EXHIBIT KK

Soil: The Environmental Source of *Escherichia coli* and Enterococci in Hawaii's Streams

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ABSTRACT

The concentrations and sources of *Escherichia coli* and enterococci in a typical stream (Manoa) in Hawaii were determined. The concentrations of these two sanitary indicator bacteria in Manoa Stream consistently exceeded the new U.S. Environment Protection Agency recreational water standard in freshwater of 126 *E. coli*/100 mL or 33 enterococci/100 mL. *Escherichia coli* but not enterococci was shown to multiply in stream water samples. Soil samples obtained near the stream bank, 10 m from the stream bank as well as from a grassy area on the university campus, were determined to be sources of both *E. coli* and enterococci. These indicator bacteria were recovered from the surface of the soil as well as from soil samples at depths down to 36 cm. Soil is considered the most likely source for the high concentrations of indicator bacteria naturally present in the freshwater streams of Hawaii.

INTRODUCTION

We (Fujioka, 1983; Fujioka and Shizumura, 1985; Fujioka *et al.*, 1988) previously reported that the freshwater streams on Oahu, the major island in the state of Hawaii, consistently contain fecal coliform and fecal streptococci bacteria far in excess of the traditional recreational water quality standard of 200 fecal coliforms/100 mL. Based on these results, it was concluded that these indicator bacteria are naturally present in the streams of Hawaii and do not necessarily reflect the

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degree of fecal contamination of these waters. Similar findings have been reported in a series of studies conducted in Puerto Rico and recently reviewed by Hazan (1988). Based on the results of studies conducted in Hawaii and in Puerto Rico, it has been concluded that indicator bacteria such as fecal coliform, *Escherichia coli,* and fecal streptococci may be naturally present in the environment of tropical countries.

Recently, U.S. Environmental Protection Agency (U.S. EPA, 1986) proposed that the recreational water quality standards be changed to 126 *E. coli*/100 mL or 33 enterococci/100 mL for fresh water. The objectives of this study were to determine the concentrations of *E. coli* and enterococci in a typical stream on Oahu, and to determined the most likely source for these indicator bacteria.

MATERIAL AND METHODS

Study Site and Experimental Design

Manoa Stream originates from rainfall in the Koolau mountains of Oahu. Manoa Falls, a popular swimming site located at the base of the mountain, is the first accessible part of this stream and is usually considered the origin. From this site, Manoa Stream flows for 11 km through primarily urbanized areas before flowing out to the ocean. This stream does not receive discharges from sewage plants, from industrial plants, or from large agricultural fields. It can be characterized as being typical of many streams in Hawaii and was selected as our model stream for study. Our sampling site was where this stream flowed by the University of Hawaii, which is approximately 8 km from its origin and well within an urbanized area. Water and soil samples from this stream were collected in sterile containers and analyzed for indicator bacteria within four hours of collection. Sterile spatulas were used to collect soil samples. For depth samples, the soil was dug to a certain depth and sterile spatulas were used to collect soil from a hole dug laterally at a given depth.

Microbial Assays

Water samples were analyzed for fecal coliform, *E. coli,* and enterococci using membrane filtration methods as described in *Standards Methods* [American Public Health Association (APHA), 1989]. For fecal coliform, the (mFC) medium, for *E. coli,* the mTEC medium, and for enterococci, the mE medium were used. All bacteriological media used were supplied by either Difco Co. or Becton Dickinson and Co. Soil samples were analyzed for *E. coli* and enterococci using a modification of the most probable number (MPN) method as described in *Standard Methods* (APHA, 1989). Results of the completed tests were used to determine the concentrations of indicator bacteria in soil. For *E. coli*, the presumptive counts were done using lauryl tryptose broth and confirmed in 2% brilliant green bile broth. The completed test was the recovery of metallic green sheened colonies on EMB agar from confirmed samples. These green-sheened colonies correlated with the formation of *E. coli* colonies on mTEC medium. For enterococci, the presumptive counts were done using Enterococcus presumptive broth, followed by a confirmatory test using Enterococcosel broth. The completed test was the recovery of red colonies on modified Enterococcus agar. In bacterial survival studies, a dialysis bag (Allied Fisher) with 12,000 to 14,000 MW maximum permeability was used.

RESULTS AND DISCUSSION

Selection of Manoa Stream

Initially water samples from four streams (Manoa, Nuuanu, Waiawa, Waikele) located in various parts of the island of Oahu were assayed for indicator bacteria. The results showed that all four samples exceeded the new U.S. EPA recreational water quality standard of 126 *E. coli*/100 mL or 33 enterococci. Manoa Stream was selected as the model stream for further study since it flowed primarily through only urbanized areas, did not receive any obvious source of discharge, and flowed next to our university. The average concentrations of indicator bacteria recovered from Manoa Stream water samples obtained on three different days were 7813 CFU/100 mL of *E. coli* and 3220 CFU/100 mL of enterococci.

Stream Water as Source of Indicator Bacteria

The persistent recovery of high concentrations of indicator bacteria from the streams of Hawaii could not be explained by obvious sources of contamination such as a sewage effluent. Since Hawaii is in the tropical latitude and maintains relatively warm temperatures throughout the year, one possibility is that these indicator bacteria are multiplying in the stream water.

To determine the potential for the multiplication of these indicator bacteria in the stream, water samples from Manoa Stream were obtained and immediately assayed for concentrations of *E. coli* and enterococci. Approximately 100-mL aliquots of this same stream water were

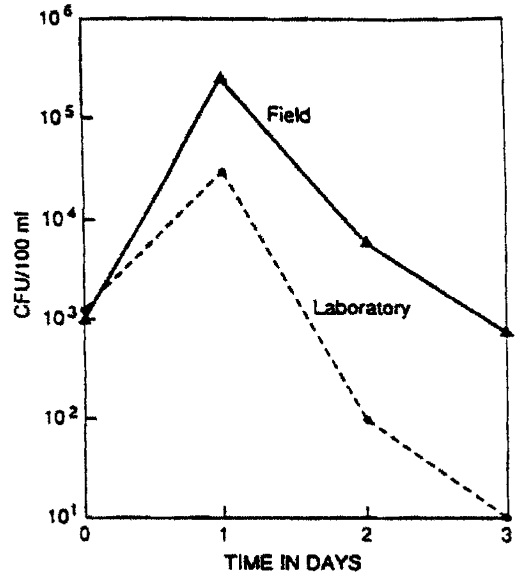

Fig. 1. Growth and survival of *E. coli* in Manoa Stream water incubated under laboratory (23–25°C) and field conditions (18–26°C).

placed into 2-cm wide dialysis bags, which were double knotted at both ends to prevent leakage. Three of these samples were suspended in a plastic gallon bottle that had been perforated to allow for water movement. This bottle was submerged and anchored into two feet of free-flowing water within Manoa Stream. The ambient temperature of the stream environment was estimated to range from 18 to 26°C. Three samples of the same water were similarly placed into dialysis bags and suspended in a 2-Liter Erlenmeyer flask filled with Manoa Stream water. This flask was kept in the laboratory where the temperature was maintained between 23 and 25°C.

Over a three-day period, one dialysis bag kept under laboratory conditions and one kept in Manoa Stream were removed daily and assayed for indicator bacteria. This experiment was repeated on three different occasions with similar results. The results of a typical experiment (Fig. 1) show that *E. coli* concentrations in the dialysis bag held in the laboratory as well as submerged within Manoa Stream increased after 24 h, and decreased during the second and third day of incubation. In contrast, the results (Fig. 2) show that enterococci concentrations in samples held in the laboratory and in Manoa Stream remained unchanged after 24 h, and decreased after the second and third day of incubation. Although it is recognized that these dialysis bag experiments do not directly measure the events in the streams, these results

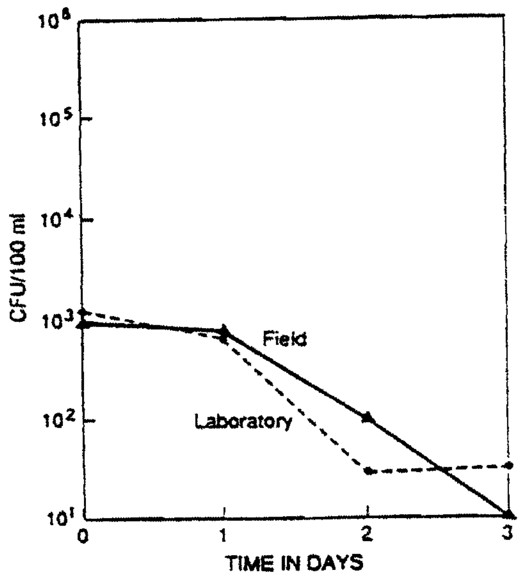

Fig. 2. Growth and survival of enterococci in Manoa Stream water incubated under laboratory (23–25°C) and field conditions (18–26°C).

provide evidence that ambient temperatures and nutrients in Manoa Stream are sufficient to allow the growth of *E. coli* but not enterococci.

In the interpretation of these data, two findings argue against the hypothesis that multiplication in the stream water phase is the major source of the indicator bacteria in the stream. First, stream waters consistently contain high concentrations of both enterococci and *E. coli*. The results of this experiment indicate that *E. coli* multiplied in the stream water but enterococci did not. Second, due to the relative short length (11 km) of the stream as well as the rapid flow rate, the stream water flows from its origin in the mountain out to the ocean within several hours. This does not allow time for extensive multiplication of indicator bacteria under the less than ideal conditions of restricted nutrients, suboptimal temperatures, and competition with other bacteria more suited to grow in the stream environment.

Differential Multiplication of *E. coli* and *Klebsiella* Bacteria

One of the advantages of using the new mTEC medium to recover *E. coli* is that this method readily allows for the enumeration of yellow *E. coli* colonies from other thermotolerant fecal coliforms (*Klebsiella*), which produce pink to red colonies and are lactose/urease positive. In the dialysis bag experiment, it was observed that the ratio of *E. coli*

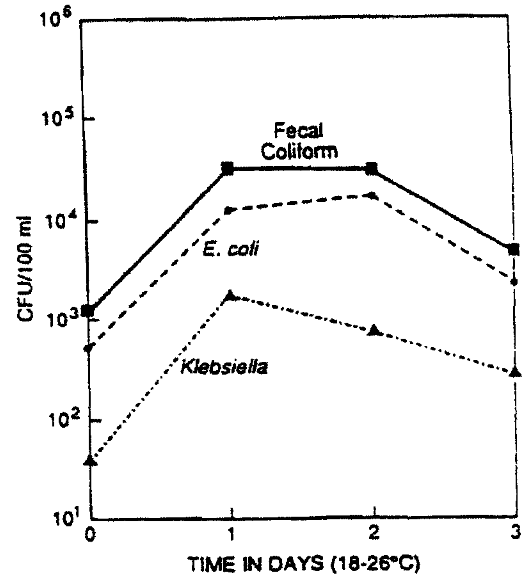

Fig. 3. Growth and survival of fecal coliform, *E. coli*, and *Klebsiella* in Manoa Stream water incubated under field conditions.

colonies to non-*E. coli* colonies enumerated on mTEC medium remained constant in the samples kept in Manoa Stream, but there appeared to be an increase in the ratio of non-*E. coli* to *E. coli* colonies in samples kept in the laboratory.

To determine the populations of coliform bacteria that are multiplying in dialysis bags kept under laboratory conditions as compared to field conditions, the previously described experiment was essentially repeated. However, samples obtained from the dialysis bags were analyzed for fecal coliform, using mFC agar, and for *E. coli*, and non-*E. coli* colonies (*Klebsiella*) on mTEC agar. The results (Fig. 3) show that samples kept in Manoa Stream resulted in a proportionate increase and decrease in the populations of fecal coliform, *E. coli*, and *Klebsiella* over the three-day experiment. In contrast, the samples kept under laboratory conditions resulted in a minor increase in *E. coli* but a major increase in *Klebsiella* (Fig. 4). Thus, by day three, the population of *Klebsiella* in the sample was now greater than the population of *E. coli*.

These results indicate that conditions for bacterial growth in the dialysis bags held under laboratory conditions and under field conditions are different. There are two differences in these conditions that may account for the observed results. First, the temperature ranges of the two conditions (18–26°C vs 23–25°C) were not the same yet they were similar in that they were suboptimal but adequate to support the growth of these indicator bacteria. Thus, the temperatures of the

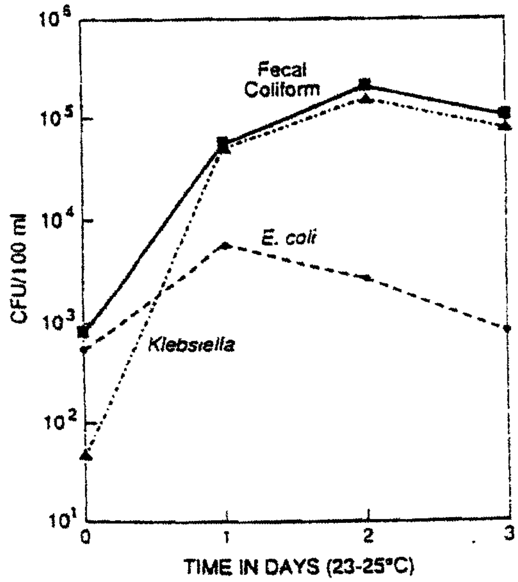

Fig. 4. Growth and survival of fecal coliform, *E. coli*, and *Klebsiella* in Manoa Stream water incubated under laboratory conditions.

incubation conditions were not believed to be the major factor for the observed differences in the results. The major factor responsible for the observed difference in the results was more likely due to differences in the quality of the water surrounding the bacteria in the dialysis bags. These dialysis bags allow for the exchange of water and molecules of less than 14,000 MW through the bag. Under laboratory conditions, Manoa Stream water surrounded the dialysis bags but this water was not changed over the three-day experiment. Thus, the bacteria in the dialysis bag will be limited to total nutrients in this closed vessel system. Moreover, the bacteria in the bag will also be exposed to the increasing concentrations of the by-products of microbial growth occurring within and outside the dialysis bag. In contrast, the dialysis bag held in the stream is constantly surrounded by the flowing water in the stream bringing new nutrients and washing away the by-products of microbial growth in the bag.

In assessing these results, we observed that Manoa Stream water is generally clear and flows from its origin in the mountain out to the ocean within a few hours. The concentrations of nutrients in this stream are known to be very low, and based on the results of this study, are insufficient to support the growth of bacteria such as enterococci, which requires relatively complex growth factors (Beaudoin and Litsky, 1981). On the other hand, there appears to be sufficient nutrients in Manoa Stream to support the multiplication of coliforms such as *E. coli* and

TABLE I
Recovery of *E. coli* and enterococci from soil samples obtained from bank and 10 m from bank of Manoa Stream

Soil location	Soil depth	MPN index/100 g	
		E. coli	Enterococci
Stream bank			
Sample 1	Surface	2.4×10^5	2.1×10^4
	3 cm	2.4×10^5	7.9×10^3
	6 cm	2.4×10^5	5.4×10^3
Sample 2	Surface	2.4×10^5	3.5×10^5
	6 cm	3.5×10^4	2.7×10^3
	12 cm	3.5×10^4	4.9×10^3
10 m from bank			
Sample 1	Surface	9.4×10^4	1.1×10^4
	8 cm	3.4×10^3	2.3×10^2
	16 cm	1.7×10^3	3.3×10^2
Sample 2	Surface	2.7×10^4	8.0×10^3
	18 cm	5.0×10^2	1.3×10^2
	36 cm	2.2×10^2	5.0×10^1

Klebsiella, which are known to have minimal nutritional requirements for growth and have been reported to grow in streams with minimal nutrient levels (Hendricks, 1972). One conclusion from these results is that fecal coliform, *E. coli*, and *Klebsiella* are capable of growing in the stream water environment of Hawaii. If these indicator bacteria are able to grow under environmental conditions, they do not fulfill one of the basic criteria of a good indicator of fecal contamination (Dutka, 1973).

Soil as a Source of Indicator Bacteria

A second hypothesis for the source of the high concentrations of indicator bacteria in streams is the soil. Since, streams result from the channeling of rainwater, which drains the soil, rain may be acting to simply wash the bacteria from the soil into the stream. To test this hypothesis, soil samples were initially obtained from the bank of Manoa Stream and 10 m from the stream bank. Soil samples from the stream bed were not obtained as the stream bed was primarily of rocky material. These soil samples were assayed for *E. coli* and enterococci using the MPN method.

The results (Table I) of the soil analysis show that *E. coli* at concen-

TABLE II
Recovery of *E. coli* and enterococci from soil samples obtained from grassy area of University of Hawaii campus

Soil depth	MPN Index/100 g	
	E. coli	Enterococci
Surface	5.4×10^4	3.5×10^4
3 cm	4.9×10^2	7.0×10^1
6 cm	1.3×10^2	2.0×10^1

trations ranging from 35,000 to 240,000/100 g and enterococci at concentrations of 2700 to 350,000/100 g were recovered from surface and subsurface (6 and 12 cm) soil samples obtained from the banks of the streams. Similar concentrations of *E. coli* and enterococci were recovered from surface soil samples obtained 10 m away from the bank in a forested area. At this site, deeper soil samples (16 to 36 cm) could be obtained and concentrations of *E. coli* from 220 to 1700/100 g of soil and enterococci concentrations from 50 to 330/100 g of soil were recovered.

For comparative purposes, soil samples were obtained from a grassy area located on the campus of the University of Hawaii. This site was approximately 200 m from the stream and at an elevation at least 5 m higher than the stream bed. The results (Table II) show that the same indicator bacteria could be recovered from soil taken from a typical grassy area on campus. *E. coli* was recovered at 54,000/100 g from surface soil and 130 to 490/100 g of soil obtained at depths of 18 and 36 cm. Enterococci were recovered at 35,000/100 g of surface soil and from 20 to 70/100 g from soil obtained at depths of 18 and 36 cm. These results indicate that *E. coli* and enterococci can be recovered from typical grassy area in an urbanized setting, even at depths down to 36 cm. The recovery of *E. coli* and enterococci from surface and subsurface soil sample obtained from the stream bank, from soil 10 m away from the stream bank, as well as from a typical grassy area on the campus of the university, support our (Fujioka *et al.*, 1988) earlier hypothesis that these indicator bacteria are naturally present in the environment of Hawaii.

In assessing these results, several observations listed below lead us to conclude that soil is the primary source of indicator bacteria in the environment of Hawaii and that rain washes the bacteria from the soil into the stream. First, high concentrations of both *E. coli* and enterococci were recovered from all soil samples. These results are consistent with the observation that both of these indicator bacteria are present in high concentrations in stream water. Second, the land drainage area increases as streams flow from the mountain down to the sea. These results are consistent with the observation that the concentrations of indicator bacteria increases as the stream flows from the mountain to the ocean. Third, soil maintains a constant, warmer temperature relative to the surrounding environment. Fourth, soils are known to concentrate nutrients from the water phase. Thus, soil creates a microenvironment of warmer temperature and higher nutrients, which favor the multiplication of indicator bacteria. These observations are consistent with evidence that enteric bacteria will multiply and survive longer in sediment of the stream as compared to the water phase of the stream (Hendricks and Morrison, 1967; Burton *et al.*, 1987). Although direct evidence was not presented, we conclude from the evidence available that these indicator bacteria are multiplying in the soil of Hawaii.

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EXHIBIT LL

Soil: the environmental source of *Escherichia coli* and Enterococci in Guam's streams

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1. SUMMARY

We have previously documented that faecal indicator bacteria (*Escherichia coli*, faecal coliform, enterococci) recommended by the U.S. Environmental Protection Agency (USEPA) to establish recreational water quality standards are naturally found in high concentrations in the surface and subsurface of soils in Hawaii. Rain, the source of all streams in Hawaii, washes the soil sources of faecal bacteria into all the streams of Hawaii, at concentrations which consistently exceed the USEPA recreational water quality standards. The objective of this study was to test the hypothesis that faecal bacteria are able to establish themselves in the soil environments of tropical islands by conducting the same study in Guam, a tropical pacific island with warmer temperatures and higher humidity than Hawaii. The same methods and study design used in Hawaii was used in Guam. The results of the study conducted in Guam revealed that all streams contain consistently high concentrations of faecal coliform, *E. coli*, and enterocci which exceeded the old USEPA recreational water quality standard of 200 faecal coliform/100 ml as well as the new water quality standards of 126 *E. coli*/100 ml or 33 enterococci/100 ml. These same faecal indicator bacteria were recovered in high concentrations in surface and subsurface (18–36 cm depth) soil samples in Guam. Limited coastal water analysis showed that most coastal marine waters contain low concentrations of faecal bacteria but coastal waters impacted by stream run-off showed elevated levels of faecal bacteria. The results of this study support the hypothesis that environmental conditions in the tropical areas of the world can support the growth and establishment of populations of faecal bacteria in the soil. Thus, soil becomes an environmental, non-faecal source of faecal indicator bacteria. These results indicate that USEPA water quality standards may not be directly applicable to tropical island environments.

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2. INTRODUCTION

From 1972 to 1986, the U.S. Environmental Protection Agency (USEPA) recommended recreational water quality standard was a monthly mean of 200 faecal coliforms/100 ml for both fresh and marine waters. During this period, studies conducted by our laboratory clearly documented that most of the fresh water streams in Hawaii consistently contained concentrations of faecal coliforms exceeding that standard (Fujioka *et al.* 1988). For most of these streams, there were no obvious point sources of sewage to account for these high concentrations of faecal coliform. In 1986, USEPA recommended that all states abandon the 200 faecal coliforms standard because the results of a carefully conducted USEPA water quality and epidemiological study indicated that increasing concentrations of faecal coliform in recreational waters did not correlate with increasing incidences of diarrhoeal diseases among swimmers (Cabelli 1983; Dufour 1984). In those studies, increasing concentrations of enterococci in fresh and marine recreational waters and *Escherichia coli* in fresh recreational waters did correlate with increasing incidences of diarrhoeal diseases among swimmers. As a result, the U.S. Environmental Protection Agency (1986) recommended that all US states adopt new recreational water quality standards based on monthly mean concentrations of 35 enterococci/100 ml^{-1} for marine waters and 126 *E. coli* or 33 enterococci/100 ml^{-1} for fresh waters. To address these new standards, our laboratory completed a study using USEPA recommended methods to determine the concentrations of *E. coli* and enterococci in Hawaii's streams and concluded that the streams in Hawaii could not meet these new USEPA recreational water quality standards (Fujioka 1989). In a subsequent study, we (Hardina and Fujioka 1991) determined that soil was the primary environmental source of faecal indicator bacteria (faecal coliform, faecal streptococci, *E. coli,* enterococci) and came to two significant conclusions. First that these faecal bacteria must be multiplying in the soil environment of Hawaii, and rain was the mechanism of transporting high concentrations of these soil bound faecal bacteria to streams. Second, since soil is a significant environmental source of these faecal bacteria and this source is not related to concentrations of faeces in the environment, the USEPA recreational water quality standards are not applicable to Hawaii.

We speculated that our findings in Hawaii should apply to other humid tropical islands. To address this possibility, a study was conducted in Guam because this island is located closer to the equator in the Pacific Ocean and therefore is more characteristic (warmer, more humid) of the many tropical islands than Hawaii. The same study design used in the Hawaii study was used in the study conducted in Guam. Significantly, one of the authors (CSD), had conducted the study in Hawaii as part of her master degree thesis and returned to Guam to supervise the study there. The objective of this study was to compare the results of the study conducted in Guam with the results of the study conducted in Hawaii and to determine whether the conclusions as applied to Hawaii are applicable to Guam and other tropical islands.

3. APPROPRIATE WATER QUALITY STANDARDS FOR TROPICAL ISLANDS

Microbial recreational water quality standards were developed by USEPA based on scientific principles verified by field data and application of some assumptions. In this regard, the studies conducted to evaluate the usefulness of faecal indicator bacteria and to establish recreational water quality standards were primarily conducted in North America or Europe. Thus, the data to verify the scientific principles of water quality were collected from environments which were characteristically from continents located in the temperate region of the world. These environmental conditions differ drastically from those in small islands located in the tropical region of the world. It is well known that environmental conditions determine which groups of micro-organisms will grow and which will not. Thus, ambient concentrations of micro-organisms reflect specific environmental conditions. In this regard, studies conducted in the continental USA indicated that the only significant sources of faecal indicator bacteria such as faecal coliform, *E. coli* and enterococci are faeces of man and other warm-blooded animals. In the application and interpretation of recreational water quality standards to all states and territories of the US, USEPA assumes that there is no significant environmental source of these faecal indicator bacteria. However, this assumption is not valid in tropical island conditions because independent and extensive studies conducted in Hawaii (Fujioka *et al.* 1988) and Puerto Rico (Hazen 1988) have provided convincing field data that the same faecal indicator bacteria used for water quality standards are naturally present in the environment (stream, soil, plants) of tropical islands. Additional studies have provided data that the faecal indicators are able to multiply in the environment of Puerto Rico (Lopez-Torres *et al.* 1987) and in Hawaii (Fujioka and Byappanahalli 1996). It is clear that if the basic assumption applied in the use of recreational water quality standards is not valid in tropical island environments, then the water quality standards are not applicable in these environments. In summary, there is a need to obtain additional field data from another tropical island environment to provide convincing data that the USEPA recommended recreational water quality standards are not applicable to all tropical environments which are characterized by year-round warm temperatures and high humidity.

4. GUAM: THE TROPICAL ISLAND STUDY SITE

Guam is located 5920 km west-south-west of Honolulu, Hawaii, and only 384 km north of the equator in the Pacific Ocean. Guam is therefore well within the tropical region of the world (Fig. 1). Its warm year-round temperature (mean: 27·2 °C), high annual rainfall of 200–250 cm, high humidity and lush vegetation makes this island characteristically much more tropical than the islands of Hawaii. The climatic conditions of this island are similar to the many tropical islands in the Pacific Ocean. This island of ≈549 km^{-2} is characterized by a northern region which is comprised of raised, porous limestone and no flowing streams. In contrast, the southern region of the island is characterized by volcanic rocks, many valleys and more than 40 streams. Figure 1 shows the island of Guam and the location of the coastal marine recreational beaches as well as the fresh water rivers and springs sampled in this study.

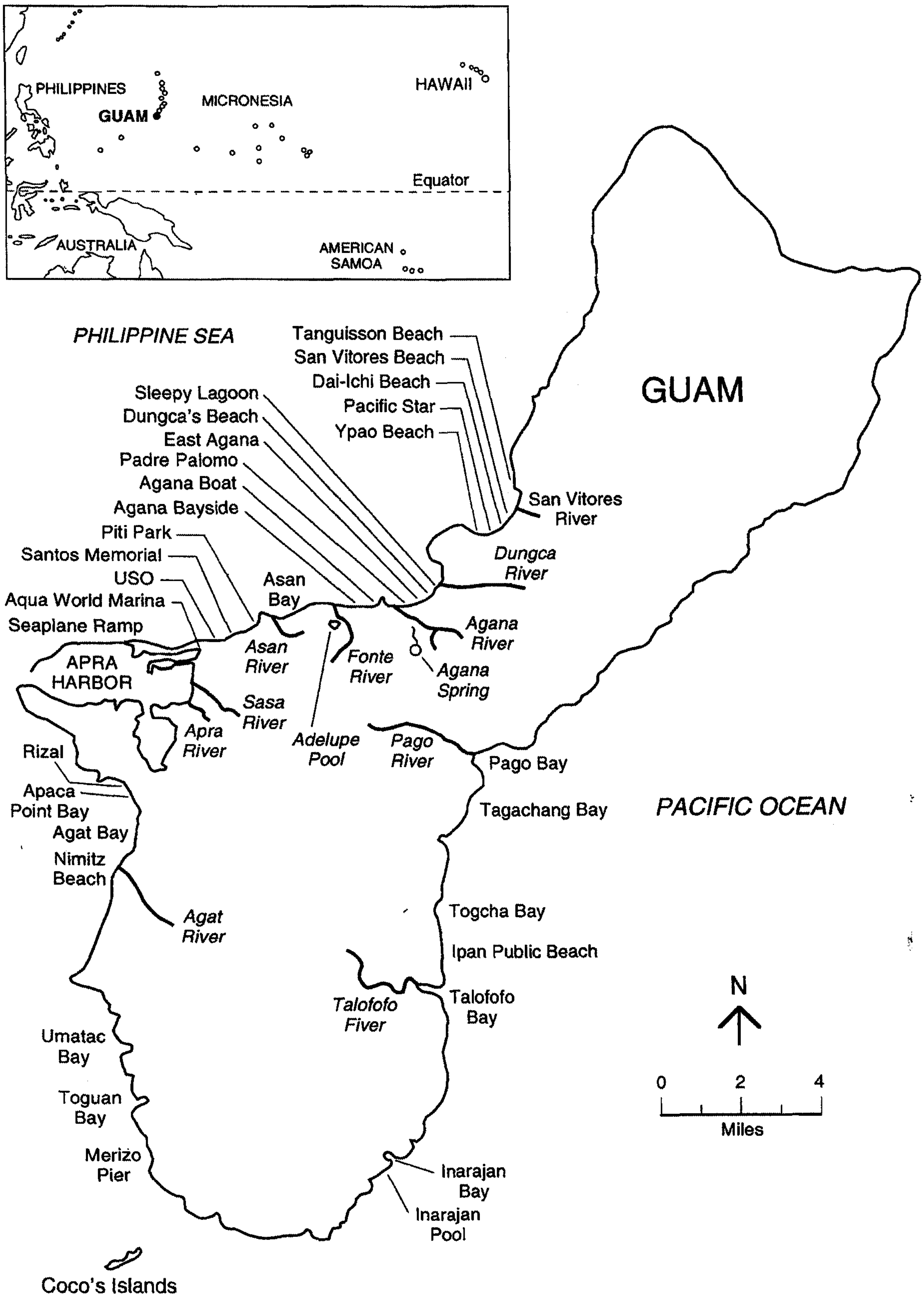

Fig. 1 Island of Guam with location of coastal beaches and rivers sampled in this study.

5. EXPERIMENTAL DESIGN AND METHODOLOGY

5.1. Methods of analysis

The same experimental design for the study conducted in Hawaii (Hardina and Fujioka 1991) was used in the study conducted in Guam. Water samples were analysed for faecal coliform, *E. coli* and enterococci using membrane filtration methods as described in *Standard Methods* (American Public Health Association 1989). For faecal coliform the mFC medium, for *E. coli*, the mTEC medium and for enterococci, the mE medium were used. All bacteriological media used were supplied by either Difco Co. (Detroit, MI, USA) or Becton Dickenson and Co. (Cockeysville, MA, USA). Soil samples were analysed for *E. coli* and enterococci using a modification of the most probable number (MPN) method as described in *Standard Methods* (APHA 1989). Results of completed tests were used to determine the concentrations of indicator bacteria in soil. For *E. coli*, the presumptive counts were done using lauryl tryptose broth and confirmed in 2% brilliant green bile broth. The completed test was the recovery of metallic green-sheened colonies on EMB agar from confirmed samples. For enterococci, the presumptive counts were done using Enterococcus presumptive broth, followed by confirmatory test using EVA broth. The completed test was the recovery of red colonies on Enterococcus agar. Water and soil samples were collected in sterile containers and analysed for indicator bacteria within 6 h.

5.2. Sampling

The Pago River area was selected for the soil sampling experiment because this is a typical major river which was not greatly impacted by urbanization. Site A was 30 m away from the river bank whereas Site B was taken from the river bank. Sterile spatulas were used to collect soil samples. For depth samples, the soil was dug to a certain depth and sterile spatulas were used to collect soil from a hole dug laterally at a depth of 18 cm and 36 cm. Water samples were collected from established coastal marine beaches. The sampling sites represent the monitoring sites established previously by Guam EPA.

6. CONCENTRATIONS OF FAECAL BACTERIA IN FRESH WATER STREAMS

In Hawaii, nearly all of the fresh water streams contain concentrations of faecal coliform, *E. coli* and enterococci far exceeding the USEPA standards using these faecal bacteria (Fujioka 1989). To determine if this same situation occurs in Guam, most of the major fresh water rivers and springs were sampled and analysed for *E. coli* and for enterococci at least once but for some sites on 2 or 3 separate days. The results summarized in Table 1 show that the concentrations of *E. coli* in the fresh water rivers ranged from 0 to 6560 c.f.u./100 ml^{-1} and 14/21 or 66·6% of the fresh water samples exceeded the *E. coli* standard of 126 c.f.u./100 ml^{-1}. The results in Table 1 also show that concentrations of enterococci ranged from 0 to 8800 c.f.u/100 ml^{-1} and 23/26 or 88·5% of the same fresh water river samples exceeded the enterococci standard of 33 c.f.u./100 ml^{-1}. These results are similar to those obtained in Hawaii (Fujioka 1989; Hardina and Fujioka 1991) and support the conclusion that data obtained in Hawaii are applicable to other humid tropical islands.

7. CONCENTRATIONS OF FAECAL BACTERIA IN SOIL

In Hawaii, soil was determined to be the major environmental source contributing to the high concentrations of faecal bacteria which are consistently found in streams. To determine if the same situation occurs in Guam, surface as well as 18

Table 1 Monitoring various rivers in Guam for concentrations of *Escherichia coli* and Enterococci during 1–3 sampling days

Sampling site	*E. coli* (c.f.u. 100 ml^{-1})	Enterococci (c.f.u. 100 ml^{-1})
Pago River	158	648
	48	220
	ND	180
Dungca River	1200	492
	2960	1064
Agana River	2720	4840
	5600	2040
	ND	3520
Agana Springs	6560	152
	0	8800
	ND	64
San Vitores River	3	0
Lower Fonte River	384	2080
	2480	1800
	ND	184
Upper Fonte River	48	520
Adelup Pool	0	24
Talofofo River	152	1440
Sasa River	140	880
	ND	800
Asan River	720	120
Agana Springs	0	8800
Upper Apra River	450	480
Lower Apra River	220	160
Lower Agat River	48	20
Upper Agat River	1800	880

ND = Not done.

and 36 cm subsoil samples were obtained from the bank of Pago River (Site B) and another site located 30 m from the bank (Site A). These soil samples were analysed for concentrations of *E. coli* and enterococci using the MPN method during one or two separate sampling day. The results summarized in Table 2 show that the concentrations of *E. coli* were highest in surface soil samples ($\approx$1000 000 viable cells 100 g^{-1} of soil). At soil depths of 18 cm and 36 cm, the concentrations of *E. coli* dropped to $\approx$100–9000 viable cells 100 g^{-1} of soil but were still significant. During a separate sampling day, soil samples were analysed for concentrations of enterococci. The results summarized in Table 2 show that the concentrations of enterococci were highest in surface soil samples ($\approx$700 viable cells 100 g^{-1} of soil). The concentrations of enterococci dropped to 20–60 viable cells/100 g^{-1} of soil at depths of 18 and 36 cm. These results are similar to the results obtained in Hawaii and support the hypothesis that soil is the major environmental source for these faecal indicator (Hardina and Fujioka 1991). Moreover, since rain is the source of water for streams, rain is the most likely mechanism by which these soil bound faecal indicator bacteria are transported to fresh water streams and rivers.

8. IMPACT OF FRESH WATER RUN-OFF ON COASTAL WATER QUALITY

All streams on small island flow out to coastal waters and the quality of stream water can impact the quality of coastal waters. In Hawaii the quality of water at most of the coastal marine beaches readily meets the USEPA recreational water quality standard of 35 enterococci/100 ml^{-1} (Fujioka 1989). However, streams which discharge near coastal marine beaches were shown to definitely increase the concentrations of faecal indicator at these beach sites (Fujioka 1990). To determine whether the quality of water at the coastal marine beaches in Guam will meet the new USEPA marine recreational water quality standard of 35 enterococci/100 ml^{-1}, a single water sample was obtained from each of the major coastal marine beaches and analysed for concentrations of enterococci. The results summarized in Table 3 show that the concentrations of enterococci at the 16 northern beaches ranged from 0 to >200 c.f.u./100 ml^{-1} and 6/16 or 37·5% of the beach water samples exceeded the new recreational standard of 35 enterococci/100 ml^{-1}. The results in Table 3 also show that the concentrations of enterococci at the 15 southern beaches ranged from 0 to 43 enterococci 100 ml^{-1} and 4/15 or 26·6% of the beach water samples exceeded the new recreational standard of 35 enterococci/100 ml^{-1}.

In the interpretation of the results, it must be emphasized that the data must be considered preliminary because it represented the first time these waters were analysed for these faecal indicator bacteria using the recommended USEPA methods. The results obtained suggest that some of Guam's marine beaches may have some difficulty in meeting the 35 enterococci/100 ml^{-1} marine recreational water quality standard. More detailed studies must be conducted to determine the impact of river and other sources of non-point discharges vs. point source discharges such as sewage on the quality of water at the various beaches in Guam. However, it was clear that higher concentrations of enterococci were recovered from the northern beaches as compared to the southern beaches. These results reflect the greater urbanization in the areas near the northern beaches of Guam as compared to the southern beaches of Guam. As was observed in Hawaii, greater urbanization increases the level of faecal indicator bacteria in nearby streams and rivers. Two obvious outcomes of urbanization are associated with increasing concentrations of faecal indicator bacteria in nearby streams. The first is the channelization of storm drains and other urban run-off into nearby streams and rivers. This greatly increases non point source pollution into streams. The second is increase in number of sewer lines and discharges from sewage treatment plants or septic tanks. This greatly increases point source pollution which can impact coastal waters.

Table 2 Analysis of soil samples obtained from two sites near Pago River for concentrations of *Escherichia coli* and Enterococci

Faecal Indicator	Site	Date	MPN index 100 g^{-1} at soil depth		
			Surface	18 cm	36 cm
Escherichia coli					
	A	5/23/89	$1{\cdot}6 \times 10^6$	$1{\cdot}1 \times 10^2$	$1{\cdot}7 \times 10^3$
		5/30/89	$1{\cdot}6 \times 10^6$	$5{\cdot}4 \times 10^3$	$3{\cdot}3 \times 10^2$
	B	5/23/89	$1{\cdot}6 \times 10^6$	$3{\cdot}4 \times 10^2$	$9{\cdot}2 \times 10^3$
		5/30/89	$9{\cdot}2 \times 10^5$	$3{\cdot}3 \times 10^2$	$7{\cdot}9 \times 10^2$
Enterococci					
	A	6/14/89	$7{\cdot}0 \times 10^2$	$2{\cdot}0 \times 10^1$	$4{\cdot}0 \times 10^1$
	B	6/14/89	$7{\cdot}2 \times 10^2$	$6{\cdot}0 \times 10^1$	$4{\cdot}0 \times 10^1$

Table 3 Survey of northern (A) and southern (B) coastal beaches on Guam for concentrations of Enterococci

(A)	Enterococci (c.f.u. 100 ml^{-1})	(B)	Enterococci (c.f.u. 100 ml^{-1}
Tanguisson	2	Aqua World	41
San Vitores	22	Rizal Beach	8
Dai – Ichi	>200	Apaca Point	15
Pacific Star	0	Agat Bay	11
Ypao	4	Nimitz	19
Sleepy Lagoon	2	Umatac Bay	38
Dungca's	63	Toguan Bay	20
East Agana	68	Merizo Pier	10
Padre Palomo	>200	Inaranjan Pool	5
Agana Boat	96	Inaranjan Bay	18
Agana Bayside	>200	Talofofo Bay	40
Asan Bay	0	Ipan	0
Piti	21	Togcha	4
Santos Memorial	30	Tagachang	15
USO	0	Pago Bay	43
Seaplane Ramp	26		

9. CONCLUSIONS

A water and soil monitoring study in Guam was completed using the same experimental design as the study conducted earlier in Hawaii. The results obtained in Guam were similar to the results obtained in Hawaii and provided convincing evidence that the faecal bacterial indicators selected by USEPA to establish recreational water quality standards are able to colonize the soil environments of warm, humid tropical islands. Since the multiplication and concentrations of faecal bacteria in soil are not related to concentrations of faeces and faecal borne pathogens, these results support our earlier conclusion that the USEPA recreational water quality standards are not applicable to Hawaii and other warm and humid tropical islands. The results in Guam are significant for several reasons. First, unlike Hawaii, Guam contains few birds. In this regard, bird faeces in Hawaii have been proposed to explain the widespread occurrence of faecal indicator in the streams. Second, Guam is clearly located in the tropical region of the world and represents the climatic conditions of the many other tropical islands in the Pacific Ocean. In contrast, the islands of Hawaii are considerably further north of the equator and are located in the subtropical region of the world. Moreover, there are fewer pacific islands with the same climatic conditions as the islands Hawaii. Finally, the climatic conditions of Guam and Hawaii are similar to the conditions of Puerto Rico where independent data on the environmental sources of faecal indicator have been reported (Lopez-Torres *et al.* 1987; Hazen 1988).

It is important for all regulatory agencies such as USEPA and the World Health Organisation (WHO) as well as those implementing these regulations to recognize that the current hygienic water quality standards which are based on concentrations of faecal indicator bacteria may not be applicable in tropical islands and perhaps other subtropical and tropical countries in the world. In these countries, stream waters can be expected to contain elevated levels of faecal bacteria. By pragmatically applying water quality standards to these countries most of the available water sources may be classified as unsuitable for various uses such as drinking, household uses, swimming, and raising food crops. Two significant consequences can be expected. The first is the implementation of expensive treatment systems to remove or disinfect the concentrations of faecal bacteria in these water sources. The second is the frustration related to the inability to obtain faecal indicator-free waters in tropical islands; and the conclusion that this observation is due to poor sanitation practices in the island as well as the scientific ineptitude of people in tropical islands responsible for delivering clean water. This frustration is shared by all levels of authority and can perpetuate low self-esteem among the people who live in these tropical islands because they must follow the guidelines and information obtained from other countries which are not applicable to their environments.

If the USEPA recreational water quality standards are not applicable to tropical islands, then another, more appropriate recreational water quality standard for tropical islands should be developed. In Hawaii, based on extensive studies we (Fujioka *et al.* 1997) have recommended that *Clostridium perfringens* be used to establish recreational water quality standards in tropical islands. Since *C. perfringens* is an anaerobic spore forming bacteria, it cannot multiply to establish itself in the soil environments of tropical countries. The State of Hawaii is currently taking steps to establish recreational water quality standards based on *C. perfringens.*

10. ACKNOWLEDGEMENTS

The study conducted in Guam was funded by the USGS Water Resources Research Institute Program through Water and Energy Research Institute of the Western Pacific, University of Guam. The work was conducted at the facilities and by the personnel of Guam Environmental Protection Agency. This paper is written in memory of two of the authors (MB, KM) who recently passed away.

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EXHIBIT MM

Mamala Bay Study

FINAL REPORT

Volume III

Prepared by the Mamala Bay Study Commission

April 1996

MAMALA BAY STUDY

WATER QUALITY MANAGEMENT FOR MAMALA BAY

PROJECT MB-11

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3 CONCLUSIONS

The Mamala Bay Study report presents a comprehensive assemblage of new data and information on ocean circulation and water quality. It describes state-of-the-art techniques for acquiring these data and for applying them in assessment of risks to public health and the marine ecosystem. It evaluates an array of alternatives designed to improve water quality in Mamala Bay. This executive summary of the study report has outlined principal tasks of the Study, analyzed results of the individual investigations, and presented specific recommendations for the creation of a practical Integrated Coastal Management Plan. The stage is now set for implementation of such a plan, one that will meet the expectations of environmental leaders, public officials and an informed public in assuring the future health of Mamala Bay.

In conclusion, it is appropriate to identify some of the most significant findings of the Mamala Bay Study :

a) Ocean circulation in Mamala Bay is extremely complex, driven largely by tidal fluctuations with major components paralleling the shoreline, but influenced seasonally by thermal stratification and Trade and Kona winds.

b) Sewage plumes from the City's outfalls are greatly diluted within the zone of the diffusers. Plumes are retained below the ocean surface during periods of greatest stratification, usually in the summer. The greatest frequency of plume surfacing and highest dilutions occur in the winter.

c) Contamination in discharges through the Sand Island WWTP outfall can reach most beaches and offshore areas of Mamala Bay at the present level of wastewater treatment. Contamination originating from the Honouliuli WWTP only reaches the western beaches at detectable levels.

d) Non-point sources are most responsible for contamination of the eastern beaches of Mamala Bay, such as Waikiki, Ala Moana, Queens Surf beaches, especially during high runoff storm events. About two-thirds of the annual flow into Mamala Bay originates from uncontrolled non-point sources. Runoff from the Ala Wai Canal is a major source of contamination of Waikiki Beach.

e) Pathogens and bacteria of fecal origin were isolated from the waters of Mamala Bay and from both point and non-point sources of pollution. New techniques for isolation of pathogens from ocean water indicate that some may remain viable for periods of a day or more, but not culturable by conventional methods.

f) Present levels of wastewater treatment at the City's WWTPs are not sufficient to meet regulatory standards. Increased removals of biochemical oxygen demand (BOD) are needed and reductions in suspended solids in plant effluents are necessary to ensure effective disinfection.

4 RECOMMENDATIONS

Based on factual findings and interpretation of results of scientific investigations conducted during the course of the Study, the Mamala Bay Study Commission presents the following recommendations:

1) that the data base developed by the Study be maintained by an appropriate agency of the City and County of Honolulu or the State of Hawaii for the beneficial use of all who may wish to access it.

2) that regular water quality monitoring be continued at sites identified during the Study and coordinated with water quality sampling programs of the City and County and other appropriate agencies and that data developed in these programs be entered into the data base.

3) that monitoring of ocean circulation and the driving forces that govern circulation within the bay be continued by an appropriate scientific agency.

4) that a Mamala Bay ecosystem monitoring program be instituted to include periodic samplings of benthic communities, including coral stands, in areas adjacent to the Sand Island outfall and offshore of principal sources of non-point accretions, e.g., the Ala Wai Canal, Pearl Harbor, and Keehi Lagoon.

5) that the mathematical models developed in the Mamala Bay Study be maintained by an agency of the City and County of Honolulu or the State of Hawaii capable of implementing them as needed to evaluate the effectiveness of measures or facilities proposed to improve the water quality of Mamala Bay.

6) that the level of wastewater treatment practiced at the Sand Island and Honouliuli WWPTs be upgraded at least to the level of efficiency of chemically enhanced primary treatment (CEPT) to increase removal of suspended solids and BOD and to facilitate effective disinfection.

7) that provision be made at the Sand Island and Honouliuli WWTPs to evaluate the performance of CEPT, including assessing the effectiveness of alternative chemical enhancement additives and their proper aging and mixing.

8) that appropriate disinfection be provided for the ocean outfall discharge at the Sand Island WWTP.

9) that ultraviolet irradiation as a means of disinfection be investigated by means of pilot plant studies as an alternative to chlorination/dechlorination at the Sand Island WWTP.

10) that effective and responsible methods of disposal of sewage sludge, chemical precipitates, UV lamps (in the event of UV disinfection) and other treatment by-products be developed and applied at Sand Island and Honouliuli WWTPs.

11) that a feasibility study be undertaken by the City and County of Honolulu to evaluate the effectiveness of alternative measures to control non-point sources of contamination of Mamala Bay including the Ala Wai Canal, particularly during and immediately following intense storm events, and to implement the measures found to be most feasible.

12) that an Integrated Coastal Management Forum be created to bring together scientists, managers and representatives of stakeholder groups with the objective of providing a sustained environment within which the products of the Mamala Bay Study will be applied and the recommendations of the Study implemented for the benefit of all interests.

MAMALA BAY STUDY

WASTEWATER MANAGEMENT STRATEGIES IN AN INTEGRATED COASTAL MANAGEMENT PLAN FOR MAMALA BAY

PROJECT MB-11A

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6. RECOMMENDATIONS

The major recommendations of the MB-11 study are listed below:

Wastewater Treatment Plants

CEPT is justified at both Sand Island and Honouliuli because it is the most environmentally sound and cost-effective way of upgrading the overall efficiency of the existing facilities. It will increase the BOD removal at both treatment plants. This is necessary to obtain renewals of secondary treatment waivers.

Sand Island has facilities for both CEPT and dissolved air flotation (DAF); however, the CEPT upgrade is preferable to DAF. While both increase BOD removal, DAF decreases TSS removal and CEPT increases it. The latter is important in facilitating the option to disinfect Sand Island effluent by ultraviolet rather than by chlorination.

CEPT + disinfection is justified at Sand Island, but not at Honouliuli, because it is effective in reducing fecal coliform and enterococci concentrations, at beaches and especially at offshore stations. The disadvantages of chlorine toxicity in the tropical marine environment, increased safety regulation concerns and the advantage of UV in terms of its efficacy in inactivating most viruses, spores, and cysts argue in favor UV disinfection for Sand Island. Pilot tests of CEPT + UV disinfection would need to take place at Sand Island to verify the viability of this recommendation.

Honouliuli is constructing facilities to treat flows in excess of 25 mgd to a biological secondary level for effluent reuse on land. Honouliuli, which has no DAF option, should implement CEPT for the 25 mgd that will continue to be discharged through the ocean outfall. Based on the findings of the Mamala Bay Study, disinfection is not needed at Honouliuli.

There is no evidence from the Mamala Bay microbiological or hydrodynamic modelling studies that secondary treatment at either Sand Island or Honouliuli will provide any effective benefits for effluent discharged to Mamala Bay.

Sand Island

- CEPT + UV disinfection

Honouliuli

- CEPT for 25 mgd flow that continues to be discharged through the ocean outfall

Ala Wai Canal

- Non-point source management of the Ala Wai Canal;

- Source control/pollution prevention;
- Boat waste management;
- Community-based watershed management program.

EXHIBIT NN

BASIS OF DESIGN

NORTHERN DISTRICT TREATMENT PLANT OUTFALL EXTENSION

TUMON BAY INFRASTRUCTURE AND BEAUTIFICATION PROJECT

Prepared for:
Guam Waterworks Authority
and
Department of Public Works

SEPTEMBER 2001

ASSOCIATES, INC.
ENGINEEERS/ARCHITECTS

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PROJECT

1.1 NORTHERN DISTRICT WASTEWATER PLANT

The Northern District Wastewater Plant (NDWWTP) is the only publicly operated treatment plant in northern Guam. When the plant was commissioned in 1980, it's service area was made up of the developed areas and various subdivisions in the Dededo and Yigo Municipalities, Andersen Air Force Base, Naval Communications facilities, and military personnel housing in north and south Finegayan. In late 1991, the service area was expanded by diverting wastewater from the Agana Treatment Plant Collection System. This expansion included the subdivisions, Barrigada Heights, Liguan Terrace, USN Marbo Annex and the Fujita Pump Station which services all of the major hotels, except the Guam Hilton located in Tumon. The plant has been designed to treat an average daily flow of 12 mgd with peak hourly flow of 28.6 mgd. As of September 1998, the average daily flow was 6.3 mgd and the peak hourly flow 15.9 mgd.

The plant is designed to provide advanced primary treatment. The unit operations in the liquid process stream are comminution, pre-aeration, aerated grit removal, primary clarification, and chlorine disinfection. Primary sludge can be recycled to the pre-aeration tanks to enhance settling in the clarifiers. It has been the practice not to chlorinate the effluent. The liquid process unit operations are arranged in parallel which provides redundancy at current flowrates. The solids process stream operations are primary and secondary anaerobic digestion and sludge dewatering with two solid bowl centrifuges. Recent improvements to the plant include replacement of clarifier weirs, baffles sludge collectors and drives, replacement of primary scum and sludge pumps, repairs of digester covers and substitution of the primary digester gas mixing equipment with a mechanical mixer in the primary digester.

1.2 EXISTING OUTFALL

The treatment plant is located on a plateau approximately 300 feet above the Philippine Sea. Primary effluent is transported from the chlorination contact chamber to the cliff edge 1,160 feet away by a reinforced concrete gravity sewer, 48 inches in diameter. The transmission line then changes to a 30 inch diameter polyethylene-lined ductile iron pipe for the route down the cliff to the shoreline. The descent is 272 feet over a distance of 3,915 feet. This section of the transmission line was replaced in 1998. Twelve feet from the high water line, the transmission line changes to 30 inch diameter reinforced plastic mortar pipe encased in concrete for the 1,150 feet transition across the reef flat. The descent from the reef edge to the diffuser 60 feet below is made with 30 inch ductile iron pipe encased in a concrete trench for the distance of 590 feet. The diffuser lies 60 feet below the surface in a south to north orientation that is approximately parallel to the shoreline. The diffuser is constructed from flexible joint ductile iron pipe in five segments of decreasing diameter as listed in Table 1.1 Pipe segments were laid in a trench and backfilled with Tremie concrete. Twenty two risers capped with 4 inch 90 degree elbows were installed on the five segments at approximately 18 feet centers. The five segments total 422 feet.

TABLE 1.1
NORTHERN SEWER DISTRICT
OUTFALL DIFFUSER ARRANGEMENT

Section Diameter	30"	24"	20"	16"	12"
No. Of Ports	4	5	4	4	5

An underwater inspection by E.K. Noda and Associates determined the following conditions in November 1998.

1) At the south end, the first three risers on the 30 inch diameter segment are blind flanged.

2) Effluent was observed discharging from the next thirteen ports plus the first port on the 12 inch diameter segment.

3) Blockages in four risers was found to be in the header, while the fifth was in the riser.

4) Two risers were missing elbows.

5) Most risers discharged offshore.

The underwater inspection was videotaped.

1.3 PROPOSED OUTFALL

Section 301 (h) of the Clean Water Act allows the USEA administrator to issue National Pollution Discharge Elimination System (NPDES) permits for the discharge of less than secondary treated effluent by a publicly owned treatment works (POTW) to marine waters. The plant had received a 301 (h) modified permit which expired on June 30, 1998. Guam Waterworks Authority (GWA) applied for a renewal. This application included the intent to construct a new outfall with a discharge further offshore. The new pipeline would be installed under the sea floor by Horizontal Directional Drilling (HDD). This construction method has shown to provide superior protection from storm surge and to be more cost effective than cut and cover placement, as evidenced by the outfall installed at Tipalao Point in 1996.

GWA also requested that the end of permit term flow be increased from 6 to 10 mgd and that the allowable mass loadings for BOD and Suspended Solids be likewise increased proportionally with flow.

SECTION 2

SECTION 2

OUTFALL PERFORMANCE REQUIREMENTS

The design begins with determination of required hydraulic capacity and initial dilution.

2.1 HYDRAULIC CAPACITY

Plant flow records were analyzed from January 1992 to November 1998. The initial date was selected because the first significant diversion of sewage collected in the northern Tumon service area from the Agana to Northern District plant occurred in late 1991. This analysis examined:

1) Maximum, average, and minimum daily flows

2) Seasonal variations in daily flows against corresponding rainfall data; and

3) Diurnal flow cycles on weekdays and weekends.

Figure 2.1 shows the average monthly flow over a six-year span while Figure 2.2 shows the maximum monthly flow. Over the term, average flow is observed to increase because of the aforementioned sewer diversion and continue to grow. Over the last decade, four major hotels have opened in the service area, while the population in the largest residential district, "Dededo" has expanded 35% to 42,980[1]. The average daily flow has exceeded the flow limit set by the last NPDES permit at 6 mgd.

Guam experiences distinct wet and dry seasons with August throughout November receiving more rainfall, while July and December are transition months. The flow records for each year were grouped according to season, as defined by the rainfall distribution for that year.

Comparisons were made between groups on both a group average basis and graphically on a year by year basis. The difference between seasons was observed to have been indistinguishable. Hence, it is concluded that season variations are not a factor in the selection of design flows.

Hourly flow records were examined for the week of November 9 to 15, 1998. The diurnal cycle was modest with minimum flow at 9% below average occurring in the early morning between 2 to 4 a.m., and maximum flows at 9% above average at noon and early evening. Otherwise, this cycle was not observed to shift from weekday to weekend. Diurnal variations are within the range observed on an average daily basis and, therefore, will not effect the selection of design flows.

In 1994 Guam Island wide Wastewater Facilities Plan[2] projects an average daily flow of 10.9 mgd with a peak hourly flow of 28.6 mgd in the year 2014; i.e. the 20 year planning horizon.

It has been concluded from the foregoing analysis that the Northern District outfall should be able to operate successfully for a range of flows from 5 mgd to 28.6 mgd. This range will encompass the variations normally experienced on both daily and seasonal cycles. As seen in Table 2.1.

Table 2.1

NORTHERN DISTRICT WASTEWATER TREATMENT PLANT INFLUENT

Classification	flow (mgd)	Occurrence
Annual:		
Average Daily	6.31	
Max. Daily	8.5	Jun-98
Min Daily	5	Oct-97
Peak Hour	15.9	1/30/97
Wet Season:		
Average Daily	6.37	
Max. Daily	7.3	Sep-98
Min Daily	5.1	Oct-98
Dry Season:		
Average Daily	6.27	
Max. Daily	8.5	Jun-98
Min. Daily	5.1	Jun-98
Projected (2014):		
Average Daily	10.9	
Peak Hour	28.6	
Design:		
Average Daily	12	
Peak Hour	27	

Figure 2.1
Northern District Wastewater Treatment Plant Monthly Flow Over a Six Year Span

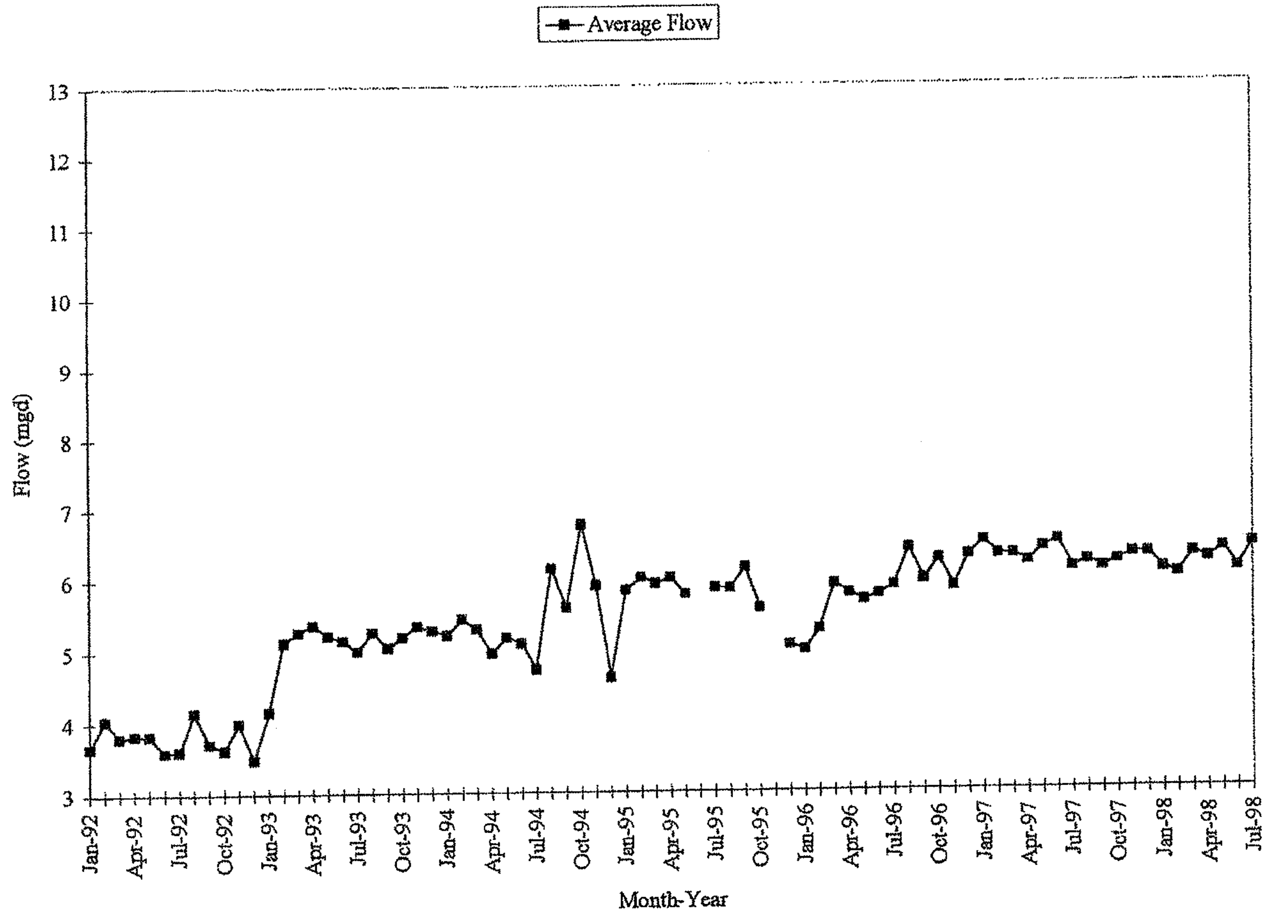
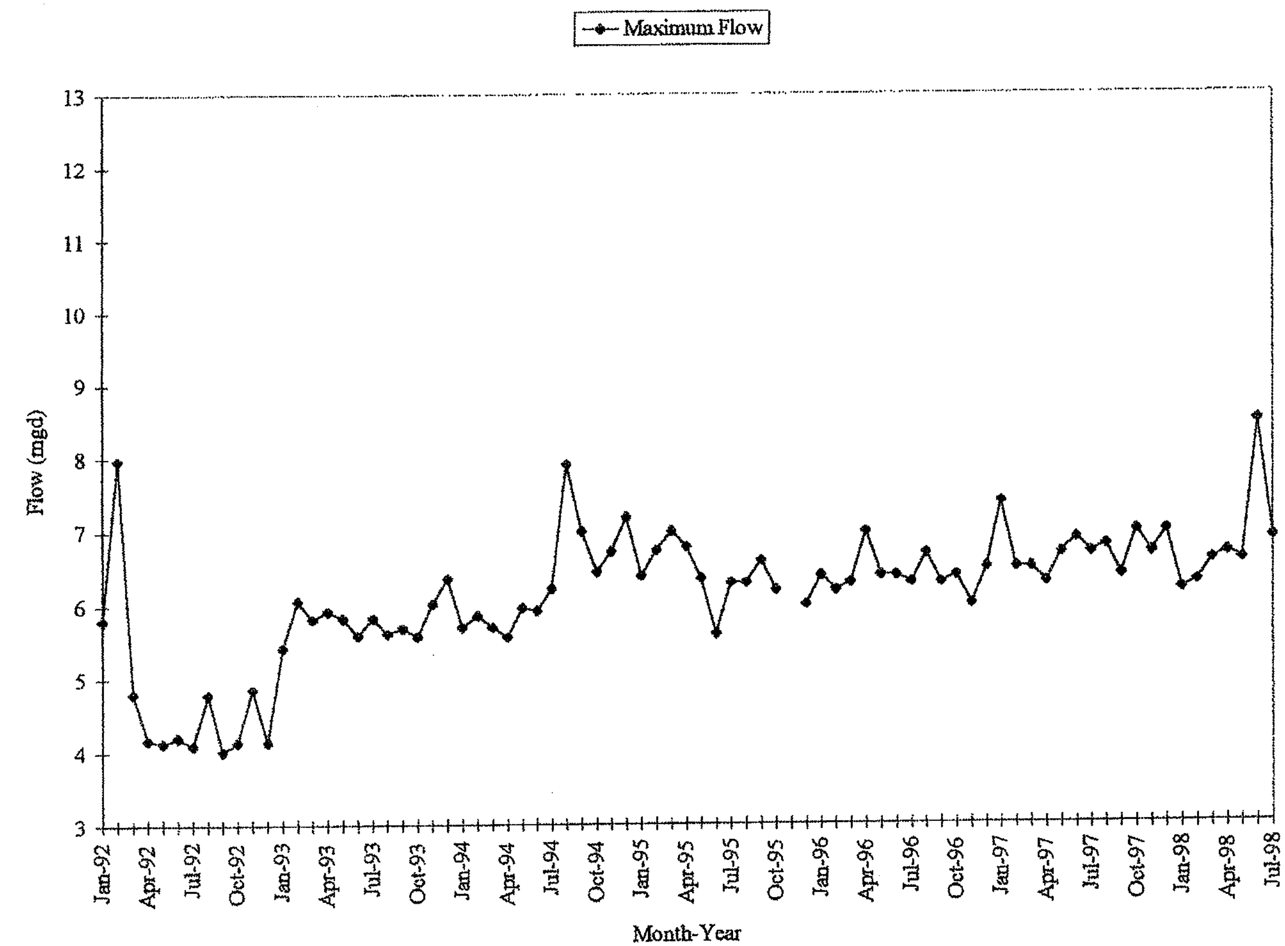


Figure 2.2
Northern District Wastewater Treatment Plant Monthly Flow Over a Six Year Span



2.2 INITIAL DILUTION

The initial required dilution for a specific compound or indicator is a function of water quality standard for the receiving water, ambient concentration in the receiving water, and the concentration in the wastewater treatment plant effluent.

2.2.1 WATER QUALITY STANDARDS

The water quality standards applicable to the receiving waters off Tangussion Point are established by the Revised Guam Water Quality Standards adopted on January 2, 1992. These standards have undergone a triennial review resulting in a draft final revision[3]. Final adoption is subject to the approval of the Guam EPA Board of Directors, Attorney General, Governor, Senate, and USEPA. Both the adopted standards and draft final revision were consulted for this analysis.

The outfall will discharge into marine waters classified as M-2, Good.

Water in this category must be of sufficient quality to allow for the propagation and survival of marine organisms, particularly shellfish and recreation. Other similarly harvested aquatic organisms, corals and other reef related resources, and whole body contact recreation. Other important and intended uses include mariculture activities, aesthetic enjoyment and related activities.[3]

The numerical criteria for those water quality standards that are likely to be impacted by sewage effluent are listed in Table 2.3.

2.2.2 RECEIVING WATER CONDITION

A water quality survey was conducted on September 22 at the four corners of the mixing zone for the proposed outfall site. Water samples were taken at surface, mid-depth and bottom. The analytical results are tabulated in Appendix A, while values averaged over depth and four locations are listed in Table 2.3. Water quality is consistent with the standards for M-2 waters.

2.2.3 WASTEWATER EFFLUENT CONCENTRATIONS

The plant effluent is routinely analyzed for the following constituents to comply with the monthly reporting requirements of its discharge permit:

a) Suspended Solids (SS)

b) Biochemical Oxygen Demand (BOD)

c) Settable Solids

d) Oil & Grease

e) pH

A composite effluent sample was taken on March 9, 1998 and subjected to a priority toxic pollutant scan. Four pollutants out of a possible 126 were detected and are listed in Table 2.3 Two additional chemical constituents that are not yet regulated were also detected in the parts per billion range.

The concentration reported for lead at 2,900 ug/l in the toxic pollutant scan appears to be concentrations in the range of 4 to 19 ug/l with one household reporting 30 ug/l. Table 2.2 lists lead concentrations measured in the effluents of three treatment plants on Guam and two plants on Oahu, Hawaii. These collaborative results support the conclusion that the lead concentration reported in the pollutant scan is overstated by at least one order of magnitude and possibly two.

Table 2.2

SURVEY OF EFFLUENT LEAD CONCENTRATIONS AT VARIOUS WASTEWATER TREATMENT PLANTS

Plant & Locations	Effluent	Date Sampled	Lead Conc. ug/l
Agana WWTP, Guam	Primary	3/10./98	nd[1]
Apra Harbor WWTP COMNAVMAR, Guam	Primary	8/91 to 7/92	14 to 56[2]
Agat WWTP, Guam	Secondary	7/90 to 10/9	5.6[2]
Sand Island WWTP, Oahu	Primary		42[3]
Honouliuli WWTP, Oahu	Primary		186[3]
Ft. Kam WWTP, Oahu	Secondary		28[3]

[1] Laboratory Report #41239, Montgomery Watson Laboratories, Pasadena Ca, March 1998
[2] Feasibility Study Tipalao Bay Outfall , CH2M Hill, October 1992
[3] Stevenson, M., O'Connor, J., & Aldrich, J.,
Pollutant Source Identification, *Mamala Bay Study*, (July 1995)

2.2.4 REQUIRED DILUTION

Required dilution is the volume ratio of ambient seawater plus wastewater effluent to wastewater effluent that will not allow exceedance of the water quality standards for that particular constituent. Generally, the required dilution is calculated with the expression taken for

USEPA (1994)[5]:

$$Sa = (Ce - Ca) \;/\; (Cs - Ce)$$

Where Ce = effluent concentration

Cs = water quality standard

Ca = receiving water concentration

Sa = dilution

Values for the three parameters and resulting dilution are listed in Table 2.3 for the constituents found in the wastewater effluent.

The indicator bacteria "Enterococci" requires the largest dilution of 8000. However, this dilution is beyond the performance of an outfall that could be constructed at reasonable cost. The second highest required dilution is for suspended solids 170. The design criterion for intail dilution is selected at 200.

Table 2.3

REQUIRED DILUTION CALCULATION
FOR NORTHERN DISTRICT WASTEWATER TREAMENT PLANT OUTFALL

Constituent Regulated by Guam Water Quality Standards	Unit	Water Quality Std.	Ambient Conc.	Effluent Conc.	Required Dilution
Enterococci	#/100ml	104	0	**830,000**	7,7981
pH		6.5 to 8.5	8.2	7.2	10
Orthophosplate	ug/l	50	0	**4240**	85
Nitrate-Nitrogen	ug/l	200	0	29	0
Dissolved Oxygen	mg/l	4.6	6	0	6
Salinity	ppt	0%+ambient	32	0.8	0
Suspended	ug/l	20000	19000	190000	170
Turbidity	NTU	1+ambient	0.27		
Temperature	°C	1+ambient	29.7	30	0
Priority Toxic Pollutants					
p-Dichlorobenzene	ug/l	2600	0	1.1	0
Toluene	ug/l	5000	0	1.9	0
Copper	ug/l	3.1	0	53	17
Zinc	ug/l	86	0	2110	2
Additional Toxic Pollutants					
Ammonia	ug/l	20	0	**1045**	52
Sulfide	ug/l	5	0	**110**	22
Nonregulated Chemical Constituents					
Acetone	ug/l			86	
4-Methylphenol	ug/l			45	

Table 2.3 (cont'd)

FOOTNOTES

* Effluent Values in bold Italics are estimated from analyses of primary effluent form Oahu wastewater treatment plant
* Ammonia and orthophosphate are averaged from grab samples
* Application factor of 0.05 applied to total NH_3 conc. of 20.9 mg/l.
* Sulfide conc. is from an inplant survey at Sand Is. WWTP.
* Enterococci is from a five plant survey of primary effluent.
* Effluent suspended solids conc. is the maximum average value recorded from Jan. 1997 to Sept. 1998
* Required Dilution for dissolved oxygen assumes 3 mg/l immediate demand.

SECTION 3

SECTION 3

OUTFALL DESIGN

3.1 ALIGNMENT AND TERMINUS

The outfall terminus or discharge location is determined by three factors. First. A seafloor slope of 8% but not more than 12% is needed for constructability of the diffuser. Second, the terminus shall be beyond the near shore water -- i.e. beyond 10 fathom depth (60 ft., 18.3 m). Third, the depth at the diffuser shall provide the required initial dilution.

The bathymetric survey for the receiving water off Tanguisson Pt. Shows two potential sites (1) a canyon located between the 125 and 150 ft contours, and (2) a plateau between the 200 and 250 ft contours.

The feasibility of constructing a shallow outfall with multiport diffuser at depths between 135 to 150 ft versus a deep outfall with a single point discharge at depths ranging from 225 to 325 ft was evaluated on the basis of initial dilution, farfield dilution at the shoreline, and construction cost. E.K. Noda and Associates (EKNA) estimated initial dilutions under the various conditions listed in Table 3.1 Two alternatives were selected for further study; 1) an outfall at 150 ft with a multi-port 400 ft diffuser and 2) an outfall at 250 ft with a single discharge port.

Table 3.1

INITIAL DILUTION CALCULATION

Deep Outfall with Single Point Discharge				
Average Dilution Q max = 28.6 mgd				
Discharge Depth (ft)	UM	Point Plume		Approximate Distance for Shoreline (ft)
225	94-97	91		
250	108-112	109		2,300
275	124-129	128		2,400
300	139-146	148		2,450
325	155-164	169		
Shallow Outfall with 40 Port Diffuser				
Diffuser Length at 100ft				
Average Dilutions Q max = 28.6 mgd				
Discharge Depth (ft)	UM	RSB	2D	Approximate Distance from Shoreline
135	92	84	85	1,390
150	99	106	94	1,550
Diffuser Length at 200ft				
Average Dilutions Q max = 28.6 mgd				
Discharge Depth (ft)	UM	RSB	2D	Approximate Distance from Shoreline
135	140	149	134	1,390
150	153	163	149	1,550

Table 3.1

INITIAL DILUTION CALCULATION (cont.)

Diffuser Length at 300ft				
Average Dilutions, Q max = 28.6 mgd				
Discharge Depth (ft)	UM	RSB	2D	Approximate Distance from Shoreline
135	182	192	176	1,390
150	198	212	196	1,550
Diffuser Length at 400ft				
Average Dilutions, Q max = 28.6 mgd				
Discharge Depth (ft)	UM	RSB	2D	Approximate Distance from Shoreline
135	220	226	213	1,390
150	239	254	237	1,550
Diffuser Length at 100ft				
Average Dilutions, Q min = 5.0 mgd				
Discharge Depth (ft)	UM	RSB	2D	Approximate Distance from Shoreline
135	244	294	271	1,390
150	266	327	301	1,550
Diffuser Length at 200ft				
Average Dilutions, Q min = 5.0 mgd				
Discharge Depth (ft)	UM	RSB	2D	Approximate Distance from Shoreline
135	380	467	430	1,390
150	416	482	478	1,550

Table 3.1

INITIAL DILUTION CALCULATION (cont.)

Diffuser Length at 300ft				
Average Dilutions, Q min = 5.0 mgd				
Discharge Depth (ft)	UM	RSB	2D	Approximate Distance from Shoreline
135	491	592	564	1,390
150	538	563	626	1,550
Diffuser Length at 400ft				
Average Dilutions, Q min = 5.0 mgd				
Discharge Depth (ft)	UM	RSB	2D	Approximate Distance from Shoreline
135	584	678	683	1,390
150	644	615	759	1,550

Dilutions estimated by the UM and RSB models are based on the density profiles measured in the November 1998 survey.

Dilutions estimated by the Point Plume model used the average density of the aforementioned profiles.

From March 1990 through 1993, GWA sampled and analyzed for fecal coliform bacteria monthly at two shoreline location generally known as Tanguisson Point and NCS Beach.

The results listed in Table 3.2 show that the water quality standard for this indicator -- i.e. 400 mpn/100 ml was exceeded with increasing frequency in the last two years of the survey.

Table 3.2

FREQUENCY OF EXCEEDENCE OF FECAL COLIFORM WQS NORTHERN DISTRICT WWTP OUTFALL RECEIVING WATER

Year	Tanguisson Point	NCS Beach
1990	0	1 in 11
1991	2 in 12	1 in 12
1992	7 in 12	1 in 12
1993	6 in 12	3 in 12

Therefore, EKNA were asked to determined if the deeper outfall being 880 ft further offshore resulted in a greater farfield dilution. Their preliminary evaluation based upon the current study conducted in November 1998 (Appendix B) placed the dilution of the deeper outfall at 550 and the shallower multi port diffuser at 520.

The third issue in this feasibility study is construction cost, -- i.e. will the additional cost for HDD and pipeline to the deeper discharge be offset by the cost for installing the simpler diffuser.

The preliminary construction cost estimate for the deeper outfall was $480,000 or 11 percent greater than the outfall with the multi-port diffuser.

The alignment selected for the new outfall is from the existing force main at Tanguisson Point to the underwater canyon at the 140 ft. contour with a heading of 316 degrees northwest.

3.2 DIFFUSER DESIGNER

A 400 ft multiport diffuser was selected to provide the required dilution with an adequate margin. Design criteria are;

1) Maximum port velocity is between 15 to 20 fps

2) Maximum velocity in the header is 20 fps

3) Minimum velocity in the header is greater than 1 fps

4) Area ratio is between 1/3 to 2/3

5) Maximum effluent flow is 44.25 cfs (28.6 mgd)

6) Minimum effluent flow is 7.73 cfs (5 mgd)

7) Port spacing is at 10 ft centers

Preliminary sizing based on the above sets the port diameter at 3.35 inches resulting in a maximum port velocity of 18 fps. An initial header diameter of 30" sets the maximum velocity at 9 fps and minimum velocity at 1.6 fps. The header diameter decrease in five segments: 1)30in, 2)24in, 3)20in, 4)16in, and 5)12in. Each segment will be joined by a reducing transition.

Each port will have a two foot riser with a 90 degree elbow. The utility of using a duckbill check valve and riser fabricated from molded rubber with nylon reinforcement and manufactured by Red Valve Co., Inc. will be evaluated.

Header will be fabricated from HDPE pipe with polyethylene lined ductile iron pipe as an alternative.

SECTION 4

SECTION 4

CONSTRUCTION METHODOLOGY

4.1 OUTFALL PIPELINE

The selected construction method is horizontal directional drilling (HDD). The selection is based upon:

1) The pipeline length and diameter are within the capability of this method, i.e. up to 6000 feet and 48-inch pipe diameter.
2) The method minimizes underwater construction
3) The method has proven successful in similar consolidated limestone strata found at Tipalao Pont.
4) The method is compatible with the seafloor bathymetry in the receiving waters off Tanguisson Point. Conversely, pipeline installation by cut and cover would be difficult.
5) The method provides adequate cover and protection from storm surge.
6) The method has proven to be more economical than the cut and cover method.
7) The method causes less impact to the marine environment during construction.

Construction begins with drilling a 12-inch diameter pilot hole from Tanguisson Point. The project site is a terrace between the beach and toe of the Northern plateau. The entry point was selected to provide sufficient space for the drilling operation while segregating this operation from the more environmentally sensitive beach area. The pilot hold should exit within a 30-foot square of the proposed location at the 135 foot depth. The cutting head is directed by manipulating its orientation relative to the drill string. Cutting head location is monitored continuously by measuring the magnetic field to determine latitude and longitude and inclination to determine depth.

Upon exiting, the cutting head and drill string are retrieved by a barge onstation. The pilot hole is then reamed to succeeding larger diameters until suitably sized for the pipeline. This operation is accomplished by replacing the cutting head with a reamer and pulling the reamer and additional string back to the entry point.

After the hole is sufficiently enlarged, the pipeline is pulled through it. The pipeline is prefabricated at a designated staging area and pulled through the hole by the drill string to the barge onstation. In all three operations, large quantities of bentonite slurry are used to maintain hole integrity, remove cuttings, and drive the cutting head motors.

The pipeline profile is determined by the entry angle, radius of curvature, and exit angle. Initially, a shallow 12° entry angle has been selected to clear the beach strand and provide adequate cover at the reef flat. The radius of curvature is 3400 feet to accommodate a 34-inch diameter pipe. A shallow exit angle of 6° at the exit is used to clear the seafloor.

4.2 PIPELINE SIZE AND MATERIAL

High-density polyethylene (HDPE) is selected because:

1) It is impervious to seawater environment,
2) Strength and flexibility properties are suited to construction method, and
3) It is cost competitive to epoxy-coated steel pipe.

A 34-inch diameter pipe with an SDR=17 (standard ratio pipe diameter to wall thickness) is selected to accommodate the peak hourly flow of 28.6 mgd.

4.3 DIFFUSER

The multiport diffuser has been described in Section 3.2. The diffuser will be fabricated from HDPE pipe with polyethylene lined ductile iron as are alternative.

The diffuser header will be held in place as a gravity structure, -.i.e. with ballast supports and/or pedestal . The header will be accessible for inspection, maintenance, and repair if necessary. Both header and ballast components will be fabricated onshore, transported to the site, and lowered into place. Construction divers would direct alignment and fasten header segments. The header will be aligned along the 140 ft contour, south to north. This location allows flexibility for the pipeline exit point and provides a uniform bottom grade of 8 to 9% along the header length to set the diffusers on.

REFERENCES

REFERENCES

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2. Duenas & Associates & CH2MHill, *Guam Island Wastewater Facilities Plan, Vol. I,* Public Utility Agency of Guam (Dec. 1994).

3. Guam Water Quality Standards (Final Draft Revision) (Dec. 1999).

4. Joanne Boyd, Guam Waterworks Authority, Memorandum (1998).

5. Office and Coastal Protection Division (4504F), Office of Wetlands, Oceans and Watersheds, *Amended Section 301(h) Technical Document,* EPA 842-B-94-007 (Sept. 1994).