentration in Savaii freshwater springs was comparable. The surface streams had elevated total phosphorus readings, but the concentration of total phosphorus from spring waters was even higher. No iron content was recorded in any of the freshwater pools in the wet season, so that the comment by Kear *et al.* (1979) that iron may be a problem in groundwaters of Savaii was not substantiated.

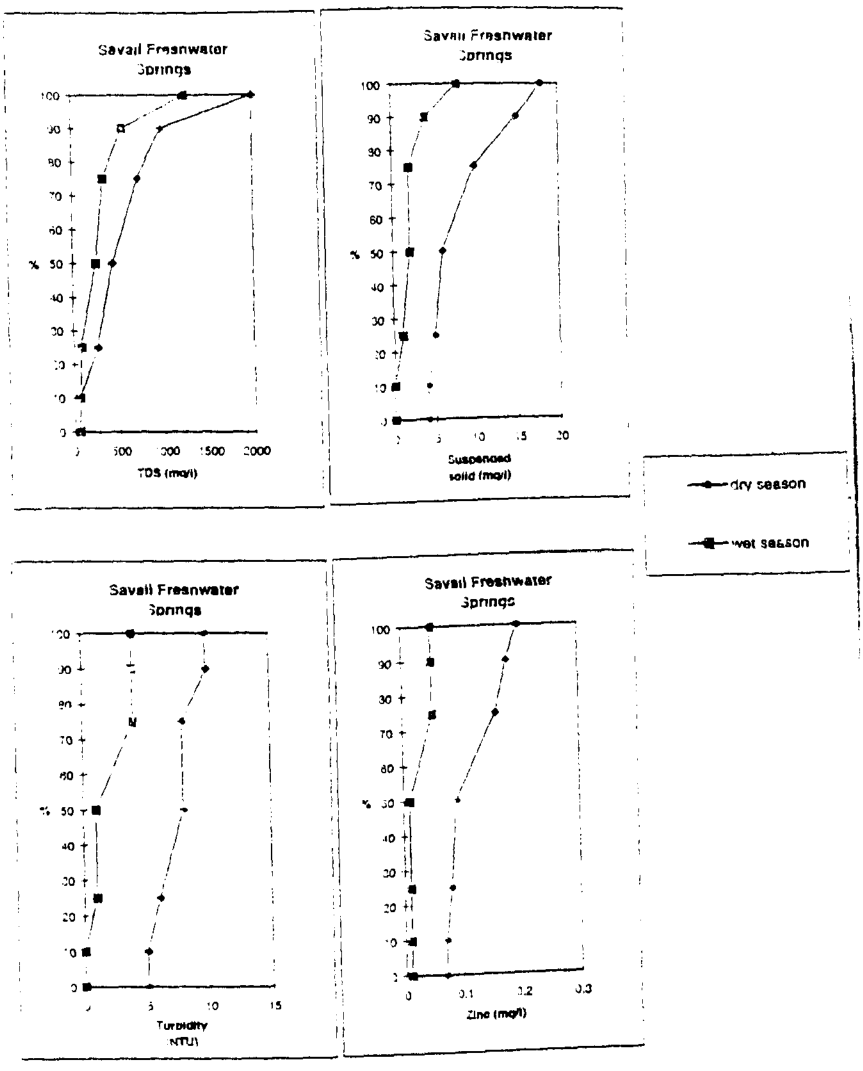

FIGURE 3.11: Cumulative Frequency Curves of TDS, Suspended Solids, Turbidity and Zinc for Savaii Freshwater Springs. Source: Author's research

The average zinc concentration of 0.03 mg/l was similar to values in unpolluted waters of the world (Wetzel 1975). The average zinc value during the wet season was over four times lower than for the dry season. This lower value is evident in Figure 3.10(d), and like salinity, conductivity and TDS concentrations, this is probably a dilution effect from groundwater recharge from rainfall and surface runoff in the wet season.

A spatial variation in the freshwater springs of Savaii appeared to exist between pools in south Savaii and the rest of the freshwater pools sampled. The Mann-Whitney test was again used to test this assertion and the salinity, conductivity and sulphate of the two sets of springs were compared (Appendix 5.2). The null hypothesis that was tested was that both the northern and southern springs were from the same population. The null hypothesis was rejected at the 99% confidence level for the water quality parameters examined, indicating that Petesa and Vailupe pools in southern Savaii indeed displayed different water characteristics from the other freshwater pools. The reason for this difference may be either a climatic factor in response to rainfall distribution, or a geological one with the freshwater springs located on different geological formations (Section 2.2) or both. The relatively high rainfall and presence of surface streams in southern Savaii contribute to the recharge of these freshwater springs. Alternatively, the freshwater pools in southern Savaii may be located on an impermeable layer separating the freshwater lens from the saline water (UN 1983). For the majority of Savaii, the saline water intrusion is a problem in springs located too close to the coastline (ESCAP 1995) but the springs at Petesa and Vailupe were significantly fresher than the rest.

In conclusion, it has been found that the fresh water springs of Savaii have relatively cool waters with an average temperature of 24°C and pH values in the range 6.7 to 6.9 units. Salinity varies from pool to pool, depending on location and pool usage. Swimming pools have higher salinities at the 580ppm chloride, while the average value is around 240ppm chloride. Conductivity readings fluctuated between 1 500 and 2 000 uS/cm between the two seasons. The TDS average is about 500 mg/l, while an average turbidity reading of 1.5 NTU is acceptable for WHO standards. Total phosphorus levels can be as much as three times the world average, and this is due to human activities. The freshwater springs of Savaii are not contaminated with sulphate, nitrogen, iron or zinc.

A comparison of the perennial streams to the freshwater springs of Savaii revealed significant differences in salinity, conductivity, TDS and sulphate concentrations, where the freshwater springs displayed higher concentrations (Table 3.6 and Table 3.7). The sea water contamination of the freshwater springs, especially those near the coast, is paramount to this difference. Total phosphorus was also noted to have a higher concentration in the freshwater springs, and is probably an indication of pollution in the form of polyphosphates from swimming and washing activities picked up by the sampling exercise (UNESCO/WHO 1978). Polyphosphates are important raw material in manufacturing of synthetic detergent household laundry powders, which may account for up to 25% of elevated phosphorus in water (Davidsohn and Milwidsky 1972; Autralian Independent Assistance Commission 1977). The rest of the phosphorus is thought to be from fertiliser and human excrements as Wright (1963) noted that phosphorus might be in short supply in the soils of Samoa.

3.4 UPOLU PERENNIAL STREAMS

All the data collected for Upolu perennial streams in the dry season are given in Appendix 4.2. Due to the amount of samples examined in Upolu, the data is discussed according to regions given in Table 3.3. The physical water parameters the perennial streams of Upolu is separated into regions and given in Table 3.9. Reference is made to the overall result of the perennial streams of Upolu throughout the discussion.

3.4.1 The Dry Season

Table 3.8 indicates that the overall average water temperature in the dry season was just over 27°C, with only the Fagaloa Bay streams registering a higher average value than this. The mean pH value was a slightly acidic value of 6.6. Average salinity values for Fagaloa Bay and NorthWest Upolu were higher than the overall mean salinity level of 0.05 mg/l. The overall mean conductivity value of 114 uS/cm was surpassed by the average readings of this parameter at NorthEast Upolu and Fagaloa Bay. Suspended solids and TDS mean values were low (Table 3.11). While the overall mean turbidity reading of 2.5 NTU for all the perennial streams was within the WHO standard, the perennial streams of North East Upolu had very turbid waters due to excessive turbidity levels at Namo, Lepa and Falefa (Appendix 4.2). These rivers were flowing at their peaks at the time of sampling. River discharges averaged 0.47 m^3/s, although the mini streams at Fagaloa Bay were found to be just flowing.

TABLE 3.8: Regional Average Water Quality Parameters for Upolu Perennial Streams in the Dry Season. Source: Author's research

	REGION						
WATER QUALITY PARAMETER	NE Upolu	Aleipata	Fagaloa Bay	NW Upolu	Lefaga	South Upolu	UPOLU MEAN
Discharge (m^3/s)	1.59	0.58	0.09	0.12	0.14	0.43	0.47
Temperature (°C)	25.2	26.1	29	26	26.3	25.4	27.3
PH	6.7	6.5	6.6	6.8	6.9	6.7	6.6
Salinity (mg/l)	0.05	0.02	0.06	0.07	0.04	0.04	0.05
Conductivity (uS/cm)	123	66	133	86	106	101	114
TDS (mg/l)	58	29	58	60	53	48	52
Suspended solids (mg/l)	3.2	7.9	1.0	1.0	0	0.2	1.2
Turbidity (NTU)	8.3	3.4	1.3	1.0	1.0	0.4	2.5
Iron (mg/l)	0.007	0.01	0.01	0.01	0.006	0.014	0.009
Sulphate (mg/l)	4.7	3.4	1.8	0	2.3	1.0	2.4
Total nitrogen (mg/l)	4.0	2.1	3.8	1.2	1.4	2.6	2.9
Total phosphorus) (mg/l)	0.09	0.06	0.21	0.14	0.05	0.24	0.17
Zinc (mg/l)	0.06	0.03	0.03	0.04	0.07	0.04	0.03

It is also seen from Table 3.8 that the Fe^{++}, $SO_4^{=}$ and total nitrogen average values were low, and fell within the limits of unpolluted waters given by Wetzel (1975). Although the total phosphorus average value of 0.17 mg/l was calculated, low values were recorded in some streams in parts of Upolu (Appendix 4.2). Salesatele Stream in southern Upolu had the highest value of both total phosphorus at 0.9 mg/l and total nitrogen at 16 mg/l. Some agricultural discharges from the plantation lands in the interior mountains must have found their way into the streams to give rise to these elevated readings. The streams of Fagaloa Bay and southern Upolu appeared to contain considerably more phophorus than the rest of the island. The mean zinc concentration value of 0.03 mg/l was surpassed by the zinc averages at NE Upolu and Lefaga regions.

Several correlations between water quality parameters of Upolu perennial streams are given in Figure 3.12.

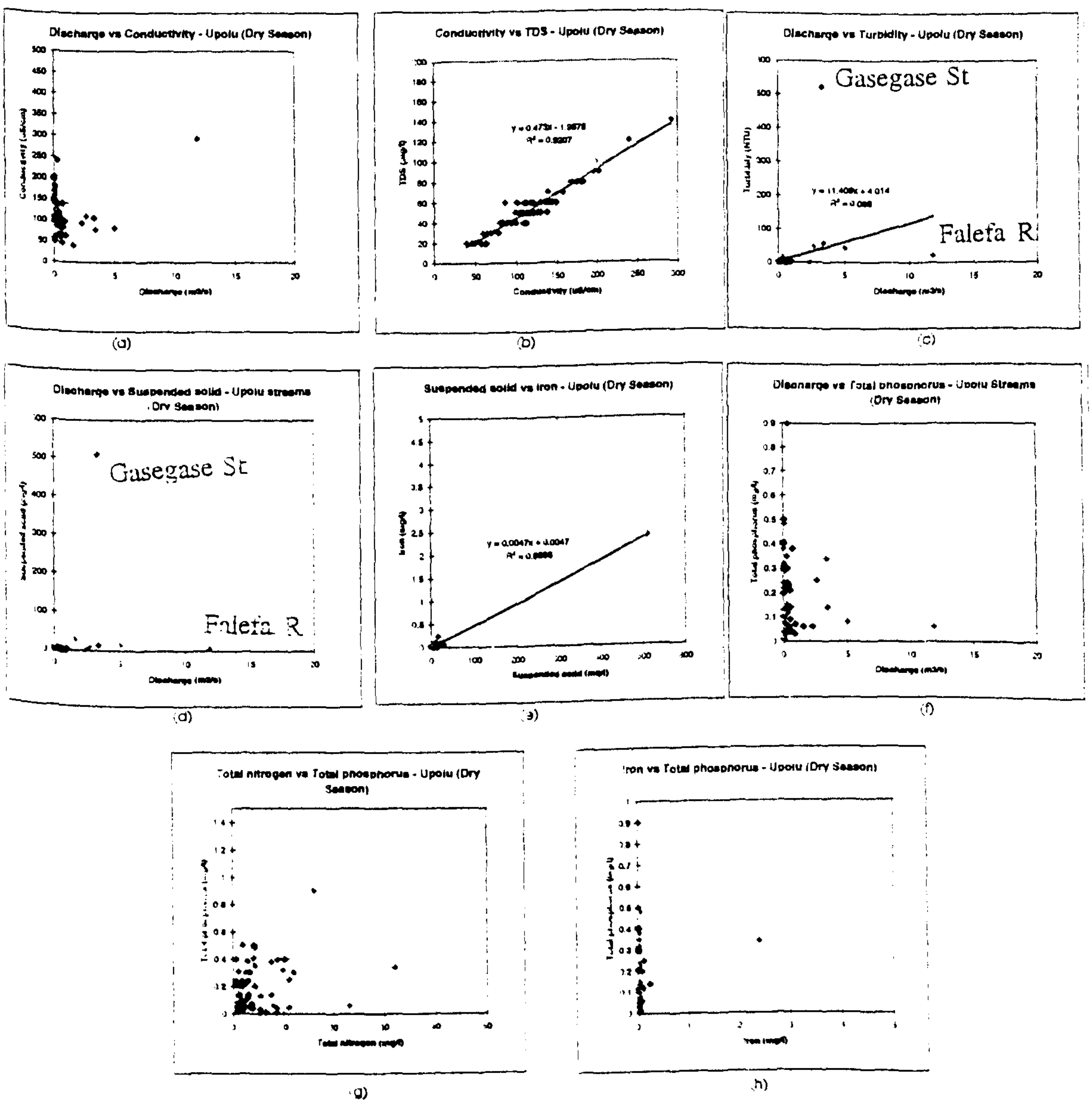

FIGURE 3.12: Correlations between Some Water Quality Parameters of Upolu Perennial Streams. Source: Author's research

Unlike the distinct relationship found between discharge and conductivity for Savaii, an inconclusive relationship was found for Upolu [Figure 3.12(a)]. The reason was unclear. Upolu conductivity values increased proportionately with TDS, as was the case for Savaii [Figure 3.12(b)]. Although not statistically significant, turbidity values increased with discharge [Figure 3.12(c)]. The two anomalous readings noted in Figure 3.12(c) occurred at Gasegase Stream in Apia suggesting urban influence, and from Falefa River in North East Upolu probably reflecting a less disturbed catchment area in the mountains. No correlation existed between discharge and suspended solid concentrations [Figure 3.12(d)], but again the Gasegase and Falefa waters were plotted as outliers to the general trend. There appeared to be a direct correlation between iron and suspended solids in the perennial streams of Upolu as depicted in Figure 3.12(e), indicating perhaps that iron has been transported adsorbed onto the sediments. It can be seen from Figure 3.12(f) that phosphorus occurred independently of discharge, and iron and phosphorus occurred independently of one another [Figure 3.12(h)]. In Figure 3.12(g), total nitrogen and total phosphorus were found to be independent of each other.

In looking for spatial trends in the perennial streams of Upolu, regional cumulative distribution curves for selected water quality parameters were drawn, as shown in Figure 3.13. The regional distribution curves for salinity and conductivity, given in Figure 3.13(a) and Figure 3.13(b) respectively, showed that Aleipata and south Upolu streams tended to have lower values for these two parameters than the rest of Upolu. Further, NorthEast Upolu and Fagaloa Bay streams both displayed rather irregular distribution patterns, with anomalous readings conspicuously evident at the higher end of the scale. The regional cumulative distribution curves of suspended solid [Figure 3.13(c)] and turbidity [Figure 3.13(d)] showed that these two parameters were comparable throughout Upolu, with the exception of the anomalous reading from Gasegase Stream in Apia (Appendix 4.2).

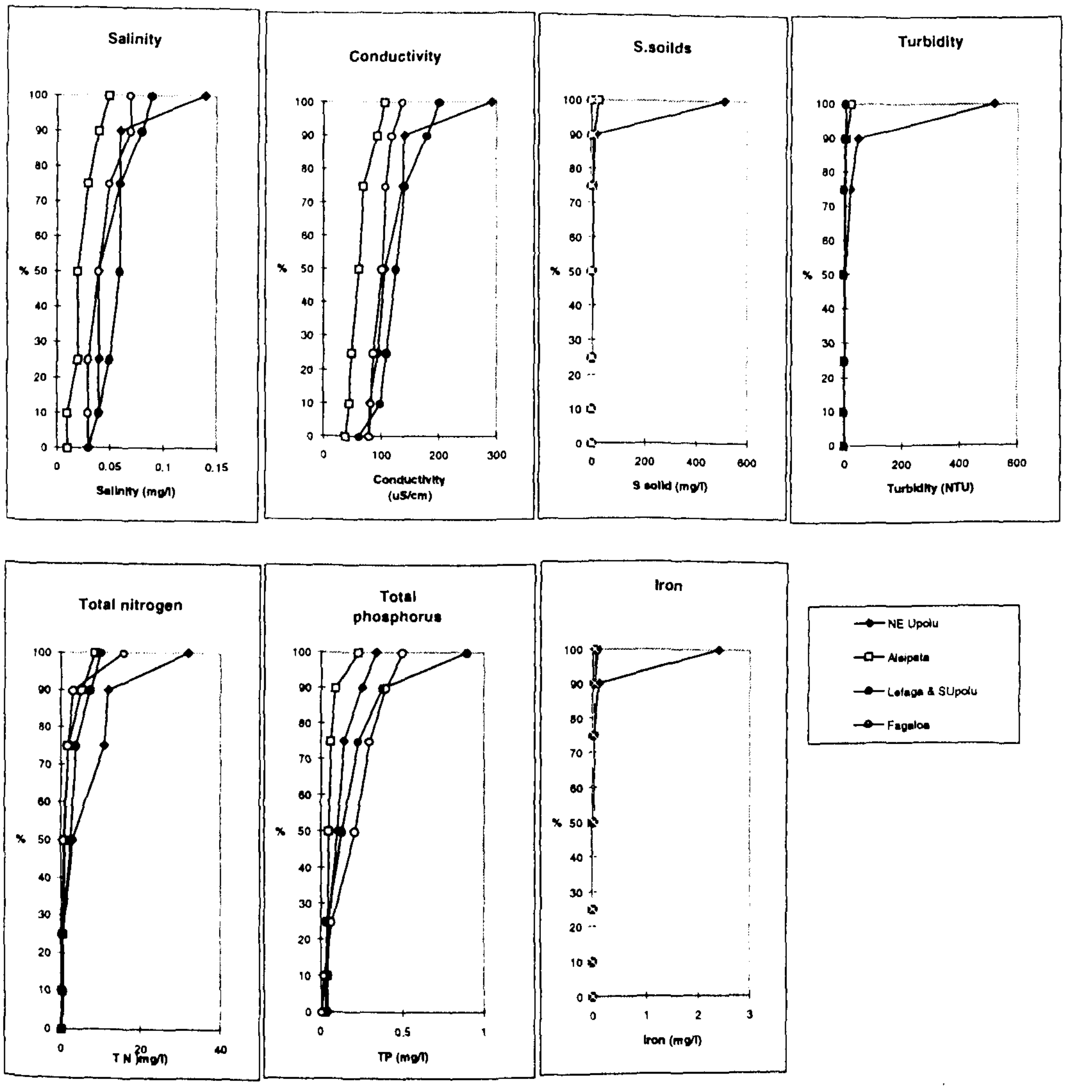

FIGURE 3.13: Regional Cumulative Distribution Curves for Selected Water Quality Parameters of Upolu Perennial Streams. Source: Author's research

From these observations, it seemed that the streams of Aleipata and South Upolu exhibited different salinity and conductivity characteristics from the rest of the Upolu perennial streams. This is most probably a climatic effect. As noted in Section 3.1.1 the dominant weather patterns of Samoa provided the eastern and southern parts of the country with more rain, so that the lower salinity and conductivity of the Aleipata and southern Upolu streams may be one of dilution.

The results of the ephemeral water pools of Upolu were very similar to those of the perennial streams (Appendix 4.2), with only the water from Samusu showing higher values for salinity, electrical conductivity and TDS, probably due to evaporation factors.

NorthEast Upolu and Fagaloa Bay waters gave higher total nitrogen values than the other regions of Upolu [Figure 3.13(e)]. Specific anthropogenic activities such as the proximity of latrines to waterways (Plate 3.5) and allowing pigs and chicken to roam the villages freely in these areas increases the probability of nutrients entering the Fagaloa Bay waters.

PLATE 3.5: Salesatele Stream in the Fagaloa Bay area. The latrine is just a few meters from the stream channel. Photograph by author

Figure 3.13(f) attests to the higher total phosphorus averages recorded at Fagaloa Bay and South Upolu, where about 50% of the Fagaloa Bay streams had total phosphorus concentrations of more than 0.2 mg/l. The same percentage of South Upolu streams had total phosphorus concentrations of more than 0.1 mg/l. The streams of NorthEast Upolu also showed high levels of total phosphorus. Iron distribution was seen to be uniform around Upolu streams except for the elevated value at Gasegase Stream, Apia [Figure 3.13(g)].

3.4.2 The Wet Season

The data collected for the Upolu streams in the wet season is given in Appendix 4.2 Changes to the physical characteristics of some streams were observed that were not evident during the dry season. Six streams at Aleipata that had water in the dry season were dry in the wet season. This was visibly pronounced at Lepa River (Plate 3.6). Vaivase Stream did not carry water in the dry season, but flowed freely in the wet season. Despite these seven anomalies, Table 3.9 gives the water quality parameters for Upolu perennial streams in the wet season.

TABLE 3.9: Regional Average Water Quality Parameters for Upolu Perennial Streams in the Wet Season. Source: Author's research

WATER QUALITY PARAMETER	REGION						
	NE Upolu	Aleipata	Fagaloa Bay	NW Upolu	Lefaga	South Upolu	UPOLU MEAN
Discharge (m^3/s)	0.66	0.42	0.11	0.68	0.82	0.94	0.38
Temperature (°C)	25	26	29	27	28	27	28
PH	6.8	6.8	6.8	6.9	6.9	6.9	6.8
Salinity (mg/l)	0.04	0.11	0.07	0.05	0.05	0.05	0.06
Conductivity (uS/cm)	101	230	143	87	105	115	138
TDS (mg/l)	34	78	38	30	33	35	40
Suspended solids (mg/l)	3.3	1.5	2.2	2.0	1.0	1.2	2.1
Turbidity (NTU)	1.2	0.8	1.0	1.0	0.0	0.2	0.9
Iron (mg/l)	0	0	0.006	0.01	0.003	0.002	0.004
Sulphate (mg/l)	0.54	3.0	2.6	2.0	0	0.1	1.8
Total nitrogen (mg/l)	0.58	0.23	1.7	0.5	0.77	4.1	1.7
Total phosphorus (mg/l)	0.09	0.09	0.12	0.06	0.14	0.12	0.11
Zinc (mg/l)	0.05	0.04	0.03	0.05	0.06	0.05	0.04

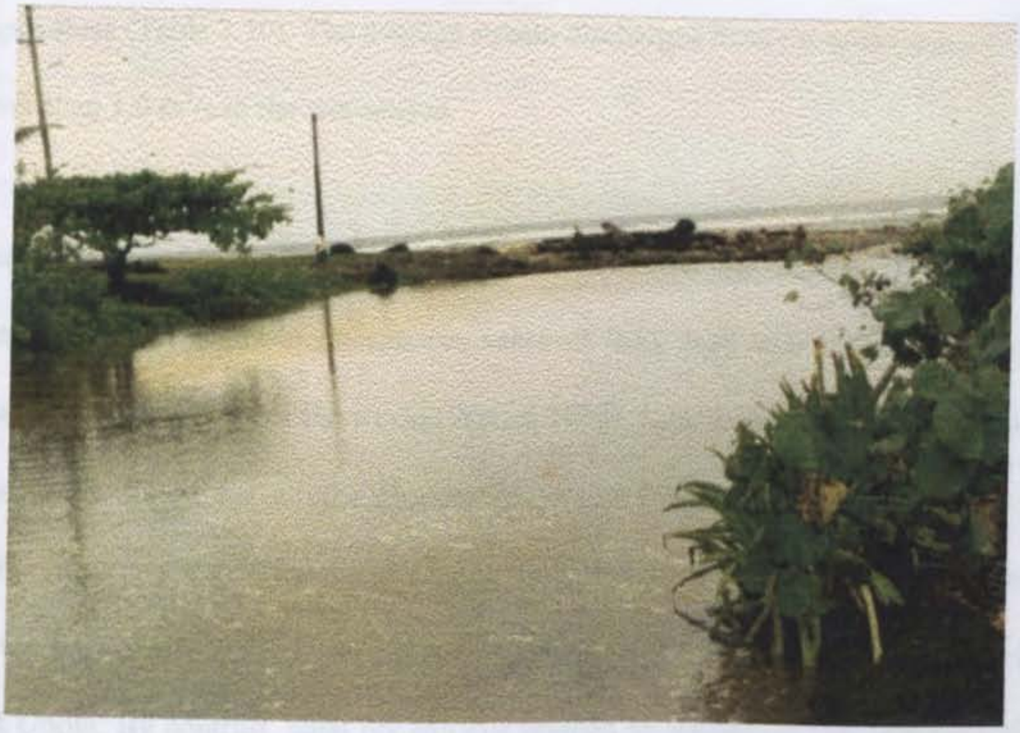

Plate 3.6: Lepa River, Aleipata. The river flowed in the dry season (top). It was found dry in the wet season (bottom). Photograph by author

The water temperature of the Upolu perennial streams in the wet season fluctuated around 28°C. The waters also had near neutral pH values, low salinities, low electrical conductivities and low TDS average concentrations. Suspended solids and turbidity readings recorded low average values (Table 3.10). The average stream discharges from the areas around Upolu were all lower than 1.0 m^3/s in the wet season.

Chemical analyses for the Upolu perennial streams in the wet season, shown in Table 3.9, revealed that only the mean phosphorus value of 0.11 mg/l was higher than the level for unpolluted surface waters of the world (Wetzel 1975). Low average values of all the chemical analyses were found for all the streams of Upolu (Table 3.9). Iron occurred in almost negligible amounts in all regions of Upolu. Sulphate and total nitrogen both gave average concentrations of less than 2.0 mg/l and elevated readings appeared to be occurring at random around Upolu. By contrast, total phosphorus seemed to display uniform concentrations in all regions of Upolu (Table 3.9). It is suggested that there is a problem with the representativeness of the samples in both time and space (Section 3.1.2) which is producing inexplicable results.

3.4.3 Comparison Between Upolu Perennial Streams in the Dry and Wet Seasons

The comparison between the perennial streams of Upolu in the two seasons was again made by reference to the means of the physical water parameters and chemical analyses. Further, the coefficient of variation (CV) has been adopted as a measure of the dispersion, because its unitless nature allows for ready comparison between and across the variables (Griffin 1962; Gregory and Walling 1965). The CV is defined as the quotient of the standard deviation and the mean. Table 3.10 depicts the mean and CV values for each water quality parameter measured for Upolu perennial streams in both the wet and dry seasons. From Table 3.10, it can be seen that stream discharges exhibited comparatively high CVs in both seasons. This probably indicates the importance of catchment shape and stream channel characteristics on the streamflow of the perennial streams of Upolu (Gregory and Walling 1965).

TABLE 3.10: Average Water Quality Parameters for Up olu Perennial Streams in the Dry and Wet Seasons. Source: Author's research

WATER QUALITY PARAMETER	DRY SEASON		WET SEASON	
	Mean	CV	Mean	CV
Discharge (m^3/s)	0.45	2.7498	0.38	2.2281
Temperature (°C)	27.3	0.0859	27.9	0.0692
PH	6.6	0.0295	6.9	0.0243
Salinity (mg/l)	0.05	0.4261	0.06	0.8958
Conductivity (uS/cm)	115	0.3651	138	0.7272
Total dissolved solids (mg/l)	52	0.3947	41	0.6291
Suspended solids (mg/l)	1.78	6.7338	2.08	1.1501
Turbidity (NTU)	2.56	5.6943	0.87	1.7369
Iron (mg/l)	0.009	6.0615	0.004	3.4439
Sulphate (mg/l)	2.44	1.2801	1.84	2.7604
Total nitrogen (mg/l)	2.94	1.3812	1.7	1.9708
Total phosphorus) (mg/l)	0.17	0.9222	0.11	0.8128
Zinc (mg/l)	0.04	0.7407	0.04	0.4736

The temperature and the pH values of the Upolu perennial streams remained fairly constant at around 27°C and 6.8 respectively between the seasons. These two parameters showed the lowest vaiabilities of all the parameters in both seasons, reflecting their independence on environmental and landuse factors. The salinity and TDS readings were also deemed comparable for both seasons and gave moderate CVs, although the CV for the wet season was twice that for the dry season for both parameters.

Conductivity, suspended solids and turbidity appeared to display differences in their average concentrations in the two seasons. However, the cumulative distribution curves of these parameters showed otherwise (Figure 3.14). The cumulative frequency curves showed that for the three parameters, their distributions were identical, with the exception of anomalous elevated readings [Figures 3.14(a), 3.14(b), 3.14(c)]. Ignoring the excessive readings, the conductivity, suspended solids and turbidity values of Upolu perennial streams were comparable in both seasons. Suspended solids and turbidity displayed high CVs, due to their dependence on intensity and duration of storm events (Gregory and Walling 1965), and land use factors such as logging and catchment degradation. Turbidity values and river discharges both recorded higher readings in the dry season as most streams were flowing at their peaks at the time of sampling.

Table 3.10 also shows that sulphate, total nitrogen and total phosphorus gave lower average values in the wet season than the dry season. Cumulative distribution curves for these parameters in the dry and wet seasons showed that this apparent shift of sulphate concentrations to lower values in the wet season was not always evident (Figure 3.14).

According to Figure 3.14(d), lower sulphate values in the wet season occurred 75% of the time. The shift to lower values of total phosphorus in the wet season was only noticeable when concentrations of more than 0.10 mg/l were recorded [Figure 3.14(e)]. Lower total phosphorus concentrations were comparable in the two seasons, and this occurred about 50% of the time. The average total nitrogen concentration decreased by half in the wet season, mainly due to the seasonal differences in nitrogen contents of NorthEast Upolu and Aleipata areas between the seasons (Appendix 4.2). The cumulative distribution curve of total nitrogen for Upolu streams, however, gave a very similar trend to that of total phosphorus. Seasonal total nitrogen values were comparable for almost 90% of the time, but shifted to lower values in the wet season, when concentrations of more than 4.0 mg/l were recorded in the streams of Upolu [Figure 3.14(f)].

Iron concentrations in the dry season were about half the equivalent values in the wet season. During the wet season, no iron was found in the NorthEast Upolu region, and minimal iron contents were found in the Aleipata area (Table 3.8 and Table 3.9). This observation is reflected in the high CVs exhibited by iron in both seasons, indicating the high varability of iron in the waters of Upolu. This variability of iron values seemed to coincide with variable discharges, suspended solids and to a lesser extent total phosphorus concentrations.

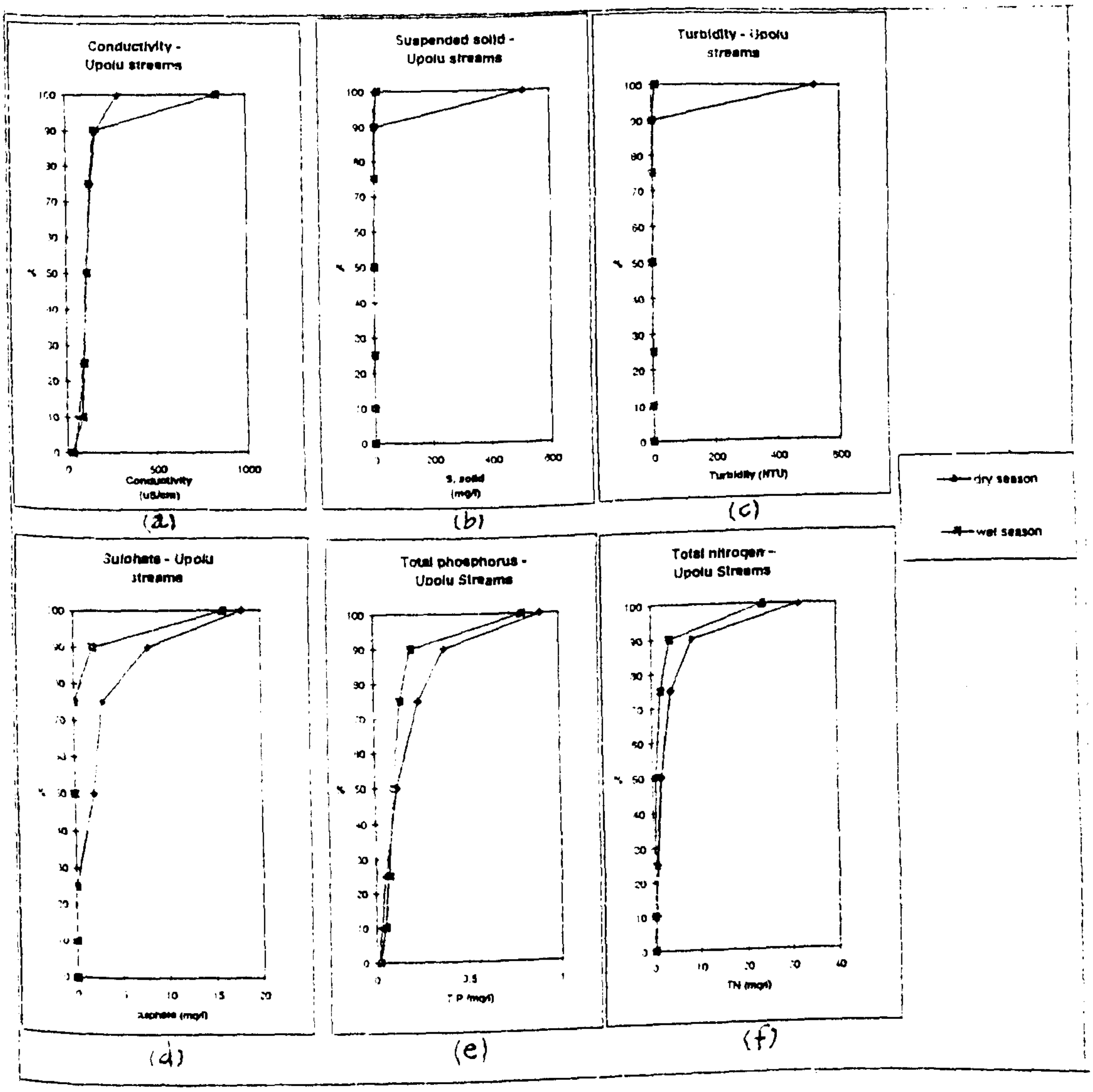

FIGURE 3.14: Cumulative Distribution Curves of Selected Water Quality Parameters for Upolu Perennial Streams. Source: Author's research

These findings suggested that the apparent difference in the water quality of Upolu perennial streams between the seasons was not statistically significant. Reference has already been made to the contribution of urban streams to elevated water quality readings in Upolu. But how significant are the differences between the rural and urban perennial streams of the island? From Figure 3.12, it is seen that some of the anomalous readings in turbidity, suspended solids, total nitrogen and total phosphorus in the perennial streams of Upolu were recorded in the urban streams of Gasegase and Mulivai. To compare the urban and rural streams, the Mann-Whitney test was again applied to some selected water quality parameters. The null hypothesis tested was that the parameters from the rural and urban streams were from the same population. The urban streams were identified as the Fuluasou, Gasegase, Mulivai and Vaisigano rivers. The water temperature and pH values gave minimal variabilities and were not used. Conductivity was selected to represent TDS as these two are closely related (Hownslow 1995). The results of the Mann-Whitney test applied to conductivity, suspended solids, turbidity, iron, total nitrogen and total phosphorus in both seasons are shown in Appendix 5.3. For all these parameters, the null hypothesis was rejected at the 99% confidence level, concluding that the four streams flowing through the urban area displayed quite different characteristics from the rural streams of Upolu.

In summary, the perennial streams of Upolu have water temperatures around 27^{o}C, and near neutral pH values averaging 6.8 units. Salinity and conductivity values were found to be around 0.05 to 0.06 mg/l and 100 to 150 uS/cm respectively. Turbidity and suspended solids values varied according to the streamflow. On average, 2.5 NTU and 2.0 mg/l values for turbidity and suspended solids occurred. The average total phosphorus concentration is about 0.09 mg/l. The Upolu perennial streams are not polluted with nitrogen, where average concentrations in the range 1.0 to 3.0 mg/l are common. Sulphate average values are also minimal at around 4 mg/l, far below the maximum permissible value of 500 mg/l. Iron concentrations are very low averaging around 0.01mg/l. Zinc values are similarly low, averaging between 0.03 to 0.04 mg/l. Like the perennial streams of Savaii, the water quality of the Upolu perennial streams is quite clean, except when the streams are subjected to human influences in the immediate vicinity of the streams.

3.5 UPOLU FRESHWATER SPRINGS

Of the springs that are discussed in this section, Vavau, Vini and Salimu were used for drinking, the springs at Piula, Afega and Tuanai were used exclusively for swimming, and the rest of the pools served the dual purpose of supply for drinking and swimming. The springs at Pesega, Tufuiopa and Vini were located inland in the Apia area, and the Vavau and Salimu springs were also several hundred meters from the coast. The results of all the sampling of freshwater springs are given in Appendix 4.2 Table 3.11 gives the average water quality parameters for the Upolu freshwater springs in the dry and wet seasons along with their respective CVs.

3.5.1 The Values Obtained

The Upolu springs had an average water temperature in the dry season around 27^{O}C, while pH values averaged 6.6 units. As was the case with the perennial streams of Upolu, these two parameters again displayed the lowest variabilities. Spring salinities ranged from 0.98 mg/l at Afega to 0.06 mg/l at Salimu, and the fairly high CV indicates the dependence of salinity on location, geology and landuse factors. Average conductivity and TDS values were 630 uS/cm and 401 mg/l respectively (Table 3.11) and all the springs recorded low turbidity values.

TABLE 3.11: Average Water Quality Parameters of the Upolu Freshwater Springs in the Dry and Wet Seasons. Source: Author's research

WATER QUALITY PARAMETER	DRY SEASON		WET SEASON	
	Mean	CV	Mean	CV
Temperature (°C)	26.8	0.0498	26.3	0.0372
PH	6.7	0.0256	6.7	0.0128
Salinity (mg/l)	0.32	1.0274	0.15	0.8607
Conductivity (uS/cm)	630	0.9683	322	0.7206
Total dissolved solids (mg/l)	402	1.3557	112	0.9904
Suspended solids (mg/l)	0.45	1.7204	0.54	1.2139
Turbidity (NTU)	0.36	1.7677	0.2	2.2836
Iron (mg/l)	0.003	2.4238	0.001	2.8747
Sulphate (mg/l)	23	1.9938	15	2.7962
Total nitrogen (mg/l)	12	0.9747	11	0.9976
Total phosphorus) (mg/l)	0.12	0.9796	0.11	0.4427
Zinc (mg/l)	0.03	0.7944	0.05	0.4824

Total phosphorus concentrations averaged 0.12 mg/l, with Tufuiopa Pool registering the maximum amount of 0.4 mg/l. Total nitrogen values averaged 12 mg/l and Tufuiopa pool also had the highest total nitrogen value of 40 mg/l. The elevated readings from Tufuiopa pool suggest human influence due to its location in central Apia. Only four pools registered the presence of sulphate ions, with the highest value at Afega pool (Appendix 4.2). With the exception of the low values found at Vailoa2 and Tufuiopa pools, there was a virtual absence of iron in the freshwater springs of Upolu. However, the large CV of iron values suggested the high variability of the distribution of iron in the freshwater springs of Upolu. Average zinc values were also low at 0.03 mg/l.

During the wet season, the mean temperature of the Upolu freshwater springs was around 26°C, and mean pH value was 6.7, with the two water parameters maintaining the lowest variabilities (Table 3.11). The variation due to location of the freshwater springs is again reflected in the salinity values, which ranged between 0.45 mg/l at Vailoa1 to 0.04 mg/l at Vini Pool. The mean conductivity value was found to be 322 uS/cm, and the average TDS value was 112 mg/l. Little turbidity and suspended solids concentrations were observed in the freshwater springs of Upolu in the wet season. Piula Pool (Plate 3.4) recorded the highest total phosphorus concentration of 0.25 mg/l, which may indicate the effects of swimming activities. The calculated average value for total phosphorus was 0.11 mg/l. Areas with higher phosphorus values are Fagaloa Bay, Apia Urban and south Upolu. Spatial differences in the freshwater springs of Upolu can be accounted for by reference to factors such as surrounding land uses, location from the coast and the characteristics of the surrounding environment. Although the total nitrogen average was low at just under 11 mg/l, Tufuiopa pool continued to contain the highest nitrogen value. Sulphate values averaged 14.8 mg/l. Iron concentrations continued to be conspicuously absent from the pool waters (Appendix 4.2). A mean zinc value of 0.05 mg/l was found.

An attempt was made to explain the differences in water quality values of the springs in Upolu. Table 3.12 shows that those springs exclusive to swimming gave higher values for salinity, conductivity, TDS, sulphate and total phosphorus than those reserved for drinking. Total nitrogen, iron and zinc averages seemed to occur independently of pool usage. The pools used for both drinking and swimming had intermediate concentrations of these water parameters, although a high total nitrogen average was recorded, due mostly to the contribution of total nitrogen from the urban springs Tufuiopa and Pesega.

TABLE 3.12: Average Water Quality Values of Upolu Freshwater Springs According to Land Use, Location and Environment. Source: Author's research

	salinity	conductivity	TDS	Sulphate	TN	TP	iron	zinc
Swimming pools	0.81	1516	1073	74	6.2	0.18	0	0.03
Drinking pools	0.07	162	76	0	4.9	0.04	0	0.04
Dual purpose	0.18	380	194	6	19	0.14	0.008	0.03
Coastal springs	0.52	1003	663	41	8.5	0.14	0.001	0.03
Inland springs	0.08	184	88	0.2	16	0.11	0.006	0.03
Urban springs	0.09	200	96	0.3	25	0.16	0.01	0.05
Rural springs	0.41	791	516	31	6.5	0.11	0.001	0.02

A comparison of the coastal and inland springs (Table 3.12) showed that the coastal springs had higher concentrations of salinity, conductivity, TDS and sulphate than their inland counterparts. Saltwater intrusion close to the coast was held responsible for this observation (UN 1983). While average concentrations of total phosphorus, iron, and zinc were comparable between coastal and inland springs, the two-fold increase of total nitrogen in the inland waters is attributed to the proximity of those springs to the Apia urban area. It is perhaps the sulphate and total nitrogen concentrations that clearly distinguish urban from rural springs. The urban springs displayed a total nitrogen concentration almost five times more than the rural springs. The rural springs on the other hand had a sulphate reading over 100 times than that of the urban springs. The fact that almost all of the rural springs are located near the coast is probably the reason for this latter observation. It is also noted from Table 3.12 that the drinking pools and the inland freshwater springs gave very similar water qualities, and resemble those of the perennial streams of Upolu (Table 3.10).

From Table 3.11, it is observed that the average temperature and pH values were comparable in both seasons, both in their numerical values and in their variabilities. There was a marked lowering of the salinity average value from the dry to wet season. This was largely a function of the lower salinity levels of the Tuanai, Afega, and Piula pools in the wet season, and is most probably a result of groundwater recharge from runoff and precipitation in the wet season. Further, these pools are located close to the sea and well within the tidal fluctuation zone. The lower concentrations of TDS and conductivity in the wet season are shown in Table 3.11. Cumulative distribution curves for TDS and conductivity given in Figure 3.15 showed that the apparent lower values in the wet season were not uniform. For all the three water parameters analysed, the shift to lower concentrations in the wet season occurred for only about 50% of the time. Lower concentrations occurred in the wet season for values of more than 0.10 mg/l salinity, 200 uS/cm conductivity and 60 mg/l TDS.

Iron concentrations were seasonally comparable and continued to be the most variable of all the parameters in both seasons. Although sulphate recorded a lower numerical average in the wet season, it had a higher variability index, which coincided with correspondingly high turbidity variability (Table 3.11). This suggests a possible contamination effect from the groundwater recharge of the freshwater springs in the wet season. Total nitrogen, total phosphorus and zinc average values were deemed comparable in both seasons.

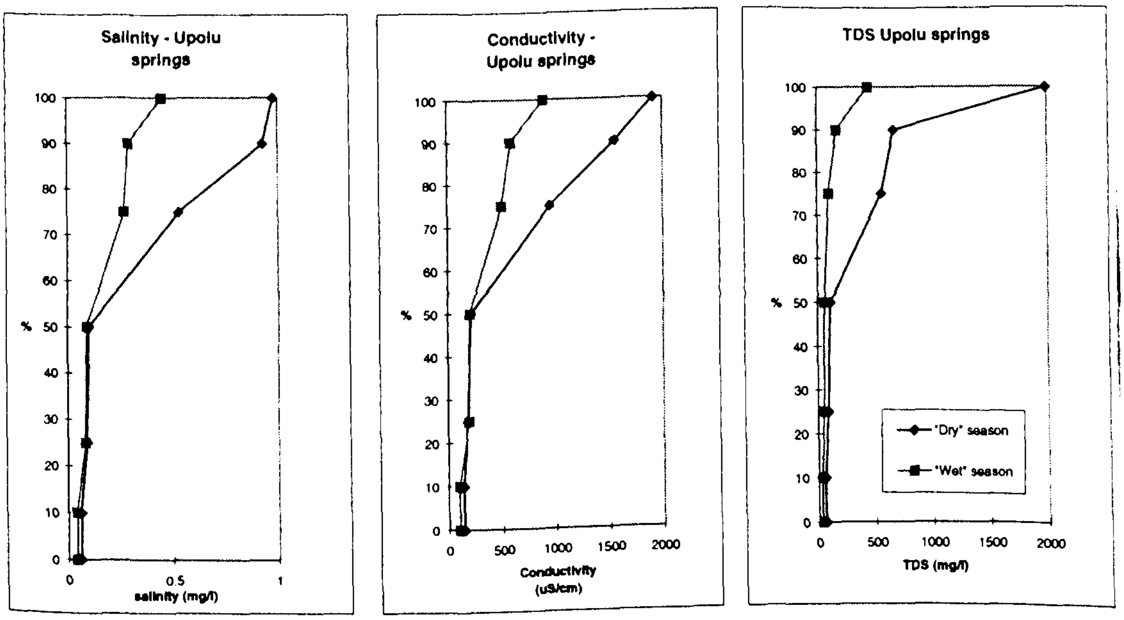

FIGURE 3.15: Cumulative Frequency Curves of Salinity, Conductivity and TDS of Upolu Freshwater Springs. Source: Author's research

The water quality characteristics of the freshwater springs of Upolu can now be summarized. The freshwater springs of Upolu have an average temperature of 26°C. pH values are in the neutral range between 6.6 and 6.7. Average salinity values are about 50ppm chloride, although values vary according to spring location. Inland springs like Vini recorded salinity as low as 10ppm chloride. Most freshwater springs have low turbidity and suspended solid material, with mean values of less than 1.0 NTU and less than 1.0 mg/l respectively. The pools have moderately high concentrations of total phosphorus at around 0.11 mg/l which is about three times the world average for unpolluted waters. It is suspected that this is perhaps due to groundwater contamination. Average total nitrogen values are low at around 12 mg/l. There is a tendency for higher nutrient values to occur in the urban springs of Upolu. Sulphate concentrations vary from 15 to 23 mg/l between seasons, with higher concentrations in the coastal springs. Iron values are minimal and usually not detected. Zinc concentration ranged from 0.03mg/l to 0.05mg/l. There are minimal seasonal differences in the concentrations of water quality parameters for most springs.

3.5.2 Comparison Between the Perennial Streams and Freshwater Springs of Upolu

A comparison between the surface waters (perennial streams) and freshwater springs of Upolu may be made by reference to Tables 3.10 and 3.11. It is clear from the two tables that both temperature and pH values were not only comparable but gave the lowest variabilities in both water types. Apart from these two, there seemed to be significant differences in the other water quality parameters of the perennial streams and freshwater springs of Upolu. Higher average concentrations of salinity, conductivity and TDS were observed in the freshwater springs due to the salt water intrusion of coastal springs. The cumulative frequency curve of conductivity distribution in the two water types in both seasons is given in Figure 3.16, where indeed lower conductivity values were recorded in the perennial streams in both seasons.

Seventy five percent of the freshwater springs of Upolu recorded conductivity values less than 900 uS/cm in the dry season and less than 500 uS/cm in the wet season. The same percentage of perennial streams of Upolu had values less than 150 uS/cm in both seasons. As salinity and TDS correlate strongly with conductivity (Hownslow 1995), the same argument can be extended to include the former parameters. The suspended solids and turbidity readings appeared to be higher in the perennial streams than freshwater springs in both seasons. However, the contribution by the urban stream Gasegase not only projected the averages to higher levels, but also gave high variability indices of the Upolu perennial streams. Otherwise, comparable values of suspended solids and turbidity were found in the two water types.

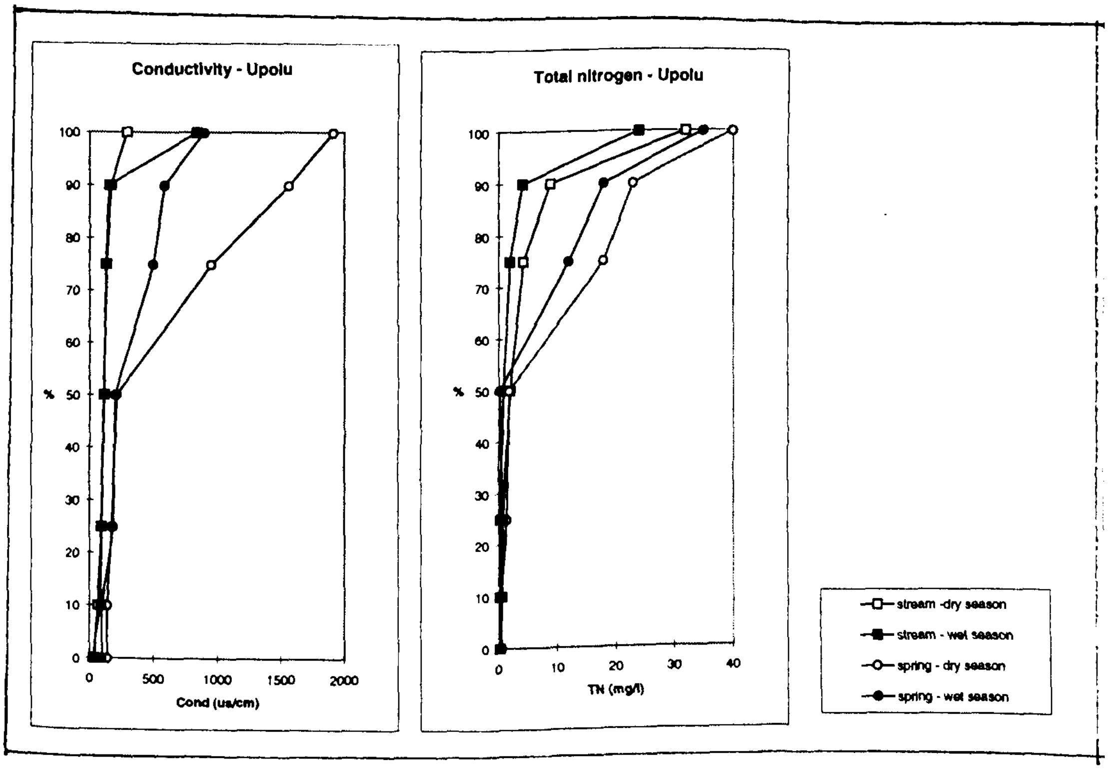

FIGURE 3.16: Cumulative Frequency Curves for Conductivity and Total Nitrogen of Upolu Streams and Springs in both Seasons. Source: Author's research

Iron, total phosphorus and zinc registered equivalent concentrations in the two types of water, while both sulphate and total nitrogen posted higher values in the freshwater springs. The cumulative frequency curve of total nitrogen in both types of water, given in Figure 3.14, showed that the shift to higher values in the freshwater springs were dominant only 50% of the time, at concentrations of more than 2.0 mg/l. The increase in total nitrogen values over 2.0 mg/l for the dry season is clearly evident in Figure 3.14. Freshwater springs exhibited much higher concentrations of total nitrogen than the perennial streams in both seasons, and the urban freshwater springs were thought to be instrumental to this cause. The higher sulphate values found in the freshwater springs are attributed to the effect of salt water, especially from the springs close to the coast.

3.6 UPOLU DRAINS

Three drains on Upolu were sampled in both the dry and wet seasons and the results are given in Appendix 42. The data reveals that the physical water parameters of Fugalei Drain are quite different from those of the other two. Elevated levels of salinity and conductivity were noted for the Fugalei Drain. It also contained higher total nitrogen values of 32 mg/l and 40 mg/l in the dry and wet seasons respectively. Fugalei is a much more polluted site than the other two, given its location in the Apia urban area.

3.7 INTER-ISLAND COMPARISON

A comparison between the seasonal characteristics of the perennial streams of Savaii and Upolu has already been done in Section 3.2.3 and Section 3.3.3 respectively. The discussion now shifts to an examination of the relationship between the water quality of the two islands Savaii and Upolu. The water quality status of Samoa is then put into perspective with those of other Pacific islands.

3.7.1 Comparison Between the Perennial Streams of Savaii and Upolu

The general water quality status for the perennial streams of both islands is summarized in Table 3.13. From the table it is evident that the water quality of Savaii and Upolu perennial streams is comparable in almost every aspect, except in their total nitrogen and total phosphorus values.

TABLE 3.13: Range of Water Quality Parameters for Savaii and Upolu Perennial Streams. Source: Author's research

WATER QUALITY PARAMETER	SAVAII	UPOLU
temp (^oC)	24 - 25	27 -28
pH	6.7 - 6.9	6.7 - 6.9
Salinity (mg/l)	0.04	0.05 - 0.06
Conductivity (uS/cm)	80 - 90	110 - 140
TDS (mg/l)	25 - 35	40 - 50
Suspended soild (mg/l)	3 - 10	2 - 3
Turbidity (NTU)	2 - 8	1 - 3
Iron (mg/l)	0 - 0.03	0 - 0.01
Sulphate (mg/l)	0 - 8	2 - 3
Total nitrogen (mg/l)	0.04 - 0.3	2 - 3
Total phosphorus (mg/l)	0.04 - 0.1	0.10 - 0.17
Zinc (mg/l)	0.03 - 0.13	0 - 0.04

The average phosphorus value of 0.14 mg/l for Upolu was just over 2.5 times higher than that of the Savaii average value of 0.048 mg/l. The areas contributing to the higher phosphorus and nitrogen concentrations in Upolu were the Fagaloa Bay area, South Upolu and NorthEast Upolu (Table 3.8). The sewage disposal problem at Fagaloa Bay has already been mentioned, as well as the frequent use of the rivers as washing places in southern Upolu. Further, the agricultural runoff from plantation lands to Salesatele and Sapunaoa streams and the contribution of urban pollutants to the Gasegase stream must not be ignored. While there are numerous ways of increasing phosphorus levels in surface runoff over and above background levels (Wetzel 1975), the most relevant to Samoa is probably urbanization. The 1991 Census of population of the country showed 45 000 people living in Savaii as compared to 116 000 on

Upolu, so that the 3:1 ratio of nutrient levels observed in the perennial streams of the two islands is perhaps more than coincidental.

3.7.2 Comparison Between the Freshwater Springs of Savaii and Upolu

This section compares the findings of Sections 3.3.3 and 3.5.3. A spatial variation was detected in the freshwater springs of Savaii, with the springs in southern Savaii displaying characteristics comparable to the perennial streams. In Upolu, a similar observation was noted where the water chemistry characteristics of both the inland springs and the drinking water pools were similar to surface streams. The similarity in the physical parameters of the freshwater springs to surface runoff was attributed to groundwater recharge where the springs are located close to areas of high rainfall and surface runoff (Section 3.3.3). Similar characteristics were seen in the coastal springs of both islands, where salinity, conductivity and TDS values were high. The salinity problem in the coastal springs of Samoa, as expressed by many author's (Cox 1960; Kear *et al.* 1979; UN 1983; ESCAP 1985), was highlighted in this study. High nutrient levels recorded in the urban freshwater springs evidenced the effect of urbanization on the freshwater springs of Upolu.

3.7.3 The Water Quality of Samoa Versus Other Pacific Islands

As seen in Table 3.2, limited data on water quality from the Pacific area was found in the literature, and was confined largely to the documentation of the water quality of streams from Fiji. Results of surface stream water quality from other parts of the region were restricted to grab samples that were analysed from streams for a specific purpose. The water quality of Samoa as discussed in this chapter may be compared to the water quality parameters given in

Table 3.2. For this purpose, Table 3.14 has been compiled. From this table, it is evident that the water quality of Samoa is comparable in part to some of the streams of Fiji. With the exception of the higher iron content displayed in the Wailoa River in Fiji, the rest of the water quality parameters of the Wailoa River are comparable to those found in Samoa.

TABLE 3.14: Water Quality Parameters of Samoa and Some Pacific Islands. Source: Compiled by Author

STREAM	Number Samples	Cond (uS/cm)	Iron (mg/l)	PH	$SO_4^{=}$ (mg/l)	TN (mg/l)	TP (mg/l)	Source
Tipitaru (Cook Is)	1	1260	0.05	7.4	6			Downes (1981)
Qarani-ni-ki (Fiji)	7	0-5000		7.1		5.6-14.4	0.05-0.22	Naidu *et al.* (1989)
Vitogo (Fiji)	3	60-2500	0.2-20	5.8-9.1	1-3740	2.1-11	0.03-0.45	Gangaiya *et al.* (1986)
Waidina (Fiji)	5			6.4-8.1			0.01-0.04	Ammax Exploration (1978)
Wailoa (Fiji)	3		0.1-0.37	7.0-7.9		1.5-2.2	0.01-0.05	Naidu *et al.* (1989)
Siufaga (Samoa)	2		< 0.05	7.2-7.7	< 1.0			Downes (1981)
Vaisigano (Samoa)	1	72			10		1.8	Zavala (1985)
Savaii (Samoa)	7	56-112	0.0-0.03	6.7-6.9	0.4-8	0.04-0.3	0.04-0.10	This Study
Upolu (Samoa)	75	39-292	0.007-0.14	6.7-6.8	0-2.4	1.7-2.9	0.11-0.17	This Study

In comparison to the rivers of Savaii and Upolu, the Qarani-ni-ki in Fiji was quite polluted (Naidu *et al.* 1989b), and had the higher total nitrogen and total phosphorus values than reported in Samoan streams. Comparable high nutrient values were recorded in the Vitogo river from Fiji. In Table 3.2, it was noted that the Fijian waters were flowing through cultivated land and forested areas, most probably the sources of the higher nutrient concentrations observed. The comparatively higher total phosphorus content in the Vaisigano River as reported by Zavala (1985) was questionable, as it was a grab sample. On the other hand, the water quality of piped water supply at Siufaga, believed to be stream waters

(Downes 1981) showed consistency with the values of the perennial streams of Samoa as found in this study. Until further comprehensive water quality studies from areas around the region become available, the comparison between water qualities of the Pacific Island states will continue to be rather superficial.

In conclusion, the water quality of the perennial streams of Savaii and Upolu islands was found to be comparable in both the dry and wet seasons, except when streams were subjected to human influences. The hypothesis outlined at the start of this chapter, that the perennial streams of Samoa are free of pollutants, has been largely substantiated. The amount of pollutants found in the surface waters of Samoa were minimal, although elevated readings of phosphorus and nitrogen, and in isolated cases iron and zinc did occur. In general, the concentrations of pollutants in Samoan surface waters were very low, and comparable to unpolluted waters around the world. The streams mostly exhibited water qualities reflecting a pristine environment, especially in Savaii. Elevated concentrations of these parameters were only noticeable where human interference was involved. Salinity and sulphate concentrations in the perennial streams of the country recorded such low levels that minimal mention of their presence will be made in the ensuing chapters.

The freshwater springs of Samoa indeed have a salinity problem, especially those springs located adjacent to the coast. Spatial variations were observed in the freshwater springs of Samoa. These were attributed to the surrounding land uses and the location away from the coast of the freshwater springs. High nutrient levels recorded in the urban springs of Upolu indicated a probable effect of urbanisation on springs close to the capital city Apia.

The terrestrial inputs of nutrients and certain ions to the coast therefore appeared minimal and insignificant. The urban streams and rural streams close to settled areas have both been identified as the main sources of elevated readings of nutrients, iron, suspended solids and turbidity. The water quality parameter concentrations documented in this chapter serve as good baseline material for further research into the water quality status of Samoa. But is the input of these contaminants into the coastal zone gradual, periodic or related to specific hydrological events? The identification of periods of high contaminant input into the coastal environment of Samoa is the focus of the next chapter.

CHAPTER FOUR
TEMPORAL VARIATION IN THE HYDROLOGY OF SELECTED STREAMS IN SAMOA

Man searches for the sources of the rivers
And brings hidden things to light
Job 28: 11

Even though there has been some investigation of the water resources of the Pacific region there have been few studies linking water quality to land use activities (Morrison 1990). There have been even fewer works documenting water quality on a temporal basis in the region, but those studies that have done so are reviewed here. Mining activities in Papua New Guinea and Fiji have been the subject of extensive environmental impact assessment (Brodie and Morrison 1984b). Maunsell & Partners (1982) in their Ok Tedi Environmental Study, reviewed previous water quality studies on the Ok Tedi tributaries which had been initiated by the Papua New Guinea Mines Division Laboratory in 1973, and subsequently followed by the Cambridge Expedition as documented by Boyden *et al.* (1974) and Cusbert (1977). The Ammax Exploration Mining Company (1977 & 1978) reported the impacts of copper contamination associated with mining operations in the headwaters of the Waidina River in Fiji. They found trace concentrations of copper in the surface waters of the area, at the time. A study by Wiegman (1995) in American Samoa examined three different sites on each of the Afono, Asili and Leone streams and found that turbidity and suspended solids increased downstream as the land use changed from native forest to plantation to urban settlement.

Water quality studies in some South East Asian countries have been documented by ESCAP (1995). There it was reported that Indonesia experiences water problems in rural areas where freshwater is of limited supply, and that monitoring of the groundwater showed that sea water intrusion had already spread inland a distance of 10 km from shore. ESCAP (1995) claimed that the water quality of Malaysian surface waters was deteriorating rapidly because of economic development. In Thailand, ESCAP (1995) reported water quality problems associated with discharges of pollution from populated areas and industrial plants.

A summary of the water quality parameters from the Pacific area is given in Table 4.1. The compilation reflects the paucity of meaningful water quality data for the Pacific islands, with quite a range in the types of parameters measured and the small number of samples collected at most sites.

This Chapter now presents a detailed analysis of the hydrology of the urban Apia area, and examines the impacts of land based activities on five tropical streams. Periods of greatest contaminant input into the coastal environment will be assessed.

For the ten months from July 1994 to April 1995, hydrological data were collected from the four main streams and rivers, which flowed through Apia urban area. These are the Fuluasou and Vaisigano rivers and the Gasegase and Mulivai streams, as well as from the Fagalii rural stream located one kilometer east of the boundaries of urban Apia. The location of the sampling sites is shown in Figure 2.13. As noted in Section 3.4.3 and Table 4.2 Fagalii Stream is a typical non-urban catchment in Samoa, and was within easy reach of the urban streams to enable data collection at comparable times.

The suitability and consistency of the meteorological and hydrological data used in this chapter is given in Section 4.1. This is followed by a description of the physical and hydrological characteristics of the five catchment areas (Section 4.2). A calculation of the water balance of the five catchments and the sampling regime for this study (Section 4.3) then follows.

TABLE 4.1: Summary of Water Quality in the Pacific Area Associated with Land Use Activities.
Source: Compiled by author

COUNTRY	RIVER	LANDUSE	SAMPLES	WATER QUALITY PARAMETERS conductivity (uS/cm)	iron (mg/l)	pH	sulphate (mg/l)	sus. solids (mg/l)	TDS (mg/l)	total N (mg/l)	total P (mg/l)	turbidity (NTU)	zinc (mg/l)	SOURCE
AMERICAN SAMOA	Asili	plantation	12					0 - 8		0.05-0.25	0.04-0.21	1.2-8.9		Weigman, 1995
		urban area	12					0 - 8		0.07-0.41	0.04-0.22	0.6-9.9		
		forest	12					1.0-6.0		0.05-0.28	0.04-0.25	0.1-7.9		
	Afono	plantation	12					0.2-7.0		0.1-0.30	0.05-0.24	0.5-8.2		Weigman, 1995
		settled area	12					0.5-8.0		0.07-0.41	0.05-0.22	0-8.6		
		forest	12					0-4.0		0.07-0.30	0.05-0.24	0.0-6.4		
	Leone	plantation	12					1.0-7.0		0.06-0.28	0.08-0.25	0.09-6.8		Weigman, 1995
		urban area	12					1.0-13.0		0.13-0.51	0.09-0.22	0.6-9.1		
		forests	12					1.0-6.0		0.08-0.51	0.09-0.79	1.1-7.4		
FIJI	Qarani-ni-ki	farming	7											
	Vitogo	pine forest	12											
	Wailoa	power plant	3											
	Waidina	mining	81		0.04-0.5	6.4-6.8		20-238	39-50		2.0-7.2		0.01-0.02	Ammax Exploration, March 1978.
	Waidina	mining	144		0.05-0.09	6.4-8.1			30-148		0.01-0.04		<0.005	Ammax Exploration, February 1979
PAPUA NEW GUINEA	Fly River		11	38-118	0.002-0.08	6.4-7.3	0.5-7.0				0.01-0.14	10.0-32.0	0.002-0.07	Maunders & Partners, 1982
	Ok Ma	mining	13	113-186	0.02-0.26	7.2-8.2	4.0-10.0				0.01-0.2	20-500	0.005-0.08	Maunders & Partners, 1982
	Ok Ma	mining	11	108-248	0.33-5.6	7.6-8.0	5.2-16.7			0.05-1.2	0.05-50	9.0-230	0.005-0.10	Cusbert, 1977
	Ok Tedi	mining	48	126-285	0.005-0.27	6.7-8.3	0.18-10.0			0.01-0.8	0.01-0.14	3.0-200	0.005-0.21	Maunders & Partners, 1982
	Ok Tedi	mining	16	166-332	0.14-10.0	7.2-7.9	7.7-15.0			0.05-0.40	50-50	6.0-240	0.005-0.09	Cusbert, 1977
	Strickland	mining			42.2	7.7 - 7.9		77 - 830					0.09	Gawne, 1988
WESTERN SAMOA	Vaisigano	power plant				6.9 - 7.5			40 - 50					Stednick, 1990
	Vaisigano	power plant	1	72			10			0.09	1.8			Zavala, 1985

The results of the sampling exercise are presented and discussed in Sections 4.4 and 4.6. Section 4.5 documents the sediment and solute loads carried by the five streams into the coastal zone. The chapter concludes with the comparison between the urban and rural hydrology of Samoa in Section 4.7

TABLE 4.2: Mean Water Quality Values of Fagalii Stream and Rural Streams of Upolu. Source: Author's research.

WATER QUALITY PARAMETER	FAGALII STREAM	UPOLU RURAL STREAMS
	Mean	Mean
Discharge (m^3/s)	0.33	0.43
Temperature (°C)	26.1	27.6
pH	7.1	6.7
Salinity (mg/l)	0.05	0.05
Conductivity (uS/cm)	116	119
Total dissolved solids (mg/l)	53	46
Suspended solids (mg/l)	6.4	2.1
Turbidity (NTU)	7.3	2.0
Iron (mg/l)	0.02	0.007
Sulphate (mg/l)	2.4	1.7
Total nitrogen (mg/l)	4.4	2.3
Total phosphorus (mg/l)	0.19	0.14
Zinc (mg/l)	0.09	0.04

4.1 THE METEOROLOGICAL AND HYDROLOGICAL DATA

4.1.1 Data Availability

Rainfall records for Upolu Island have been published by GWS (1979), and the list is updated and reproduced in Appendix 6.1. Most stations showed a lot of missing and broken records and most of the data collected after 1979 were reportedly destroyed in the cyclones of 1990 and 1991. In this chapter, monthly and daily precipitation records from Mulinuu Station at sea level, Moamoa Station at 120 meters elevation and Afiamalu Station at 700 meters altitude have been used (Appendix 1.4). The Apia Observatory Office at Mulinuu supplied the data. The rest of the stations listed in Appendix 6.1 lie outside the study area and their records were accordingly not used. Monthly precipitation records for Pago Pago in American Samoa from 1964 to 1994 were also available for usage. All rainfall data were converted to millimeters, and are given in Appendices 1.1 to 1.4. The specific precipitation examined in this thesis is given in Table 4.3.

TABLE 4.3: Annual Precipitation Records used in this Thesis.
Source: Compiled by author

STATION	..................YEARS FOR WHICH DATA HAS BEEN COLLECTED..................					
	1940	1950	1960	1970	1980	1990
Afiamalu	1	1	1	1	1	1 ..
Moamoa	1	1	1	1	1	1 ..
Mulinuu	1.........	1.........	1.........	1.........	1.........	1....
Pago Pago	1	1	1	1.........	1.........	1....

Runoff records from different stations around the country, given in Appendix 6.2 showed that most of the stations in the study area had poor quality records, and were outside the boundaries of the study area. Only the Alaoa East and Alaoa West data were used in this thesis. Daily streamflow data for these two gauges supplied by the Apia Observatory Office for their years in operation are given in Appendices 1.5 and 1.6. Compound broad crested weirs control both gauging stations. Damage to the weirs during floods, recorder malfunctioning and the silting of stilling wells were common mishaps reported for the stations. The Mulinuu Observatory Office also provided daily dry bulb readings for temperature at Mulinuu from 1941 to 1994, which were relevant to hydrological considerations (Appendix 1.2).

4.1.2 Data Quality Tests

The precipitation data from Afiamalu, Moamoa and Mulinuu stations were identified as useful because they were in close proximity to the study area. To test the consistency of the annual and monthly hydrological data, the double mass curve technique was used (Searcy and Hardison 1960). The double mass curve is a graph of the cumulating of one quantity against another during the same period. It plots as a straight line so long as the data is proportional, but displays a break-in-slope when changes between the two variables occur (Searcy and Hardison 1960). A comparison of different data sets ensures that any trends that may be detected are not due to changes in gauge location, exposure or observational methods (Searcy and Hardison 1960). The double mass curve for Pago Pago and Mulinuu for thirty-one years from 1964 to 1994 is given in Figure 4.1.

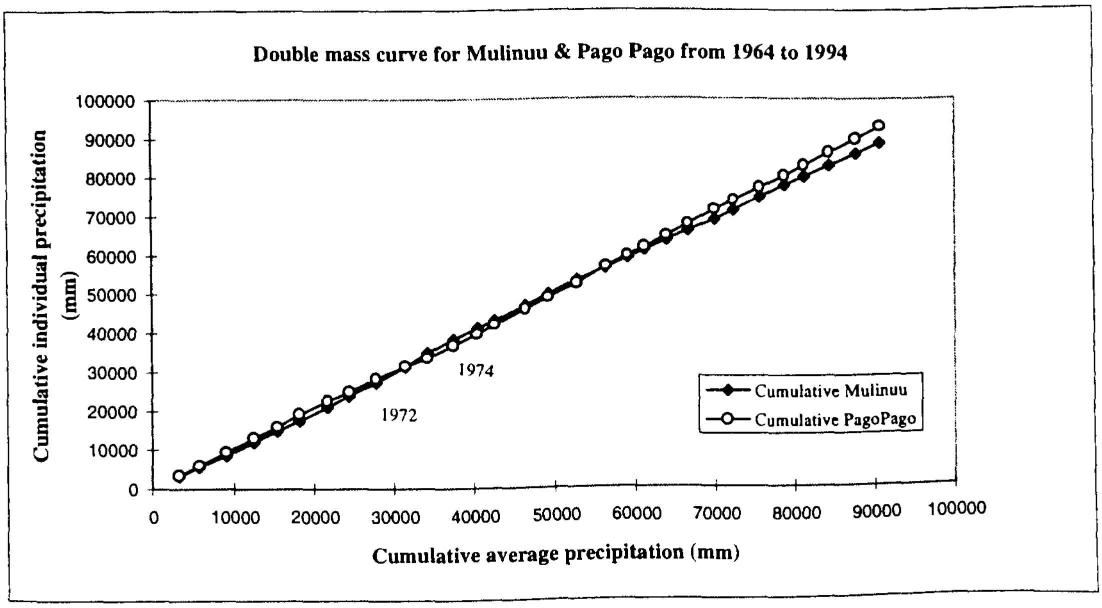

FIGURE 4.1: Double Mass Curves for Mulinuu and PagoPago from 1964 to 1994. Source: Author's research

The figure shows that there are two breaks in slope corresponding to the years 1972 and 1974. Before and after the breaks, the graphs followed a straight line, reflecting consistency and reliability in these particular sections of the data set. Thus, the precipitation record for Mulinuu, which is considered useable in this work, is restricted to the post-1974 period.

Double mass curves for the daily data for Mulinuu, Moamoa and Afiamalu stations for the sampling period from July 1994 to April 1995 are given in Figure 4.2. Afiamalu Station located higher up in the hills not only received more rain but also received rainfall when the other two stations remained dry. Upon inspection of Figure 4.2 the graphs are found to be virtually straight lines with r^2 values of 0.9957, 0.9993 and 0.9972 for Mulinuu, Moamoa and Afiamalu stations respectively. The absence of any sustained breaks in the slopes of the graphs indicates reliability in the data set.

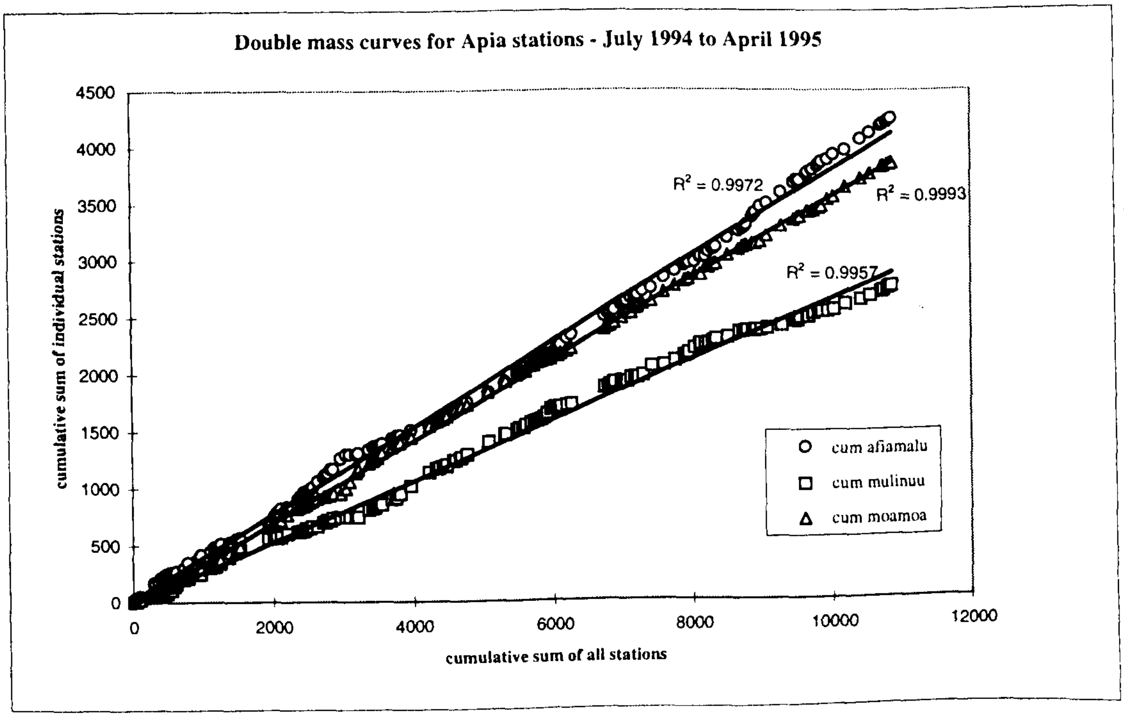

Figure 4.2: Double Mass Curves for Mulinuu, Moamoa and Afiamalu Stations from July 1994 to April 1995. Source: Author's research

Streamflow records for the Alaoa East and Alaoa West gauging stations were chosen for analysis in this project as together they constitute the streamflow data for the Vaisigano River, which was one of the sampling sites in this project. The double mass curve for Alaoa East and Alaoa West from 1973 to 1982 showed three breaks in slope corresponding to the start of

1976, 1981 and 1982 (Figure 4.3). The breaks were attributed to the damage to weirs by floods on the Alaoa West station and possibly the construction of the Cross Island Road at Tiavi in 1981 respectively (GWS 1979). Consequently, the periods of pre-1976 and post-1980 streamflow data were deemed unacceptable and only the 1976 to 1980 streamflow data was used, as it was the longer of the two acceptable periods.

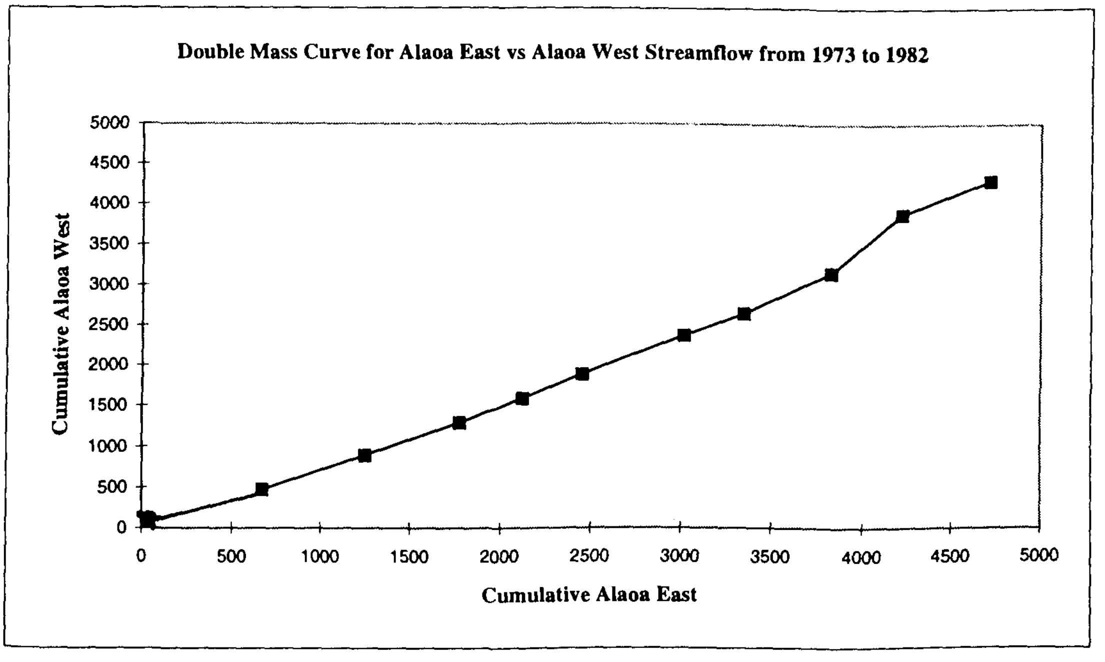

FIGURE 4.3: Double Mass Curve for Alaoa East vs Alaoa West from 1973 to 1982. Source: Author's research

As a second check on the quality of the hydrological data, a double mass curve for Mulinuu precipitation against Alaoa East and Alaoa West streamflow was drawn (Figure 4.4). These quantities plotted as straight-line graphs without breaks in slope up to 1980, indicating acceptable streamflow records pre-1980. This verified that data for the 1976 to 1980 period was reliable, and was of sufficient quality to warrant its use in further analyses.

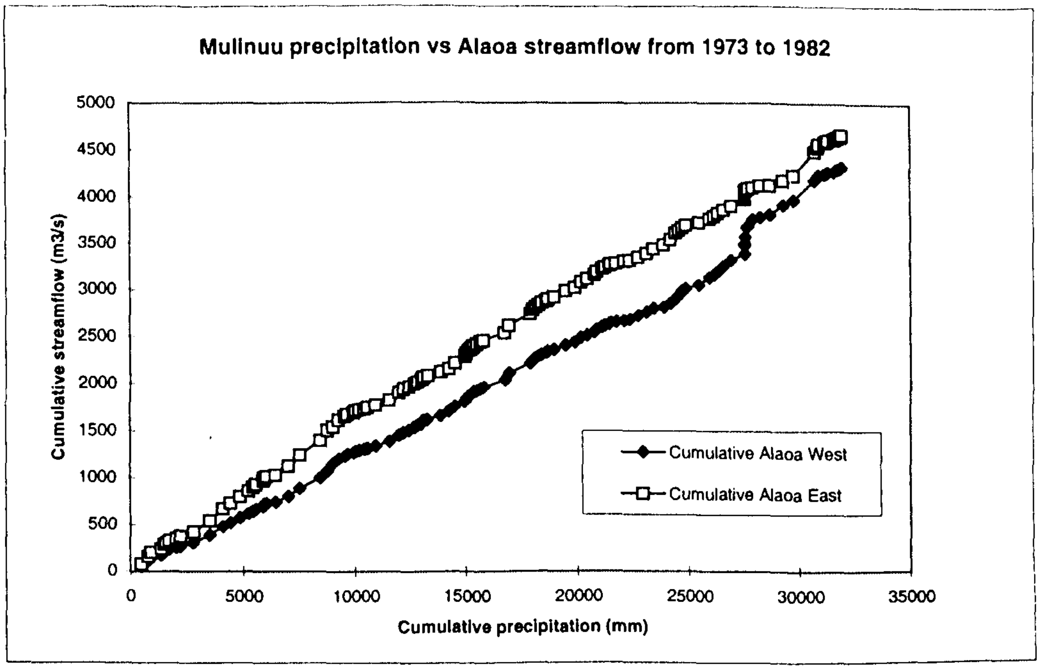

FIGURE 4.4: Double Mass Curve for Mulinuu Precipitation vs Alaoa Streamflow from 1973 to 1982. Source: Author's research

4.1.3 Data Collection for This Project

Prior to the commencement of this project, hydrological data in Samoa consisted of several rainfall and stream gauges on the major rivers, as given in Appendix 6. To extend the hydrological data beyond the existing program, field measurements and chemical tests were carried out on water samples from the five streams and rivers in the Apia urban area. The sites were sampled regularly for ten months from July 1994 to April 1995. As such, the collection period spanned both the wet and dry seasons typical of the Samoan climate (Chapter Three). The sampling frequency was usually two to three times per week, except during storm events when the frequency increased to twice daily on occasions (Plate 4.1).

PLATE 4.1: Gasegase Stream in high flow (top) and low flow times (bottom). Photograph by author

A total of 445 samples were collected for the five rivers and streams. For every time of data collection, values for the discharge, TDS, pH, temperature, salinity, conductivity, suspended solids and turbidity were taken. One of the weekly samples and those of storm events were analyzed for sulphate, total nitrogen, total phosphorus, iron and zinc concentrations. The methods and instruments used in the determinations are outlined in Appendix 3.

In order to determine how representative the 1994-1995 season was of the long-term hydrological regime, probability analysis curves were constructed. Probability analysis curves show the proportion of the time during which the discharge equaled or exceeded certain values (Smith and Stoop 1978). Probability analysis curves for daily precipitation over a ten-year period from 1985 to 1994 for Mulinuu and one for the sampling period from July 1994 to April 1995 were drawn. The results are given in Figure 4.5.

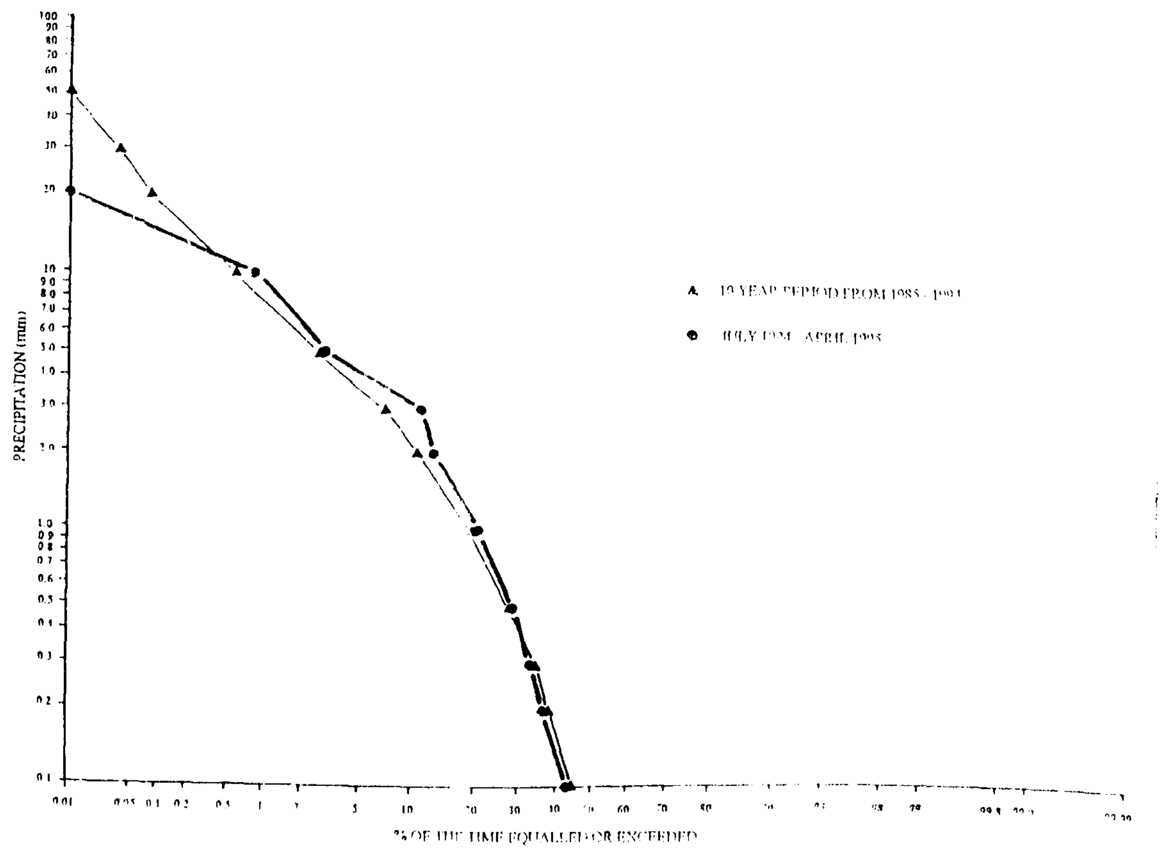

FIGURE 4.5: Probability Analysis Curves for Daily Precipitation at Mulinuu for July 1994 to April 1995 and for 1985 to 1994. Source: Author's research

Figure 4.5 shows that for precipitation values of less than 0.8 mm, the sampling period and long-term average was virtually identical, whereas the sampling period was slightly wetter than average for the 0.8 mm to 12.0 mm range, and drier than average for precipitation greater than 12.0 mm. From this analysis, it is seen that the sampling period was representative of the ten-year period, except for high precipitation or rare events.

It has been stated that the Alaoa East and Alaoa West gauging stations together constitute the Vaisigano River discharge. The flow duration curve for the combined Alaoa East and Alaoa West streamflow values from 1976 to 1980 is given in Figure 4.6, and the discharge values obtained for the Vaisigano River during the 1994-1995 sampling exercise are overlaid onto this plot.

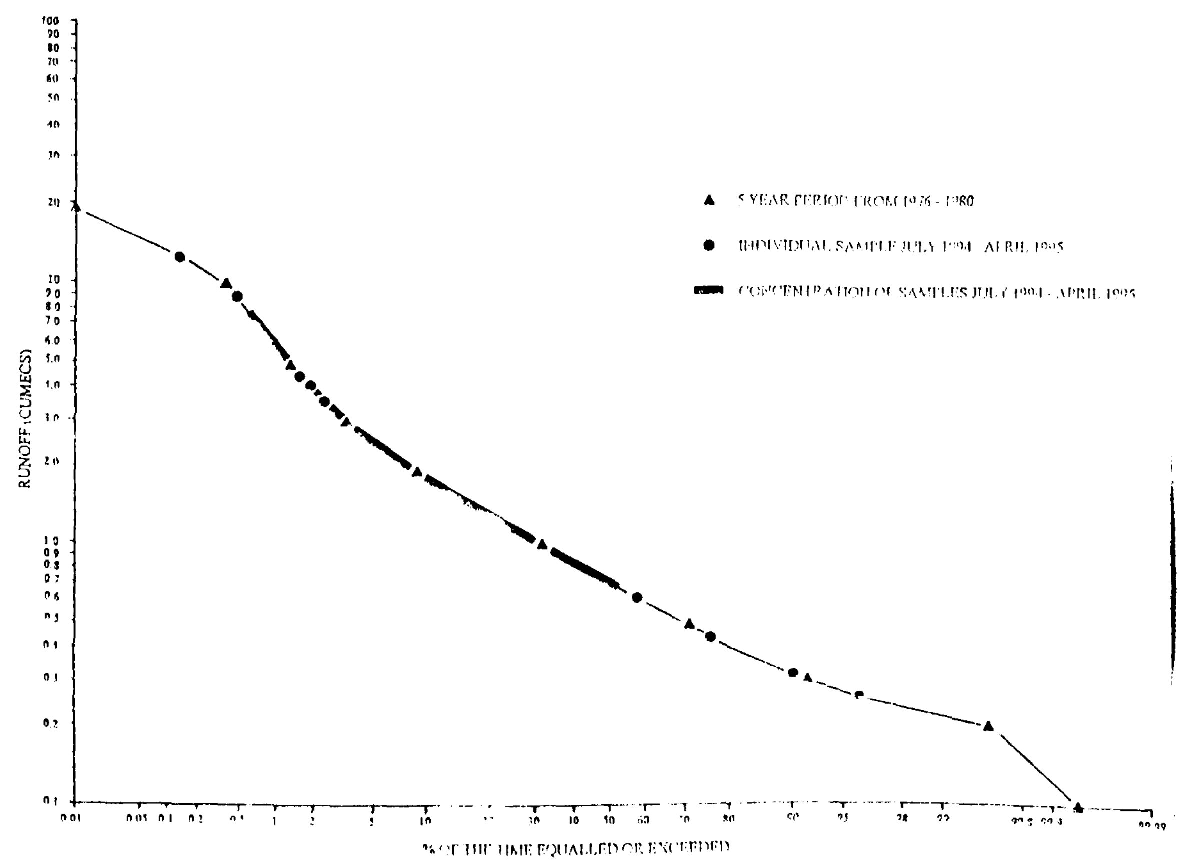

FIGURE 4.6: Flow Duration Curve for Alaoa East and Alaoa West from 1976 to 1980. Source: Author's research

It is noted that the majority of the discharge values from the sampling period fall into the range 0.7 cumecs and 8.0 cumecs. There were very little low flows less than 0.7 cumecs and very few high flows. In fact no discharge from the sampling exercise exceeded 12.0 cumecs.

It is concluded that the sampling exercise from July 1994 to April 1995 coincided with an average precipitation year, and particularly low and high precipitation values were not sampled. All the results that follow should be viewed with this in mind.

4.2 PHYSICAL CHARACTERISTICS OF THE FIVE CATCHMENT AREAS

The five water bodies sampled flow through, or close to, the capital Apia. This Section discusses the physical, geological, geomorphological, soil and vegetation characteristics of these five catchments. The five catchments occupy a total area of 97.8 square kilometers (author's calculations). According to Wright (1963) only 12% of the area has a steep topography, but over half is undulating to strongly rolling country. While all the sampling sites are located near sea level, the rain gauges in the study area are all located above 100 meters elevation. The Fagalii and Mulivai catchments each cover an area less than ten square kilometers, and are smaller than the other three catchments. The Vaisigano and Fuluasou rivers both showed slightly different flow directions to the South-North flow followed by the three other catchment streams.

The shapes of the catchments as represented by their elongation ratios and form factors demonstrated that the Vaisigano, Fuluasou, Gasegase and Mulivai catchments are very similar (Table 4.4). The lower values exhibited by the Fagalii catchment is due to its longer basin length as compared to its area.

TABLE 4.4: The Physical Characteristics of the Five Catchments. Source: Author's calculations. Formulas from Gregory and Walling (1965)

	FAGALII	FULUASOU	GASEGASE	MULIVAI	VAISIGANO
Area (A) -km^2	6.9	25.7	23.9	7.5	33.8
Highest Point (m)	820	790	912	465	1003
Rain Gauge elevation (m)	274	122	120	334	686
Sampling Site elevation (m)	10	2.0	1.0	0	5.0
Stream length (L) – km	9.0	12	11	6.0	13.3
Flow direction	S-N	SW-NE	S-N	S-N	SE-NW
Perimeter (P) – km	16.3	26.2	23.4	14.6	35.2
Elongation (=[2/A/pi]L	0.294	0.476	0.501	0.494	0.493
Form factor (= A/L^2)	0.068	0.170	0.197	0.191	0.191

The long profiles of all the streams (Figure 4.7) approximate an ideal one, especially that of the Fagalii Stream (Beavis 1985).

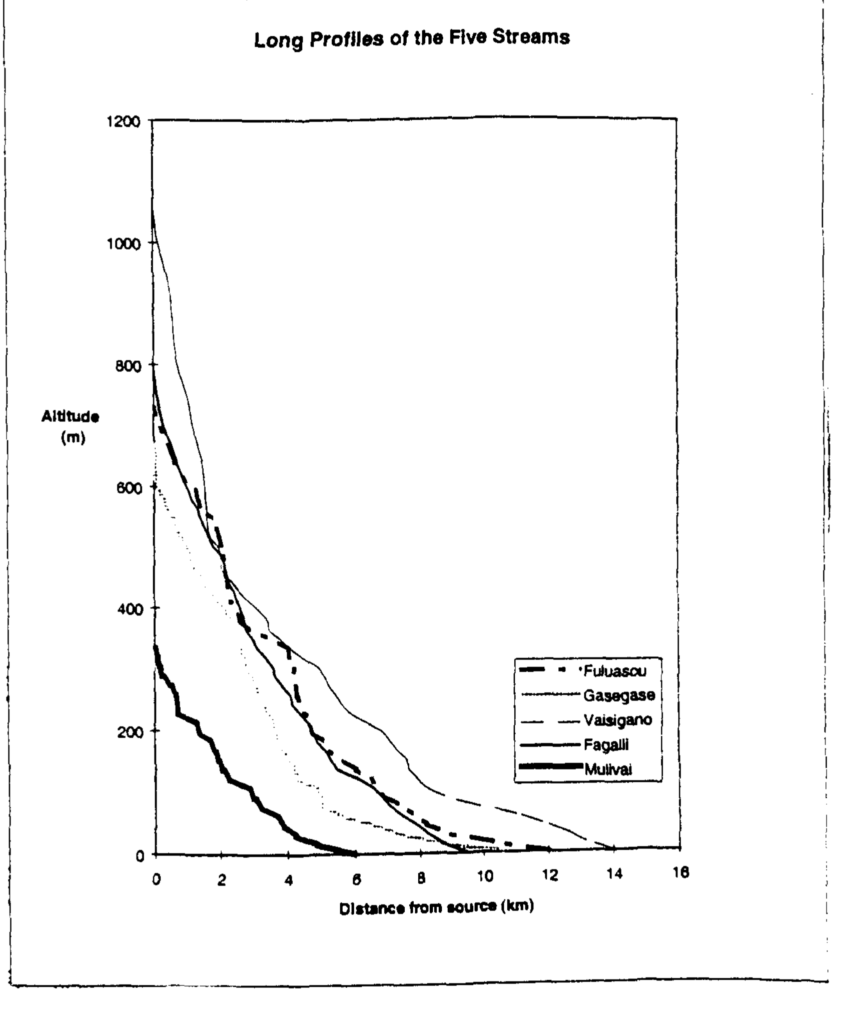

FIGURE 4.7: Long Profile of Streams in the Five Catchment Areas. Source: Author's research

Initial stream gradients are approximately 1: 5 for Vaisigano and Gasegase streams, decreasing to gradients of about 1: 70 below fifty meters elevation. The Fagalii, Mulivai and Fuluasou streams showed less steep initial gradients of about 1: 7 in the upper catchment. Noticeable is the fact that Mulivai Stream is much shorter than the other streams, and its source has a lower elevation than the other streams.

The rocks underlying the five catchments are mainly basic igneous rocks, predominantly weathered olivine basalt. Analysis of these rocks showed that SiO_2, Al_2O_3, FeO, CaO and MgO are the abundantly found minerals in the rock composition as seen in Table 2.3 (Ishii 1984). The high SiO_2 to sesquioxide ratio is apparent from the table.

The geological nature of the catchments shown in Figure 4.8 highlights that there are three main geological formations represented in the five catchments. The oldest Fagaloa Volcanics are present in all the catchments except Fuluasou and cover an average of 14% of the total catchment area (Table 4.5). The second oldest rock formation, the Salani Volcanics, is represented in all the catchments and accounts for more than 70% of the total area on average. The younger Lefaga and Mulifanua Volcanics are found only in the Fuluasou catchment (Table 4.5). The two oldest rock formations, the Fagaloa and Salani Volcanics, together account for over 85% of the geology of the region. Small alluvial deposits occupy a little over 1% of the total area, and are confined to the lower reaches of the rivers and streams around the capital Apia (Table 4.5). The Fagalii and Vaisigano catchments appear to have a similar geological composition. The same could be said for the Mulivai and Gasegase catchments, where both contain alluvial deposits in the coastal areas of their catchments. The difference however is that the oldest Fagaloa Volcanics covers almost half the area of the Mulivai catchment as opposed to just under 20% for the Gasegase catchment.

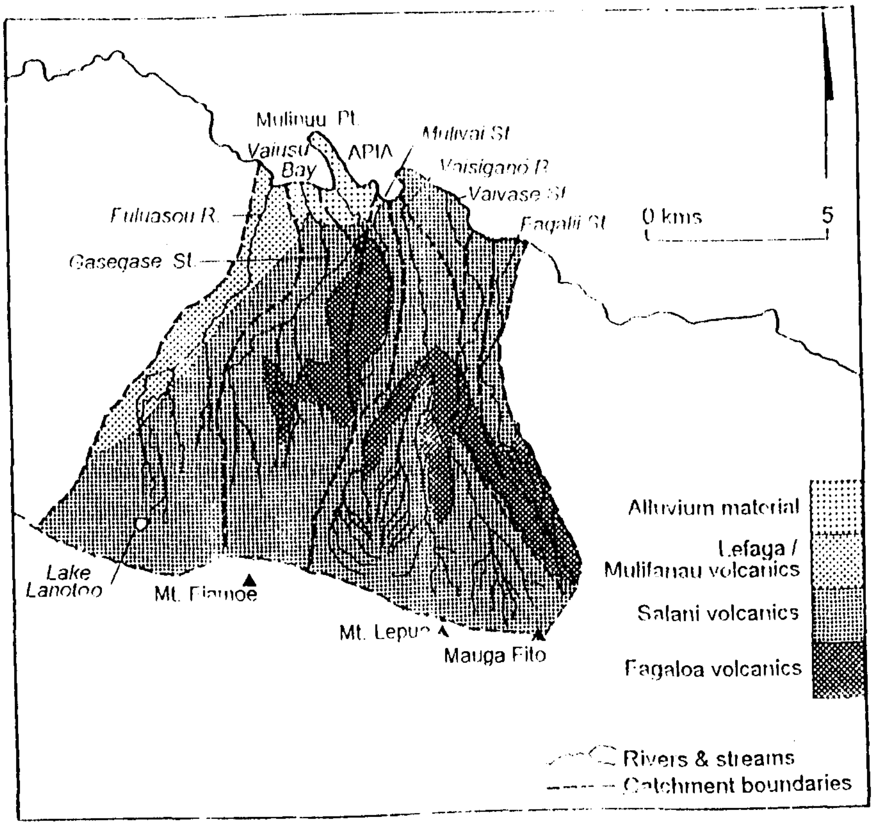

FIGURE 4.8: Geology of the Five Catchment Areas. Source: Adapted from Kear and Wood (1959).

TABLE 4.5: A Comparison of the Geology and Geomorphology of the Five Catchments. Source: Author calculations based on Figures 4.8 and 4.9

CATCHMENT	GEOLOGICAL FORMATION: Fagaloa Volcanics km^2	%	Salani Volcanics km^2	%	Lefaga/ Mulifanua km^2	%	Alluvium km^2	%
Fagalii	1.68	24.3	5.22	75.7	0.0	0.0	0.0	0.0
Fuluasou	0.0	0.0	14.90	58.1	10.4	41.9	0.0	0.0
Gasegase	3.8	16.0	19.30	81.0	0.0	0.0	0.75	3.0
Mulivai	3.43	45.5	3.75	50.0	0.0	0.0	0.32	4.5
Vaisigano	5.04	15.9	28.40	84.1	0.0	0.0	0.0	0.0

CATCHMENT	GEOMORPHOLOGY: Steep (slope = 15-25°) km^2	%	Moderately Steep (slope = 5-15°) km^2	%	Rolling Country (slope = 2-5°) km^2	%	Flat to Undulating (slope = 1-2°) km^2	%
Fagalii	0.96	13.6	2.76	40.5	1.36	18.9	1.82	27.0
Fuluasou	0.0	0.0	12.35	48.0	5.26	20.7	8.09	31.3
Gasegase	3.63	15.4	7.08	29.8	7.54	31.4	5.65	23.4
Mulivai	2.21	29.5	0.62	9.0	0.43	4.5	4.24	57.0
Vaisigano	5.48	18.3	12.74	37.8	10.7	31.6	4.87	12.3

It seemed that only the Fuluasou catchment is geologically different from the others in that it is the only one to have been overlain by the younger Lefaga and Mulifanua Volcanics.

The general topography of the area consists of an almost flat coastal plain, a region of undulating rolling slopes, moderate to very steep sloping foothills, and upland region (Figure 4.9).

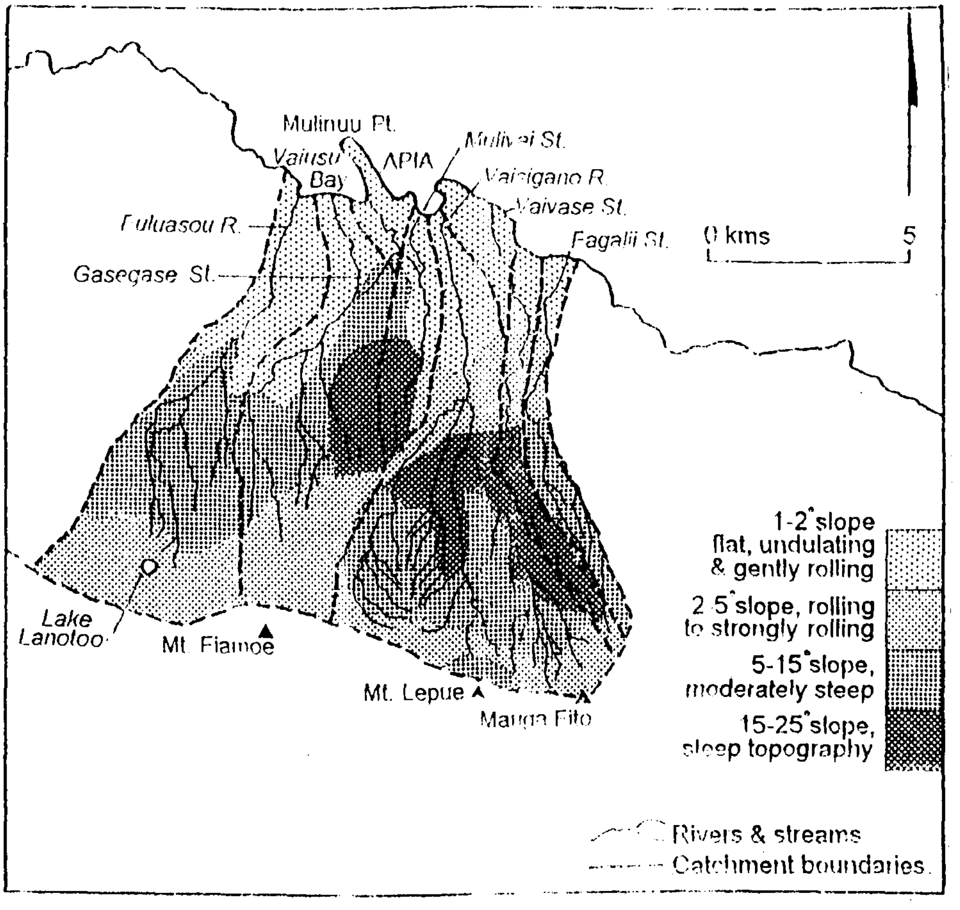

FIGURE 4.9: Landforms of the Five Catchment Areas.
Source: Adapted from Wright (1963)

These steep slopes rise upwards to over 1 100 meters in the interior of the catchments area. In some places, the even slopes are broken by short steep pitches, so that the foothills often climb upwards in a series of giant shallow steps or ripples (Wright 1962). These steps often mark terminal points of successive lava flows or indicate a change in physical condition of the lava.

All the five catchments contain high percentages of moderately steep to steep terrain with the Vaisigano and Fagalii catchments registering 56% and 54% respectively with these steep landform categories (Table 4.5). Mulivai catchment has the lowest proportion of steep terrain (38%), and more than 60% of its area is flat to undulating land less than five-degree slopes.

The soils of Samoa have been mapped by Wright (1963) and have been classified as uncommon laterites as they contain 7 to 13% titanium oxide. In general, higher altitudes have smeary silty clay loams, which are very friable and dry. The mid-altitudes have soils ranging from stony clay loams to bouldery silty clays with much outcropping rock. Around the coastal lowland areas soils are gley and organic, derived from basic alluvium from rivers and streams mixed with organic residues, as well as recent sands and marine marshes supporting mangrove forests (Wright 1963). The chemical compositions of soil samples similar to those found in the five catchments are discussed in Section 2.1.6. The low cation-exchange capacities and low content of primary minerals typical of laterites are evident in the soils as seen in Table 2.6.

Figure 4.10 gives the vegetation characteristics of the five catchments according to Wright (1962). Whistler (1992a) outlined five vegetation categories within one of the forest types classified by Wright, and of his five vegetation categories only the Volcanic vegetation type is not represented in the five catchment areas. Wetland vegetation in the coastal areas of Samoa comprises mainly swamp and mangrove forests and occupies only 3% of the total land cover (Table 4.6). Although Wetland vegetation is absent in both the Vaisigano and Fagalii catchments, Lowland forests are well represented in all the catchments, especially the Vaisigano catchment where more than 50% of its area is of this forest type. The Fagalii, Fuluasou and Gasegase catchments registered over 70% of their areas being covered in Foothill and Upland forests (Table 4.6).

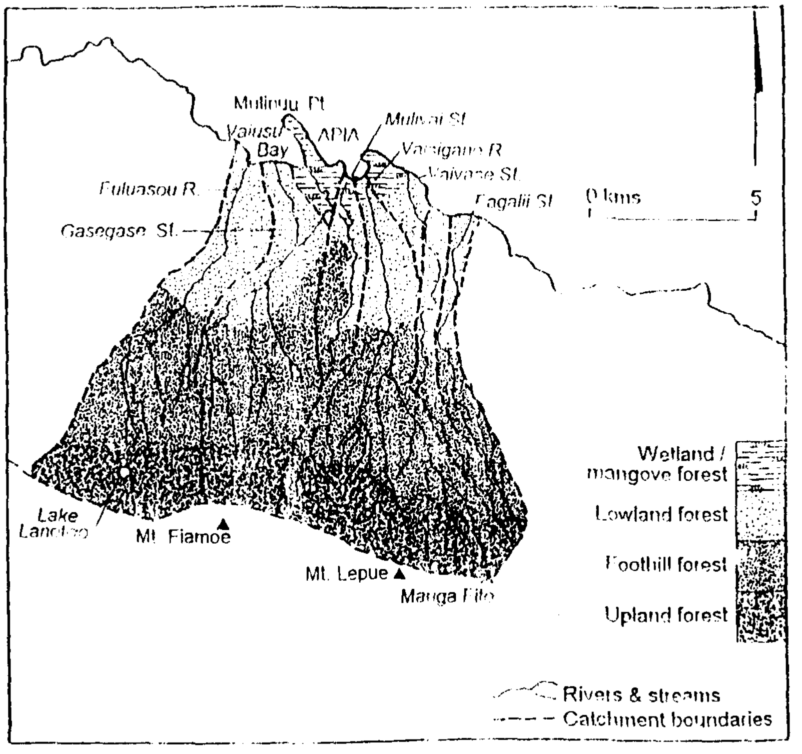

FIGURE 4.10: Vegetation Characteristics of the Five Catchment Areas.
Source: Adapted from Wright (1963).

TABLE 4.6: Comparison of the Natural Plant Cover of the Five Catchments.
Source: Wright (1963)

CATCHMENT	VEGETATION TYPE							
	Wetland Forest (sea level)		Lowland Forest (sea level to 250m)		Foothill Forest (250m to 600m)		Upland Forest (above 600m)	
	km²	%	km²	%	km²	%	km²	%
Fagalii	0.0	0.0	2.01	29.2	4.31	62.5	0.46	8.3
Fuluasou	0.65	2.6	6.17	24.0	14.07	54.8	4.81	18.6
Gasegase	0.64	2.9	6.27	26.1	12.17	50.7	4.81	20.3
Mulivai	1.50	20.0	2.50	33.3	3.50	46.7	0.0	0.0
Vaisigano	0.0	0.0	17.12	50.7	5.48	16.0	11.2	33.3

Although 62% of the total catchment area is covered in forests of this nature, commercial logging is absent in the five catchments. In the past, however, a lot of trees have been felled for fale construction, canoe building, and for firewood (Cameron 1962). Whistler (1992a) classified the lowland and foothill forests in the vicinity of Apia as disturbed vegetation due mainly to human activity, such as the clearing of land for plantation purposes and road construction (Taulealo 1993). Extensive damage to all forests occurred due to cyclone Ofa in February 1990 and cyclone Val in December 1991, where 40% of indigenous and 47% of plantation trees were snapped in half or uprooted (Chase and Veitayaki 1992).

Overall, the five catchments have demonstrated close similarities in their physical characteristics. All catchments are underlain by old volcanic formations. Consequently, the five catchments have similar soil types and landforms. Indeed, all the catchments have rolling to steep terrain occupying more than half their respective total areas. Forested areas are well represented in the five catchments, where lowland forests, foothill and upland forests cover over 80% of the total area. Any variations observed in precipitation, runoff and water balance of the five catchments would therefore be attributed to catchment sizes, local climate or altitudinal differences.

4.3 THE WATER BALANCE

In this section, the water budgets for the five catchments are computed. A water budget is essentially a balance sheet that accounts for all the water entering and leaving a catchment, where input equals output. In simple hydrological terms :

$$P = Q + E + \Delta S$$

where P is the total precipitation input, Q is the streamflow, E is the total potential evapotranspiration loss and ΔS the change in storage (Gregory and Walling 1973). The GWS (1979) assumed that the change in storage was negligible, as changes in soil moisture channel storage and groundwater storage are relatively minor elements in basin balances in Samoa. This is a debatable issue as freshwater springs, which are essentially groundwater, frequently occur as discussed in Sections 3.4 and 3.5. The spatial variation of the parameters in the above equation is now discussed.

4.3.1 Precipitation

The dispersion of the energy and precipitation falling on a catchment and hence the quantity of runoff are modified by parameters like soils, vegetation, orientation, geology, elevation and local climate (Satterland 1967). Only Curry (1962) and Wright (1963) have attempted to give a precipitation distribution pattern for Samoa, but the reliability of their rainfall distribution maps given are questionable, necessitating the production of an accurate rainfall distribution map of the five catchments. The spatial variation in precipitation of north-central Upolu would be due mainly to altitudinal differences, as the catchments have a northerly aspect (Table 4.4), and possess similar physical characteristics (Section 4.2). A relationship between mean annual precipitation and elevation was sought. Figure 4.11 shows the graph of the station elevation against mean annual rainfall for Afiamalu, Moamoa and Mulinuu stations. A direct relationship between the two variables was seen, where the slope of the line of best fit relates to an increase of 330 millimeters for every 100-meter rise in altitude. This information was then related to the 1:20 000 topographic map series, from which a realistic rainfall distribution map of Central-northern Upolu was generated (Figure 4.12). The isohyets approximate a contour interval of 150 meters.

The precipitation data from the four stations for the 1976 to 1980 period and Figure 4.12 were then utilized to produce catchment precipitation as calculated in Appendix 7.1 and given in

Table 4.7. The Isohytel method was chosen to determine the average precipitation for the catchment areas as it was the most accurate (Linsley *et al.* 1975).

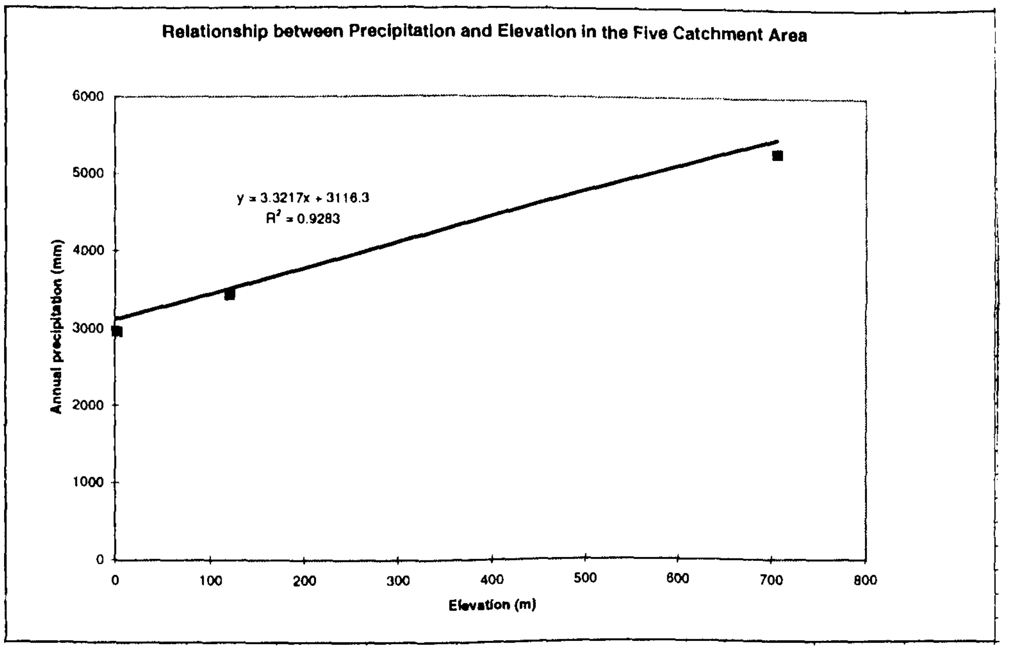

FIGURE 4.11: Mean Annual Precipitation vs Elevation for the Rain Gauges in the Five Catchment Areas. Source: Author's research

TABLE 4.7: Catchment Average Precipitation from the Isohyetal Method. Source: Author's research based on calculations in Appendix 7.1

NAME OF CATCHMENT	AREA (km^2)	PRECIPITATION VALUE (mm)
Fagalii	6.9	3990
Fuluasou	25.7	4160
Gasegase	23.9	4105
Mulivai	7.5	3680
Vaisigano	33.8	4550

From Table 4.7, it is evident that the average catchment precipitation reflects the catchment sizes. The Vaisigano catchment with the largest area receives the most precipitation. Although Fagalii has a smaller catchment area than Mulivai, it received more rain because a considerable portion of its catchment is situated higher in altitude and thereby exposed to a higher probability of rain (Figure 4.12).

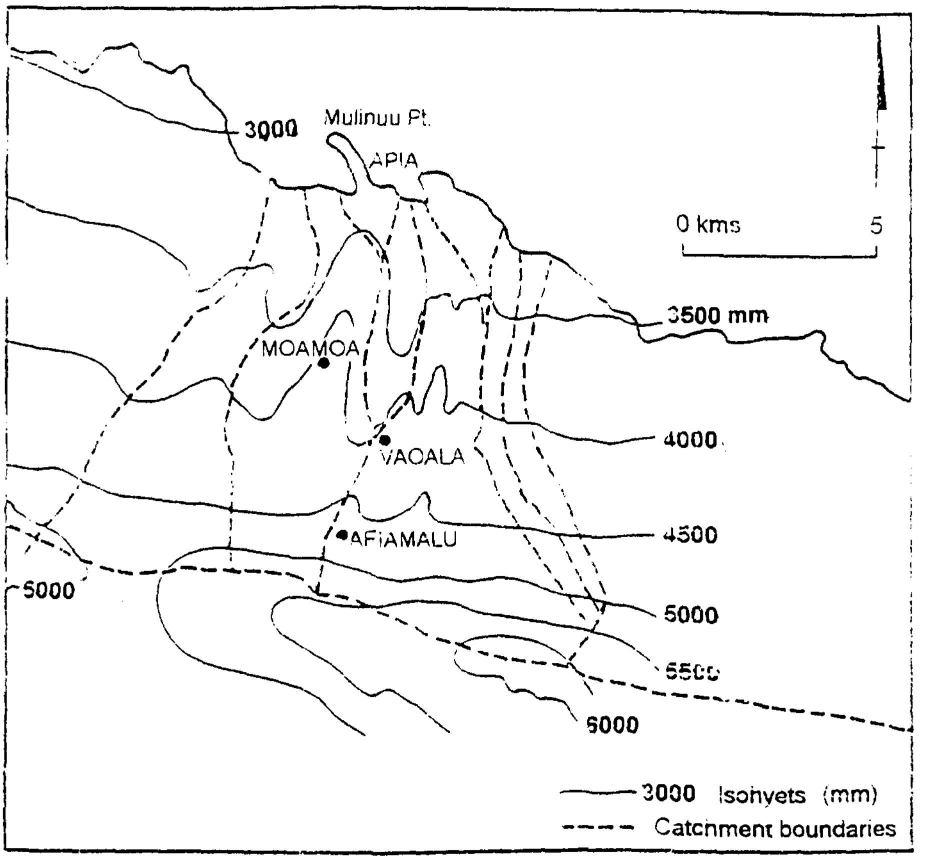

FIGURE 4.12: Rainfall Distribution Map of Central-northern Upolu.
Source: Author's research

4.3.2 Streamflow

The literature outlining variables affecting runoff is voluminous. In the humid tropics, the proportion of rainfall which eventually becomes runoff varies from almost zero for experimental plots under small-scale agriculture in Tanzania to 65% for forested catchments in monsoonal northeast Queensland (Lundgren 1980; Bonell *et al.* 1983). Thomas (1974) commented that there is little quantitative information on natural runoff processes under tropical forests, with most work confined to broad scale water balance studies in Malaya, West Africa and North East Australia (Low and Goh 1972; Ledger 1975; Gilmour and Bonell 1979). The use of streamflow data from Samoa outlined in this section should redress this lack.

As mentioned earlier, streamflow data from the five catchment areas were obtained only for Alaoa East and Alaoa West stations (Appendix 1.5 and 1.6). Annual and monthly average runoff values for Vaisigano River from 1973 to 1982 are given in Figure 4.13.

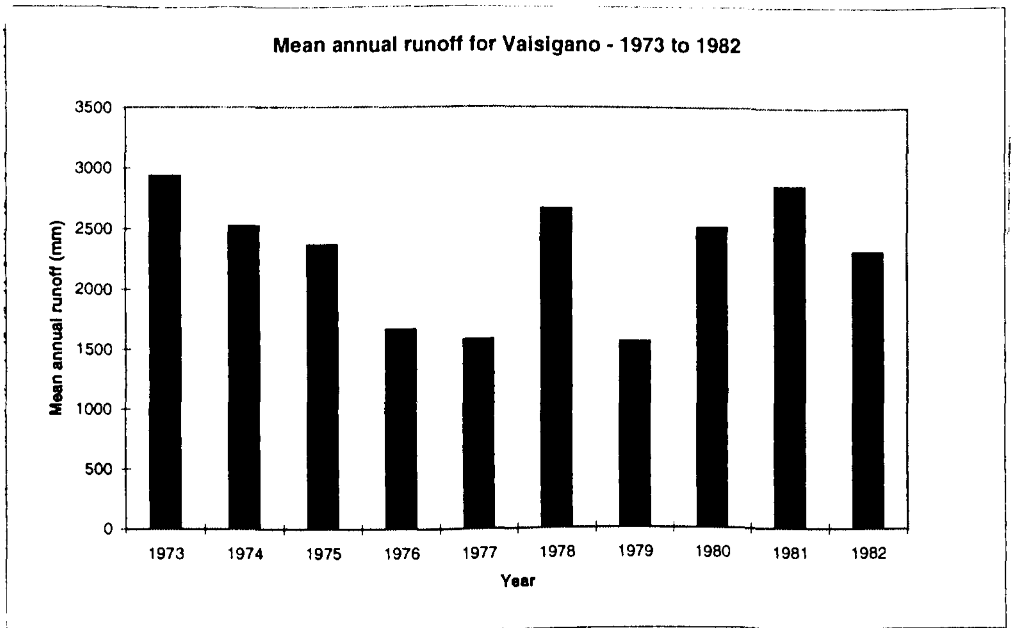

FIGURE 4.13: Mean Annual Runoff Values for the Vaisigano River.
Source: Computed by author from Appendix 1.5 and 1.6

A mean annual runoff value of 2 300 millimeters was calculated for the Vaisigano River. The highest annual runoff value of 2 930 millimeters occurred in 1973, and the lowest value of 1 565 millimeters in 1979. The seasonal variation in runoff reveals that maximum streamflow occurs in December, January and February, and the lowest values in June to September (Figure 4.14).

The observed trend follows the precipitation pattern very closely. The flat slope of the Flow Duration Curve for Vaisigano River (Figure 4.6) suggests a slow response to rainfall with appreciable amounts of storage or baseflow within the catchment (Smith and Stoop 1978).

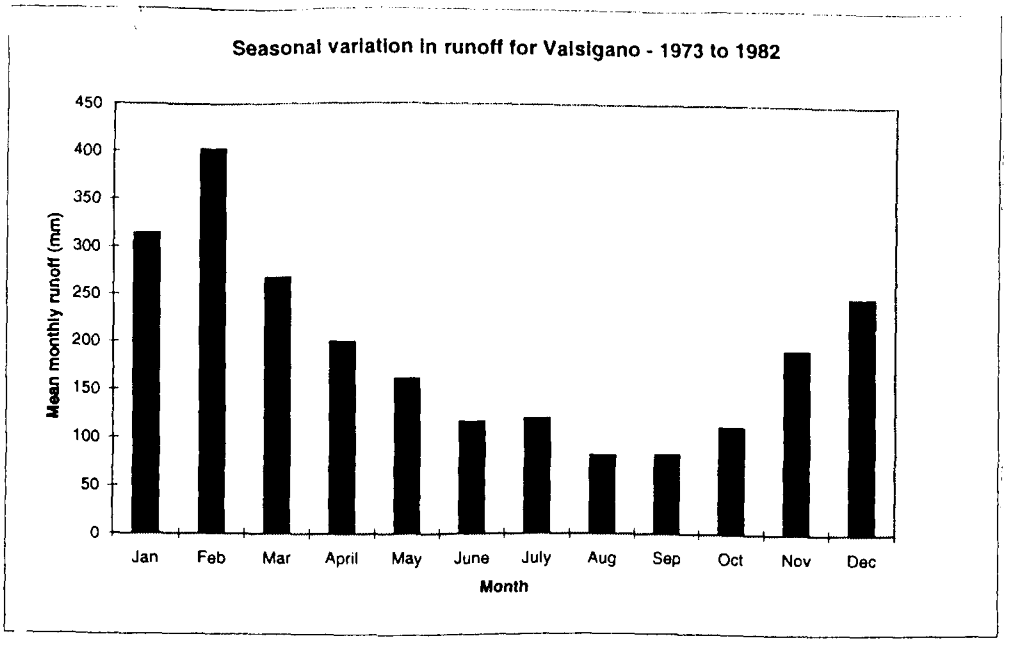

FIGURE 4.14 : Seasonal Variation in Runoff for Vaisigano from 1973 to 1982.
Source : Computed by author

Mean annual runoff values were calculated for Alaoa East, Alaoa West and Vaisigano rivers using the method of Smith and Stoop (1978) using the Observatory data. According to these authors, annual runoff can be calculated using the equation:

$$Q = d \times 60 \times 60 \times 24 \times 365 / A \times 1000 \times 1000$$

where Q is the runoff in meters, d is the average discharge in cumecs, and A the drainage area in square meters. The result is directly comparable with rainfall. The calculated runoff values are given in Table 4.8 together with values calculated from average discharge values measured during this study, and the values documented by GWS (1979).

TABLE 4.8: Mean Annual Runoff Values for some Stations in the Five Catchment Areas. Source: Compiled by author

SOURCE	STATION	AREA (km^2)	PERIOD	MEAN ANNUAL RUNOFF (mm)
GWS Data (1979)	Alaoa East	16.5	07/75 to 06/77	1960
	Alaoa West	12.5	10/72 to 09/76	2640
	Vaisigano	29.0	07/75 to 06/77	2070
	Fuluasou	6.9	10/72 to 09/76	3280
Observatory Data	Alaoa East	16.5	01/76 to 12/80	1270
	Alaoa West	12.5	01/76 to 12/80	1143
	Vaisigano	33.8	01/76 to 12/80	2414
This Study	Fagalii	6.9	07/94 to 04/95	1550
	Fuluasou	25.7	07/94 to 04/95	1590
	Gasegase	23.9	07/94 to 04/95	1450
	Mulivai	7.5	07/94 to 04/95	1760
	Vaisigano	33.8	07/94 to 04/95	2280

The GWS (1979) and the present study both showed that runoff values do not vary according to catchment size, although the values given by the GWS for Fuluasou and Vaisigano are higher than those calculated by this study (Table 4.8). The runoff values calculated in this study are likely to be an underestimation of the actual runoff figures, because the values were extrapolated from only ten months of sampling and no heavy storm events were sampled. It was felt that the higher runoff value computed for the Vaisigano River from the Observatory data would be a more realistic approximation. The runoff values for the five catchments are accordingly adjusted by the application of a conversion factor, and the adjusted runoff values for the five catchments are given in Table 4.9.

TABLE 4.9: The Adjusted Runoff Values for the Five Catchments. Source: Author's calculations

CATCHMENT	AREA (km^2)	PERIOD	MEAN ANNUAL RUNOFF (mm)
Fagalii	6.9	07/94 to 04/95	1700
Fuluasou	25.7	07/94 to 04/95	2090
Gasegase	23.9	07/94 to 04/95	1590
Mulivai	7.5	07/94 to 04/95	1930
Vaisigano	33.8	07/94 to 04/95	2500

According to Smith and Stoop (1978), discharge characteristics of a stream can be inferred from its flow duration curve. Flow duration curves for the five streams are given in Figure 4.15, where it is seen that the respective discharges (position of curve) followed roughly the catchment sizes, with Vaisigano River having the highest discharge, and Fagalii Stream the lowest.

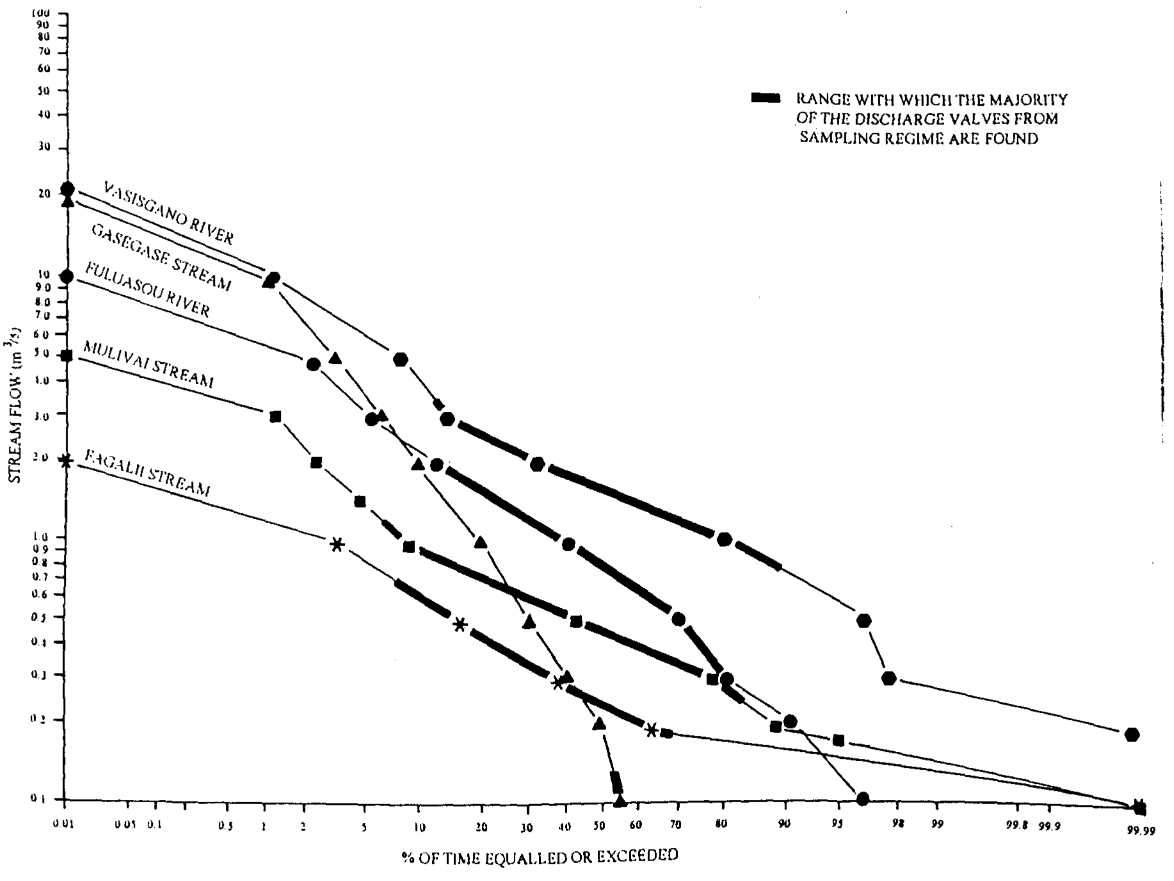

FIGURE 4.15: Flow Duration Curves for the Streams of the Five Catchment Areas. Source: Author's research

The steep slope throughout of the Gasegase Stream curve indicated a very variable stream (Smith and Stoop 1978). The flatter slopes of the curves of the other four streams reflect slower responses to rainfall. The discharge values from the sampling exercise given in Appendix 8 were plotted on the respective flow duration curve, where the following was observed. Gasegase discharges were concentrated at 0.04 m^3/s to 0.08 m^3/s. Fagalii discharges were clustered between 0.11 m^3/s and 0.70 m^3/s, and those of Mulivai were concentrated in the 0.27 m^3/s to 1.10 m^3/s range. The Fuluasou discharges were concentrated between 0.6 m^3/s and 1.9 m^3/s, and the Vaisigano discharges were found clustered at 0.9 m^3/s to 2.8 m^3/s. No extremely high flows were sampled in the exercise with only the Vaisigano and Gasegase streams recording flows of over 10 m^3/s.

As mentioned earlier, the sampling regime covered both the dry and wet seasons typical of the Samoan climate. The variation of the respective daily stream discharges for the two seasons is summarized in Table 4.10, with their overall discharge coefficient of variation (CV) readings.

TABLE 4.10: Mean Daily Discharge of the five Streams in the Dry and Wet Seasons. Source: Author's research

STREAM	MEAN DAILY DISCHARGE (mm)			
	CV	Dry Season	Wet Season	Ratio Wet : Dry Season
Fagalii	0.8787	3.4 (n=33)	4.8 (n=55)	1.41
Fuluasou	1.0296	2.0 (n=31)	5.6 (n=55)	2.80
Gasegase	1.7670	2.2 (n=37)	4.5 (n=55)	2.04
Mulivai	1.0700	4.0 (n=33)	6.1 (n=53)	1.52
Vaisigano	0.7827	4.8 (n=36)	6.8 (n=55)	1.42

As seen from Table 4.10, the variability of the Gasegase Stream discharge is reflected in the comparatively high CV value it obtained. Although Fuluasou and Gasegase streams appeared to have twice as much daily discharge in the wet season as in the dry season (Table 4.10), the Mann-Whitney results for all the five streams (which assumed that the two season readings came from the same population) yielded the same result. The null hypothesis was rejected at the 99% confidence level (Appendix 5.4). It was concluded therefore that indeed, discharges for all the streams in the dry and wet seasons were significantly different.

The sampling exercise also measured some storm-flows. According to Burt (1996), flood flows are at most three to four times the mean flow, while the 95% point of the time the mean flow is exceeded remains a useful low flow parameter. Using these definitions, the relationship between daily baseflow and storm-flow discharge values for the five streams is given in Table 4.11. Because the flow duration curve of the Gasegase Stream did not reach the 95% mark, base flows for this stream were taken as those flows recording values less than 0.05 m^3/s.

TABLE 4.11: Average Discharge Values for the five Streams during Storm-flow and Baseflow. Source: Author's research

STREAM NAME	MEAN DAILY STORMFLOW DISCHARGE (mm)	CUTOFF DISCHARGE VALUE (1)	NUMBER OF STROMFLOW SAMPLE	MEAN DAILY BASEFLOW DISCHARGE (mm)	NUMBER OF BASEFLOW SAMPLES	RATIO STORMFLOW TO BASEFLOW
Fagalii	19.9	>1.1 m^3/s	3	1.7	12	11.7
Fuluasou	19.3	>4.0 m^3/s	4	0.4	7	48.2
Gasegase	19.3	>3.2 m^3/s	10	0.2	19	96.5
Mulivai	21.6	> 1.2 m^3/s	7	1.4	9	15.4
Vaisigano	22.7	> 7.0 m^3/s	4	1.5	3	15.1

Table 4.11 shows that while the Mulivai and Vaisigano streams registered daily storm-flow discharges over 21 mm per day, Fagalii, Fuluasou and Gasegase streams all had storm-flow values close to 20 mm per day. On average, the mean daily storm-flow discharges were over ten times higher than the average daily base-flows, although Gasegase and Fuluasou streams recorded much higher differences, perhaps reflecting the variability of these two streams with many quick-flows and few base-flows (Burt 1996). This is also evident from the steeper slopes of their flow duration curves than the other three streams (Figure 4.15).

It is concluded therefore that during this intensive sampling exercise, average daily discharges for the five streams recorded values twice as high in the wet season than the dry season, and had discharge values over ten times higher during storm events than baseflow events. This should be remembered in the discussions that follow.

4.3.3 Evapotranspiration

The lack of evaporation data has prompted the use of temperature readings to estimate potential evapotranspiration. Smith and Stoop (1978) noted that reasonable estimates of potential evapotranspiration could be obtained by using dry bulb temperatures, and using the formula:

$$PE = T - 32 / 9.5$$

where PE is the potential evapotranspiration in inches, and T is the mean monthly temperature in degrees Fahrenheit. The PE in millimeters is obtained by multiplying by the appropriate conversion factor. Daily dry bulb readings of temperature for the period from 1941 to 1994 given in Appendix 1.2 were used to obtain monthly average temperature and correspondingly the potential evapotranspiration values for Mulinuu (Table 4.12). Figure 2.7 depicts the seasonal variation in temperature, which clearly shows the small range in temperature between wet and dry seasons in Samoa. A mean annual value of 27.5°C was obtained.

TABLE 4.12: Average Monthly Evapotranspiration Values for Mulinuu: 1976 to 1980. Source: Computed by author based on Smith and Stoop (1978)

	MONTH												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Temp (°C)	27.8	27.9	27.7	27.8	27.4	27.1	26.5	26.9	27.5	27.9	28.2	28.3	
Ep (mm)	134	134	133	134	131	130	128	130	132	134	136	137	1590

The total evapotranspiration value of 1 590 mm calculated from the temperature readings was lower than that of 1 820 mm cited by GWS (1979). Curry (1962) calculated potential evapotranspiration loss using Thornthwaite's method and gave a value of 1 620 mm for sea level conditions, which is comparable to the value computed in Table 4.12. Although potential evapotranspiration values are often underestimated in tropical island situations (Nullet and Giambelluca 1990), the value of 1 590 mm as calculated in Table 4.10 was deemed reliable for further calculations. Curry (1962) found that there was an exponential decrease of evapotranspiration with altitude, so that the most rapid changes occurred nearest the coast. The contour interval of 150 meters used in Curry's work ties in nicely with that used in this study to produce the rainfall distribution map of Central-northern Upolu given in Figure 4.12. The catchment evapotranspiration values calculated in the same manner as for catchment precipitation in Appendix 7.2, are given in Table 4.13. The catchment evapotranspiration values for the five catchments ranged between 1 150 mm and 1 360 mm. The highest value, calculated for the Mulivai catchment, is probably because more than half its area lies below 150 meters elevation, the area which experiences the greatest evapotranspiration loss. In the other four catchments, there is a decrease in evapotranspiration values as catchment size increases. Also noticeable was the fairly good agreement of the computed value with that given by the GWS (1979). Stednick's (1990) estimation of the total evapotranspiration loss (about 23% of the total rainfall) however gave a lower value, and exposes the inaccuracy of the generalization used in his study.

TABLE 4.13: Potential Evapotranspiration for the Five Catchments. Source: Computed by author

		POTENTIAL EVAPOTRANSPIRATION (mm)		
CATCHMENT	AREA (km^2)	This Study	GWS (1979)	Stednick's (23% of pptn)
Fagalii	6.9	1250		850
Fuluasou	25.7	1230		950
Gasegase	23.9	1240		944
Mulivai	7.5	1360		800
Vaisigano	33.8	1150	1180	1015

4.3.4 The Water Balance for the Five Samoan Streams

The water balance for the five catchments can now be calculated from the data in Tables 4.7, 4.9 and 4.13. It is emphasized that all the values computed for catchment precipitation, runoff and potential evapotranspiration are estimates, but they were based on the best available data. Table 4.14 shows that runoff values vary from catchment to catchment but that, on average, surface runoff accounts for almost 48% of the total input in the five catchments. The smaller catchments of Fagalii and Gasegase showed lower runoff percentage of 42.6% and 38.7% respectively. If it is assumed that the balance of the runoff and the evapotranspiration values infiltrates to groundwater, then it is seen that about 22% of the total precipitation of the five catchment areas end up below the land surface. Indeed, this is reflected in the presence of freshwater pools located near the coast within these catchments at places like Pesega, Vailoa, Tufuiopa, Vini and Moataa. Gasegase and Fagalii streams contribute considerable quantities to groundwater, where 31% and 26% respectively of their total precipitation is computed to penetrate into the ground. Almost all of the rainfall falling on Mulivai catchment is used up as either runoff or potential evapotranspiration. The higher percentage of rainfall converting to runoff in the larger Fuluasou and Vaisigano streams were probably the reasons why these two catchments were considered for hydro power generation.

TABLE 4.14: Annual Water Balance for the Five Catchments.
Source: Author's research

CATCHMENT	AREA (km^2)	RAINFALL (P) (mm)	RUNOFF (Q) (mm)	RUNOFF (Q) (%)	POT. ET (Eo) (mm)	POT. ET (Eo) (%)	STORAGE (mm)	STORAGE (%)
Fagalii	6.9	3990	1700	42.6	1250	31.3	1040	26.1
Fuluasou	25.7	4160	2090	50.2	1230	29.5	840	20.2
Gasegase	23.9	4105	1590	38.7	1240	30.2	1275	31.1
Mulivai	7.5	3680	1930	52.4	1360	36.9	390	10.5
Vaisigano	33.8	4550	2500	54.9	1150	25.3	900	19.8
Average	19.6	4100	1960	47.8	1246	30.4	894	21.8

The water balance for Vaisigano given by the GWS (1979) was comparable with that found in this study, but the water balance computed for Fuluasou by the same study gave a higher value. The average percentage of the rainfall occurring as streamflow found in this study was comparable to Stednick's (1990) assumption of 48% of the rainfall ending up as streamflow. His estimation that 29% of rainfall contributed to groundwater, however, was higher than the value estimated in this study of only 22%. This study estimated that a lot more water (31%) is lost to evapotranspiration.

Comparing the water balance of the five catchments to other tropical catchments of similar sizes it is seen that the percentage of rainfall occurring as streamflow for the Malaysian catchments and Lien-Hua-Chi from Taiwan are comparable to those of Fuluasou, Mulivai and Vaisigano (Table 4.15). While the runoff value from Oahu, Hawaii, was much lower than that recorded in Samoa, no catchment in Samoa recorded runoff values as high as that of the extremely wet catchment from Guma, Africa.

TABLE 4.15: Water Balance of Other Tropical Catchments.
Source: Compiled by author

CATCHMENT	AREA (km^2)	PERIOD OF RECORD	RAINFALL (mm)	RUNOFF (mm)	RUNOFF (%)	WATER LOSS (mm)	SOURCE
Sungei Lui 2, Malaysia.	54.4	09/68 to 08/69	2109	1100	47.8	1009	Low (1971) in Low and Koh, 1972
Sungei Lui 3 Malaysia.	30.57	09/68 to 08/69	2162	1100	50.8	1062	Low (1971) in Low and Koh, 1972
Guma, West Africa	8.7	1967 to 1974	5785	4649	80.0	1011	Ledger, 1975
Lien-Hua-Chi, Taiwan	0.09		2100	1100	52.3		Hsia and Koh, 1983
Niger, River at Sigiri	70 000		1640	420	25.6	1220	Balek in Ayibotele, 1993
Oahu, Hawaii	459		5950	920	15.0	2638	Shade and Nichols 1996
Vaisigano, Samoa	29.0	07/75 to 06/77	4550	2070	46.0	2450	GWS, 1979
Fuluasou, Samoa	6.7	10/72 to 09/76	4830	3280	68.0	1550	GWS, 1979
The Five Catchments, Samoa	97.8	07/94 to 04/95	4100	1960	48.0	1246	This Study

4.4 PHYSICAL WATER QUALITY PARAMETERS

According to Meybeck *et al.* (1989) water quality changes are almost exclusively due to human activities. Some of these human activities relevant to the Samoan setting are: building dams for hydropower generation; water diversion and dredging of estuaries; forest cutting, intensive agriculture, road building and release of domestic organic wastes; and the release of both natural and synthetic substances to the water bodies.

With these in mind, the water quality relationships between the parameters measured in this study are discussed. The raw data for all the water quality parameter results of the five streams are given in Appendix 8. As demonstrated in Chapter Three, water temperature, pH, salinity and sulphate ions all exhibited little variability in the streams of Samoa. Their effects on other water quality parameters are deemed negligible, and the low values shown by salinity and sulphate parameters bear no threat to the fluvial environment.

The average physical water characteristics for the five streams are given in Table 4.16, together with the average concentrations of the respective parameters in unpolluted surface waters of the world, as documented by Wetzel (1975). These will now be discussed.

4.4.1 <u>Temperature</u>

The low CV values of temperature for the five streams shown in Table 4.15 reflects the independence of temperature from such factors as heat energy transfers, vegetational shading or influences from groundwater (Pluhowski 1970; Webb and Walling 1986). Although temperature values can change according to different flows (Calow and Petts 1992), this was not evident in the temperature readings recorded in the five streams, where temperatures were comparable during storm-flows and base-flows (Table 4.16). Seasonal variation in temperature both within and between the streams was minimal.

TABLE 4.16: The Average Physical Water Quality Values for the Five Streams. Source: Author's research

WATER QUALITY PARAMETER		FAGALII	FULUASOU	GASEGASE	MULIVAI	VAISIGANO	WORLD AVERAGE (Wetzel 1975)
Temperature (°C)	Mean	26.1	26.0	27.8	27.6	25.7	
	CV	0.0669	0.0627	0.0709	0.0548	0.0549	
	Dry Season	26.1	26.9	28.5	27.6	25.4	
	Wet Season	26.3	26.1	27.6	27.6	25.9	
	Storm-flow	25.2	25.4	25.7	25.8	24.9	
	Baseflow	26.3	26.6	28.3	28.0	25.9	
PH	Mean	7.0	7.1	6.8	6.9	7.0	6.9
	CV	0.0656	0.0418	0.0339	0.0411	0.0473	
	Dry Season	6.9	6.9	6.8	6.8	7.0	
	Wet Season	7.1	7.2	6.8	6.8	7.1	
	Storm-flow	7.1	7.3	6.9	7.1	7.1	
	Baseflow	7.1	7.1	6.8	6.8	7.0	
Turbidity (NTU)	Mean	7.8	5.8	21.4	12.6	6.4	5
	CV	2.8619	1.701	3.532	3.591	1.809	
	Dry Season	8.4	5.7	30.1	15.1	5.4	
	Wet Season	6.7	5.9	14.6	11.1	7.1	
	Storm-flow	27.3	14.4	73.2	78.2	17.1	
	Baseflow	3.3	3.8	11.4	5.1	4.2	
Suspended Solids (mg/l)	Mean	6.4	5.8	15.9	10.4	6.4	
	CV	1.8919	1.717	3.592	3.984	1.803	
	Dry Season	5.2	2.4	20.7	13.4	5.2	
	Wet Season	6.7	7.6	12.3	8.4	7.2	
	Storm-flow	17.1	13.7	62.3	60.6	13.2	
	Baseflow	4.3	4.0	6.9	4.5	4.9	
TDS (mg/l)	Mean	53	55	92	125	56	500
	CV	0.2588	0.2779	0.4399	0.8225	0.2891	
	Dry Season	61.7	60.3	115.2	155	59	
	Wet Season	48.4	52.1	76.6	106	52	
	Storm-flow	37.3	33.7	43.3	77.7	37	
	Baseflow	56.6	59.8	101.5	130.9	60	

4.4.2 pH

Like temperature, the pH readings for Samoan streams exhibited very low CV values. The pH values remained constant around the neutral range both during the dry and wet seasons, and also in times of high and low flows (Table 4.16). The slightly acidic pH values of the waters are probably due to domestic and industrial effluents. The maximum pH values of 8.1 and 8.2 recorded at Fuluasou and Vaisigano rivers respectively (Appendix 8.2 and 8.5) reflect the basic nature of the dominant volcanic rocks present in the five catchment area as discussed in Section 4.2.

4.4.3 Turbidity

The average turbidity readings from the five streams ranged from 6.0 NTU at Fuluasou to over 21.0 NTU at Gasegase. However, both Gasegase and Mulivai streams recorded turbidity values in excess of 400 NTU in one of the storm events (Appendix 8.3 and 8.4). The variation of turbidity with discharge of the five streams is given in Figure 4.16. The dependence of turbidity on such factors as rainfall intensity, stream discharge and land use is indicated by the high CV values observed in all the streams, especially Gasegase and Mulivai (Table 4.16). Seasonal differences in turbidity readings varied between streams. Fuluasou and Vaisigano streams recorded marginally higher turbidity readings in the wet season, while Fagalii, Mulivai and Gasegase streams had higher turbidities in the dry season. During storm-flow events, all the five streams carried between four to fifteen times more material than base-flows. While this observation reflects the direct proportionality of turbidity values with stream discharges, especially during high rainfall periods (Figure 4.16), it also portrays the effect of human activity such as uncontrolled land clearing for agriculture on the catchment areas (Falkland and Brunel 1993). Of particular note was the fact that many of the turbidity values observed in the urban (and control) streams were greater than the 5 N.T.U. value recommended by the World Health Organization (1993).

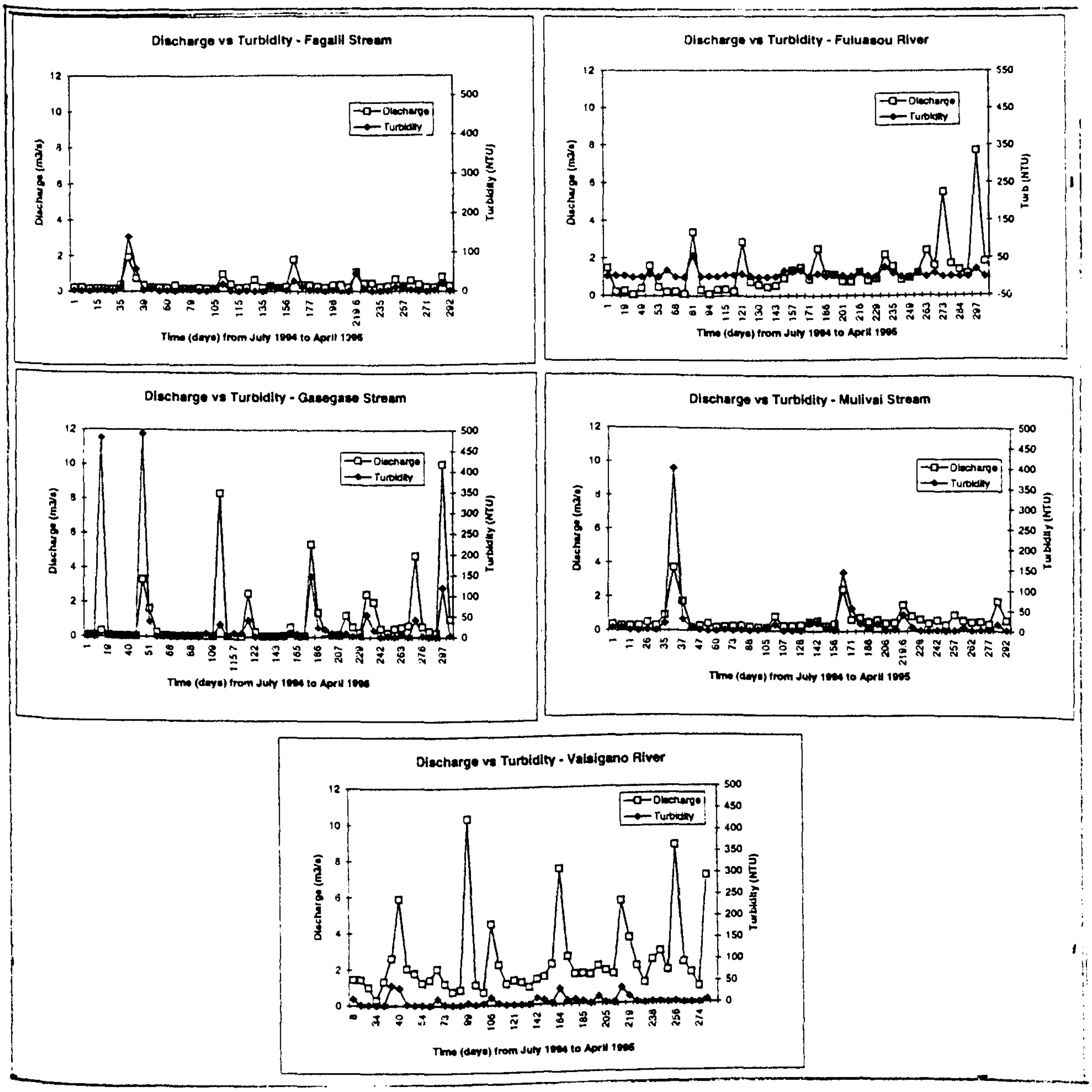

FIGURE 4.16: The Variation of Turbidity with Discharge for the Five Streams.
Source: Author's research

4.4.4 Suspended Solids

The relationship between suspended solids with flow for the five streams followed the trend observed with the turbidity readings, where high suspended solids concentrations were associated with periods of high stream discharges (Figure 4.17).

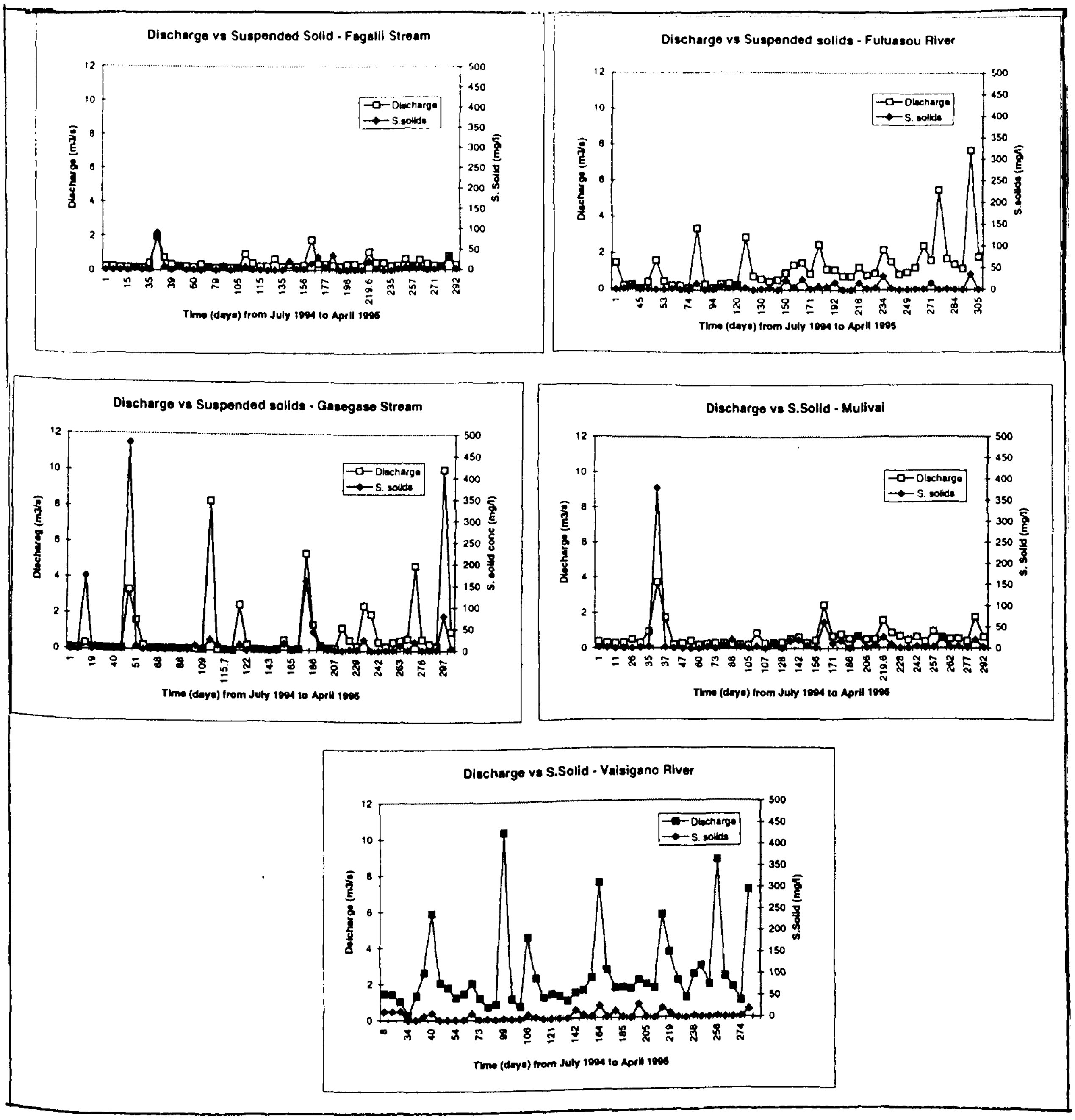

FIGURE 4.17: The Variation of Suspended Solids Concentration with Discharge for the Five Streams. Source: Author's research

Mulivai and Gasegase streams again registered high levels of suspended solids, and posted the highest CV values of the five streams examined, suggesting the large spread of suspended solids concentrations in these two streams. The variation of suspended solids concentrations observed for the five streams showed seasonal influences. Fagalii, Fuluasou and Vaisigano streams recorded higher suspended solids concentrations in the wet season, while Gasegase and

Mulivai streams posted higher suspended solids concentrations in the dry season (Table 4.16). The slower responses to rainfall of the former three streams may account for the observed result (Section 4.3.3), although the effect of human activity at the Mulivai and Gasegase catchments in the dry season cannot be ruled out.

It is noted that both Mulivai and Gasegase streams are displaying distinct water quality properties when compared to the Fuluasou and Vaisigano streams. This is probably due to urbanization and road construction, which has been shown to result in a five to twenty fold increase in suspended solid concentrations (Meybeck *et al.* 1989). Suspended solids concentrations are strongly influenced by flow conditions where a large proportion of the suspended sediment transport occurs during storm events when rainfall and storm runoff mobilizes sediment (Calow and Petts 1992). This is demonstrated in the suspended solids concentrations of the five streams by comparing storm-flows to base-flows (Table 4.16). Gasegase and Mulivai streams carried between nine and thirteen times more suspended solids during storm-flows, while Fagalii, Fuluasou and Vaisigano carried between two to four times more suspended solids during the same events.

4.4.5 Total Dissolved Solids

Total dissolved solids is a measure of the total inorganic constituents in the water column. As such, TDS is closely related to ionic composition and electrical conductivity of the water (Hownslow 1995). The average TDS concentrations for the five streams are given in Table 4.16, where not only lower values were recorded in the wet season compared to the dry season, but also lower values were noted in the storm-flow events when compared to baseflow events. This decrease of TDS values with increased flow is probably due to dilution of dissolved salts dissolved salts with fresh water runoff (Maunsell and Partners 1982). While an average TDS value of around 60 mg/l was found for Fagalii, Fuluasou and Vaisigano streams in both the dry season and during base-flows, Gasegase and Mulivai streams recorded two times as much TDS concentrations in these same episodes. This probably reflects the consequences of a greater urbanization effect on these two catchments.

The presence of suspended sediment or solids in river water can have a direct effect on aquatic life. An alteration in the concentration of either parameter can result in changes to organisms and their habitat (Muncy *et al.* 1979; Calow and Petts 1992). Sedimentation has been identified as one of the causes of marine pollution in the coasts of Samoa (Johannes 1982; Taylor 1991). Using the suspended solids and TDS concentrations measured, sediment yield and solute loads for the five catchments will now be calculated, to evaluate quantitatively their sedimentation inputs into the coastal zone.

4.5 SEDIMENT AND SOLUTE LOADS

Asquith *et al.* (1994) reviewed the present state of knowledge on the amounts and effects of suspended material transported to the ocean by rivers in the South Pacific, and estimated the quantities of nutrients, metals and organic substances entering the marine environment. Their estimate of annual sediment yields for the South Pacific island states was based on an empirical model, as extended or detailed sampling programs were impractical given the resources and the existing minimal primary data base. Asquith *et al.* 1994:3) admitted that:

> The estimate was made in the absence of any known comprehensive regional calculation of sediment yield, and the resulting estimate while largely unsubstantiated by measured sediment yield data provides a useful tool for the prediction of sediment yield magnitudes and patterns on a regional and sub-regional scale

Apart from the study by Asquith *et al.* (1994) Turvey (1975) recorded a sediment yield of 36.29 $m^3/km^2/yr$ for Ei Creek, while Clarke and Morrison (1987) noted erosion rates of 100 t/ha/yr from lands grown with sugarcane in Fiji.

Sediment yield in areas close to the Pacific region were calculated for Australia and Malaysia by Douglas (1968, 1973), where the Barron River and Millstream Creek in Queensland gave suspended solid denudation rates of 5.65 $m^3/km^2/yr$ and 6.15 $m^3/km^2/yr$ respectively. The value from Sungei Gombak from Malaysia was 24.9 $m^3/km^2/yr$. Griffith (1982) reported a denudation value of 28 x 10^6 t/yr for the Waiapu River of New Zealand.

Douglas's formula for calculating denudation rates has been adopted in this study, as it incorporated suspended sediment concentrations, water discharges and catchment areas - three parameters which were directly measured during the course of this study. According to Douglas (1968; 1975), the volumes of dissolved and suspended solids carried by streams past a certain point over a given period of time can be obtained by using the formula:

$$Q_s = C * Q_w / A_d * G$$

where Q_s is the dissolved or suspended load, C is the concentration of dissolved or suspended matter, Q_w is the discharge, A_d is the drainage area and G is the specific gravity of rocks in the drainage area. If all the parameters are measured in metric units and allowance is made for the units of time used in the discharge measurements, then the units of Q_s will be in $m^3/km^2/yr$. The average specific gravity of 2.65 assumed by Holeman (1968) in his calculations was used in this study for suspended and solute loads computations. As this value was also used by Asquith *et al.* (1994) to obtain total maximum sediment yields in their study, this allows for direct comparison of the results. Allowing for the units of time used in the discharge measurements and units of concentration, the formula used then became:

$$Q_s = C * Q_w * 60*60*24*365 / A_d * 2.6 * 1000$$

Using the same equation given by Douglas (1968) and average daily discharges, mean TDS and suspended solids concentrations measured from the five streams during the sampling exercise, annual sediment yields and solute loads were computed for the five catchment areas in Appendix 9.1 and listed in Table 4.17.

TABLE 4.17: Suspended Sediment Loads and Solute Loads for the Five Catchments. Source: Author's research

STREAM NAME	SUSPENDED LOAD	SOLUTE LOAD	TOTAL LOAD
FAGALII (area = 6.9 km^2)	4060 m^3/km^2/yr or 10556 t/km^2/yr or 72841 t/yr (10.8%)	33511 m^3/km^2/yr or 87130 t/km^2/yr or 601196 t/yr (89.2%)	674037 t/yr
FULUASOU (area = 25.7 km^2)	3318 m^3/km^2/yr or 8628 t/km^2/yr or 221757 t/yr (10%)	29852 m^3/km^2/yr or 77616 t/km^2/yr or 1994729 t/yr (90%)	2216486 t/yr
GASEGASE (area = 23.9 km^2)	6326 m^3/km^2/yr or 16449 t/km^2/yr or 393134 t/yr (14.5%)	36918 m^3/km^2/yr or 95988 t/km^2/yr or 2294111 t/yr (85.5%)	2687245 t/yr
MULIVAI (area = 7.5 km^2)	7873 m^3/km^2/yr or 20470 t/km^2/yr or 153523 t/yr (7.5%)	9836 m^3/km^2/yr or 255731 t/km^2/yr or 1917988 t/yr (92.5%)	2071511 t/yr
VAISIGANO (area = 33.8 km^2)	4915 m^3/km^2/yr or 12778 t/km^2/yr or 431914 t/yr (10.2%)	43186 m^3/km^2/yr or 112284 t/km^2/yr or 3795200 t/yr (89.8%)	4227114 t/yr
TOTAL (Area = 97.8 km^2)	1 273 169 t/yr	10 603 224 t/yr	11 876 393 t/yr
MEAN	254 634 t/yr	2 120 645 t/yr	2 375 278 t/yr

Notes : 1. An average specific gravity of 2.65 is assumed in the calculations
2. The values in brackets are percentages of the total (suspended and solute) load

It is evident from Table 4.17 that the suspended sediment loads of the five streams account for only 7% to 15% of the total loads. This means that the routine dismissal of solute loads as being insignificant in denudation estimates (Reading *et al.* 1994) does not hold true. The four urban catchments carried two to six times more suspended load than the Fagalii Stream. For all the five streams, the solute loads far outweighed the suspended sediment loads by as much as six to ten times. A total suspended sediment load for the five catchments came out to 1 273 169 t/yr, which is about 24% of the total maximum sediment yield value of 5 335 488 t/yr estimated for the whole of Upolu Island by Asquith *et al.* (1994). Comparison of the results in Table 4.17 with sediment loads calculated by Asquith *et al.* (1994) reveals the following. The total suspended sediment load for the five catchments is almost twice the maximum sediment yield given for Tutuila Island, American Samoa, about five times the total maximum load assumed for Rarotonga, Cook Islands, and on par with the total maximum sediment load assigned to Epi Island, Vanuatu. This indicates that Asquith *et al.* (1994) underestimated the sediment loads for Samoa, and possibly for other Pacific Island areas.

The suspended loads carried by the five streams during storm-flows, base-flows and in the dry and wet seasons were compared. The respective loads of the five streams expressed in $m^3/km^2/day$ (Table 4.18) shows that all five streams carried over 90% of their respective total sediment loads to the coastal zone during storm events. Gasegase and Mulivai streams in particular carried almost all of their sediment loads to the coast during storm events. There was no clear trend in the suspended loads carried by the five streams in the dry and wet seasons.

TABLE 4.18: Suspended Sediment Loads for the Five Streams according to Seasons and Flow Characteristics. Source: Author's research

STREAM	AREA (km^2)	DRY SEASON ($m^3/km^2/day$)	WET SEASON ($m^3/km^2/day$)	STORMFLOW ($m^3/km^2/day$)	BASEFLOW ($m^3/km^2/day$)
Fagalii	6.9	6.9 (34%)	13.6 (66%)	70.5 (93%)	5.1 (7%)
Fuluasou	25.7	1.8 (10%)	16.6 (90%)	61.0 (93%)	4.0 (7%)
Gasegase	23.9	17.5 (45%)	21.7 (55%)	381.1 (99%)	3.4 (1%)
Mulivai	7.5	20.7 (51%)	19.7 (49%)	395.4 (98%)	6.8 (2%)
Vaisigano	33.8	9.7 (34%)	18.9 (66%)	76.0 (90%)	7.9 (10%)

Suspended sediment loads from other areas in the Asia-Pacific region are given for comparison in Table 4.19, where catchments from Malaysia showed denudation rates of 3 755 $m^3/km^2/yr$ and 6 198 $m^3/km^2/yr$ at Station1 and Sungei Pasir respectively, which were comparable to those calculated from Samoa.

TABLE 4.19: Suspended Sediment Loads from Selected Areas. Compiled by author

CATCHMENT	AREA (km^2)	SEDIMENT YIELD	SOURCE
Sungei Gombak, Malaysia (Station1)	26.5	3755 $m^3/km^2/yr$ or 258712 t/yr	Douglas (1968)
Sungei Gombak, Malaysia (Sungei Pasir)	3.26	6198 $m^3/km^2/yr$ or 52531 t/yr	Douglas (1968)
Waipaoa Kanakanaia, NZ	1578.0	5 1616 $t/km^2/yr$ or 81 450 048 t/yr	Holeman (1968)
Kenya (forested area)		20 - 30 $t/km^2/yr$	Dunne (1979)
Kenya (wet, steep, culivated catchments)		>4000 $t/km^2/yr$	Dunne (1979)
Fly River, PNG	6100.0	30 000 000 t/yr	Pickup *et al.* (1981)
Purari River, PNG	3100.0	80 000 000 t/yr	Pickup *et al.* in Milliman and Meade (1983)
Fiji (sugarcane plantation)		100 000 $t/km^2/yr$	Clarke and Morrison (1987)
Sabah, Malaysia	0.18	900 $t/km^2/yr$	Malmer (1990)
Taiwan		14 000 $t/km^2/yr$	Milliman (1990)
American Samoa	145.0	656 596 t/yr	Asquith *et al.* (1994)
Cook Islands	67.2	248 972 t/yr	Asquith *et al.* (1994)
Epi Is, Vanuatu	444.0	1 763 405 t/yr	Asquith *et al.* (1994)

Note : A specific gravity of 2.65 is also assumed in the calculations where applicable

Milliman (1990) gave normalized sediment yields for drainage basins in the Asian region where the high sediment yield at Taiwan reflected that country's intensely cultivated lands. Malmer (1990) reported suspended sediment loss from a plantation forest in Sabah, Malaysia. Milliman (1990) argued that the very high input of sediments from islands in Oceania is because the smaller drainage basins common in these islands have less area to store sediments. This explanation probably applies to both Fagalii and Mulivai streams.

It is clear that the five streams are continually carrying huge quantities of material towards the coast every year. The contribution by the solute load of the rivers and streams of the five catchments (and consequently all of Samoa) to the sedimentation process is far too great to be ignored. Consequently, the problems associated with sedimentation in Samoa will worsen if watershed management and detrimental human activities in the catchment areas are not addressed soon.

4.6 CHEMICAL WATER QUALITY PARAMETERS

The average concentrations of the chemical water parameters extracted from the raw data in Appendix 10 are presented in Table 4.20. The discussion of salinity and sulphate parameters will be restricted to a look at their mean values as not only are these found in low quantities in the streams of Samoa, but they are also related to conductivity (Falkland and Brunel 1993).

4.6.1 Conductivity

This is a measure of the total ionic concentration of the water column, governed by contributions from rock sources, atmospheric deposition and balances between evaporation and precipitation (Wetzel and Lickens 1990). Human activities also contribute to a high concentration of ions in the water. Tropical waters that drain strongly weathered soils are usually poor in electrolytes (Wetzel 1975). This poor electrolytic status is evident from the average conductivity values for the five streams where Fagalii, Vaisigano and Fuluasou streams averaged around 120 mg/l (Table 4.20). Mulivai and Gasegase streams both had average conductivity values about two times higher than the other three streams. It is also evident from Table 4.20 that all the streams recorded lower conductivity readings in both the wet season and in storm-flows than at other times, further evidence that there is a dilution of ions with fresh water runoff during high flow times. The rather low CV values exhibited by all streams except

Mulivai indicates the independence of conductivity values of the five streams on the factors given by Wetzel and Lickens (1990).

TABLE 4.20: Average Concentrations of Chemical Water Quality Parameters for the Five Streams. Source: Author's research

WATER QUALITY PARAMETER		FAGALII	FULUASOU	GASEGASE	MULIVAI	VAISIGANO	UNPOLLUTED AVERAGE (Wetzel 1975)
Conductivity (uS/cm)	Mean	116	120	196	295	121	
	CV	0.1687	0.1416	0.3738	0.9178	0.2148	
	Dry Season	126	129	237	350	130	
	Wet Season	110	115	167	244	114	
	Storm-flow	90	97	100	156	90	
	Baseflow	121	125	214	300	127	
Iron (mg/l)	Mean	0.03	0.04	0.18	0.11	0.03	0.67
	CV	1.356	1.636	2.961	2.804	1.3076	
	Dry Season	0.02	0.04	0.2	0.08	0.03	
	Wet Season	0.02	0.03	0.07	0.13	0.03	
	Storm-flow	0.04	0.04	0.43	0.26	0.05	
	Baseflow	0.02	0.03	0.07	0.08	0.02	
Sulphate (mg/l)	Mean	2.4	3.1	5.5	5.4	2.4	11.2
	CV	1.2794	1.2703	1.402	1.2569	1.392	
	Dry Season	2.6	2.8	6.0	5.8	2.6	
	Wet Season	2.2	3.2	5.2	5.1	2.2	
	Storm-flow	4.4	5.0	12.8	15.8	3.0	
	Baseflow	1.9	2.6	4.1	4.2	2.2	
Total Nitrogen (mg/l)	Mean	4.4	2.5	13.2	18.1	3.7	10
	CV	1.559	1.3427	0.8289	0.7204	0.7578	
	Dry Season	4.8	1.9	15	18.6	4.2	
	Wet Season	4.2	2.9	11	17.6	3.3	
	Storm-flow	5.7	2.7	14	23.7	2.9	
	Baseflow	4.2	2.5	13	17.4	3.9	
Total Phosphorus (mg/l)	Mean	0.19	0.26	0.24	0.25	0.24	0.05
	CV	0.6899	0.6461	0.5586	0.4351	0.7014	
	Dry Season	0.21	0.22	0.26	0.25	0.23	
	Wet Season	0.17	0.29	0.22	0.25	0.23	
	Storm-flow	0.31	0.23	0.26	0.32	0.25	
	Baseflow	0.16	0.27	0.23	0.24	0.23	
Zinc (mg/l)	Mean	0.09	0.07	0.08	0.08	0.07	0.01
	CV	0.7503	0.8518	1.093	0.8522	0.7963	
	Dry Season	0.09	0.04	0.06	0.06	0.06	
	Wet Season	0.09	0.06	0.10	0.09	0.07	
	Storm-flow	0.08	0.04	0.05	0.07	0.07	
	Baseflow	0.09	0.06	0.09	0.08	0.06	

4.6.2 Iron

Natural waters contain variable but minor amounts of iron, normally present as the ferrous ion (Fe^{2+}). Iron is naturally found in igneous rocks as ferrous sulphide (FeS), iron pyrite (FeS_2), magnetite (Fe_3O_4), and sandstone rocks (Everett 1980). Elevated levels of iron can be found in waters prone to iron-bearing industrial wastes, effluents from pickling operations or from mine drainage (HACH 1971; Meybeck *et al.* 1989). Enzyme detergents and corrosive pipes are other sources of elevated concentrations of iron in waters (Forstner and Wittmann 1979).

The average iron concentrations of the five streams given in Table 4.20 are all within the 0.3 mg/l maximum permissible value for drinking water set down by the WHO (1993). However, the maximum values reported from Mulivai and Gasegase streams of 2.2 mg/l and 2.4 mg/l respectively were more than six times this value. If it is assumed that the average iron concentration recorded at Fagalii, Fuluasou and Vaisigano waters of 0.03 mg/l is representative of the background levels in Samoan streams, then the Mulivai and Gasegase streams contained five times more iron than background levels. These elevated levels of iron are attributed to industrial and domestic effluents, as all the streams are subjected to similar conditions of geological weathering. This was not surprising as the Mulivai and Gasegase streams have served as sinks for the inorganic and organic chemicals from the National Hospital and the Alafua Laboratory of the University of the South Pacific respectively for quite some time (Klinckhammers 1992). Although iron, as Fe^{2+}, can accumulate in sediments after biotic decomposition (Wetzel 1975), it is not clear that this is occurring at Mulivai and Gasegase streams, as often cases where iron and suspended solids peaked simultaneously coincided with high discharge values (Figure 4.18). The contribution of suspended solids to the iron content, therefore, is perhaps confined to isolated events. From Figure 4.18, there was a large peak in iron concentration in the Mulivai Stream in November 1994. On checking the field notes made at the time of collection, it was recorded that at the time of sampling at 6 p.m., there was a pronounced smell coming from the river. It seems probable that in November 1994 the data collection intercepted a dumped pollutant.

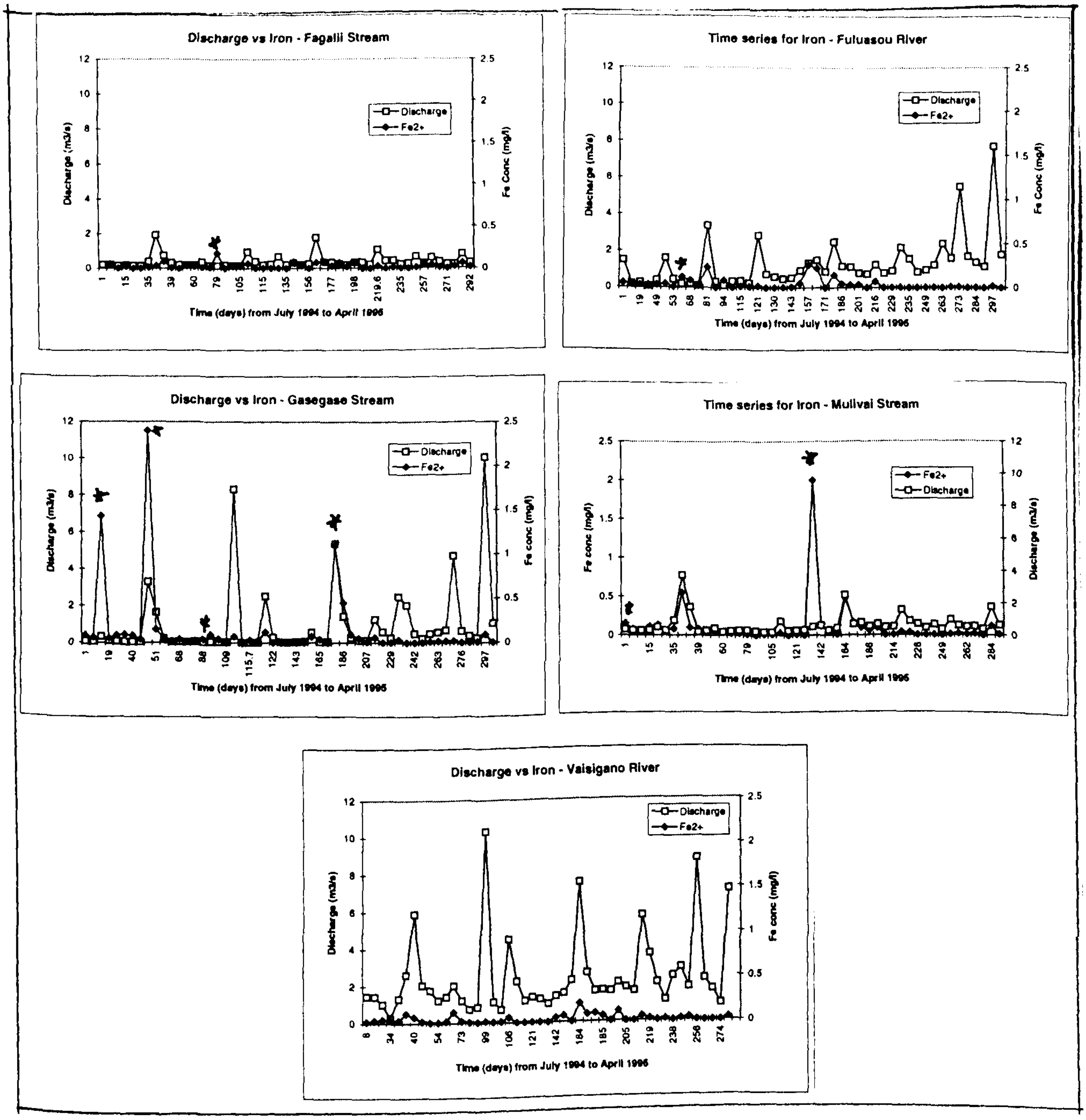

FIGURE 4.18: The Variation of Iron with Flow for the Five Streams. Stars indicate anomalous readings. Source: Author's research

A similar peak was observed in the Gasegase Stream in July 1994. As shown in Table 4.20, the variability of iron in all the stream waters is reflected in the high CV values recorded, most significantly Gasegase and Mulivai streams. The variation of iron according to season and flow characteristics appeared minimal for Fagalii, Fuluasou and Vaisigano. For Gasegase and Mulivai streams however, three times more iron w carried during storm-flows as compared to base-flows. The fact that Gasegase carried more iron in the dry season and Mulivai carried more iron in the wet season reflected the time the maximum iron concentration was picked up by the respective streams (Figure 4.18).

4.6.3 Zinc

Zinc exists naturally from rocks where mean values ranged from 40ppm in granites to 100ppm in basaltic rocks (Krauskopf 1972). Increased zinc concentrations in water stem from the release of zinc from drainage pipes due to corrosion and from enzyme detergents (Forstner and Wittmann 1979). Elevated levels of zinc also come from industrial waste-waters from industries like soft drinks and flavoring manufacture, laundry, ice cream factories, meat processing plants, galvanizing, candle and soap factories, bakeries and breweries (Klein *et al.* 1974). Zinc is also found in relatively abundant amounts in animal and human excretions gradually finding their way into the water environment (Meybeck *et al.* 1989). According to Forstner and Wittmann (1979), uncontaminated surface waters contain 0.01 to 0.015 mg/l of zinc.

The five streams under examination in Samoa were contaminated with as much as four to six times more zinc than expected for uncontaminated waters (Table 4.20). While the zinc concentrations in the urban streams would be elevated due to waste-waters from the soft-drinks and ice-cream factories, bakeries, breweries, laundries and soap factories abundant around Apia (Klinckhammers 1992), the high zinc levels from the Fagalii Stream probably points to the contribution from animal and human excretions (Meybeck *et al.* 1989). The greater effect of urbanization on the Mulivai and Gasegase streams is reflected not only on the highest zinc concentrations of 0.42 mg/l and 0.58 mg/l respectively being recorded in their waters, but also from the greater number of peaks occurring independently of discharge in their time series graphs (Figure 4.19).

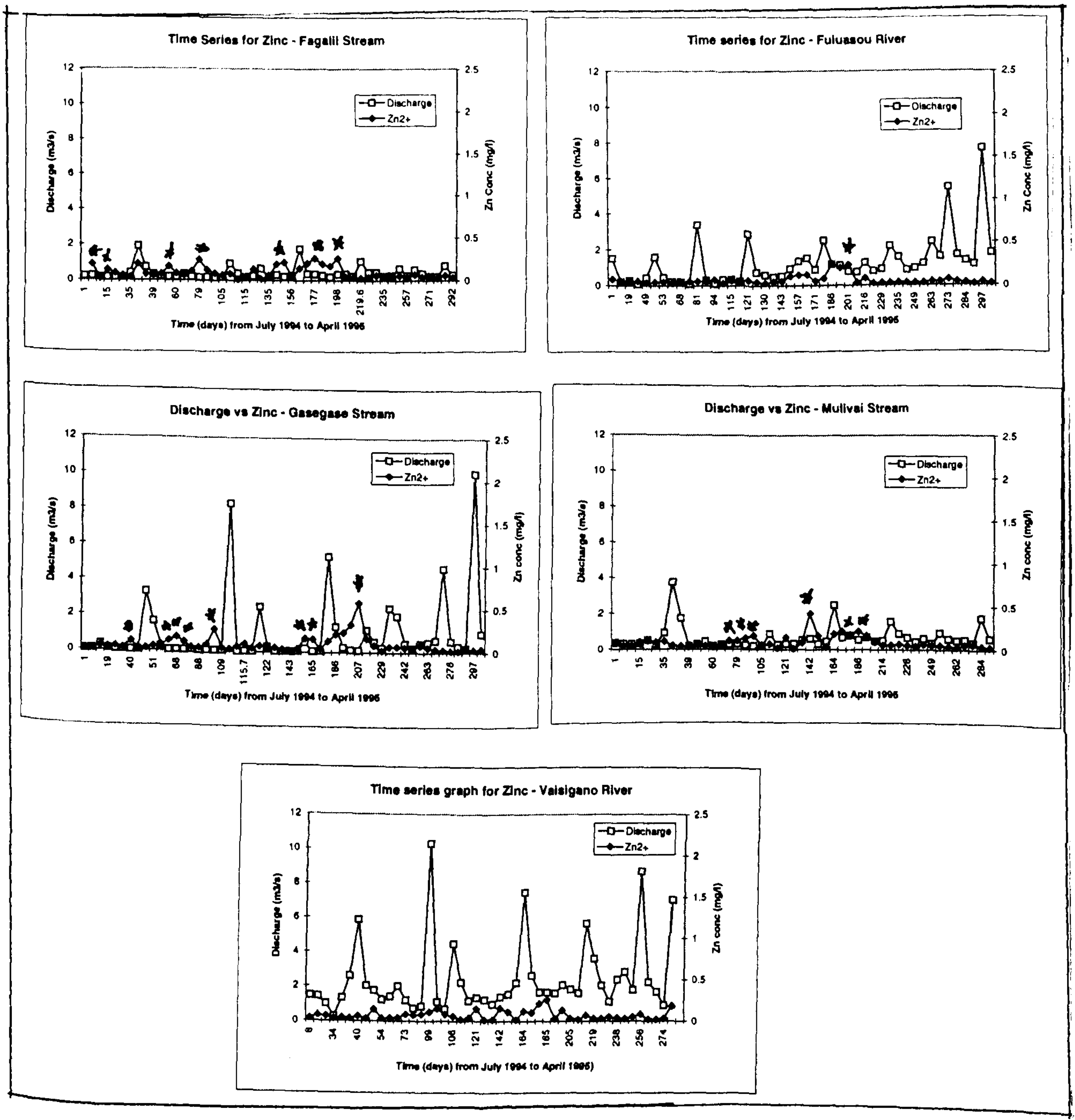

Figure 4.19: The Variation of Zinc with Discharge for the Five Streams. Stars indicate anomalous readings. Source: Author's research

The variation of zinc concentrations due to seasonal and flow characteristics were the same for all the five streams, where about equal amounts were carried to the coast during the two seasons, and in times of storm-flows and base-flows (Table 4.19).

4.6.4 Sulphate

Sulphate occurs in water from parent rock weathering (Ishii 1984). Elevated concentrations of sulphate are found in effluents from mining activities, industrial and domestic effluents, from the use of fertilizers and the use of sulphuric acid. The guideline value given by the WHO for sulphate in drinking waters is 250 mg/l. Relatively high concentrations of sulphate are found in waters of regions containing volcanic rocks with significant quantities of sulphides (Morrison *et al.* 1984). According to these authors, sulphate ions are released into solution when sulphides react with water, and unless suitable ions in significant amounts precipitate the sulphate out, relatively high quantities of sulphate will stay in solution.

The average and maximum sulphate concentrations found in the five streams revealed that sulphate pollution is not a threat in the waters of Samoa (Table 4.20). The highest concentrations of 46 mg/l and 36 mg/l found at Gasegase and Mulivai streams respectively were about five times lower than the allowable limit for drinking water standards given by the WHO (1993). Although the waters of the country would naturally be high in sulphate concentrations due to basaltic rocks (Ishii 1984), elevated amounts observed in the Mulivai and Gasegase streams are probably from chemical wastes.

Figure 4.20 is a time series plot of discharge and sulphate concentrations for the five streams. The difference between the dry season from July to October (Days 1-155), and the wet season from November to May is apparent in the discharge plots. In general, Fagalii Stream registered high sulphate values whenever there was high discharge, although on three occasions during the dry season, sulphate concentrations peaked in the absence of discharge peaks.

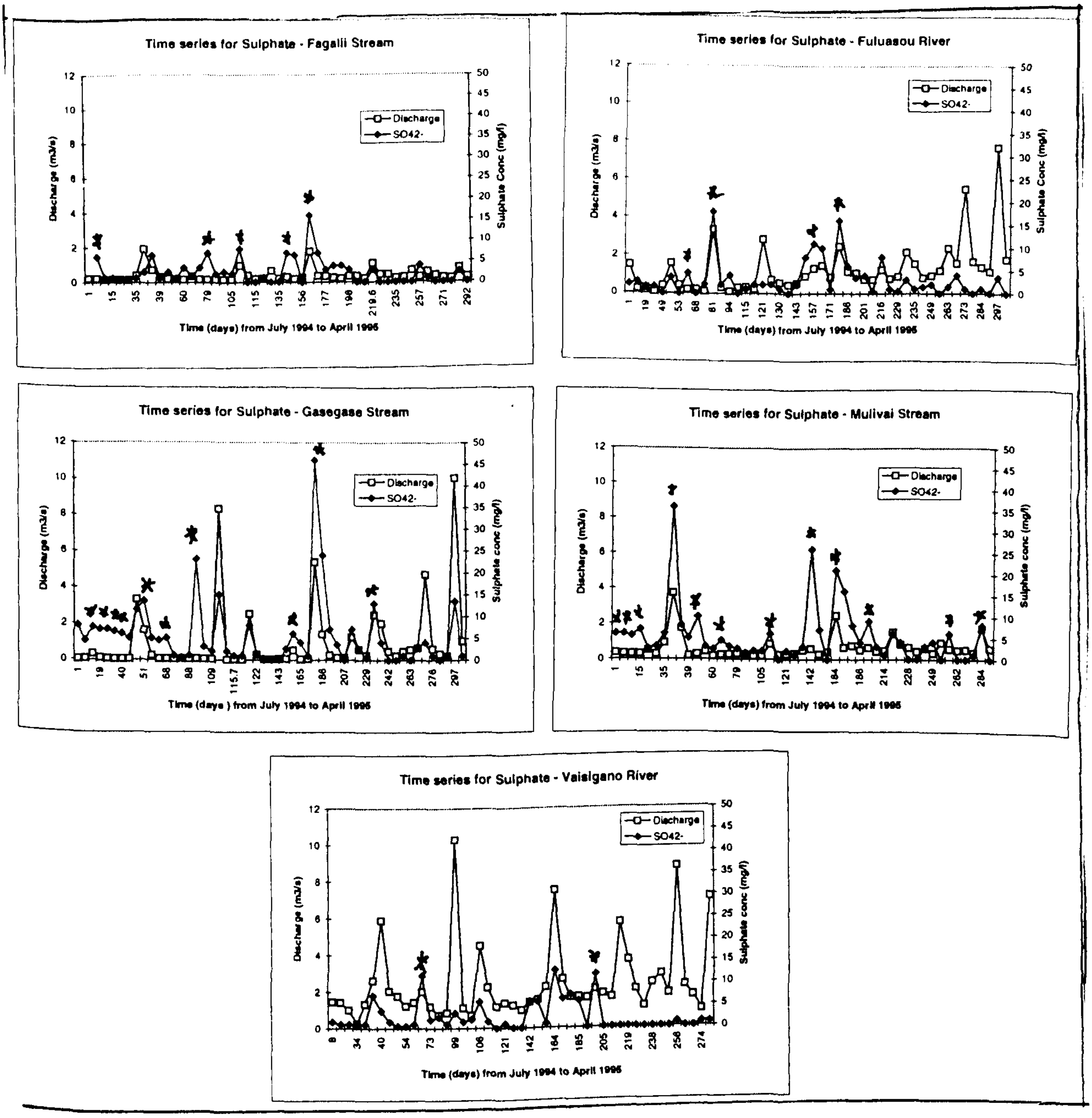

FIGURE 4.20: The Variation of Discharge with Sulphate for the Five Streams. Stars indicate anomalous readings. Source: Author's' research

The same general pattern occurred for the urban streams. Mulivai and Gasegase streams, in particular, recorded large peaks independent of discharge in August and November 1994. It is possible that at this time, chemical wastes were sampled. Fuluasou and Vaisigano rivers recorded fewer such peaks. The sulphate time series plots were found to correlate with the turbidity pattern, suggesting that the sulphate particles were transported along the streams by being adsorbed on the soil particles. Gasegase and Mulivai streams carried substantially more sulphate during storm-flows than the other three streams.

4.6.5 <u>Total Nitrogen</u>

Nitrogen accumulates mostly in living organisms and where it is bound with living organic matter or humus (Orlov 1992). Waters with low nitrogen content contain less than 0.25 mg/l, and rivers through mountainous regions contain up to 1.0 mg/l (Vollenweider 1971). Meybeck *et al.* (1989) noted that the concentration of nitrogen expressed as nitrate-N (as done in this study) in unpolluted surface waters ranges from 0.1 mg/l to 1.0 mg/l. Levels in excess of these values indicate anthropogenic influences such as municipal waste, urban and agricultural runoff. These factors are probably the main causes of the elevated values of nitrogen observed in the waters of the five streams where Fagalii, Fuluasou and Vaisigano contained up to five times higher nitrogen values, while Mulivai and Gasegase streams registered up to eighteen times the unpolluted nitrogen limit (Table 4.20). The nitrogen-time series graph (Figure 4.21) shows that nitrogen values peaked independently of discharge. It is thought that the unusually large peaks at Fagalii Stream are the effects of land cultivation in the upper reaches of the catchment area. Here, fertilizer is used in the plantations and plantation workers use the forest as latrines. Herds of cattle, pigs and chicken raised in plantation plots roam close to the stream channel. It was also noted that the presence of nitrogen in the waters of the five streams was not selective. Rather, it occurred in substantial amounts throughout the sampling period, as reflected by the almost equal quantities of nitrogen carried by the five streams both in the dry and wet seasons, and during storm-flows and base-flows (Table 4.20). The fact that sampling took place in abnormal conditions may affect the analysis of the water samples (Section 3.1.2).

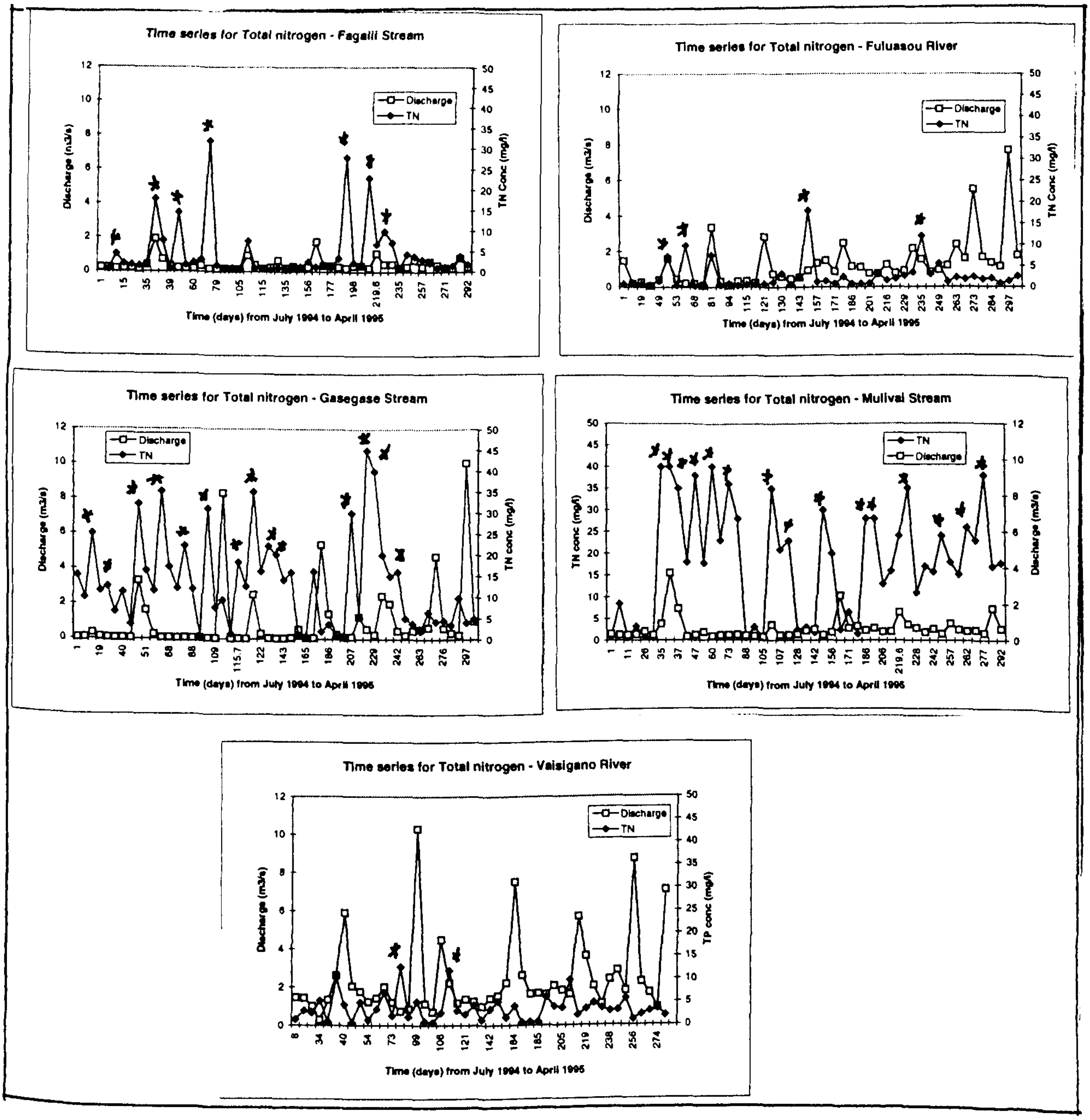

FIGURE 4.21: The Variation of Nitrogen with Flow for the Five Streams. Stars indicate anomalous readings. Source: Author's research

4.6.6 Total Phosphorus

Both phosphorus and nitrogen are organogenic, and their accumulation is associated with the accumulation of organic matter (Orlov 1992). The concentration of phosphorus in uncontaminated surface waters is between 0.01 to 0.05 mg/l and depends mostly on the geochemical structure of the region (Wetzel 1975). Increased levels of phosphorus are from application of fertilizers and urbanization discharges to surface waters. Weible (1969) found elevated phosphorus levels to be in direct proportion to population densities, storm sewage drainage, domestic sewage and cleaning detergents. Figure 4.22 gives the variation of total phosphorus with discharge for the five streams.

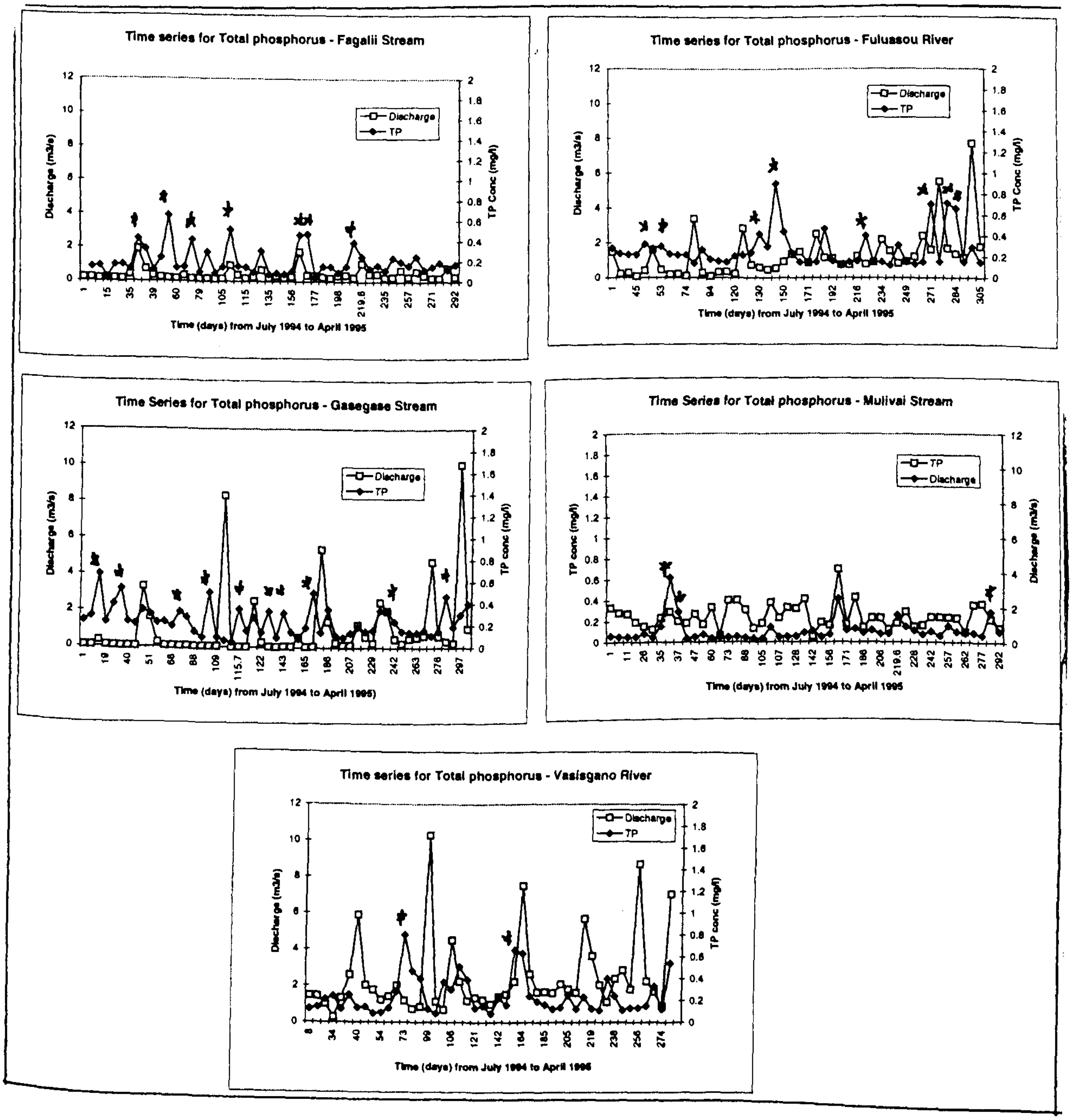

FIGURE 4.22: The Variation of Phosphorus with Flow for the Five Streams. Stars indicate anomalous readings. Source: Author's research

It is clear from Table 4.20 that the five streams are contaminated with relatively high levels of phosphorus, where average values ranged from 0.19 mg/l for Fagalii Stream to 0.26 mg/l for Fuluasou River, which are four to five times higher than the unpolluted value. The medium CV values exhibited by all the streams reflect the rather uniform distribution of phosphorus values between the seasons and during storm-flows and base-flows. This is further evidenced from the time series plot where high phosphorus levels occurred independently of high discharges throughout the sampling regime (Figure 4.22). Although Wetzel (1975) noted that phosphorus release from the sediment doubles if the sediments are disturbed, as is the case with flowing water, this was not evident from the results obtained.

The findings of the preceding sections can be summarized thus far. Gasegase and Mulivai streams registered higher values for turbidity, suspended solids, TDS, conductivity, iron, total nitrogen and total phosphorus compared to the other three streams. All the five streams are contaminated with nitrogen, total phosphorus and zinc, and recorded excessive turbidity levels. Gasegase and Mulivai streams are contaminated with iron. The contaminants are carried to the coastal zone almost exclusively in times of high flows. The elevated levels of contaminants were quite substantial in the Mulivai and Gasegase streams. A closer look at the urban-rural relationship continues in the next section.

4.7 COMPARISON OF URBAN AND RURAL WATER QUALITY

4.7.1 Comparison of Urban and Rural Streams

The comparison of cumulative frequency curves is adopted for use here as it was in Chapter Three. Not only is this technique useful when two sets of data are compared, but, also, trends in water quality can be determined when the test is applied. The cumulative frequency curves for turbidity, suspended solid, TDS, conductivity, iron, total nitrogen, total phosphorus and zinc have been drawn for the five streams as given in Figure 4.23.

While the mean values for turbidity and suspended solids for the Gasegase and Mulivai streams were higher than the other three streams (Table 4.16), the cumulative frequency curves for these parameters showed that it is only when extremely high values are recorded that the difference in turbidity and suspended solids concentrations between the five streams are prominently displayed [Figures 4.23(a) and (b)]. According to Figures 4.23 (a) and (b), these low probability occurrences are encountered for only 10% of the time. For the most part, however, turbidity and suspended solid values were deemed comparable between the rural and urban streams. This similar trend is observed with the distribution of iron in the five streams as shown by the cumulative frequency curve of iron in Figure 4.23 ©. What is apparent is that the difference in iron values between the urban and rural streams were negligible in low concentrations. The distinct difference emerged when maximum iron levels were recorded in the stream waters, and, like turbidity and suspended solids, these elevated levels of iron occurred only 10% of the time. The cumulative frequency curves for conductivity and TDS for the five streams given in Figure 4.23 (d) and (e) respectively were almost identical and not surprisingly so as these two water quality parameters are inter-related (Falkland and Brunel 1993; Hownslow 1995). The TDS curve shows that the urban streams of Gasegase and Mulivai contained higher TDS values than the Fagalii, Fuluasou and Vaisigano streams: the difference again becoming more pronounced at high TDS readings. From the curve, it is seen that for the Fagalii, Fuluasou and Vaisigano streams, 90% of their TDS values were below 70 mg/l. For Gasegase and Mulivai streams, the corresponding TDS values were 130 mg/l and 180 mg/l respectively, reflecting at least a two-fold increase.

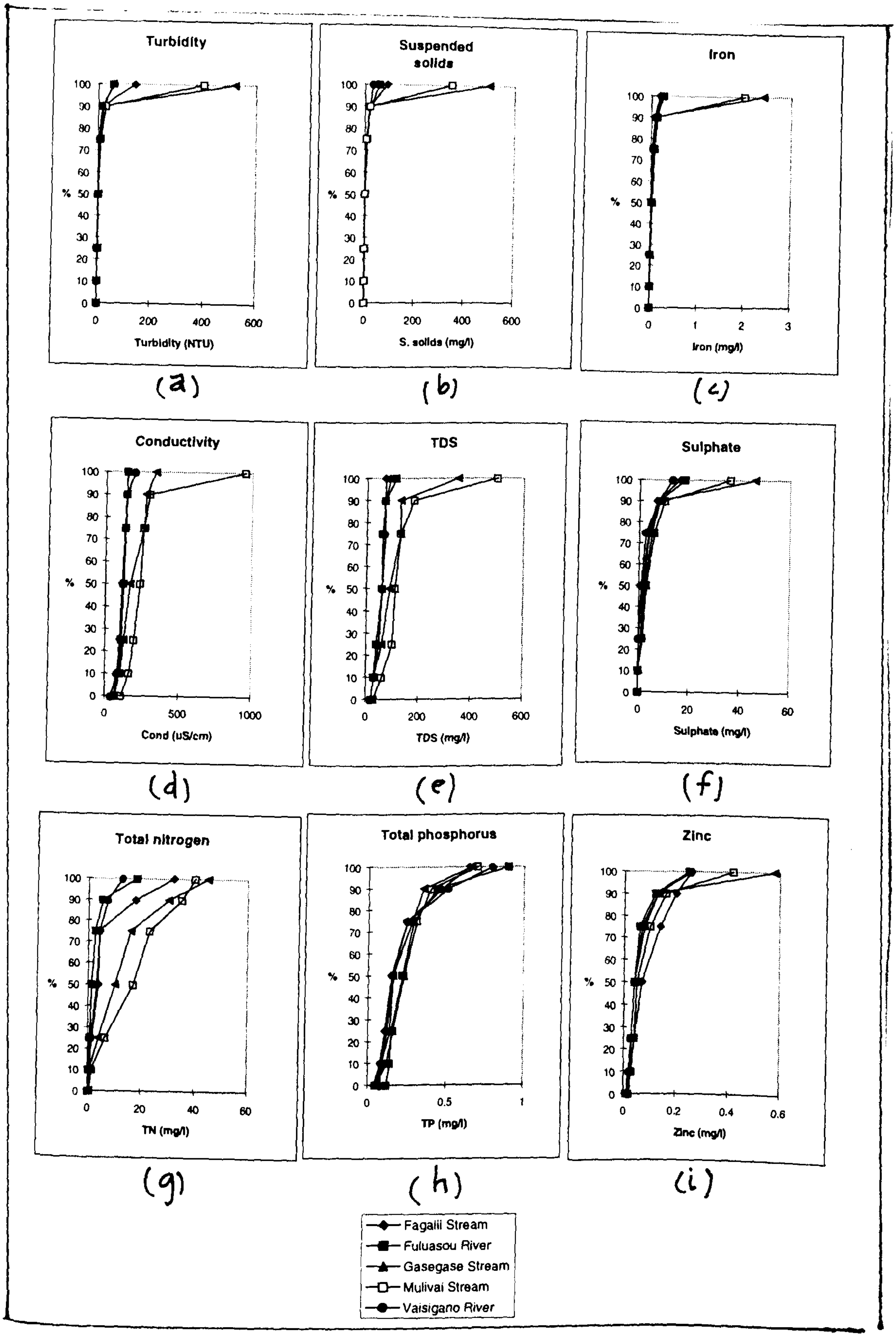

FIGURE 4.23: The Cumulative Frequency Curves of Selected Water Quality Parameters for the Five Streams. Source: Author's research

The same result is shown by the cumulative frequency curve of conductivity for the five streams in Figure 4.23 (d), where the Gasegase and Mulivai streams exhibit consistently higher conductivity values.

The cumulative frequency curves of sulphate and total nitrogen for the five streams are given in Figure 4.23 (f) and (g) respectively. Although the Gasegase and Mulivai streams noted higher sulphate concentrations than the Fagalii, Fuluasou and Vaisigano streams in Table 4.20, the cumulative frequency curve showed that this is true only 70% of the time, and is only distinct for the 75th percentile. Beyond this point, Gasegase and Mulivai streams displayed higher sulphate concentrations than the other three streams.

It is the total nitrogen cumulative frequency curve that clearly shows differences between the five streams [Figure 4.23 (g)]. The curve showed that Gasegase and Mulivai streams contained significantly more nitrogen than the rural Fagalii stream and the Fuluasou and Vaisigano rivers, as was recorded in Table 4.20 and Section 4.6.5. The total nitrogen concentrations of 16 mg/l and 23 mg/l for Gasegase and Mulivai streams respectively contributed to the values contained in the top quartile. The total nitrogen values for which the five streams were similar were for values less than 5.0 mg/l. At the 90th percentile the Fagalii value increased three-fold to 18 mg/l. Arguably, it is felt that the urbanization effect is clearly evident between the 10th and 75th percentile, where the total nitrogen contents of the Gasegase and Mulivai streams increased while those of the other three streams remained constant at less than 5.0 mg/l [Figure 4.23 (g)]. Above the 75th percentile point, it is thought that the contribution from agricultural runoff is dominant for all catchments.

The cumulative frequency of total phosphorus for the five streams did not reveal the distinct urban-rural difference in the five streams that were depicted in the previous water quality parameters [Figure 4.23 (h)]. Rather, it substantiates the claim made earlier in Section 4.6.6 that all the five streams are contaminated with phosphorus. In fact, the curves show that the Fagalii, Fuluasou and Vaisigano streams appeared to be slightly more contaminated with phosphorus than the Gasegase and Mulivai streams. Ninety percent of the phosphorus readings of all the Fagalii, Fuluasou and Vaisigano streams were lower than 0.4 mg/l, and for the Gasegase and Mulivai streams readings were lower than 0.3 mg/l.

The observed phosphorus distribution may be accounted for as follows. There is either a much higher contribution of total phosphorus from domestic sewage, cleaning detergents in the rural areas; or, agricultural runoff in the five catchment area is much more than expected; or, the contribution from other water quality parameters such as suspended solids and iron to the overall phosphorus content is significant. The presence of contaminated levels of phosphorus in all the streams highlights the absence of a reliable sewage system in the Apia urban and adjacent areas.

The cumulative frequency of zinc for the five streams given in Figure 4.23 (I) shows that higher zinc values for the urban streams were evident only in the high concentration range. While the five streams recorded comparable zinc concentrations up to the 25th percentile, the elevated zinc levels in the Fagalii Stream from then on to the 90th percentile was conspicuous. The correspondingly high levels of total nitrogen and total phosphorus noted at the Fagalii Stream points strongly to a contribution from animal and human excretions from the plantation lands in this catchment (Section 4.6.5).

So far, it seems that Fuluasou and Vaisigano rivers exhibit physical and chemical characteristics comparable to those of the rural Fagalii Stream as noted in Tables 4.16 and 4.20. Further, Mulivai and Gasegase streams seem to be subject to greater pollution than the Fuluasou and Vaisigano rivers, probably because they have smaller catchments and carry less flow to dilute the contaminants. The next part of the discussion is aimed at verifying the validity of this comment and in the process to quantify the amounts of nutrients being carried by the five streams into the coastal environment near urban Apia.

4.7.2 The Nutrient Loadings

Material loadings is one of the statistical techniques listed by UNESCO/WHO (1978) as useful in examining water quality data. This technique is adopted for use here, given that the actual concentrations and corresponding discharge values of the five streams were calculated in this sampling exercise. Loading values are obtained by multiplying the concentration by the discharge value at the time of sampling as indicated by the expression:

$$l = f \text{ x } c \text{ x } d$$

where l is the total load, f is the units' conversion factor, c is the concentration of nutrients and d is the discharge. As the units used in the sampling exercise for c and d were mg/l and m^3/s respectively, the conversion factor was 86.4 (UNESCO/WHO 1978). The loadings of total nitrogen and total phosphorus were calculated accordingly, then divided by the respective drainage areas to account for the dilution effect of the larger streams. The nutrient loadings of the five streams in $kg/km^2/day$ are listed in Table 4.21.

TABLE 4.21: The Total Nutrient Loadings of the Five Streams.
Source: Author's research

STREAM	TOTAL NITROGEN LOAD ($kg/km^2/day$)		TOTAL PHOSPHORUS LOAD ($kg/km^2/day$)	
	Total	Mean	Total	Mean
Fagalii	1291	15.8	59.0	0.67
Fuluasou	618	6.7	62.0	0.63
Gasegase	2529	27.0	51.5	0.53
Mulivai	5875	70.4	78.8	0.88
Vaisigano	1194	13.4	82.0	0.85
TOTAL	11507		333.3	

From Table 4.21, it is seen that the urban Gasegase and Mulivai streams are carrying nitrogen to the coastal zone at a much higher rate than the Fagalii, Fuluasou and Vaisigano streams. In fact, these two urban streams carry over 73% of the overall total nitrogen load of the five catchment areas. The total nitrogen load carried by the five streams was calculated to be 11 507 $kg/km^2/day$, or 411 605 t/yr.

For total phosphorus loads, the same trend was observed, where all the five streams carried comparable phosphorus loads. The total phosphorus loading for the five streams was 333 $kg/km^2/day$ or 11 887 t/yr, almost thirty five times lower than the total nitrogen loading. The same pattern of nitrogen and phosphorus distribution is reflected in their respective loading cumulative frequency curves given in Figure 4.24.

What is perceived from Figure 4.24 is the similarity in the patterns of the loading curves and the frequency curves given in Figures 4.23 (g) and 4.23 (h) for total nitrogen and total phosphorus respectively. It seems that incorporating the drainage areas into the equation made no difference to the relative amount of contaminants carried by the respective streams. Therefore, it is concluded that the higher nutrient levels carried by the urban streams of Gasegase and Mulivai was principally due to a higher rate of human induced activities in their catchment areas, and not related to either discharge or the size of the catchment.

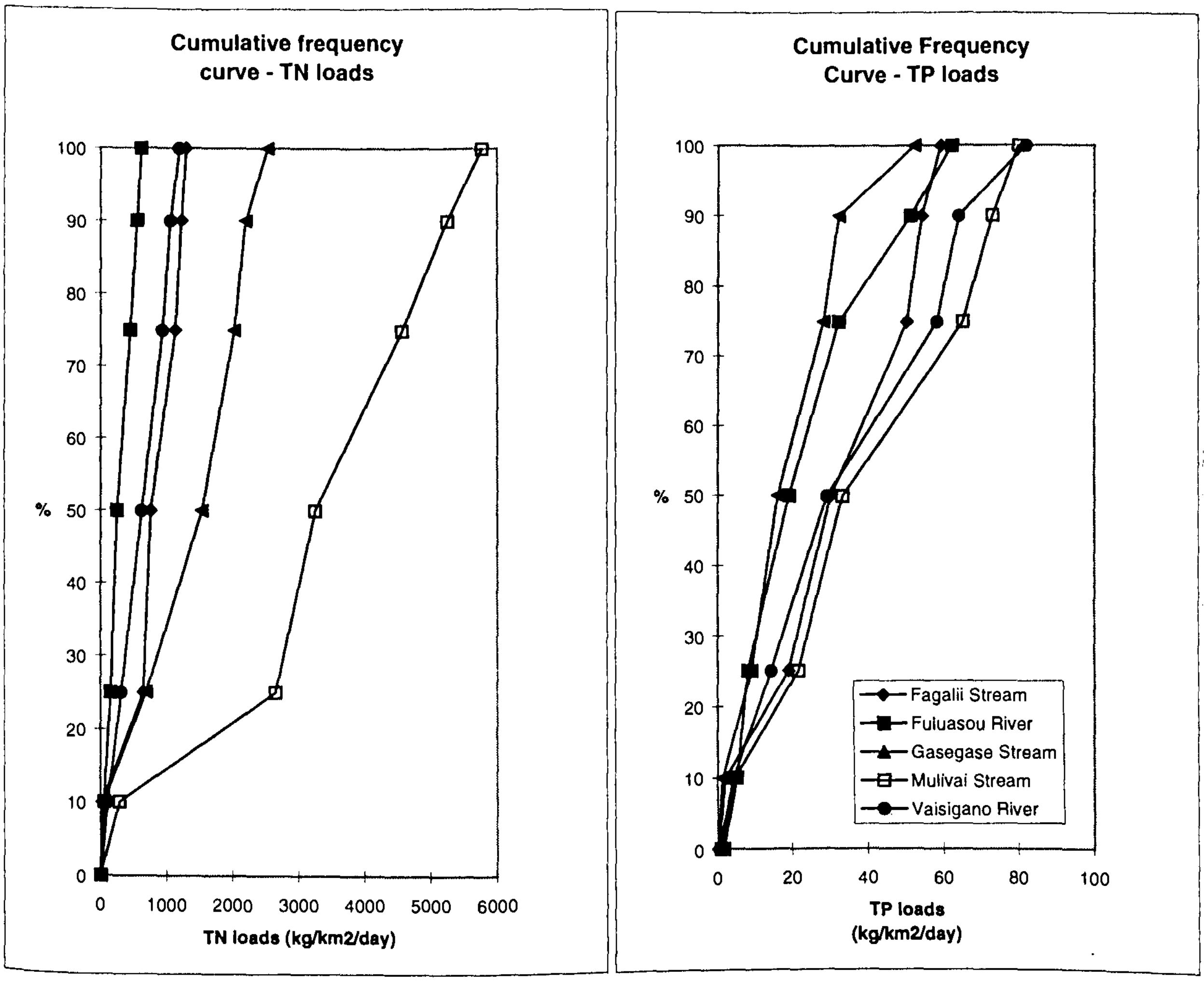

FIGURE 4.24: The Cumulative Frequency Curves of Nitrogen and Phosphorus Loadings for the Five Streams. Source: Author's research

In light of the results of Sections 4.4 and 4.6, it is becoming obvious that Gasegase and Mulivai streams are subjected to more pollution than the other three streams. Gasegase and Mulivai streams possessed significantly higher conductivity, TDS, sulphate and total nitrogen than the Fagalii, Fuluasou and Vaisigano streams as evidenced from the cumulative frequency curves of these parameters given in Figures 4.23(f) and 4.23(g) respectively. Gasegase and Mulivai also contained elevated levels of turbidity, suspended solids, iron and zinc but only in the few instances of extremely high concentrations as noted in Figures 4.23(a), 23(b) and 23(c).

From these findings, it is concluded that only the Mulivai and Gasegase streams are adversely affected by urban activities.

4.7.3 Discussion of the Results Observed

What then are the main factors contributing to the results observed? In the case of the non-urban streams, it is apparent that many streams displayed high turbidity and suspended solid values. The main factor contributing to these results is the unregulated clearance of native forests to make way for family plantation expansion (Taulealo 1993). Not only are the native forests cleared, but Samoan families actively maintain a weed-free plantation environment, which sometimes promotes the exposure of soils to rain splash action and the resultant movement of particulate matter downslope and downstream. As noted by Stednick (1990), the clearance of plantation and forestlands and particularly the practicing of shifting agriculture on steep slopes and riverbanks without buffer zones, is common in the Vaisigano catchment. The role of cyclones in clearing forests was very evident in 1990 and 1991 when Ofa and Val struck (Chase and Veitayaki 1992).

The variable pattern of nutrient concentrations in non-urban streams, as typified in Figures 4.21 and 4.22 are probably the result of land use activities close to the coast. In all non-urban settings, the local streams are used both as a source of drinking water and a sewer to remove unwanted liquid waste. Plate 3.5 depicts the Salesatele Stream in the Fagaloa Bay area, and illustrates the proximity of dwellings and out-houses to the streams that is typical of most

Samoan villages. Toilets are typically placed adjacent to streams in the absence of communal sewage collection or disposal systems. Zann (1991) reported that many lagoons in the non-urban areas of Samoa are nutrient rich due to human wastes. It is apparent that the sporadically elevated nutrient values found in this study are related to inappropriate disposal of human waste. The use of the streams for washing clothes (Plate 4.2) or the fact that unpenned pigs are allowed to roam freely in river environments may also contribute to the results obtained.

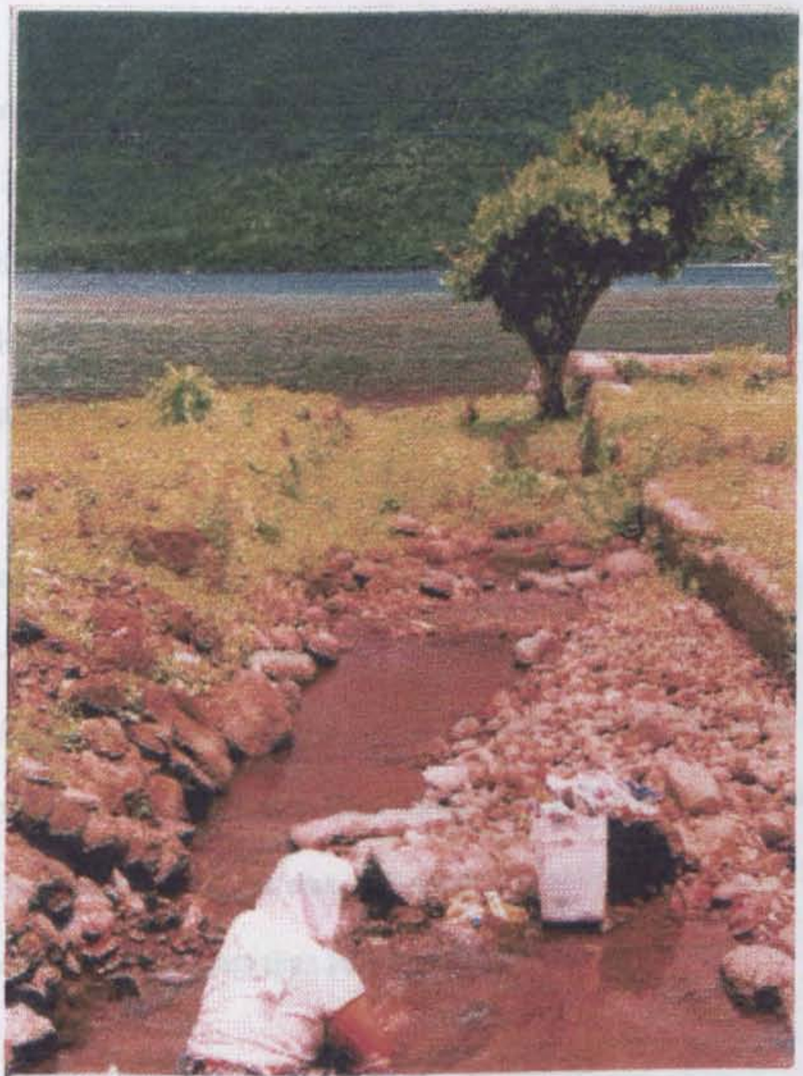

Plate 4.2: Musumusu Stream in the Fagaloa Bay area being used to wash clothes. Photograph by author

In addition, it is possible that the application of phosphate-based fertilizers such as superphosphate to the plantation lands have contributed to the peaks in phosphorus that are independent of discharge peaks. The use of pesticides by the local community as a fish harvesting technique has polluted water catchment reservoirs (Stednick 1990).

Thus, the background levels of particulate matter and nutrients in the non-urban streams of Samoa are surprisingly high. Even so, the role of urbanization on the water quality of the Samoan streams is pronounced. The two urban streams monitored in the Apia area revealed elevated T.D.S., suspended solids, turbidity, conductivity, sulphate, iron, total nitrogen, total phosphorus and zinc values. For Mulivai and Gasegase streams, peaks in sulphate, iron, nitrogen, phosphorus and zinc occurred independently of high discharge values. As was the case for the non-urban streams, human waste may account for some of the anomalous nutrient readings, but are not responsible for all the other peculiar inorganic values obtained. Domestic sewerage, cleaning detergents and a higher population density are other documented sources of pollutants (Weible 1969).

As mentioned in Section 2.6.3, most industrial activity in Samoa is centered on Apia. Of the industries located in the Apia urban area, those located within the catchments of the Fuluasou, Gasegase, Mulivai and Vaisigano streams which produce liquid waste are detailed in Table 4.22. The majority of the liquid effluent from industrial activity in Apia is disposed of directly or indirectly into adjacent fluvial systems. It is apparent from Table 4.22 that Mulivai and Gasegase streams receive more pollutants than Fuluasou and Vaisigano rivers.

Pollutants which find their way into the water courses flowing through Apia include dust, grease, diesel, oil, fruit residues, sugar residues, milk residues, organic residues, cleaning chemicals, acidic materials, paints, caustic soda, mineral oil and unused laboratory chemicals.

TABLE 4.22: Industrial Waste finding its way into Streams in the Apia Urban Area. Source: Adapted from Klinckhamers (1992)

Industry Name	Industry Type	Pollutants contained within wastewater	Site of waste disposal
Air Cool and General Refrigeration	Imports and repairs air conditioners and refrigerators	Dust and grease	Enters Mulivai Stream
Apia Bottling	Bottling drinks	Residual sugars and cleaning chemicals	Discharged into Mulivai Stream
Apia Bottling – fruit juices	Bottling fruit juice drinks	Fruit residues and cleaning waters	Discharged to a sump hole in Mulivai Stream catchment
EPC – Upolu	Power plant for Upolu	Diesel and oil	Flushed into the Vaisigano River
H.J Keil and Company	Sale of car spare parts	Rubber and oil parts and tyres, tyre repairs	Enters a drain emptying into Fugalei River
Icecream Factory	Icecream production	Milk and sugar and acidic material	Discharged to a soak hole in Mulivai Stream catchment
Island Styles	Manufacture of garments, soaps and printed textiles	Wasted paint	Not specified; factory is about eight km from the coast in Vaisigano River catchment
Manuia Breweries	Local beer brewing	1 - 2 tonnes / day of liquid waste	Released into Fugalei Stream
Photo Mart	Development and printing of film	Developer and bleach	Waste removed to Vaitoloa dumpsite in Vaiusu Bay
Rees Refrigeration Services	Repair of freezers, air conditioners and refrigerators	Dust and grease	Enters Gasegase River
Talofa Wines	Wine producer	Organic waste and caustic soda	Same site as 'Island Styles'; waste dumped in the garden
Aggie Greys Hotel	Largest hotel in Samoa having 154 rooms	Minimal liquid waste	On banks of Vaisigano River; septic tank and soakage field system minimizes pollution
Ah Kam's Motel	Small motel of 10 rooms	Minimal liquid waste	In Mulivai Stream catchment; sewage pollution minimal
Motel Insel Fehmarn	Large motel with 54 rooms	Minimal liquid waste	In Mulivai Stream catchment; sewage pollution minimal
Temple View Lodge	Small accommodation quarters	Minimal liquid waste	In Pesega Creek catchment; sewage pollution minimal
Valentine Parker's Accommodation	Small motel with 12 rooms	Minimal liquid waste	In Fugalei Stream catchment; sewage pollution minimal
Motootua National Hospital	Hospital and laboratory	Chemicals, blood samples, drugs, contaminated dressings and sewage effluent	All chemicals and blood discharged into a drain leading into Mulivai Stream; sewage treatment minimal; some solid waste enters river
University of the South Pacific	Chemical laboratories	Ethanol, methanol, KCl, NaOH, H_2SO_4, NH_4OAc, $K_2Cr_2O_7$, $CuSO_2$, H_2PO_2, HNO_3, $HClO_4$, H_2O_2 and mineral oil	Dumped into a ravine which is a tributary of the Gasegase River

The most worrying contaminants to the Apia community finding their way into the Mulivai Stream are the chemicals, blood samples, drugs, contaminated dressings and sewage effluent from the Motootua National Hospital. It is little wonder that the Apia water quality sampling program recorded some unaccounted peaks in inorganic substances, given the substances

Klinckhamers (1992) recorded finding their way into the streams. It is probable that a coliform count would have been extremely high in the Mulivai Stream had ~~this~~ parameter been measured.

In conclusion, it has been proven statistically that there are significantly more contaminants in the urban streams of Apia than in the rural streams. The danger time for elevated levels of suspended solids, turbidity, sulphate and iron is immediately following storm events in the dry season. Total phophorus, total nitrogen and zinc contents in all the streams examined were high all the year round. Both the suspended sediment and solute loads carried by the five streams into the coastal environment are quite excessive. While the total nitrogen and phosphorus loadings were much lower than the suspended sediment loads, the long-term effect of the nutrients being continually deposited into the coastal environment may be disastrous. These results suggest that the urban waters of Samoa are more contaminated than for other Pacific island nations, but the results may be an artifact of the thorough sampling regime applied in Samoa rather than anything else.

Now that the waters around the Apia urban area have been shown to be quite polluted, apprehensions about the consequences they may have to the biota of the coastal zone are justified. What is the distribution of the pollutants carried by these waters once they reach the coast? What is the impact of the polluted water on the sediments? Are human activities in the terrestrial catchments the main cause of marine productivity decline? These questions will be examined in the following two chapters, where the sediments and one coastal vegetation community are examined for selected coastal areas.

CHAPTER FIVE
CONTAMINANTS IN THE SEDIMENTS OF SAMOA

"Iron is taken from the earth and copper is smelted for ore.
Man's hand assaults the feinty rock and lays bare the rocks of the mountains"
Job 28: v2,9

Sediments consist of a combination of organic matter in various stages of decomposition, particulate mineral matter, and an inorganic component of biogenic origin (Wetzel 1975). Sediments can act as reservoirs for nutrients in natural systems (Stumm and Morgan 1970) and are increasingly being recognized as both a carrier of, and a source of, possible contaminants in aquatic systems (Forstner 1989). According to Salomons and Forstner (1984:63) sediments are, depending on environmental conditions, a sink or a source of contaminants in surface waters. Sediments contain appreciable amounts of organic matter, which act as both an absorbent for heavy metals and a substrate for microorganisms (Alloway 1990). Highly polluted sediments may continue to pollute a localized environment through resuspension and mobilization even though the source of pollution has been removed (Thomas and Meybeck 1992). Sediments are also sites where certain substances are concentrated from solution and thereby represent profitable sources of raw materials (Salomon and Forstner 1984).

5.1 SEDIMENT STUDIES IN THE PACIFIC AREA

Studies of riverbed sediments in the Pacific region have been confined to the rivers of the larger islands of Papua New Guinea and Fiji. In Papua New Guinea, sediment studies were conducted during the Environmental Impact Assessment phases of mining activities on several river systems. The Ok Tedi Environmental Study by Maunsell and Partners (1982) reported elevated concentrations of zinc and copper in the riverbed sediments of the Ok Tedi at Bukrumdaing and

Ok Kam tributaries in Papua New Guinea. Analysis of the Strickland River sediments by Gawne (1988) revealed high concentrations of iron, while the concentrations of copper and zinc were comparable to those recorded from the Fly River by Maunsell and Partners (1982). The elevated metal concentrations noted in the above studies were due to mining operations in the vicinity of the respective river systems. Petr and Irion (1983) reported on the elemental composition of the sediments from the Purari River and tributaries, and compared those sediments to that of other rivers of Papua New Guinea. They found heavy metal concentrations varied considerably from one river to another. Gangaiya *et al.* (1986) found that levels of copper, iron, manganese and zinc in the area were not high, concluding that the sediments from the Vitogo River in Fiji were relatively unpolluted.

Lagoon and estuary sedimentology in the Pacific region have been restricted to the effects of sediments on corals or coral reefs. Randall and Birkland (1978) and Hubard (1986) reported that sediment loads influenced the structure of coral communities and that sediments acted as a control on reef development. Petr and Irion (1983) reported on the sediment composition of the Pie River estuary from Papua New Guinea, where differences were seen between the heavy metal content of the estuary sediment to that of the Purari River sediment. Alongi *et al.* (1991) looked at vertical profiles of copper distribution in sediments from the Fly River delta, and found copper levels were not abnormally high, and that copper levels did not change with depth. Core sediments from the Fly River delta were also analyzed by Baker and Harris (1991), who noted that no significant change occurred in the distribution of copper and zinc concentrations with depth. In their discussion of heavy metal anomalies in coastal sediments of Oahu Hawaii, McMurty *et al.* (1995) documented heavy metal concentrations in stream sediments of Pearl Harbour, the Kahana Stream and Waikiki beach, as collected by the Water Resources Research Center (1973) and the Naval Civil Engineering Laboratory (1973). De Carlo and Spencer

(1995) reported high inputs of lead and other heavy metals in the sediments of the Ala Wai estuary.

Sediment analysis results from the above mentioned papers together with world average values are given in Table 5.1.

TABLE 5.1: Sediment Analysis from some Rivers of Fiji, Papua New Guinea and Hawaii. Compiled by Author

	HEAVY METAL CONCENTRATION						
RIVER / COUNTRY	Cr	Cu	Fe	Mn	Pb	Zn	Source
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	
Vitogo (Fiji)	35-88	96-150	9.0-15.0+	570-1400	8-10	54-150	Gangaiya *et al.* (1986)
Ok Tedi (Papua New Guinea)		15		500	45	25	Maunsell and Partners (1982)
Ok Kam (PNG)		10		270	35	25	Maunsell and Partners (1982)
Fly River (PNG)		28			25	85	Maunsell and Partners (1982)
Strickland River (PNG)		24	42200		13	91	Gawne (1988)
Fly River (PNG)	85	50		900	15	150	Petr and Irion (1983)
Purari R (PNG)	94	114		1323	14	137	Petr and Irion (1983)
Sepik R (PNG)	185	80		780	13	140	Petr and Irion (1983)
Waikiki beach (Hawaii)	16	3.6			37	6	Water Resources Res Center (1973)
Pearl Harbour Stream (Hawaii)	64-76	110-146			82-110	172-223	Naval Civil Eng Lab (1973)
Kahana Stream (Hawaii)	105	73			18	53	Water Resources Res Center (1973)
Ala Wai*- core G8 (Hawaii)		210			315	381	De Carlo and Spencer (1995)
Pie R* (PNG)	101	89		1063	14	140	Petr and Irion (1983)
World average of River Suspended Matter	100	100		1050	20	95	Martin and Meybeck (1979)
Unpolluted River Sediments		45	4.72+	600		95	Turekian and Wedepohl (1961)
Unpolluted Estuarine Sediments		10		360		63	Perkins *et al.* (1973)
World average conc in surficial continental rocks (mg/kg dry wt)		32	35 900	720		127	Martin and Meybeck (1979)
Average trace metal conc in basic igneous rock (mg/kg dry wt)		90		1500		100	Alloway (1990)

* Estuary
\+ Concentrations given as a percentage (%)

5.2 A CASE STUDY OF SAMOAN SEDIMENTS

Prior to this study, sediment studies in Samoa were restricted to economically driven projects by the South Pacific Applied Geoscience Commission (SOPAC), to develop an understanding of the processes which influence the coastal and nearshore sedimentary systems in the Apia area. Sediment samples collected from some beaches and river mouths from around Upolu were high in mineral content (Richmond 1991). Dredging has been (and still is) carried out in the Apia harbour and bay area since 1964 when the main Apia wharf was constructed and the land area west of the inner harbour was reclaimed (Gauss 1981). Rubin (1984) claimed a silting rate of 0.5 cm per annum was occurring.

The sediments within the harbour range from fine to medium sand to silt and mud (Gauss 1981), primarily terrestrially-derived volcanic (Solomon 1994). Fine sediments along Mulinuu Peninsula and Vaiusu Bay are sandy muds associated with mangrove swamps along the nearshore coast in the lee of the peninsula. The band of fine sediments is about 500 to 1000 meters wide. Further offshore is a zone of slightly muddy sand that has been mined for aggregate off Mulinuu Point since 1970 (Solomon 1994). Richmond (1991) noted that the lagoon sediments from Samoa varied from marine-floral blanketed substrates to irregular areas of coral pinnacles interspersed with sediments.

5.2.1 <u>Aims of This Study</u>

It was established in Chapters 3 and 4 that contaminants from the terrestrial environment are being continually carried into the marine environment by streams and rivers. It is then appropriate to ask the following questions. Are the water parameters indicative of pollution in the stream waters reflected in the sediments? What are their relative quantities in the sediments compared to those in the stream waters? What are the distribution patterns of these contaminants within and across the sediments? This chapter examines these questions and, in doing so, adds considerably to the understanding of the sediments in the coastal zone of Samoa.

5.2.2 Site Selection and Descriptions

Several sites were selected to determine the effects of urbanization on contaminant distribution. In the Vaiusu Bay area, six sites were selected to examine the sediments adjacent to the Gasegase and Fuluasou streams. It was felt that the rubbish dump, which had been present for 25 years at Vaitoloa, may have an effect on the sediments of the adjacent area, and so some Vaiusu Bay samples were drawn from that area. One core was taken in the Apia Bay area near the mouth of the Vaisigano River. The Apia Bay is continually disturbed due to dredging, precluding the appropriateness of intensive sampling. It was assumed that the one core collected was outside the range of areas dredged. The Moataa cores were selected to determine the characteristics of sediments from an estuarine urban catchment. Sediment samples were also taken at Sataoa, which represented an estuarine urban catchment that is supplied by groundwater inputs rather than fluvial inputs. Sediment samples were also taken from Sataoa, which represented an undisturbed estuarine fluvial area, and acted as the control site. The focus of this part of the research was not on dating the sediment cores, but rather a determination of the distribution of contaminants within the sediments.

Salani Volcanics(Richmond 1991) underlie the Sataoa area, and strong dissection by surface streams is evident. The weak Sataoa Stream brings terrestrial sediments from the center of the island into the coastal area. A predominant longshore drift towards the northeast has created a buildup of material adjacent to the river mouth at Sataoa (Richmond 1991). Cyclone Ofa in 1990 deposited a fair amount of sand in the estuary mouth (Pearsall and Whistler 1991). Mangrove trees of mainly *Bruguiera* species surround both sides of the stream channel. The substrate of the mangrove community is sandy to muddy with large volcanic rocks present which are suitable for algae and invertebrate growth (Thollot 1993). The three sediment samples from Sataoa were taken from one of the bends in the tidal channel (Figure 5.1).

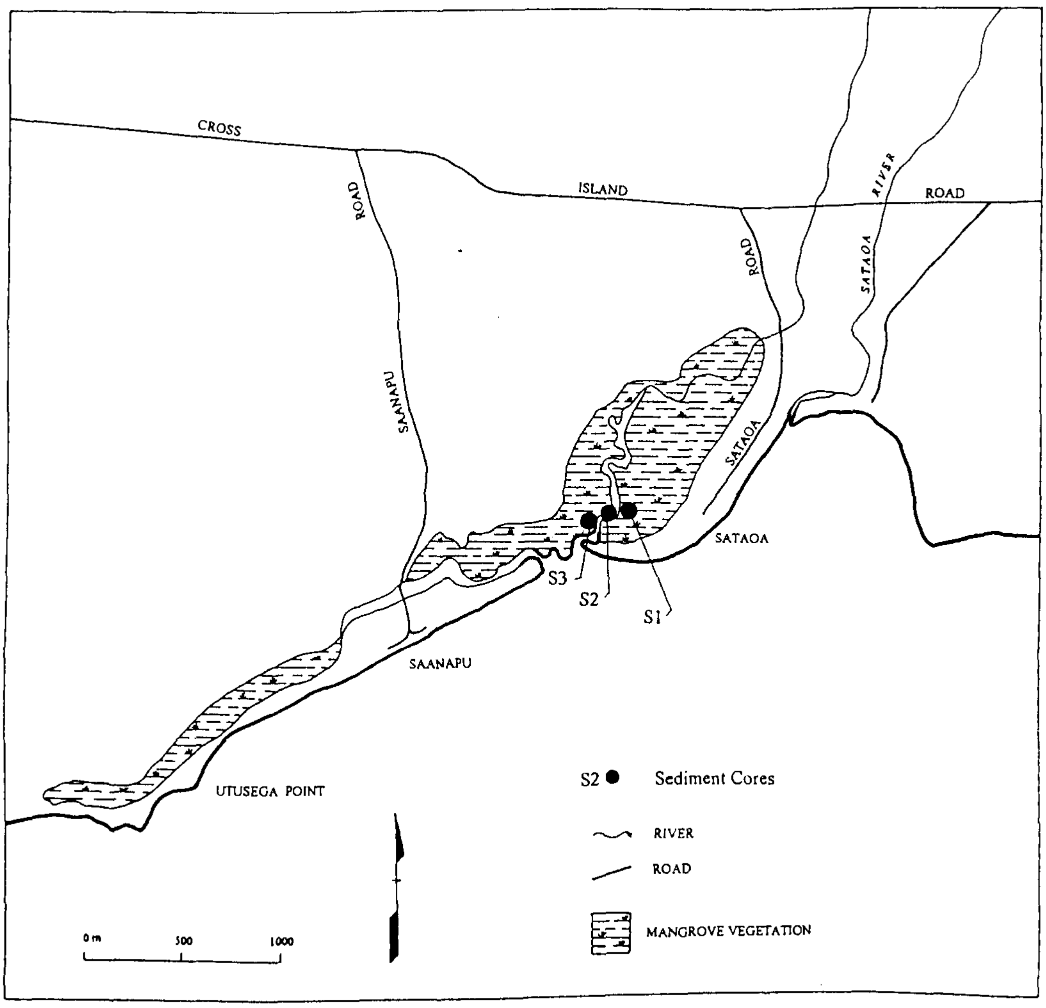

FIGURE 5.1: Location of Sediment Cores at Sataoa Mangroves. Source: Adapted from 1:20 000 Topographic map series

Vaiusu Bay is a shallow bay located between the Mulinuu Peninsula and the west mainland of Apia at 171°47' W and 13°49'30" S. The area is underlain by Fagaloa Volcanic. The Fuluasou

River, Gasegase Stream and Fugalei Stream laid down a veneer of Holocene alluvium overlying the volcanic to the south of the Bay (Richmond 1991). A large spit barrier known as the Mulinuu Peninsula forms the western edge of the Bay, which is comprised of terrigenous and carbonate sands. Richmond (1991) found that the sediments in Vaiusu Bay coarsened and increased in carbonate content seaward. Currents within the lagoon are driven primarily by the wind, and are so weak that there is a four to eight day delay in the exchange of water between the lagoon and the ocean (Taylor 1991; Zann 1991). The bay is supplied with terrestrial sediment from the rivers entering from the south, and with marine sediment via longshore drift from the east. The bay is protected from strong ocean currents by the coral reef located to the north and from longshore currents by the presence of Mulinuu Peninsula. *Rhizophora samoensis* is the dominant mangrove fringing Vaiusu Bay, but a few specimens of *Bruguiera gymnorrhiza* are also present (Klinckhamers 1992). Various Government offices, urban Apia, industrial plants, village dwellings and plantations, and remnant coastal vegetation flank the mangroves at Vaiusu Bay. The locals fish the inter-tidal area extensively for the cockle shell and mud crabs. Six cores were collected from this area (Figure 5.2).

The sample at the mouth of the Vaisigano River (VZ) was taken at the sea-freshwater exchange zone in an area of mainly pebbly alluvium material. The Apia harbour area is a disturbed site, with terrigenous sands and gravels at the river mouth periodically excavated for construction purposes (Richmond 1991). These sediments are replaced during floods. The location of the sampling site at the mouth of the Vaisigano River was outside both the excavation site and the dredged area near the wharf (Figure 5.2).

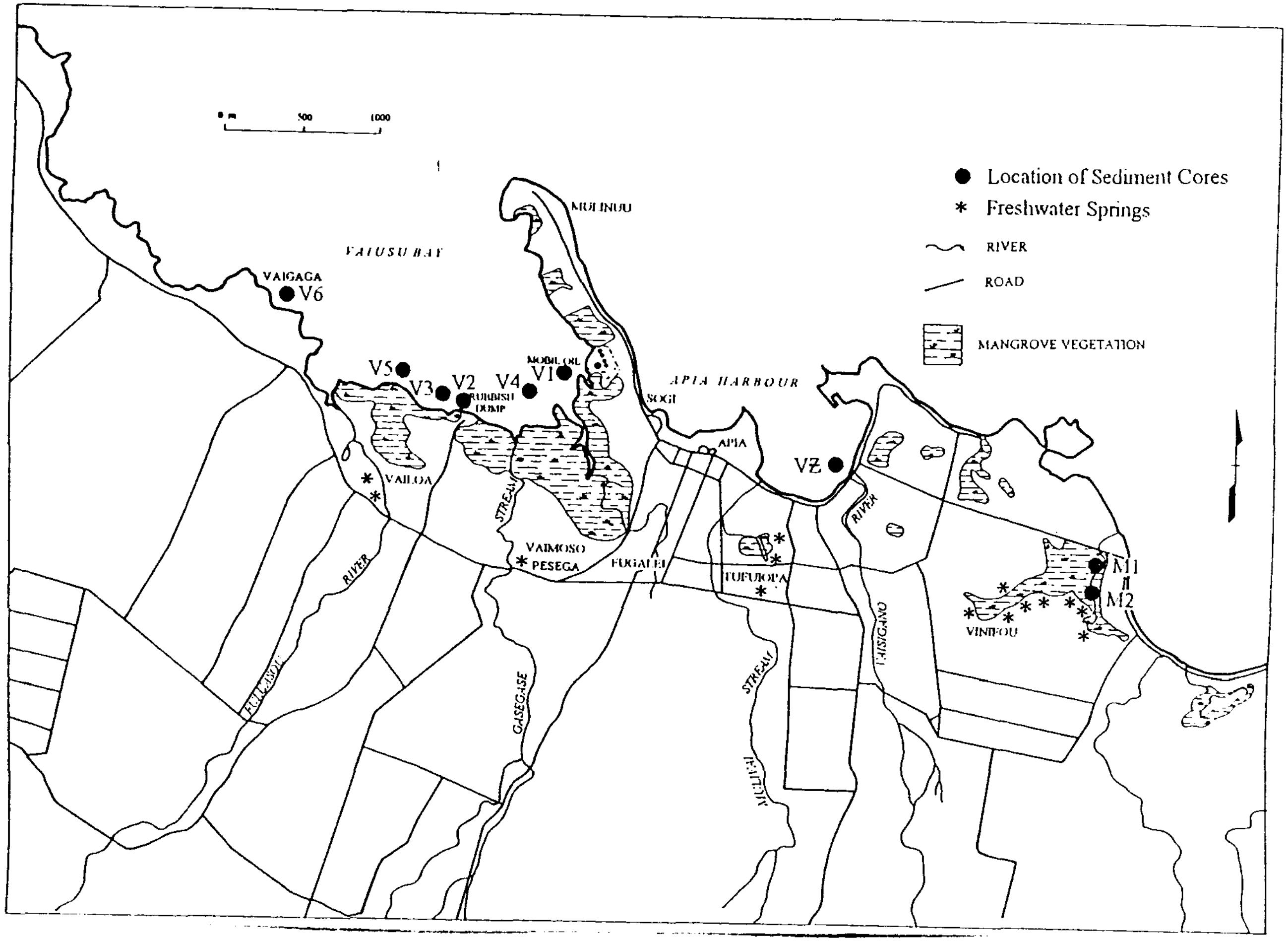

FIGURE 5.2: Location of Sediment Cores at Vaiusu Bay, Moataa and Vaisigano Areas.
Source: Adapted from 1:20 000 topographic map

The sediment samples at Moataa were taken from an area flanked by mangroves located at 171°44'30" W and 13°50' S (Figure 5.2). The Moataa mangroves are bounded to the west by a spit barrier known as the Taumeasina Peninsula, which was formed by longshore drift to the northwest. The Taumeasina Peninsula is a shallow sand bar sitting on top of about 30 meters of soft silt indicating that sandy material has encroached onto previous estuarine areas. The Peninsula encloses a tidally influenced embayment, with a small stream flowing through the estuary which is fed by about ten natural springs on the south side of the bay. Older Salani Volcanic underlies the two sampling sites at Moataa. The mangroves in the estuary are exclusively *Rhizophora* species, flanked by remnant coastal vegetation and village dwellings. Half of the mangrove area at Moataa was reclaimed in the early 1970s for a hotel development, which never eventuated (Zann 1991). This reclamation activity is discussed in detail in Section 6.2.3.

5.2.3 Field Data Collection

The multiple-plot method (Cain and Castro 1959) was employed to collect the sediment samples, with the sampling sites selected at random. The sediment samples were obtained in the inter-tidal zone at low tide when the sites were easily accessible by foot. One-meter lengths of 70mm diameter PVC pipes were manually pushed into the soft sediments. The (open) top end was capped while pulling the whole PVC tube out. The soil sediments were extracted from the tube, and sediment compaction was noted. Each core was logged on the basis of colour and texture. A description of all the samples is given in Table 5.2. A cursory examination of the cores in Table 5.2 and Plates 5.1 and 5.2 indicated that the estuary sediment of the coastal environment of Samoa were mainly loamy sand to sandy material, probably from coral reefs.

TABLE 5.2: Descriptions of all the Sediment Samples. Source: Author's research

SAMPLE NUMBER	LOCATION	DEPTH (cm)	TEXTURE	COLOUR	PHYSICAL DESCRIPTION
S1	Taken from the deeper part of the stream some five metres north of S2 site.	0-10 10-13 13-18 18-23 23-28	sand sand sand sand sand	5YR 2/1 7.5YR 2/0 5Y 2/2 5Y 2/1 5YR 2/1	Weathered wood and leaves in the top 10cm. Organic rich sediment especially in the top 20cm. Dark colour fades with depth. (No photo)
S2	Sampled in the middle of the shallow sandy spit formed in the middle of the channel.	0-6 6-16 16-25	sand sand sand	7.5YR 2/0 2.5Y 2/0 2.5Y 2/0	Fine sand material covered with a lot of organic matter. Rather dry and firm. (Plate 5.1)
S3	Taken three metres south of S2 site, again in the deeper part of the channel.	0-8 8-16 16-22 22-27 27-34 34-47	loamy sand loamy sand sand sand sand sand	10YR 3/1 10YR 3/1 10YR 3/1 7.5YR 2/0 7.5YR 2/0 7.5YR 2/0	Organic rich sediment with wood and litter in the top 8cm. Fine sand mixture (Plate 5.2)
V1	Sampled 60 metres south of the Mobil Oil complex at Sogi. A muddy area innundated at high tide but mostly exposed at low tide.	0-6 6-21 21-28 28-35	sandy loam sandy loam sandy loam sandy loam	5Y 3/1 5Y 3/1 5Y 3/1 5Y 3/1	Sticky mud, rich in organic matter Grey with some coarse sand at depth. (Plate 5..3)
V2	Taken 50 metres from dry land where the rubbish dump used to be. The area was innundated to ankle high at the time of sampling.	0-5 5-10 10-15 15-25 25-35 35-45 45-50 50-58	loamy sand loamy sand loamy sand sandy loam loamy sand sandy loam sandy loam sandy loam	2.5Y 2/0 5Y 2.5/1 2.5Y 2/0 5Y 2.5/1 2.5Y 2/0 5Y 2.5/1 2.5Y 2/0 2.5Y 2/0	Organic rich sediment with colour fading to greyish-brown at depths. Fine sandy material throughout the profile. (Plate 5.4)
V3	Sampled 200 m west of V2 site and 100 m from dry land. Muddy area innundated at high tide. Cockle harvesting area.	0-8 8-25 25-40 40-50	sandy loam sandy loam loamy sand sandy loam	2.5Y 2/0 5Y 2.5/1 2.5Y 2/0 5Y 2.5/1	Moist organic rich sediment. Sticky mud on top 10 cm. Shell fragments and coarse sandy material at depth. (Plate 5.5)
V4	Taken 500 m from shore in the deeper part of the bay north of site V2. Water was knee high at sampling area.	0-11 11-24 24-40	sandy loam sandy loam sandy loam	5Y 2.5/1 5Y 3/1 5Y 3/1	Grey brown sediment. Sand aggregates and shell fragments abundant at lower end of the profile. (No photo)
V5	Sampled a further 300 metres west of site V3, again some 100 metres from dry land.	0-10 10-26 26-45 45-56 56-64 64-72	sandy loam loamy sand loamy sand loamy sand loamy sand loamy sand	2.5Y 2/0 2.5Y 2/0 2.5Y 2/0 2.5Y 2/0 2.5Y 2/0 2.5Y 2/0	Dark colour on top 10cm with high organic matter content. The colour cahnges to brown with depth. Likewise, consistency changes from sticky on top to dey at depths. (Plate 5.6)
V6	Taken 50 metres from shore off Vaigaga village, about 400 metres west of V4 site. Innundated to knee high at the time of sampling.	0-9 9-21 21-29 29-37 37-42	sandy loam silt loam silt loam sandy loam sandy loam	5Y 2.5/1 2.5Y 2/0 7.5YR 3/2 7.5YR 3/2 7.5YR 3/2	Sticky mud on the top 10 cm, dark with organic matter. Abrupt change to brownish and firm material in the lower parts (Plate 5.7)
VZ	Taken at the mouth of the Vaisigano River. Mainly pebbly alluvium material.	0-17 17-33 33-42	sand sand sand	5YR 2.5/1 5YR 2.5/1 5YR 2.5/1	Mainly sandy material coated with organic matter. Shell fragments throughout the profile (Plate 5.8)
M1	Sample was taken 50 m from the bridge in the middle of the stream channel. The area was innundated to knee high at the time of sampling.	0-7 7-16 16-25 25-30 30-34 34-36	sandy loam sand sand sand sand sand	2.5Y 2/0 5YR 2/1 2.5YR 2/1 7.5YR 2/0 7.5YR 2/0 7.5YR 2/0	High organic matter in the top 20cm, with colour fading with depth. Sandy material and shells found at the bottom parts. (No photo)
M2	Sampled 500 metres further inland in an exposed area now without water	0-14 14-39 39-64	sandy loam loamy sand loamy sand	2.5Y 2/0 2.5Y 2/0 7.5YR 2/0	Organic rich sediment with high organic matter content. Coarse sand and shells fragments at depths. (Plate 5.9)

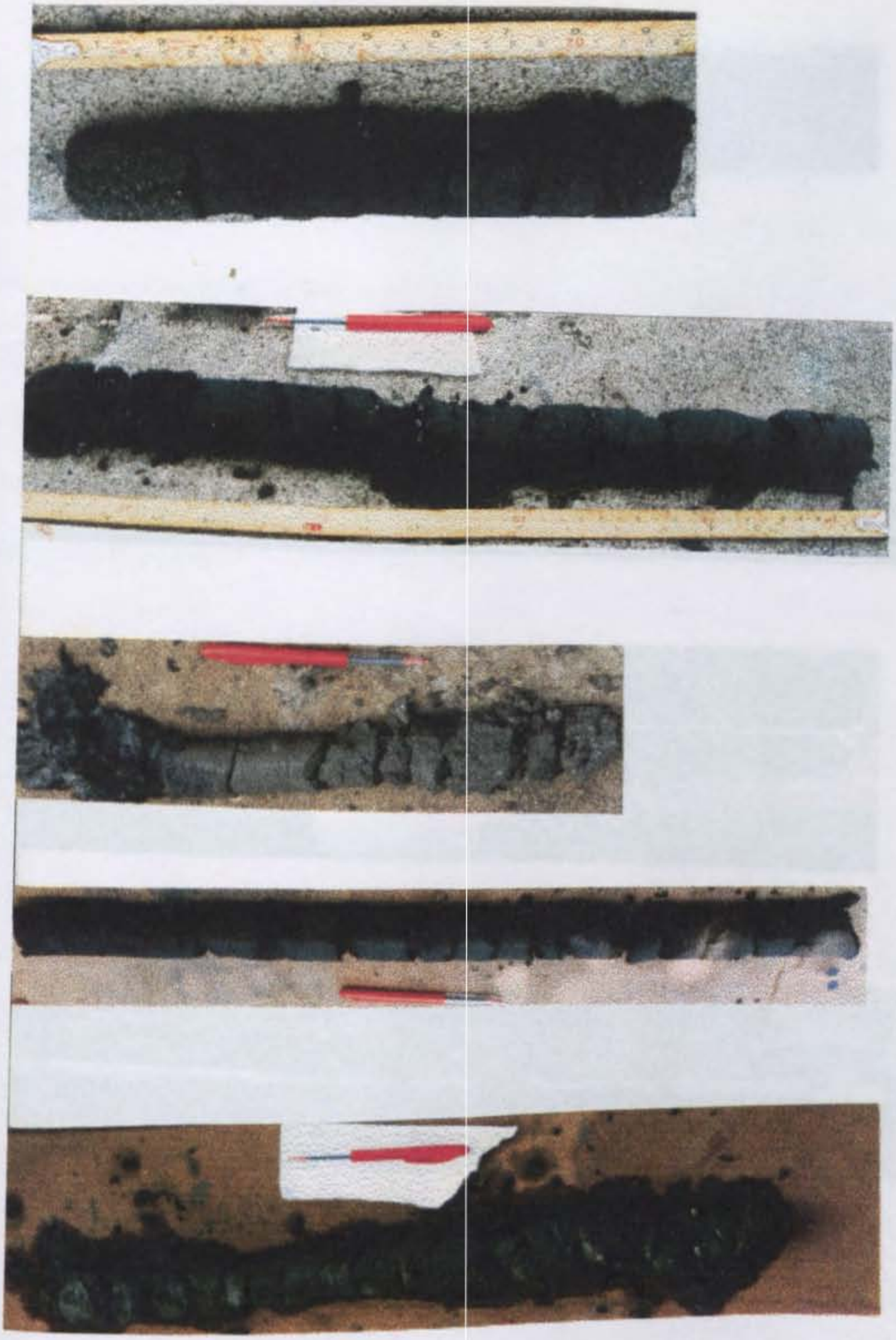

PLATE 5.1: Sediment Cores S1(a), S3(b), V1(c) V2(d) and V3(e)

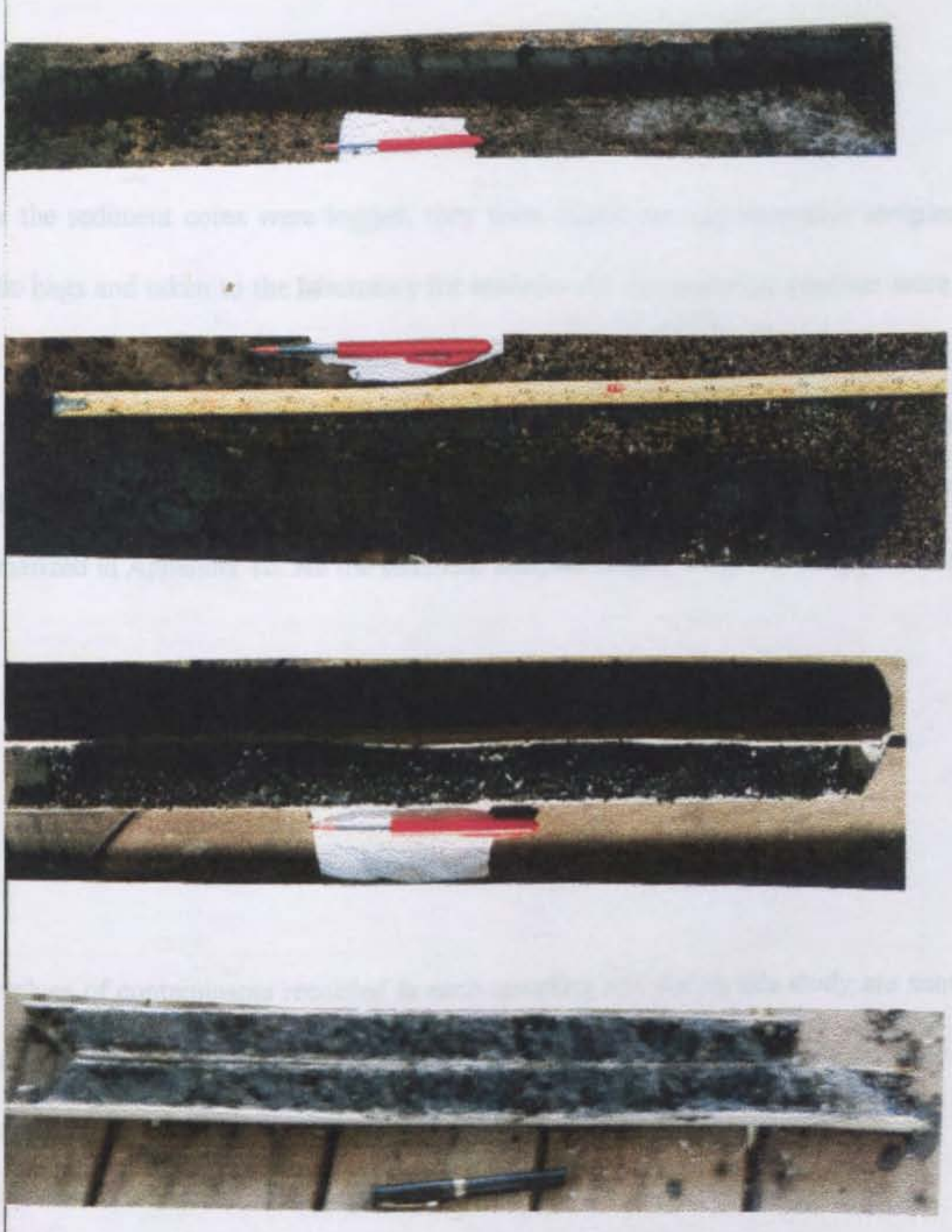

PLATE 5.2: Sediment Cores V5 (a), V6 (b), Vaisigano (c) and M2 (d)

The sandy texture was especially evident in the Vaisigano sample (Plate 5.2c). Organic matter was abundant in all the sediments as characterized by the dark appearances of the samples.

5.2.4 Laboratory Methods

After the sediment cores were logged, they were sliced into representative samples, sealed in plastic bags and taken to the laboratory for analysis. All the analytical analyses were performed at the University of the South Pacific Laboratory at Alafua. Each soil sample was determined for texture, moisture content (MC), pH, total nitrogen, total phosphorus and the metals iron, manganese, copper and zinc. The procedure for the determination of each chemical analysis is summarized in Appendix 10. All the sediment analyses results are given in Appendix 11.

5.3 POLLUTANTS IN SAMOAN SEDIMENTS

5.3.1 Concentrations of Contaminants

The values of contaminants recorded in each sampling site during this study are summarized in Table 5.3. For comparison purposes, data on the chemical characteristics of some soils from Samoa are also given in Table 5.4.

At Sataoa the mean sediment pH value was 7.5, although the minimum acidic pH of 5.9 probably indicates the presence of organic matter (Metson 1961). Table 5.4 showed that 0.29% nitrogen was recorded in one oxisol from Samoa (Hunter 1995), while Wright (1963) noted 0.24% nitrogen in a lowland swamp forest near the coast. The average total nitrogen value from the Sataoa sediments was lower than these soil values at 0.17%. It is apparent that the Sataoa sediments are not contaminated with nitrogen. On the other hand, the average total phosphorus concentration at Sataoa sediments was 188ppm (Table 5.3). This value is higher than both the average phosphorus values from the soils of Samoa, and the average phosphorus concentration of 0.07 mg/l carried by the Sataoa stream into the coast (Appendix 4.2), suggesting phosphorus contamination of the Sataoa sediments

TABLE 5.3: The Maximum, Minimum, and Mean Values Recorded from each Sediment Site. Source: Author's research

PARAMETER		SATAOA (n = 3)	VAIUSU BAY (n = 6)	MOATAA (n = 2)	VAISIGANO (n = 1)
pH	maximum	8.2	8.7	9.0	8.6
	minimum	5.9	7.6	4.9	8.0
	mean	7.5	8.3	6.6	8.4
Total Nitrogen (%)	maximum	0.25	0.29	0.48	0.13
	minimum	0.12	0.11	0.11	0.11
	mean	0.17	0.16	0.24	0.11
Total Phosphorus (ppm)	maximum	345	419	231	389
	minimum	13	12	60	254
	mean	188	192	166	314
Iron (ppm)	maximum	908	436	159	818
	minimum	81	27	43	558
	mean	409	187	111	709
Manganese (ppm)	maximum	10	38.4	8.5	54
	minimum	4.4	11.9	3.2	47
	mean	7.0	22.0	5.9	49
Copper (ppm)	maximum	1.0	2.5	3.3	3.4
	minimum	0.4	0.9	1.1	1.9
	mean	0.6	1.6	1.9	2.6
Zinc (ppm)	maximum	3.9	8.4	7.1	3.9
	minimum	0.6	0.4	1.0	2.3
	mean	2.1	1.8	3.3	3.2

Note : All the values are recorded in parts per million (ppm) except TN which is given in a percentage (%)

TABLE 5.4: Chemical Characteristics of some Soils from Samoa. Compiled by author

SOIL NAME	TN (%)	T P (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Source
Togitogiga Oxisol	0.29	6.0	40	40	2.4	2.0	Hunter (1995)
Alafua Subsoil		120	34	125	4.0	4.0	Bekker (1992)
Aleisa Subsoil		153	50	124	5.0	5.0	Bekker (1992)
Lowland swamp forest	0.24						Wright (1963)

The average iron concentration in the sediments from Sataoa was over 400ppm, and the highest maximum iron concentration of over 900ppm was also recorded at Sataoa (Table 5.3). The average iron concentrations in selected soils from the highland areas of Samoa in Table 5.4 showed levels six to seven times lower than this value. Possibly, the high iron concentration observed in the sediments is geological in origin. Kear *et al.* (1979) noted the presence of high iron contents in the groundwater of the country is normal for all young volcanic sediments. According to Orlov (1992), the soil and groundwater from catchment areas carry with them a considerable amount of reduced iron. This reduced iron increases in concentration in zones of high organic matter. This may well be the case at Sataoa where the sampling area was full of organic litter from the mangrove trees nearby. Liss (1976) further argued that there is a large-scale removal of iron from solution when freshwater mixes with saline water.

The metals copper, manganese and zinc recorded average values of 0.6ppm, 7.0ppm and 2.1ppm respectively at Sataoa (Table 5.3). The zinc value was comparable to those found in the soils of Samoa, while copper and manganese values found in the sediments of Sataoa were respectively six times and fourteen times lower than those reported in soils of Samoa (Table 5.4). According to Petr and Irion (1983), this low abundance of metals is indicative of highly weathered sediments.

Comparing the sediment characteristics of the other three sites to those of Sataoa (Table 5.3), it is noted that all the three sites recorded higher maximum pH values, indicating highly weathered soils and the presence of calcium carbonate (Metson 1961; Wild 1993).

While the average total nitrogen content from the Vaiusu Bay and Vaisigano sediments were comparable to those of Sataoa, the Moataa sediments recorded the highest nitrogen content of

0.48% (Table 5.3), and an average nitrogen content comparable to those found in the soils of Samoa (Table 5.4). The higher nitrogen value at the Moataa site is probably related to contamination from the groundwater (Todd 1980), as a lot of freshwater springs are in found in this area (Figure 5.2). The results outlined in Chapter Three confirmed the high nitrogen content of the freshwater springs in the Apia urban area.

The average total phosphorus concentrations from the sediments of Moataa and Vaiusu Bay were also comparable to that at Sataoa, although Vaisigano sediments recorded a higher average value of over 300ppm (Table 5.3). Olsen and Englestad (1972) noted that tropical soils contain on average around 200ppm of total phosphorus, but Bekker (1992) reported a lower value of 150ppm total phosphorus from the sub-soils of Samoa. It appears, therefore, that the sediments of all the four sites contain about three times more phosphorus than in the arable soils. The net difference is most certainly due to human activities. Phosphorus enters the sediments as a result of mineralization of organophosphates and application of fertilizers (Orlov 1992). Both Johannes (1982) and Stednick (1990) reported clearing of the Vaisigano watershed area for plantations, and this would account for the higher phosphorus contents found in the sediments from the mouth of the Vaisigano River (Table 5.3). This same argument can be extended to explain the higher phosphorus concentrations seen in sediments close to river mouths at Vaiusu Bay (V5 and V6) and at Sataoa (core S3).

The average concentration of iron reported at Sataoa was found to be comparable to iron averages from the other three sites (Table 5.3), and were high compared to iron concentrations found in the soils of Samoa (Table 5.4). Apart from iron, the metals copper manganese and zinc recorded low quantities in the sediments of the other three sites, although higher average concentrations were observed for manganese and copper than those found at Sataoa.

Manganese values were about six times those of copper and zinc, especially at the mouths of rivers as noted in the Vaisigano sediment, and at cores V5 and V6 from Vaiusu Bay (Table 5.3). This higher manganese concentration is probably due to both weathering products from the terrestrial environment and the dissociation of organic matter (Aubert and Pinta 1977). The low manganese concentrations recorded from all the sediments examined in Samoa are indicative of sediments subjected to weathering over a long period of time (Petr and Irion 1983).

It is apparent from the above discussion that the control site Sataoa contained high levels of both iron and total phosphorus in comparison to Vaiusu Bay, Moataa and Vaisigano. Only manganese and copper recorded lower values than the other three sites. This indicates that the control site is similar in parts to the other sites.

If the sediment characteristics from Samoa are compared to other Pacific islands, it can be seen that the maximum iron concentration of over 900ppm from Sataoa was about 40 times lower than the iron value from the mine-influenced sediment of the Strickland River in Papua New Guinea. The maximum values of 54ppm, 3.4ppm and 8.4ppm for manganese, copper and zinc respectively in the sediments of Samoa were low, and well below the world average of these elements in unpolluted river sediments or unpolluted estuarine sediments (Table 5.1). The baseline values for copper and zinc of 28ppm and 91ppm respectively from the Fly River delta reported by Baker and Harris (1991) were over eight times higher than the values reported in Samoan sediments. Similarly, baseline concentrations for copper and zinc of 45ppm and 95ppm respectively in unpolluted sediments as documented by Turekian and Wedepohl (1961) were far from being challenged. It is concluded therefore that the low concentrations of copper, manganese and zinc from the sediments of Samoa are exclusively from weathering of the volcanic parent material.

5.3.2 Vertical Distribution of Contaminants

Skei (1981) showed that there was an accumulation of contaminants in the surface layers as compared to lower depths of dated sediment cores of mercury, zinc, lead and copper from Sorfjord, Norway. Variations in metal accumulation rates through time, from dated profiles in the Baltic Sea, revealed the same distribution pattern (Larsen and Madsen 1986). These increases in contaminant accumulation in the surface sediments are almost certainly linked to human activities over the past 100 or so years (Jickells *et al.* 1990). Previous studies have found that polluted sediments contain enhanced element concentrations in the surface layers, and decreasing concentrations with depth. This Section examines the vertical distribution of contaminants in each sediment core to see if surface (or recent) sediments have different levels of contaminants than the deeper sediments.

The variation of total nitrogen with soil depth of each sediment sample is given in Figure 5.3. The element enhancement in the surface sediments was observed only at Moataa in core M2 indicating pollution at this site. It has been suggested that this might be due to contamination from groundwater. At Sataoa, all the three sites showed no significant change in the percentage of nitrogen concentration with depth, as with the Vaisigano sediment and all the Vaiusu Bay sediments.

Figure 5.4 depicts the variation of total phosphorus concentration with soil depth for each sediment core sample. From Figure 5.4, an increase in phosphorus content with soil depth in the Sataoa sediments is seen. This trend is also evident in the vertical distribution of total phosphorus at core V6 from Vaiusu Bay. The reason for this higher phosphorus concentration at lower depths of these cores is not clear.

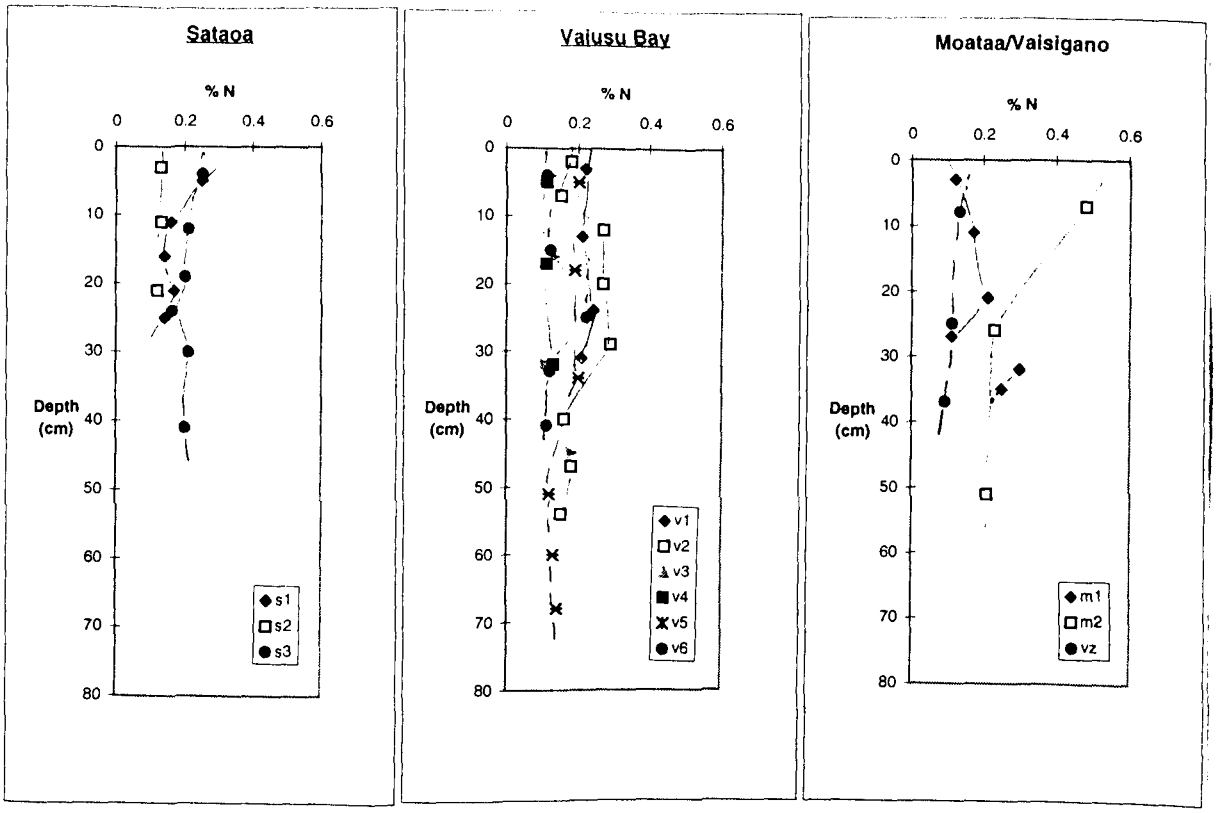

FIGURE 5.3: The Variation of Nitrogen with Soil Depth for Sediments from Samoa. Source: Author's research

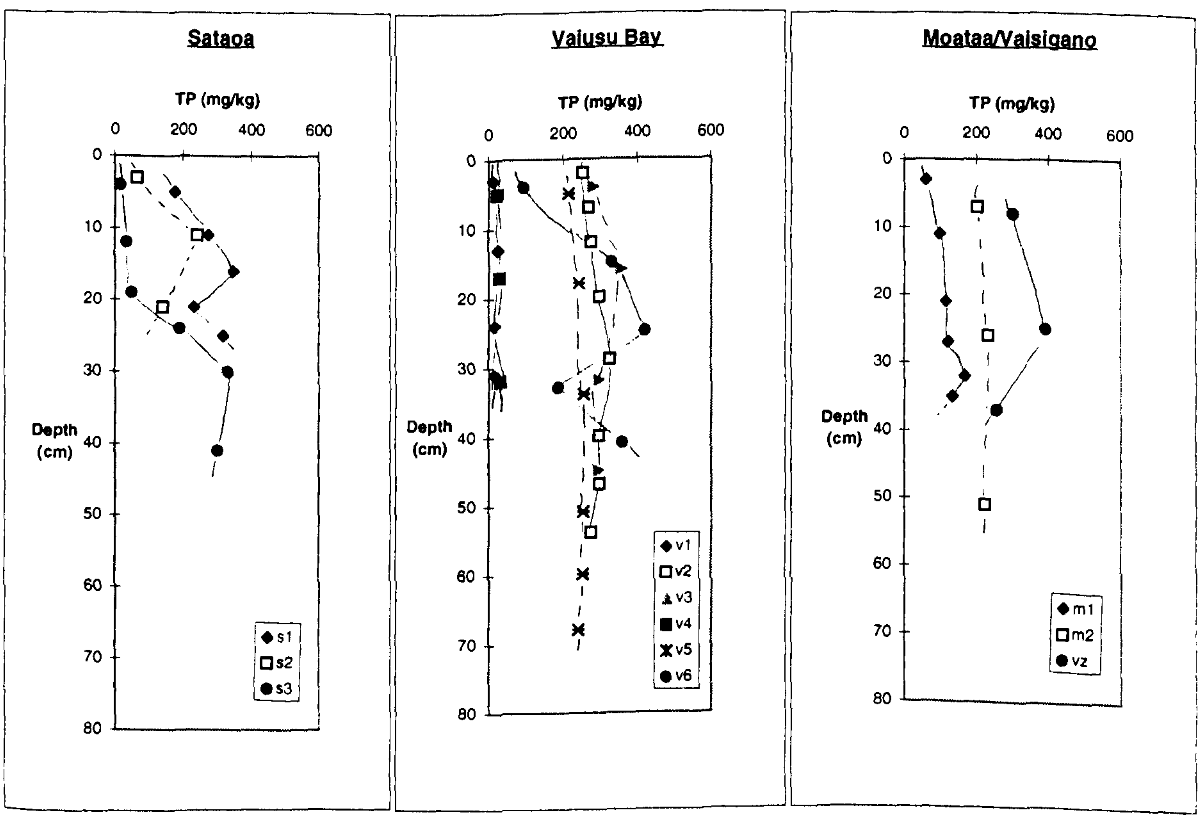

FIGURE 5.4: The Variation of Total Phosphorus with Soil Depth for Sediments from Samoa. Source: Author's research

However, it is probable that a phosphorus contaminant was transported to the marine environment at Sataoa and Vaiusu Bay. The vertical distribution of phosphorus from the other cores showed no significant increase with soil depth.

It was also noted from Figure 5.4 that cores V1 and V4 recorded quite low phosphorus concentrations as compared to the other sediments from around Vaiusu Bay (Table 5.2). Two possible explanations for this observation are given: the current circulation within the bay area favours the deposition of material towards the southern embankment of the bay; and a probable spatial distribution in which phosphorus from the terrestrial environment is adsorbed onto the sediments closer to the coast. While both cores at Moataa showed no significant changes in phosphorus content with depth, core M2, which is closer to the freshwater springs, contained about two times more phosphorus, again suggesting probable contamination from groundwater.

The iron concentration distribution with soil depth for all the sediments examined are given in Figure 5.5. The increase of iron with soil depth seen at core S3 from Sataoa and the Vaisigano sediment core ran parallel with their phosphorus distribution patterns, suggesting perhaps an iron-phosphorus binding effect in these sediments (Orlov 1992). All the Vaiusu Bay cores, the Moataa cores and cores S1 and S2 showed no significant changes in their iron concentrations with depth. Liss (1976) has pointed out that large-scale removal of iron from solution occurs when freshwater mixes with saline water. This may explain both the higher iron values noted in cores V4, V5 and V6 as compared to the other cores from Vaiusu Bay, and the high iron concentration found throughout the Vaisigano core. Further, oxidation conditions favour the precipitation of phosphorus and iron (Thomas *et al.* 1992) and the correlation of iron and phosphorus concentrations reported in the sediments from Vaiusu Bay attested to this.

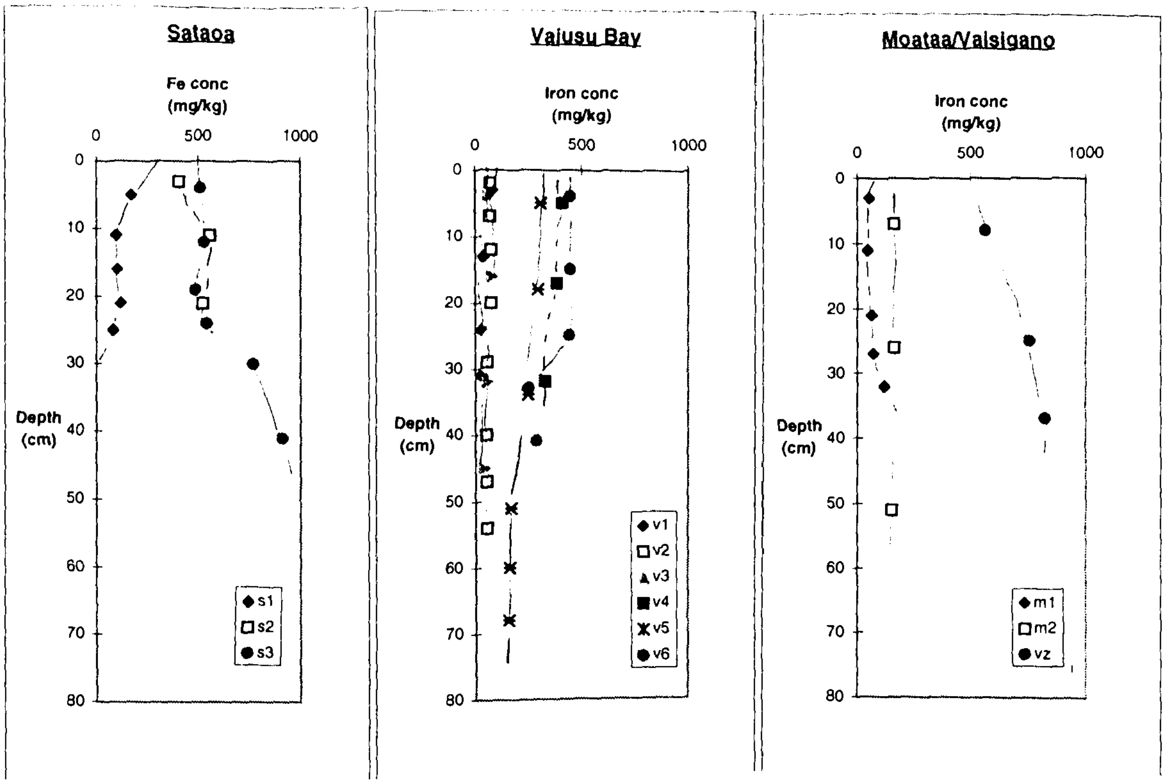

FIGURE 5.5: The Variation of Iron with Soil Depth for Sediments from Samoa. Source: Author's research

The presence of dredging operations close to sediment cores sites V4, V5 and V6 may add to the elevated levels of iron observed in these cores. Dredging induces oxidation conditions which then favours the precipitation of iron, and dredged materials are known to contain a high heavy metal load (Bourg and Loch 1995; Salomon and Forstner 1988).

The variation of manganese, copper and zinc with sediment depth is given in Figures 5.6, 5.7 and 5.8 respectively. As noted in Section 5.3.1, the concentrations of these metals in the sediments of Samoa are exclusively volcanic in origin, and contained low values compared to the world averages, and values reported from around the region (Table 5.1). The low representation of these metals in the sediments of Samoa is probably a dissolution effect during sediment transportation (Petr and Irion 1983). The manganese concentration is greater than the copper and zinc values for all the sediments (Appendix 11). This is expected as high concentrations of manganese are found in basic igneous rocks where manganese is present as a substitute for the ferrous ion in sites of clay minerals (Gilkes and McKenzie 1988). Managnese, like iron, shows a non-uniform distribution in soils (Orlov 1992).

The vertical distribution of manganese at the Sataoa cores showed no change in concentration with depth (Figure 5.6). In fact only core V6 at Vaiusu Bay showed the non-uniform distribution characteristic of manganese in soils (Orlov 1992). This is probably due to sand mining activities close to this site at Mulinuu Point. All the cores from Moataa and Vaisigano showed no significant changes in their manganese levels with depth. Although not distinct, there appears to be a slight accumulation of manganese in the surface layers of sediments in all the cores from Vaiusu Bay (Figure 5.6).

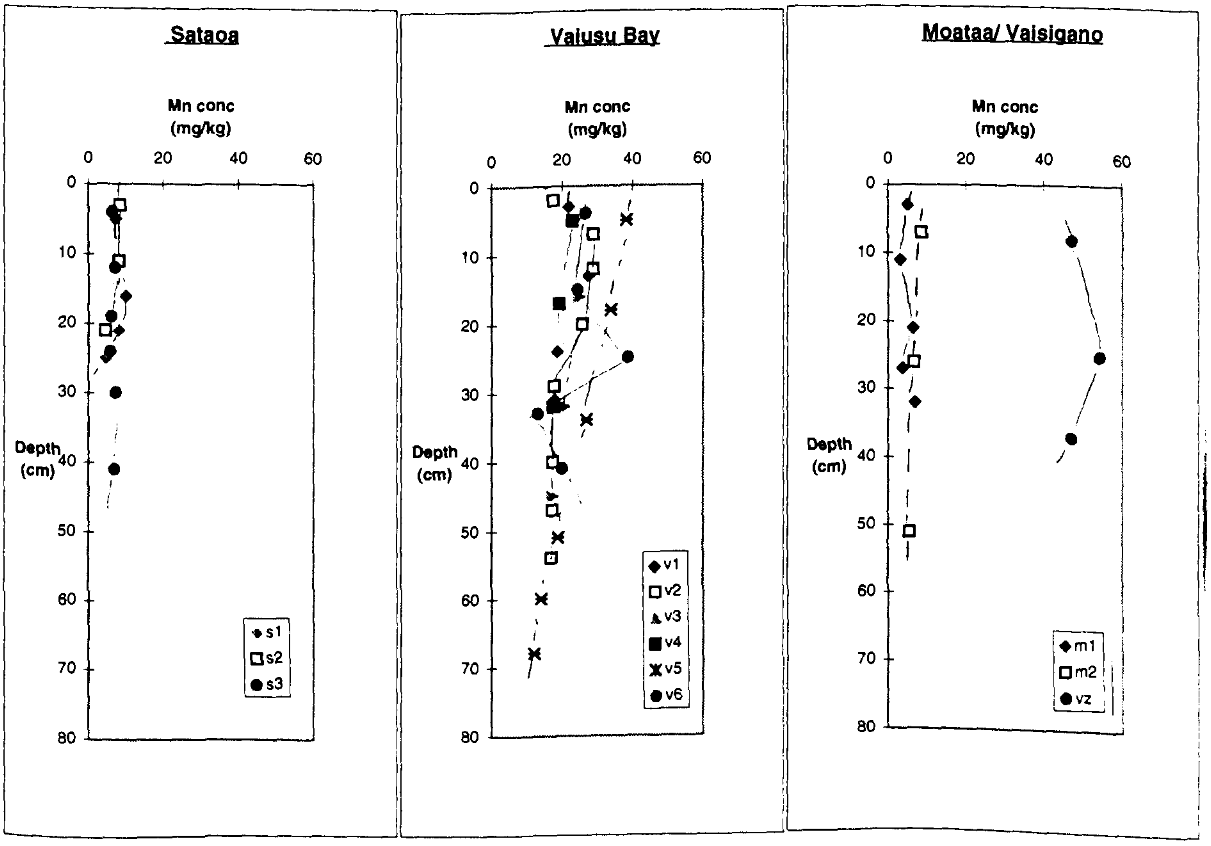

FIGURE 5.6: The Variation of Manganese with Soil Depth for Sediments from Samoa. Source: Author's research

Core V5 close to the mouth of the Fuluasou River showed a distinct increase in manganese distribution towards the surface, and probably indicates pollution (Skei 1981). These higher concentrations of manganese at the river mouths are also observed at the Vaisigano core. Comparatively, it is seen that the cores from Vaiusu Bay and Vaisigano contained higher manganese levels than the cores at Sataoa and Moataa.

The variation of copper levels with depth is given in Figure 5.7 where the sediments at Sataoa again showed no change in copper concentrations with depth. The cores at Vaiusu Bay showed a similar copper distribution trend to that of manganese, where an indistinct pattern was noted, although cores V1 and V4 showed explicit accumulation of copper in the surface layers (Figure 5.7).

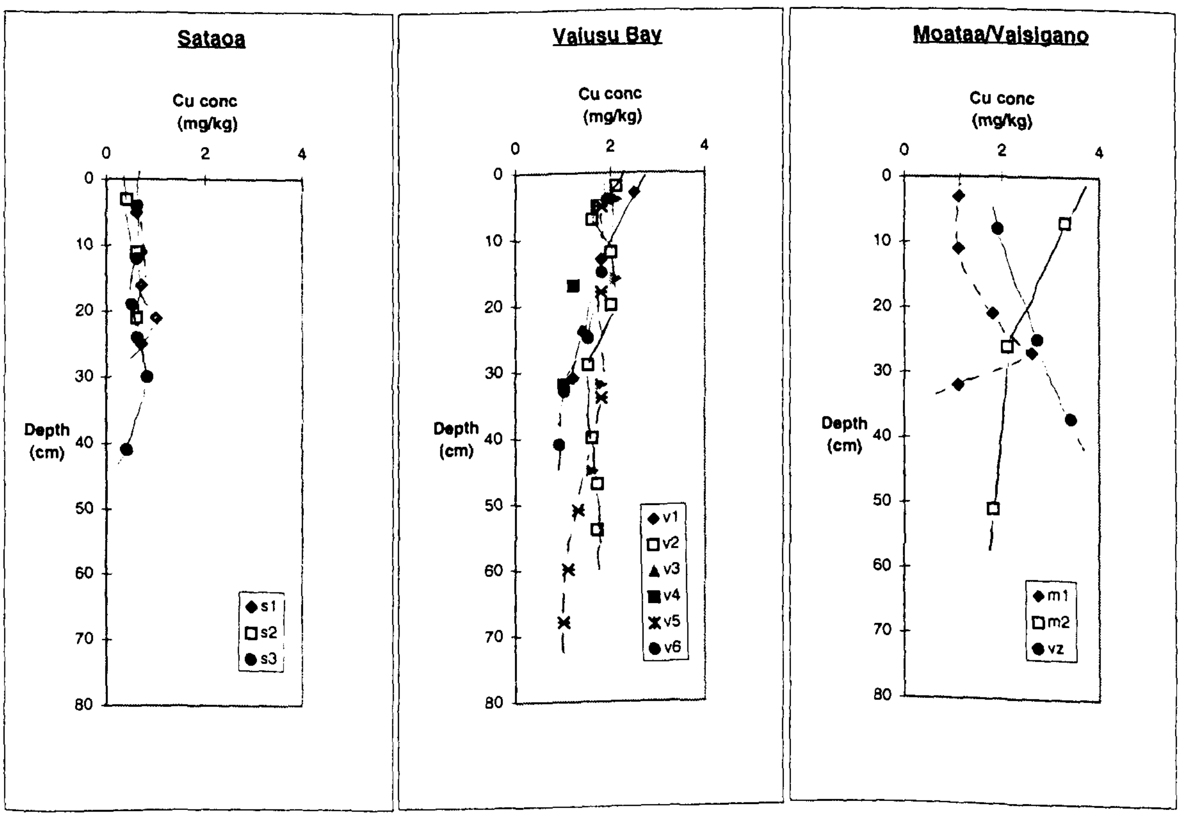

FIGURE 5.7: The Variation of Copper with Soil Depth for Sediments from Samoa.
Source: Author's research

This suggests that copper is being transported from the northern part of the bay to the marine environment. While the source of this copper contamination is unknown, corrosion of some of the water supply networks is a possibility (Forstner and Wittmann 1979). The higher copper reading in the top 10 cm of core M2, which coincided with higher levels of nitrogen, suggests pollution, again probably contamination from groundwater feeding into the Moataa Bay. Overall, there appeared to be a higher quantity of copper in the Vaiusu Bay, Vaisigano and Moataa areas than at Sataoa (Figure 5.7).

The variation of zinc levels with depth is given in Figure 5.8. At Sataoa, cores S1 and S2 showed no significant changes of zinc concentration with depth. The vertical distribution of zinc in core S3, however, showed higher zinc levels at lower depths. The cause of this higher zinc level at lower depths in core S3 is not clear.

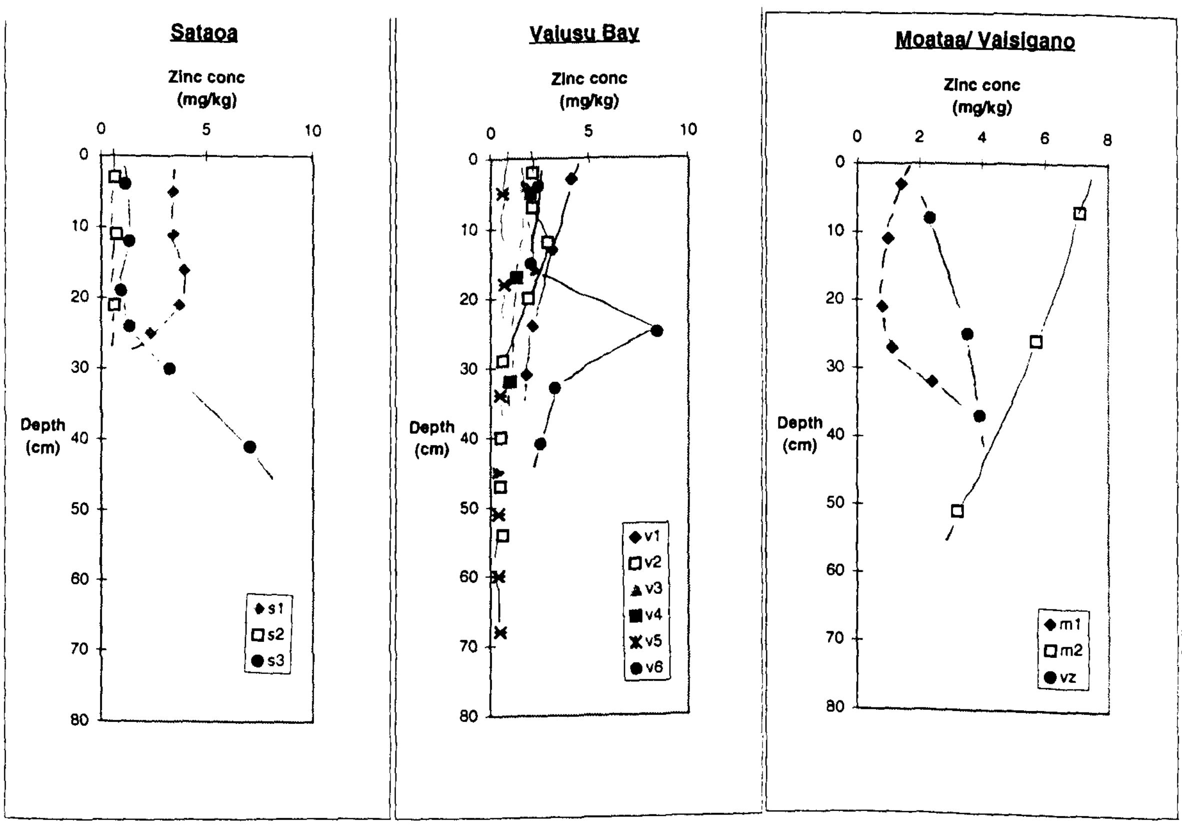

FIGURE 5.8: The Variation of Zinc with Soil Depth for Sediments from Samoa. Source: Author's research

However, it is worth noting that the zinc distribution in this core resembles closely its total phosphorus distribution (Figure 5.4). Further the similarity in the total phosphorus and zinc plots of core S3 and V6 is clearly evident. At the time when that sediment was deposited, phosphorus and zinc contaminants were obviously being transported to the marine environment at parts of Sataoa and Vaiusu Bay.

The source of the contaminants is unclear. At Sataoa, the rise in zinc and phosphorus levels may have coincided with the introduction of septic tanks and European-style toilets to the village. Before this time, the beach, the mangrove area and the area behind village dwellings would have been used as toilets. According to Forstner and Wittmann (1979), sewage sludge contains 2600 mg/kg of zinc and 700 mg/kg copper. Core V6 was located close to where the Fuluasou River discharges into the sea, and a high amount of zinc was probably incorporated in one of its discharges and deposited in the sediment. The zinc distribution in core V1 showed a slight increase in concentration in the surface layer, as was the case with the copper distribution. It is possible that a water supply network is responsible for the contamination by these two metals observed in this core.

The peak in zinc values below 10 cm in core V2 probably signals the relocation of the rubbish dump away from Vaiusu Bay. With the high level of unsorted solid waste like car batteries that were dumped in the adjacent dry land, zinc from car batteries may have accumulated in the sediments nearby. When the rubbish dump was relocated, the levels of zinc dropped. The high zinc reading at the surface of core M2 which coincided with similar high levels of copper and total nitrogen in this sediment, confirms the claim that this core has been contaminated from local pollution sources, via groundwater discharges to the bay area.

From these observations it is noted that certain contaminants may have been transported to the marine environment at the time the sediments were deposited. The results of core M2 from Moataa indicated strongly the probability of groundwater contamination. Nitrogen, copper and zinc pollution is evident from their vertical distribution graphs (Figures 5.3, 5.7 and 5.8). The vertical distribution of zinc showed evidence of stages of anthropogenic activities. The higher levels of both copper and zinc in core V1 suggested contamination from a water supply network. The vertical distribution of phosphorus and iron at Vaiusu Bay (Figures 5.4 and 5.5) demonstrated both the influence of the tidal movement within the bay area in contaminant deposition, and the tendency of phosphorus to accumulate close to settled areas.

5.3.3 Horizontal Spread of Contaminants

The examination of the horizontal spread of contaminants has been restricted to the Sataoa, Moataa and Vaiusu Bay areas due to the greater number of cores examined there. The top 10 centimeters of each sediment core was examined to assess the horizontal spread of the contaminants.

At Sataoa, there was no clear depositional pattern for total nitrogen, manganese, copper and zinc in the top 10 cm of sediments (Appendix 11). There seemed to be a decrease in total phosphorus concentration with distance towards the sea, while iron levels demonstrated an increase in concentration in the same direction. The large-scale removal of iron from solution during estuarine mixing as noted by Liss (1976), probably explains the increase in iron content towards the sea. According to Orlov (1992), the presence of mobile ferrous ions in sediments is usually accompanied by increased solubility of phosphorus. This perhaps explains the decrease in phosphorus levels with increased iron content. The amounts of total phosphorus and iron carried by the Sataoa Stream were 0.07 mg/l and 0.01 mg/l respectively, which is not reflected in the distribution of these contaminants in the top 10 cm of sediment. Therefore, the contribution of organic matter to the amounts of iron and total phosphorus in the Sataoa sediments seems to be quite significant. At Moataa, it is noted that all the parameters examined had higher concentrations in core M2 than core M1. This points to a decrease in values with distance from the springs. The comparatively high levels of contaminants in core M2 is most probably contamination from the groundwater, feeding into the bay area (Figure 5.2).

The horizontal spread of contaminants at Vaiusu Bay was found to be variable. For total nitrogen, there appeared to be a tendency for nitrogen to accumulate closer to stream mouths as seen in Figure 5.9.

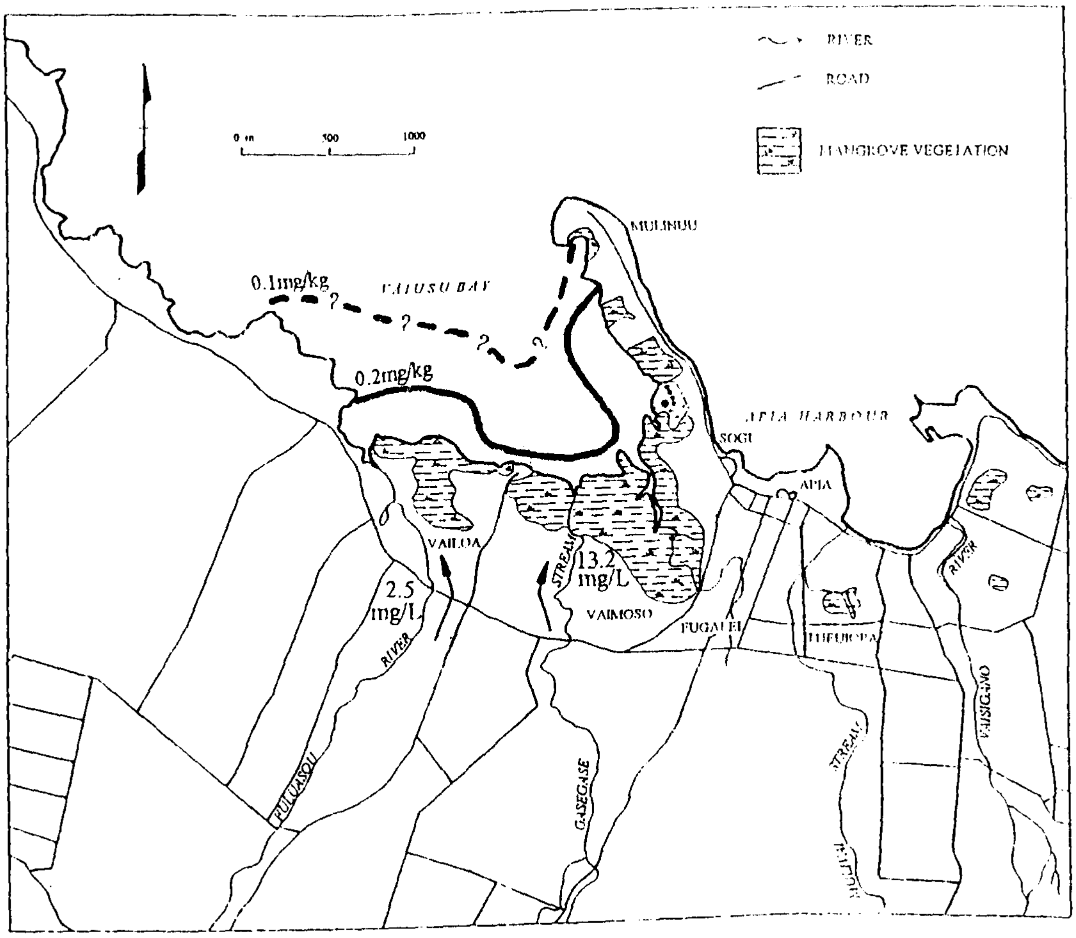

Figure 5.9: The Distribution Map of Total Nitrogen in the top 10 centimeters of Sediment from Vaiusu Bay. Source: Author's research

The Gasegase Stream was found to be carrying a lot more nitrogen than the Fuluasou River (Section 4.6.5), but this was not reflected in the nitrogen distribution in the top 10cm of sediments adjacent to the respective river mouths. The fact that the nitrogen was not found concentrated in the sediment cores closer to the stream mouths of these two streams suggests that the nitrogen may not be sinking, but could be carried further out into the marine environment.

The surface distribution of total phosphorus, given in Figure 5.10 shows an enrichment of phosphorus in the southern part of the bay closer to settled areas.

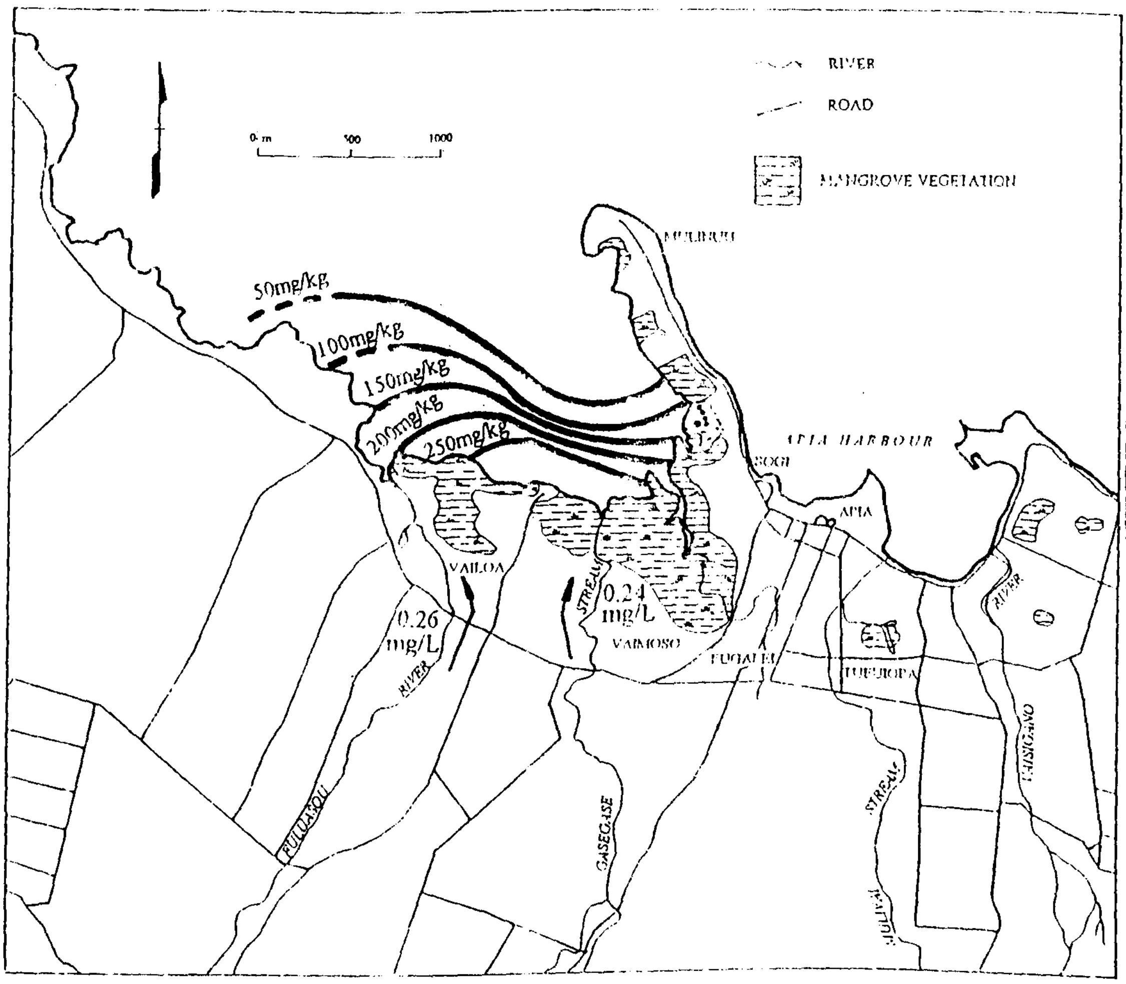

Figure 5.10: The Distribution Map of Total Phosphorus in the top 10 centimeters of Sediment from Vaiusu Bay. Source: Author's research

This has been attributed to both terrestrial inputs and the current circulation within the bay area. Isolines clearly show this higher phosphorus concentration in sediment cores closer to land and near stream mouths. From this observation, it appears that some of the phosphorus is probably sinking to the sediments as it is discharged to the coast. Both the Fuluasou and Gasegase streams carried comparable phosphorus contents to the coast (Section 4.6.6).

Figure 5.11 depicts the horizontal distribution of iron in the top 10 cm of sediments, where a rather complicated accumulation pattern is observed.

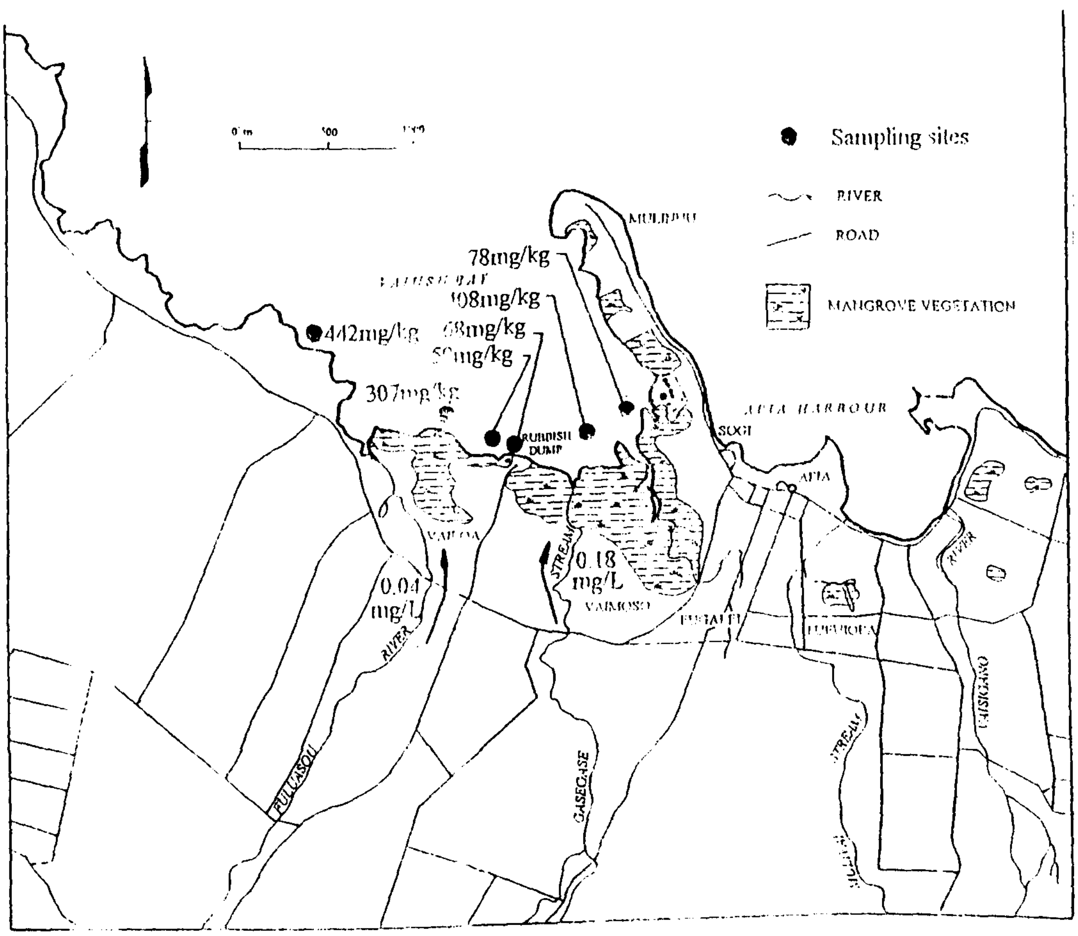

Figure 5.11: The Distribution Map of Iron in the top Sediments from Vaiusu Bay. Source: Author's research

While Gasegase Stream carried four times more iron than the Fuluasou River (Appendix 8.2 and 8.3), this was not reflected in the iron levels in the top 10cm of the sediment cores close to the mouths of these two water courses (Figure 5.11). It was difficult to draw lines of similar iron content in the bay area. The elevated iron value in cores V4 and V6 was surprising. As was the case with nitrogen, iron seemed to be carried further out to sea, and was not sinking into the sediments, as it was discharged from the terrestrial environment.

There was no clear horizontal deposition trend apparent for either manganese or copper in the sediments of Vaiusu Bay (Appendix 11). Comparable values of these two metals were observed in the top 10cm of sediments in all the six cores from the area.

In contrast, zinc showed a rather complex pattern in its horizontal distribution as shown in Figure 5.12. While both Fuluasou and Gasegase streams carried comparable zinc values of about 0.08 mg/l, this was not reflected in the surface sediment distribution map. The lines of similar zinc concentrations drawn showed that zinc values increased with distance from the coast (Figure 5.12), again suggesting that the zinc was not sinking to the sediments. The highest zinc value was noted at core V1. A water supply network is perhaps responsible for this, through rusting of pipes carrying the water. This rusting contamination is also possible from the British Petroleum storage facility located nearby, where galvanized iron roofing materials are used for the buildings.

From these observations, it is apparent that the horizontal spread of contaminants in the Vaiusu Bay area does not follow a regular pattern of distribution. There was no trend observed in contaminant concentration with distance from stream mouths. However, there appears to be a clear difference in contaminant accumulation in the deeper and shallower parts of the area, suggesting that most of the contaminants are not sinking to the sediments as they are discharged from the terrestrial environment. It is probable that there is an influence of lithology in the accumulation rate of contaminants, where the type of sediment plays an important part (Baker and Harris 1991; Shintu *et al.* 1991). An investigation into the variation of contaminant accumulation with grain size and carbonate content may give clearer trends in the horizontal distribution of contaminants in the sediments of Samoa.

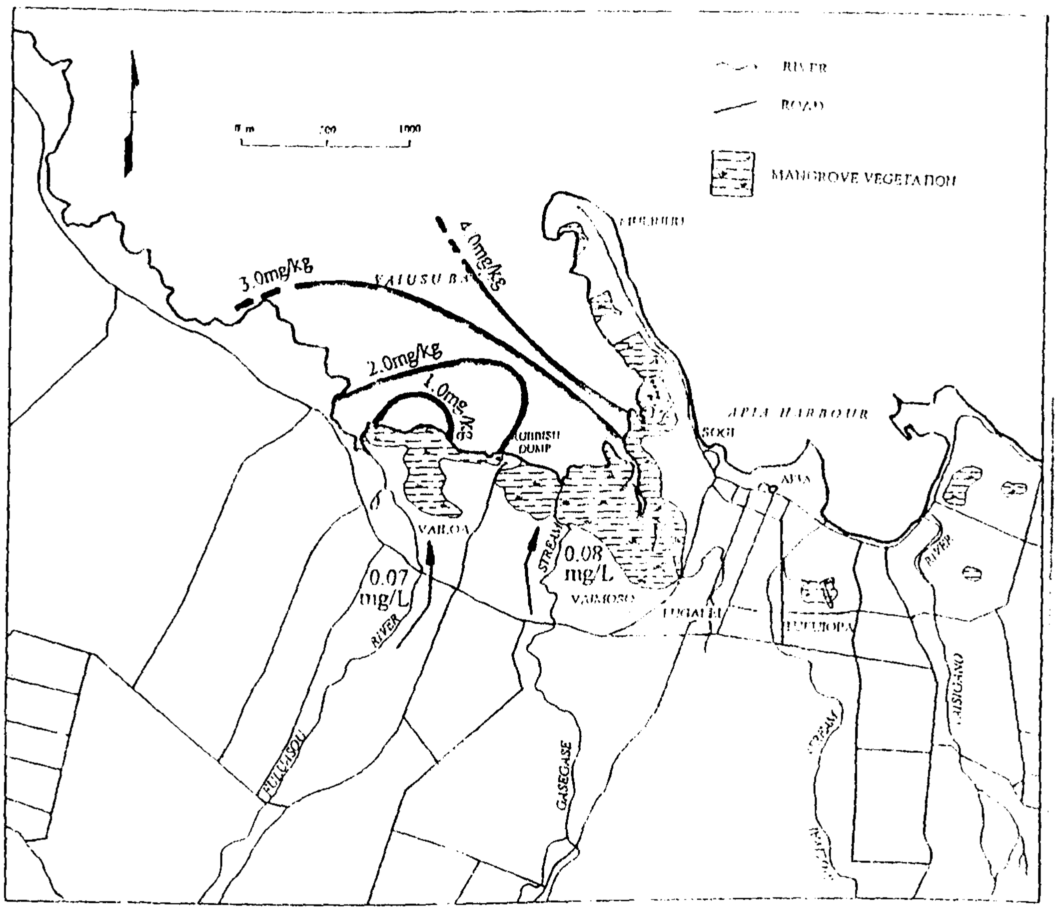

Figure 5.12: The Distribution Map of Zinc in the surface Sediments from Vaiusu Bay. Source: Author's research

5.3.4 <u>Summary of the Results Obtained</u>

No geochemical analysis to determine the effects of human impact in the coastal environment of Samoa has been attempted until now. The results of Chapter Four showed that the Fuluasou and Gasegase streams were carrying on average 8.3 mg/l of nitrogen, 0.25 mg/l phosphorus, 1.2 mg/l iron and 0.07 mg/l of zinc to the coastal zone (Appendix 8.2 and 8.3). A comparison of these values to those in Table 5.3 shows that there was a lot more contaminant values in the sediments than those carried by the streams. This suggests that anthropogenic loadings of all the examined contaminants occurred in the sediments of Samoa, especially iron and total phosphorus. Zinc concentrations in the sediments, although low, have proved important indicators of anthropogenic pollution. There is a high probability that Core M2 from Moataa is contaminated from groundwater. This result suggests the possibility that groundwater maybe a greater threat to sediment contamination than surface water.

The differences in accumulation patterns of certain contaminants in the deep and shallow parts of Vaiusu Bay suggest that the sediments are not acting as sinks for the contaminants from the terrestrial environment. Although total phosphorus and total nitrogen seemed to be sinking to the sediments, this was not clearly defined. The sediments of Samoa examined were not contaminated with manganese, copper and zinc, and the low concentrations of these three metals came exclusively from the weathering of the volcanic parent material. The values found for manganese, copper and zinc in the sediments of Samoa during this study provide baseline values for these metals for future investigations. The exercise was a major contribution to the field of tropical geochemistry in relation to the Samoan setting.

The next question that needs to be addressed is: what is the effect (if any) of the contaminated sediments on the coastal vegetation? Mangrove communities have been selected for examination of this question. Are anthropogenic factors contributing to the degradation of mangrove health in addition to the contaminated sediments? This is the focus of the next chapter.

CHAPTER SIX
MANGROVES AND MARINE RESOURCES OF SAMOA

"A nation has invaded my land....and ruined my fig trees"
Joel 1: v6,7

The term 'mangrove' is both well understood and difficult to accurately define at the same time (Hutchings and Saenger 1987). Ecologically, mangroves are "characteristic littoral plant formations which occur along sheltered coastlines on muddy substrates at the interface of land and sea if certain conditions prevail" (Hutchings and Saenger 1987:5). But to many people, mangroves are more than just plant formations. Vannucci (1985:1) noted that:

> To hundreds and thousands of people, the mangroves are their world, the only world they know, the world off which they live, only too often abused.

6.1 MANGROVES IN TROPICAL AREAS, THE PACIFIC AND SAMOA

Mangroves and mangrove swamps essentially occur in tropical and subtropical areas although one or two species of the genus *Avicennia* have penetrated into the warm temperate areas of parts of both hemispheres (Chapman 1984). There are two main groups of mangrove: the Indo-Pacific group from East Africa to Samoa, and the New World-West Africa group (Chapman 1984). Although fifteen main genera and 53 species have been identified worldwide (Table 6.1), only three genera are common to both groups: these are the *Rhizopora*, *Avicennia* and *Xylocarpus*. Introduced species are found in Hawaii and Fiji and the presence of *R. mangle* in Fiji and adjacent islands is attributed to human transport due to its value as a source of tannin (Chapman 1984).

TABLE 6.1: Distribution of Mangrove Genera and Species in the South Pacific. Source: Adapted from Chapman (1984)

Genus	Total species	Indo-Pacific and E. Africa	Fiji	F S M*	Palau	Papua New Guinea	Solomon Islands	Tonga	Samoa
Rhizophora	7	5	3	2	1	2	2	1	1
Bruguiera	6	6	1	1	1	1	1	1	1
Ceriops	2	2	-	-	1	1	1	-	-
Kandelia	1	1	-	-	-	-	-	-	-
Avicennia	11	8	-	-	-	1	-	-	-
Xylocarpus	10?	8?	1?	1	-	1	-	-	1
Laguncularia	1	-	-	-	-	-	-	-	-
Conocarpus	1	-	-	-	-	-	-	-	-
Lumnitzera	2	2	-	-	1	1	1	-	-
Camptostemon	2	2	-	-	-	-	-	-	-
Aegialitis	2	2	-	-	-	-	-	-	-
Sonneratia	5	5	-	1	1	1	-	-	-
Syphiphora	1	1	-	-	-	-	-	-	-
Nypa	1	1	-	-	1	1	-	-	-
Osbornia	1	1	-	-	-	-	-	-	-
Total	53?	44?	5?	5	6	9	5	2	3
Other genera	15	18	-	-	-	-	-	-	-
Grand Total	68?	62?	5?	5	6	9	5	2	3

* Federated States of Micronesia

Mangroves are found most abundantly in the South East Asia region, extending eastwards along the north coast of Australia and Papua New Guinea (Chapman 1984). In the Pacific region, the major mangroves are found in Papua New Guinea where they occupy an area of approximately 370 000 ha (Robbins 1968; Paijmans 1967; Unua 1992). Mangroves flourish in the high islands of Micronesia where a total areal extent of 8 600 ha is reported, dominated by five species (Merill 1945; Fosberg 1947; Devoe 1992). Around 38 550 ha of mangroves occur along the eastern coast of Viti Levu Island, Fiji, near Suva (Swarp 1992; Watling 1985). Mangroves also occur in Tonga scattered along protected coastlines of Tongatapu and Vavau groups (Crane 1979). Kwanairara (1992) reported 64 200 ha of mangroves in the Solomon Islands, while Minagawa (1992) noted nine mangrove species in Vanuatu found mainly in river mouths. The mangroves of Palau have been documented by Brel (1992) while those in Samoa mark the eastern limit of the Indo-Pacific mangrove distribution (Liu 1992). The distribution of the *Bruguiera* and *Rhizopora* species in the Pacific is given in Figure 6.1.

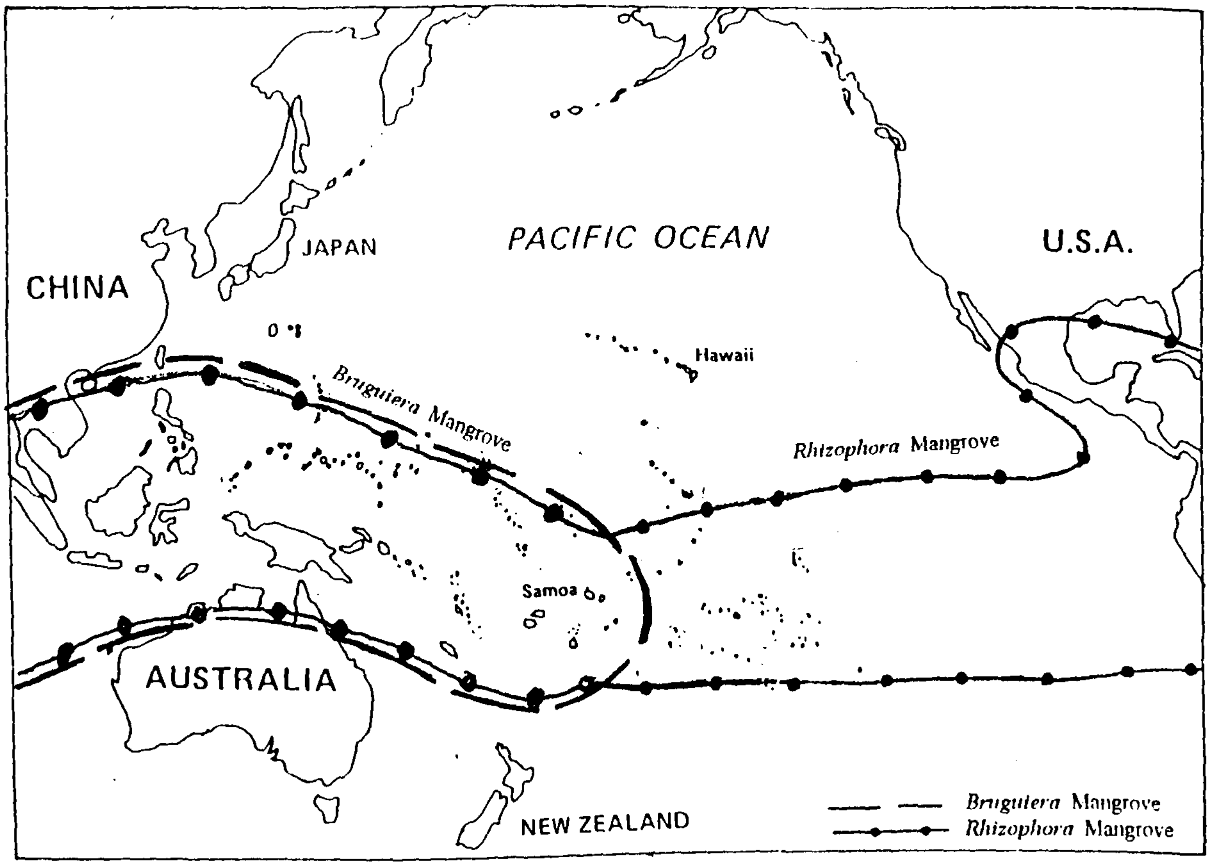

FIGURE 6.1: The Distribution of the *Bruguiera* and *Rhizopora* species in the Pacific. Source: Adapted from Biosystems Analysis Inc (1992)

The utilization of mangroves for food, cash income, shelter and medicine is universally accepted (Pillai 1984; Thaman 1994). The habitat also constitutes a reservoir for many plants and animals. Several authors have noted the importance of mangroves as nursery grounds for many fish species. Lear and Turner (1977) recorded 70 fish species known from Australian mangroves and Saenger *et al.* (1977) recorded 66 species of fish in the mangroves of East Australia. Shamsudin (1989) reported that marine fishes utilizing mangrove environments as nursery and feeding areas in Malaysia include the sea perch (*Lates calcarifer*), grouper (*Epinephelus* spp) and snapper (*Lutjanus* spp). Lal *et al.* (1983) reported on the fishes associated with the mangroves in Wairiki Creek, Fiji. From American Samoa, Yamasaki *et al.* (1985) mentioned thirteen fish species inhabiting the Nuuuli and Tafuna mangroves, while Knudsen (1991) reported 70 fish species in mangroves of Tutuila and Aunuu islands. Thollot (1993) surveyed the fish in the mangroves of Sataoa-Saanapu and Vaiusu Bay in Samoa and will be discussed in this Section. Soemodiahardjo and Soerianegara (1989) noted the extensive conversion of Indonesian mangroves to tambaks (brackish-water fish pond) where milkfish (*Chanos chanos*) were grown and more recently the highly priced prawn *Penaeus monodon*. In Thailand the destruction of mangroves for tiger prawn (*Penaeus monodon*) culture has become a serious problem (Chantadisai 1989).

Mangroves form a small but significant component of the biota of Samoa. In their survey of twenty-one terrestrial eco-systems in Samoa, Pearsall and Whistler (1991) recognized three mangrove communities. The most common mangroves were *Bruguiera gymnorrhiza* and the red mangrove (*Rhizophora samoenses*), both of which are characterised by aerial stilt roots and small flowers. In Samoa, these two communities typically occur adjacent to each other: The *R. samoenses* on the seaward fringe below the high water mark and *B. gymnorrhiza* on the landward side at about the high water mark. As Sasaki (1992) observed, the mangrove species are flanked by tidally adapted plants such as *Acrostichum aureum* and *Hibicus tiliaceus* on the landward side of the mangroves (Figure 6.2). In marginal habitats, the *B. gymnorrhiza* appears as depauperate, scrubby, and multi-branched. The *R. samoensis* is very difficult to distinguish from the *R. mangle*, and may be regarded as a Western Pacific outlier of the *R. mangle* (Tomlinson 1986). One very small and rare occurrence of the *Xylocarpus moluccensis* mangrove has also been found at Sala'ilua on the south coast of Savaii (Pearsall & Whistler 1991). The total extent of mangrove communities in Samoa has been estimated to be about 1270 hectares, or less than one percent of the land area of Samoa (Zann 1991).

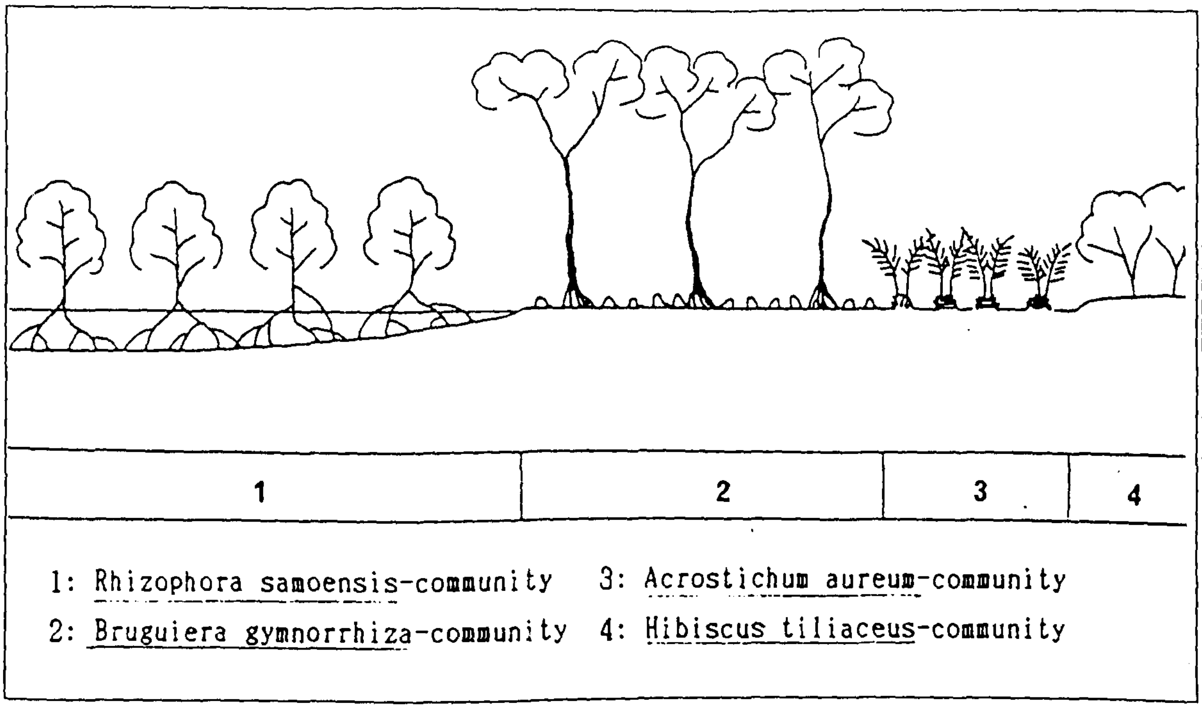

FIGURE 6.2: Typical Mangrove Zonation in Samoa.
Source: Sasaki (1992)

The distribution of mangrove ecosystems in Samoa is shown in Figure 6.3. Most mangrove ecosystems are located in Upolu. The largest areas are in Vaiusu Bay west of Apia, at Moataa village east of Apia, and at three sites on the south coast of Upolu adjacent to the villages of Pata, Sataoa and Vaiee. Indeed, Vaiusu Bay contains the largest area of mangroves in eastern Polynesia (GWS 1991). Mangrove communities in Samoa are usually located in drowned valleys and barrier-impounded stream mouths, and all of the most extensive mangrove communities listed above are situated behind large barrier spits (Richmond 1991).

It is the use of mangrove areas as a refuge for fish populations, on which the Samoan people so much depend, that is probably the least understood value of the mangrove communities in Samoa. Thollot (1993) conducted a survey of fish occupying the mangrove areas of Sataoa and Vaiusu Bay.

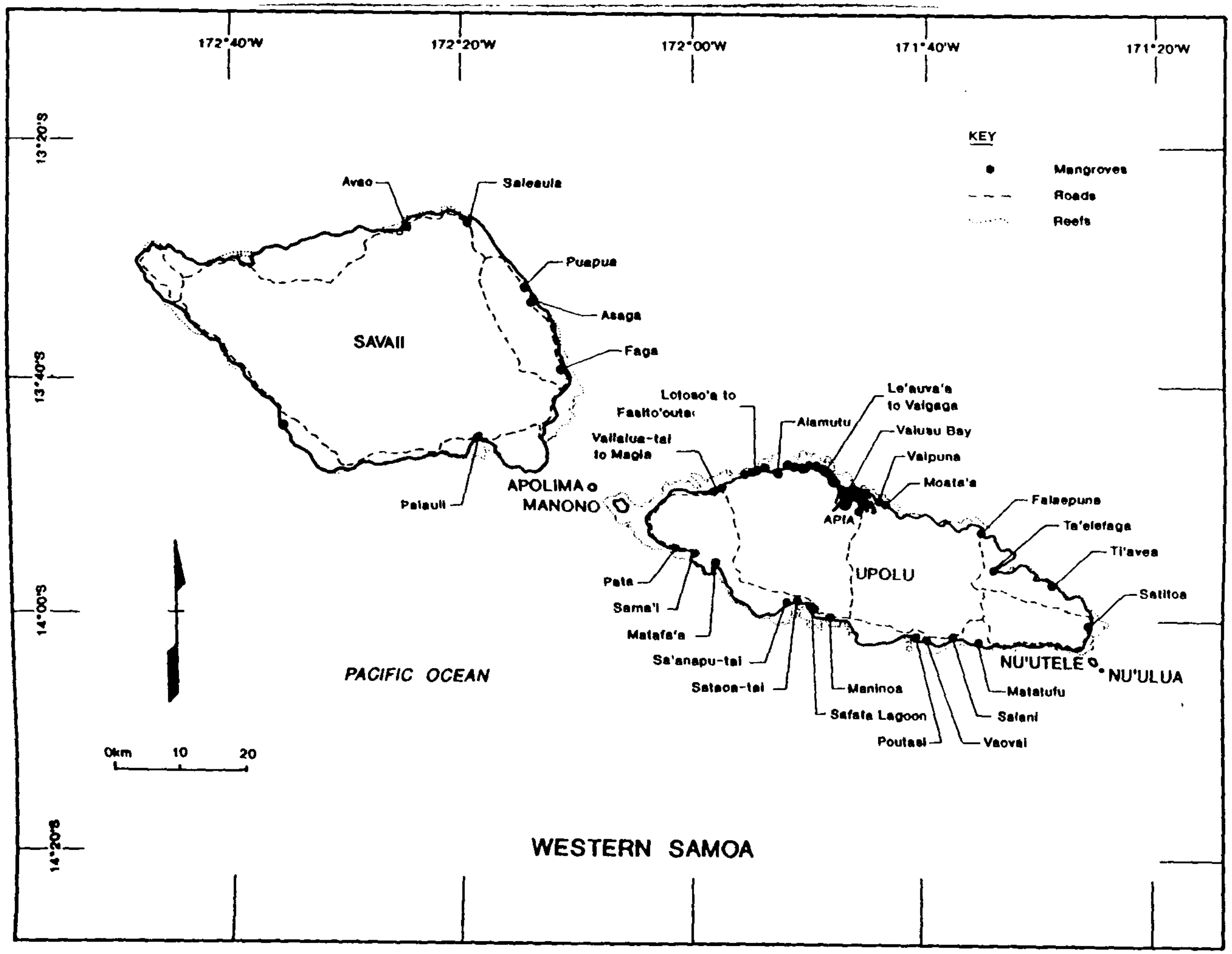

FIGURE 6.3: Mangrove Areas in Samoa. Adapted from Western Samoa Department of Lands and Environment (1992)

He found that 35 species of fish distributed among 22 families were found in the mangrove areas examined. The most specious families were found to be the Gobiddae (5 spp.), Mullidae, Mugilidae and Ophichthidae (3 spp. each). The dominant species numerically were the mullets (*Liza melinoptera* and *Valamugil engeli*), the putterfish (*Arothron manillensis*) and the crescent perch (*Therapon jarbua*). Thollot (1993) considered that it was possible that a total of 216 fish species distributed amongst 61 families may be found in mangroves in Samoa.

In addition to fish, Samoan mangrove areas are home to a number of birds, mammals and invertebrates. For example, at the Sataoa-Saanapu mangrove site, recorded bird sightings include the Pacific Reef Heron (*Egretta sacra*), Pacific Black Duck (*Anas superciliosa*), Pacific Golden Plover (*Pluvialis fulva*), Purple-capped Fruit-Dove (*Ptilinopus porphyraceus*), Samoan Whistler (*Lalage sharpei*), Samoan Broadbill (*Myiagra albiventris*) and Cardinal Honeyeater (*Myzomela cardinalis*). Flying foxes (*Pteropus* spp.) also occur in the Sataoa-Saanapu mangroves, as do invertebrates such as the mangrove crab *Scylia paramamosian* and crabs of the genus *Uca* (Schuster 1993a).

Mangrove communities in Samoa are important not only as refugia for biota, but also the following reasons (Department of Lands & Environment 1992). Firstly, the complex root system of the mangrove trees trap sediments and act as an agent of land reclamation, forming natural breakwaters, which protect the land from wave action and coastal erosion. Secondly, nutrients in land-based runoff may be retained within the mangrove ecosystem before they reach the reefs and cause damage. Thirdly, many fish species inhabit the mangrove areas at some stage during their life cycle, especially prior to spawning. Fourthly, they provide multiple resources to the local village economies. For example, they are the source of mangrove crabs, mangrove wood for fuel and outriggers of small canoes, and bark which is used to make a dye for tapa cloth. The crab fishery contributes significantly to the subsistence and income of families living adjacent to mangrove areas.

Ironically, while Samoans may be aware of the importance of the mangrove ecosystems, they have carried out and continued to undertake activities that lay peremptory blame to the degradation of mangroves. Growing population expansion and the needs for food and shelter have exposed mangroves to ecological degradation in Samoa."Overfishing coupled with a worrying loss of fish nurseries from mangrove destruction" was one of three main environmental issues facing Samoa identified by Thistlethwait and Votaw (1992: 139). Indeed, as early as 1963, it was recognized that mangrove swamps had previously been more extensive, and that removal of mangroves for firewood had contributed to coastal erosion (Wright 1963). Richmond (1991) claimed that the removal of mangrove vegetation was of special concern, not only because the mangroves shielded vulnerable coastlines from wave attack, but also because their disappearance would have unforeseen consequences for local sediment budgets and sediment transport pathways.

The lack of appreciation of mangroves by the Samoan people is demonstrated by the following activities that have taken place in mangrove communities. Mangrove areas have been reclaimed to construct the Royal Samoan Hotel at Moataa and establish the industrial development at Vaiusu. Mangroves were also reclaimed to extend the area available for village dwellings, to create a sheltered boat harbour at Tafitoala, or to allow for road construction, causeways or access tracks. Seawall construction or land drainage works that have contributed to their degradation has affected other mangrove areas. Concurrent land use activities such as sand mining in Vaiusu Bay and causeway construction at Saanapu and Moataa have altered the natural circulation patterns in the embayment areas, so as to adversely influence the mangrove communities. Also, some sites around Apia have been exposed to pollutants through rubbish dumping. Fish poisoning in the water channels of mangroves using the pounded roots of the *Derris elliptica* has been a common practice (Johannes 1982).

There is abundant circumstantial and qualitative evidence to suggest that the mangrove environment in Samoa is diminishing in extent and quantity. Hence, the question needs to be asked: is the mangrove ecosystem in Samoa robust or are the effects of anthropogenic degradation evident? Rapport (1989) noted that ecosystem breakdown may be characterized by: reduced primary productivity, loss of nutrients, loss of sensitive species, increased instability in component populations, increased disease prevalence, and increased circulation of contaminants. Some of these symptoms will be examined to assess the current health status of selected mangrove stands in Samoa in Section 6.3.

A general assessment of the current status of the mangrove communities in Samoa is given in Table 6.2. The basis on which the degradation levels were defined stemmed from two considerations. Firstly, the 1970 and 1990 aerial photos were compared to obtain differences in areal extent of mangrove communities over two decades. Secondly, the sites were examined in the field for physical obstructions to optimal current circulation and mangrove expansion.

The 'very seriously degraded' mangrove stands were defined as those areas where more than half the mangroves had been reclaimed, or the mangrove areas are being used as rubbish dumps or as recipients of industrial waste. Watercourses have been altered and the areal extent of mangroves has been reduced dramatically. In many of these areas, cutting for firewood has been quite severe. The 'seriously degraded' sites are defined as areas that had between 25% and 50%

of their areas reclaimed or in-filled. The cutting of the mangrove forests was severe in these areas.

TABLE 6.2: Location, Extent and Status of Mangroves in Samoa. Source: Adapted from an unpublished document on mangroves in Samoa supplemented by author's fieldwork

LOCATION	EXTENT	STATUS OF MANGROVE COMMUNITY
Moataa	25 ha	Very seriously degraded. Half has been reclaimed for the Royal Samoan development and now drains through a canal into the sea.
Vaipuna	5 ha	Seriously degraded. Areas cleared for housing, drainage, etc. Entrance disturbed by road construction. Shore disturbed by Royal Samoan reclamation.
Vaiusu Bay	65 ha	Very seriously degraded. Back forest reclaimed for housing, plantations, industrial development, drainage. Part of seaward area reclaimed for rubbish dump. Water quality poor. Domestic and industrial discharges into Bay. High bacteria levels. Circulation disrupted by Mulinuu sand mine.
Leauvaa to Vaigaga	10 km of shore	Moderately degraded. About 25% of length has been disturbed with infilling by locals, construction of seawalls, etc.
Alamutu	5 ha	Seriously degraded. Entrance and shore reclaimed during construction of North Coast Road. Drainage restricted.
Lotosoa	4 ha	Seriously degraded. North Coast Road cuts mangroves from the sea. Swamps drained and reclaimed for housing, plantations, etc.
Vailuu-tai	4 ha	Moderately to seriously degraded. Partly reclaimed for housing, plantations, drainage canals.
Pata to Samai	28 ha	Moderately degraded. Shoreline reclaimed with seawalls. Part of Pata forest cleared for plantations.
Matafaa	10 ha	Slightly degraded. Seawalls and infilling for housing and plantations by locals.
Saanapu	20 ha	Moderately degraded. Causeway restricts circulation through upper forest. Partly infilled for housing.
Sataoa	20 ha	Slightly degraded. Back forest partly cleared for plantations. Least degraded mangrove ecosystem in Western Samoa.
Safata Lagoon	30 ha	Moderately degraded. Some cleared for housing at Tafitoala, a boat harbour at Vaieetai, plantations, access tracks, etc.
Maninoa	5 ha	Moderately degraded. Back forest largely cleared at Maninoa.
Poutasi / Vaovai	10 ha	Moderately degraded. Local clearing and infilling.
Matatufu	5 ha	Moderately degraded. Local clearing and infilling
Lotopue	2 ha	Moderately to seriously degraded. Much cleared, infilled and drained.
Tiavea	5 ha	Moderately to seriously degraded. Much cleared, infilled, and destroyed by the cyclones
Taelefaga	1 ha	Moderately degraded. Road and causeway at seaward entrance.
Faleapuna	4 ha	Moderately degraded. Back forest partially cleared, infilled and drained.
Salailua	0.5 ha	Not degraded as access to mangrove is difficult. The only occurrence of the *Xylocarpus sp* in the country
Palauli	2 ha	Moderately degraded. Local clearing and reclamation
Sapapalii	3 ha	Moderately to seriously degraded. Much cleared, reclaimed, and destroyed by the cyclones
Lano / Faga	1 ha	Moderately degraded. Local clearing and infilling
Asaga	5 ha	Moderately degraded. Local clearing and reclamation
Satoalepai	5 ha	Moderately degraded. Local clearing and infilling
Avao	0.5 ha	Moderately degraded. Local clearing and reclamation
Matavai	1 ha	Moderately to seriously degraded. Much cleared, infilled, and destroyed by the cyclones

Key : slightly degraded = >5% change in areal extent over 20 years
moderately degraded = 5-24% change in areal extent. seawall construction at leeward edge
seriously degraded = 25-49% change in areal extent, road construction
very seriusly degraded = >50% change in areal extent, roads, incompatible uses (rubbish dump, recipient for industrial waste)

'Moderately degraded' sites are those subjected to local in-filling activities, clearing for plantations and construction of seawalls. Between 5% and 25% of their land areas have been cleared. The 'slightly degraded' areas are those with little change over 20 years, restricted to local rubbish in-filling behind settled areas. The cutting of the mangrove trees in these areas was only on a small scale. Thus the use of the word 'degraded' in Table 6.2 is a reference to the physical sense and not ecosystem health.

6.2 A CASE STUDY OF THREE MANGROVE COMMUNITIES

Of all the sites in Samoa which carry stands of mangroves, three have been selected for in-depth study. The mangroves at Saanapu and Sataoa on the south side of the island are described in Table 6.1 as only 'slightly degraded', while the mangroves at Vaiusu Bay and Moataa near Apia are both 'very seriously degraded'. The Saanapu and Sataoa site is considered to be the least degraded wetland in Samoa and of high conservation value (Pearsall & Whitsler, 1991; Thollot, 1993; Atherton, 1994). Saanapu and Sataoa is thus used in this study as a control site against which to compare the very seriously degraded sites.

This section describes the biogeographical setting of the mangrove communities at each site, as well as the history and current status of the mangroves. Aerial photographs of each site taken in 1970 and 1990 have been examined to determine changes in the extent of mangrove coverage over that time period. Unfortunately, no aerial photography postdating the two recent cyclones was available (Taulealo 1993). Land uses influencing the distribution of mangrove communities are discussed. Fish surveys at two of the sites have previously been conducted and the importance of each mangrove site for fish breeding will be highlighted.

6.2.1 Site 1: Saanapu and Sataoa

The mangrove community between the villages of Saanapu and Sataoa is located on the south-south-west side of Upolu immediately to the west of Safata Bay, and are approached by short terminal access tracks from the main South Coast Road (Figure 6.4). The mangroves at Saanapu are located north of a large fringing sandy spit, which indicates a predominant longshore direction towards the north-east (Richmond 1991). Indeed, between 1970 and 1990 there has been a decrease in the width of the fringing spit near Saanapu, with a corresponding buildup of material adjacent to Sataoa. A stand of coastal rain forest separates the mangroves at Saanapu and Sataoa, and a tidal channel runs through both stands of mangroves. Relatively young Lefaga Volcanic characterised by a lack of surface streams and dissection (Wright 1963) underlie Saanapu area. Salani Volcanic underlies the Sataoa area, where strong dissection by surface streams is evident (Richmond 1991). The substrate of the mangrove community is sandy to muddy with large volcanic rocks present which are suitable for algae and invertebrate growth (Thollot 1993).

In 1970, the combined extent of mangroves at Saanapu and Sataoa was 28.4 hectares. The Sataoa mangroves were abutted on the south-east side by the village, on the north side by tidal flats and plantations, on the west side by coastal rain forest, and on the south side by a strip of coastal forest (Figure 6.4). Likewise at Saanapu, the area north of the mangroves grew plantation crops, and to the south was a narrow strip of coastal forest and the village. A causeway through the mangrove forest at Saanapu provided vehicular access to the village. The tidal channel through each stand of mangroves was irregular and, through the Sataoa mangroves, was particularly narrow.

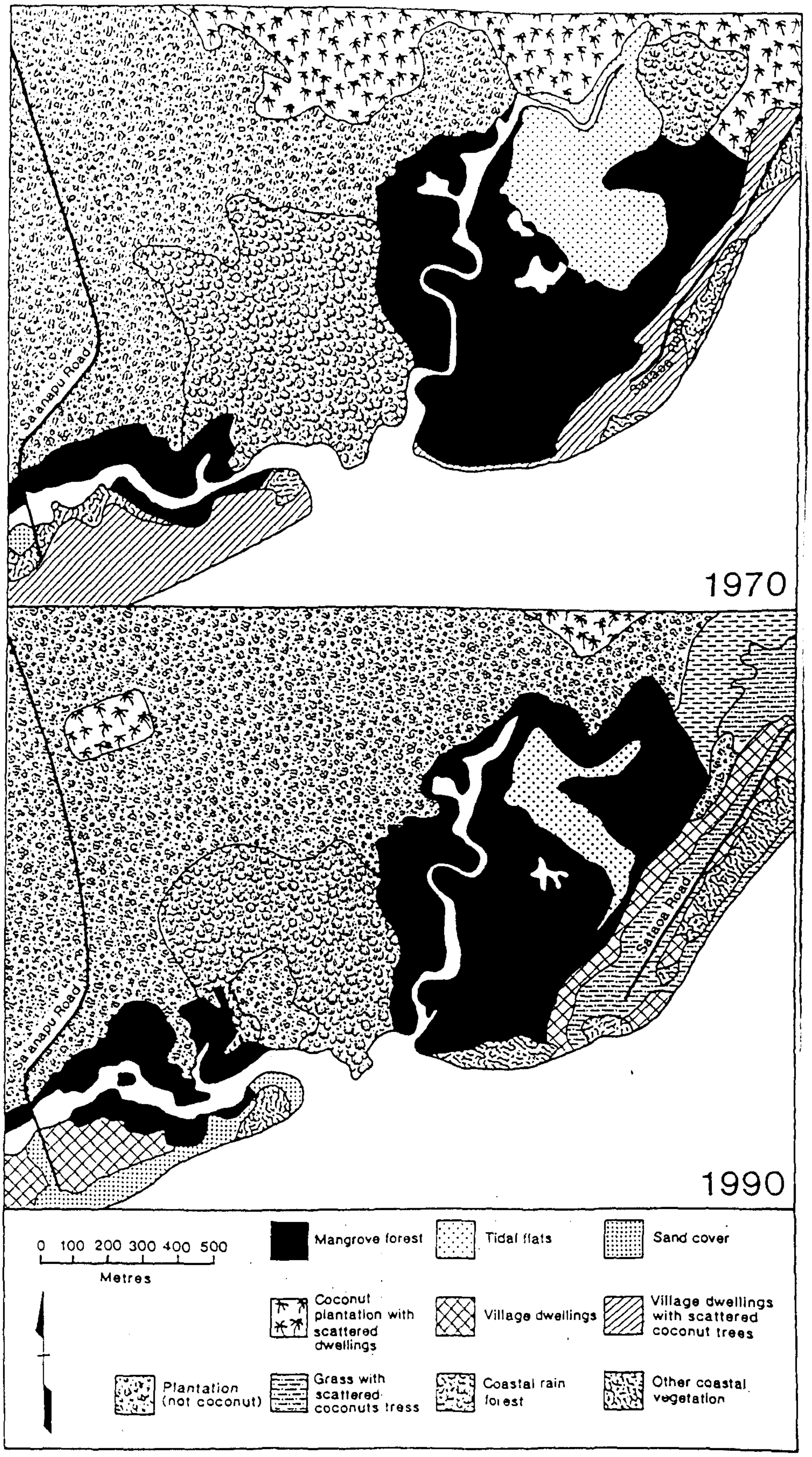

FIGURE 6.4: Changes in Vegetation Cover at the Saanapu and Sataoa Area in 1970 and 1990. Source: Author's research.

By 1990, changes to the extent as well as the distribution of the mangroves had occurred. It is apparent from Figure 6.4 that the mangroves at Saanapu had extended their range away from the tidal channel except in the vicinity of the road and a lobe of plantation crops. At Sataoa, the mangroves west of the tidal channel had remained static, whereas mangroves had colonized the northern extremity of the tidal flats. Some clearance of the mangroves in the northwestern part of the village dwellings had also taken place. The tidal channel through the Sataoa mangroves had noticeably increased in width and the area of tidal flats adjacent to the mangroves had become substantially smaller. The combined area of mangroves at Saanapu and Sataoa in 1990 was 30.1 hectares: a net increase of six percent. The increase in areal extent appears to be representative of a healthy mangrove community where the mangroves are acting to colonize previously unvegetated ground.

In 1992, Thollot (1993) considered that the mangrove community at Sataoa was healthy, and noted that large *Bruguiera gymnorrhiza* with numerous epiphytic species grew up to fifteen meters high in the inner side of the mangrove community, while a narrow fringe of *Rhizophora* spp. was located at the seashore. Other species present at the site included the ferns *Acrostichum aureum*, *Humata heterophylla*, and *Barringtonia asiatica*. Schuster (1993a:439) reported that "In 1990, Hurricane Ofa deposited a fair amount of sand in the estuary mouth, but otherwise the ecosystem remains in good condition". Lovegrove *et al.* (1992) and Atherton (1994) were of this same view, although they feared that a significant decrease of bird species and species richness had taken place since the cyclone.

When the fish population occupying the Saanapu and Sataoa mangrove area were examined by Thollot (1993) a total of 20 species were found to be present (Table 6.3). Cresent perch, mullet and damselfish were the most commonly found species. All were caught for food. Diversity indices and evenness values were calculated from the catch, and Thollot (1993) concluded that the fish population at the mangrove area was quite stable. This result is in harmony with the many claims that the Saanapu and Sataoa mangroves are the healthiest communities in Samoa.

TABLE 6.3: Fish Sampled from the Saanapu and Sataoa Mangrove Area. Source: Adapted from Thollot (1993)

Samoan name	English name	Scientific name	Number caught	% of total	% weight of total
Avaava	Crescent perch	*Therapon jarbua*	48	21.3	39.4
Moi / Poi	Mullet	*Liza melinoptera*	31	13.8	20.7
Aua / Fuafua	Mullet	*Valamugil engeli*	69	30.7	9.6
Tuu'u	Damselfish	*Chrysiptera notialis*	22	9.8	4.8
Tauleia	Goatfish	*Parupeneus indicus*	1	0.4	4.4
Ava / Avali	Milkfish	*Chanos chanos*	2	0.9	3.2
Popoto / Anae	Mullet	*Valamungil seheli*	3	1.3	2.9
Pasina / Vete	Goatfish	*Mulloide flavolineatus*	4	1.8	2.8
Pone / Palagi	Surgeonfish	*Acanthurus xanthopterus*	2	0.9	2.3
Filoa-vai	Lethrinidae	*Lethrinus harak*	5	2.2	1.8
Lalele	Mountain bass	*Kuhlia marginata*	10	4.4	1.5
Matu-Iua	Mojarra	*Gerres ovatus*	3	1.3	1.2
Ula'oa	Goatfish	*Upeneus vittatus*	1	0.4	1.1
Malauli sinasama	Trevally	*Caranx papuensis*	4	1.8	0.9
Mutu	Damselfish	*Abudefdufseptemfasciatus*	1	0.4	0.9
Tamala	Snapper	*Lutjanus fulvus*	4	1.8	0.9
Malauli apamoana	Trevally	*Caranx melampygus*	6	2.7	0.5
Name not known	Mono	*Monodactylusargenteus*	1	0.4	0.4
Name not known	Halfbeak	*Zenarchopterus dispar*	6	2.7	0.4
Fo	Cardinalfish	*Apogon lateralis*	2	0.9	0.1

Thollot (1993) measured the length and weight of all fish caught, and the stomach content of some of the species. He found that the size of the fish caught tended to be small, indicating that the fish probably sheltered in the mangrove areas during their immature stages. That the fish caught in the mangroves were feeding on organisms found within the mangroves area was evidenced by the fact that the stomach content of the fish analyzed consisted of algae, crab, bivalves and worms which inhabit the mangrove environment. This data provides strong evidence that the mangroves are being used as nursery grounds for many species of fish. Zann (1991) reported that 130 kilograms of fish per hectare per year were caught from the nearshore lagoon waters adjacent to Sataoa, which was one of the most productive areas in Samoa.

6.2.2 Site 2: Vaiusu Bay

The geology and physical characteristics of Vaiusu Bay have already been given in Section 5.2.3. The geomorphological setting of Vaiusu Bay makes it an ideal setting for the development of extensive mangrove communities. The Bay is supplied with terrestrial sediment from the rivers entering from the south, and with marine sediment via longshore drift from the east. It is protected from strong ocean currents by the coral reef located to the north and from longshore currents by the presence of Mulinuu Peninsula. *Rhizophora samoensis* is the dominant mangrove fringing Vaiusu Bay, but a few specimens of *Bruguiera gymnorrhiza* are also present (Klinckhamers 1992). At Saanapu and Sataoa, these species grew to a height of fifteen meters, but Thollot (1993) noted that at Vaiusu Bay the same species grow less than five meters high. This author found trees over fifteen meters high in one of the Vaiusu Bay transects (Appendix 12.7). Various Government offices, industrial plants, village dwellings and plantations, and remnant coastal vegetation flank the mangroves at Vaiusu Bay.

Figure 6.5 depicts the land cover surrounding Vaiusu Bay in both 1970 and 1990. The distribution of mangrove forest in the Vaiusu Bay area appears to have changed over two decades. The most obvious changes have been the clearance of mangroves to make way for the Apia Rubbish Dump, the Fish Farm, and some urban areas on Mulinuu Peninsula. Alternatively, there have been notable increases in mangrove coverage on the leeward side of the Mulinuu Peninsula and the landward side of the mangrove fringe along the Fugalei Stream. From Figure 6.5, the extent of mangroves in 1970 was calculated to be 51.0 hectares, and in 1990 was 40.6 hectares. Two points are of note here. Firstly, the area calculations given here are 20% less than that given in Table 6.1. The reason for the over-estimation in mangrove extent given earlier is not clear, although Thollot (1993) noted an error in the Department of Lands and

Environment's figure of the total mangrove area in the country as documented by Liu (1992). Secondly, there has been a nett decrease in mangrove extent at Vaiusu Bay of 20.4% in contrast to the increase experienced at Sataoa. Although there has been some recruitment of mangroves in favourable locations, field checking of the majority of the mangroves indicated that they were seriously stressed (Section 6.3).

Concern about the condition of the Vaiusu Bay mangroves has been expressed by a number of authors, of which Thistlethwait and Votaw (1992: 137) are an example:

> The largest lagoon, located around the Apia area on the north side of Upolu contains a mangrove area which, together with the wetlands in Apia Bay and Vaiusu Bay, are the main fish nurseries for Samoa. The mangroves are currently [1992] being used as Apia's rubbish dump, and the wetlands are being filled for reclamation.

Indeed, there are a number of land uses, which mitigate against the continued health of the mangrove communities at Vaiusu Bay. The dumping of rubbish in the mangrove areas bordering Vaiusu Bay has occurred since the early 1970s. A temporary rubbish dump existed at Sogi on the eastern side of Vaiusu Bay in the early 1970s, but was short-lived. In 1972, the official rubbish dump for Apia was relocated to the southern side of Vaiusu Bay at Vaitoloa (McQuitty 1972). The major contributors to, and types of industrial waste dumped at Vaitoloa until 1992 is given in Table 6.4. No sorting of waste material occurred and dangerous goods such as lead and acids in car batteries were given no special treatment. It was estimated that about 17 000 cubic meters or 3000 tonnes of waste were deposited annually at this dump site during the twenty years of its existence (Taulealo 1993). During Cyclone Ofa in February 1990, waves over five meters high damaged the dump, and much of the refuse was washed out to sea (Taylor 1991).

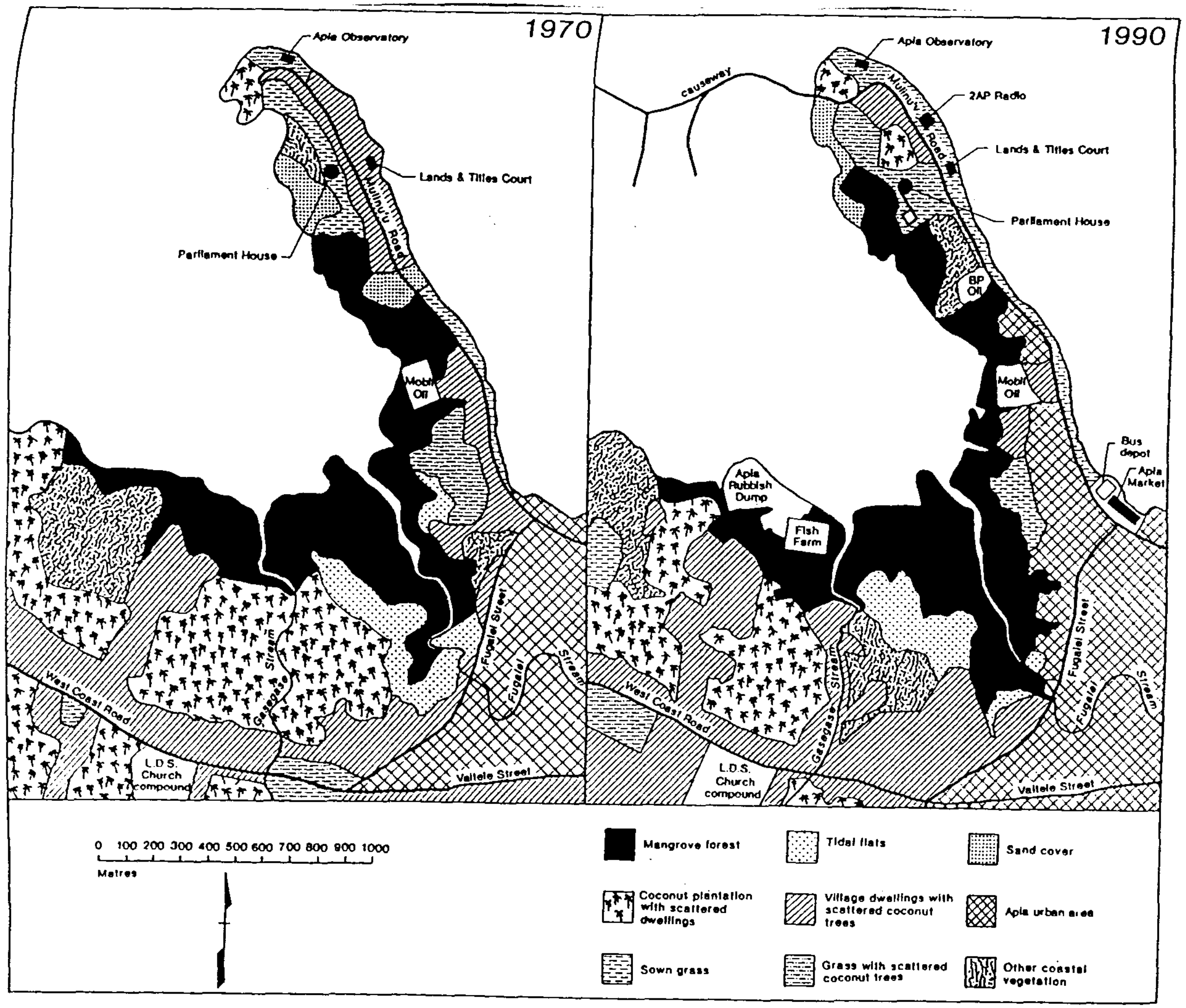

FIGURE 6.5: Changes in Vegetation cover in the Vaiusu Bay Area in 1970 and 1990. Note that the Fuluasou River empties into Vaiusu Bay immediately to the left of the area shown on this map. Source: Author's research.

TABLE 6.4: Major Industries Dumping Waste at Vaitoloa until 1992.
Source: Adapted from Klinckhamers (1992)

INDUSTRY NAME	INDUSTRY TYPE	WASTE GENERATED and DUMPED AT VAITOLOA
Natural Foods	Snack foods, Ice lollies and taro chip production	Plastic bags and lolly wrappers
Vailima Breweries	Local beer brewing	Solid materials from brewing tank and broken plastic crates
Samoa Coconut Products	Coconut product canning	Sand, dust, metal, bad coconut cake, worn out sacks and general rubbish (three loads / week)
Samoa Tropical Products	Coconut cream canning	Packaging materials (one truckload / week)
MacDonalds Motors	Sale of household machinery and repairs	Broken spare parts (eg. Relays, compressors)
Public Works Mechanical Shop	Mechanical works	Spare parts, packaging rubbish, old tyres, useless batteries
Photomart	Development of films	Empty rolls of film, photopaper, undiluted developer (2 litres / week), bleach (2 litres / week)
Pacific Printers and Publishers	Printing of newspapers, magazines, etc	Paper (100 sheets / week) and rubber
Samoa Upholstery	Production of foam, manufacture of furniture, re-upholstering	Woods parts, foam parts, empty packaging material
Yazaki	Production of wiring looms for cars	Cardboard boxes
South Pacific Industries	Production of soap and plastic bottles	Solid wastes and packaging materials
MacKenzies Wholesale	Sale of imported frozen and canned food	Packaging materials

The closing of the Vaitoloa dump in the mangrove area west of Apia marked a big step forward in the conservation of mangrove swamps and wetlands in Samoa (Taulealo 1993). However, the rubbish that had accumulated over 20 years at that site has not been removed, and until the Vaitoloa dump is subject to a restoration program, leachate from the dump will continue to pollute the area.

The rubbish dump is not the only threat to the Vaiusu Bay mangroves. Reclamation of the landward edge of the mangrove forest occurred prior to the 1970s particularly in the urban expansion areas on the southern end of the Mulinuu Peninsula (Figure 6.5). The fish farm located near the Apia Rubbish Dump is one of a number of aquaculture operations in Samoa which were started but later aborted before any production took place (Kearney and Rivkin

1981). In 1994, 25 hectares of mangroves at Fugalei was subdivided and sold as freehold land. A church, restaurant and night club have since been built (Plate 6.1).

PLATE 6.1: The extensive cutting of mangroves at Fugalei. Shown are the church building and the nightclub. Photograph by author

Perhaps the most worrying threat to the Vaiusu Bay mangroves is the pollution of the waters in the Bay from local seepage and runoff. Private homes use either septic tank with soakage facilities, pour-flush toilets, pit latrines or primitive toilets over the sea without pits. The Government of Western Samoa (1992c) found that the groundwater in the low-lying areas of Apia, such as the Vaiusu Bay area, was being polluted by effluent from many of the sewage disposal facilities. In addition, liquid waste from the industries given in Table 6.5 finds its way into Vaiusu Bay via either seepage into the shallow groundwater aquifer around Apia or as direct runoff into the Fuluasou River, Gasegase Stream or Fugalei Stream. The delivery of untreated cleaning chemicals, stock manure, brewing waste, oils and laboratory chemicals into the Vaiusu Bay area is of continuing concern, as there have been no moves to alter these practices.

Taylor (1991) reported that a water sample taken from an open drain that discharged sewage effluent from the Tusitala Hotel into the tidal area of the Fugalei Stream contained high concentrations of nitrogen, phosphorus and faecal coliform bacteria. A water sample taken from the Vailima brewery outfall also contained high concentrations of nitrogen and phosphorus. Water samples taken in Vaiusu Bay adjacent to the dump site in 1994 showed phosphate values at 2.4 mg/l and faecal coliform counts of 1000 mg/l (Gangaiya and Wele 1994). Consequently, total phosphorus concentrations within Vaiusu Bay were so high that algal growth in undesirable amount had occur (Taylor 1991). However, two samples of the bivalve shellfish (tugane: *Gafraruim* spp.) analysed for zinc, copper, lead, and mercury concentrations did not indicate contamination by those metals. Average values for total phosphorus and total nitrogen carried by the Fuluasou River towards Vaiusu Bay during this study (Section 4.4) were 0.26 mg/l and 2.5 mg/l respectively. Gasegase Stream carried on average 0.24 mg/l total phosphorus and 13.2 mg/l total nitrogen, while the grab sample from the Fugalei drain had a total phosphorus concentration of 0.65 mg/l and a total nitrogen concentration of 42.0 mg/l. The lower nutrient values reported in this study are most probably due to the dilution effect of the flowing waters, or the selective sampling by other researchers.

Another factor influencing the health of the mangroves is the presence of two sand mining operations in Vaiusu Bay. Since 1980, the Ulberg Brothers have been directing the Mulinuu dredging operations west of the head of Mulinuu Peninsula (Thompson 1991), where they have built a number of causeways to facilitate the dredging of material (Figure 6.5). The amount of material excavated from the Mulinuu dredging operations and the Apia Concrete Products site has been estimated to be 28 000 and 8 000 cubic meters per annum respectively. Dredged areas have been found to be partially in-filled after storms by westward-flowing currents (Richmond 1991), thus ensuring a continued supply of material in Vaiusu Bay.

TABLE 6.5: Industrial Waste finding its way into Vaiusu Bay via Seepage or along Stream Channels. Source: Adapted from Klinckhamers (1992)

INDUSTRY NAME	INDUSTRY TYPE	POLLUTANTS CONTAINED WITHIN WASTEWATER	SITE OF WASTE DISPOSAL
Natural Foods	Snack food production	Untreated cleaning chemicals and oil	Dumped in swamp behind the factory which drains into Fugalei Stream
Selprize	Production of plastic bags, taro chips and breadfruit chips	Unknown composition	Probably finds its way into Vaiusu Bay
Smack	Chicken farm (4000 chickens)	Chicken feed and manure	Flows via a drain into Vaiusu Bay
Vailima Breweries	Local beer brewing	9500 m^3 / month of caustic soda, acid, sugar and yeast	Discharged directly into Vaiusu Bay when the sedimentation tank is full
Manuia Breweries	Local beer brewing	1 or 2 tonnes / day of liquid waste	Released directly into the mangroves at Vaiusu Bay
Samoa Coconut Products	Canning of coconut products	Cleaning chemicals	Storm water drain emptying into Vaiusu Bay
Alexander Coolstore	Sale of meats	Bloods, scraps, fat and cleaning chemicals	Dump pit near coolstore which is tidally influenced
Mobil Oil	Distribution of LPG, oil, gasoline and diesel	Small amounts of oil in seawater (10 tonnes / week)	Pumped into Vaiusu Bay
British Petroleum	Distribution of LPG, oil, gasoline and diesel	Small amounts of oil in seawater (4 tonnes / week)	Released into Vaiusu Bay
H.J Keil and Company	Sale of car spare parts	Rubber and oil parts and tyres, tyre repairs	Enters a drain emptying into Fugalei Stream
Mr Leiu	Truck repair garage	Oil and washing water	Enters a drain emptying into Vaiusu Bay
MacDonalds Motors	Sale of household machinery and repairs	Soap and detergent	Enters a drain emptying into Vaiusu Bay
Burns Philp	Sale and repair of cars	Oil	Enters a drain emptying into Vaiusu Bay
Rees Refrigeration Services	Repair of freezers, air conditioners and refridgerators	Dust and grease	Enters Gasegase Stream
Pacific Aluminium	Production of aluminium joints	Cleaning fluids	Enters Vaiusu Bay
Pepa Industries	Production of small roles of toilet paper	Cleaning agents	Enters mangrove swamp on Fugalei Stream
University of the South Pacific	Chemical laboratories	Ethanol, methanol, KCl, $NaOH$, H_2SO_4, NH_4OAc, $K_2Cr_2O_7$, $CuSO_2$, H_2PO_2, HNO_3, $HClO_4$, H_2O_2 and mineral oil	Dumped into a ravine which is a tributary of the Gasegase River about 5 kilometres from Vaiusu Bay

The result of the sand mining operations has been a restriction of the natural circulation of waters in Vaiusu Bay. Longshore drift along the outer edge of Mulinuu Peninsula used to spill around the head of the Peninsula forming a recurved spit (Figure 6.5). With the construction of the causeways, the longshore drift has been impeded, effectively protecting the inner side of Mulinuu Peninsula from strong wave action. It is in this vicinity that there has been a noticeable increase in mangrove extent between 1970 and 1990 (Figure 6.5). As a result of the lack of circulation and continuing mining operations, the waters in Vaiusu Bay have become very turbid (Klinckhamers 1992).

Thus, there are four main land uses interacting with the mangrove communities at Vaiusu Bay. Physical destruction of the mangroves has been caused by the rubbish dump and land reclamation works, and chemical alteration of the waters in the Bay has been produced by the rubbish dump, sewage effluents, and polluted wastewater. Although the dredging operations are physically removed from the mangroves, the presence of the causeways has restricted the flushing of Vaiusu Bay after storm events, thus trapping pollutant material in the Bay. Klinckhamers (1992: 40) summed up the situation as follows:

> Human impacts on Vaiusu Bay have caused major degradation to the marine environment. Vaiusu mangrove wetlands are partially cleared for roads, buildings and the rubbish dump at Vaitoloa. Causeways used for mining off Vaitele and Mulinuu block water circulation in Vaiusu Bay. Cyclone banks also now restrict ocean exchange. The lagoon is very turbid from lagoon mining and the discharge of the Fugalei Stream. The lagoon is seriously polluted by domestic and industrial waste which enter via storm drains, freshwater springs. Very high nutrient levels and faecel coliform bacterial counts have been reported. The lagoons are eutrophic: seagrasses [*Halophila* and *Syringodium*] and mangroves are expanding and corals are dying. The likelihood of bacterial and heavy metal pollution make the consumption of seafood from the Bay a health hazard, especially the shellfish that are caught in the area. Children are, however, selling baskets of shellfish on the street, which are caught in Vaiusu Bay.

Thus, the decrease in the extent of mangroves in Vaiusu Bay as indicated in Figure 6.5 is due to many factors mitigating against the health of the stands. The health of the Vaiusu Bay mangroves is further discussed in Section 6.3.

With this background on the degraded condition of the Vaiusu Bay mangrove area, the results of Thollot's (1993) fish survey at that location are not surprising. A total of 20 fish species were found to be present when sampling was conducted in November and December 1992, with one fish species (*Liza melinoptera*) comprising more than two-thirds of the total catch (Table 6.6). This contributed to the very low diversity index and evenness value (Thollot 1993).

TABLE 6.6 : Fish Sampled from the Vaiusu Bay Mangrove Area.
Source: Adapted from Thollot (1993)

Samoan name	English name	Scientific name	Number caught	% of total	% weight of total
Moi / Poi	Mullet	*Liza melinoptera*	705	68.4	62.3
Avaava	Crescent perch	*Therapon jarbua*	68	6.5	21.9
Sue	Pufferfish	*Arothron manillensis*	172	16.7	2.8
Gatauli	Snake eel	*Cirrimura tapeinotus*	5	0.5	2.8
Name not known	Goby	*Yongeichthys nebulosis*	19	1.8	1.7
Tilapia	Tilapia	*Oreochromis mossambica*	1	0.1	1.7
Pusi	Moray eel	*Uropterygius concolor*	3	0.3	1.4
Ava / Avalii	Milkfish	*Chanos chanos*	1	0.1	1.4
Malauli sinasama	Trevally	*Caranx papuensis*	5	0.5	1.0
Ulaoa	Goatfish	*Upeneus vittatus*	3	0.3	0.7
Name not known	Goby	*Oxyurichthys ophthalmonema*	16	1.6	0.6
Name not known	Snake eel	*Muraenichthys macropterus*	6	0.6	0.5
Mumu	Ponyfish	*Leiognathus equulus*	15	1.5	0.3
Name not known	Sleeper	*Ophiocara porocephala*	2	0.2	0.2
Manoo	Goby	*Glossogobius biocellatus*	2	0.2	0.2
Name not known	Snake eel	*Yirrkala lumbricoides*	1	0.1	0.2
Name not known	Livebearer	*Poecilia sp. cf. mexicana*	1	0.1	0.2
Matu	Mojarra	*Gerres macrosoma*	3	0.3	0.1
Name not known	Goby	*Taenioides jacksoni*	2	0.2	0.03
Name not known	Goby	*Periophthalmus cantonensis*	1	0.1	0.03

In comparison to the Saanapu and Sataoa site, the results obtained for Vaiusu Bay are striking. Thollot (1993) noted that both areas showed similar species richness, but that the two fish communities did not have the same species composition. They shared only five species, most of which are known to live in habitats as diverse as from clear to brackish polluted waters. The common fish were the milkfish, crescent perch, trevally, goatfish and mullet (*Liza melinoptera*). It was also noted that the fish fauna from the two sites did not have the same community structure, and that the low diversity index found for Vaiusu Bay was indicative of disturbed communities (Thollot 1993). While human impacts maybe largely responsible for the disturbance observed, it is reminded that natural factors like differences in aspect, habitat and geomorphology between the two mangrove communities also play a part in effecting the observed changes. Boon (1997) noted that the mangrove reclamation is not solely responsible for the decline in fish, shellfish and crab catches. It was suggested that overexploitation of these resources for cash to meet newly stimulated demands by the villagers themselves is another factor.

6.2.3 Site 3: Moataa

The third mangrove community examined in this study is located at Moataa west of Apia. The Moataa mangroves are bounded to the west by a spit barrier known as the Taumeasina Peninsula, which was formed by longshore drift to the northwest. The Taumeasina Peninsula is a 1.2 metre high sand bar sitting on top of about 30 meters of soft silt, indicating that sandy material has encroached onto previous estuarine areas. The Peninsula encloses a tidally influenced embayment, with a small stream flowing through the estuary which is fed by about ten natural springs on the south side of the bay. The mangroves in the estuary are predominantly *Rhizophora samoensis*.

The most dramatic changes to any of the mangrove communities examined in this study have occurred at Moataa. Figure 6.6 indicates that, in 1970, a large stand (9.1 hectares) of mangroves existed west of Taumeasina Peninsula. Tidal flats coconut plantations and some village dwellings fringed the mangroves.

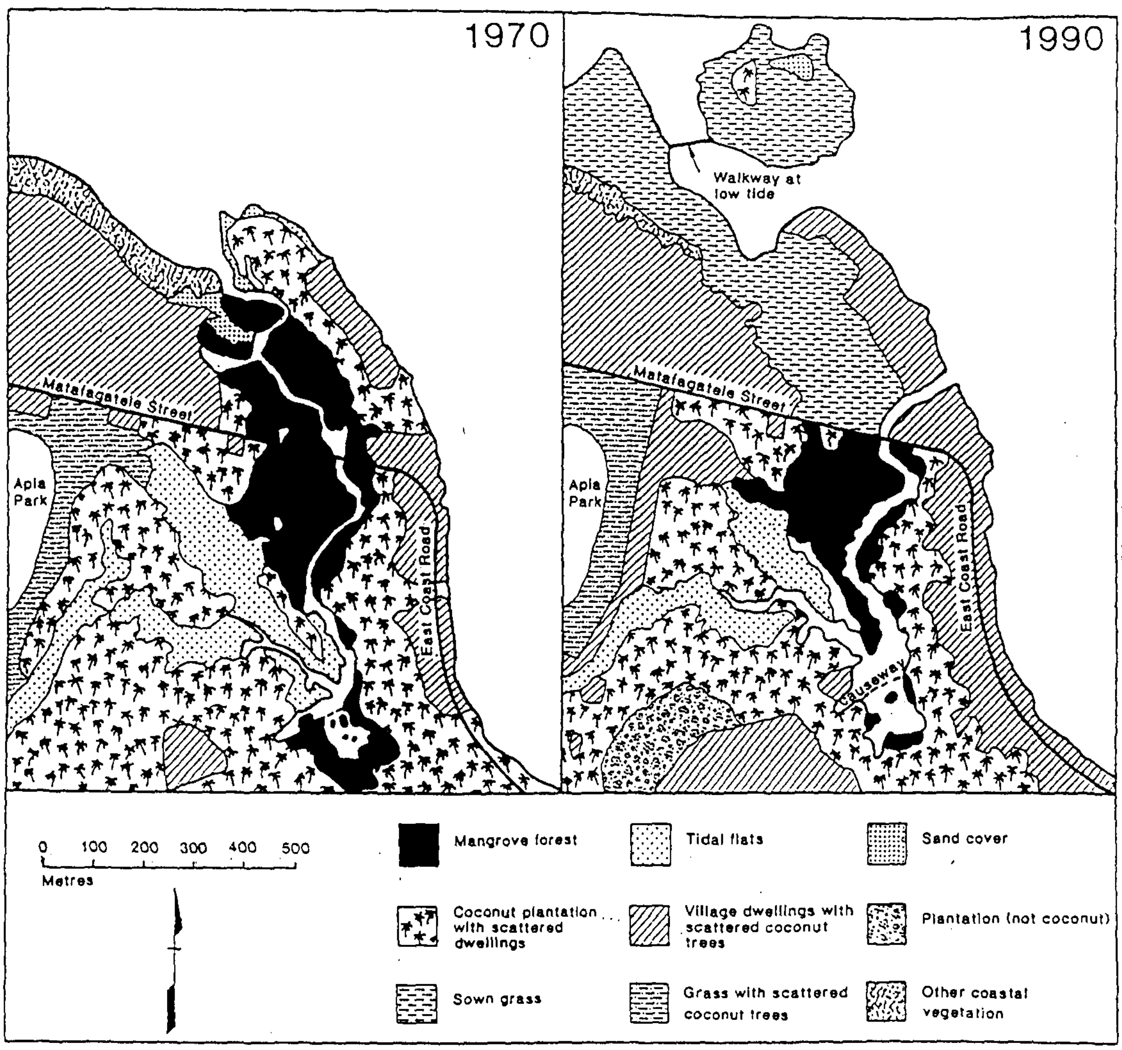

FIGURE 6.6: Changes in Vegetation Cover at Moataa between 1970 and 1990. Source: Author's research.

By 1990, the extent and distribution of mangroves had dramatically changed. Only 5.0 hectares of mangroves remained and the drainage pattern of the tidal channel had been completely altered. The width of the mangrove fringe at the southern end of the estuary had narrowed, and there was a corresponding increase in the width of the channel. Of note was the complete disappearance of all the mangroves north of Matafagatele Road. This was due to plans to develop a tourist resort in the area. In July 1974, the government Minister for Lands signed a lease for an American company to develop a tourist complex at Moataa to be known as the Royal Samoan Hotel.

The proposal allowed for the diversion of the natural tidal channel through an artificial canal so that land at the mouth of the natural channel could be reclaimed for the hotel site. During the early stages of development of the Royal Samoan Hotel, an independent engineering firm examined the original proposal and found it to be erroneous. They asserted that inadequate hydrological analyses had been conducted, and that the canal did not have the capacity to accommodate all the runoff from the Moataa Stream at times of peak flow. Furthermore, the Director for Public Works claimed that the department had failed to make a study of the effects of the diversion on the marine life and fishing potential of the area. Government had also failed to consider and ensure access to the sea of the large number of people living around the estuary. As a consequence, the Minister for Lands ordered the work on a river diversion channel to stop in September 1975. No further progress towards the development ever eventuated, and in the following years the reclaimed land remained unused. For 20 years, the land was not available to the village people. In August 1994, the village council negotiated with the government for the use of the land on a lease basis, whereupon plans were activated to convert the area to a sports complex to complement the facilities at Apia Park (Figure 6.6).

Thus about half of the mangroves at Moataa were destroyed for an aborted tourist development. There has been a long tradition of catching fish and other marine organisms from the environs of the Moataa Stream estuary, but the richness of that resource has been severely depleted since the reclamation works started (Section 7.2). At present there is no information available on the fish resources of the Moataa mangrove site. The structure and composition of the Moataa mangroves is further documented in the next section.

6.3 HEALTH OF THE THREE MANGROVE COMMUNITIES

There are many ways to assess ecosystem health and to note characteristics of a 'stressed' ecosystem (Rapport 1989). In this section, the mangrove ecology and population dynamics of the Sataoa, Vaiusu Bay and Moataa mangrove stands will be examined. In particular, the structure of mangrove populations will be examined with reference to tree species, tree diameter, tree height and the number of seeds and seedlings from the respective mangrove sites. These variables were selected because they are measured easily in the field, and also describe the physical environment of the vegetation (Chessel and Gautier 1984).

The belt transect method was used to measure mangrove health as, according to Cain and Castro (1959), it is the best method to operate in areas where progress is difficult. This was certainly the case in the mangrove areas of Western Samoa. This method combines some of the advantages of both the line transect and quadrant methods (Kuchler and Zonneveld 1988). According to Knapp (1984) the advantages of using the quadrant method include: quadrants are easily visible in their totality to the surveyor standing in the centre of the square; and, the margins are relatively short, thereby decreasing the numbers of uncertainties in determining whether parts of marginal plants are included in a certain quadrant.

In order to measure disturbance, the control site at Sataoa which is regarded as the least disturbed mangrove site in Samoa (Table 6.2) was compared to the other two sites at Vaiusu Bay and Moataa. In order to quantify the characteristics of the mangrove communities at the three sites, transects were established at strategic locations. Each transect comprised a set of continuous quadrants 10m x 10m (100 m^2) in area which started from the seaward end and terminated at the most landward mangrove plant. For each 100 m^2 quadrant, all plants more than one meter tall were mapped according to their location within the quadrant, and their height, and the circumference at knee height (ckh) of each tree trunk was measured. The presence of dead (or cut) trees, seedlings (plants less than one meter tall) and seeds were recorded and mapped for each quadrant. Four transects were measured for the Sataoa site (Figure 6.7), seven for the Vaiusu Bay area and three for the Moataa site (Figure 6.8). The raw data from the fourteen transects are given in Appendix 12. The results will be discussed according to the species present, tree size, and the number of seeds and seedlings present. Some transect characteristics are given in Table 6.7.

TABLE 6.7: Some Characteristics of the Transects from the Three Sites.
Source: Author's research

				Range of diameter of trees at knee height (cm)									
Transect	No of quads each 100m^2	Mean no. Seed / 100m^2	Mean no. Seedlings / 100m^2	0-25	26-50	51-75	76-100	101-125	125-150	Av dkh (cm)	Av ht (m)	Cut trees	Dead Trees or trunks
S1	20	80	182	48	30	6	15	5	1	40	8.4		15
S2	9	19	510	5	20	17	1	1		47	13.6		3
S3	16	50	240	17	59	12	4	0	2	38	8.5		1
S4	5	12	280	0	7	7	3	4	3	74	8.3		
V1	7	11	3	12	1					14	2.1		
V2	10	42	92	13	7	4				30	2.5	71	
V3	20	62	71	101	17	8	7	1		29	5.5		
V4	7	40	250	7						8	2.6	51	
V5	7	38	3	20						10	2.6		
V6	9	18	31	13	3					19	4.1		
V7	17	7	7	102						10	2.0		
M1	7	35	36	19						8	2.5		
M2	3	11	20	16						6	2.3		
M3	4	1	1	12						6	2.2		

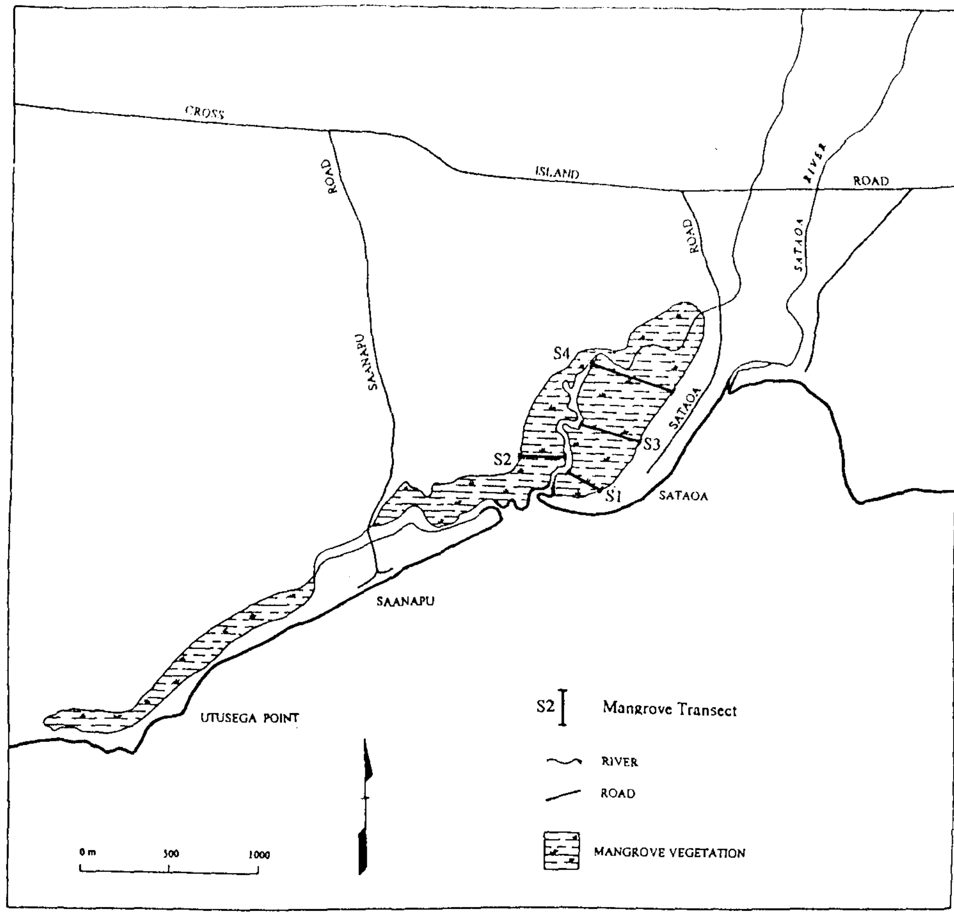

FIGURE 6.7: The Location of Transects through the Sataoa Mangroves. Source: Author's research

The two dominant mangrove species in Western Samoa are the *Bruguiera gymnorrhiza* and the *Rhizophora samoensis* (Pearsall and Whistler 1991; Sasaki 1992; Nakamura 1992; Thollot 1993; Atherton 1994). These mangrove species were both encountered during the fieldwork and will be discussed separately. Both species were found at Sataoa and Vaiusu Bay, while only the *Rhizophora* species was found at Moataa.

6.3.1 The *Bruguiera* Mangroves

The *Bruguiera* mangroves were found in all four transects at Sataoa, and transects V2, V3 and V6 at Vaiusu Bay. The tallest *Bruguiera* trees reached 30 meters in transect S1 (Appendix

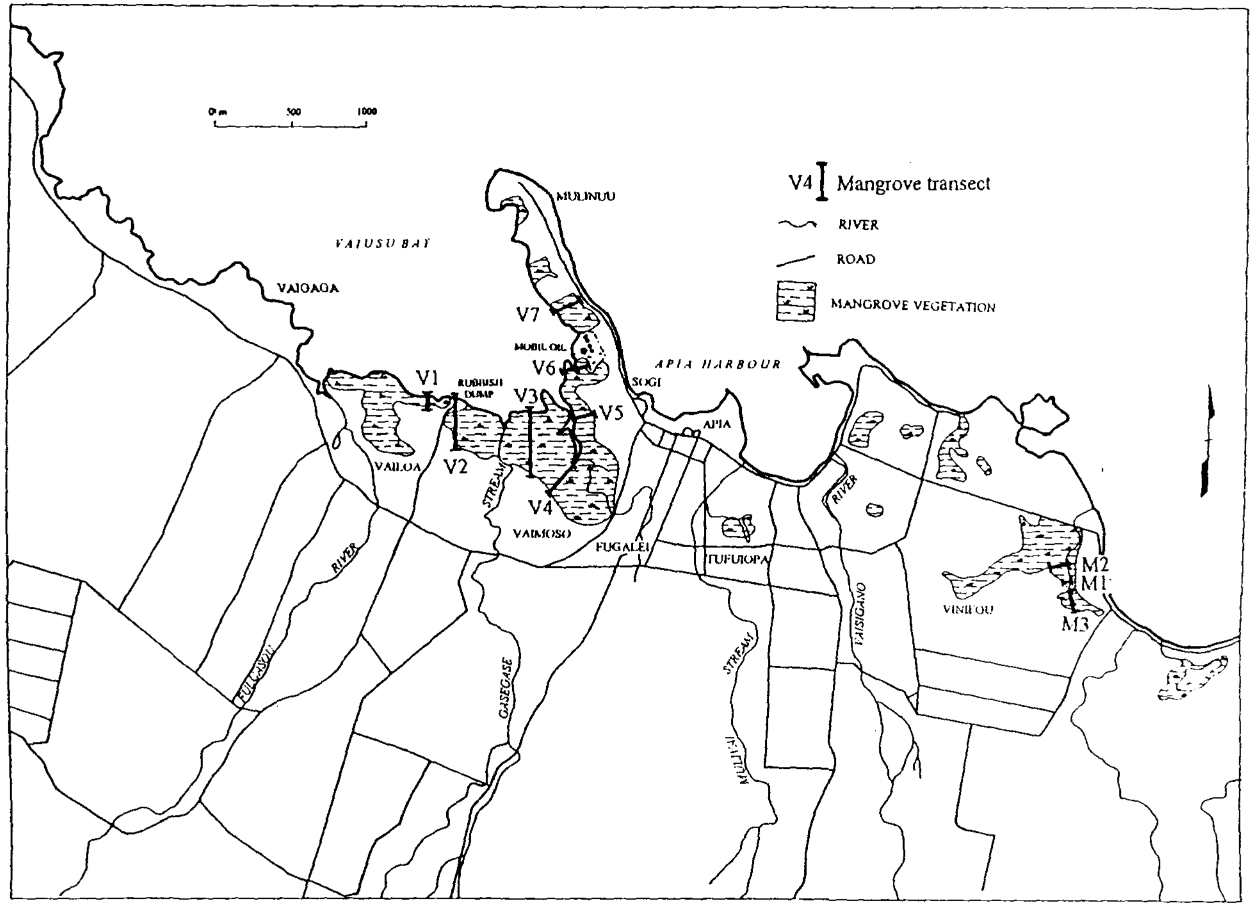

FIGURE 6.8: The Location of Transects at Vaiusu Bay and Moataa Mangroves.
Source: Author's research

12.1) and up to 20 meters at Vaiusu Bay (Appendix 12.7). The distribution of average tree heights and average tree sizes according to both transects and mangrove type is given in Figure 6.9.

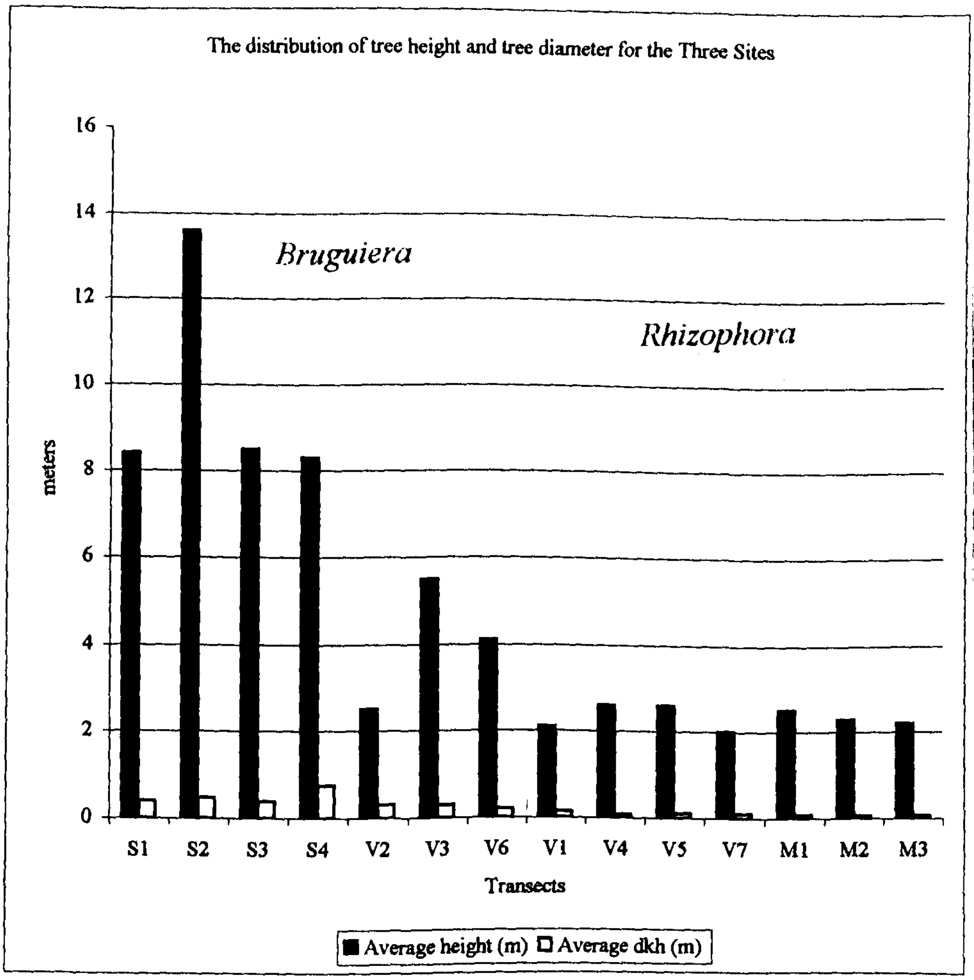

FIGURE 6.9: The Distribution of Tree Heights and Tree Sizes at the Three Sites. Source: Author's research

The figure shows that much taller and larger *Bruguiera* trees were found at Sataoa (transects S1 to S4) than at Vaiusu Bay (transects V2, V3 and V6). Whether this is a reflection of disturbance is not clear. While extensive cutting of mangrove trees has been reported at Vaiusu Bay, differences in natural factors like exposure and aspect of the mangrove sites must be considered.

Also, the impact of recent cyclones on the two mangrove communities might have been different. Figure 6.9 also shows that larger *Bruguiera* trees were found at Sataoa. The overall average tree diameter of the *Bruguiera* species found in this study was about 62 cm. Sasaki (1992) gave a comparable average tree diameter of about 58 cm. It must be kept in mind that Sasaki (1992) looked at only 13 trees at Sataoa and 16 trees from an unspecified site near Apia. It is worth noting that while the trees of transect V2 had the highest diameter of the *Bruguiera* stands at Vaiusu Bay, the average height of the trees was lower than the other two *Bruguiera* stands. The reason for this was the fact that a lot of cut-trees in this area were quite large.

The abundance of seedlings throughout the Sataoa mangrove area is evident in Table 6.7; a lot more seedlings per quadrant are recorded there, than at Vaiusu Bay and Moataa. The distribution of average seeds and seedlings numbers per unit is given in Figure 6.10. The figure shows that there is about four times seedlings per quadrant at Sataoa, than at Vaiusu Bay. The high distribution of seedlings per unit area noted in the *Bruguiera* stands at Sataoa suggests the importance of mature trees in the production of seedlings. This is illustrated further at Vaiusu Bay, by the presence of a higher number of seeds and seedlings in the middle part of transect V3, where the *Bruguiera* species are located (Appendix 12.7). These seedlings congregated around the roots of the mature trees (Plate 6.2). According to Bird and Barson (1982), this is evidence of a propagating mangrove system.

The cutting of *Bruguiera* trees has had a direct impact on the numbers of seeds and seedlings present. This is noted in transect S1, where the initial decreasing trend in the distribution of seeds and seedlings ends in the middle of the transect (Appendix 12.1). The field notes indicated the abundance of tree trunks in this section. The high representation of seeds throughout transects S1 and S3 is probably due to tidal movements (Chapman 1976). It is probable that these two transects, located at the bends of the stream channel, act as reservoirs for seeds when the tide goes out (Figure 6.7).

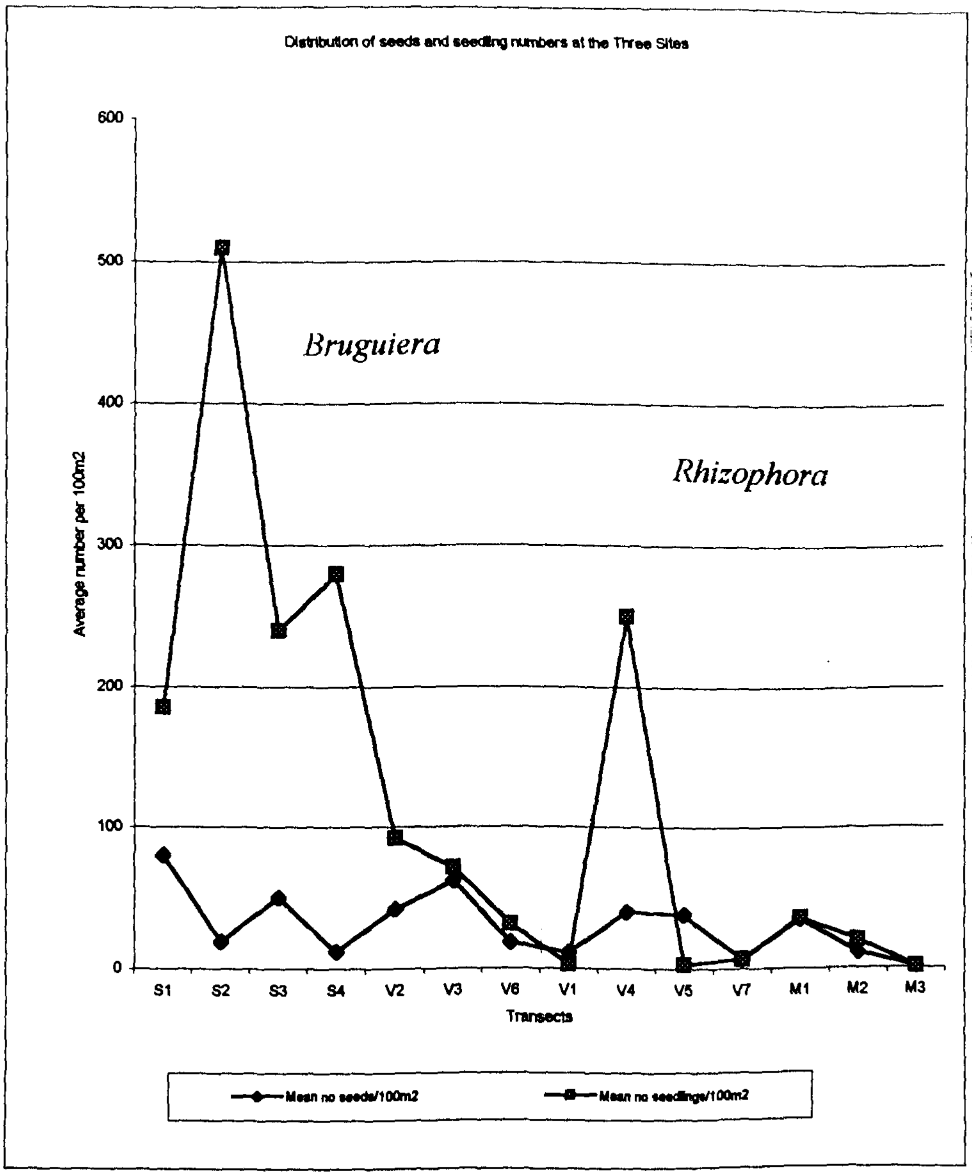

FIGURE 6.10: The Distribution of Seeds and Seedlings per Quadrant at the Three Sites. Source: Author's research

6.3.2 The *Rhizophora* Mangroves

Transects V1, V4, V5 and V7 from Vaiusu Bay and the three transects from Moataa contain *Rhizophora* mangroves. These trees have smaller diameters and are shorter, than the *Bruguiera* mangroves (Figure 6.2). Many *Rhizophora* trees occur behind the Parliament House at Mulinuu, attesting to the fact that mangroves grow well in sheltered areas (Lear and Turner 1977; Oliver 1982). In contrast to the typical mangrove distribution pattern in Western Samoa (Figure 6.2) the *Rhizophora* species in the Sataoa area were found closer to village dwellings (Appendix 12.1, 12.2 and 12.3). This distribution pattern was also noted at Vaiusu Bay in transects containing the two species, especially transect V3 (Appendix 12.7). It seems that the pattern of species distribution in the mangrove areas of Western Samoa examined in this study does not necessarily conform to the one given in Figure 6.2.

Plate 6.2: Typical Sataoa Transect with huge *Bruguiera* trees and Abundance of Seedlings. Photograph by author

Average tree height and diameter for *Rhizophora* trees were 2.3 meters and 12.0 cm respectively. These parameter values were lower than for young mangrove trees examined by Sasaki (1992) in an unspecified site near Apia, where an average diameter at breast height (dbh) of 22.6 cm was given. Sasaki (1992) also found *Rhizophora* trees at Sataoa to have average diameter of 4.0 cm and average height of 4.0 meters.

In comparison to the *Bruguiera* trees, the *Rhizophora* trees are about four times smaller in both height and diameter (Figure 6.9). Further, it is noted that the mangrove population of both the Vaiusu Bay and Moataa sites are quite young, with the percentages of trees having a diameter less than 25 cm being 77% and 100% respectively. Only 22% of trees in the Sataoa area fell into this category. While 78% and 23% of trees at Sataoa and Vaiusu Bay had a diameter of more than 25 cm, this was not the case at Moataa.

The distribution of seedlings and seeds for the *Rhizophora* mangroves is given in Figure 6.10, where the distribution of seeds per unit area was about the same for all three sites. The distribution of seedlings per quadrant for the *Rhizophora* mangroves was lower than for the *Bruguiera* mangroves. These observations on the number of seeds and seedlings per unit area for the *Rhizophora* mangroves illustrate the difference between the two types of mangrove trees in the production of seeds and seedlings. Figure 6.10 also shows a high value of seedlings per unit area at transect V4. This was where the mangroves had been cut for development (Plate 6.1). It is apparent that the destruction of mangrove trees had not resulted in the destruction of the mangrove habitat. Seedlings and seed numbers recorded at Moataa were comparatively low. Although not clearly evident, there seems to be a decrease in seedling and seed numbers with distance from the springs, with the low representation of seedlings at transect M3, compared to seedling occurrences at transect M1. It was demonstrated in Section 5.3 that there is contamination from groundwater in this particular area. Edyvane (1991) showed that there is a very strong correlation between the increased death of mangrove seedlings and high levels of the cabbage weed *Ulca* in the mangroves of the Port Gawler area, South Australia. She also noted that the excessive nutrients from the discharges around the area promoted the growth of the cabbage weed *Ulca*, which smothers the mangrove seedlings. This could well be the case here, and very likely is one of the factors causing the low abundance of seeds and seedlings close to the springs. This argument can also be extended to the situation at Vaiusu Bay. In transects V5 and V3, where nutrients carried by the Fugalei and Gasegase streams were observed to have promoted the growth of seaweed in the area, there was a comparatively lower number of seeds and seedlings.

6.3.3 Dead and Cut Trees

One notable feature in the Sataoa mangrove area was the occurrence of huge *Bruguiera* mangrove tree trunks without branches or leaves, especially in transect S1 and a few at transect S2 (Plate 6.3). Whether these trees died naturally or otherwise is uncertain. Although similar tree trunks were also seen in transect V3 at Vaiusu Bay, they were not as abundant as in the Sataoa area. Cut trees were frequently encountered at the Vaiusu Bay area. In particular, transects V2 and V4 had been subjected to a lot of tree-cutting activity recently (Appendix 12.4 and 12.6). The reason for this extensive cutting was not clear, although it is probably mainly for firewood and for house posts at transect V2. Both the size and durable nature of the *Bruguiera* mangroves have made it one of the ideal trees for posts of the Samoan fale (Schuster 1993a). Clearance at V4 was associated with the location of a proposed brewery. The continued criticisms by both the local villagers and Non-government Organizations (like the Siosiomaga Society) has stopped this land clearing at transect V4.

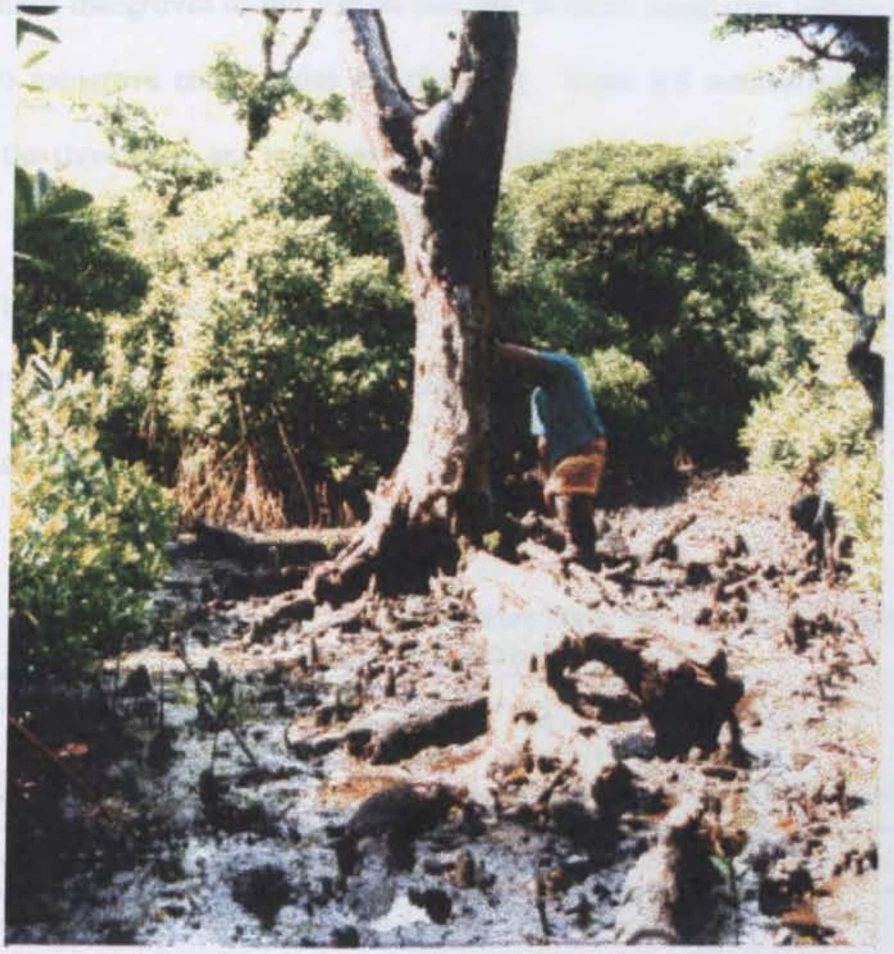

Plate 6.3: One on the many mangrove trunks without branches or leaves at Sataoa. Photograph by author

6.3.4 Mangrove Ecosystems

The results given in Sections 6.3.1 to 6.3.3 have not only provided quantitative criteria for the control Sataoa area, but also documented the corresponding characteristics of the Vaiusu Bay and Moataa mangroves for comparison. The characteristics of the Sataoa mangrove area, which was predominantly *Bruguiera* species are as follows. The mangrove trees are tall and large averaging 10 meters and 60 centimeters in height and diameter respectively; they contain an abundance of both seeds and seedlings throughout the area; they contain a fair number of old tree trunks; and they show little evidence of being degraded by human activities. A comparison of the Sataoa mangroves to the Vaiusu Bay and Moataa mangroves indicates that, indeed, the latter two mangrove communities are disturbed. Table 6.8 summarizes the main difference between the three sites, and indicates that the mangrove plants at the Sataoa site are twice as big as in Vaiusu Bay, which in turn are twice as big as those found at Moataa. According to Harper (1977), the mangroves at Vaiusu Bay and Moataa are young, compared to those at Sataoa. This may be a feature of the differences in times of formation during the late Holocene sea level changes (Kawana *et al.* 1995).

TABLE 6.8: Average Plant Structure from the Three Mangrove Sites. Source: Author's research

SITE	Average Height (meters)		Average Diameter (cm)		Average number of Seeds/100m^2		Average number of Seedlings/100m^2		Old Tree Trunks	Cut Trees
	B	*R*	*B*	*R*	*B*	*R*	*B*	*R*		
Sataoa	10	2.6	70	10	52	17	414	134	19	
Vaiusu Bay	8.5	2.4	48	10	66	39	105	81	2	120
Moataa	n/a	2.4	n/a	7	n/a	25	n/a	23		

Another major difference between the three sites is in the number of seeds and seedlings found. The abundance of seeds and seedlings throughout the Sataoa site and parts of Vaiusu Bay suggest a high degree of recruitment in these places. Sadly, this can not be said of the Moataa mangrove site. The high degree of recruitment of mangrove trees at Sataoa coincides with the number one priority for conservation given to this area by Pearsall and Whistler (1991).

To further compare the state of health of the mangroves at the three sites, frequency distribution plots for each site were drawn. The skewed-distribution of the frequency distribution graphs of the *Bruguiera* species at Sataoa (Figure 6.11) represents an uneven-aged stand.

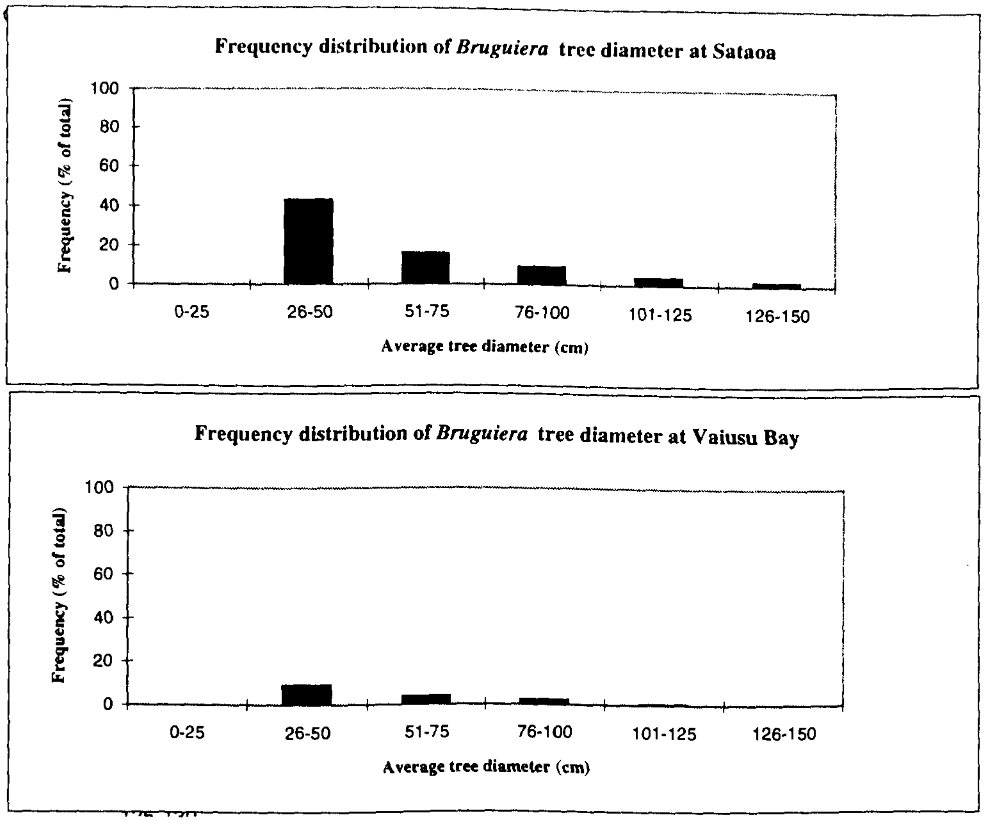

FIGURE 6.11: Diameter-frequency diagrams for the *Bruguiera* species at Sataoa and Vaiusu Bay. Source: Author's research

This result is indicative of a stable population of mangroves (Harper 1977; Odgen 1985). The frequency distribution curves also highlighted the presence of older trees with over 100 cm in diameter at Sataoa that were absent at Vaiusu Bay.

A similar plot of the *Rhizophora* mangrove trees at the three sites is given in Figure 6.12 where a number of observations are made. The skewed-distribution pattern is seen for the Sataoa *Rhizophora* curve. Further, the absence of trees less than 5.0 cm in diameter from Sataoa is

Rhizophora curve. Further, the absence of trees less than 5.0 cm in diameter from Sataoa is evident. These trees however, were found abundant in the Moataa transects. A high representation of larger *Rhizophora* trees more than 10.0 cm in diameter is seen for both Sataoa and Vaiusu Bay. The Moataa site recorded no *Rhizophora* tree more than 20.0 cm in diameter. These observations are further evidence that the Sataoa mangroves are in a much more stable state than those at Vaiusu Bay and Moataa. Odgen (1985) claimed that these latter two mangrove sites are in their recovery stages from past disturbances. On the other hand, the Sataoa mangroves may have been formed in a much earlier time than the Vaiusu Bay and Moataa mangroves (Kawana *et al.* 1995).

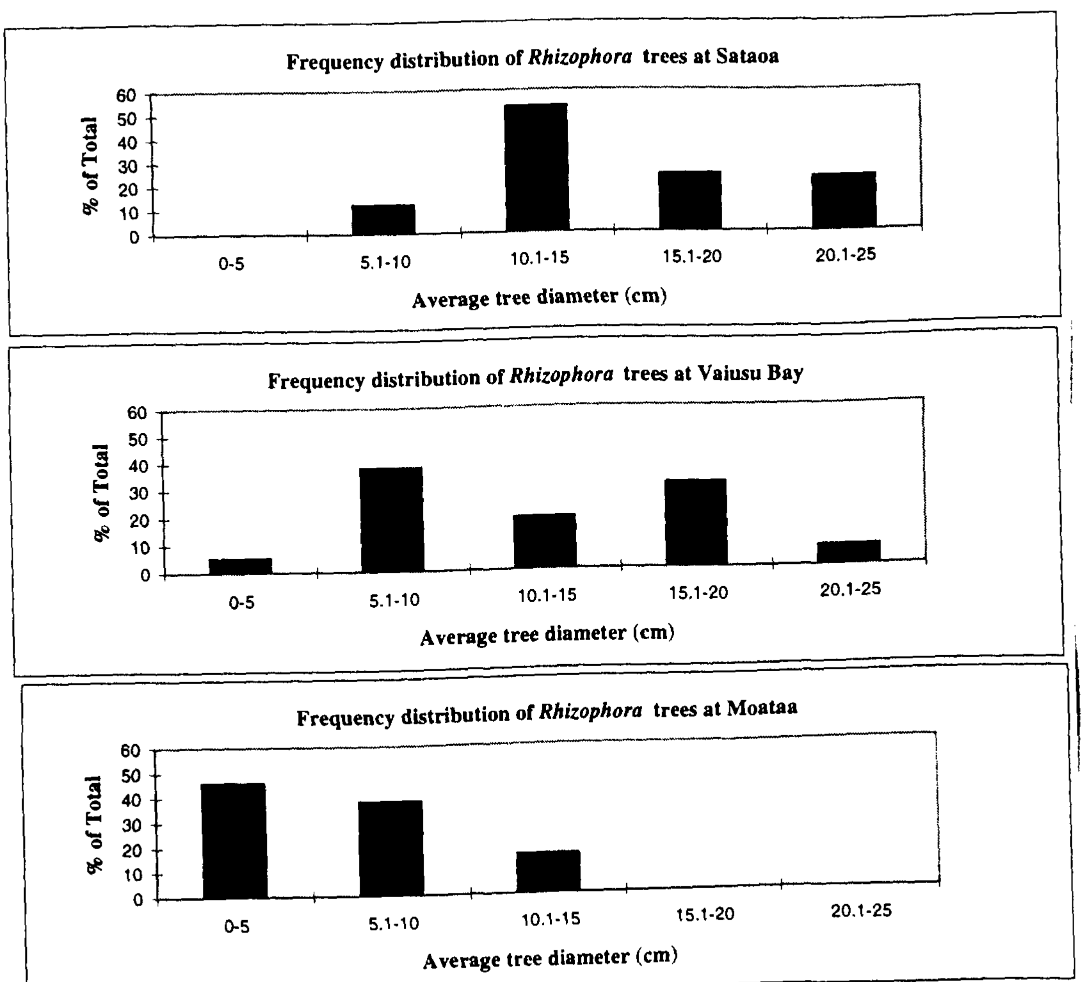

FIGURE 6.12: Diameter-frequency diagrams for the *Rhizophora* species at the Three Sites. Source: Author's research

Figure 6.12 also suggests that there is a difference apparent in the two disturbed mangroves at Vaiusu Bay and Moataa. The mangroves at Moataa seem to be in a more disturbed state than at Vaiusu Bay, as they contain smaller trees, no *Bruguiera* trees, and lower numbers of seeds and seedlings. This is visually evident from Plate 6.4. The absence of *Bruguiera* trees at Moataa suggests that the *Rhizophora* species only had repeated *in situ* regeneration (Bird and Barson 1982); and, that the *Bruguiera* species are sensitive to changes in the environment. On the other hand, the *Rhizophora* species appears to be more tolerant to these environmental changes.

While the main reason for mangrove decline at Vaiusu Bay and Moataa appears to be the extensive cutting of the trees and reclamation, natural causes are also considered likely agents of change. The natural differences in topography, exposure and habitat have been mentioned. Vaiusu Bay is in a sheltered shallow embayment while Moataa and Sataoa are in lower estuarine situations. Further, Sataoa is in the exposed south, while Moataa and Vaiusu Bay are in the leeward side of Upolu. The cyclones may have had different impacts on the three sites, and the different times in which the mangroves were formed may explain the differences observed. Saltation and sedimentary processes provide another explanation for the differences noted. The contribution of pollution to these areas may well become an increasingly important factor. Seaweed growth will be promoted due to the high amount of nutrients dumped into the bays each year by the rivers and industrial discharges, and by groundwater contamination, as documented in Chapters Three and Four.

The healthy status of the Sataoa mangroves as asserted by many authors (Pearsall and Whistler 1991; Department of Lands and Environment 1992; Sasaki 1992; Schuster 1993a; Thollot 1993) has been substantiated by the findings of this study.

PLATE 6.4: The Mangroves at Moataa, where the absence of the *Bruguiera* species can be seen. Sediment Core M2 was taken in the middle of the stream in the foreground. Photograph by R. Lawrence

This chapter has demonstrated that not only is the Sataoa mangrove community is in a healthy condition, but also the mangrove areas at Vaiusu Bay and Moataa have been degraded over the years. The question that needs to be asked is: have these degradation practices gone unnoticed? Did the mangrove degradation have any effect on the water quality of the streams, or on the lifestyle and economy of the people who have been using these areas? This is the focus of the next chapter, where the recollections of people living near the mangrove areas are documented, and the changes observed to the respective mangrove environments in the past 50 years are recalled.

CHAPTER SEVEN

ETHNOHISTORICAL EVIDENCES OF COASTAL CHANGE

"There is no remembrance of men of old, and even those who are yet to come will not be remembered by those who follow"
Ecclesiastes 1: v11

Ethnohistory is a means of addressing certain problems in cultural history, and offers a way of utilizing the rich record of historical experience in the search for process (Fenton 1962). Ethnohistory can be characterized by an abundance of non-written historical sources such as oral traditions (as is the case in Africa: Vansina 1962). While the terms oral history and oral tradition have been used interchangeably, they are quite different. Oral history refers to the study of the recent past by means of life histories or personal recollections, and oral traditions are recollections of the past that are commonly or universally known in a given culture (Henige 1982). As Perks (1992) pointed out, oral history is spoken history: it is the recording of peoples' unique memories and life stories. According to Robertson (1995), oral history is a picture of the past in peoples' own words. A practical definition of oral history, as described by Willa K. Baum, is documented by Douglas *et al.* (1982) as:

> A tape-recorded interview, or interviews, in question-and -answer format conducted by an interviewer who has some, and the more the better, knowledge of the subject to be discussed with a knowledgeable interviewee, someone who knows whereof he or she speaks from personal participation or observation on subjects of historical interest.

This chapter is neither an anthropological view of history nor a historical view of anthropology. However, ethnohistorical method has been 'borrowed' to utilize oral histories gathered in this research. In particular, ethnohistorical reconstruction called "upstreaming" as innovated by Fenton (1962) is adopted here, where restructuring goes from the known present to the unknown past.

The use of the oral history concept in this research is not aimed at considering cultural data. Rather, it is used as a means of reconstructing the environmental status of Samoa in the recent past. This approach was used by Lederman (1986) in her work on The Mendi tribe in the Highlands of Papua New Guinea (PNG), by Healy (1985) on the settlement and land redistribution among the Maring tribe of the PNG Highlands; and in the oral and documentary history of *The Young Dick Attack* by Keesing (1986). The use of non-written material to recollect what the past was like is the common factor in the above-mentioned researches, as was the case in this study.

7.1 METHODOLOGY

Zann (1991) used the use of ethnohistorical evidence to address past experiences in Samoa in his work on the inshore resources of Upolu. In his work, questionnaires were issued to 1 000 households in a total of twenty urban and thirty-eight rural villages. Fishermen were asked for their opinions on trends in fish landings over the past decade, as little accurate historical information on fish catches was available (Zann 1991). From the questionnaires and interviews, variables like frequency of fish meals, total number of fishing trips per year, percentage of fish sold and trends in fish catches were determined. It was found that fish is eaten on an average of 2.6 days per week in rural areas and 1.8 days per week in the urban areas. Over 530 000 fishing trips are made on Upolu each year; the amount of fish sold varied from place to place, although on average 64% of households consume all their catches; fish catches had declined over the past ten years. Zann's (1991) work was conducted on a national level, and this study aimed to examine three areas in Samoa in greater detail in order to highlight the changes in the coastal environment.

Ethnohistorical evidence of changes in mangrove communities was designed to complement the fieldwork on mangrove health as discussed in Section 6.3. Interviews were conducted with villagers from Saanapu and Sataoa, the Vaiusu Bay area and Moataa to gain insight as to what each mangrove environment was like in the recent past. A total of forty-six interviews were conducted: eighteen from Sataoa and Saanapu, fourteen from Vaiusu Bay and fourteen from Moataa. The names and occupation of the interviewees are given in Table 7.1. A cross section of people were selected in an attempt to interview a diverse population to account for variations in age, gender, occupation and status within the village community, although more older people were interviewed than younger people. The interviews targeted people living directly next to the mangrove areas, as these people were assumed to interact with mangrove communities the most. The use of questionnaires in the research was deemed to be too rigid, and the interviews were carried out in an unstructured manner. The biographical approach adopted was that of Perks (1992) where the interviewees were asked for their recollections on the past and present status of mangroves, the importance of mangroves to their families and their thoughts on mangrove conservation. Each interview was recorded on audiotape and then translated into English by the author.

According to oral testimony, the mangrove area had been, and still is, an important resource for catching fish, mud crabs, shellfish, peanut worms, freshwater eels, beach crabs and for obtaining firewood. However, in utilizing this resource for obtaining these human needs, changes to the mangrove environment have occurred. In relation to the changes observed in the mangrove environment, the oral history was analyzed into three main areas: the differences observed in the vegetation; water quality changes in the recent past; and changes observed on marine resources around the respective areas.

TABLE 7.1: Names and Positions of People Interviewed for Ethnohistorical Information. Source: Author's research

Village	Name	Age	Years spent in the village	Position and Occupation	Issues commented upon
Sataoa (S-01)	Lefanoai Lemafa	45	10	Mother and school-teacher	M
Sataoa (S-02)	Tunumafono Siaki	58	58	Matai, plantation worker	Q,O
Sataoa (S-03)	Aumalosi Fake	70	70	Matai, fisherman	M
Sataoa (S-04)	Togisala Togisala	42	42	Untitled male, fisherman	M
Sataoa (S-05)	Toma Afemata	51	51	Untitled male; fisherman	Q,V,M
Saanapu (S-06)	Salome Tuaumu	32	32	Housewife and mother	Q,M
Saanapu (S-07)	Ali'imuamua Iese	72	72	High chief; retired teacher	Q,V,M,C,O
Saanapu (S-08)	Misa Moli Patu	57	37	Matai, fisherman	V,M,C
Saanapu (S-09)	Mati Talai	62	62	Matai, fisherman	V,M
Saanapu (S-11)	Tua Kerisimasi	57	28	Untitled male, fisherman	Q,V,M,C,O
Saanapu (S-12)	A'apa M Lea'ana	63	40	Housewife and mother	M
Saanapu (S-13)	Auvele M Lea'ana	64	64	Matai, retired school teacher	Q,V,M,C,O
Saanapu (S-15)	Silivaga Tuimaleaga	59	59	Housewife and mother	M,C
Saanapu (S-16)	Falasia Tuagi	43	43	Housewife and mother	C
Saanapu (S-17)	Auvele Suli Tuaniu	39	39	Matai, public servant in Apia	V,M
Sataoa (S-18)	Faafetai Toma	21	21	Untitled male, fisherman	Q,V,M
Vaitoloa (V-01)	Ario Atonio	49	49	Housewife and mother	V,M,C,O
Vaitoloa (V-02)	Toni Atonio	31	31	Untitled male, fisherman	V,M,C
Mulinuu (V-03)	Siaosi Tagaloa	67	30	Matai, retired sea captain	V,M,O,C
Vailoa (V-04)	Uili Tuaolo	32	32	Untitled male, cockle harvester	Q,V,M
Vailoa (V-05)	Fenumiai Tavita	10	10	Female student, cockle harvester	
Sogi (V-06)	Pemita Toetu	15	15	Male student, collects mud crabs	V,C
Vaimoso (V-07)	Afele Loi	28	28	Untitled male, harvests mud crab	V,M,C,O
Sogi (V-08)	Teuloto Tokoma	37	37	Works in an office in Apia	Q,V,M,C
Sogi (V-09)	Kerisiano Tokoma	16	16	Untitled male, student	V
Sogi (V-10)	Valoaga Tokoma	57	57	Untitled male, harvests mud crab	Q,V,M,C
Sogi (V-11)	Leiataua Tokoma	63	63	Matai, retired public servant	Q,V,M,C
Vaimoso (V-12)	Ili Mika	64	64	Untitled male, fisherman	Q,V,M,C,O
Vaimoso (V-13)	Mika I Mika	43	43	Untitled male, fisherman	M,C
Vaimoso (V-14)	Faaeteete Leitu	64	36	Housewife and mother	Q,V
Moata'a (M-01)	Maanaima Sopo	18	18	Untitled male, unemployed	Q,V,M
Moata'a (M-02)	Palepua Lua	67	67	Matai, fisherman	Q,V,M,C,O
Moata'a (M-03)	Fale Moata'a	58	58	Matai, fisherman	V,M,C,O
Moata'a (M-04)	Kirita S Samoa	51	25	Housewife and mother	Q,V,M
Moata'a (M-05)	Sililoto La'asaga	75	49	Matai, fisherman	Q,V,M,C,O
Moata'a (M-06)	Aleki Te'o	52	30	Untitled man, on holiday from NZ	Q,V,
Moata'a (M-07)	Pouvalu Lale Imo	45	30	Matai, on holiday from Sydney	V,O
Moata'a (M-08)	Leuga I Samau	40	40	Housewife	Q,V,M,C
Moata'a (M-09)	Vaagi Palu	67	67	Matai, fisherman	Q,V,O,C
Moata'a (M-10)	Muavaefaatasi Faleata	58	38	Matai, shop owner	Q,V,O,C
Moata'a (M-11)	Alaitaua Punefu Toa	45	45	Matai, public servant	Q,V,M,O,C
Moata'a (M-12)	Tavita Tuasivi	45	45	Untitled male, fisherman	Q,V,M
Moata'a (M-13)	Asi L Alekana	68	48	Paramount chief, public servant	Q,V,O,C
Moata'a (M-14)	Saiaulama T Suluvale	74	54	Housewife	Q,V

Notes: Q = Water Quality, V = Vegetation changes, M = Changes to marine resources, O = Mangrove ownership
C = Conservation

7.2 ETHNOHISTORICAL EVIDENCE OF CHANGES IN VEGETATION

The changes to the mangrove vegetation of Sataoa and Saanapu in the recent past were found to be minimal. The villagers were not aware of any major changes to the mangrove forest itself, although they did note that some of the larger mangrove trees had been blown down in the cyclones of 1990 and 1991 (Table 7.2). The informants who commented on the mangrove vegetation issue were 100% unanimous in their opinion that the mangrove area is still the same today as it had been in the recent past, both in areal extent and in health.

One resident mentioned the cutting of trees in the Sataoa-Saanapu mangrove area, and evidence of both this activity and the huge mangrove trees in the Sataoa and Saanapu area were found in the field work (Section 6.3). The fact that the Sataoa and Saanapu residents acknowledged the tree cutting activities, yet argued that the mangrove area had not changed over many years suggested that tree cutting has always been an integral part of the mangrove ecosystem, and that it has always been done on a sustainable basis.

TABLE 7.2: The Changes in Vegetation of the Three Sites According to Ethnohistorical Evidence. Source: Author's research

SITE	CHANGES IN VEGETATION NOTED
Sataoa and Saanapu	Slight damage from cyclones. Some cutting for firewood
Vaiusu Bay	Loss of huge mangrove trees. Excessive cutting for firewood. Infilling for houses and pigsty
Moataa	Complete disappearance of huge trees. Reclamation of half the mangrove area. Excessive cutting of trees for firewood.

The changes in vegetation identified for the Vaiusu Bay area were mainly related to the loss of huge mangrove trees. This occurred as a result of both cutting by locals for domestic use and through reclamation for the Apia settlement areas. Oral testimony from the older informants in the Vaiusu Bay area recalled the presence of huge mangrove trees which were like a forest in the old days, very tall and very straight, and therefore suitable for house posts. The reporting of mangrove cutting by the younger generation in their testimonies indicated that this practice is still continuing in the Vaiusu Bay area.

The effect of urbanization in the Vaiusu Bay area was also evident from the oral histories presented, where mention was made of clearing mangrove areas for housing spaces and pigsty (Table 7.2). One local resident gave evidence that the presence of the rubbish dump increased her family income. This family owned a large number of pigs that were allowed to roam at large through the dump area. Consequently, they became very fat and large, and provided a generous income when required for ceremonial occasions. While two other residents mentioned this financially profitable activity, they noted that this gain was at a cost of reclaiming those mangroves closer to the homesteads for pigsty.

The most obvious and distinctive change to the mangrove vegetation was observed at Moataa, where mangroves in the northern half of the estuary have been reclaimed for a hotel development which never materialized (Zann 1991). The majority of the oral testimonies from the area, especially from the men, were unfavorable accounts about the whole issue, especially how the project started, and how the villagers were conned into the initial stages of cutting down the mangrove forests. Although the oral histories did not put an exact date on the reclamation exercise, their approximations were in accordance with the dates given in the *Samoa Times* article of September 1975, which reported that the reclamation had already started.

The majority of the oral testimonies touched on the reclamation issue, and attributed the following degrading effects in the mangrove environment observed today to this reclamation exercise. The stream water is now salty; the health of the southern mangroves has declined; there is a change in the streamflow; accelerated soil erosion of the riverbank; and the complete loss of the village annual mullet catching activity. One talking chief noted that "the reclamation of the northern mangrove forest has produced die-back of the southern section". He also added that "the mangrove trees were previously very large like coconut trees, but those specimens have disappeared, and most trees on both sides of the causeway have disappeared". This comment seems to indicate that Samoans did not recognize the difference between the two mangrove species found in the area. That canoes were used for transportation in the mangrove area suggests how big the trees were in the Moataa area in the recent past. The fate of the huge trees was mainly for firewood, according to the oral history. While some of these big mangrove trees were encountered at Vaiusu Bay during the fieldwork, the complete absence of the *Bruguiera* trees at Moataa was striking, and reflects the severity and magnitude with which the cutting of mangroves has proceeded in the Moataa area in the recent past. The abundance of the fern *Acrostichum aurem* at Moataa now bears evidence to this mass cutting of the mangroves as, according to Chapman (1976), the invasion of this fern takes place when mangrove areas are felled or destroyed.

Mangrove tree decline at Moataa has been aided by the longtime habit of villagers to cut mangrove trees for firewood. Throughout Samoa, the village of Moataa has been known to produce firewood, which burns at very hot temperatures. The village sports teams, choirs, stores, etc. carry the name Togoaasa, which literally means 'very hot mangrove'. Unfortunately, this village tradition has been self destructive, as it has led to the extinction of the *Bruguiera* mangrove species on which the tradition was based.

Two other oral testimonies from Moataa noted that the change in the mangrove vegetation has accelerated soil erosion from the estuary edges into the stream, and the loss of trees has removed habitat for certain birds like the reef heron.

It is clear from the discussions that there seems to be a bias in the recollections, as no one talked about the *Rhizophora* species, but only about the disappearance of the larger *Bruguiera* trees. This is because the Samoans do not discriminate between the two species of mangroves. It is their belief that the *Rhizophora* species will in time, grow large and become *Bruguiera* trees.

7.3 ETHNOHISTORICAL EVIDENCE OF WATER QUALITY CHANGES

The healthy nature of the mangroves at Sataoa and Saanapu has produced clean waters, where the following average water quality parameters were recorded (Appendix 4.2): salinity - 0.05 mg/l; TDS - 40 mg/l; iron - 0.01 mg/l; sulphate - 0.5 mg/l; total nitrogen - 0.7 mg/l; total phosphorus - 0.07 mg/l; and zinc - 0.05 mg/l. At Sataoa and Saanapu, one informant noted the excellent water quality of the stream in the mangrove area. However, six other informants commented on the fish poisoning practice carried out here, which had probably altered the good water quality of the area temporarily.

According to oral testimony, water quality has changed at both the Vaiusu Bay and Moataa areas in the recent past. One old resident of Sogi noted that:

> The water in the mangrove area in those days was very deep. You cannot walk to the villages on the other side of the bay even in low tide. The water current flowed freely in and out. The water is shallow now, and you can walk from Sogi to the villages south of the bay at low tide. One thing I have seen often in the stream is the poisoning effect of a

> dry cleaning (laundry) industry not far from here. Sometimes, the area smelled with dead fish when the tide went out.

The death of many fish in the stream was also noted in the recollections of two other informants from the same village. One resident of Sogi recalled gleaning a sea hare (*Dollabella auricularia*) larger than any he has ever seen from the stream water directly behind his house. This was interesting as it indicates that at that time, the bay was a lot deeper than it is at present. There has probably been a shallowing of the Bay area due to either reclamation and sand mining activities in the vicinity of Mulinuu Peninsula, or that sea levels may have changed over the last 50 years (Nunn 1994). Either way, this suggests that the sediment material examined in the sediment cores (Chapter Five) maybe less than fifty years old.

One talking chief of the village summed up the observed changes of the water quality at Moataa:

> The loss in mangroves has produced another problem. A lot of erosion is evident. Our backyard is literally washing away. More silt and mud are deposited in the stream. We made a swimming pool west of our house where one swims any time and was really cool. Today you cannot swim there anymore. It is as salty as the sea and muddy as anything even at low tide.

The changes to the water quality of the Moataa stream were noted by over half the people interviewed. The consensus was that, not only has the water become muddied and salty, but the water flow also has decreased markedly in the recent past. The recollections of 50 years ago all point to the clear and clean water of the stream providing beautiful swimming spots abundant in and around the mangrove area. Traditionally, the tidal stream passing through the mangroves has also been used for washing, bathing, and swimming. The abundant fresh water springs around the estuary were a reliable source of water for drinking, prior to the supply of piped water to the area in the late 1950s. That was the situation seen by one Moataa resident before migrating to New Zealand:

> There was no piped water in the village at the time. All people drank and bathed at the fresh water springs that were abundant some one kilometer behind the village proper.

Today, washing, swimming and bathing in the river, as well as drinking from the fresh water springs, is restricted to times when the tap water supplies are dirty. Two interviewees attributed the reason for the now-salty stream water to the inland movement of the exchange point between fresh and seawater in the recent past.

The most interesting evidence of water quality decline at Moataa, however, was the observance of the introduction of the limulimu (seagrass: *Halophila ovalis*) in the area, as recollected by one housewife from Moataa. According to Zann (1991), the presence of seagrass indicates excess nutrients in the water. It is believed that a combination of increased nutrient levels and decreased water flow of the stream has slowed down the transference of the nutrients from the terrestrial environment to the sea. Consequently, the nutrients are concentrated in the stream waters and provide an ideal environment for the growth of the seagrass. Two informants also talked about the healthy taro patches and water cabbages that grew well in the stream channels in the past years. Today, these are no longer fruitful activities, and are attributed to water quality decline at Moataa.

Ethnohistorical data on water quality decline has shown that there was little changes seen at Sataoa and Saanapu. While the water quality change at Vaiusu Bay was mainly in the water depth, evidences observed at Moataa were quite substantial. Probably, the changes in water quality decline in the three areas are a fair indication of the degradation stage the particular area is in.

7.4 CHANGES TO THE MARINE RESOURCES

7.4.1 The National Survey

Some of the findings from the National Survey of the inshore fisheries of Upolu undertaken by Zann in 1991 were that: there was a decline in fish stocks and inshore landings in Upolu; the fish catches have declined over the past ten years according to fishermen's testimonies; the inshore invertebrates have declined greatly between 1989 and 1991; and there has been a disappearance of certain species like the sea hare (gau: *Dolabella auricularia*), sea cucumber (sea: *Holothuria*) and giant clams (faisua: *Tridacna squamosa*) in the lagoon areas of Upolu.

Information on the use of local marine resources by the residents of the villagers surrounding the mangroves at Saanapu and Sataoa, Vaiusu Bay and Moataa, as documented by Zann (1991) can be seen in Table 7.3.

In 1990, 89% of the households in the villages of Sataoa and Saanapu were classified as fishing households, 5% for the Vaiusu Bay villages, and only 2% for Moataa. The frequency with which villagers from the three different areas eat fish is not significantly different, nor is the annual per capita fish consumption. The major differences between the Saanapu and Sataoa area and the Vaiusu Bay or Moataa areas is the percentage number of fishermen in the villages, the number of fishing trips per week and the annual fish landings. Thus it appears that the use of fish in the diet of villagers in the three areas examined is not significantly different, but only the means by which that fish is obtained.

TABLE 7.3: Comparison of Fishing Activities in the Saanapu-Sataoa, Vaiusu Bay and Moataa Areas in 1990. Source: Adapted from Zann (1991)

	Sataoa and Saanapu[1]	Vaiusu Bay villages[2]	Moataa
Population	511	2992	1363
Number of fishermen	96	23	30
Percentage of fishermen	17.4	1.0	2.2
Households	66	190	152
Fishing households	59	10	20
Percentage of fishing households	89.4	5.3	1.5
Number who sold 0% of fish	40	6	10
Number who sold 25% of fish	13	1	5
Number who sold 50% of fish	2	2	3
Number who sold 75% of fish	4	1	2
Number who sold 100% of fish	0	0	0
Number of canoes	55	4	6
Number of boats	0	0	0
Trips per week	175	21	44
Frequency of fish meals (meals / week) *	1.8	1.8	1.8
Annual per capita consumption (kg / capita / yr) *	21	18	18
Average catch fish / trip (kg) *	3.5	2.6	2.6
Catch per unit effort (kg / man / hour) *	0.78	0.4	0.4
Annual fish landings (metric tons / yr) *	130	33	33
Percentage use of netting *	40	55	55
Percentage use of speardiving *	60	38	38
Percentage use of hook and line *	0	6	6
Percentage use of collecting techniques *	0	2	2
Percentage fishing from the shore *	0	7	7
Percentage fishing in the lagoon *	80	68	68
Percentage fishing on the reef *	20	25	25

1 Data a combination of both Sataoa and Saanapu villages

2 Data a combination of four villages: Fugalei, Sogi, Vaitoloa, Vailoa

* Results averaged for the fishing district, i.e. several villages in the immediate vicinity. Because the Vaiusu Bay villages and Moataa were within the same fishing district, an average result is given covering both areas.

7.4.2 Sataoa and Saanapu Area

The fact that the Sataoa and Saanapu mangroves have remained healthy over the past 50 years (Chapter Six) and maintained a stream with good water quality points to a healthy marine resource base in the area. However, oral historical evidence presents a slightly different picture. Table 7.4 lists the changes to the marine resources observed at Sataoa and Saanapu.

TABLE 7.4: The Changes in Marine Resources of the Three Sites According to Ethnohistorical Evidence. Source: Author's research

SITE	CHANGES IN MARINE RESOURCES OBSERVED
Sataoa and Saanapu	Time taken to obtain a profitable catch has increased. Decrease in both sizes and quantity of fish and marine organisms harvested from the lagoon. Movement of fishing grounds to further areas. Disappearances of species like trevaly, bonefish and mullet in the stream. Destruction of fishing grounds. Increase of mullet and beach crab in the mangrove area.
Vaiusu Bay	Time taken to obtain a profitable catch has increased. Decrease in both sizes and quantity of fish and marine organisms harvested from the lagoon. Movement of fishing grounds to further areas. Disappearances of species like peanut worm and herring. Increase of cockles in the mangrove area.
Moataa	Time taken to obtain a profitable catch has increased. Decrease in both sizes and quantity of fish and marine organisms harvested from the lagoon. Movement of fishing grounds to further areas. Disappearances of species like mullet, sea hare, sea cucumber, unicornfish. Destruction of fishing grounds, loss of corals.

Elderly fishermen who had lived all their lives at Sataoa and Saanapu, and fished in the area have noticed a number of trends. Firstly, the effort required (time taken) to catch the same amount of fish had increased in comparison to the past. As one fisherman of Saanapu recalled in past days, he would just swim to the reef and come back with a good haul, whereas today, it takes almost a whole day to obtain a comparable catch. Secondly, there is an apparent decrease in fish numbers and sizes in the lagoon area where a lot of destruction to the marine environment was observed. One old informant had this to say of his fishing trips:

> In those days, the fish was caught right in front of my house. Today, I have to go beyond the reef to get an appreciable haul. There, the coral is all broken up and smashed because of the frequency of dynamiting in the lagoon area. Most of the fish habitat has been destroyed.

The above recollection not only attested to the degrading practice of dynamiting occurring in the Sataoa and Saanapu lagoon, but also gave evidence on the movement of fishing grounds further away to the deeper areas of the lagoon. Although it was not mentioned in the oral histories, human activities may also be the cause of the infrequent rising of the palolo worm in these parts of Samoa.

Responses to the changes in quantity and sizes of mud crabs caught in the area in the recent past was contradictory, although a lot more people believed that there has indeed been a decrease in both the size and quantity of mud crabs harvested from the stream. According to a prominent crab catcher of the village, crabs worth $30 were common in his hauls in the old days. Today, crabs worth only $20 are caught. Oral testimonies from the Sataoa and Saanapu area were unanimous in their belief that there had been an increase in numbers of the beach crabs in the area, in the recent past.

Sataoa interviewees claimed that some fish commonly caught in the past were now only rarely, if ever, seen. These included the one spot snapper (taiva: *Lutjanus monostigma*), mullet (aua: *Valamugil engeli*), bonefish (ava: *Albula vulpes*), and the unicornfish (manini: *Acanthurus triostegus*). A very informative recollection by the oldest interviewee from Saanapu was the disappearance of fish species from the stream like the bonefish (ava: *Albula vulpes*), trevally (malauli: *Alectis ciliaris*) and mullet (anae: *Mugil* spp). Considering the amount of fish poisoning activities reported in the stream channel, it is not surprising that there has been a decrease in size and quantity of the marine organisms harvested, and the disappearance of fish species from the stream observed in the recent past.

7.4.3 Vaiusu Bay Area

The decrease in both size and quantity of marine organisms were also noted at Vaiusu Bay according to oral testimonies from the area. The mass fishing activities that the locals practiced in the past are held responsible for the decrease in fish quantities harvested from the stream. The puni exercise for catching fish at Vaiusu Bay is now an infrequent activity.

According to one Vaimoso resident:

> The puni is a traditional way of catching fish handed down from previous generations. Coconut leaves are woven into mat-like designs, which bordered the mangrove stands when the tide is high. Fish collecting structures (egu) made from roots of the tuataga (pandanus-like) tree are placed in the deeper parts of the bordered area. When the tide goes out, the fish from the collectors are just emptied into canoes. Hundreds of fish are caught which the families consume or sell to get money.

The local villagers traditionally fished the area extensively by collecting the bivalve shellfish cockle (tugane: *Gafraruim* spp) from the intertidal area, the peanut worm (ipo: *Sipunculus* spp.), and the mangrove crab (paalimago: *Scylia paramamosian*). The locals also fish the stream using throw nets or by setting fish traps. All interviewees over 50 years old recalled carrying out these activities in their younger days. These observations are significant from several points of view. Whether the scarcity of these fishing practices today is due to smaller fish hauls, or that the younger generation is out of touch with this traditional fishing method is not clear. What is clear though is the fact that the quantity of fish taken from the stream twenty years ago far outweighed those of recent times. The fish haul decline and the loss of mangroves was seen by one Vaimoso resident to be related, when he noted that "the reclamation of the mangroves had not only destroyed breeding grounds for the fish, but also narrowed the channel allowing less fish through to the mangrove area". The high percentage of the people living around the bay harvesting cockles and mud crabs probably reflects the potential of these organisms as 'fast' money earners.

Oral history from Vaiusu Bay has also attested to the diminishing size and quantity of fish and mud crabs caught at Vaiusu Bay over the years. Some recollections from the residents concerning this topic include: mullets in the stream were plenty and big in previous days; not only were the crabs plentiful, but their sizes were all large; the ponyfish (mumu: *Leiognathus equula*) were as wide as the back of your hand; and the big mullets that used to be found in the waterway just in front of certain houses were no longer seen. Oral testimony by one female resident of Sogi concerning changes to the marine resources reads:

> I was born and lived all my life here in Sogi and I have seen many changes in the area. The mangrove areal extent has decreased, and the huge mangrove trees are all gone. A lot has been cut for firewood and housing spaces as more and more people settled in. In past years, there were a lot of beach crabs on those big mangrove tree trunks. Today, you seldom see any beach crabs. The tilapia (*Tilapia nilotocus*) were everywhere in the stream, and the mud crabs crawled aimlessly behind our homesteads. The peanut worm and the cockleshell were harvested in the muddy area directly behind our cooking houses. Today, one has to travel some 200 to 300 metres out into the mangroves to find some beach crabs. The tilapia found are only the smaller ones and the mud crabs are now plentiful in the outer villages of Faleula and Malie. The peanut worm has faded out of prominence, and the cockleshell are found way out in the vicinity of the sand mining activities at Mulinuu. I believe all these is due to the destruction on the mangrove area by the people.

The above recollection was enlightening in the fact that not only did it produce further evidence of changes to the marine resources already discussed, but also depicted a number of other changes to the marine resources in the Vaiusu Bay area. These are the relocation further away of harvesting sites for organisms like mud crabs and cockleshell; and the complete disappearance of the peanut worm from this part of the area. One Vaimoso resident also noted the disappearance from the area of the herring (pelupelu: *Sardinella albella*) which is seen once annually in the stream. The disappearance of species at Mulinuu was documented by Bell (1985, 1989) and attributed to dredging activities. The movement of fishing grounds to outer areas and the destruction of fishing grounds are the two factors responsible for the longer effort taken by the fishermen to obtain reasonable catches at Sataoa, Saanapu and Vaiusu Bay areas.

7.4.4 Moataa Area

The changes to the marine resources appeared to be particularly pronounced at Moataa, in view of the high percentage of responses giving evidence on this issue. Sixty four percent of the residents interviewed noted the decrease in both the size and quantity of the fish caught from the stream and lagoon area of Moataa, and another 57% noted the decrease in both size and quantity of the mud crabs and the beach crabs from the area. The oral testimony by one of the fisherman of the village noted these changes:

> The fish population in the lagoon area is not the same as in the old days. I have seen a huge difference. Species that were plentiful in the lagoon area like the sea hare [gau: *Dolabella auricularia*], sea cucumber [sea: *Holothuria*], the pen shells [fole: *Pinna spp*], and the violet asaphis [pipi: *Asaphis violacea*] are gone now. The sizes of the fish and organisms have diminished especially the boring urchin [tuitui: *Echinometra matheae*], the mojarra [maku: *Gerres* spp], the rabbitfish [lo: *Siganidae*] and the mullet [anae: *Mugil* spp]. The lagoon area also was full of coral. Now, it is all gone, except where the lagoon was deepened. Coral grew there, but is dying out again. In the stream, the mud carbs and the beach crabs were plentiful, large and much easier to catch.

Indeed, all the fishermen from Moataa village who were interviewed noted many changes to the marine resources of the village. Other changes to the marine resources noted were: the movement of organisms away from shore to the deeper parts of the lagoon; the decrease in fish population necessitating the use of fishing grounds belonging to adjacent villages; the decline in certain fish species like the unicornfish (ume: *Naso unicornis*); the destruction and decline of coral in the lagoon area; and an increase in the time taken to obtain a good haul. The disappearance of a lot of marine organisms was echoed by over 50% of the residents from Moataa. Ethnohistorical evidence of the fish resources of the Moataa area was supplied by several interviewees and is summarized below.

Mangrove crabs were caught using the 'lure and trap' technique (Plate 7.1), while beach crabs on the mangrove tree trunks were scraped into containers, to be later cooked in coconut cream. The fish were caught by either spearing, using throw nets, overturning the grass by the river banks, or by using an underwater sling shot whilst wearing goggles. Mass fishing of the streams and the lagoon area by the whole village has traditionally been a major part of the Moataa village lifestyle.

PLATE 7.1: A Crab fishermen with a Lure and Trap. Behind is the *Rhizophora* species abundant in the area. Photograph by author.

Prior to the mangrove reclamation shown in Figure 6.6, the tidal stream through the mangroves was used as a major source of food for a faalavelave. A large tahitian chestnut tree (ifi) in the mangrove area had been fitted with a lapa (sound maker) which, when sounded, notified all the Moataa villagers that they were required to assemble to fish the stream. The villagers would then move throughout the length and breadth of the stream stirring up the muddy substrate so that the fish and organisms would float to the top or the side of the stream. In this way, a large volume of fish could be acquired to supply visitors with the needed food. This activity was only practiced once or twice a year, but has not been practiced over recent years due to the altered estuarine conditions.

Undoubtedly the most notorious activity of the Moataa village was the annual mullet- catching exercise. Between August and October each year, the village fishermen set up a fish trap adjacent to the outlet of the tidal channel east of Taumeasina Peninsula. In anticipation of the large school of mullet, which annually crossed this lagoon area, two sections of mesh wire were joined end to end and supported by wooden poles and erected in a V-shape between the shore and the reef. At the vertex of the V, which was located in the middle of the lagoon, a mesh-wire trap was constructed for retaining the fish (Figure 7.1). Halfway along the mesh-wire lines, wooden structures were erected for the master fishermen to stand in to sight the fish. When the fish was sighted, the master fisherman waved his coconut leaf hat in the air and all movement was prohibited. Once the school of fish passes the master fisherman, the canoes are rowed at maximum speed towards each other while the nets are thrown overboard. The nets are then dragged towards the mouth of the trap. In this way, huge catches of mullet (anae: *Mugil* spp) were caught annually in an operation which involved the entire village.

One talking chief from the village noted that one year there were 32 000 fish netted by this method, but usually between 5 000 and 10 000 fish were caught. The fish caught were more than enough for consumption by the Moataa villagers, and surplus fish were always sold.

However, with the proposal to build the Royal Samoan Hotel, the fishing grounds of Moataa were irretrievably affected. About half of the mangroves in the north of the tidal channel were cleared, the land was reclaimed, and an artificial island was constructed in the lagoon area opposite the original tidal outlet (Figure 6.6). These reclamation works produced the following effects on fishing activities as recorded by the local community in their oral testimonies: the number of mullet making their annual passage through the lagoon area diminished to negligible numbers in the 1990s; there was a marked decrease in the size and

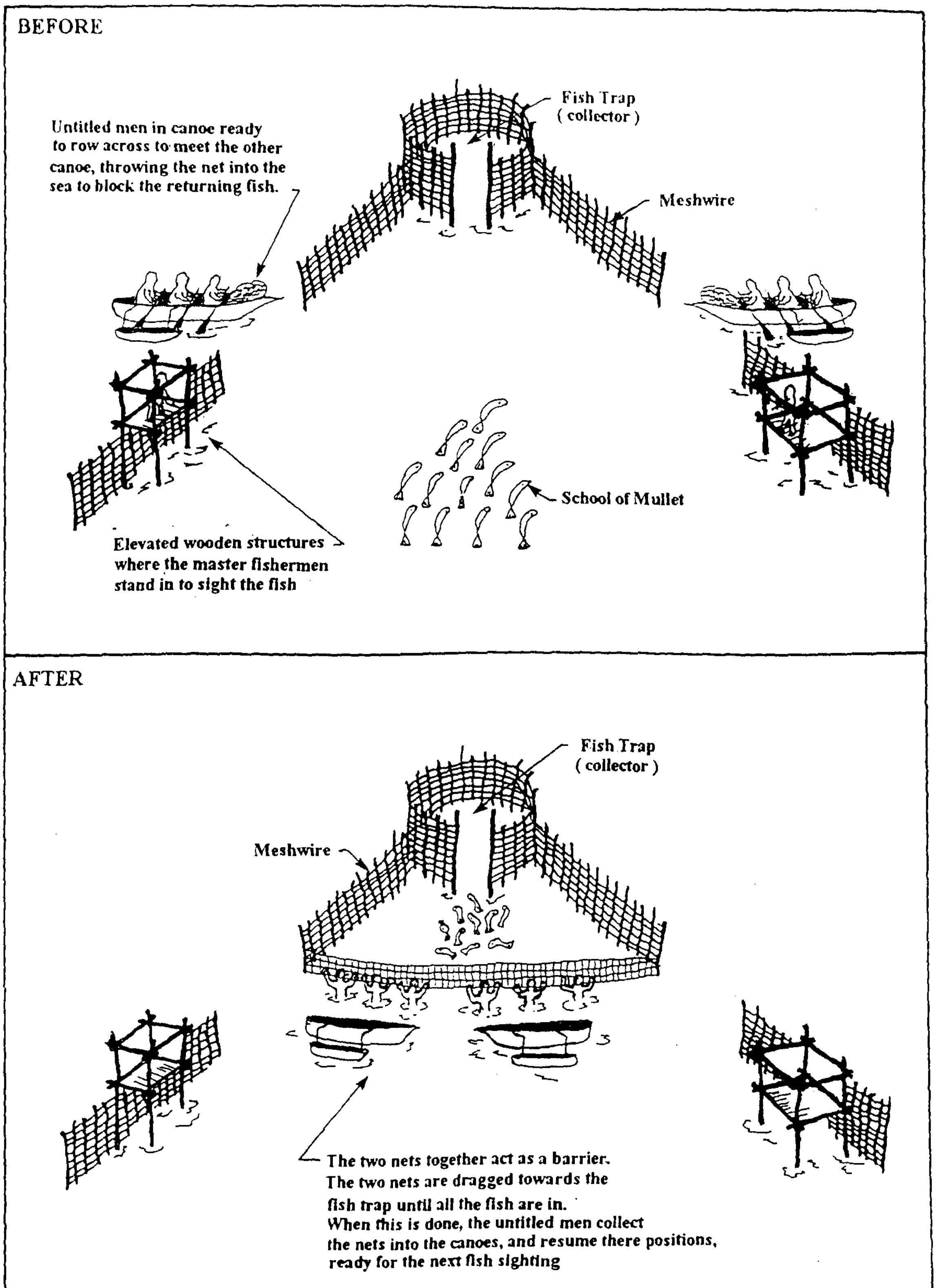

FIGURE 7.1: Diagrammatic Representation of Catching Schools of Mullet by the Moataa Village. Source: Ethnohistorical Data and Author's' Experience.

quantity of fish caught in the tidal stream after the 1970s, as well as an increase in the time needed to catch any fish; the mud crabs traditionally present in the Moataa mangroves decreased markedly in both size and numbers; there was a disappearance from the mangrove areas of the freshwater shrimps (ulavai: *Macrobrachium lars*), and the beachcrabs (u'a and kupa: *Cardisoma* spp.) which used to live on the mangrove stems; there have been diminishing numbers of trevally (malauli: *Carangidae*), boring urchin (tuitui: *Echinometra matheae*), mojarra (maku: *Gerres* spp.), rabbitfish (lo: *Siganidae*) and mullet (anae: *Mugil* spp.) found in the lagoon area; and there has been a disappearance of species which were previously plentiful in the lagoons - the sea hare (gau: *Dolabella auricularia*), sea cucumber (sea: *Holothuria*), pen shells (fole: *Pinna* spp.) and the violet asaphis (pipi: *Asaphis violacea*).

In Section 7.4.1 it was shown that the Moataa residents still consume as much fish as occupants of other villages that still engage in traditional fishing activities. The unavailability of fish from the lagoons adjacent to Moataa implies that the villagers currently obtain their fish from the Apia fish market. However, there is evidence to suggest that this situation has not always occurred. A comparison of the occupations of residents of Moataa in 1970 and 1994 is given in Figure 7.2. It is evident that the number of people with jobs in Apia has increased from 3% to 58% over quarter of a century. Although the percentage of fishermen and plantation workers decreased from 97% to 33% in the same period, the percentage of the villagers still engaged in fishing activities in the 1990s is quite high, considering the close proximity of the village to Apia (Moataa was included in the Apia urban municipality in the 1991 Census of Population). Also noticeable is the number of self employed and shop owners in the village, which is probably a reflection of the financial status of some of the villagers.

From the data in Figure 7.2, it seems apparent that prior to the reclamation of the Moataa mangroves, the occupation of the villagers would have been very similar to that of present-day Sataoa and Saanapu (Table 7.3). In fact, the proportion of Moataa residents who were fishermen in 1970 may have exceeded that of Sataoa and Saanapu in 1994, and may have been the reason why Moataa had the reputation of being one of the premier fishing villages in Samoa at the time. Today, only a few Moataa villagers call themselves fishermen (Figure 7.2).

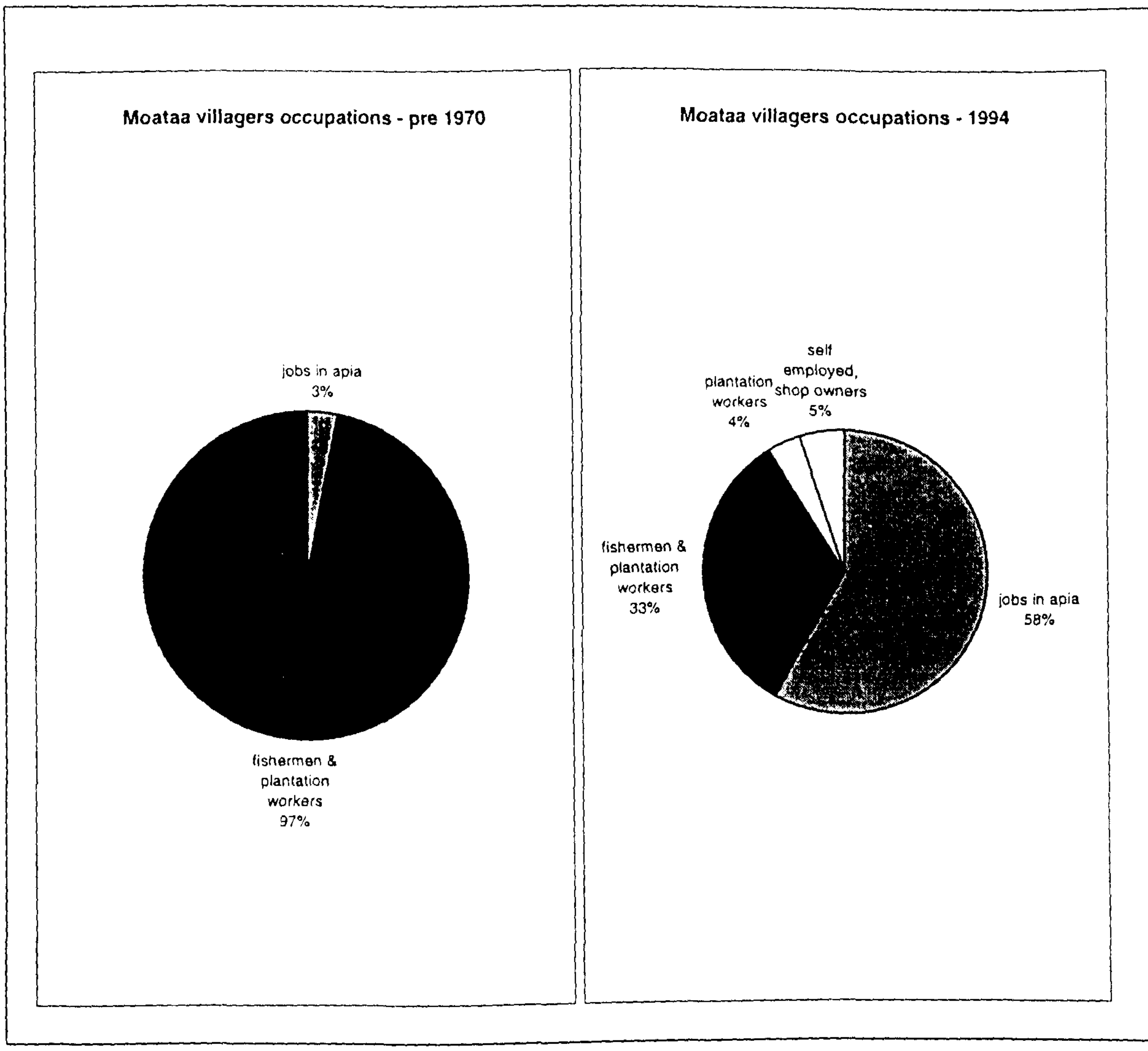

Figure 7.2: Occupations of Residents of Moataa in 1970 and 1994.
Source: Ethnohistorical data and Author's experience.

Some fishermen use a rod and line to fish the waters of the lagoon area, and others set up eel traps near the site of the artificial island. Fishing in the stream is restricted to a few families who continue to catch mangrove crabs, and the communal fishing of the stream by the village is no longer practiced. Throw nets are seldom seen, although once in a while the grasses by the riverbanks are seen overturned.

Although the reclamation works cannot be reversed, the Moataa village council has acted to save the remaining mangrove forest from further destruction, despite opposition from some matais (Section 7.6.2). The village council has recognized the importance of mangroves as a mullet breeding ground, and put a ban on any further removal of mangrove trees in 1993, despite the unresolved mangrove ownership issue (Section 7.6.1). Villagers say that this action has produced an increase in the number of small fish occupying the estuary.

The mullet catching exercise practiced by the Moataa villagers was a source of great wealth to the village. The large catches of mullet always provided enough fish for everyone in the village. There was always fish left over, that could be sold. Many Moataa people built themselves European style houses, acquired cars, and purchased items of modern equipment. The Moataa people could also afford to send their children to the best schools in the country and sometimes to overseas educational institutions. As a result of their education, the Moataa people were then able to acquire jobs in Apia. In fact, in the mid-1960's, oral testimony from one of the old residents of Moataa recalled that "the majority of the office workers (approximately 100) in Apia at the time came from Moataa". The movement of the Moataa people from a subsistence lifestyle to a more western style lifestyle was largely due to the twin factors of their wealth from the mullet catching exercise and their proximity to Apia.

On the other hand, the proximity of Moataa to Apia has been somewhat of an economic compensation. Because the villagers were already wealthy by 1970, and because Moataa provided an ideal location for city workers to reside, the loss of income from the mullet catching exercise has been effectively replaced by the income generated from the wages of office workers. One can only speculate as to the economic wealth of Moataa villagers had the reclamation works not proceeded and the mullet catching exercise continued to the present.

7.6 ETHNOHISTORICAL INSIGHTS ON OWNERSHIP AND CONSERVATION OF MANGROVE AREAS

7.6.1 Mangrove Ownership

The inconsistency and misinformed nature of mangrove ownership in Samoa was evident in the oral histories of the three areas surveyed. At Sataoa and Saanapu, all but one of those residents who commented on this issue were of the opinion that the respective village councils are the rightful owners of mangrove areas. The odd man out believed that the mangrove area directly behind a family's dwelling belonged to that family. The majority of the people from Sataoa Saanapu and Moataa were of the opinion that the village council owns the mangroves. Two talking chiefs of Moataa openly claimed the mangrove areas as theirs. Indeed, the mangrove ownership issue at Moataa is far from a settled affair. According to oral testimony from Moataa, court disputes between the village council and other chiefs of the village are still in the balance and so the fate of the remaining mangroves remains unclear. The ownership issue at Sataoa and Saanapu area is being disputed by the respective village councils as well, where Sataoa residents claimed all the mangroves to be theirs, and Saanapu residents likewise believed that they are the rightful owners of the mangrove area. From Vaiusu Bay the interviewees who expressed their views on the issue were all of the opinion that the families who are living adjacent to the mangroves owned that area. As noted in Chapter Two, the mangrove ownership issue is still not clearly defined in the *Constitution* of Samoa, or any of the *Acts* related to the environment (Peteru 1993). Indeed, the mangrove ownership is far from a settled affair under customary law either.

7.6.2 Mangrove Conservation

The majority of people interviewed were in favour of the conservation and protection of the mangrove areas. Fifty six percent of residents from Sataoa and Saanapu supported the idea, as well as 79% from Vaiusu Bay and 36% from Moataa. In response to the Department of Lands and Environment declaring the Sataoa-Saanapu area a conservation site in 1992, the two village councils took action to continue to preserve the mangroves. The two village councils recognized that the mangroves were a breeding ground for marine organisms, and so banned the use of poisons in the entire mangrove area. Offenders were deemed to be subject to severe punishment not only by Samoan law, but also by village law. As one of the high chiefs of Saanapu explained:

> The fine imposed by the village council [for use of poisons in the mangrove area] included a cooked pig [equivalent to WST$500] and two cartons of herrings [WST$180] if supplied on the day of the village council meeting, or otherwise an additional cash fine of WST$500.

This amounts to a fine of about ten weeks wages since the average Samoan weekly income is of the order of WST$60.

Despite this action by the Government and the Sataoa and Saanapu village councils, some fish poisoning in the mangrove areas still takes place. It is believed that the offenders are residents of other villages who are not subject to the laws of either the Sataoa or Saanapu villages. This raises the issue of fishing rights in mangrove areas, which will be addressed in Chapter Eight. The situation at Sataoa, where there has been noticeable fish decline due to poisoning, is representative of the general decline in fish resources seen throughout Samoa in recent years.

A clear majority of oral history interviewees from Vaiusu Bay were in favour of conserving the mangrove areas. The main reason put forward for conservation was to sustain the productivity of the area, as many people are heavily dependent on the mangrove environment for their livelihood. As one old resident of Vaimoso pointed out:

> My family's survival has been the mangrove area as this is where the crabs, the cockleshell and the fish are found. We lived on these in the old days and all my children went through school from the money I got from selling cockleshell and from the fish that I caught and sold.

At Moataa, only one third of the interviewees were in favour of the conservation of the remaining mangroves. To ensure a safe breeding site for the small fishes and other organisms harvested from the area was a good enough reason for conserving and protecting the mangrove areas, according to the oral testimony of a young boy from Moataa. The majority of the Moataa people did not share the boy's view, where, 43% of the interviewees (all of whom were matais) wanted the remaining mangrove area to be reclaimed. The reason behind this thought is probably personal gain, as one talking chief explained:

> By reclaiming, the village can have new land that can be divided up as the population is increasing or alternatively, it could be used for village developments like a school building or sports complex

The contradictory nature of the thoughts expressed on ownership and conservation concerning the mangrove areas in Samoa sums up the situation well. The varied views on the issues discussed continue to deprive the mangroves of appropriate management strategies to ensure their ecological sustainability. Oral histories from the three areas demonstrated that mangroves have been good providers to many local people over the years, and their conservation, protection and management must be given high priority. As one resident from Sogi proclaimed, the mangrove area behind his family is the story of his life, the history of his family, and the anecdote of the settlement of Sogi village.

From the information presented in this Chapter, it has been demonstrated that the use of ethnohistorical evidence has provided complementary evidence on environmental changes in certain coastal areas of Samoa in the recent past, which were undiscovered until now. The correlation of some of these ethnohistorical accounts with scientific knowledge and written material were noteworthy. Three of the informants from Moataa have died since they were interviewed, and their extensive knowledge of the Samoan environment in the past 50 years would have been lost completely. Certainly, ethnohistorical evidence has shown how the village people in parts of Samoa have adapted their lifestyle in response to changing conditions. A lot more use of ethnohistorical data collection is recommended to obtain past recollections on such topics as past natural disasters and their effects on the environment.

It is also apparent that mangroves play an integral role in much of the marine resources of Samoa, and that marine resources contribute a large component of the average Samoan village economy. It is also apparent that the importance of mangroves has not been fully appreciated, allowing mangrove destruction to continue unabated in the past. The question which then remains is: what strategies should be adopted to manage the remaining mangroves in a sustainable manner so that future generations will indeed have access to the same marine resources that their forebears enjoyed. This is discussed in the next chapter, together with management strategies for the maintenance of good water quality and a healthy coastal ecosystem.

CHAPTER EIGHT
CONCLUSION AND RECOMMENDATIONS

"But where can wisdom be found?
The fear of the Lord - that is wisdom, and to shun evil is understanding"
Job 28: v28

8.1 ENVIRONMENTAL PROBLEMS IN THE COASTAL ZONE

In the first Chapter of this thesis (Section 1.3.1), the environmental problems experienced by South Pacific countries were outlined. These environmental issues specifically affecting Samoa were further detailed in Section 2.8, where it was shown that the coastal zone was under stress. In Section 2.9, it was pointed out that prior to this study, there was no systematic data available on streamflow and sediment loads brought down by the Samoan rivers (Baisyet 1989). Both the amount of sediment delivered to the coast by streams was unknown (Richmond 1991), and Samoa was almost void of information on water quality (Taylor 1991). Asquith *et al.* (1994) had estimated sediment loads for Samoa using precipitation data, and prior water quality measurements were confined to grab samples documented by Downes (1981) and Zavala (1985). This study undertook the first ever comprehensive water sampling for all streams in Samoa, and the first ever intensive sampling of the urban streams in the vicinity of the capital city Apia. This study was also the first study of its kind in Samoa, with respect to both sediment analyses and mangrove health. Not only has this thesis documented extensive and original data collected for the coastal zone of Samoa, it has attempted to synthesize several areas of environmental research. This, too, has not been attempted before.

The following environmental concerns associated with the development of Samoa have been highlighted in this thesis. Firstly, water quality analyses indicated that although the streams of

Samoa were not particularly contaminated with sulphate and total nitrogen, substantial amounts of suspended solids, iron, total phosphorus and zinc occurred particularly close to settled areas, and especially near Apia. Groundwater contamination was noted at Moataa, and higher nutrient levels were found in the freshwater springs in the capital city, Apia. The majority of freshwater springs registered elevated salinity readings, especially those located near the coast. Secondly, inappropriate land use practices particularly those associated with domestic and industrial waste from the Apia urban area, were found to be producing a decline in water quality and associated marine productivity. SPREP (1982), Dahl and Baumgart (1983), Dahl (1984b) and Thistlethwait and Votaw (1992) noted that this problem was occurring in the coastal environment of Samoa (Table 1.4). Thirdly, the periods of greatest contaminant input into the coastal zone were shown to occur either during storm events or at times of low flows, when contaminants were discharged from industrial enterprises in Apia. Fourthly, analysis of sediment material adjacent to selected stream mouths showed that iron and total phosphorus are contaminants of note in the coastal sediments of Samoa, and that zinc was an important indicator of anthropogenic activities. Fifthly, the mangroves adjacent to the Apia urban area at Vaiusu Bay and Moataa were not found to be in a healthy state compared to the stable mangrove area at Sataoa and Saanapu. As noted by SPREP (1982) and Thistlethwait and Votaw (1992), this was another serious environmental concern in Samoa (Table 1.5). Sixthly, both biogeographical and enthnohistorical evidence demonstrated that changes to mangrove ecosystems due to anthropogenic causes had produced pronounced effects on both the economy and lifestyle of the people living near and using the coastal zone.

The results of this study have shown that the stream waters of Samoa appear to contain high levels of turbidity, nitrogen and phosphorus. This result was partially attributed to the thorough sampling carried out in the streams of Samoa, although the occurrence of elevated levels of iron, total phosphorus and zinc in the waters is a worrying issue. Higher sediment loads were calculated for Samoa in this study than those estimated by Asquith *et al.* (1994). These high sediment loads may have an effect on the coral population decline noticed in the lagoon of Apia and its environs, and this topic warrants further research. The sediments of the coastal zone of Samoa appear to be acting as sinks for total nitrogen and total phosphorus. This study found the concentrations of the metals manganese copper and zinc in the sediments to be low, compared to those found in the sediments of Fiji and Papua New Guinea. It is evident that changes to the coastal zone of Samoa in the recent past have been due to both anthropogenic and natural causes. As documented in the text, the contribution of cyclones to environmental change was considerable. Climate change, sea level rise and ENSO events have been cited as probable causes of environmental changes observed in Samoa in the recent past. The indirect effect of nutrient enrichment on mangrove seedling deaths is yet another topic for concern. Taulealo (1993) noted that the state of the environment in Samoa is one of progressive decline. Since the faa-Samoa was developed in the context of a clean and natural environment, perhaps this decline of the environment status is an ominous indicator of the direction the faa-Samoa is heading.

The key requirement in the reversal of environmental decline in Samoa is that the government, village decision-makers, and individuals throughout Samoa need to work towards effecting change (Taulealo 1993). To ensure the protection and management of the coastal environment of Samoa, the following propositions are made. Any suggestions made as to appropriate ways to manage environmental concerns must be structured within the framework of the faa-Samoa. The participation of village councils in management plans must be made a priority; and the issue of mangrove ownership must be clarified. The dual legal system operating in the country must be addressed.

The dual legal system has been discussed in Section 2.8.3, where the two systems have been compared in their mode of operations and philosophy. The relevance of the system to management strategies will now be discussed, followed by some suggestions on how to manage the environment of Samoa in an ecologically sustainable manner.

8.2 THE DUAL LEGAL SYSTEM AND THE NGO S

There appears to be a large gap between events that occur in the parliament at Mulinuu and their effect on village affairs. Compliance with written legislation is a major problem because it is contrary to the faa-Samoa (Taylor 1991). As Fingleton (1991) noted, the uniqueness of the dual legal system in Samoa is the extent to which the application of custom has been installed and elaborated. Samoan custom is ranked equally as a source of law with both statute law and the adopted common law, and the *Constitution* allocates subject areas to be governed by custom, in areas such as those relating to matai titles and customary land. Village councils can pass measures, which run contrary to the law and sometimes the *Constitution*, creating a lot of friction and uncertainty in many social and environmental issues (Peteru 1993). Villages have been known to disregard court orders and ignore laws which they disagree (Department of Lands and Environment 1991). Three examples in the context of environment illustrate the problem. Firstly, dynamiting fish is apparently a widespread and ongoing practice despite its prohibition by State law in 1972. This practice has continued because not all village councils in the country have banned the practice and hence it is not policed at a village level. Secondly, land in the Mulivai Stream catchment designated for catchment protection for the purposes of supplying town water to Apia was illegally cleared and cultivated following the construction of an access road by village law. In this case, customary law overrode State law. Thirdly, pigs totaling 200 000 in number remain free to roam despite the State law which requires that they are penned and kept a minimum of 200 meters from any dwelling. These examples illustrate that it is essential that any management plan be instituted according to faa-Samoa and not through legislation alone.

Non-government Organizations (NGOs) can provide vital support for environment management, especially in key areas such as education and public awareness (Taulealo 1993:54). In many cases the NGO s are the preferred avenue of aid assistance with regards to environment and development (Peteru 1993; Cox and Elmqvist 1997). This is based on the assumption that these organizations are better at administering aid than local governments, more trusted, more effective at reaching the poorest groups and have a stronger interest in issues central to development (Cox and Elmqvist 1997).

About 200 NGOs are registered in Samoa, but only a handful undertakes activities associated with the environment (Faasavalu 1991). Most prominent is the Ole Siosiomaga Society, which is an environmental group that was founded in 1990 and aims to monitor and protect the environment of Samoa amongst other things. While the society has managed to secure the conservation of the rainforests of Uafato village in Upolu, its participation in talks to preserve the rainforests of Tafua village in Savaii proved disastrous (Cox and Elmqvist 1997). The insistence of the NGO officers to drop the traditional custom of the kava ceremony before meetings, and the lack of communication between the village council and the NGO officers were the principle reasons for the failure of the Tafua project. This led Cox and Elmqvist (1997) to conclude that while urban NGOs may represent a potential political voice for conservation at the national level, they may not truly represent indigenous values and concerns at the village level.

8.3 MANAGEMENT STRATEGIES

8.3.1 Management of Water Quality

Given the unusually high levels of contaminants in the waters of Samoa, and particularly those in the Apia urban area, some serious management strategies need to be employed to counter the problem. The majority of the Samoan population is dependent on the terrestrial and marine environments for their continued livelihood, and yet is not aware that inappropriate land use practices are producing the decline in water quality and associated marine productivity. Domestic and industrial waste from the Apia urban area is contributing to water quality problems in Samoa, and the twin management strategies needed to address this problem are to control erosion in the total catchment and to reduce the liquid waste generated from the Apia urban area.

Two basic ways in which the water pollution problem needs to be addressed in Samoa are suggested. Firstly, the widespread pollution of streams and freshwater springs which is associated with the traditional Samoan lifestyle needs to be addressed, and secondly, the issue of industrial effluent in the Apia urban area needs special attention.

There is legislation in place to address the problems of stream pollution. Within three years of gaining independence, the Government of Samoa passed the *Water Act* (1965). Under that *Act*, it is an offence to pollute any river, stream, watershed or catchment area used for water supply. Also under that *Act*, the Government grants concessions to any person, company or committee who is responsible for administering water supply for villages in Samoa (Fingleton 1991). The *Lands and Environment Act* (1989) is also in place to prevent, control and correct pollution of air, water and land resources. However, the later Act only applies to those parts of Samoa which are specified by Order, and Fingleton (1991) reported that no such order had been made up to 1991. There are no known incidents of the legislation having been applied to individuals or companies found polluting Samoan rivers (Peteru 1993).

To counter the widespread pollution of streams and freshwater springs that stems from the traditional Samoan lifestyle, the following suggestions are made. The Government of Samoa could embark on a major environmental awareness campaign, containing the following facets.

(1) The Department of Lands and Environment could administer a litter prevention scheme. This should include a better rubbish collection scheme, whereby waste is differentiated by type, and disposed of appropriately. The use of cut 44-gallon drums as rubbish bins are a nuisance to garbage collectors (Gangaiya and Wele 1994) and containers for solid waste storage should have lids to keep the wastes covered at all times. This program should include both the urban and rural areas, and a 'mayor' (pulenuu) in each village should be given this responsibility. The provision of rubbish bins in villages and public places should become a routine, and signs advising people not to litter should be erected.

(2) A program administered by the Public Health Section of the Motootua National Hospital should be instituted to educate people on appropriate locations for toilet facilities. A standard distance away from streams should be set for the location of toilets (for example, twenty meters). This program should provide incentives to poorer communities for the provision of septic tank systems (cement and PVC pipes) and could be administered through the church or women's committees, with loan agreements guaranteed by the village council. Currently, individuals install all septic systems, and the size of a septic unit installed is

proportional to the finance available rather than the size required to meet the needs. This program should cover the Apia urban area as well as the non-urban areas, as some septic systems in Apia are still known to overflow and are not properly designed (Gangaiya and Wele 1994).

(3) The Department of Education should initiate an environmental awareness program. Although there has been an increasing emphasis on environmental issues in Samoa over the last decade, there is still the need to include conservation and management issues on the national agenda (Department of Lands and Environment 1991; Taulealo 1993). An emphasis on environmental management should become part of the national school curriculum. Publicity on the adverse impacts of human activities on the terrestrial and marine environment should be made available both to children and to village administrators and occupants.

(4) Groundwater management must be made one of the priorities of environmental concern for the Apia urban area. This aspect of water quality monitoring in Samoa has not been given ample attention in the past. The most likely places and times of runoff infiltration into the groundwater (Section 2.2.3) must be clarified to the people. The link between groundwater discharge in inland areas and discharge sites near the coast needs to be shown to many people especially the plantation workers who are cultivating the catchment areas, where a lot of discharge points into the groundwater are likely to be present (Figure 2.9). This groundwater management issue should be included in national forum discussions. The Government of Samoa should also set aside funding for research into groundwater monitoring and conservation.

There are basically two ways to bridge the gap between issues of national importance which have national legislation, and the grass-roots level of Samoan village life. The first would be to institute a system of regular national forums, where members of each of the 330 villages in the country attend a national conference to be informed of national issues, such as water quality, which need to be policed at the village level. This could be done as part of the Independence Day celebrations when many people visit Apia as part of the festivities. Legislation could be introduced to make attendance at these forums a requirement. The second method would work within the current structure of faa-Samoa, but would be more difficult and time consuming. Here it is suggested that steps be taken to inform the relevant village councils about issues of national importance, such as the need to avoid water pollution. This would require members of government departments or other interested parties to visit many villages with a view to convincing them to take the necessary action at village level to protect the river environment.

To address the problem of industrial effluent in the Apia urban area, the following suggestions are made.

(1) Reform on the part of the government institutions, which are contributing to the water quality problem is urgently needed. Current practices adopted by the Motootua National Hospital and the University of the South Pacific should cease immediately, and toxic waste should be sent to an overseas country which has the capacity to manage it until suitable facilities are provided in Samoa (Klinckhamers 1992).

(2) The regulations of the *Water Act* (1965) should be enforced to prevent industries polluting urban streams. The Government of Samoa should not hesitate to prosecute industries

polluting the waterways, and should make sure that suitable personnel are available to prosecute offending parties. The job of prosecuting industries from polluting urban streams and the marine environment would be difficult for a Samoan to administer due to the faa-Samoa philosophy, so it should be given to someone without Samoan cultural ties.

(3) The question of who is responsible for the maintenance of clean water in the Apia urban area where village rule does not prevail should be clarified. Figure 2.13 indicates that most of the non-traditional urban settlement in Apia is located within the catchment of the Mulivai Stream, and so village rule does not apply to those people. The mayors could be given the responsibility of countering pollution problems in those settlements.

8.3.2 Management of Mangrove Areas

In order to address the question of sustainable management of mangroves, it is first necessary to determine who owns the mangroves. Traditionally, according to customary law, Samoans regarded the boundary between land and sea as the high water mark, and the space between the high water mark and the water's edge at any particular time to be a traffic route (Von Bulow 1902). The lagoon was regarded as the fishing grounds, was owned by either the village communities or the families of the chiefs. Offences against these ownership laws were punishable by the local village councils. Fishing outside the reefs was free to anyone but subject to the rules of the guild of fishermen (the tautai). Traditionally, fishing rights were considered non-saleable, although in the 1870s the Apia Harbour area was surrendered to the German Administration of the time (Von Bulow 1902).

According to the custom outlined by Von Bulow (1902), it is not totally clear who traditionally owned the mangrove forests. Technically, the mangroves always occur below the high tide mark and so may be regarded as part of the traffic route. However, in reality, the deep mud associated with mangrove ecosystem render them unsuitable to the passage of traffic. It is assumed that the traffic route concept was only applicable to sandy beach environments, and that because mangroves usually occur in estuary environments without a beach on their landward side that they formed part of the village land.

However, the establishment of the Samoan *Constitution* in 1962 has further complicated the issue of mangrove ownership and fishing rights. Article 104 of the *Constitution* provides that all land lying below the line of the high water mark is vested in the State, and that the public (i.e. anyone) has a right to fish in any waters provided they do not damage the fishery (GWS 1991). However, the *Lands and Environment Act* (1989) redefined the boundary of State-owned land as all land 50 meters inland from the mean low water mark in addition to all marine waters (Taylor 1991). Given the high tidal variation typical of mangrove stands, it is likely that all mangrove areas would be located 50 meters inland from the low water mark, and hence would not belong to the State but would rather be lands under customary title. This would mean that mangrove areas in Samoa would belong to the villages located adjacent to the mangroves. In addition, Peteru (1993: 53) asserted that "whatever the legal situation, in practice, the inshore waters and their fisheries are under the control of each village fono (village council)". As Johannes (1982) points out, the ownership by the government of coastal waters need not prevent the government from recognizing traditional fishing rights in those waters.

It is probably in response to a test case relating to the *Lands and Environment Act* (1989) that one member of the Moataa village council claimed that his village owned the mangroves. There is still some confusion present about the legal status of the mangrove stands, however, because another member of the same village council thought that the mangroves behind any house should belong to the corresponding family. This issue needs to be fully clarified before proper management of the mangroves can be achieved.

As a flow on from the ownership issue, the other major issue which needs to be addressed for effective mangrove management, is that of the policing of offences. At a national level, the *Lands and Environment Act* declares it an offence to pollute Samoan waters through discharges from floating crafts or land sources such as manufacturing establishments, or any place where they ultimately reach Samoan waters (i.e. surface runoff and groundwater). Peteru (1993) alluded to Sections 119 to 123 of the *Lands and Environment Act* as a means of protecting the remaining wetland and mangrove areas of Samoa, although gave no details of either the wording of the *Act* or the precise punishment of offences under the *Act*. Thus, even though the issue of mangrove ownership may have been established, regulations to enforce the *Act* so as to protect the mangroves and marine environment do not appear to exist.

As was the case with water quality protection and conservation, the topics of marine management and mangrove conservation could be included in national forum discussions and talks by members of government departments with village councils. The aim should be to convince the village council to take the necessary action at village level to protect the marine environment. The anticipated result of either of those methods would be the passing of village laws applicable to villagers and non-villagers alike. In this way, the mangroves and marine areas could be locally policed and protected against continued degradation.

But the problems of mangrove management are not always restricted to local practices. In the case of Vaiusu Bay, where mangrove degradation has occurred due to remote influences such as river inputs, it is the practices outside the local village that need to be addressed. This is where the regulations emanating from the *Lands and Environment Act* (1989) should be enforced. Again it is stressed that the Government of Samoa should not be hesitant to prosecute industries contributing to marine pollution.

To address the issue of development projects that impinge on environmental concerns, two forms of action are recommended. Management agreements between the Government and developmentalists such as the two sand dredging enterprises operating in Vaiusu Bay should be established, to ensure maintenance of the flow dynamics of the Bay. To avoid repetition of this sort of problem, meaningful environmental impact assessments should become a routine prerequisite for any future developments. Since most developments will be made by, or with the support of the Samoan government, legislation to this effect should be both introduced and enforced.

After Pearsall and Whistler (1991) they suggested that three mangrove sites be preserved, including the Sataoa and Saanapu mangroves, because they are the most healthy stands in Samoa. However, this thesis has demonstrated the vulnerability of other mangrove stands that were not specifically mentioned by Pearsall and Whistler (1991). It is asserted that every effort should be made to conserve all mangroves in Samoa. Furthermore, it is a belief that both national legislation and village laws should be enacted to ensure their continued existence.

8.3.3 The Best Management Strategies

Due to the structure of the Samoan society, where village leaders act as policemen and village laws are the authority under which everyone lives, it is evident that the best way to manage mangrove areas is by customary law. In this way, practices such as fish poisoning in mangrove areas can be both policed and punished. If it was established that the relevant village council owned the mangrove areas, then the situation which occurs at Sataoa and Saanapu, where offenders from other villages continue to use poison in the mangrove areas without fear of punishment from their own village council, would not occur. As Cox and Elmqvist (1997:87) wrote: "the lesson of trusting local institutions such as village councils is applicable to conservation projects, and that preservation of indigenous knowledge systems and cultures are equally important as the preservation of the environment". According to McNeely (1993), conservation initiatives should be built on the foundation of the local culture and the responsibility should be given to the local people.

Under that paradigm, it is important that steps be taken to inform the relevant village councils about issues such as the importance of continued maintenance of the mangrove communities for fish breeding purposes, and the financial benefits to villagers if these ecosystems are maintained effectively. This should then lead to the passing of village laws applicable to villagers and non-villagers alike.

It is apparent that some environmental concerns highlighted in this thesis originate in the village land belonging to one village, but impact on the land belonging to a separate village. For example, land use practices in plantation lands are almost certainly linked to elevated nutrient levels in groundwater springs accessed near the coast. This sort of problem can only be addressed by the involvement of multiple village councils acting in a united manner. To date, there has been no evidence of a confederation of village councils meeting to jointly tackle any issue, let alone and environmental issue. This sort of administrative change to customary law could be encouraged.

Another option for management of sensitive ecosystems such as mangrove communities would be to establish a system of heritage agreements between the Samoan Government and the local village councils. This type of conservation practice has some precedence in the case of the rainforest preservation at Falealupo on Savaii (Kendall 1991). Negotiations between the village council of Falealupo and an overseas organization involved overseas funding to build the village school building, in exchange for an agreement to manage the natural environment on the customary lands for fifty years (Taulealo 1993).

Johannes (1982) has made a number of other suggestions as to the means of protecting marine resources through improving environmental education and public awareness. Environmental education should be made a priority in Samoa because it is the behaviour of the people, which will be required to change. This is perhaps the single most critical aspect of any management plan, given that villages are essentially autonomous in managing their coastal resources. Before people can act, they must understand first (SOPAC 1993). Environmental education has not traditionally been a part of the Samoan culture, but there are many avenues through which this could be possible. It is suggested that the village council, the women's committee, the education system and the church all are appropriate forums for effecting change. In-service training should be made available to the teachers of Samoan children, so that for example, the importance of mangroves and other vegetation communities is taught to the younger generation. The women's committees who are given the task of policing the majority of the freshwater springs in the villages must be informed of the probable sources of contaminants, and the importance of their task in ensuring clean waters. Although the pastors of churches have no official status in village decision making, because they hold a lot of power and influence, and so it may be appropriate to convince the pastors of the need for environmental conservation. Offenders in mangrove and reef destruction are usually of youthful age, and it may be appropriate that the youth group gatherings that occur on Sunday evenings in churches across Samoa to be the time for public awareness talks. The cooperation and commitment of the community will be far more effective if it fits culturally, socially and economically into their way of life (SOPAC 1993). If all these avenues for environmental education were used, the current problems of coastal degradation may be alleviated.

As with other countries of the South Pacific, Samoa is a beautiful place in which to either live or visit. The environmental issues addressed in this thesis are not necessarily obvious to tourists and casual visitors. However, if the people continue to operate without thought for environmental conservation and the Government of Samoa continues to encourage economic development without any thought about environmental impacts, the country may not continue to provide a haven for both residents and tourists. All members of the Samoan culture need to work together to ensure that the country maintains the charm it currently possesses.

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APPENDIX 1 : Climatic Data Used in this Thesis

1.1 Rainfall Records for Mulinuu from 1941 to 1994

All values are in millimetres (mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
1941	171.7	513.1	319	104.9	41.2	58.2	154.2	176.6	59.7	108.2	176	154.2	2036.9
1942	246.9	238.6	212.1	210.8	116.6	147.1	163.3	68.1	178.1	275.6	242.3	521.5	2621
1943	203	266.6	225.8	256	157.2	30.2	41.2	26.7	135.4	252.7	37.3	276.4	1910.5
1944	526.3	223.3	414.3	115.6	89.7	58.2	64.5	402.6	305.3	151.9	178.3	178.3	2708.3
1945	265.7	346.7	347.2	217.7	226.3	341.6	129.5	185.4	232.4	264.9	466.6	214.6	3238.6
1946	529.9	396	298.5	209.3	311.4	158	158.5	176.5	98	175.5	205.7	381	3098.3
1947	420.4	263.1	340.4	121.4	260.6	301.8	212.1	77	259.8	192.8	328.2	468.4	3246
1948	432.3	568.2	84.6	313.4	270	65	75.2	77	59.4	405.6	406.7	836.2	3593.6
1949	300.2	216.2	380.9	177.8	293.9	88.1	179.1	159.5	191.3	245.9	103.6	595.9	2912.4
1950	450.6	548.1	695.5	207.3	394.7	297.9	149.6	115.3	110.2	203.7	161.8	858	4192.7
1951	267.2	261.4	190.8	287	187.5	259.6	31.5	10.4	62	291.9	192.5	315	2356.8
1952	297.9	303	330	323	175.3	120.4	53.3	43	136	190.3	43	252	2267.2
1953	177	330	180	64	173.5	52	275	17	15.5	257	250	158	1949
1954	259	225	720.1	276.8	141.5	188	147	240	106.4	341	433	474	3551.8
1955	503.2	353	607.3	83.1	275	80	100	269	268.5	267	190.3	464	3460.4
1956	542.3	501.1	346	163	24.1	215.4	75.2	270.2	87	133	391.2	328.2	3076.7
1957	366	464	251	220	96.3	145	163.3	10.2	97	77	298.2	325	2513
1958	156.2	145	469.4	173.2	145.3	131.1	100.3	228	49	108	377.4	218	2300.9
1959	301.2	472	298	155	140	26	103	71	173	376	359.1	672.1	3156.4
1960	417.1	396	281.2	110.2	237	201	89.2	75.7	45.5	101	413	338	2706.9
1961	395.2	346.5	696	183	164	221	39	170	197.1	226.1	346	178	3161.9
1962	499.9	265.4	292.9	85.3	191.8	43.9	92.2	306.8	124.5	435	357.4	471.2	3166.3
1963	242.8	172.2	511.3	265.4	67.3	121.7	59.2	62.7	116.3	121.4	99.8	240.8	2081.4
1964	365.3	306.1	248.7	361.7	238.5	259.1	216.2	122.9	334.3	145.8	206.3	364	3168.9
1965	329.5	450.9	226.3	305.3	236.2	195.6	106.7	27.4	106.4	280.4	25.4	76.7	2369.5
1966	512.6	116.8	518.2	310.4	93.5	280.7	144	130.3	186.4	276.4	142.5	343.7	3055.5
1967	292.9	307.3	298.7	528.6	175.5	208	192.3	273.3	129.5	319.7	243.8	381	3350.5
1968	335	502.9	426.7	331	128	169.2	78.7	201.4	192.3	364.7	115.1	102.6	2947.6
1969	418.9	385.1	320.3	203.2	114.3	36.3	161.8	160	104.4	55.1	176.5	289.5	2425.4
1970	338.6	250.9	565.4	350.3	164.1	220.7	95.3	111.8	176	136.1	355.9	932.7	3707.8
1971	392.7	357.9	240.5	389.6	238	120.7	54.5	64	268.5	142.6	266.8	277.2	2813
1972	545	197.1	364.8	269.7	70.2	55.1	110.6	129.8	465.9	354	203.8	721.1	3487.1
1973	472.2	312.8	135.7	434.1	129.8	94	131.1	303.2	179.5	579	727.3	585.1	4083.8
1974	331.8	428.3	381.6	207.2	130.9	327.3	35.7	18.7	103.8	406.4	567.4	511.5	3450.5
1975	924	321	260.7	238	291.5	114.8	278.7	97.6	171.9	209.4	159.5	364	3431.1
1976	620.6	421.6	211.3	242.2	241.3	137.5	186.9	35.7	4.4	49.9	183.4	602.2	2937
1977	366.9	261.8	454.9	61.9	97.9	85.6	59.4	44.1	57.1	132.7	149.5	134	1905.8
1978	959.7	197.1	640.9	100.5	141.6	125.7	130	207.7	70.1	281.6	513.3	412.9	3781.1
1979	290.3	270.4	332	100.3	244.3	119.9	208.7	51.7	236.2	348.9	247.8	391.6	2842.1
1980	372.2	310.2	464.4	302.7	216.1	161.2	162.4	161.9	593.1	488	208.8	180.1	3621.1
1981	259.3	361.3	634.9	m	m	m	67.5	75.2	198.6	350.3	438.2	596.6	2981.9
1982	481.1	947.1	132.6	33.9	289.3	51.6	71.6	276.3	63.1	100.9	125.4	63.1	2635.9
1983	228.5	141.1	256.5	130.9	75.8	113.3	14.5	105.2	23.6	82.6	202.4	573.7	1948.1
1984	274.1	260.2	277	131	59.4	301.2	90.5	158.3	191.6	159.2	67.4	619.9	2589.7
1985	440.1	379.1	354.9	240.4	288.6	141.7	96.6	84.5	71.3	86.4	65.8	145.5	2394.8
1986	489.1	162.6	349.8	349.9	288.2	158.3	149.2	75.2	202.2	155.7	125.5	460.6	2966.3
1987	508.8	351.9	192.1	163.6	154.9	69.1	41.9	68.4	1.2	47.2	80.5	559	2238.6
1988	848.6	348.4	312.3	207	364.5	97.4	198.3	130.7	177.7	207.9	251.1	259.2	3403.1
1989	720.7	863.6	308.8	321.6	132.1	76.6	89.2	7	62.3	116.7	302.2	182.7	3183.5
1990	280.9	78.8	497.8	225.7	127.9	116.9	93.3	45.5	61	110.9	359.1	176.8	2174.6
1991	359.5	935.1	256.9	146.2	150.8	147.3	143.8	101.4	25.7	166.2	351.6	60.6	2845.1
1992	200.4	519.8	451.4	380.5	232.7	43	133.1	180.7	166.8	119.5	295.1	404.7	3127.7
1993	509.4	m	491.4	229.3	168.5	42.2	72.5	201.4	208.2	278.3	199.8	321.6	2722.6
1994	245.4	168.4	301.9	310.6	224.3	79.7	232.5	252.2	85	195.4	421.5	396	2912.9
mean	401.6	353	359	225	183	141.5	120.4	132	148.6	221.3	256	378	2903
maximum	959.7	947.1	720.1	528.6	394.7	341.6	278.7	402.6	593.1	579	727.3	932.7	4192.7
minimum	156.2	78.8	84.6	33.9	24.1	26	14.5	7	1.2	47.2	25.4	60.6	1905.8

1.2 Dry Bulb Temperature Readings at Mulinuu from 1941 to 1994

All values are in degrees Centigrade

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual Mea
1941	28.1	28.1	28.7	28.7	28.6	27.6	25.9	26.8	26.8	27.3	28.5	28	27.7
1942	28.2	28.2	27.8	27.7	27.6	27.3	26.2	26.8	27.1	27.3	27.6	27.3	27.4
1943	27.9	27.8	27.5	27.7	27.5	26.7	26.4	27.2	27.7	27.4	28.7	27.8	27.5
1944	27.7	26.8	27.9	27.5	27.4	26.9	26.7	27	27.7	27.2	27	28.6	27.8
1945	27.8	27.7	27.5	27.3	27	26.6	26.8	26.9	27.2	27.7	27.9	28.6	27.8
1946	27.7	27.9	28.8	28.1	27.9	27.6	26.8	27.7	27.6	28.4	28.6	28.7	27.8
1947	28.6	28.2	28.8	28.6	27.8	27.7	27.3	27.1	28	28.6	27.8	28.7	27.9
1948	27.9	27.2	28.2	28	27.7	27.5	26.3	27	27.8	27.8	28.2	27.7	27.6
1949	28.6	28	27.6	28.8	27.6	27.7	26.5	27.8	27.9	27.6	28.7	27.2	27.7
1950	27.9	27.6	26.6	27.8	26.7	26.8	26.6	26.8	27.4	27.9	28.7	26.8	27.2
1951	27.3	28.6	27.9	28.2	27.6	26.9	25.8	27.2	27.3	27.9	28.2	28.5	27.6
1952	28.2	28.1	28.6	27.7	27.8	27.8	27.6	27.6	27.7	27.6	28.7	28.6	27.9
1953	28.7	28.1	28.3	28.9	27.4	27.6	26.9	26.3	27.6	28	27.9	28.6	27.8
1954	28.7	27.6	27.1	28.7	27.8	27.1	27.6	26.8	28.6	27.4	27.4	28	27.6
1955	27.7	27.8	26.7	27.7	27.3	27.9	26.9	26.8	26.9	27.7	27.8	27.7	27.8
1956	26.7	26.7	27.2	27.6	27.7	26.5	26.3	27	27.7	28	28.2	27.4	27.7
1957	28	27.7	27.1	28	27.7	27.6	26.6	27.7	27.9	27.7	28	28.6	27.6
1958	28.6	28	28.2	28.7	28.1	26.9	26.6	26.8	27.9	28.6	28.5	28.8	27.8
1959	28	27.9	28.8	28.7	28.5	27.6	27	27.1	27.6	28	28.3	27.7	27.9
1960	28.1	27.9	27.9	28.7	27.6	27	26.8	27.7	27.8	27.9	28.4	28.6	27.8
1961	28.8	27.3	26.8	28.7	28.7	27.6	27.6	26.9	27.8	27	27.8	28.9	27.6
1962	27.8	27.9	27.6	28.6	27.9	26.8	26.8	26.5	27.5	27.3	28.6	27.6	27.3
1963	28	27.9	27.3	27.7	27.5	26.8	26.8	27	27.6	27.9	28.2	28.6	27.5
1964	28.2	28.6	28.4	28.4	27.3	26.8	26.6	27.6	27	27.9	27.8	28.2	27.6
1965	27.4	27.2	27.7	27.9	27.7	26.7	26.6	26.9	27.6	27.1	28	28.4	27.2
1966	28.7	28.9	28.3	28	28.6	27.1	26.7	26.4	27.4	28.6	28	28.6	27.7
1967	27.9	27	28.6	27.2	27.7	26.3	25.9	26.8	27.4	27.8	27.6	27.9	27.7
1968	28.6	27.4	27.8	26.9	27.7	27.7	26.9	26.8	27.1	27.6	28.3	28.9	27.5
1969	28.2	28.2	28.6	28	27.7	27.6	26.3	26.5	27.7	28.8	28.8	28.9	27.8
1970	28.7	28.6	27.6	28.1	28.5	27.9	27.1	26.9	27	27.8	28.7	26.8	27.7
1971	27.2	27.4	27.6	27.4	27.3	26.7	26.4	26.7	26.7	27.8	28	27.9	27.3
1972	27	27.3	27.6	28.3	27.6	27.5	26.4	27.1	27	27.8	27.8	28.1	27.5
1973	28.2	28.4	27.2	28.5	27.8	27.3	26.6	26.9	27.8	26.6	26.8	27.4	27.1
1974	27.6	27.1	27.1	27.2	27.2	26.7	27.3	27.2	27.6	27.7	27.3	27.8	27.3
1975	27.5	27.4	28	27.5	27.1	26.9	26.7	27	27.3	27.9	27.9	27	27.4
1976	27.4	27.2	27.6	27.5	27.1	26.5	26.4	26.8	27.5	28.6	28.8	28.1	27.1
1977	28.3	28.7	27.4	28.3	27.3	27.2	26.5	26.8	27.5	27.8	28.1	28.7	27.7
1978	27.5	27.9	27.1	27.6	27.5	27.1	26.6	27	27.5	27.6	27.4	28.4	27.4
1979	27.9	27.9	28.2	27.9	27.7	27.7	26.6	27.2	27.7	27.9	28.1	27.8	27.7
1980	28.3	28.2	28.2	28.1	27.3	26.9	26.6	27.1	27.2	27.8	28.5	28.3	27.7
1981	28.3	27.7	27.4				26.8	27.4	27.3	26.7	27	28	27.4
1982	27.9	27.2	28.6	28.9	27.8	26.8	26.8	26.8	27.3	28.3	28.3	28.4	27.6
1983	28.2	29.1	28.2	27.8	28.2	27	26.4	26.7	27.7	28.2	28.6	28	27.8
1984	27.6	28.4	27.4	28.3	28.3	27.7	26.5	26.8	27.4	27.9	28.4	27.4	27.7
1985	27.5	27.3	28.1	27.4	27.6	26.9	26.7	26.9	27.6	28.1	28.2	28.9	27.6
1986	27.9	27.9	28.1	27.7	27.1	27.3	26.4	26.5	27.3	28.2	28.5	28.3	27.6
1987	28.1	28.3	28.6	28.4	27.2	26.4	26.5	26.4	27.2	28	29.1	28.4	27.7
1988	28.4	28.6	28.8	28.1	28.1	27.4	28.1	27.2	27.4	27.5	27.3	27.4	27.9
1989	27.4	26.8	27.4	27.3	27.2	26.8	26.3	26.9	27.7	27.9	27.7	28.2	27.3
1990	27.8	28.2	27.5	27.6	28	27.5	27	27.3	28.1	28.7	28.3	28.2	27.9
1991	28.8	28.2	28.7	28.7	27.8	27.6	27.5	27.4	27.8	27.9	28.4	28.5	28.1
1992	28.3	27.8	28.1	27.9	27.6	27.2	27.2	27.4	27.8	28.4	27.9	28.6	27.8
1993	28.5	27.6	27.7	28.4	28	26.5	26.4	27.3	27.2	27.5	28.4	28.5	27.6
1994	28.5	28.9	29										
mean	28	27.8	27.9	28	27.7	27.1	26.7	27	27.5	27.8	28.1	28.1	27.6
maximum	28.8	29.1	29	28.9	28.7	27.9	28.1	27.8	28.6	28.8	29.1	28.9	28.1
minimum	26.7	26.7	26.6	26.9	26.7	26.3	25.8	26.3	26.7	26.6	26.8	26.8	27.1

1.3 : Rainfall Records for Pago Pago from 1964 to 1994

Values are given in millimetres (mm)

Year	January	Februrary	March	April	May	June	July	August	September	October	November	December	Annual Tot
1964	379	0	279.4	297	266	241	261	195	381	190	424	416	3329
1965	250	232.3	152	0	450	307	53.34	96.5	50.8	500	35.5	330	2458
1966	416	150	274	264	254	233.7	162.56	193	216	472	147	411	3461
1967	177	218	127	622	178	297	228.6	330	109	406	388	416	3578
1968	118	829	297	320	124.5	68.6	91.44	116.8	203	480	109	157	2968
1969	456	297	302	406	124	99	289.56	187	58.4	254	238	424	3137
1970	240	225	548	345	223	309.8	119.38	205.8	196	144.8	203	670	3430
1971	291	363.9	195.6	298	167.6	304.8	81.28	132	66	185	233	170	2443
1972	451	283.7	241	165	167	94	187.96	142	642.6	264	165	515	3330
1973	562	214.3	124	246	200	155	205.74	218	132	411.5	482	378	1978
1974	235	240	246.4	223	205.7	137	17.78	30.5	25.4	60.9	322	233.7	1978
1975	562	251	167.6	579	454.5	132	208.28	76	142.2	53.3	195	361	3182
1976	144	339	101	261.6	482	180	220.98	104	132	88.9	309	543	2908
1977	185	160	294	177.8	513	132	73.66	60.1	78.7	256	375	175	2483
1978	542	241.8	650	233	221	66	88.9	419	119.4	254	652	396	3884
1979	322.6	366.5	228	241	106	200.6	223.52	182	231.1	297	200	213	2814
1980	247	189.7	375	165	495	302	104.14	355	393	546	187.9	340	3702
1981	362	361	644.4	558	236	241	259.08	269	101	416	256	497.8	4203
1982	231	768	195	104	200.1	106.6	177.8	411.8	160	111.7	162	71	2700
1983	240	307	154	279	40.6	68.6	27.94	53.3	198	182.8	335	332.7	2219
1984	246	204	491	170	122	188	48.26	109	132	386.6	205.7	685	2988
1985	424	210	127	475	264	320	96.52	147	243	264	233	160	2965
1986	632	240	174	477.5	312	144.8	223.52	129	450	226	218	574	3801
1987	433	381	256	205.7	139.7	101.6	99.06	160	15.2	99	96.5	416	2403
1988	211.8	236.7	324	269	249	158	238.76	101.6	172	233.7	409	619	3223
1989	466.6	373	208	345	190	137	243.84	7.6	36	248.6	454	358	3069
1990	225.3	572.5	251	330	89	160	121.92	63.5	93.9	246.4	287	236	2676
1991	347	533.6	229	214	287	200.1	233.68	111.7	86.3	243	259	574	3320
1992	391	316	349	721	271.8	51	132.08	160	177.8	167.6	579	226	3542
1993	596	184	438	317	223.5	99	104.14	218.2	236	236	210	320	3183
1994	263.3	172	278	575	481.6	96.5	398.272	300.5	293	438	394	424	4116
Mean	343.4	305.1	281.3	318.8	249.6	172	162	170.5	179.7	269.8	282.7	375.5	3080
Maximum	632	829	650	721	513	320	398.272	419	642.6	546	652	685	4203
Minimum	118	0	101	0	40.6	51	17.78	7.6	15.2	53.3	35.5	71	1978

1.4 : Precipitation at Afiamalu & Moamoa from June 1994 to April 1995

Source : Apia Observatory Office. All values are in millimetres (mm)

Afiamalu Station

Day	June '94	July '94	Aug '94	Sept '94	Oct '94	Nov '94	Dec '94	Jan '95	Feb '95	March '95	April '95
1	4.2	0.3	3.2	0.7	0.2	0	2	32.6	48	0.4	19.5
2	0.5	0	0	2.5	0	4.8	8.9	10.6	10.2	21.8	19.3
3	0	0	0	25.8	15.5	5.3	6.4	4.9	1.4	3	0.1
4	0.3	6.2	0	0.2	14.8	0.6	0	24	23	18.5	0.1
5	0	2.2	2.7	0	50.5	33.5	0.6	8	0	0.2	0
6	13.5	14.4	0	1	32.3	23.3	0.5	4.6	30.2	0	2
7	2	4.2	0	0.5	0.2	3	36.4	10.8	0	81	0
8	2.3	0	15.2	0	12	0.6	1.9	2.2	1.1	60	2.1
9	5	0	0	0	1.3	0	9.2	8.3	4.5	21.2	0.5
10	2.3	4.5	6.5	0	9.4	0.3	3.7	2.3	16	2	29.2
11	0	24	0	0	0	2.4	0.3	16	2.8	0.3	3.5
12	19.4	4	7.9	0	0	5.2	0.4	13.9	32	17.5	5
13	0.1	50	13.6	28.3	0.1	5.6	0.6	0	25.7	0	5.9
14	113.2	36	28.7	17	11.3	5.7	4	0	93	0.2	23.3
15	0	0.9	11.5	1.4	3.1	0.4	18.5	0	58	19	18.3
16	2.7	14	115.2	70.5	0.3	5.4	32.2	0	51.8	0	1.4
17	0	2	0	14.2	33.5	43	1.3	0	0.6	68.4	44.4
18	3.9	0	0.4	5	0	9.6	2.3	27.6	1.7	12.3	36
19	0	3	0	0.8	95.5	13.4	40.5	5.9	12	7.1	100.7
20	0.4	0	65.8	0	0	1.4	0.9	1.5	8.7	14.5	54.7
21	0.4	0	2.4	0	0	5.7	83	17	5	0	64.8
22	13.5	10.2	1.2	22	0.1	0.6	0	56	44.5	5.8	9.7
23	26.3	0.8	0	13.7	33	0	76	33	0.1	53	7.1
24	6.4	0	0	0	0.4	0	8.5	161.2	2.4	28.9	12.9
25	0.1	0	0.5	2.4	0	0	69.8	25	3	94	3.8
26	0.6	0	1.1	1.9	0	38	13	5.4	0	86	13.2
27	14.4	0	3.3	4.7	0	4.5	27	0.5	0.6	22	6.6
28	6	0	1.3	4.7	0	40	0	1.6	40.9	1.8	4.5
29	0	29	0	0	0	34.3	7.3	11.8		0	1
30	1.5	0	0	3.9	0	2	12	2.1		0.1	2.6
31		32.5	2.2		0		4.2	4		52.9	

Moamoa Station

Day	June '94	July '94	Aug '94	Sept '94	Oct '94	Nov '94	Dec '94	Jan '95	Feb '95	March '95	April '95
1	0	0	0	0	0	0	10.5	1.5	45.3	0	0
2	0	0	0	1	0	0	0	28.6	0	19.5	10
3	0	0	0	0	5.3	0	6.3	1.8	37.3	14	0
4	0	4.5	0	0	7.8	0	0	5.3	6	0	0
5	0	4.8	4.8	0	20.5	52.4	0	1.6	0	0	0
6	0	20.9	0	0	15.4	20.6	0	0.2	0	0	0
7	0	0	15.5	0	0	5	7.3	10.1	0	74	0
8	2.8	0	0	0	0	0	0	0	0	53	0
9	0	0	0	0	0	0	20.2	2.6	44.5	25	4
10	0	3	0	0	6	6	3.3	8.8	7.5	0	22
11	0	38.9	0	0	0	9.2	0	25.5	4.6	0	0
12	18.3	0	2.3	0	0	5.9	0	1.8	25.6	14	0
13	0	0	67.5	20.9	0	40	0	0	22	0	0
14	66	78.1	25.9	47.5	2.9	0	55.5	0	80	0	15
15	3	0	23.4	0	0	0	8.8	0	56.8	0	61
16	0	0	198.8	55	0	3.5	16.7	0	43.1	0	0
17	0	0	0	13.8	1.3	49.3	2.2	0	2	13	24
18	0	0	0	0	18.5	34.4	0	0	1.8	0	82
19	0	1	0	0	1.3	0	15.8	0	4.5	0	78
20	0	0	6.8	7.3	0	0	0.8	0	10	0	43
21	0	0	0	0	0	6.8	108.2	19.8	36	0	60
22	16.7	0	0	0	0	0	0.8	22.2	1	0	7
23	11.9	0	0	0	40.6	0	92.4	22	0	17	0
24	5.9	0	0	0	1	0	0.9	164.5	0	53	14
25	0	0	0	0	57.9	0	53.7	24.6	0	89	0
26	0	0	0	5.8	83.9	44.6	15	8.9	0	54	0
27	12.8	0	0	9.9	3	0	13.2	0.2	64	20	4
28	3.9	0	0	17.6	0	103.2	0	2.1	0	6	9
29	0	44.8	0.9	0	22.9	33.2	0	18		0	0
30	1.5	0	0.7	0	1.9	0	0	0		0	0
31		11.7	0		0		51	0		44	

1.5 : Sreamflow Data for Alaoa East

Values are reported in millimetres (mm)

Year	January	Febuary	March	April	May	June	July	August	Septembe	October	Novembe	December
1973	39.5	18.6	6.1	8.6	25.2	6.7	6	3.3	7.1	3.9	5.9	19.1
	22	32.6	10.1	7.1	6.6	6.7	4.4	2.6	4.8	4.1	10	51.7
	17.3	21.1	9.9	8.6	8.3	5.8	3.5	3.1	4.2	5.1	98.7	56.6
	14.2	14.4	9.6	5.3	6.8	5.1	3.5	3.2	3.4	3.3	18.2	66.6
	12.8	13.9	8.7	4.8	6.4	5.1	3.6	8.4	3.5	3.3	15.2	49.1
	10.7	14.6	8.3	13.3	6.4	4.7	3.3	17.3	3.3	3.3	34.8	37.2
	8.5	12.2	8.3	4.8	5.5	4.9	3.3	4.4	3.3	3.1	37.7	31.1
	8.8	14.4	7.6	6.3	5.1	4.6	3.1	7.9	3.9	29.5	33.2	27.7
	8.6	13.3	7.7	3.5	4.9	4.4	3	4.1	3.4	10.4	25.7	21.2
	7.9	11.9	7.7	3.3	5.1	4.3	2.9	3.9	3.1	7.6	50.8	36.2
	7.7	11.2	7.3	3	4.4	3.8	2.4	3.8	2.7	18.6	27	21
	6.8	10.6	6.8	2.9	4.7	3.7	2.9	3.4	3	15.5	19.6	18.4
	6.7	10.6	6.4	2.6	6.2	4.1	3.6	3.3	3.1	13.3	16	20.1
	6.9	9.6	6.4	5.3	4.8	3.7	2.9	3.2	3	9.5	14	16.1
	6.8	13.4	7.3	4.3	14.7	3.7	2.9	3.3	3.6	8.5	13.3	16.3
	8.5	41.3	7.2	12.9	7.5	3.1	2.7	7	3.2	7.6	15.5	15
	8	13.8	6.9	4.4	7.3	2.8	2.8	4.6	3.3	6	10.6	15.7
	6.3	12.7	6.2	3.7	6.8	3.1	2.8	4.3	2.9	8.4	10	15.5
	6.2	11.2	6	3.8	6.3	3.4	2.8	4.1	2.8	7.7	9.2	14
	6.8	11.1	6	5.1	7	3	2.9	3.9	3	12.5	9.6	12.2
	7	13.3	5.9	4	6.3	2.7	2.9	3.9	2.7	8.4	21.9	11.9
	6.9	10.8	5.7	4.1	6.9	2.7	3.2	4.1	3.3	6.6	9.9	11
	6.5	9.5	5.3	3.5	15.2	2.7	3	3.8	2.9	6.2	9	11
	6.4	9.2	5.1	3.4	10.3	5.1	2.9	3.7	2.6	6	8.6	10.6
	5.7	17	4.9	12.9	7.3	3.5	2.7	3.8	2.6	5.5	11.1	10.3
	6.4	23.5	5.1	5.1	7.7	3.2	2.6	7.1	2.8	5.3	7.9	9.4
	10.1	12.9	5.9	23.6	9.8	3	2.5	4.6	2.9	5.7	7.3	9.4
	11.9	11.2	5.5	9.4	10.3	2.8	2.9	3.3	6.2	5	6.7	9.2
	29.6	0	6.6	10	7.3	3.3	2.9	3.2	3.8	5.1	14.4	8
	59.8	0	5.3	8.1	7.1	4.3	2.5	3.3	3	6.4	47.5	10
	28.5	0	10.1	0	6.9	0	2.4	5	0	9.9	0	9.2
1974	4.5	12.8	10.6	10.6	5.1	3.1	6.6	3	1.7	3.4	2.2	9.3
	8.3	12.4	9.4	9.3	5.3	3.2	6.2	3	1.7	1.6	2.1	8.6
	7.5	11.5	9.6	12.1	4.8	2.7	6.3	3	1.7	1.5	2.5	7.1
	7.9	11.3	9.5	9.3	4.6	2.7	5.7	2.9	1.7	17.1	2.1	6.4
	7.4	9.5	8.5	8.4	4.9	3.1	5.7	2.9	1.8	3.9	1.7	5.3
	7.7	8.8	7.9	8.1	5	5.9	5.7	2.8	1.7	2.5	1.5	6.1
	7.3	8.4	7.4	7.6	5.1	9.5	5.9	2.7	1.8	2.1	1.4	9
	7.1	9.2	7.4	6.9	4.8	6.4	5.1	2.7	4	1.9	1.2	7.2
	5.4	9.3	8.8	6.8	4.6	5.1	5.1	2.6	2.3	1.8	1.2	7.1
	8.2	9.3	11	6.7	4.1	4.9	4.4	2.6	2	1.7	2.1	12.4
	7.5	8.1	8.4	6.4	4	4.6	4.1	2.6	1.9	2.7	4.3	14.1
	9.2	13.4	6.7	7	4.3	4.9	3.7	2.6	1.9	2.5	3	17
	15.1	12.9	6.3	6.3	3.9	5.6	4	2.6	1.9	1.7	2.3	16.6
	11.6	23.1	6.7	5.7	4.6	5.3	3.8	2.6	1.8	1.9	1.7	19.8
	10.9	21.9	5.7	5.8	4.6	5.5	3.3	2.6	1.8	1.5	2	15
	12	19.1	5.9	5.3	4.3	5	3.2	2.5	1.7	1.5	36.6	13.3
	10.5	13.5	7.6	5	4.3	5.1	3.1	2.5	1.7	1.5	64.2	15.1
	10.7	11.5	5.9	4.9	4.1	4.9	3.1	2.5	1.6	1.5	172.7	40.6
	9.6	11.3	5.1	8.5	4.7	5.1	3.1	2.4	1.7	1.5	33.3	90.3
	11	16.6	5.6	6	5	5.3	3	2.4	1.6	1.5	22.5	73.1
	9.4	15	11.2	5.7	5.9	4.9	2.8	2.4	1.5	1.5	17.4	42.5
	9.3	15.3	15.7	5.7	5.9	5.6	2.7	2.3	1.5	1.5	14.3	32.3
	15.3	17.5	17.7	5.5	4.7	5.9	2.9	2.3	1.5	1.5	16.5	26.6
	10.6	15	18.4	5.1	5.5	5.5	2.9	2.3	1.5	1.4	9.8	19.8
	9.2	13.5	19.5	8.5	5.1	5.1	3	2.3	1.5	1.4	10.5	11.5
	8.7	11.5	16.8	7.1	4.4	37.3	2.5	3	1.4	1.4	24.4	15.1
	10.9	10.8	21.8	6.4	4.1	10.6	2.8	2.5	1.4	1.4	15.8	15.6
	13.1	10.6	17.5	5.6	4.1	7.5	2.6	2.4	1.6	2.2	13.9	13.2
	9.8	0	14.8	5.5	4.9	7	3.2	2.3	1.5	11.3	11.6	13.1
	11.6	0	13.8	5.5	3.7	8.5	2.7	2.3	1.5	4.3	11.1	11.1
	25.6	0	12.1	0	3.4	0	2.8	2.2	0	2.4	0	10.9
1975	12.2	93.2	8.8	24.5	5.7	6.4	2.7	4.6	2	1.6	2.7	2.1
	11.1	57.3	8.9	29.3	5.1	5.1	2.7	13.4	1.7	1.7	2.3	2.9

1.6 : Streamflow Data for Alaoa West

Values are reported in millimetres (mm)

Year	January	Februray	March	April	May	June	July	August	Septembe	October	Novembe	December
1973	37.4	17.6	10.7	5.7	23.9	6.3	5.7	3.1	6.8	3.7	5.6	18.1
	20.8	30.8	9.5	6.7	6.2	6.3	4.2	2.5	4.6	3.8	9.5	49
	16.3	20	9.3	5.7	7.9	5.5	3.3	3	3.9	4.8	93.6	53.6
	13.5	13.5	9.1	5	6.5	4.9	3.3	3	3.2	3.2	17.3	63.1
	12.1	13.1	8.2	4.6	6.1	4.8	3.5	8	3.3	3.1	14.4	46.6
	10.1	13.8	7.8	12.6	6.1	5	3.1	16.4	3.2	3.2	33.1	35.3
	8	11.5	7.8	4.6	5.2	4.7	3.1	4.1	3.2	3	35.7	29.5
	8.4	13.5	7.2	6	4.8	4.3	3	7.5	3.7	28	31.5	23.3
	8.1	12.6	7.8	3.4	4.6	4.2	2.8	3.9	3.3	9.9	24.4	20.1
	7.4	11.2	7.3	3.1	4.3	4.1	2.8	3.7	3	12.1	48.1	34.3
	7.3	10.6	6.9	2.8	4.2	3.7	2.3	3.6	2.6	17.6	25.6	19.9
	6.4	10	6.4	2.8	4.5	3.5	2.8	3.2	2.8	14.7	18.6	17.5
	6.3	10	6.6	2.5	5.9	3.9	3.5	3.1	3	12.7	15.2	19
	6.5	9.1	6.1	5	4.6	3.5	2.8	3	2.8	9	13.2	15.2
	6.4	12.4	7	4.1	15.9	3.5	2.8	3.1	3.5	8.1	12.6	15.5
	6.7	36.7	6.8	12.3	7.1	3	2.6	6.6	3.1	7.2	11.3	14.3
	7.6	13.1	6.6	4.1	7	2.7	2.7	4.3	3.2	5.7	10	14.9
	5.8	12	5.9	3.5	6.4	3	2.6	4.1	2.8	8.5	9.5	14.8
	6.9	10.6	5.7	3.6	6	3.2	2.6	3.9	2.6	7.4	8.7	13.2
	6.6	10.4	5.7	4.8	6.6	2.8	2.7	3.7	2.8	11.9	9.1	11.6
	6.5	12.5	5.7	3.8	6	2.6	2.7	3.7	2.6	7.9	20.8	11.2
	6.1	10.2	5.5	3.9	6.6	2.6	3	3.9	3.2	6.7	9.4	10.4
	6.1	8.9	5	3.3	14.4	2.6	2.8	3.7	2.8	5.9	8.6	10.4
	5.4	8.6	4.8	3.2	8.8	4.8	2.8	3.5	2.5	5.7	8.2	10
	6.1	16	4.7	12.3	7	3.4	2.6	3.7	2.5	5.2	10.6	9.8
	9.6	22.2	4.9	4.9	7.3	3	2.5	6.7	2.6	5	7.9	8.9
	9.6	12.3	5.6	22.4	8.3	2.8	2.4	4.3	2.8	5.4	6.9	8.9
	28	10.6	5.2	8.9	8.8	2.7	2.8	3.1	5.9	4.8	6.3	8.7
	56	0	6.2	9.5	6.9	3.2	2.8	3	3.6	4.4	13.6	8.6
	27	0	5	7.7	6.8	4.1	2.4	3.1	2.8	6.1	45	9.5
	0	0	4.8	0	6.6	0	2.3	4.8	0	9.4	0	8.7
1974	9.2	12.1	10	10.1	4.9	3	6.3	2.8	1.7	3.2	2.1	8.8
	7.8	11.8	8.9	8.8	5	3	5.9	2.8	1.7	1.5	2	8.1
	7.1	10.9	9.1	11.5	4.6	2.6	6	2.8	1.6	1.4	2.4	6.8
	7.4	10.6	9	8.8	4.3	2.6	5.5	2.8	1.6	16.8	2	6.1
	7.1	8.9	8.1	7.9	4.7	2.9	5.5	2.8	1.7	3.7	1.6	5
	7.3	8.3	7.5	7.7	4.8	5.6	5.4	2.7	1.7	2.4	1.4	5.8
	6.9	8	7	7.2	4.9	9	5.6	2.6	1.7	2	1.3	8.6
	6.7	8.6	7	6.6	4.6	6.1	4.8	2.6	3.8	1.8	1.2	6.9
	10	8.5	8.3	6.5	4.3	4.9	4.4	2.5	2.2	1.7	1.2	6.7
	7.8	8.5	10.4	6.3	3.9	4.7	4.1	2.5	1.9	1.6	2	11.7
	7.1	7.6	7.9	6.1	3.8	4.4	3.9	2.5	1.8	2.6	4.1	13.4
	8.3	12.6	6.3	6.6	4.1	4.7	3.5	2.5	1.8	2.4	2.9	16.1
	14.3	12.2	6	6	3.7	5.3	3.8	2.5	1.8	1.7	2.1	15.7
	11	21.9	6.3	5.5	3.9	5	3.7	2.5	1.7	1.5	1.7	18.7
	10.3	20.7	5.4	5.5	4.3	5.2	3.1	2.5	1.7	1.4	1.9	14.2
	11.4	18.1	5.6	5	4.1	4.8	3	2.4	1.7	1.4	7.1	12.6
	9.9	12.8	7.2	4.8	4.1	5	3	2.4	1.6	1.4	60.8	14.4
	10.1	12.8	5.6	4.6	3.9	4.7	3	2.4	1.5	1.4	163.7	38.5
	9.1	10.7	4.9	8.1	4.5	4.4	2.9	2.3	1.6	1.4	31.6	85.6
	10.4	15.7	5.3	5.7	4.8	5	2.8	2.3	1.5	1.4	21.3	69.3
	8.9	14.2	10.6	5.5	5.7	4.7	2.7	2.3	1.4	1.4	16.5	40.8
	8.8	14.5	14.8	5.5	5.6	6.2	2.6	2.2	1.4	1.4	13.5	30.7
	14.5	16.6	16.8	5.2	4.5	5.6	2.8	2.2	1.4	1.4	15.7	24.7
	10	14.2	17.5	4.8	5.2	5.2	2.8	2.2	1.4	1.3	11.2	18.8
	8.7	12.8	18.5	8.1	4.9	4.4	2.8	2.2	1.4	1.3	9.9	15.9
	8.3	10.9	15.9	6.8	4.1	35.3	2.4	2.9	1.3	1.3	23.1	14.4
	10.3	10.2	20.7	6.1	3.9	10.1	2.6	2.5	1.3	1.3	14.9	14.8
	12.4	10	16.6	5.3	3.9	7.2	2.5	2.3	1.5	2.1	13.2	12.5
	9.3	0	14.1	5.2	4.6	6.7	3	2.2	1.4	10.8	11	12.4
	11.5	0	13.1	5.2	3.5	8.1	2.6	2.1	1.4	4.1	10.5	10.6
	24.3	0	11.8	0	3.2	0	2.6	2.1	0	2.3	0	10.4
1975	11.5	88	8.3	23.3	5.4	6.4	3	4.3	2.4	2	3.7	2.7
	15.3	54.3	8.5	27.8	4.9	5.9	3.1	9.5	2.4	1.9	2.9	3.5

	10.9	30.3	9.4	19.5	8.3	5.3	3	5	2.4	1.9	2.2	4.3
	11.4	26.4	8.1	15	6.1	5.1	3.8	4	2.3	1.9	2.1	3.5
	10.3	23.6	7.7	12.8	6.2	5.2	3.1	3.9	2.4	2.1	2.1	3
	9	21.4	7.2	12.5	9.1	5	3	3.8	2.2	1.9	2.3	4.9
	10.7	19.2	7.7	10.8	6.7	5	2.9	3.5	2.3	1.9	2.9	3.8
	8.9	17.6	7.9	10.8	6.1	5.6	2.8	3.2	2.3	1.9	2.6	3.5
	10.5	15.2	7.1	9.2	13.9	4.4	2.8	3.2	2.6	1.9	2	12.1
	10	13.5	7	9.1	7.5	4.2	2.8	3.2	2.3	1.8	1.8	10.1
	10	13.4	6.5	8.1	6.8	4.1	3.5	3	2.3	1.8	1.7	7.2
	10	11.9	6.2	7.8	6.6	4.3	2.9	3	2.4	1.9	1.7	5.9
	10.6	12.3	6.1	7.6	6.8	4.1	2.8	3	2.7	1.8	3.2	5.4
	10.3	13.8	5.9	7.2	6.1	4	2.7	2.9	2.3	1.9	6.9	5.6
	8.7	11.5	5.5	7.1	5.8	3.9	2.9	2.8	4.5	1.9	3.1	5.8
	9	9.7	5.4	6.8	8.1	4	2.7	2.8	2.7	1.8	2.8	5
	9.1	9.1	5.1	7	10.1	3.9	2.8	2.7	2.3	1.8	2.6	5.6
	12.8	10.9	5.9	6.8	9	3.7	2.7	2.8	2.5	1.8	2.6	4.8
	10.7	9.4	6.6	8.6	7.4	4.6	2.6	2.8	2.1	1.8	2.4	10.5
	19.8	8.5	5.4	8.8	7	3.8	2.6	2.7	2.2	1.8	3	6.6
	11.3	8.9	5	6.7	6.6	3.8	2.6	2.6	2.1	1.8	2.8	5.6
	9.5	9.8	4.8	6.1	6.6	3.7	2.6	2.6	2.1	1.8	2.3	5.2
	9.4	10.8	4.6	5.9	6.8	3.5	2.6	2.6	2.1	2.3	2.3	4.6
	11.3	8.4	4.4	5.7	5.9	3.4	3.7	2.6	2.1	3.2	5.5	4.9
	27.3	8.5	4.2	6.6	6.7	3.3	3.2	2.7	2.1	2.3	4.6	4.4
	94.8	8	4.1	6.1	5.9	3.3	3.6	2.7	2	4.1	4	4.5
	86.7	7.7	4.1	5.5	5.9	3.5	8	2.5	1.9	2.4	3.4	5.3
	50.6	0	4.1	5.3	5.7	3.3	4	2.5	2	2.6	2.8	4.7
	158.7	0	4.9	5.5	7.5	3.3	3.2	2.6	2	3.2	2.9	4.3
	74	0	8.9	0	6.6	0	8.8	2.6	0	2.5	0	11.5
1976	8.7	6.3	7.5	6.1	7.7	4.3	3.3	3.9	2.6	1.9	1.8	2.3
	5.4	6.6	7.5	6.1	5.9	4.3	3.2	3.7	2.5	2	1.7	2.3
	4.9	9.1	7.4	5.9	5.9	4.1	3.6	3.6	2.5	1.9	3.9	2.4
	4.6	6.5	7.9	6.1	5.3	4.2	3.5	3.7	2.5	2.1	3	4.3
	4.3	11	7.6	5.7	5.2	4.3	3.3	4.7	2.4	1.9	2.3	3.5
	4.6	8.8	6.5	5.6	4.8	4.1	3.3	3.9	2.3	2.5	2.1	4.5
	4.7	7.4	6.1	5.2	5	3.9	3.3	3.9	2.5	2.3	2.3	4.1
	8.4	6.7	6.1	5.3	4.7	4	3.6	4	2.5	1.9	2.5	5.4
	8.1	6.4	6.7	5	4.6	3.8	3.3	3.9	2.3	1.8	3	21.2
	8.7	6.4	6.6	4.8	4.4	3.7	3.2	3.7	2.8	1.8	2.6	13.7
	7	7.5	8	4.4	12.1	3.7	3.2	3.2	2.3	1.7	2.3	65.5
	7.1	8.2	8.2	4.3	6.1	3.7	3.7	3.2	2.4	2.3	1.9	12.6
	6	7.7	6.3	4.2	5.2	3.6	5.2	3	2.3	2.3	1.7	10.1
	6.5	40.5	5.9	4.1	5	4.2	6.1	3	2.3	1.7	1.8	8.1
	9.4	74.8	6.1	4.3	11.9	4.7	5.4	3	2.3	1.9	1.8	7.3
	32.8	29.4	6	4	14.2	3.8	4.2	3	2.3	2.1	1.7	8.6
	15.5	19.9	5.8	3.9	8.1	3.9	4	3	2.2	2.2	1.7	6.2
	14.9	26.8	5.5	3.9	6.8	6.4	5.2	2.9	2.3	2	1.7	5.7
	14.4	16.4	5.3	3.8	6.6	4.3	4	2.9	2.3	2.3	1.7	5.2
	22	15	6.1	4.3	6.3	3.8	3.9	2.9	2.3	2.3	9.3	4.8
	19.2	15.6	5.2	3.9	6.3	3.7	4.2	2.8	2.1	2.1	3	4.5
	14	13	12.1	3.8	5.8	3.6	3.9	2.8	2.2	1.8	2.7	4.5
	11.8	11.8	7.9	3.9	5.5	3.5	3.6	2.9	2.3	1.8	2.4	6.6
	11.7	10.6	5.9	3.8	5.3	3.5	3.5	2.8	2.2	1.7	2.3	4.2
	10.9	9.9	5.7	5	5.2	3.5	3.5	2.7	2.1	1.6	2.3	4.5
	9.8	9.5	6.9	5	5.2	3.4	4.1	2.6	2.1	1.6	2.2	4
	8.5	8.9	11	9.5	5.1	3.3	8.3	2.7	1.9	1.6	2.9	5
	8.2	8.5	9.7	6.7	5.5	4.2	5.6	2.6	1.9	1.5	3.7	5.3
	7.1	8	7.3	9.7	5.1	6.3	4.6	2.8	2.2	1.6	2.4	5.5
	6.6	0	6.7	7.2	4.9	3.5	4.2	2.8	1.9	1.6	2.3	5.7
	6.5	0	6.3	0	4.7	0	4.1	2.8	0	2.1	0	7.5
	24.2	0	11.8	0	3.2	0	2.6	2.1	0	2.3	0	10.4
1977	5.4	8.7	9.5	12.4	4.6	3.9	2.8	2.3	1.9	1.9	2.9	3.5
	7.1	8.8	18.5	8.9	4.6	3.9	2.8	2.4	1.9	1.7	2.6	3.3
	6	7.1	12.6	8.3	5.2	3.7	2.8	2.3	1.9	1.7	2.3	3.1
	5.1	7.4	12	7.8	8.1	3.9	2.8	2.3	1.9	2.7	2.3	3
	5	6.6	9.3	7.7	5.2	3.6	2.8	2.3	1.9	1.9	2.1	2.8
	4.6	5.7	12.1	9.8	5.1	4.6	2.8	2.3	1.9	1.7	20.8	2.6
	4.4	5.8	9.3	8.3	4.6	4.1	2.8	2.3	1.9	1.7	5.8	2.6
	4.6	7.6	8.9	7.3	4.3	3.5	2.8	2.3	1.9	1.7	4.6	2.6
	4	6	8.9	9.5	4.7	3.3	2.7	2.2	1.9	1.7	3.9	2.6

APPENDIX 2: HISTORY TIME LINE FOR SAMOA.

Adapted from McKay (1937), GWS (1966), Meleisea (1987) and McGovern (1988)

B.C. 1000	Approximate date for earliest settlement in Samoa
600 - 1250	Tongan occupation of Samoa. Origin of the *Malietoa* title first held by Malietoa Savea
1420	Nafanua's war at Falealupo. A government was established at Fil*i* ma Puletu that became her headquarters, where parties from all over Samoa came to ask for their share of authority. When Malietoa Fitisemanu asked or his share of the government, Nafanua told Malietoa Fitisemanu his government will come from the heavens. To the Samoans, this prophesy was fulfilled when the white man(missionaries) came.
1722	Roggewein (Dutch) sighted the islands and calls them the Navigator Islands. The islands were known as this until 1875
1760	Eruption in Savaii of Mauga Mu inland of Aopo and overwhelmed the whole coast from Sasina to Asau
1800	European beachcombers began settling in Samoa
1830	John Williams of the London Missionary Society (LMS) arrived at Sapapalii The Samoan leaders believed this as the fulfilment of Nafanua's prophesy and the church was accepted willingly by *Malietoa Vainuupo* (Tavita)
1835	Samoan and prepared a Samoan dictionary and grammar. The work was done jointly by Mala'itai Leuatea Talavou, Leota Penitala and Vaaelua Petaia
1844	Malua Theological College was established
1845	The Roman Catholic Mission commenced at Lealatele, Savaii.
1854	A great storm caused famine amongst the Samoans
1857	The German firm Godeffroy and Sons established headquarters in Apia. This was the predecessors of the Hamburg firm generally known as DH and PG
1861	Excessive land purchases by the DH and PG firm under the direction of Weber started and continued for the next three years. 75,000 acres were acquired and turned into coconut plantations.
1867	Importation of Melanesian labourers to work the plantation was at its peak. War between districts were common which went on for the next fifteen years
1887	Brandeis, an artillery officer who arrived in the previous year to work for DH and PG introduced the cultivation of cocoa
1889	Samoa was on the brink of war when the hurricane on March 16 wrecked 3 German ships, 3 American ships and the British "Callipoe" escaped. The Treaty of Berlin was established where: Malietoa Laupepa is King; Lands Commission set up and further land alienations prohibited; Municipal Council to govern Apia
1890	Robert Louis Stevenson (the sickly Scottish author of "Kidnapped") settled in Samoa at Vailima. He died in 1894 and is buried on top of Mount Vaea
1899	Treaty of Berlin annulled; Britain renounced all claims on Samoa; Germany takes over Upolu and Savaii (Samoa) and; United States took over Tutuila and Manua (American Samoa)
1902	Kramer wrote his authoritative work on Samoa and its people
1905	Matavanu volcano erupted in Savaii. Lava flowed to the sea and destroyed land and villages near Saleaula and Lealatele. Further eruptions continued till 1911
1914	Great Britain and her allies declared war on Germany. New Zealand troops landed at Matautu on August 29, peacefully assuming the control of Samoa. The New Zealand Reparation Estates took over all German plantations
1918	The world-wide infleunza epidemic reached Samoa causing 7000 to 8000 deaths after New Zealand authorities failed to quarantine the "Talune"

1926	The start of the Mau movement which extended for ten years.
1942	About 12000 United States Marines came to Samoa. Faleolo Airport and Leulumoega to Lefaga cross-island road constructed by the Americans
1947	United Nations Organisation investigated Samoas claims for self-government. Samoa Amendment Act was passed whereby the Legislative Assembly is elected by matais only; three member Council of State established and Prime Minister and Cabinet (chosen by the assembly) runs the government
1953	Samoa College opened with 227 pupils. The Vaisigano bridge was opened. Reef blasting for reclamation of banana wharf site killed one person
1957	New Zealand reparation Estates handed over to Samoa and called the Samoa Trust Estates Corporation (WSTEC). Alaoa Hydro Electric Scheme opened
1959	Steps towards self government finalised. Samoa Ammendment Act passed by the New Zealand Parliament where legal authority for Cabinet Government given by Council of State. Fiame Mataafa Faumuina elected as Prime Minister. Water Ordinance Bill introduced
1962	Independent State of Samoa came into being. Treaty of Friendship with New Zealand signed
1965	Protest march over cost of living and unemployment. Land bill barring untitled men from leasing land debated
1966	Hurricane devastates the economy and kills ten people. Alafua Agricultural College opened. The first Five Year Development Plan for Samoa
1967	Second General elections and Mataafa re-elected unopposed
1968	University of the South Pacific (USP) opened in Fiji with 68 students. New Samoa Industry Ltd started lumber production near Apia
1970	Developments intended to improve tourism were undertaken; Apia to Faleolo road sealed; airport and facilities upgraded. Potlatch Samoa Ltd logging firm from America started operations at Asau, Savaii
1972	Fish Dynamiting Act established the prohibition of using dynamites to catch fish. Plans for luxury resort at Taumeasina (Moataa) with initial land development. The new Parliament House was completed. The pollution of lagoons and destruction of mangroves was noted by the World Health Organisation (WHO) leading to decreased in fish supplies and food resources of the coastal villages
1974	Reclamation of Moataa mangroves to build a hotel almost complete. No hotel was built up to this day. Tusitala Hotel opened at Sogi
1975	Fiame Mataafa died and Tupua Tamasese Lealofi IV took over.
1976	Tupuola Efi becomes Prime Minister and his government proposed ambitious rural development programmes: rural access roads; improved wharf and airport facilities; improved telecommunications. Establishment of a beer factory, a cigarette factory, a feed mill and coconut processing plant were on the pipeline. During this three years of Parliament, the idea of political parties was introduced. The first was the Human Rights Protection Party (HRPP)
1981	Public Service Association (PSA) strike on low wages, poor working conditions and the high cost of living brought government to a standstill for three months
1982	Three changes of government was observed. Vaai Kolone was elected as Prime Minister but lost his seat on an election petition. Tupuola Efi was chosen by the Head of State to take over. The balance of power shifted and Tofilau Eti became PM
1985	Two parties contested the general election (HRPP and the newly formed Christian Democratic Party - CDP). HRPP split into two factions and the one under Vaai Kolone formed a coalition with the CDP.
1989	The Land and Environment Act established.
1990	Cyclone Ofa strikes. Village Fono Act established
1991	Cyclone Val devastated the country. Universal suffrage was introduced to the general elections. HRPP still maintained as government. Yasaki Samoa Ltd established at Vaitele
1993	Taro Leaf blight disease annihilated the taro plantations of the country. The giant African snail was introduced and has since not exterminated

APPENDIX 3 : Instruments Used & Procedures Followed in the Chemical Analyses

Source: _HACH Chemical Company WATER ANALYSIS Handbook, Third Edition.

Temperature:
A typical laboratory mercury thermometer (0-110°C) measured the temperature.

pH:
The pH was measured by the use of a portable HANNA-made (Singapore) meter, powered by 4x1.4V duracell batteries. As a check, pH was measured at the University of the South Pacific's Alafua laboratory, with a power operated ORION research (model 301) analog pH meter, after calibration with standard buffer solutions of pH4 and pH7.

TDS:
A HANNA-made portable tester (model DIST1) powered with 4x1.4 duracell batteries measured the total dissolved solids (TDS) parameter. The instrument has a range of 1-1990ppm, a resolution of 10ppm and an accuracy of +/-2%. The display reading is multiplied by 10 to give the actual value in ppm.

Conductivity:
The conductivity values were obtained from another battery operated HANNA-made instrument. The conductivity meter (model HI 8033) with three measurement scales for conductivity measurement (0/199.9 uS/cm; 0/1999 uS/cm; 0/19.99 mS/cm) and one for measuring the water hardness index (0/19.99 ppm $CaCO_3$). The hardness index was taken as a measure of water salinity. A probe (equipped with stainless steel electrodes protected by a PVC sleeve) is immersed in the water, and the registered value is displayed on the LCD display. The instrument is powered by a 9V battery and has an operating temperature of 0-50°C.

Discharge:
The water discharge values were obtained by using the "float measurement" method outlined by Smith and Stoop (1978:9). A straight reach of the stream ten metres long was measured out. A weighted phial (film pastic container filled with pebbles) was dropped into this selected portion of the stream and timed over the measured length of the stream. Three runs were conducted for each stream reach and a mean surface velocity is obtained for each vertical profile. Because the surface velocity in any given vertical profile is greater than the average velocity, the accepted conversion factor of 0.85 was used. The procedure was repeated every one metre interval across the stream channel, measuring the water depths each time. The discharge (in m^3/s) is the product of the average velocity and the depth.

Chemical analyses for the nutrients phosphate, sulphate, nitrate, ferrous and zinc ions in the water as well as suspended solids and turbidity values were carried out using a portable HACH dr-el/2 spectrophotometer from the Geography Department, University of Adelaide. Sealed HACH chemical powder pillows for these analyses were bought from SELBYS Scientific Ltd (Melbourne), Australia. The pillows were opened only at the time of use, eliminating the suspicion of contamination.

Iron:
Iron as ferrous ion (Fe2+) in the water was measured using the 1,10-Phenanthroline method. The FerroVerIron powder pillow reagent converts all the iron in the water to the ferrous state and reacts with the 1,10-Phenanthroline to give the orange colouration seen if a positive reaction occurs. The colourimetric measurements of the absorbances were done at 510nm, and the results reported in mg/l of ferrous ion.

Total nitrogen:
Total nitrogen measurements used a modification of the cadmium reduction method which used a very sensitive chromotropic acid indicator. The method registers both nitrate and nitrite nitrogen. All the necessary reagents have been combined into two powder pillows NitraVerVI and NitraVerIII. A pink colour (measured at 500nm) develops if nitrate is present in the water. The results are recorded as mg/l of nitrate nitrogen (N).

Total phosphorus:

Total (organic and inorganic) phosphorus concentrations were obtained from the PhosVerIII Reagent Method. This is a modification of the molybdenum blue procedure, with all the reagents combined into one powder pillow. The oxidation to orthophosphate was initially done by treating the water sample with Potassium persulphate and sulphuric acid. The mixture was boiled gently for half an hour, cooled and then neutralised with sodium hydroxide. The orthophosphate then reacts with the contents of the powder pillow (acidic ammonium molybdate and ascorbic acid) to produce the intense molybdenum blue colour which was readily observed. The absorbances at 700nm were directly proportional to the intensity of the blue colour. The results are given in mg/l phosphate.

Sulphate:

The procedure for determining Sulphate ions is a modification of the Barium Sulphate Turbidimetric Method. A single dry powder reagent SulfaVerIV Sulphate causes a milky precipitate if sulphate is present in the water. The powder pillow also has a stabilising reagent to hold the precipitate in suspension for the analysis at 450nm. Like the phosphorus test, the amount of turbidity was proportional to the amount of sulphate present. The results are given as mg/l.

Zinc:

The Zincon Method was used to obtain zinc concentration values of the samples. The zinc in the water was firstly complexed with cyanide by adding the ZincoVerV reagent, then freed to be complexed further with the Zincon indicator by addition of the cyclohexanone. The test was done at wavelength 620nm and results expressed as mg/l Zn.

Suspended solids:

Suspended solids in the water were measured by the Photometric Method, where a pre calibrated Meter Scale was used, and working at the IR wavelength end of the instrument. The sample values in mg/l were read directly from the HACH instrument.

Turbidity:

The Absorptometric Method was used to obtain Turbidity values. The test measures an optical property of the water sample from the scattering and absorption of light by the particulate matter present in the water. Set at 450nm, the Turbidity Meter Scale reads off values in Formazin Turbidity Units (FTU).

APPENDIX 4 : Raw Data for Savaii & Upolu Sampling Regime

4.1 : Raw Data for the Savaii Sampling Exercise

SAVAII PERENNIAL STREAMS (Dry Season)

Name	Time	Discharge	Temp	pH	Salinity	Cond	TDS	Fe++	SO4--	S.solids	Turbidity	TN	TP	Zn2+
		(m3/s)	(oC)		(mg/l)	(uS/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)
Mulivaitala	10.20am	0.33	25	6.7	0.05	110	50	0.03	7	18	5	0.3	0.03	0.07
Afuaau	10.45am	2.08	25	6.8	0.04	102	50	0.04	7	10	6	0.2	0.03	0.08
Tiaseu	11.10am	1.97	25	6.8	0.03	110	50	0.04	7	10	8	0.4	0.04	0.09
Vaitu	11.51am	1.35	25	6.7	0.04	102	50	0.04	8	15	10	0.3	0.06	0.16
Mupagoa	12.23pm	7.08	24	6.6	0.02	56	20	0.02	7	4	10	0.2	0.06	0.18
Sinaloa	1.05pm	4.64	24	6.9	0.02	59	20	0.03	8	6	8	0.4	0.5	0.2
Avao	6.39am	0.22	24	6.7	0.04	91	50	0.04	11	5	10	0.3	0.03	0.14
	mean	2.5	24.6	6.7	0.03	90	41	0.03	7.8	9.7	8.1	0.3	0.1	0.13
	max val	7.08	25	6.9	0.05	110	50	0.04	11	18	10	0.4	0.5	0.2
	min val	0.22	24	6.6	0.02	56	20	0.02	7	4	5	0.2	0.03	0.07

SAVAII EPHEMERAL Streams (Dry Season)

Name	Time	Temp	pH	Salinity	Cond	TDS		Fe2+	SO42-	S.solids	Turbidity	TN	TP	Zn2+
		(oC)		(mg/l)	(uS/cm)	(mg/l)		(mg/l)	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)
Aopo	3.58pm	34	6.4	0.06	134	60		0.09	13	8	22	0.8	0.17	0.08
Letui	4.23pm	28	6.4	0.23	467	230		0.28	23	12	82	0.4	0.29	0.08
Lano	10.02am	28	6.4	0.15	191	90		0.07	11	3	18	0.6	0.06	0.08
Aliape	10.35am	29	6.6	0.04	185	40		0.07	7	5	14	0.2	0.09	0.15
Nofoa	1.25pm	32	6.9	0.03	76	40		0.06	9	10	12	0.4	0.07	0.22
Samalaulu	9.12am	26	5.8	0.08	177	40		0.06	8	10	16	0.2	0.04	0.18
	mean	29.5	6.4	0.09	205	83		0.1	12	8	27	0.4	0.12	0.13
	max val	34	6.9	0.23	467	230		0.28	23	12	82	0.8	0.29	0.22
	min val	26	5.8	0.03	76	40		0.06	7	3	12	0.2	0.04	0.08
Fa'ani not flowing today														

SAVAII FRESHWATER SPRINGS (Dry Season)

Name	Time	Temp	pH	Salinity	Cond	TDS		Fe++	SO42-	S.solids	Turbidity	TN	TP	Zn2+
		(oC)		(mg/l)	(uS/cm)	(mg/l)		(mg/l)	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)
Asau	3.25pm	25	6.6	1.11	2090	980		0.03	68	6	4	4	0.15	0.12
Sasina	4.39pm	24	6.8	0.45	914	440		0.03	32	2	0	0.4	0.13	0.14
Mataoleale	4.56pm	22	6.8	0.64	1477	720		0.02	52	2	0	2.4	0.19	0.12
Puapua	9.36am	25	6.8	0.4	828	430		0.05	32	8	2	0.3	0.32	0.16
Feagaimale	10.22am	25	6.5	2.74	5600	2000		0.03	160	12	6	0.3	0.08	0.14
Vaipotpoto	10.30am	25	6.8	0.42	805	340		0.04	23	14	7	0.3	0.05	0.17
Vailupe	10.07am	25	6.6	0.25	515	260		0.04	18	2	0	0.4	0.06	0.18
Petesa	10.33am	25	7	0.05	125	60		0.03	8	0	0	0.2	0.28	0.15
	mean	24.5	6.7	0.76	1544	653		0.03	49	5.7	2.4	1	0.15	0.14
	max val	25	7	2.74	5600	2000		0.05	160	14	7	4	0.32	0.18
	min val	22	6.5	0.05	125	60		0.02	8	0	0	0.2	0.05	0.12

SAVAII PERENNIAL STREAMS (Wet Season)

Name	Discharge	Time	Temp	pH	Salinity	Cond	TDS	Fe++	SO4--	S.solids	Turbidity	TN	TP	Zn2+
	(m3/s)		(oC)		(mg/l)	(uS/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)
Afuaau	0.57	2.51pm	25	6.8	0.05	112	30	0	0	2	1	0	0.03	0.01
Tiaseu	0.44	3.00pm	25	6.7	0.04	104	30	0	0	1	1	0	0.04	0.03
Vaitu	0.2	3.22pm	25	7.1	0.04	95	30	0	0	0	0	0	0.08	0.05
Mupagoa	1.2	3.40pm	25	7.1	0.02	56	20	0	2	8	4	0	0.05	0.01
Avao	0.76	4.42pm	27	6.8	0.03	69	20	0	0	4	4	0.2	0.04	0.05
	0.6	mean val	25.4	6.9	0.04	87.2	26	0	0.4	3	2	0.04	0.048	0.03
	1.2	max val	27	7.1	0.05	112	30	0	2	8	4	0.2	0.08	0.05
	0.2	min val	25	6.7	0.02	56	20	0	0	0	0	0	0.03	0.01

4.2 : Raw Data for Upolu Sampling Exercise

UPOLU PERENNIAL STREAMS - DRY SEASON

Name	Time	Discharge	Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
NORTH EAST UPOLU														
		(m3/s)	(oC)		(mg/l)	(uS/cm)	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
fuluasou	4.24pm	3.39	26	6.8	0.03	78	30	15	58	0.23	18	7.5	0.14	0.05
gasegase	5.56pm	3.31	24	6.8	0.04	105	50	510	520	2.4	12	32	0.34	0.03
mulivai	4.42pm	0.26	27	6.8	0.11	240	120	3	3	0.02	5	23	0.06	0.04
vaisigano	6.37pm	2.61	24	6.9	0.04	110	60	10	46	0.11	8	11	0.25	0.03
fagalii	5.14pm	0.34	27	6.9	0.06	138	70	1	1	0.01	2	3	0.14	0.06
laulii	6.42am	0.3	25	6.6	0.06	139	70	3	12	0	3	12	0.3	0.11
laulii2	7.00am	0.32	23	6.9	0.04	99	50	0	1	0	0	2.8	0.12	0.12
leusoalii	7.45am	0.25	24	6.7	0.04	98	50	0	0	0	0	0.7	0.04	0.02
luatuanu	8.05am	0.23	25	6.7	0.04	88	40	5	10	0.02	3	0.9	0.15	0.12
namo	8.36am	5	24	6.9	0.04	81	40	15	42	0	12	0.35	0.08	0.01
watl/eva	9.09am	0	26	6.9	0.06	136	60	0	0	0	1.5	0.5	0.04	0.08
eva	9.20am	0.48	25	6.6	0.04	94	40	0	0	0.01	3.5	7.8	0.06	0.12
fusi1	9.53am	0.02	26	6.5	0.04	94	40	1	2	0.02	7.5	5.4	0.13	0.06
fusi2	9.58am	0.03	26	6.4	0.05	113	60	5	2	0.03	6	11	0.05	0.03
falefa/trb	11.14am	0.7	27	6.7	0.06	140	60	1	2	0	7.5	0.7	0.04	0.03
fal4/main	11.23am	11.8	26	6.7	0.14	292	140	5	20	0	8	2	0.06	0.02
	mean	1.8	25.3	6.7	0.05	127	61	36	45	0.17	6	7.5	0.12	0.06
ALEIPATA														
vaipu	11.58am	2.27	25	6.4	0.04	93	40	2	1	0	2	0.6	0.06	0.02
siupapa	2.17pm	0.22	27	6.3	0.02	64	30	8	4	0.02	5	1	0.23	0.04
siupapa2	2.27pm	0.03	26	6.6	0.02	57	20	0	1	0.02	5	5.3	0.03	0.02
lepa	2.40pm	1.55	25	6.4	0.01	39	20	28	24	0.06	6	0.4	0.06	0.03
lepa2	2.50pm	0.42	27	6.2	0.03	82	40	1	0	0	1	0.5	0.05	0.03
fall/subs	2.55pm	0.13	27	6.7	0.05	107	50	0	0	0	0	0.6	0.04	0.01
aufaga	3.15pm	0.49	25	6.8	0.02	59	30	5	0	0.01	17	1.9	0.04	0.03
sinalele1	3.29pm	0.06	27	6.4	0.02	62	20	8	4	0	1.5	2	0.04	0.04
sinalele2	3.35pm	0.54	26	6.2	0.03	69	30	1	3	0	1	0.8	0.09	0.04
vavau3	3.57pm	0.08	26	6.8	0.02	49	20	0	0	0	0	1	0.04	0.07
sopoaga	4.20pm	0.64	26	6.7	0.01	46	20	1	1	0	1	8.6	0.04	0.04
	mean	0.58	26	6.5	0.02	66	29	4.9	3.4	0.01	3.6	2.1	0.06	0.03
NORTH WEST UPOLU														
falevai	10.36am	0.12	26	6.8	0.07	86	60	1	1	0.01	0	1.2	0.14	0.04
LEFAGA														
matafaa1	12.24pm	0.22	26	6.9	0.05	101	60	0	1	0	0	3.2	0.05	0.02
matafaa2	12.51pm	0.072	27	7.1	0.05	112	50	0	1	0.02	7	0.4	0.08	0.15
matafaa3	1.04pm	0.12	26	6.9	0.04	106	50	0	1	0	0	0.6	0.03	0.04
	mean	0.13	26	6.9	0.05	106	53	0	1	0.006	2.3	1.4	0.05	0.07
SOUTH UPOLU														
sataoa1	2.01pm	0.11	26	6.9	0.04	108	50	0	0	0	0	0.25	0.24	0.06
sataoa2	2.10pm	0.87	25	6.8	0.04	97	50	0	1	0.01	0	0.6	0.03	0.05
nuusuatia	2.26pm	0.46	26	6.9	0.04	108	50	0	0	0.01	2	1	0.23	0.06
tafitoala	2.43pm	0.66	25	6.9	0.03	93	40	0	1	0	1	0.4	0.04	0.06
saagafou	8.06am	0.36	25	6.7	0.03	79	40	1	0	0	0	1.8	0.24	0.02
ttogiga	8.22am	0.73	24	6.6	0.03	83	40	0	0	0.01	1.5	2.8	0.38	0.01
malaemalu	9.00am	0.22	26	6.7	0.04	88	40	0	1	0.1	0	0.7	0.12	0.02
sapunaoa	9.20am	0.55	25	6.6	0.04	104	50	1	1	0	1	0.5	0.21	0.02
salestele	9.33am	0.34	26	6.4	0.05	118	60	0	0	0.01	3	16	0.9	0.03
salani	10.08am	0.017	26	6.9	0.07	138	60	0	0	0	1.5	1.9	0.03	0.07
	mean	0.43	25.4	6.7	0.04	101	48	0.2	0.4	0.01	1	2.6	0.24	0.04
FAGALOA BAY														
falefa1	10.42am	0.006	28	6.7	0.06	125	50	0	1	0	0	0.6	0.06	0.03
falefa2	10.50am	0.18	28	6.7	0.05	121	50	3	1	0.01	2.5	0.3	0.06	0.01
sauano1	11.09am	0.22	28	6.5	0.05	112	40	0	0	0	0	0.6	0.07	0.04
sauano2	11.22am	0.086	28	6.9	0.05	120	50	1	1	0	1.5	1.3	0.2	0.05
sauano3	11.30am	0.01	30	6.4	0.06	145	60	6	2	0.07	6	4.4	0.2	0.02
vaisa	11.42am	0.01	29	6.9	0.05	117	50	0	0	0.01	2.5	7.5	0.38	0.03
sa/aai1	11.49am	0.1	29	6.8	0.07	141	60	1	1	0	2.5	8.8	0.4	0.03
sa/aai2	11.56am	0.02	31	6.5	0.08	182	80	5	4	0.02	4	4.2	0.48	0.03
sa/aai3	12.00pm	0.05	30	6.8	0.07	158	70	2	3	0.04	2	6.4	0.01	0.02
salestle1	12.03pm	0.01	27	6.5	0.06	143	60	0	1	0.02	1.5	8.6	0.01	0.03
salestle2	12.09pm	0.042	30	6.7	0.05	109	40	1	2	0.02	3.5	5.3	0.006	0.02
salestle3	12.15pm	0.02	33	6.9	0.06	136	60	1	2	0.02	3	1.2	0.02	0.02
salestle4	12.23pm	0.01	31	6.6	0.05	108	50	2	1	0.01	1.5	2.5	0.1	0.03
salestle5	12.28pm	0.01	29	6.4	0.05	112	60	1	2	0.02	2.8	3.6	0.07	0.02
salestle6	12.33pm	0.05	29	6.3	0.05	110	40	1	1	0	6	0.6	0.4	0.02
musumusu	1.02pm	0.02	29	6.6	0.06	137	50	2	1	0	2	4	0.41	0.01
salimu3	1.23pm	0.01	31	6.6	0.06	129	50	3	4	0	0.5	0.7	0.03	0.01
taelefga2	1.42pm	0.93	28	6.5	0.03	63	20	2	3	0.02	7	1.4	0.07	0.02
ulisese	1.51pm	0.005	34	6.6	0.09	195	90	0	2	0.01	2	1	0.31	0.02
taelefga4	1.55pm	0.02	30	6.7	0.06	126	50	1	1	0	0	0.6	0.22	0.02
taelefga5	2.01pm	0.09	29	6.9	0.09	180	80	2	1	0	2	2.7	0.3	0.01
maasina1	2.09pm	0.01	35	6.6	0.09	202	90	0	2	0.02	0	3.3	0.3	0.02
maasina2	2.13pm	0.07	28	6.6	0.08	175	80	0	1	0	0	4.2	0.5	0.01
maasina3	4.43pm	0.001	29	6.7	0.09	198	100	0	0	0	0	1.8	0.2	0.07
maasina4	4.38pm	0.01	29	6.7	0.07	168	80	0	1	0	0	1.9	0.5	0.05

Name	Time	Discharge	Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
		(m3/s)	(oC)		(mg/l)	(uS/cm)	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
maasina5	2.20pm	0.03	27	6.6	0.07	149	60	2	1	0.01	0	0.8	0.1	0.06
maasina7	2.25pm	0.05	27	6.6	0.06	130	60	0	0	0	0	0.7	0.24	0.03
lona1	2.31pm	0.04	28	6.8	0.05	114	50	0	1	0.01	1	3.8	0.04	0.05
lona3	2.37pm	0.09	27	6.4	0.05	106	50	0	0	0	2	0.7	0.24	0.06
lona6	4.20pm	0.02	27	6.7	0.08	166	80	0	2	0	2	3	0.24	0.03
samame1	2.48pm	0.06	27	6.7	0.04	99	40	0	1	0	1	1.6	0.1	0.01
uafato1	3.12pm	0.01	33	6.8	0.07	138	70	0	0	0.01	0	9.8	0.32	0.03
tagaila	3.20pm	0.26	28	6.9	0.04	93	40	0	1	0	3	2.5	0.22	0.01
vaisima	3.33pm	0.54	28	6.7	0.05	103	50	0	0	0.01	0	0.6	0.14	0.03
uafato2	3.44pm	0.24	27	6.6	0.05	104	50	0	1	0.01	3	4.2	0.35	0.02
uafato3	3.47pm	0.07	28	6.8	0.04	94	40	1	1	0.01	1	2.5	0.29	0.04
uafato5	3.59pm	0.01	28	6.2	0.05	121	60	0	1	0.02	2	10.2	0.4	0.03
	mean	0.09	29	6.6	0.06	133	58	1	1.3	0.01	1.8	3.2	0.21	0.03
OVERALL UPOLU														
	mean	0.47739	27.30779	6.661039	0.050519	114.9481	52.22078	2.209091	3.036364	0.012026	2.457143	2.983117	0.16839	0.038701
	max	11.8	35	7.1	0.14	292	140	36	45	0.17	17	16	0.9	0.15
	min	0	23	6.2	0.01	39	20	0	0	0	0	0.25	0.006	0.01
UPOLU FRESHWATER SPRINGS (Dry Season)														
Name	Time		Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
vailoa1	1.34pm		28	6.6	0.47	954	490	2	0	0	27	13	0.04	0.02
piula	10.40am		25	6.5	0.53	1069	560	0	0	0	28	1.2	0.24	0.03
pesega	8.40am		27	6.6	0.11	222	110	0	0	0	0	23	0.03	0.01
vailoa2	8.50am		26	6.7	0.1	212	110	0	0	0.01	0	18	0.06	0.01
vavau	3.42pm		28	6.6	0.08	175	90	0	0	0	0	1.4	0.03	0.02
afega	9.35am		28	6.8	0.98	1915	1990	2	2	0	160	6.4	0.02	0.03
tuanai	9.45am		27	6.9	0.93	1564	670	1	1	0	34	11	0.28	0.04
vini	4.00pm		25	6.9	0.09	169	80	0	0	0	0	13	0.07	0.1
tufuiopa	5.02pm		27	6.5	0.09	211	100	0	1	0.03	1	40	0.4	0.03
salelesi	9.41am		25	6.9	0.14	305	160	0	0	0	0	1.7	0.2	0.07
salimu	1.14pm		29	6.4	0.06	141	60	0	0	0	0	0.5	0.03	0.01
	mean		26.8	6.7	0.32	630	402	0.45	0.36	0.004	22.7	11.7	0.13	0.03
	max		29	6.9	0.98	1915	1990	2	2	0.03	160	40	0.28	0.1
	min		25	6.4	0.06	141	60	0	0	0	0	0.5	0.02	0.01
UPOLU DRAINS (Dry Season)														
Name	Time		Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
sallsi/dran	9.47am		27	6.8	0.05	121	60	2	6	0.02	1	8.4	0.11	0.02
eva/drain	9.30am		26	6.4	0.07	154	80	2	8	0	0	2.5	0.08	0.06
fugalei drain	5.30pm		32	6.8	1.04	1766	100	8	12	0.04	2	32	0.14	0.06
	mean		28	6.6	0.3	680	73	4	8.6	0.02	1	14.3	0.11	0.04
	max		32	6.8	1.04	1766	100	8	12	0.04	2	32	0.11	0.06
	min		26	6.4	0.05	121	60	2	6	0	0	2.5	0.08	0.02
UPOLU EPHEMERAL Streams (Dry Season)														
Name	Time		Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
saleapaga	1.55pm		27	6.4	0.04	103	40	4	2	0.02	4	25	0.03	0.02
poutasi	8.42am		27	6.5	0.02	65	30	0	0	0.02	2	45	0.24	0.01
satalo	9.11am		27	6.6	0.05	116	50	0	0	0	0	3.5	0.46	0.05
vaigalu	3.03pm		28	6.7	0.06	139	70	1	2	0	24	1.7	0.1	0.01
	mean		27.2	6.5	0.04	1.6	47	1.2	1	0.01	7.5	18.8	0.2	0.02
	max		28	6.7	0.06	139	70	4	2	0.02	24	45	0.46	0.05
	min		27	6.4	0.02	65	30	0	0	0	0	1.7	0.03	0.01
Vaivase Stream ephemeral today														
Maninoa and Siumu ephemeral														
UPOLU PERENNIAL STREAMS - WET SEASON														
NORTH EAST UPOLU														
Name	Time	Discharge	Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
		(m3/s)	(oC)		(mg/l)	(uS/cm)	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
fuluasou	5.52pm	2.4	25	6.9	0.05	96	40	1	1	0	2	3	0.15	0.04
gasegase	5.47pm	0.57	27	6.8	0.08	154	60	12	8	0.02	0	2	0.14	0.06
mulivai	5.25pm	0.36	27	6.8	0.14	287	100	1	1	0.03	4	24	0.24	0.05
vaisigano	5.18pm	2.85	25	7.1	0.05	113	40	1	2	0.02	0	4	0.11	0.03
fagalii	6.13pm	0.68	26	7	0.06	119	50	8	12	0.01	0	3.8	0.2	0.06
laulii	9.01am	0.21	25	6.9	0.04	100	40	2	1	0	0	1.6	0.07	0.05
laulii2	9.09am	0.34	24	6.9	0.03	90	40	2	0	0	0	0.8	0.15	0.05
leusoalii	9.30am	0.45	24	6.7	0.03	91	30	1	0	0	0	0.2	0.16	0.06
luatuanu1	9.39am	0.29	23	6.9	0.02	71	30	4	1	0	0	0.5	0.11	0.05
luatuanu2	9.47am	0.14	25	6.9	0.04	95	40	1	1	0	0	0.6	0.1	0.04
namo	9.57am	0.57	25	6.8	0.05	124	30	1	0	0	0	0.4	0.08	0.04
watfl/eva	10.18am		27	7.2	0.05	108	40	1	0	0	0	0.1	0.06	0.04
eva	10.25am	0.12	24	6.8	0.05	118	40	8	4	0	0	0.6	0.08	0.06
falefa	11.26am	4.44	27	6.8	0.04	107	30	2	1	0	0	0.1	0.03	0.08
fusi1	10.49am	0.016	26	6.9	0.04	97	30	12	4	0	6	0.6	0.08	0.06
fusi2	10.54am	0.078	25	6.8	0.05	114	30	2	1	0	0	0.9	0.1	0.04
	mean	0.9	25.3	6.8	0.05	117	41.8	3.7	2.3	0.005	0.75	2.7	0.11	0.05
ALEIPATA														
vaipu	11.55am	0.74	24	6.6	0.02	63	20	2	2	0	0	0.5	0.1	0.02
siupapa			emphemeral today											
siupapa2			emphemeral today											
lepa			empheral today		bridge damaged by waves last night									
lepa2	3.03pm	0.074	28	6.6	0.05	96	50	2	1	0	1	0.2	0.11	0.06

Name	Time	Discharge (m3/s)	Temp (oC)	pH	Salinity (mg/l)	Cond (uS/cm)	TDS (mg/l)	S.solids (mg/l)	Turbidity (NTU)	Fe2+ (mg/l)	SO42- (mg/l)	TN (mg/l)	TP (mg/l)	Zn2+ (mg/l)
lepa3	3.08pm	0.09	24	6.8	0.06	125	40	2	1	0	0	0.2	0.06	0.05
aufaga			emphemeral today											
sinalele1			emphemeral today											
sinalele2	3.24pm		27	6.4	0.06	130	60	1	1	0	0	0.1	0.16	0.03
vavau3			emphemeral today											
sopoaga	4.00pm	0	26	6.9	0.06	128	60	1	0	0	1	0.2	0.04	0.05
tiavea	12.51pm	1.2	28	7.6	0.45	837	240	1	0	0	16	0.2	0.12	0.06
	mean	0.42	26	6.8	0.11	229	78	1.5	0.83	0	3	0.23	0.09	0.04
NORTH WEST UPOLU														
falevai	11.22am	0.68	27	6.9	0.05	87	30	2	1	0.01	2	0.5	0.06	0.05
LEFAGA														
matafaa1	12.50pm	1.94	28	7	0.07	125	40	1	0	0	0	2	0.1	0.05
matafaa2	1.03pm	0.08	29	6.9	0.05	103	30	1	0	0.01	0	0.2	0.15	0.06
matafaa3	1.13pm	0.46	29	6.9	0.03	87	30	1	0	0	0	0.1	0.17	0.08
	mean	0.82	28.6	6.9	0.05	105	33	1	0	0.003	0	0.76	0.14	0.06
SOUTH UPOLU														
sataoa1	1.47pm	0.27	30	7.2	0.04	122	40	1	0	0	0	16	0.1	0.04
sataoa2	1.55pm	6.2	29	7.1	0.03	78	30	4	2	0.02	1	0.8	0.11	0.05
nuusuatia	2.07pm	0.72	28	7	0.05	113	30	1	0	0	0	0.7	0.1	0.06
tafitoala	2.44pm	1.09	28	7.1	0.09	157	40	1	0	0	0	1	0.14	0.04
saagafou	8.12am	0.03	25	6.8	0.06	142	30	1	0	0	0	20	0.17	0.05
utogiga	8.29am	0.7	25	6.8	0.04	90	30	0	0	0	0	0.6	0.15	0.04
malaemalu	9.38am	0.13	29	6.9	0.05	108	40	1	0	0	0	0.1	0.13	0.05
sapunaoa	9.56am	0.4	28	6.8	0.05	116	30	1	0	0	0	0.1	0.07	0.05
salestele	10.08am	0.11	28	6.9	0.05	118	30	0	0	0	0	1	0.12	0.05
salani	10.22am	0.017	28	6.9	0.06	141	60	1	0	0	0	0.1	0.07	0.04
	mean	0.96	27.8	6.9	0.05	118	36	1.1	0.2	0.002	0.1	4.04	0.12	0.05
FAGALOA BAY														
falefa1	10.55am	0.016	27	6.9	0.05	117	40	1	0	0	0	0.1	0.06	0
falefa2	11.10am	0.14	29	6.8	0.04	118	40	2	1	0	0	0.2	0.1	0.02
sauano1	11.30am	0.043	30	6.8	0.05	121	50	2	1	0	0	0.4	0.06	0.05
sauano2	11.41am	0.039	31	6.9	0.07	157	60	0	0	0	0	1	0.07	0.04
sauano3	11.46am	0	28	6.9	0.04	103	40	1	1	0	0	0.1	0.02	0.03
vaisa	11.53am	0.02	30	7	0.06	132	50	1	1	0	2	0.3	0.3	0.03
sa/aai1	12.00pm	0.06	29	6.8	0.04	92	30	1	0	0	0	0.2	0.2	0.03
sa/aai2	12.04pm	0.07	29	6.7	0.05	121	40	0	0	0	0	0.1	0.07	0.06
sa/aai3	12.10pm	0	29	6.8	0.06	141	50	2	1	0.01	0	0.1	0.07	0.01
salestle1	12.14pm	0.07	29	7	0.05	113	40	3	1	0	0	3.8	0.07	0.09
salesate2	12.18pm	0.09	30	6.9	0.04	94	30	2	1	0	0	13	0.1	0.03
salestle3	12.20pm	0.03	29	6.8	0.05	104	40	1	1	0	0	0.8	0.12	0.04
salestle4	12.27pm	0.04	32	6.8	0.05	114	40	0	0	0.02	2	0.6	0.14	0.05
salestle5	12.33pm	0.03	30	7.1	0.06	127	30	1	1	0	0	1.6	0.8	0.03
salestle6	12.38pm	0.09	30	6.7	0.04	97	30	1	0	0	1	3	0.1	0.04
musumusu	1.05pm	0.08	28	6.8	0.05	101	30	2	2	0.02	1	1.7	0.12	0.04
taelefga2	1.56pm	1.4	28	6.6	0.01	27	20	2	2	0.01	0	0.8	0.05	0.03
ulisese	2.05pm	0.01	29	6.7	0.06	116	40	4	3	0.01	6	0.8	0.1	0.02
taelefga4	2.08pm	0.01	29	6.9	0.05	104	20	4	1	0	0	0.5	0.05	0.01
taelefga5	2.12pm	0.02	28	6.8	0.06	141	50	1	0	0	0	2.6	0.1	0.01
maasina1	2.21pm	0.03	30	6.9	0.06	147	50	6	2	0	0	1.2	0.1	0.03
maasina2	2.24pm	0.02	28	6.9	0.06	126	50	1	1	0	0	3.4	0.04	0.05
maasina3	2.27pm	0.01	29	6.8	0.06	191	60	3	1	0	0	1	0.07	0.05
maasina4	2.31pm	0.01	29	6.8	0.06	134	50	4	1	0	0	6	0.1	0.03
maasina5	2.35pm	0.13	28	6.7	0.05	108	30	0	0	0	1	0.4	0.1	0.03
maasina6	2.40pm	0.02	29	6.7	0.07	141	40	4	2	0	0	0.7	0.09	0.05
maasina7	5.01pm	0.06	29	6.8	0.07	123	40	0	0	0	0	0.5	0.08	0.02
lona1	2.47pm	0.29	29	6.9	0.06	267	30	0	0	0	0	2.8	0.04	0.03
lona2	2.54pm	0.19	29	6.8	0.03	89	30	2	0	0	0	0.7	0.07	0
lona3	2.58pm	0.04	29	6.9	0.04	96	40	1	0	0.02	7	2.4	0.13	0.08
lona4	3.04pm	0.04	29	6.9	0.04	101	40	1	0	0	2	1.9	0.1	0.06
lona5	3.09pm	0.15	29	7.1	0.02	60	20	2	0	0	0	0.8	0.2	0.04
lona6	3.14pm	0.04	29	6.8	0.04	97	40	4	2	0	0	3.4	0.3	0.01
samame1	3.20pm	0.19	29	7.2	0.03	72	30	1	0	0	1	1.4	0.08	0.02
smamea2	3.27pm	0	30	6.9	0.04	110	40	4	2	0.04	4	1.5	0.15	0.04
uafato1	3.54pm	0.05	30	6.6	0.06	149	70	8	4	0.14	13	5.6	0.1	0.07
tagaila	4.05pm	0.15	29	6.8	0.01	44	20	1	0	0	0	2	0.3	0
vaisima	4.09pm	0.3	29	6.8	0.04	81	30	3	1	0	1	0.5	0.09	0.02
uafato2	4.15pm	0.15	29	6.7	0.06	112	30	12	8	0	0	0.8	0.12	0.06
uafato3	4.20pm	0.33	28	6.9	0.05	129	30	2	1	0	0	4.2	0.1	0.02
uafato5	4.35pm	0	29	7.1	0.04	96	40	1	0	0	0	0.8	0.05	0
	mean	0.11	29.1	6.8	0.05	115	38.5	2.2	1.1	0.006	1	1.8	0.12	0.03
OVERALL UPOLU														
	mean	0.39	27.9	6.8	0.05	123	41	2.1	0.87	0.004	0.94	1.7	0.12	0.04
	max	6.2	32	7.6	0.45	837	240	12	8	0.14	16	20	0.8	0.09
	min	0	23	6.4	0.01	27	20	0	0	0	0	0.1	0.02	0

UPOLU EPHEMERAL WATER POOLS (Wet Season)														
Name	Time		Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
vaivase		0.67	27	6.9	0.03	84	30	0	2	10	4	0.9	0.02	0.03
poutasi	8.40am		29	6.7	0.05	117	30	0.01	0	1	0	13.8	0.18	0.03
satalo	9.45am		29	6.7	0.06	120	60	0.02	3	10	6	11	0.11	0.05
	mean		28.3	6.7	0.04	107	40	0.01	1.6	7	3.3	8.5	0.1	0.04
	max		29	6.9	0.06	120	60	0.02	3	10	6	13.8	0.18	0.05
	min		27	6.7	0.03	84	30	0	0	1	0	0.9	0.02	0.03
Maninoa and Siumu still ephemeral. Vaivase Stream now flows														
Saleapag and Vaigalu without water.														

UPOLU FRESHWATER SPRINGS (Wet Season)														
Name	Time		Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
salelesi	10.36am		25	6.8	0.14	320	100	0	0	1	0	0.4	0.16	0.06
piula	11.12am		25	6.8	0.29	586	170	0	152.2	0	0	0.8	0.25	0.05
vailoa1	2.20pm		27	6.8	0.45	896	440	0	1453.0	2	2	12	0.14	0.04
vavau	3.26pm		26	6.7	0.1	207	70	0	0	0	0	0.8	0.11	0.03
pesega	9.33am		27	6.8	0.1	229	30	0.01	0	0	0	26	0.08	0.04
vailoa2	9.49am		27	6.8	0.09	200	80	0	0	0	0	9.8	0.07	0.07
afega	10.15am		27	6.7	0.27	500	130	0	2	1	1	10	0.08	0.1
tuanai	10.20am		27	6.7	0.09	188	50	0	0	1	0	18	0.09	0.04
vini	5.56pm		25	6.9	0.04	99	60	0	0	1	0	6.8	0.1	0.06
tufuiopa	5.50pm		26	6.9	0.08	198	60	0	0	0	0	35	0.12	0.06
salimu	1.12pm		28	6.6	0.06	118	40	0	1	0	0	0.8	0.11	0
	mean		26.3	6.7	0.15	322	112	0.001	14.8 7	0.54	0.27	10.9	0.11	0.05
	max		28	6.9	0.45	896	440	0.01	1453	2	2	35	0.25	0.1
	min		25	6.6	0.04	99	30	0	0	0	0	0.4	0.07	0

UPOLU WATER DRAINS (Wet Season)														
Name	Time		Temp	pH	Salinity	Cond	TDS	S.solids	Turbidity	Fe2+	SO42-	TN	TP	Zn2+
eva/drain	10.32am		25	6.7	0.07	157	30	0	0	4	2	0.5	0.11	0.04
sallsi/dran	10.43am		26	6.8	0.04	108	40	0	0	1	0	0.9	0.24	0.05
fugalei dr	9.28am		29	6.9	0.14	303	130	0.03	1	12	8	40	0.21	0.1
	mean		26.6	6.8	0.08	189	68	0.01	0.33	5.7	3.3	13.8	0.19	0.06

APPENDIX 5 : Mann-Whitney Tests Used in this Thesis

The statistical parameters are : T = sum of ranks of $n1$

$$U = n1n2 + (n1 + n2 + 1/12) - T$$

$$\lambda = U - n1n2/2\ [(n1n2(n1 + n2 + 1)/12]^{1/2}$$

The confidence levels are 99% if $y > 2.3263$, and 95% if $y > 1.645$

5.1. Mann-Whitney Test for salinity, conductivity, TDS, sulphate, TN & TP for Savaii Perennial streams versus Savaii Freshwater springs (Chapter 3)

In the 'dry' season : $n1 = 7$ (perennial streams) and $n2 = 8$ (freshwater springs)
In the 'wet' season : $n1 = 5$ (perennial streams) and $n2 = 8$ (freshwater springs)

Parameter	T value		U value		λ value	
	'Dry' season	'Wet' season	'Dry' season	'Wet' season	'Dry' season	'Wet' season
Salinity	84	55	-26.7	-13.8	6.3310	4.9487
Conductivity	84	55	-26.7	-13.8	6.3310	4.9487
TDS	84	55	-26.7	-13.8	6.3310	4.9487
Sulphate	83	53	-25.7	-11.8	6.2153	4.6559
Total nitrogen	73	52	-15.7	-10.8	5.0578	4.5095
Total phosphorus	74	53	-16.7	-11.8	5.1736	4.6559

The null hypothesis that the two populations come from the same distribution is rejected at the 99% level for all the parameters examined.

5.2. Mann-Whitney test for Savaii freshwater springs (Chapter 3)

$n1 = 4$ (springs from southern Savaii), $n2 = 12$ (rest of Savaii springs)

Parameter	T value	U value	λ value
Salinity	51	-1.33	3.074
Conductivity	53	-3.33	3.3254
Sulphate	58	-8.33	3.9390

The null hypothesis that the two populations come from the same distribution is rejected at the 99% level for all the parameters examined.

5.3. Mann-Whitney test for Upolu urban streams vs rural streams - to establish Fagalii is a typical rural stream (Chapter 3)

n1 = 12 (rural streams), n2 = 4 (urban streams)

Parameter	T value		U value		λ value	
	"Dry" Season	"Wet" Season	"Dry" Season	"Wet" Season	"Dry" Season	"Wet" Season
Conductivity	87	110	-26	-60.7	6.0975	10.279
Suspended solid	89	76	-28	-26.7	6.3414	6.1529
Turbidity	92	60	-31	-10.7	6.7073	4.2111
Iron	124	110	-63	-60.7	10.609	10.279
Total nitrogen	122	121	-61	-71.7	10.365	11.614
Total phosphorus	105	122	-54	-72.1	8.2926	11.735

The null hypothesis that the two populations come from the same distribution is rejected at the 99% level in all the parameters examined

5.4 Mann-Whitney test for discharge of the five in the dry & wet seasons (Chapter 4)

The null hypothesis Ho is that the discharges are from the same population
n1 = number of readings in the dry season, n2 = number of readings in the wet season

Stream	n1	n2	T value	U value	λ value
Fagalii	33	55	2106	-198	9.5258
Fuluasou	33	55	1881	27.5	7.5862
Gasegase	37	55	2248	-96	8.8614
Mulivai	33	55	2102	193	6.6138
Vaisigano	36	55	2177	-86	8.7479

The null hypothesis that the two discharges come from the same distribution is rejected at the 99% level in all the parameters examined

APPENDIX 6 : Rainfall & Runoff Records from around Upolu. Updated from GWS (1979)

6.1. Rainfall Records from stations around Upolu. Source : Updated from GWS (1979)

BASIN	STATION	YEARS	QUALITY
Vaisigano	Alaoa Pond	1957 - 1979	Missing 3 months 1960 - 1961
	Nafanua	1965 - 1979	Missing several months 1968-69
	Avele	1964 - 1979	Broken record
	Afiamalu	1903 - 1994	Good
	Tiapapata	1973 - 1979	Intermittent data
	Vaoala	1973 - 1979	Broken record
	Fale ole Fee	1975 - 1979	Broken record
	Utumapu	1882 - 1888	Also available 1967, 1968 and 1974
	Mulinuu	1941 - 1994	Good and reliable
	Moamoa	1994 - 1995	Good quality
Salani	Vaipu	1971 - 1979	Intermittent data
	Afulilo	1972 - 1979	Intermittent data
	Sopoaga	1972 - 1979	Intermittent data
	Fagaloa Saddle	1974 - 1979	Intermittent data
	Mt. Fogalepolo	1974 - 1979	Intermittent data
	Le Mafa	1975 - 1979	Intermittent data
	Afulilo North	1975 - 1979	Read at irregular intervals
	Afulilo East	1976 - 1979	Read at irregular intervals
Faleseela	Faleseela	1974 - 1979	Intermittent data
Lotofaga	Mt. Sigaele	1974 - 1976	Gauge damaged
	Lanutoo	1974 - 1979	Intermittent data
	Lotofaga	1975 -1979	Read at irregular intervals
Falefa	Sauniatu	1975 - 1979	Intermittent data
Mulivai	Tiavea	1974 - 1979	Read at irregular intervals

6.2. Runoff Records from different stations in Upolu. Source : Updated from GWS (1979).

BASIN	STATION	YEARS	REMARKS
Vaisigano	Alaoa West	1972 to 1982	Quality fair to good
	Alaoa P Headrace	1974 - 1979	Poor quality
	Tiapapata	1974 - 1979	Very poor quality
	Power House	1974 - 1979	Spot readings
	Power Tailrace	1974 - 1979	Fair
	Alaoa East	1973 - 1985	Quality fair to good
	Fale ole Fee	1975 - 1979	Good quality
	Fuluasou	1976 - 1977	Good Quality
Salani	Vaipu	1975 - 1979	Quality fair to good
	Afulilo	1972 - 1979	Good quality
	Sopoaga	1972 - 1979	Good
Faleseela	Faleseela	1974 -1979	Good quality
Mulivai	Tiavea	1975 - 1979	Good
Lotofaga	Lotofaga	1976 - 1979	Poor quality
Falefa	Sauniatu	1975 - 1979	Good quality

<u>Note</u> : All the stations utilised the Water Level Recorder except Alaoa Pond Headraces and Power House which had Visual Staff Gauging.

APPENDIX 7 : Catchment Precipitation & Catchment Evapotranspiration Calculations*

* According to the method described by Linsley *et al.* (1978)

7.1 Catchment Precipitation

FAGALII (Area = 6.9 km2)

Isohyet (mm)	Net Area (km2)	Average pptn (mm)	Precipitation Volume
6000	0		
5500	0.4	5250	2100
5000	0.7	4750	3325
4500	2.3	4250	9775
4000	1	3750	3750
3500	1.1	3250	3575
3000	0		
		TOTAL	22525
Catchment Precipitation			3990 mm

FULUASOU (Area = 25.7 km2)

Isohyet (mm)	Net Area (km2)	Average pptn (mm)	Precipitation Volume
6000	0		
5500	1.7	5200	8840
5000	5.6	4750	26600
4500	9	4250	38250
4000	5.3	3750	19875
3500	4.1	3250	13325
3000	0		
		TOTAL	106890
Catchment Precipitation			4160 mm

GASEGASE (Area = 23.9 km2)

Isohyet (mm)	Net Area (km2)	Average pptn (mm)	Precipitation Volume
6000	0		
5500	1.8	5200	9360
5000	2	4750	9500
4500	10.3	4250	43775
4000	7.3	3750	27375
3500	2.5	3250	8125
3000	0		
		TOTAL	98135
Catchment Precipitation			4105 mm

MULIVAI (Area = 7.5 km2)

Isohyet (mm)	Net Area (km2)	Average pptn (mm)	Precipitation Volume
6000	0		
5500	0		
5000	0		
4500	1	4250	4250
4000	3.1	3750	11625
3500	2.8	3250	9100
3000	0		
		TOTAL	24975
Catchment Precipitation			3680 mm

VAISIGANO (Area = 33.8 km2)

Isohyet	Net Area	Average	Precipitation
6500	1.1	6100	7018
6000	2.9	5750	16675
5500	6.2	5200	32240
5000	7.3	4750	34675
4500	6.4	4250	27200
4000	7.7	3750	28875
3500	2.2	3250	7150
3000	0		
		TOTAL	153833
Catchment Precipitation			4550 mm

7.2 Catchment Evapotranspiration

FAGALII (Area = 6.9 km2)

Contour (m)	Net Area (km2)	Average Et (mm)	Total Et Volume
150	1.1	1490	1670
300	1	1320	1340
450	2.3	1190	2794
600	0.7	1095	780
750	0.4	1002	409
900			
		TOTAL	8625
Catchment Evapotranspiration			1250 mm

FULUASOU (area = 25.7 km2)

(m)	(km2)	Et (mm)	Volume
150	4.1	1490	6224
300	5.3	1320	7102
450	9	1190	10935
600	5.6	1095	6238
750	1.7	1002	1739
900	0		
		TOTAL	31612
Catchment Evapotranspiration			1230 mm

GASEGASE (Area = 23.9 km2)

Contour (m)	Net Area (km2)	Average Et (mm)	Total Et Volume
150	2.5	1490	3795
300	7.3	1320	9782
450	10.3	1190	12514
600	2	1095	2228
750	1.8	1002	1841
900	0		
		TOTAL	29636
Catchment Evapotranspiration			1240 mm

MULIVAI (Area = 7.5 km2)

Contour (m)	Net Area (km2)	Average Et (mm)	Total Et Volume
150	2.8	1490	4250
300	3.1	1320	4154
450	1	1190	1215
600	0	1095	
750	0	1002	
900			
		TOTAL	10200
Catchment Evapotranspiration			1360 mm

VAISIGANO (Area = 33.8 km2)

Contour	Net Area	Average	Total Et
150	2.2	1490	3339
300	7.7	1320	10318
450	6.4	1190	7776
600	7.3	1095	8132
750	6.2	1002	6342
900	2.9	935	2746
1050	1.1	870	976
		TOTAL	38870
Catchment Evapotranspiration			1150 mm

APPENDIX 8 : Raw Water Quality Data of the Five Streams in Western Samoa.

8.1 : Raw Data for Fagalii Stream

Day	Date	Time	Discharge	Temp	Salinity	Cond	pH	TDS	Ssolid	Turb	Fe2+	SO42-	TN	TP	Zn2+
			(m3/s)	(oC)	(mg/l)	(uS/cm)		(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
1	12-Jul	4.10pm	0.14	26	0.06	138	7	60	1	1	0	2	0.4	0.08	0.07
5	16-Jul	1.05pm	0.22	26	0.05	121	7.1	60	1	1	0.05	6	0.4	0.14	0.18
11	22-Jul	1.40pm	0.15	26	0.05	132	6.9	60	1	0	0	1	4.2	0.15	0.02
15	26-Jul	4.33pm	0.16	29	0.06	136	6.8	60	1	2	0.02	1	1.8	0.04	0.12
22	2-Aug	3.57pm	0.11	26	0.06	135	6.9	70	1	2					
26	6-Aug	8.57am	0.16	24	0.06	131	6.7	70	5	2	0	0.5	1.5	0.16	0.08
30	10-Aug	7.43am	0.17	24	0.06	134	7.2	70	1	0					
31	11-Aug	5.45pm	0.14	26	0.06	143	6.8	70	1	1	0	0.5	1.4	0.16	0.05
35	15-Aug	5.21pm	0.39	25	0.04	105	7.1	50	1	10	0.01	1	1.9	0.12	0.03
36	16-Aug	6.56pm	1.92	24	0.02	71	6.8	30	90	140	0.03	2.5	17.8	0.42	0.19
37	17-Aug	10.46am	0.72	24	0.03	90	6.7	50	8	58	0.08	6.5	7.6	0.32	0.07
39	19-Aug	6.00pm	0.33	26	0.05	112	6.8	50	1	3	0.01	1	0.6	0.11	0.06
43	23-Aug	9.32am	0.2	24	0.05	121	6.8	60	5	2					
47	27-Aug	6.35am	0.21	24	0.05	126	6.9	70	8	6	0	2.5	14.5	0.23	0.07
50	30-Aug	5.46pm	0.12	26	0.06	136	6.9	70	1	0					
54	3-Sep	8.37am	0.19	25	0.06	137	7	70	1	0	0.03	1	1.6	0.65	0.16
57	6-Sep	9.00am	0.16	24	0.06	134	6.8	70	1	0					
60	9-Sep	8.50am	0.17	23	0.06	132	6.7	70	1	1	0.02	3.5	2.2	0.13	0.08
64	13-Sep	2.53pm	0.13	27	0.06	142	6.8	70	2	0					
67	16-Sep	5.14pm	0.34	27	0.06	138	6.9	70	1	0	0.01	1.5	3	0.14	0.06
70	19-Sep	6.52pm	0.17	26	0.06	138	7.1	70	1	0					
73	23-Sep	7.18pm	0.16	26	0.06	136	6.9	60	8	4	0.01	3.5	32	0.41	0.1
77	27-Sep	3.24pm	0.15	27	0.06	137	7.2	70	2	16					
79	29-Sep	3.09pm	0.15	30	0.06	144	6.8	70	1	4	0.18	6.9	1.5	0.09	0.24
84	4-Oct	4.01pm	0.15	26	0.06	134	6.8	60	1	1					
88	8-Oct	6.05pm	0.19	27	0.06	133	6.7	60	1	broke					
91	11-Oct	4.12pm	0.18	28	0.05	128	6.9	60	1	0					
94	14-Oct	4.42pm	0.17	28	0.06	134	7.1	60	10	0	0	2	0.4	0.29	0.12
98	18-Oct	5.30pm	0.14	28	0.06	135	7.2	60	1	0					
100	20-Oct	6.10pm	0.14	28	0.06	141	7.1	70	1	0	0.02	2.5	0.8	0.08	0.08
105	25-Oct	5.05pm	0.15	27	0.06	137	6.9	70	5	6	0.02	2	0.4	0.14	0.06
106	26-Oct	5.44pm	0.88	25	0.03	83	6.8	40	8	18	0.06	8	7.5	0.51	0.08
107	27-Oct	6.27am	0.3	24	0.04	98	6.8	50	1	0	0	0	0.8	0.15	0.01
111	31-Oct	6.17pm	0.35	27	0.03	101	7.2	50	3	1					
115	4-Nov	6.36pm	0.16	26	0.05	113	6.9	60	1	0	0	0	0.8	0.14	0.03
119	8-Nov	6.12pm	0.31	26	0.05	109	7.1	50	1	2					
121	10-Nov	5.01pm	0.23	28	0.05	114	6.9	50	1	2	0	1	0.4	0.09	0.13
126	15-Nov	5.17pm	0.16	27	0.05	124	7.2	60	1	0					
128	17-Nov	5.59pm	0.6	28	0.05	114	6.9	60	1	0	0	0	1	0.3	0.02
133	22-Nov	6.34pm	0.11	27	0.06	142	7.1	60	1	1					
135	24-Nov	6.10pm	0.2	26	0.06	143	7.2	70	1	0	0	0	0.4	0.07	0.06
140	29-Nov	6.00pm	0.58	25	0.02	99	7	50	1	4					
142	1-Dec	6.03pm	0.31	25	0.06	120	6.7	50	21	16	0.08	7	1.3	0.08	0.19
148	7-Dec	5.23pm	0.19	27	0.05	128	7	60	1	2					
150	9-Dec	5.42pm	0.2	26	0.06	117	6.9	60	2	10	0.03	6.5	1.2	0.07	0.21
154	13-Dec	5.13pm	0.18	29	0.06	140	7.1	50	1	1					
156	15-Dec	4.06pm	0.26	27	0.06	132	6.9	50	2	2	0	0	2.4	0.1	0.04
161	20-Dec	5.30pm	0.29	27	0.06	123	6.9	50	1	0					
164	23-Dec	4.44pm	1.77	25	0.03	98	6.8	30	16	26	0.07	16	1.2	0.46	0.14
168	27-Dec	5.08pm	0.52	25	0.04	103	6.9	40	1	0					
171	30-Dec	6.25pm	0.36	27	0.04	104	6.8	50	32	12	0.08	7	1.8	0.47	0.2
175	3-Jan	4.12pm	0.37	29	0.06	146	7.1	60	1	2					
177	5-Jan	1.54pm	0.35	26	0.05	115	7.2	60	6	3	0.03	3	1.2	0.04	0.26
182	10-Jan	4.37pm	0.48	25	0.06	131	6.9	60	1	0					
186	14-Jan	7.58pm	0.27	25	0.04	120	7	60	36	3	0.07	4	3.3	0.15	0.19
189	17-Jan	7.18pm	0.26	26	0.06	98	6.9	70	2	4					
192	20-Jan	12.41pm	0.21	29	0.05	137	7.2	60	1	0	0.02	4	28	0.15	0.17
196	24-Jan	5.55pm	0.27	27	0.04	101	7.1	60	4	10					
198	26-Jan	6.05pm	0.35	27	0.04	96	7.3	40	1	3	0.06	3	2.3	0.09	0.26
203	31-Jan	6.29pm	0.36	27	0.05	118	7.4	60	28	7					
206	3-Feb	5.13pm	0.36	27	0.05	122	7.3	60	1	1	0	0	1.7	0.15	0.04
211	8-Feb	6.05pm	0.24	27	0.05	118	7.8	60	6	8					
214	11-Feb	8.49am	0.23	25	0.05	113	7.3	50	1	0	0	0	23	0.39	0.03
218	14-Feb	3.59pm	0.38	26	0.05	111	7.4	60	16	15					

219.6	15-Feb	2.40pm	1.1	25	0.03	82	7.5	40	22	46	0.03	3	6.8	0.25	0.03
219.8		7.44pm	0.65	24	0.04	92	7.2	30	20	32					
220	16-Feb	6.03am	0.88	24	0.04	93	7.2	30	18	22					
221	17-Feb	4.36pm	0.45	25	0.05	100	7.3	50	4	8	0	0	10	0.13	0.04
225	21-Feb	6.09pm	0.43	26	0.05	115	7.3	60	4	12					
228	24-Feb	6.16pm	0.45	26	0.05	111	7.1	60	1	0	0.01	0	7.2	0.16	0.06
232	28-Feb	6.05pm	0.24	27	0.07	113	7.2	60	1	0					
235	3-Mar	5.52pm	0.24	28	0.05	129	7.4	60	1	1	0	0	0.8	0.11	0.05
239	7-Mar	10.50am	0.25	25	0.04	110	7.4	50	1	0					
242	10-Mar	6.07pm	0.28	26	0.05	110	7.3	60	4	2	0	0	4.3	0.24	0.04
246	14-Mar	6.05pm	0.2	27	0.05	118	7	30	1	0					
249	17-Mar	6.13pm	0.6	26	0.06	119	7	50	8	12	0.01	0	3.8	0.2	0.06
253	21-Mar	6.54pm	0.3	28	0.04	143	7.2	60	1	2					
257	25-Mar	4.20pm	0.22	26	0.03	88	6.9	20	12	15	0.05	4	3	0.16	0.04
258.2	26-Mar	8.17am	0.7	26	0.03	87	7.5	30	20	24					
258.8		7.13pm	0.6	27	0.03	83	7.6	30	6	4					
259	27-Mar	1.11pm	0.52	26	0.04	77	7	20	8	4	0.04	1	2.2	0.25	0.07
262	30-Mar	4.31pm	0.38	28	0.04	93	7.3	30	1	1	0.01	0	1	0.12	0.04
268	5-Apr	11.08am	0.28	27	0.04	95	7	30	1	0					
271	8-Apr	8.32am	0.24	23	0.04	110	7.7	30	2	1	0	0	1.2	0.15	0.05
275	12-Apr	12.26pm	0.26	27	0.04	105	7.6	40	1	1					
277	14-Apr	1.42pm	0.2	28	0.04	107	7.5	40	8	4	0.02	0	1.5	0.19	0.03
282	19-Apr	11.47am	0.4	25	0.03	77	7.3	30	38	28					
284	21-Apr	3.51pm	0.81	24	0.02	66	7.5	30	30	20	0.06	2.5	3.8	0.12	0.06
289	26-Apr	11.54am	0.3	27	0.04	103	7.3	50	3	3					
292	29-Apr	9.22am	0.2	25	0.04	96	7.4	30	2	1	0.01	0	1.8	0.17	0.03
	total		31.15	2356	4.39	10464	637	4810	583	656	1.23	117.4	219.7	9.52	4.5
	mean		0.34	26.1	0.05	116	7	53.4	6.5	7.4	0.02	2.4	4.5	0.19	0.09
	max value		1.92	30	0.07	146	7.8	70	90	140	0.18	16	32	0.65	0.26
	min value		0.11	23	0.02	66	4.4	20	0	0	0	0	0.4	0.04	0.01
	st.deviation		0.29876	1.457856	0.011498	19.62502	0.252082	13.83377	12.25499	17.4091	0.034042	3.065531	6.99191	0.134055	0.06891
	CV		0.878707	0.055857	0.229954	0.169181	0.036012	0.259059	1.885384	2.352581	1.70209	1.277305	1.553758	0.705554	0.765671

8.2 : Raw Data for the Fuluasou River

Day	Date	Time	Discharge (m3/s)	Temp (oC)	Salinity (mg/l)	Cond (uS/cm)	pH	TDS (mg/l)	Ssolid (mg/l)	Turb (NTU)	Fe2+ (mg/l)	SO42- (mg/l)	TN (mg/l)	TP (mg/l)	Zn2+ (mg/l)
1	28-Jun	3.50pm	1.6	28	0.06	137	7	60	0	2	0.05	2	0.7	0.28	0.07
5	2-Jul	9.10am	0.5	27	0.06	134	7.4	70	5	3	0.05	4.5			
15	12-Jul	3.30pm	0.22	28	0.07	141	7.3	60	2	4	0.04	2.5	0.8	0.23	0.05
19	16-Jul	12.10pm	0.28	26	0.06	141	7	60	8	4	0.03	1.5	0.7	0.22	0.05
43	9-Aug	5.15pm	0.16	27	0.06	143	6.8	70	0	1					
45	11-Aug	4.26pm	0.08	27	0.06	145	6.9	70	0	0	0.03	1.5	0.5	0.22	0.05
49	15-Aug	4.15pm	0.48	25	0.05	125	7.2	60	1	1	0.03	0.05	1.4	0.32	0.03
51	17-Aug	9.46am	1.8	24	0.05	112	6.9	60	0	8	0.04	3.5	7.2	0.28	0.04
53	19-Aug	5.30pm	0.5	27	0.06	133	6.8	60	0	0	0.01	0	0.4	0.3	0.04
57	23-Aug	10.14am	0.3	25	0.06	130	7.1	60	0	0					
61	27-Aug	7.20am	0.25	23	0.05	127	6.8	70	2	18	0.12	4.5	9.8	0.23	0.03
64	30-Aug	4.58pm	0.22	28	0.06	135	7.2	60	0	1					
68	3-Sep	7.24am	0.25	23	0.06	135	6.9	70	0	0	0.08	0	0.3	0.22	0.04
71	6-Sep	7.21am	0.13	23	0.06	131	7.2	70	1	1					
74	9-Sep	7.34am	0.11	23	0.05	129	7	70	0	0	0.03	2	0.2	0.22	0.05
78	13-Sep	1.49pm	0.08	29	0.07	146	6.4	60	0	0					
81	16-Sep	4.24pm	3.7	26	0.03	78	6.8	30	15	58	0.23	18	7.5	0.14	0.05
84	19-Sep	6.12pm	0.23	28	0.06	139	7.2	70	0	0					
88	23-Sep	5.05pm	0.31	28	0.06	135	7.1	60	0	1	0	2	0.4	0.27	0.05
92	27-Sep	4.09pm	0.18	28	0.06	131	7.4	60	3	16					
94	29-Sep	4.06pm	0.1	31	0.06	147	6.6	60	0	2	0.08	4	0.8	0.18	0.07
99	4-Oct	5.00pm	0.53	26	0.05	118	7.3	60	0	0					
103	8-Oct	5.40pm	0.31	28	0.06	132	6.8	60							
106	11-Oct	4.57pm	0.37	28	0.05	128	6.9	60	8	23					
109	14-Oct	4.18pm	0.33	29	0.06	133	7	60	8	1	0	0	0.4	0.16	0.03
113	18-Oct	4.43pm	0.26	30	0.06	138	6.9	60	1						
115	20-Oct	5.49pm	0.35	30	0.06	140	6.9	60	4	6	0.01	1	0.6	0.15	0.06
120	25-Oct	4.43pm	0.24	28	0.06	134	6.9	60	8	5	0.01	2	0.6	0.21	0.04
121	26-Oct	4.48pm	2.86	24	0.01	82	6.8	40	4	8	0.02	2	0.8	0.22	0.06
122	27-Oct	3.37pm	0.74	28	0.05	116	6.7	50	0	2	0	2	1.2	0.24	0.04
126	31-Oct	5.59pm	0.82	29	0.05	119	6.8	50	2	0					
130	4-Nov	6.17pm	0.59	26	0.05	119	6.9	110	2	0	0	1	3.2	0.42	0.03
134	8-Nov	5.49pm	0.63	27	0.05	124	6.9	60	4	0					
136	10-Nov	6.23pm	0.46	27	0.05	128	6.9	60	4	0	0	0	0.6	0.3	0.04
141	15-Nov	4.54pm	0.71	27	0.05	127	7.2	60	3	0					
143	17-Nov	5.28pm	0.54	28	0.05	126	6.9	60	0	1	0.01	2	2.4	0.9	0.05
148	22-Nov	5.36pm	0.96	28	0.08	145	7.2	60	2	0					
150	24-Nov	5.49pm	0.93	25	0.06	139	7	60	22	17	0.05	8	18	0.44	0.11
155	29-Nov	5.38pm	3.34	25	0.04	101	6.8	40	0	8					
157	1-Dec	5.44pm	1.35	25	0.05	121	6.8	50	6	14	0.26	11	1.2	0.24	0.12
163	7-Dec	4.28pm	0.81	26	0.05	131	6.9	60	0	1					
165	9-Dec	5.19pm	1.5	27	0.06	112	7	60	24	16	0.22	10	1.4	0.15	0.12
169	13-Dec	4.30pm	0.83	27	0.06	131	7.2	60	0	0					
171	15-Dec	4.56pm	0.87	27	0.07	122	7.1	60	2	1	0	1	0.8	0.14	0.05
176	20-Dec	4.46pm	0.98	27	0.04	100	7.2	50	0	0					
179	23-Dec	5.54pm	3.1	26	0.03	100	7.3	50	8	8	0.14	16	2.4	0.15	0.08
183	27-Dec	4.35pm	1.6	25	0.04	108	6.9	60	1	1					
186	30-Dec	6.09pm	1.2	27	0.06	105	6.9	20	8	2	0.04	6	0.7	0.47	0.25
190	3-Jan	3.54pm	0.7	28	0.06	127	6.9	70	0	2					
192	5-Jan	2.45pm	1.5	25	0.04	111	7.1	60	17	5	0.03	3.5	0.7	0.16	0.2
197	10-Jan	5.20pm	0.66	27	0.06	131	6.9	60	0	0					
201	14-Jan	7.21pm	0.76	24	0.06	129	7	70	0	3	0.03	4	0.8	0.12	0.24
204	17-Jan	6.50pm	0.82	27	0.07	138	7.2	70	3	2					
207	20-Jan	11.44am	0.74	28	0.06	139	7.2	70	0	1	0	0.5	3	0.15	0.03
211	24-Jan	6.16pm	1.1	26	0.05	116	7.4	70	3	8					
216	26-Jan	6.30pm	1.8	26	0.05	112	7.2	60	16	12	0.07	8	1.5	0.16	0.08
218	31-Jan	5.35pm	0.95	27	0.05	124	7.2	60	16	2					
221	3-Feb	4.57pm	0.78	26	0.05	125	7.4	60	2	1	0	1	1.9	0.4	0.02
226	8-Feb	6.28pm	0.67	27	0.03	131	7.6	60	17	4					
229	11-Feb	8.12am	0.9	25	0.06	121	7.5	60	4	2	0	0.5	2.6	0.15	0.03
232	14-Feb	4.43pm	1.1	25	0.05	121	7.6	40	20	10					
233.6	15-Feb	3.29pm	3.6	25	0.04	101	7.6	30	30	26	0	3	3.4	0.15	0.03
233.8		7.04pm	2.5	25	0.04	104	7.4	30	28	22					
234	16-Feb	6.35am	1.8	24	0.05	111	7.3	60	20	18					

235	17-Feb	4.15pm	1.7	29	0.04	107	7.4	50	3	9	0	1	12	0.12	0.03
239	21-Feb	5.50pm	1.1	26	0.05	116	7.4	60	5	12					
242	24-Feb	6.42pm	1.1	25	0.04	119	7.3	60	0	0	0	1.5	3	0.31	0.03
246	28-Feb	5.45pm	1.2	27	0.05	118	8.1	60	0	0					
249	3-Mar	5.36pm	1.1	27	0.06	131	7.3	60	0	0	0	2	5.4	0.15	0.03
253	7-Mar	10.10am	1.1	25	0.05	126	7.5	60	0	0					
256	10-Mar	6.57am	1.24	25	0.05	118	7.2	40	1	11	0	0	1.2	0.13	0.03
260	14-Mar	5.48pm	1.3	26	0.05	123	7.2	30	4	0					
263	17-Mar	5.52pm	2.4	25	0.05	96	6.9	40	1	0	0	1.5	2.2	0.15	0.04
267	21-Mar	6.15pm	1.6	27	0.07	131	6.9	60	2	1					
271	25-Mar	5.15pm	1.6	26	0.03	89	7.2	100	15	10	0.01	4	1.8	0.7	0.04
272.6	26-Mar	7.50am	4.1	25	0.04	103	7.4	30	30	28					
272.8		6.01pm	3.2	26	0.04	98	7.4	30	2	1					
273	27-Mar	11.11am	6.5	25	0.06	136	7.2	30	0	0	0.01	1	2.3	0.15	0.07
276	30-Mar	4.01pm	2.2	25	0.04	108	7.3	30	1	1	0	0	1.8	0.71	0.04
281	5-Apr	10.33am	2	27	0.02	70	7.4	30	4	3					
284	8-Apr	8.06am	1.5	24	0.05	118	7.6	30	0	0	0	1	2	0.66	0.03
288	12-Apr	11.58am	1.2	27	0.05	106	7.5	40	1	0					
290	14-Apr	1.25pm	1.2	28	0.04	108	7.4	40	0	0	0	0	0.8	0.15	0.02
295	19-Apr	11.18am	4.2	24	0.03	83	7.6	40	60	46					
297	21-Apr	3.22pm	8.2	26	0.03	70	7.7	30	35	20	0.02	3.5	1.4	0.29	0.04
302	26-Apr	11.13am	2.1	27	0.05	121	7.8	30	2	1					
305	29-Apr	9.06am	2.1	26	0.04	102	7.8	30	0	0	0	0	2.5	0.15	0.02
		total	113	2297	4.46	10491	622.1	4790	500	495	1.75	144.05	115.3	12.26	2.75
		mean	1.3	26.4	0.05	120	7.1	55	5.8	5.8	0.03	3.1	2.5	0.26	0.06
		max value	8.2	31	0.08	147	8.1	110	60	58	0.26	18	18	0.9	0.25
		min value	0.08	23	0.01	70	6.4	20	0	0	0	0	0.2	0.12	0.02
		st.deviatio	1.338567	1.657167	0.011725	17.07627	0.298992	15.30334	9.986632	9.902081	0.06094	3.893542	3.365516	0.172201	0.050926
		CV	1.029667	0.062771	0.234505	0.142302	0.042112	0.278242	1.721833	1.707255	2.031318	1.255981	1.346206	0.662311	0.848762

8.3 : Raw Data for Gasegase Stream															
Day	Date	Time	Discharge	Temp	Salinity	Cond	pH	TDS	Ssolid	Turb	Fe2+	SO42-	TN	TP	Zn2+
			(m3/s)	(oC)	(mg/l)	(uS/cm)		(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
1	28-Jun	2.40pm	0.07	29	0.12	257	6.9	130	1	1	0.08	8	15	0.24	0.02
5	2-Jul	10.07am	0.08	30	0.12	257	7	130	1	0	0.06	4.5	9.8	0.28	0.02
11	8-Jul	8.15am	0.21	28	0.06	131	6.9	60	1	2					
16	13-Jul	5.45pm	0.34	26	0.06	128	6.8	60	180	500	1.43	7.5	25	0.66	0.05
19	16-Jul	11.45am	0.11	29	0.11	249	7	110	1	3	0.05	7	11.4	0.23	0.04
25	22-Jul	2.47pm	0.07	29	0.12	264	7	120	2	2	0.08	7	12.4	0.39	0.05
29	26-Jul	4.03pm	0.05	29	0.12	265	6.8	130	2	1	0.09	6.5	6.4	0.53	0.03
37	3-Aug	5.15pm	0.05	28	0.12	252	6.4	130	1	1					
40	6-Aug	10.22am	0.05	27	0.12	254	7.1	120	1	2	0.08	6	11	0.23	0.11
43	9-Aug	4.43pm	0.05	28	0.12	264	6.8	130	1	1					
45	11-Aug	4.01pm	0.04	30	0.12	268	6.6	130	1	0	0.04	5	3.4	0.21	0.03
50	16-Aug	5.56pm	4.4	24	0.04	105	6.8	50	503	520	2.4	11.5	32	0.34	0.03
51	17-Aug	9.22am	1.8	24	0.05	114	6.7	60	8	36	0.15	13.5	16.2	0.3	0.05
53	19-Aug	5.11pm	0.25	28	0.1	217	6.9	110	1	0	0.04	5	11.4	0.22	0.07
57	23-Aug	5.24pm	0.08	29	0.13	276	6.5	120	1	1					
61	27-Aug	6.54am	0.06	25	0.13	264	6.4	150	1	0	0.02	4.5	35	0.23	0.12
64	30-Aug	4.28pm	0.04	29	0.12	265	6.9	130	1	1					
68	3-Sep	6.35am	0.07	26	0.12	261	6.8	150	1	0	0.04	5	17	0.19	0.16
71	6-Sep	6.52am	0.05	26	0.12	262	6.7	140	1	0					
74	9-Sep	7.15am	0.05	26	0.11	258	6.7	140	1	0	0.01	1	12	0.32	0.1
78	13-Sep	1.31pm	0.06	29	0.13	265	6.8	120	2	2					
81	16-Sep	4.00pm	0.06	31	0.12	274	6.9	130	1	0	0.02	0.5	22	0.27	0.04
84	19-Sep	5.57pm	0.08	29	0.12	263	6.9	130	1	5					
88	23-Sep	4.55pm	0.05	30	0.13	271	7.2	130	1	1	0.04	1	11.8	0.14	0.04
92	27-Sep	3.52pm	0.08	32	0.12	262	7	130	1	3					
94	29-Sep	4.00pm	0.06	29	0.11	241	6.6	120	1	0	0.09	23	0.6	0.09	0.08
99	4-Oct	4.50pm	0.04	29	0.13	268	7.1	120	1	1					
103	8-Oct	5.24pm	0.05	30	0.12	264	6.6	130	10	8	0.04	3	31	0.5	0.25
106	11-Oct	4.55pm	0.06	30	0.16	338	6.8	130	1	0					
109	14-Oct	4.05pm	0.04	30	0.13	276	7.2	130	4	0	0	2	7.5	0.09	0.04
113	18-Oct	3.55pm	0.03	33	0.13	272	7.2	130	2	0					
114	19-Oct	5.30pm	8.32	24	0.01	36	7.2	20	24	29	0.07	15	9.2	0.06	0.03
115.4	20-Oct	11.36am	1.2	32	0.12	260	6.8	120	12	2	0	2	1.2	0.05	0.06
115.7	20-Oct	5.39pm	1.5	32	0.15	313	7.1	140	2	8	0.03	1	18.2	0.35	0.09
120	25-Oct	4.32pm	0.01	30	0.13	282	6.7	140	1	8	0.02	1	12.5	0.15	0.04
121	26-Oct	4.38pm	3.2	25	0.05	96	6.8	50	12	40	0.12	8	35	0.27	0.07
122	27-Oct	3.16pm	0.6	30	0.08	162	6.8	80	1	0	0	1.5	16	0.14	0.06
126	31-Oct	5.44pm	0.04	30	0.13	280	6.6	130	1	2					
130	4-Nov	6.02pm	0.04	27	0.13	285	6.9	100	1	0	0	0	22	0.33	0.05
134	8-Nov	5.37pm	0.07	29	0.12	272	6.7	140	1	2					
136	10-Nov	6.09pm	0.03	30	0.13	277	7	140	1	0	0	0	20	0.09	0.03
141	15-Nov	4.38pm	0.08	30	0.13	279	6.8	130	10	8					
143	17-Nov	5.38pm	0.04	30	0.13	256	6.9	130	1	0	0	0	14	0.31	0.01
148	22-Nov	5.20pm	0.07	30	0.14	340	7	160	2	2					
150	24-Nov	5.30pm	0.06	25	0.14	297	6.7	60	1	0	0	2.5	15.8	0.14	0.04
155	29-Nov	5.35pm	2.8	25	0.06	125	6.6	80	4	11					
157	1-Dec	5.35pm	0.7	25	0.08	164	7.1	130	15	8	0.07	6	0.8	0.08	0.16
163	7-Dec	4.35pm	0.08	28	0.13	161	6.8	130	1	1					
165	9-Dec	5.07pm	0.05	29	0.13	292	6.7	120	1	6	0.04	4	0.6	0.18	0.15
169	13-Dec	4.25pm	0.18	29	0.14	104	6.6	150	1	0					
171	15-Dec	4.50pm	0.06	28	0.14	143	6.6	130	2	4	0	1	16	0.5	0.04
176	20-Dec	4.35pm	0.06	29	0.12	199	6.9	40	1	2					
179	23-Dec	5.41pm	5.5	25	0.03	81	6.8	40	160	146	1.1	46	1.8	0.14	0.13
183	27-Dec	4.26pm	1.8	26	0.06	118	6.7	50	1	6					
186	30-Dec	6.00pm	1.5	27	0.04	99	6.9	100	42	22	0.45	24	3.5	0.35	0.21
190	3-Jan	3.40pm	0.4	29	0.09	176	6.7	90	8	18					
192	5-Jan	2.38pm	0.3	27	0.07	167	6.8	120	8	17	0.09	7	0.6	0.11	0.23
197	10-Jan	5.15pm	0.13	28	0.12	243	6.6	130	1	0					
201	14-Jan	7.07am	0.12	26	0.12	246	6.7	120	1	8	0.05	3.5	0.7	0.09	0.32
204	17-Jan	6.43pm	0.13	29	0.14	254	6.7	140	8	2					
207	20-Jan	12.12pm	0.13	30	0.08	128	6.9	70	1	2	0.01	0	30	0.13	0.58
211	24-Jan	6.10pm	0.68	27	0.05	128	6.9	60	18	92					
213	26-Jan	6.24pm	1.4	27	0.06	114	6.9	60	1	8	0.06	7	5.5	0.19	0.16
218	31-Jan	5.26pm	0.22	30	0.09	190	6.8	90	18	3					

221	3-Feb	4.48pm	0.58	27	0.06	130	6.9	60	2	2	0	2.5	45	0.15	0.08
226	8-Feb	6.20pm	0.43	28	0.08	182	7.6	30	38	11					
229	11-Feb	8.04am	0.25	27	0.1	214	6.8	100	1	2	0	0.5	40	0.16	0.02
232	14-Feb	4.35pm	0.47	27	0.07	155	6.9	80	8	20					
233.6	15-Feb	3.17pm	3.6	25	0.04	102	7.2	30	25	54	0.03	13	20	0.34	0.07
233.8		6.58pm	2.8	25	0.05	119	7.2	60	16	25					
234	16-Feb	6.30am	1.8	25	0.05	127	7.5	70	22	20					
235	17-Feb	4.05pm	2.3	25	0.05	120	6.6	60	2	16	0	4	15	0.34	0.07
239	21-Feb	5.45pm	0.54	27	0.07	153	6.5	70	40	18					
242	24-Feb	6.36pm	0.48	26	0.07	151	6.6	80	1	0	0	0	16	0.24	0.06
246	28-Feb	5.39pm	0.36	29	0.06	146	7.8	80	1	3					
249	3-Mar	5.29pm	0.23	29	0.08	179	6.9	30	1	3	0	0	5	0.15	0.04
253	7-Mar	9.58pm	0.29	27	0.1	200	6.7	30	8	0					
256	10-Mar	6.40pm	0.48	26	0.08	167	6.8	60	2	1	0.01	1	3.7	0.14	0.08
260	14-Mar	5.39pm	0.55	27	0.08	171	7.2	70	1	0					
263	17-Mar	5.47pm	0.75	27	0.08	154	6.8	60	12	8	0.02	0	2	0.14	0.06
267	21-Mar	6.08pm	0.2	29	0.07	230	6.8	80	8	2					
271	25-Mar	5.10pm	0.8	27	0.11	103	6.8	30	2	1	0.02	3	6.4	0.16	0.04
272.6	26-Mar	7.40am	3.2	26	0.04	101	6.7	40	20	20					
272.8		5.55pm	2.1	29	0.04	109	6.7	40	1	1					
273	27-Mar	11.05am	4.9	26	0.04	84	7.1	30	20	42	0.02	4	4.2	0.11	0.03
276	30-Mar	3.53pm	1.5	28	0.03	136	6.8	30	1	2	0	1	4.5	0.15	0.02
281	5-Apr	10.26am	0.75	28	0.06	131	6.9	30	1	0					
284	8-Apr	7.36am	0.56	27	0.06	140	7.1	40	1	1	0	0	3.4	0.47	0.02
288	12-Apr	11.50am	0.49	28	0.07	153	7.1	60	1	1					
290	14-Apr	1.18pm	0.28	29	0.07	163	7	80	2	1	0.01	1	9.8	0.19	0.04
295	19-Apr	11.09am	5.2	26	0.07	73	6.9	30	58	68					
297	21-Apr	3.03pm	10.3	25	0.03	82	7.2	30	80	120	0.09	13.5	4	0.3	0.03
302	26-Apr	11.07am	4.8	28	0.02	143	6.9	50	3	2					
305	29-Apr	8.57am	2.9	28	0.05	126	6.9	40	6	4	0	1	4.8	0.4	0.04
		total	93.92	2621	8.73	18416	645.6	8670	1481	1996	7.07	295.5	698.1	12.56	4.49
		mean	0.99	27.8	0.09	195	6.9	92	15.7	21.2	0.13	5.6	13.1	0.24	0.08
		max value	10.3	33	0.16	340	7.8	160	503	520	2.4	46	45	0.66	0.58
		min value	0.01	24	0.01	36	6.4	20	1	0	0	0	0.6	0.05	0.01
		stdeviation	1.783212	1.977837	0.036397	72.99704	0.233481	40.40103	57.15929	75.7759	0.398085	7.751687	10.88997	0.132346	0.093961
		CV	1.801225	0.071145	0.404409	0.374344	0.033838	0.439142	3.640719	3.574335	3.062191	1.38423	0.831295	0.551441	1.174514

8.4 : Raw Data for Mulivai Stream

Day	Date	Time	Discharge (m3/s)	Temp (oC)	Salinity (mg/l)	Cond (uS/cm)	pH	TDS (mg/l)	Ssolid (mg/l)	Turb (NTU)	Fe2+ (mg/l)	SO42- (mg/l)	TN (mg/l)	TP (mg/l)	Zn2+ (mg/l)
1	12-Jul	2.56pm	0.22	29	0.12	261	6.8	150	2	6	0.15	6	0.8	0.33	0.07
5	16-Jul	11.02am	0.15	27	0.11	231	6.7	110	1	8	0.08	6	8.4	0.28	0.04
11	22-Jul	2.13pm	0.2	28	0.13	273	6.9	130	1	1	0.06	5.5	0.6	0.27	0.04
15	26-Jul	3.30pm	0.22	29	0.11	247	6.7	130	1	0	0.11	7	3.2	0.19	0.08
22	2-Aug	5.05pm	0.28	28	0.13	245	6.8	130	2	2					
26	6-Aug	10.06am	0.26	26	0.12	247	6.9	120	1	3	0.13	2.5	0.7	0.15	0.1
29	9-Aug	5.45pm	0.1	28	0.12	263	6.6	110	1	0					
31	11-Aug	4.48pm	0.2	28	0.12	255	7.1	120	1	0	0.06	3	0.5	0.12	0.08
35	15-Aug	4.34pm	0.56	26	0.1	224	6.8	110	3	18	0.08	6	40	0.23	0.09
36	16-Aug	6.23pm	3.27	25	0.06	133	7	70	380	400	0.55	36	40	0.29	0.04
37	17-Aug	9.12am	1.2	25	0.08	171	7.2	90	2	28	0.1	8	35	0.2	0.04
39	19-Aug	4.43pm	0.1	28	0.11	242	7.1	120	1	6	0.08	5	18	0.18	0.03
43	23-Aug	9.54am	0.32	26	0.12	245	7	130	1	2					
47	27-Aug	7.46am	0.2	25	0.11	238	7	130	1	2	0.07	10	38	0.27	0.06
50	30-Aug	5.14pm	0.3	28	0.12	228	6.7	130	1	1					
54	3-Sep	7.49am	0.35	26	0.11	247	6.7	130	1	0	0.04	3	17.8	0.17	0.04
57	6-Sep	7.51am	0.32	25	0.25	350	6.8	360	1	0					
60	9-Sep	8.09am	0.12	25	0.1	218	7	110	1	0	0.03	2.5	40	0.33	0.03
64	13-Sep	2.22pm	0.1	27	0.11	240	7.1	110	2	1					
67	16-Sep	4.42pm	0.2	27	0.11	240	6.8	120	3	3	0.02	4.5	23	0.16	0.04
70	19-Sep	6.30pm	0.2	28	0.11	242	7	120	1	0					
73	23-Sep	4.41pm	0.2	29	0.12	259	6.9	120	1	0	0.02	3	36	0.4	0.1
77	27-Sep	3.49pm	0.25	27	0.1	225	7	110	1	2					
79	29-Sep	3.36pm	0.25	30	0.12	269	6.9	120	8	2	0.01	2.5	28	0.4	0.1
84	4-Oct	4.30pm	0.2	28	0.39	950	7	500	1	0					
88	8-Oct	4.57pm	0.2	29	0.12	266	6.4	130	21	1	0	1.5	0.5	0.31	0.13
91	11-Oct	4.34pm	0.25	29	0.12	261	6.6	120	1	2					
94	14-Oct	3.46pm	0.2	29	0.1	200	7	100	4	2	0.01	2	3	0.13	0.16
98	18-Oct	4.56pm	0.1	30	0.11	232	7.1	110	1	0					
100	20-Oct	5.10pm	0.1	31	0.11	238	6.8	120	1	1					
105	25-Oct	4.17pm	0.1	29	0.11	245	6.7	120	1	5	0.01	2	0.6	0.18	0.05
106	26-Oct	5.15pm	0.62	26	0.08	175	6.6	100	5	16	0.03	6	35	0.38	0.06
107	27-Oct	2.35pm	0.2	30	0.12	258	7	120	1	0	0	0	21	0.23	0.02
111	31-Oct	5.30pm	0.35	30	0.12	264	6.9	180	1	1					
115	4-Nov	5.40pm	0.1	27	0.13	254	6.9	180	1	0					
119	8-Nov	5.19pm	0.26	29	0.11	237	7.2	120	1	1					
121	10-Nov	5.57pm	0.3	30	0.11	241	7.2	120	12	1	0.01	2	23	0.33	0.14
126	15-Nov	4.15pm	0.2	29	0.11	239	7	110	1	0					
128	17-Nov	5.00pm	0.3	29	0.18	280	7.1	110	1	0	0	1	2.4	0.32	0.01
133	22-Nov	6.05pm	0.25	29	0.13	266	6.7	120	1	2					
135	24-Nov	5.20pm	0.4	24	0.13	258	5.2	110	18	20	2	3	3	0.41	0.08
140	29-Nov	5.10pm	0.44	25	0.09	193	7	100	2	16					
142	1-Dec	5.20pm	0.5	27	0.23	471	5.9	180	19	20	0.12	26	1.8	0.25	0.42
148	7-Dec	4.05pm	0.2	28	0.19	134	6.7	210	1	0					
150	9-Dec	4.54pm	0.3	29	0.17	373	6.8	200	6	7	0.07	7	30	0.19	0.16
154	13-Dec	4.41pm	0.26	30	0.13	275	6.8	120	3	2					
156	15-Dec	4.32pm	0.38	29	0.12	268	7	120	1	2	0.01	0	20	0.16	0.03
161	20-Dec	4.58pm	0.2	28	0.59	440	6.7	160	2	5					
164	23-Dec	5.21pm	2.2	25	0.05	111	6.8	80	62	145	0.48	21	2.4	0.7	0.18
168	27-Dec	4.15pm	0.8	26	0.08	186	6.9	100	1	13					
171	30-Dec	5.45pm	0.5	28	0.08	193	6.7	100	12	56	0.16	16	6.5	0.17	0.21
177	5-Jan	2.25pm	0.62	27	0.08	176	6.7	100	18	18	0.1	8	1.5	0.43	0.17
182	10-Jan	5.00pm	0.58	29	0.12	239	6.9	120	1	0					
186	14-Jan	6.44am	0.46	26	0.12	246	6.6	140	1	6	0.06	4	28	0.14	0.21
189	17-Jan	6.29pm	0.5	28	0.12	257	7	120	1	6					
192	20-Jan	11.57am	0.35	29	0.14	298	6.6	120	1	2					
196	24-Jan	6.27pm	0.6	27	0.09	199	6.8	110	18	28					
198	26-Jan	6.51pm	0.48	28	0.09	207	6.9	110	28	18	0.09	9	28	0.23	0.16
203	31-Jan	5.49pm	0.5	29	0.13	281	6.8	140	18	5					
206	3-Feb	4.35pm	0.4	29	0.12	235	6.9	110	1	2	0	3	13	0.23	0.09
211	8-Feb	6.37pm	0.5	27	0.1	213	7.2	100	20	14					
214	11-Feb	7.41am	0.4	27	0.11	274	7.3	160	6	4	0	1	16	0.12	0.05
218	14-Feb	4.22pm	0.25	28	0.1	213	7	120	22	13					
219.6	15-Feb	3.07pm	1.2	25	0.07	153	7.3	80	24	40	0.04	6	24	0.18	0.05

219.8	15-Feb	7.12pm	1.3	25	0.07	166	7.5	30	17	28					
221	17-Feb	3.43pm	0.7	27	0.1	238	6.9	60	8	10	0.03	4	35	0.29	0.06
225	21-Feb	5.29pm	0.62	27	0.09	202	7.2	100	6	18					
228	24-Feb	6.57pm	0.51	28	0.05	207	6.7	60	1	1	0	0	11	0.15	0.05
232	28-Feb	5.20pm	0.8	29	0.12	253	7.4	140	2	2					
235	3-Mar	5.21pm	0.36	29	0.15	349	6.8	130	1	0	0	0	17	0.16	0.04
239	7-Mar	10.26am	0.4	27	0.13	262	6.8	130	1	0					
242	10-Mar	6.39pm	0.46	26	0.14	269	6.8	110	4	2	0	3	15.8	0.24	0.06
246	14-Mar	5.15pm	0.3	28	0.11	240	6.9	100	2	2					
249	17-Mar	5.25pm	0.22	27	0.14	287	6.8	100	1	0	0	4	24	0.24	0.05
253	21-Mar	6.33pm	0.36	28	0.11	245	6.9	100	2	4					
257	25-Mar	4.49pm	0.7	28	0.07	199	6.8	110	2	1	0.01	0	18	0.24	0.05
258	26-Mar	6.46pm	0.72	29	0.07	154	6.9	70	1	1					
259	27-Mar	10.45am	0.5	29	0.07	182	6.9	60	22	10	0.02	6	15.2	0.23	0.04
262	30-Mar	4.15pm	0.47	29	0.09	193	7	70	2	1	0.01	0	26	0.1	0.03
268	5-Apr	10.15am	0.42	28	0.07	198	7	70	1	2					
271	8-Apr	7.45am	0.35	27	0.08	182	7	60	4	2	0.02	0	23	0.36	0.05
275	12-Apr	11.40am	0.41	28	0.08	174	7.1	60	1	3					
277	14-Apr	1.04pm	0.3	29	0.08	180	6.9	60	2	2	0	1	38	0.37	0.06
282	19-Apr	11.28am	1.2	26	0.05	121	6.9	50	38	32					
284	21-Apr	2.50pm	1.4	26	0.05	112	6.8	60	20	16	0.12	8	17	0.22	0.04
289	29-Apr	11.30am	0.6	29	0.08	180	6.9	80	3	2					
292	29-Apr	8.24am	0.6	28	0.07	161	7.1	60	2	2	0.01	0	17.8	0.14	0.03
		Total	40.02	2409	10.26	21046	598.2	10320	901	1100	5	255	847.5	11.8	3.92
		Average	0.46	27.7	0.11	242	6.8	118	10.3	12.6	0.1	5.4	18	0.25	0.08
		max value	3.27	31	0.59	950	7.5	500	380	400	2	36	40	0.7	0.42
		min value	0.1	24	0.05	111	5.2	30	1	0	0	0	0.5	0.1	0.01
		st.deviatio	0.449421	1.5	0.06	96.5	0.28	58.4	41	45.4	0.29	6.8	13	0.1	0.07
		CV	0.977002	0.0541	0.5454	0.3987	0.0411	0.4949	3.9806	3.603	2.9	1.259	0.7222	0.44	0.875

8.5 : Raw Data for the Vaisigano River

Day	Date	Time	Discharge (m^3/s)	Temp (oC)	Salinity (mg/l)	Cond (uS/cm)	pH	TDS (mg/l)	S.solids (mg/l)	Turbidity (NTU)	Fe^{2+} (mg/l)	SO_4^{2-} (mg/l)	TN (mg/l)	TP (mg/l)	Zn^{2+} (mg/l)
1	8-Jul	7.09am	1.5	25	0.05	126	6.9	70	15	12	0.02	3			
4	12-Jul	2.15pm	1.2	26	0.05	130	7.2	60	12	18					
8	16-Jul	10.34am	1.6	24	0.05	128	6.8	60	20	15	0.02	1.5	1.3	0.12	0.03
14	22-Jul	3.15pm	1	26	0.06	132	6.7	60	4	5					
18	26-Jul	3.00pm	1.6	25	0.06	132	6.7	60	20	1	0.03	1	3.2	0.14	0.07
25	2-Aug	4.33pm	1.2	25	0.06	132	7.2	60	12	0					
29	6-Aug	9.30am	1.1	24	0.06	137	6.8	70	20	1	0.04	1	2.7	0.21	0.06
32	9-Aug	6.12pm	0.8	27	0.09	192	7.1	90	1	0					
34	11-Aug	5.10pm	0.5	26	0.09	196	6.8	90	1	0	0.04	1	5.4	0.24	0.03
38	15-Aug	5.01pm	1.5	25	0.05	133	6.8	60	1	0	0.03	1	0.8	0.12	0.04
39	16-Aug	6.37pm	2.8	24	0.04	110	6.9	60	10	46	0.11	7.5	10.5	0.25	0.03
40	17-Aug	8.34am	6.4	23.5	0.03	92	7	50	16	40	0.07	4	4.5	0.13	0.06
42	19-Aug	4.21pm	3.2	28	0.06	134	6.9	60	1	2	0.02	1.5	0.6	0.14	0.03
46	23-Aug	9.03am	2.2	23	0.05	122	6.8	60	1	0					
50	27-Aug	8.10am	1.8	23	0.05	123	7.1	70	1	0	0.01	0.5	5	0.08	0.14
53	30-Aug	5.26pm	1.2	23	0.06	146	6.8	70	1	0					
54	3-Sep	8.14am	1.2	24.5	0.06	138	6.8	60	1	0	0.01	0.5	1.2	0.09	0.03
57	6-Sep	8.29am	1.6	23	0.05	118	7.2	60	1	0					
60	9-Sep	6.50am	1.6	23.5	0.05	119	7.3	70	1	0	0.02	1	3.5	0.13	0.04
64	13-Sep	1.05pm	1.2	26	0.05	131	7.4	60	2	1					
67	16-Sep	3.41pm	2.8	25	0.04	104	7	50	15	15	0.12	12	7.2	0.28	0.04
70	19-Sep	5.33pm	0.8	26	0.07	156	6.8	70	1	0					
73	23-Sep	4.20pm	1.3	27	0.06	136	7	60	1	1	0.02	2	2.1	0.8	0.08
77	27-Sep	3.38pm	0.8	26	0.06	141	7.3	70	1	2					
79	29-Sep	3.24pm	0.8	28	0.07	146	6.9	70	2	0	0.01	2.5	12.8	0.47	0.07
84	4-Oct	4.19pm	1.9	25	0.06	136	7.4	60	1	0					
88	8-Oct	4.39pm	1.1	26	0.06	136	7.2	60							
91	11-Oct	5.00pm	0.5	27	0.06	141	7.3	70	1	1					
94	14-Oct	3.34pm	0.85	28	0.07	158	7.2	60	1	0	0.01	1	1.8	0.4	0.08
98	18-Oct	5.16pm	1.2	27	0.06	140	7.5	70	1	0					
99	19-Oct	5.10pm	10.8	24	0.01	53	6.8	20	2	5	0.02	3.5	5.2	0.12	0.11
100.4	20-Oct	11.20am	1.4	27	0.05	125	7.2	60	1	0	0.01	1.5	0.8	0.08	0.15
100.7	20-Oct	4.49pm	1.1	28	0.06	137	6.8	70							
105	25-Oct	4.02pm	0.8	27	0.06	134	6.8	60	1	3	0.01	2	0.6	0.37	0.08
106	26-Oct	5.26pm	4.8	25	0.03	83	7.2	40	10	17	0.06	6	2.7	0.3	0.06
107	27-Oct	6.05am	2.5	24	0.06	104	6.6	50	3	3	0	1.5	12	0.51	0.02
111	31-Oct	5.19pm	1.3	27	0.07	122	7.2	60	1	2					
115	4-Nov	5.19pm	1.3	26	0.07	133	6.8	60	1	0	0	0	3.2	0.39	0.04
119	8-Nov	5.07pm	1.1	27	0.07	131	6.8	60	1	0					
121	10-Nov	5.43pm	1.5	27	0.06	127	7	60	1	0	0	1	2.4	0.13	0.15
126	15-Nov	4.00pm	2.2	27	0.08	134	7	70	1	0					
128	17-Nov	4.50pm	1.24	27	0.08	129	6.8	70	1	0	0	0	4.4	0.15	0.02
133	22-Nov	6.16pm	1.1	27	0.07	158	7.1	70	1	1					
135	24-Nov	5.00pm	0.98	29	0.07	150	6.7	70	1	0	0	0	1.2	0.08	0.02
140	29-Nov	4.58pm	5.2	25	0.05	92	6.6	40	12	20					
142	1-Dec	5.12pm	1.41	26	0.07	142	6.8	60	18	15	0.05	6	3.5	0.22	0.16
148	7-Dec		0.96	27	0.06	148	6.7	70	1	0					
150	9-Dec	4.36pm	1.8	26	0.06	130	6.8	70	8	10	0.07	6	5.2	0.16	0.11
154	13-Dec	4.56pm	0.71	27	0.08	162	6.9	80	1	0					
156	15-Dec	4.18pm	2.7	27	0.06	61	6.8	50	4	2	0	1	1.7	0.66	0.02
161	20-Dec	5.11pm	1.9	26	0.05	45	6.9	50	1	2					
164	23-Dec	5.04pm	7.7	25	0.03	83	6.8	40	28	36	0.2	13	4.2	0.63	0.12
168	27-Dec	4.03pm	2.6	25	0.05	112	7	60	1	2					
171	30-Dec	5.34pm	2.8	27	0.04	109	6.6	50	2	8	0.08	6.5	0.7	0.24	0.1
174	3-Jan	3.25pm	2.2	29	0.04	119	ccidentally emptied								
176	5-Jan	3.08pm	1.9	25	0.05	114	6.8	60	16	10	0.09	7.5	0.8	0.19	0.21
181	10-Jan	4.51pm	1.9	27	0.05	114	6.8	60	16	10					
185	14-Jan	6.29pm	1.8	24	0.06	130	6.8	70	2	5	0.06	6	0.8	0.16	0.26
188	17-Jan	7.04pm	1.2	26	0.07	155	7	80	2	3					
191	20-Jan	11.30am	1.61	28	0.06	136	6.8	60	1	0	0	0	6.2	0.12	0.03
195	24-Jan	6.39pm	2.4	25	0.05	119	7.1	60	20	62					
197	26-Jan	6.21pm	2.2	26	0.05	114	6.9	60	31	16	0.11	12	4.1	0.13	0.13
202	31-Jan	6.07pm	1.63	28	0.06	123	7.5	70	19	5					
205	3-Feb	4.24pm	1.82	27	0.05	131	7.2	60	1	1	0	0	3.8	0.25	0.03

210	8-Feb	6.46pm	1.5	26	0.06	127	8.2	60	22	8				
213	11-Feb	8.38am	1.7	25	0.06	120	7.4	60	1	0	0	0	9.8	0.12	0.02
216	14-Feb	4.12pm	1.7	25	0.05	124	7.1	60	18	10				
217.6	15-Feb	2.54pm	6.6	25	0.03	84	7.3	40	22	36	0.05	0	2.2	0.23	0.07
217.8	15-Feb	6.50pm	5.5	24	0.03	80	6.8	30	34	28				
218	16-Feb	6.20am	4.8	24	0.04	101	7.3	30	26	24				
219	17-Feb	3.30pm	3.9	24	0.04	101	6.9	50	10	15	0.02	0	3.6	0.12	0.03
223	21-Feb	5.15pm	2.8	26	0.06	129	7.2	70	1	0				
226	24-Feb	7.10pm	2.4	25	0.05	125	7.1	60	1	2	0	0	4.8	0.11	0.03
228	28-Feb	5.11pm	1.5	27	0.06	131	7.8	60	1	2				
231	3-Mar	5.09pm	1.4	27	0.06	139	6.9	70	1	0	0.02	0	3.7	0.4	0.05
235	7-Mar	9.15am	2.3	25	0.05	119	7.3	60	1	0				
238	10-Mar	6.18pm	2.6	25	0.05	115	7.2	40	4	2	0	0	3	0.24	0.04
242	14-Mar	5.05pm	1.8	26	0.05	119	6.8	30	4	2				
245	17-Mar	5.18pm	3	25	0.05	113	7.1	40	1	2	0.02	0	3.2	0.11	0.03
249	21-Mar	6.42pm	1.3	26	0.07	151	7.2	60	1	0				
254	25-Mar	4.41pm	2.3	26	0.04	109	7	60	1	0	0.03	0	5.8	0.13	0.05
255.4	26-Mar	7.30am	6.7	26	0.03	86	6.8	30	16	36				
255.8	26-Mar	6.27pm	4.8	26	0.04	99	7.9	30	1	0				
256	27-Mar	10.32am	9.3	23	0.03	76	7.8	20	2	2	0	1	1.2	0.13	0.08
259	30-Mar	3.40pm	2.4	25	0.04	107	7	30	1	0	0	0	2.3	0.15	0.02
265	3-Apr	10.00am	2.3	25	0.04	86	7.8	20	1	1				
268	8-Apr	7.34am	1.8	24	0.05	118	7.7	30	1	0	0	0	3	0.33	0.02
272	12-Apr	11.24am	2.2	26	0.04	102	7.6	40	1	1				
274	14-Apr	12.53pm	1.5	28	0.05	129	7.7	70	1	0	0	1	3.5	0.12	0.03
279	19-Apr	10.20am	3.3	26	0.03	90	7.6	40	12	2				
281	21-Apr	2.35pm	7.8	25	0.03	73	7.7	30	18	8	0.03	1	2	0.54	0.18
286	26-Apr	11.43am	1.9	28	0.05	114	7.5	50	1	1				
289	29-Apr	8.10am	2.5	26	0.01	64	7.6	20	1	0	0	0	3.8	0.16	0.03
		total	219.41	2396.5	4.95	11255	651.7	5200	579	580	1.51	117.5	178	11.38	3.33
		mean	2.359247	25.7	0.05	121	7.1	56.5	6.4	6.4	0.03	2.4	3.7	0.24	0.07
		max value	10.8	29	0.09	196	8.2	90	34	62	0.2	13	12.8	0.8	0.26
		min value	0.5	23	0.01	45	4.4	20	0	0	0	0	0.6	0.08	0.02
		stdev	1.91	1.4	0.01	26	0.33	15.2	8.4	11.6	0.04	3.3	2.8	0.16	0.05
		CV	1.2352	0.05	0.29	0.21	0.05	0.27	1.3	1.8	1.3	1.4	0.75	0.69	0.7

APPENDIX 9: Suspended & Solute Loads as described by Douglas (1968)

9.1 Suspended & Solute Loads for the Five Catchment Area

EQUATION USED : Qs = C* Qw / A* G

where Qs = suspended or solute load in $m^3/km^2/yr$
C = concentration of suspended or solute matter in mg/l
Qw = stream discharge in cumecs
A = the drainage area in square kilometres
G = the specific gravity of the rock material

The average specific gravity of 2.65 as used by Holeman (1968) in his calculations is used here as well. With allowance made for the units of time used in the discharge measurements and concentration, the formula then stood as :

Qs = C* Qw * 60*60*24*365 / A* 2.65* 1000

SEDIMENT LOADS	SOLUTE LOADS
FAGALII STREAM	
Average discharge = 0.357 m^3/s	Average discharge = 0.357 m^3/s
Average Ssolids conc = 6.47 mg/l	Average TDS conc = 53.4 mg/l
Solute load = 4060 $m^3/km^2/yr$	Solute load = 33511 $m^3/km^2/yr$
At a specific gravity of 2.65 = 10556 $t/km^2/yr$	At a specific gravity of 2.65 = 87130 $t/km^2/yr$
And a drainage area of 6.9 km^2 = 72836 t/yr	And a drainage area of 6.9 km^2 = 601196 t/yr
FULUASOU RIVER	
Average discharge = 1.149 m^3/s	Average discharge = 1.149 m^3/s
Average S.solids conc = 6.12 mg/l	Average TDS conc = 55.05 mg/l
Suspended sediment load = 3318 $m^3/km^2/yr$	Solute load = 29852 $m^3/km^2/yr$
At a specific gravity of 2.6 = 8626 $t/km^2/yr$	At a specific gravity of 2.6 = 77616 $t/km^2/yr$
And a drainage area of 25.7 km^2 = 221757 t/yr	And a drainage area of 25.7 km^2 = 1994729 t/yr
GASEGASE STREAM	
Average discharge = 0.789 m^3/s	Average discharge = 0.789 m^3/s
Average S.solids conc = 15.8 mg/l	Average TDS conc = 92.2 mg/l
Suspended sediment load = 6326 $m^3/km^2/yr$	Solute load = 36918 $m^3/km^2/yr$
At a specific gravity of 2.6 = 16449 $t/km^2/yr$	At a specific gravity of 2.6 = 95988 $t/km^2/yr$
And a drainage area of 23.9 km^2 = 393134 t/yr	And a drainage area of 23.9 km^2 = 2294111 t/yr
MULIVAI STREAM	
Average discharge = 0.482 m^3/s	Average discharge = 0.482 m^3/s
Average S.solids conc = 10.1 mg/l	Average TDS conc = 125.4 mg/l
Suspended sediment load = 7873 $m^3/km^2/yr$	Solute load = 9836 $m^3/km^2/yr$
At a specific gravity of 2.6 = 20470 $t/km^2/yr$	At a specific gravity of 2.6 = 255731 $t/km^2/yr$
And a drainage area of 7.5 km^2 = 153523 t/r	And a drainage area of 7.5 km^2 = 2071511 t/yr
VAISIGANO RIVER	
Average discharge = 2.13 m^3/s	Average discharge = 2.13 m^3/s
Average S. solids conc = 6.43 mg/l	Average TDS conc = 56.5 mg/l
Suspended sediment load = 4915 $m^3/km^2/yr$	Solute load = 43186 $m^3/km^2/yr$
At a specific gravity of 2.6 = 12778 $t/km^2/yr$	At a specific gravity of 2.6 = 112284 $t/km^2/yr$
And a drainage area of 33.8 km^2 = 431 896 t/yr	And a drainage area of 33.8 km^2 = 4 133 199 t/yr

APPENDIX 10: Methodologies* for Sediment Parameter Determinations

* As described in Eaqub, M., Yappa, G. G. & Chand, K. (eds), 1993. Laboratory Manual. Fundamentals of Soil Science. Soil Science Section, School of Agriculture, University of the South Pacific, Apia.

The moisture content (MC) is the weight of 50 g sample of sediment (air dry) divided by the weight of the same sediment sample after drying in an oven at 105°C for 12 to 24 hours.

The sediment pH of each sample was measured after mixing 10 g of air dried sediment with 50 cm^3 of distilled water. The suspension was stirred vigorosusly and left standing for one hour. The samples were stirred again just before reading with an Orion 301 pH meter. To obtain the pH (KCl) reading a 1N KCl solution was substituted for distilled water.

Total nitrogen was determined by the procedure described by Bremmer & Mulvaney (1982). The sediment samples were firstly soaked overnight with 5 cm^3 of concentrated sulphuric acid and 2 g of digesting salt mixture (100g potassium sulphate mixed with 10g copper sulphate and 1g selenium powder). The samples were then digested at 420°C for one hour, allowed to cool and transferred to the distilation unit where 10 cm^3 of 50% sodium hydroxide solution was added. From this mixture, 30 cm^3 was distilled off into a flask containing 10 cm^3 of boric acid and indicator solution. The resulting solution was then titrated with standardised 0.001 N sulphuric acid until a colour change (bluish to faint pink) was observed. The total nitrogen contents were calculated using the formula:

$$N\% = ml\ H_2SO_4\ sample - ml\ H_2SO_4\ blank / g\ sample * Normality\ of\ acid * 1.4 * MC$$

The phosphorus content of each sediment sample was extracted using the modified Truog method where 100 cm^3 of 0.02 N sulphuric acid (extracting solution) was added to one gram of sediment (air dried). The mixtures were shaken on an end-to-end shaker for 30 minutes. The phosphorus contents were measured with a Spectronic 20 Spectrophotometer using Murphy & Riley's (1962) complexing reagent.

The trace metals (Cu, Fe, Mn, Zn) were extracted from a 1:5 ratio suspension of soil and extracting reagent (DTPA) which has been shaken for one hour. Measurements were carried out on a Perkin-Elmer 2280 Atomic Absorption Spectrophotometer (AAS) using an air/acetylene flame. Regression analyses were done on the standard curve of each element to determine the actual trace metal concentration in the different soils.

Soil texture was determined by the Bouyoucos method where the amount of particles in suspension is determined using a hydrometer. The hydrometer and tempertaure readings were taken after 40 seconds (by which time all the sand particles have passed below the heart of the hydrometer) and 2 hours (measures the amount of clay in suspension). The percent of sand, silt and clay were calculated using Stoke's Law, and the texture was read off from the Soil Textural Triangle.

Colour was determined from the Maunsell Colour Chart.

APPENDIX 11 : Concentrations of Selected Contaminants in the Sediments

SATAOA SEDIMENTS

Name	Sample number	Depth (cm)	MC	pH (H2O)	pH (KCl)	TN (%)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	TP (mg/kg)	OD weight (g)	B density (g/cm3)	Colour (dry)	Colour (wet)	Texture
Sataoa1	1	5	1.03	7	6.6	0.25	171.9	7.3	0.6	3.4	172.6	48.54	0.81	7.5YR 2/0	5YR 2/1	sand
(no photo)	2	11	1.05	7.2	7	0.16	96.7	8.4	0.7	3.4	274.6	47.62	2.66	5 YR 2/1	7.5YR 2/0	sand
S1	3	16	1.05	6.8	6.4	0.14	101.9	10	0.7	3.9	345.2	47.62	1.59	2.5Y 2/1	5Y 2/2	sand
	4	21	1.04	6.8	6.4	0.17	116.8	8.1	1	3.7	230.1	48.07	1.61	10YR 2/1	5Y 2/1	sand
	5	25	1.02	8	7.6	0.14	81.1	4.5	0.7	2.3	316.5	49.02	1.64	5Y 2/2	5YR 2/1	sand
Sataoa2	58	3	1.03	8.2	7.8	0.13	405.5	8.5	0.4	0.6	63	48.54	1.35	5Y 4/1	7.5YR 2/0	
S2	59	11	1.03	7.8	7.6	0.13	555.8	8.2	0.6	0.7	239.5	48.54	0.81	10YR 3/1	2.5Y 2/0	sand
	60	21	1.03	8.2	7.6	0.12	520.9	4.4	0.6	0.6	137.7	48.54	0.9	10YR 3/1	2.5Y 2/0	sand
Sataoa3	61	4	1.04	7.8	7.6	0.25	508.2	6.2	0.6	1.1	13	48.54	1.01	5Y 5/1	10YR 3/1	
S3	62	12	1.02	8	7.8	0.21	525.3	7.1	0.6	1.3	33.3	48.07	1	5Y 5/1	10YR 3/1	loamy sand
	63	19	1.04	8	7.6	0.2	483.7	5.9	0.5	0.9	44.9	48.54	1.35	-	-	sand
	64	24	1.04	7.6	7.4	0.16	538.7	5.6	0.6	1.3	185.6	48.07	1.61	5Y 3/1	7.5YR 2/0	
	65	30	1.04	6	5.6	0.21	764.2	7.1	0.8	3.2	329.3	48.07	1.15	5Y 2.5/1	7.5YR 2/0	
	66	41	1.03	5.6	5.4	0.2	908.5	6.8	0.4	7	299.4	48.54	0.62	5Y 2.5/2	7.5YR 2/0	

MOATAA & VAISIGANO SAMPLES

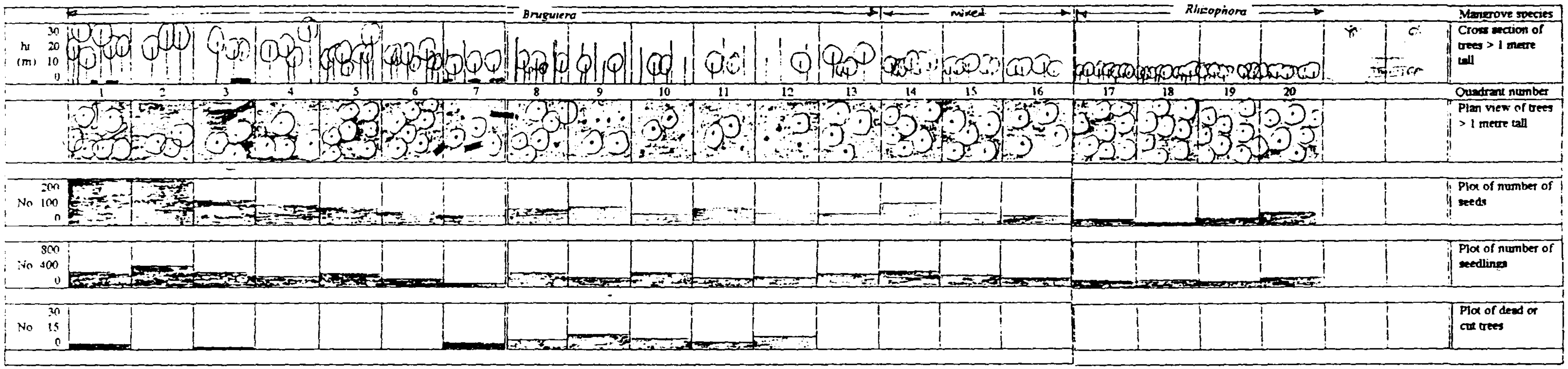
Name	Sample number	Depth (cm)	MC	pH (H2O)	pH (KCl)	TN (%)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	TP (mg/kg)	OD weight (g)	B.density (g/cm3)	Colour (dry)	Colour (wet)	Texture
Moataa1	6	3.5	1.03	7.8	8	0.12	50.6	4.9	1.1	1.4	60.4	48.54	1.16	5YR 5/1	2.5Y 2/0	
(no photo)	7	11	1.04	9	8.2	0.17	43.2	3.2	1.1	1	97.8	48.54	0.9	10YR 5/1	5YR 2/1	sand
M1	8	21	1.03	8.2	7.8	0.21	61	6.3	1.8	0.8	115.1	47.61	0.88	7.5YR 4/0	.5YR 2.5/	sand
	9	27	1.04	8.2	7.8	0.11	68.5	3.7	2.6	1.1	120.8	48.07	1.61	10YR 4/1	7.5YR 2/0	
	10	32	1.05	7.4	6.8	0.3	115.3	6.9	1.1	2.4	166.9	47.62	1.99	10YR 4/1	7.5YR 2/0	
	11	35	1.04	7.2	6.6	0.25	nes	nes	nes	nes	132.5	48.07	4.02	-	-	
Moataa2	18	7	1.07	6.2	6.1	0.48	158.7	8.5	3.3	7.1	201.1	46.72	0.56	-	-	sandy loam
M2	19	26	1.06	5	4.8	0.23	159	6.6	2.1	5.7	230.7	47.17	0.31	5Y 3/1	2.5Y 2/0	loamy sand
	20	51	1.05	5.2	4.9	0.21	147.9	5.4	1.8	3.2	221.8	47.62	0.32	10YR 3/2	7.5YR 2/0	loamy sand
Vaisigano	55	8	1.03	8.6	8.2	0.13	558.8	47	1.9	2.3	299.4	49.01	0.48	10YR 4/2	5YR 2.5/1	sand
Vz	56	25	1.03	8.4	8	0.11	752.3	54.1	2.7	3.5	389.2	48.54	0.51	"	"	sand
	57	37	1.03	8.4	8	0.09	818.5	46.8	3.4	3.9	254.5	48.54	0.9	"	"	

VAIUSU SEDIMENTS

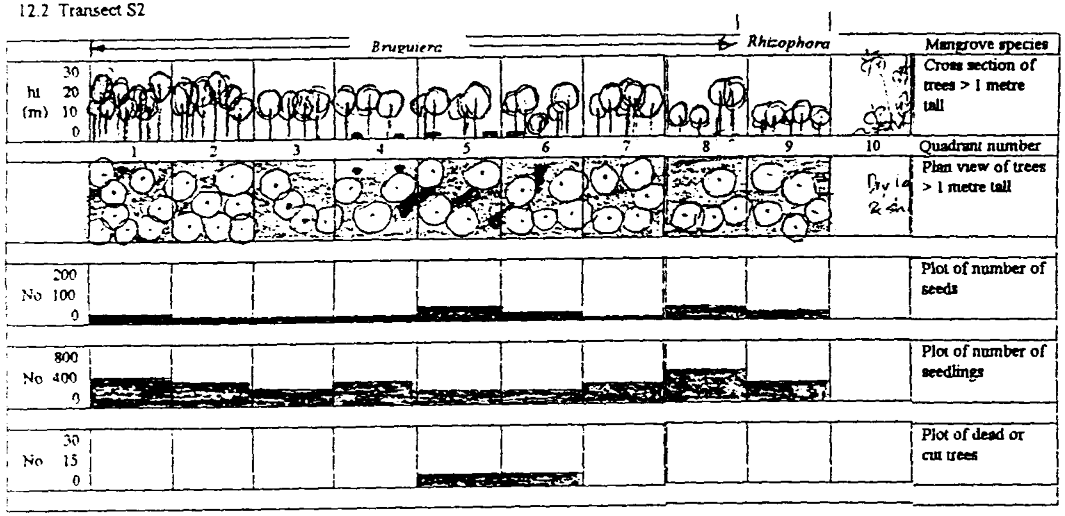
Name	Sample number	Depth (cm)	MC	pH (H2O)	pH (KCl)	TN (%)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	TP (mg/kg)	OD weight (g)	B.density (g/cm3)	Colour (dry)	Colour (wet)	Texture
Vaiusu1	21	3.5	1.07	8	7.8	0.22	78.8	21.8	2.5	4.1	11.8	46.72	1.3	10YR 5/1	5Y 3/1	
V1	22	13	1.03	8.2	8.2	0.21	40	27.3	1.8	3.1	23.7	48.54	0.54	"	"	sandy loam
	23	24	1.04	8.6	8.4	0.24	27	18.4	1.4	2.1	14.8	48.07	1.15	"	"	
	24	31	1.04	8.6	8.4	0.21	25.9	17.7	1.2	1.8	14.8	48.07	1.15	"	"	
Vaiusu2	25	2	1.05	8.4	8.2	0.18	70.2	17.3	2.1	2.1	251.4	47.62	1.59	2.5Y 3/2	2.5Y 2/0	
V2	26	7	1.04	8.6	8.2	0.15	65.9	28.8	1.6	2.1	266.2	48.07	1.61	10YR 4/1	5Y 2.5/1	
	27	12	1.05	8.6	8.2	0.27	74.5	28.6	2	2.9	275.1	48.07	1.61	"	2.5Y 2/0	loamy sand
	28	20	1.05	8.4	8	0.27	72.3	25.6	2	1.9	295.8	48.07	0.8	"	5Y 2.5/1	sandy loam
	29	29	1.04	8.4	7.8	0.29	54	17.5	1.5	0.6	325.4	47.61	0.79	"	2.5Y 2/0	loamy sand
	30	40	1.04	8.2	8.1	0.16	49.7	17.1	1.6	0.5	295.8	47.61	0.79	"	5Y 2.5/1	sandy loam
	31	47	1.04	8.4	8	0.18	50.7	17	1.7	0.5	295.8	49.01	1.64	"	2.5Y 2/0	sandy loam
	32	54	1.04	8.6	8	0.15	51.8	16.7	1.7	0.6	275.4	49.01	1.02	"	"	
Vaiusu3	33	4	1.04	8.6	8.2	0.12	59.4	26.5	2.1	1.8	281	48.54	1.01	10YR 4/1	2.5Y 2/0	sandy loam
V3	34	16	1.04	8.2	8	0.13	75.6	24.7	2.1	2.3	354.9	48.54	0.48	"	5Y 2.5/1	sandy loam
	35	32	1.04	8.4	8.2	0.11	54	20.5	1.8	0.9	295.8	48.07	0.53	"	2.5Y 2/0	loamy sand
	36	45	1.04	8.4	8.3	0.18	40	16.9	1.6	0.4	293.7	48.07	0.8	"	5Y 2.5/1	sandy loam
Vaiusu4	52	5	103	8.2	8	0.11	408.5	22.8	1.7	2	21	48.07	0.74	5Y 4/1	5Y 2.5/1	
(no photo	53	17	1.03	8.2	8.1	0.11	381	18.9	1.2	1.3	26.9	48.54	0.62	10YR 4/1	5Y 3/1	sandy loam
V4	54	32	1.03	8.2	8.2	0.13	325.2	17.2	1	1	29.9	48.54	0.51	10YR 4/1	5Y 3/1	sandy loam
Vaiusu5	41	5	1.03	8.2	8	0.2	307.3	38.2	1.8	0.6	212.6	48.54	0.81	5Y 5/4	2.5Y 2/0	sandy loam
V5	42	18	1.03	8.4	8.2	0.19	294.7	33.7	1.8	0.7	242.5	48.54	0.51	"	"	loamy sand
	43	34	1.03	8.6	8.1	0.2	244.8	26.8	1.8	0.5	254.5	48.54	0.43	"	"	loamy sand
	44	51	1.03	8.4	8.2	0.12	165.2	18.7	1.3	0.4	254.5	48.54	0.74	"	"	loamy sand
	45	60	1.03	8.6	8.4	0.13	159.2	13.8	1.1	0.4	254.5	48.54	1.01	"	"	loamy sand
	46	68	1.03	8.7	8.2	0.14	155.9	11.9	1	0.5	239.5	48.54	1.01	"	"	loamy sand
Vaiusu6	47	4	1.04	8.2	8	0.11	442.7	26.5	1.9	2.4	89.8	48.07	0.89	10YR 4/1	5Y 2.5/1	
V6	48	15	1.04	8.2	7.8	0.12	442	24.1	1.8	2	329.3	48.07	0.67	5Y 4/1	2.5Y 2/0	silt loam
	49	25	1.04	8.2	7.6	0.22	436	38.4	1.5	8.4	419.1	48.07	1	2.5Y 4/2	7.5YR 3/2	
	50	33	1.04	8.2	7.7	0.12	247	12.8	1	3.2	182.6	48.07	1	"	"	
	51	41	1.04	8.2	7.6	0.11	282	19.7	0.9	2.5	359.3	48.07	1.61	"	"	

APPENDIX 12: Transect Informations for Three Mangrove Areas in Samoa.

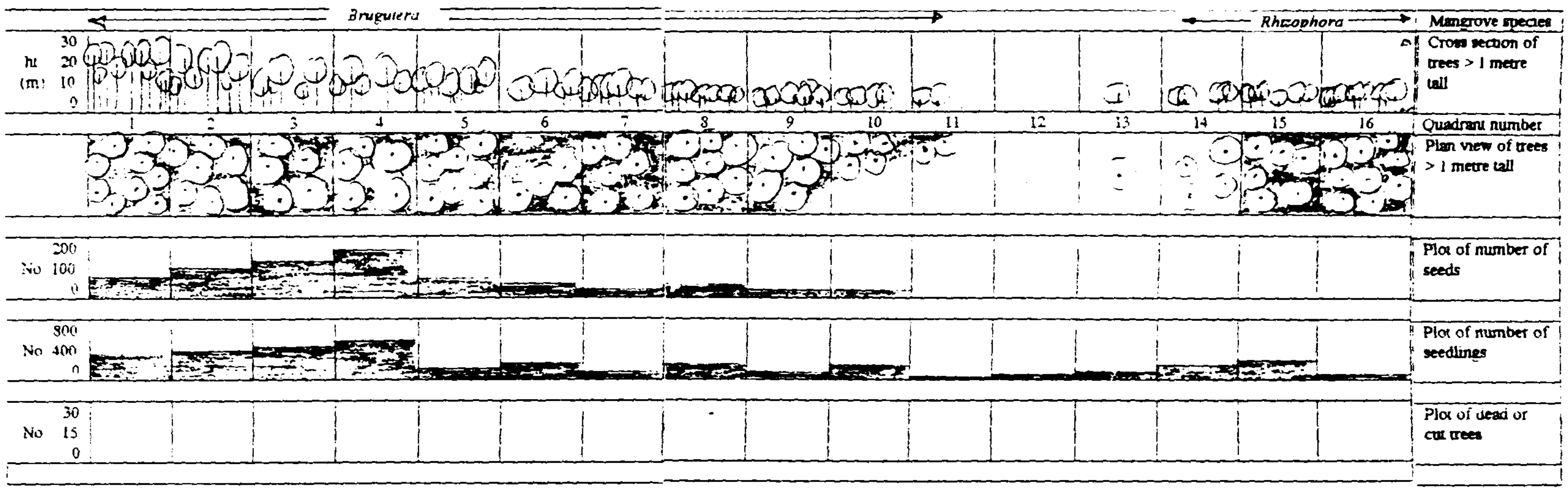
12.1 Transect S1



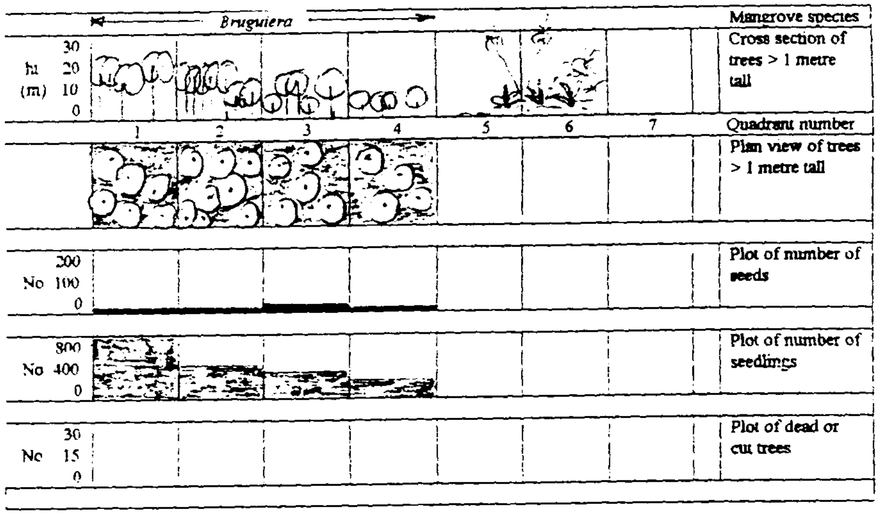
12.2 Transect S2



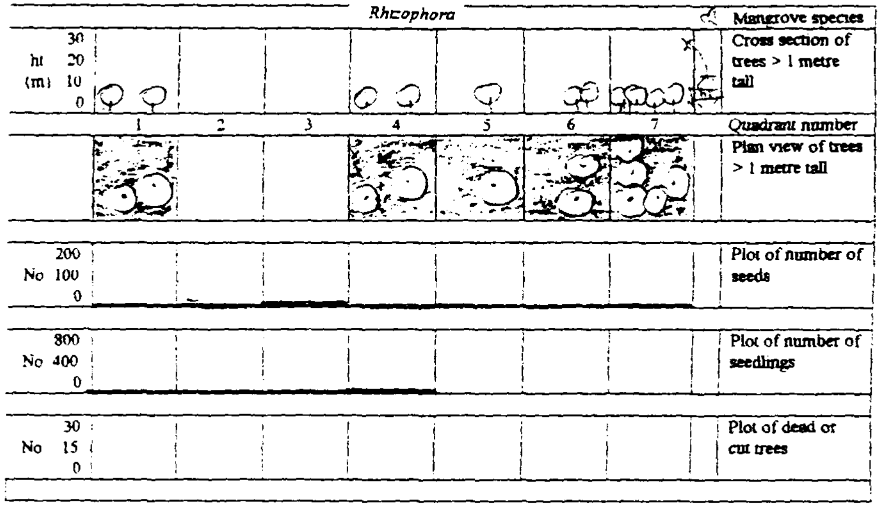
12.3 Transect S3



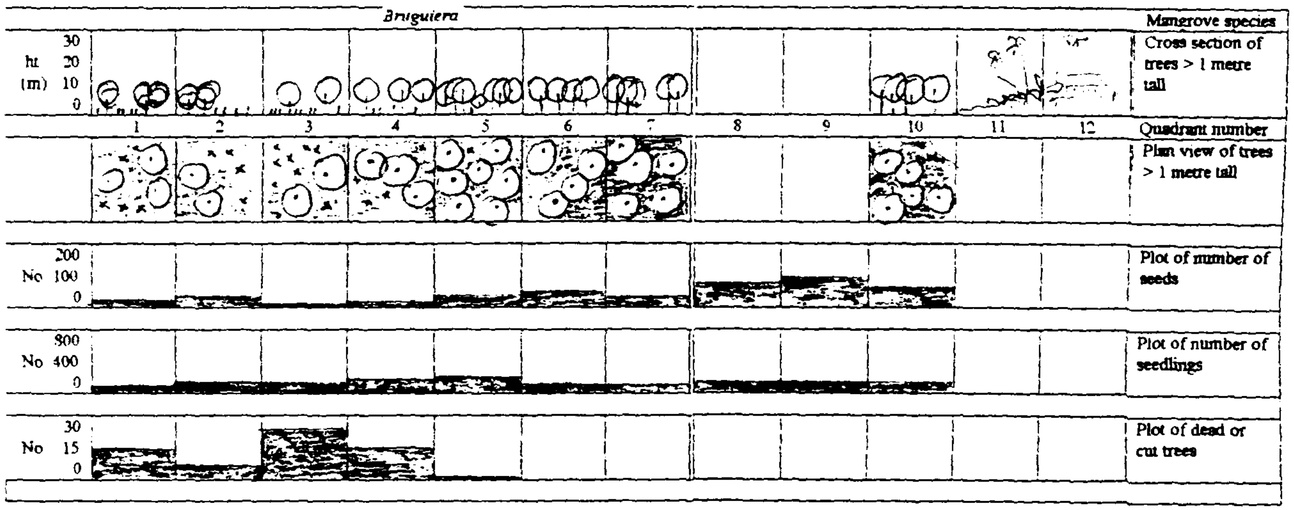
12.4 Transect S4



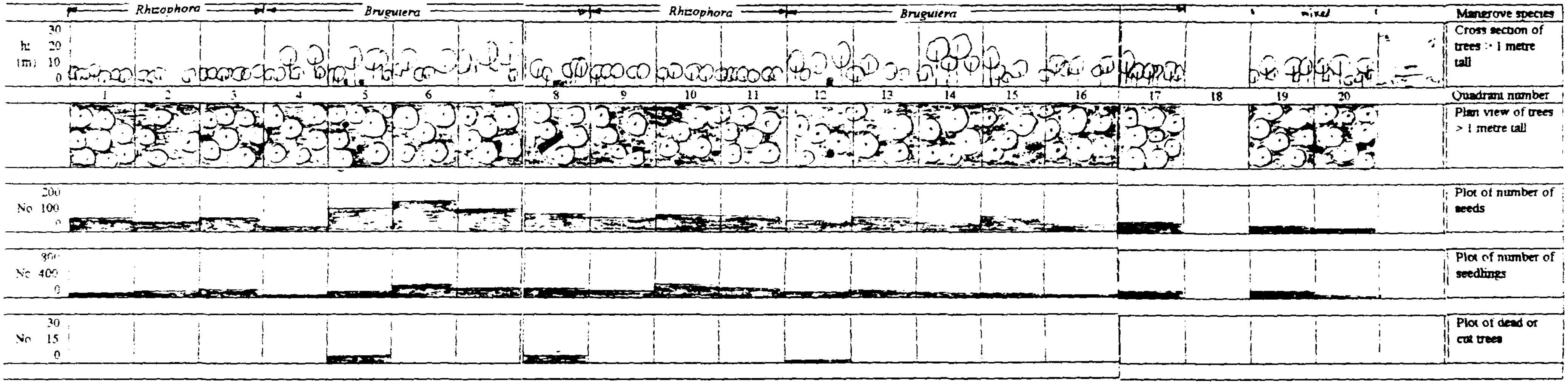
12.5 Transect V1



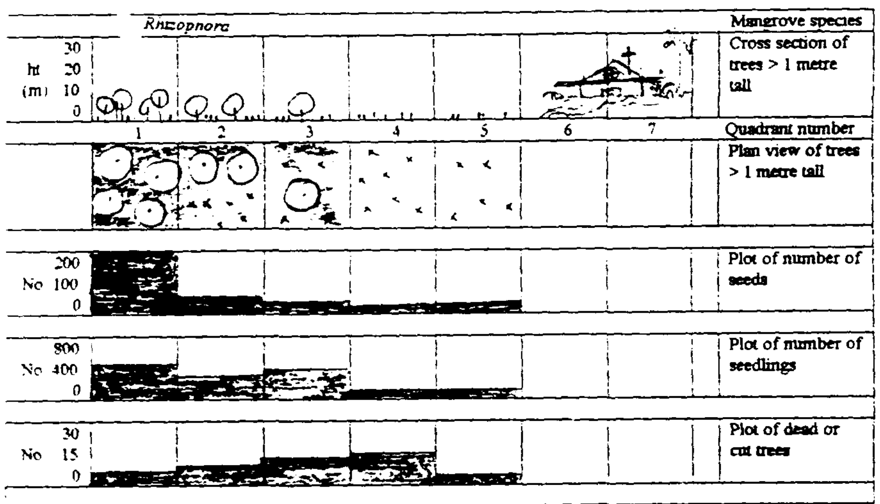
12.6 Transect V2



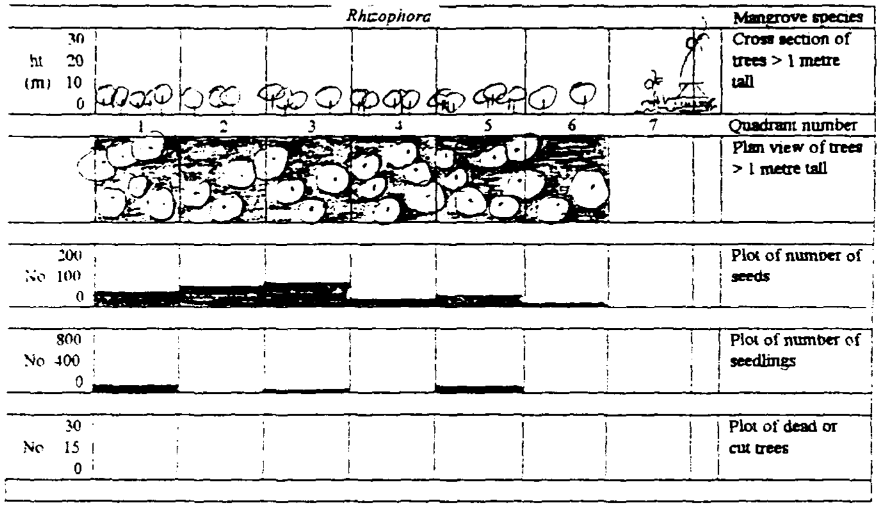
12.7 Transect V3



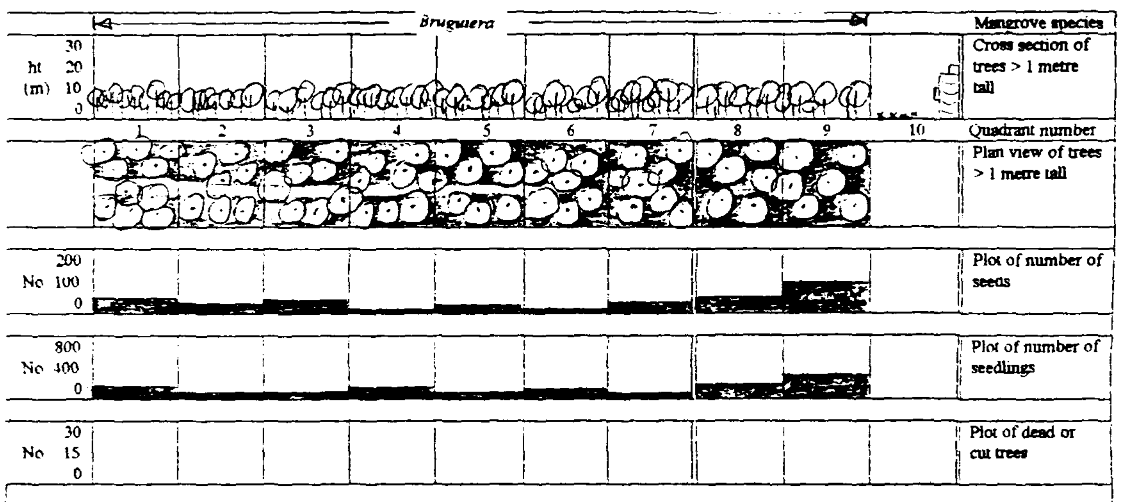
12.8 Transect V4



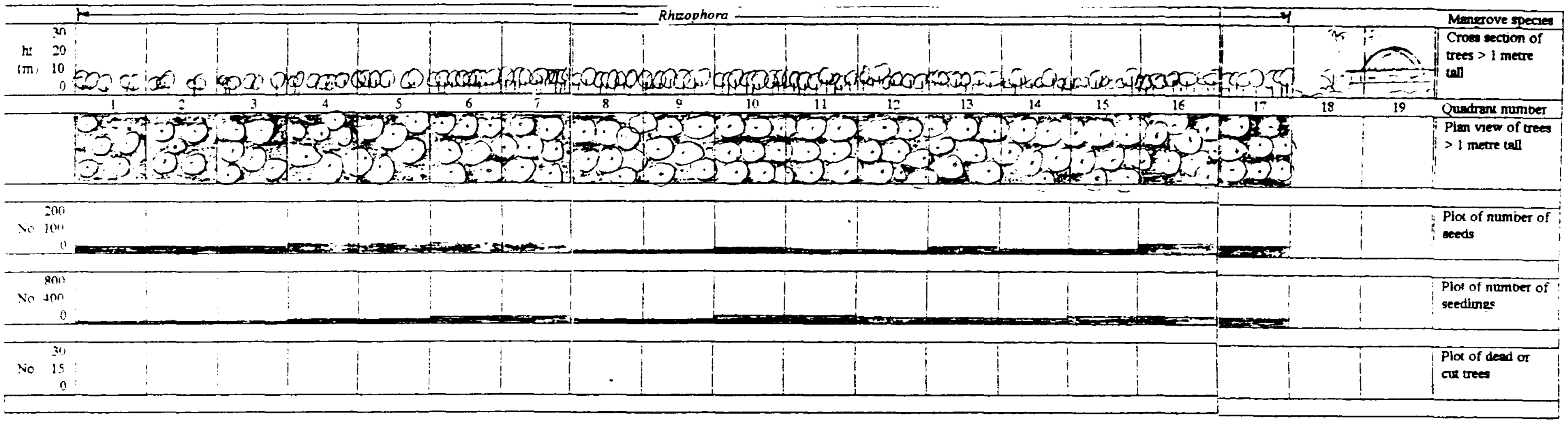
12.9 Transect V5



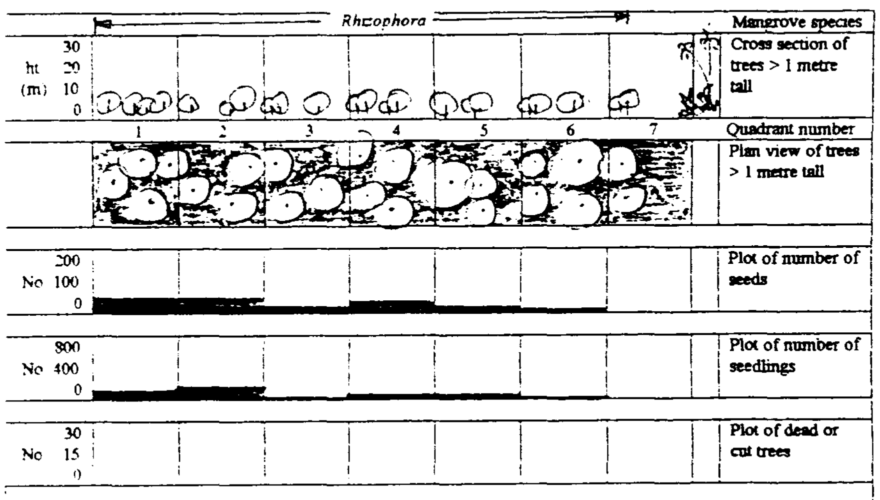
12.10 Transect V6



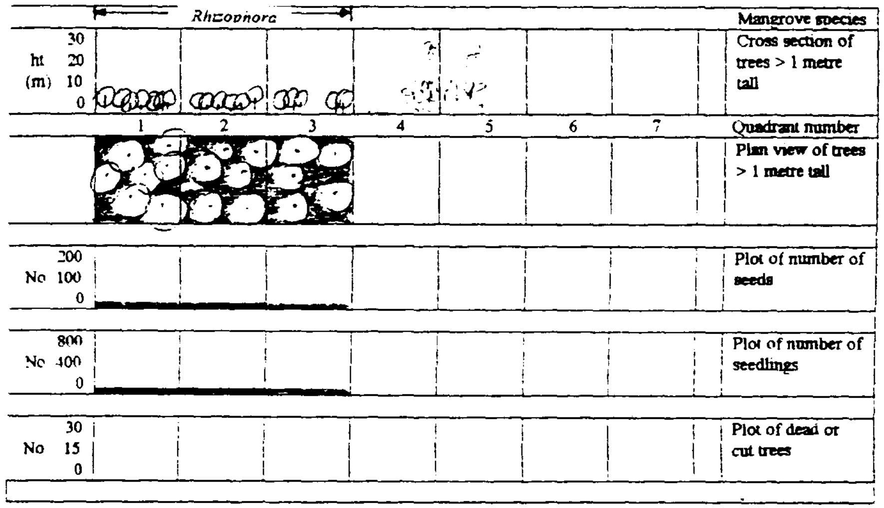
12.11 Transect V7



12.12 Transect M1



12.13 Transect M2



12.14 Transect M3