MAMALA BAY STUDY

PROJECT MB-10
ENVIRONMENTAL IMPACTS ON RECEPTORS AND RESOURCES

Part IV

PROPOSED MONITORING PLAN TO ASSESS ENVIRONMENTAL QUALITY
IN MAMALA BAY AND THE MAMALA BAY WATERSHED

PRELIMINARY DOCUMENT

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PROPOSED MONITORING PLAN TO ASSESS ENVIRONMENTAL QUALITY IN MAMALA BAY AND THE MAMALA BAY WATERSHED

Executive Summary

The future monitoring program for Mamala Bay remains in a developmental state. This document represents a discussion document that will be used by regulators, managers, and investigators as they develop the details of an integrated, regional monitoring program that can be carried out in Mamala Bay between 1996 and 2011. Herein we present what we consider to be the some salient features of that integrated, regional monitoring program with the understanding that the final form of the monitoring program must be developed to meet local, State, and Federal regulations pursuant to the numerous permits for waste discharge that have been issued to government and industry in the Mamala Bay watershed.

Some of the key features of the proposed future monitoring program that are presented in this discussion report are as follows:

- Upgrading of chemical analytical methods applied to pollutants and chemical contaminants in influent waters, effluent waters, sediments, and biota in the Bay;
- Reduced emphasis on sampling in the immediate vicinity of the diffuser discharges in favor of siting sampling stations throughout Mamala Bay;
- Increased effort for the monitoring of pollutants and chemical contaminants in nonpoint source discharges throughout the Mamala Bay watershed;
- The implementation of a Bay-wide "mini-mussel watch" program aimed at assessing the potential for the biota to accumulate chemical toxicants that cannot be measured in surface waters or in sediments; and
- The development of new techniques suitable for the measurement of bacterial, viral and protozoan pathogens in water samples taken from Mamala Bay.

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PROPOSED MONITORING PLAN TO ASSESS ENVIRONMENTAL QUALITY IN MAMALA BAY AND THE MAMALA BAY WATERSHED

1.0. Introduction

This report presents a plan for a regional, integrated, environmental quality monitoring program to be carried out in Mamala Bay over a 15-year interval, between 1996 and 2011. The need for the monitoring program arises from public perception that wastes discharged to Mamala Bay might pose a risk to marine ecosystems and to public health. The results of the Mamala Bay Study (this volume) show the Mamala Bay ecosystem to be diverse and productive, and capable of assimilating existing levels of pollutant loading with no adverse effects. However, as wastes continue to be discharged to Mamala Bay in ever-increasing quantities, regulatory and management authorities responsible for maintaining the public health and ecological integrity of Mamala Bay will need continuous input of regional environmental quality monitoring data in order to update evaluations of the existing quality of the Mamala Bay ecosystem, and to manage waste discharges to the system so that beneficial uses of the system are maintained. Principal beneficial uses of the Mamala Bay ecosystem include bathing, swimming, and other water contact recreations, aesthetic appeal, and the existence of marine ecosystems able to support the unique flora and fauna typical of the fringing reefs, hard-bottom communities, and open-water tropical marine fish, reptilian, and mammalian populations in the Bay.

Monitoring in Mamala Bay at the present time is limited almost exclusively to studies carried out as conditions of the National Pollutant Discharge Elimination Program (NPDES) permits granted to the City and County of Honolulu for the continued operation of the Sand Island and Honouliuli waste water treatments plants (WWTPs). Sand Island and Honouliuli discharge primary-treated waste water into Mamala Bay; the source of wastes to the Sand Island and Honouliuli WWTPs are the domestic sewage and pre-treated industrial wastes from business and industry in the City and County of Honolulu. Required monitoring under NPDES permits includes:

- Measurement of conventional pollutants and chemical contaminants in WWTP influent and effluent streams:
- Empirical testing of effluent toxicity to biota;
- Measurement of bacteria concentrations at beaches and in near shore areas;
- Measurement of conventional pollutants in the water column within the zone of initial dilution and the zone of mixing adjacent to the diffuser discharges from the Sand Island and Honouliuli WWTPs;
- Measurement of conventional pollutants and chemical contaminants in sediments adjacent to the diffuser discharges from the Sand Island and Honouliuli WWTPs;
- Measurement of the indicators of the health and well-being of biological populations in the waters and sediments adjacent to the diffuser discharges from the Sand Island and Honouliuli WWTPs.
- Measurement of currents and oceanographic features of Mamala Bay that may be related to the potential transport of effluent plumes from the Sand Island and Honouliuli WWTPs toward and onto the beaches bordering Mamala Bay.

The results of these monitoring efforts are reported annually (and, in the case of influent and effluent pollutant and chemical data, monthly) to regulatory agencies (US EPA and the State of Hawaii Department of Health). The results of these monitoring studies also form the basis for a large part of the evaluative synthesis reported in this final report of the Mamala Bay Study (this volume).

The results of the Mamala Bay Study (this volume) lead to two overall conclusions: 1) That the Mamala Bay ecosystem remains diverse and productive despite the volumes and masses of wastes discharged into it and its contiguous waters (Pearl Harbor, Keehi Lagoon, Kewalo Basin, and the Ala Wai Canal); and 2) That the sources of pollutants and contaminants entering Mamala Bay are diverse, are not restricted to wastewater from the Sand Island and Honouliuli WWTPs, and arise from sources throughout the watershed that drains to Mamala Bay. The second conclusion compels us to state that monitoring efforts

designed to provide information to the regulatory and management authorities responsible for maintaining the present high standard of public health and ecological integrity of Mamala Bay must be integrated so that they incorporate valid measurements representing all sources of pollutants and contaminants to the Bay.

Future monitoring efforts must use the entire Mamala Bay watershed as the basis for monitoring program design. Unfortunately there exist few monitoring programs with the objective of measuring the transport, fate, and distribution of pollutants and contaminants landward of the pierhead line for Mamala Bay. In some cases, such as the case of monitoring for nonpoint source pollutant loading, monitoring plans are under development that include measurement of pollutants and contaminants in the watershed. In other cases, such as the case of measuring bacteriological populations relative to contamination and public health, there exist important and useful data from the watershed which, while providing critical information, do not comprise monitoring programs *per se*.

The monitoring program that will be developed for Mamala Bay must be regional, rather than local, in scope. That is to say that the monitoring program must be designed to provide data on the entire Mamala Bay system rather than on small portions of the Bay that might be adjacent to specific point source or nonpoint source discharges. The monitoring program proposed herein is also an integrated monitoring program. That is to say that the monitoring program first, integrates monitoring studies of both point source and nonpoint source pollutant and contaminant discharges, and second, addresses several monitoring needs within a single program. These monitoring needs are 1) the need for regulatory compliance with chemical water quality standards, 2) the need for regulatory compliance with public health-oriented water quality standards (bacteriological sampling and analysis), 3) the need for data useful in evaluating the effectiveness of management measures aimed at reducing pollutant loading from Wastewater Treatment Plants (WWTPs) and nonpoint sources, and 4) the need to accumulate status and trends information in order to assess the health and well-being of ecological systems within Mamala Bay.

2.0 Components of the Monitoring Program

The Mamala Bay Monitoring Program (MBMP) is designed to provide data useful for the following purposes:

- Estimation of pollutant and chemical contaminant loading to the Mamala Bay system from throughout the Mamala Bay watershed;
- Estimation of chemical contaminant fate and effects in Mamala Bay;
- Estimation of the ecological health and well-being of Mamala Bay;
- Estimation of public health risk in the Mamala Bay system;
- Estimation of the efficiency of WWTP operation; and
- Estimation of the efficiency of nonpoint source pollutant controls.

Given such a data base, regulators and managers will be able to evaluate the overall status of the Mamala Bay system, anticipate adverse changes, if any should occur, and, when necessary, implement management and control measures that will be effective in maintaining beneficial uses of Mamala Bay for all concerned.

The monitoring program is based upon chemical, physical and biological measurements, combined with bioassay studies and some research into the development of critical, new, methods for application in monitoring studies of Mamala Bay. The sections that follow describe the current status of existing monitoring programs aimed at the collection of chemical, physical, and biological data, gaps in data collection that must be filled in order for the monitoring program to be successful, and recommendations for the future monitoring program. Identification of specific locations of stations to be occupied in the recommended monitoring program is not included in this report; such details are best managed when the final monitoring program has been decided upon, and when available budgets are known.

3.0 Chemical Monitoring

Chemical monitoring, in the context of this report, refers to measurements carried out on field samples aimed at quantifying chemical factors related to pollution in Mamala Bay. This includes the measurement of conventional pollutants (e.g., BOD, COD, nutrients,

suspended solids, and so forth) as well as the measurement of chemical contaminants (e.g., toxic and potentially toxic metals and organic compounds).

3.1 Existing Monitoring Programs

Existing monitoring of chemical constituents in the Mamala Bay watershed is restricted primarily to measurement of chemical parameters specified in the NPDES discharge permits for the Sand Island and Honouliuli WWTPs.

3.1.1 WWTP Influent Monitoring

Monitoring of WWTP influent includes various conventional measures as well as the measurement of toxic and potentially toxic contaminants such as metals and organic compounds.

*Status:*Influent water quality monitoring at both the Sand Island and the Honouliuli WWTP is carried out regularly and provides critical data on the quality of pre-treatment given to WWTP influent waste streams from industrial dischargers and, when combined with effluent chemical data, provides important data regarding the performance of the WWTPs. Measurements of toxic and potentially toxic metals and organics in influent water provide data that are primarily "non-detects;" that is to say, the concentrations of toxic chemicals in influent waters are, for the most part, lower than the detection limits for the methods used in the analysis.

Data Gaps: The completeness of the influent monitoring data for conventional pollutants and conventional water quality parameters is good. Influent monitoring data for chemical toxicants, including metals and organic contaminants, is poor, primarily because the methods applied in the analysis for priority pollutants in the influent waters are not sufficiently sensitive. Given that concentrations of toxics in effluent waters are more important to the ecosystem than concentrations of the same chemicals in the influent waters, this is a data gap of secondary importance. However, the lack of influent toxics makes it difficult, if not impossible, to derive estimates on the efficiency of removal of toxic materials by the WWTPs.

Recommendations for Future Monitoring: WWTP influent monitoring is satisfactory, in its frequency, for the data needs of regulators and managers. The methods used for WWTP influent monitoring of priority pollutants are inadequate and provide no useful data. Methods for the analysis of priority metal pollutants in WWTP influent waters should be changed to the EPA "200" series. Methods for the analysis of priority organic pollutants in WWTP influent waters should be changed to EPA "600" series. Future monitoring reports for WWTP influent data must include all available quality assurance and quality control data (QA/QC).

3.1.2 WWTP Effluent Monitoring

Chemical monitoring of WWTP effluent includes various conventional measures as well as the measurement of toxic and potentially toxic contaminants such as metals and organic compounds.

Status: Effluent water quality monitoring at both the Sand Island and the Honouliuli WWTP is carried out regularly and provides critical data on the concentrations of chemicals in the effluent that have the potential to affect the physical environment of Mamala Bay, as well as the biota of Mamala Bay. Effluent water quality data are converted to loading data which, when entered into the newly developed numerical models of circulation in Mamala Bay, provide information on concentrations of chemical substances throughout the Mamala Bay system. When combined with influent water quality data, effluent monitoring data help to provide important data regarding WWTP performance. Measurements of toxic and potentially toxic metals and organics in effluent water provide data that are primarily "non-detects;" that is to say, the concentrations of toxic chemicals in influent waters are, for the most part, lower than the detection limits for the methods used in the analysis.

Data Gaps: The completeness of the effluent monitoring data for conventional pollutants and conventional water quality parameters is very good. Effluent monitoring data for chemical toxicants, including metals and organic contaminants, is poor, primarily because the methods applied in the analysis for priority pollutants in effluent waters are not sufficiently sensitive. This is a data gap of major importance. Without such data all information regarding

offshore and near shore stations occupied each quarter for the collection of chemical pollutant data.

3.1.4 Nonpoint Source Chemical Monitoring

There exists no data base for chemical pollutant monitoring in nonpoint source waters flowing to Mamala Bay. Mamala Bay Study investigators estimated pollutant loading to Mamala Bay, and found it necessary to use data from the National Urban Runoff Program (NURP) studies as a surrogate for empirical data. The estimated importance of nonpoint source loading of pollutants to Mamala Bay makes it essential that monitoring for the purpose of measuring chemical pollutants and contaminants flowing to Mamala Bay be integrated into the overall Mamala Bay monitoring program.

Status: The City and County of Honolulu has an NPDES permit for the discharge of nonpoint source waste water to Mamala Bay. As of the date of this writing, programs for monitoring chemical constituents in nonpoint sources were in the developmental stage.

Data Gaps: To our knowledge, there are no monitoring data on chemical pollutants of toxic and potentially toxic contaminants in nonpoint source flows entering Mamala Bay. Individual studies of pollutant loads and bacteria concentrations in streams entering the sub-embayments of Mamala Bay have been conducted, and gaging data exist for a number of permanent streams in the Mamala Bay watershed.

Virtually all nonpoint source flow from the Mamala Bay watershed enters one or another of the sub-embayments before discharge to Mamala Bay. Accurate estimates of nonpoint source pollutant loading to Mamala Bay can only be made after monitoring data on chemical concentrations, particle-association, and settling in sub-embayments have been collected.

Recommendations for Future Monitoring: Several considerations must be addressed in the design of nonpoint source pollutant monitoring. The first, and perhaps the most important, is to be able to establish not only the identity and concentration of pollutants and contaminants in nonpoint source flows, but also to be able to identify the sources of the

pollutants in nonpoint source flows as a prerequisite for implementation of possible treatment or management. The second consideration is to be able to accurately define the extent to which pollutants and contaminants associated with nonpoint flow are trapped and confined in the natural ands man-made settling basins that already exist in the Mamala Bay watershed. The third consideration is to be able to predict with some accuracy what portion of Mamala Bay is influenced by nonpoint source pollutants that enter sub-embayments and, subsequently, enter the near shore waters of the Bay.

Sources of Nonpoint Source Pollutants in the Mamala Bay Watershed: Potential sources of pollutants in nonpoint source flows include natural weathering of rocks and soils in the watershed, agriculture, domestic use of chemicals, transportation, and industry. Future monitoring programs must be established such that streams draining distinct sub-basins of the watershed can be sampled at points above and below major potential sources of nonpoint source pollutants. For example, streams draining from mountain preserve areas through suburban and urban areas should be sampled at multiple points such that baseline pollutant concentrations can be measured as distinct from pollutants contributed first, by rural and suburban areas, and secondarily, by urban areas. In a similar manner, streams draining mountain preserve areas that flow through agricultural districts prior to entering rural, suburban, and urban areas must be sampled such that baseline pollutant concentrations can be measured distinct from the agricultural contribution, rural contribution, suburban concentration, and urban contribution. Within rural areas, sampling stations must be established such that drainage from transportation corridors can be sampled in isolation from background flow, and sampling stations to collect urban runoff must be established such that runoff from industrial areas can be distinguished from other portions of the city.

3.1.5 Chemical Monitoring of Biota

Fishes in Mamala Bay that are consumed by the human population are currently subject to monitoring under the existing NPDES permits for the Sand Island and Honouliuli WWTPs. Chemical contaminants in fish and invertebrate tissues from the Ala Wai Canal are

pollutant concentrations and pollutant loading to Mamala Bay from WWTPs loses credibility.

Recommendations for Future Monitoring: The frequency of WWTP effluent monitoring is satisfactory for the data needs of regulators and managers. The methods used for WWTP effluent monitoring of priority pollutants are inadequate and provide a limited amount of useful data. Methods for the analysis of priority metal pollutants in WWTP effluent waters should be changed to the EPA "200" series. Methods for the analysis of priority organic pollutants in WWTP effluent waters should be changed to EPA "600" series. Future monitoring reports for WWTP effluent data must include all available quality assurance and quality control data (QA/QC).

3.1.3 Receiving Water Chemical Monitoring

Monitoring for chemical pollutants in the receiving waters of Mamala Bay is restricted to measurement of conventional indicators of pollution (oil and Grease, light extinction, turbidity, nitrogen [total nitrogen, ammonia, nitrate, nitrite], total phosphorus, and chlorophyll a) at stations in the zone of initial dilution, the zone of mixing, and at near shore and offshore stations with reference to each of the permitted NPDES diffuser discharges in Mamala Bay.

Status: Receiving water chemical monitoring is carried out at a frequency of four times per year. In general the data are of high quality, and can be used to evaluate whether the discharge of nutrient chemicals (N and P) and suspended solids have any measurable impact on productivity in the Mamala Bay system. Priority toxic pollutants are not included in receiving water quality monitoring at the diffuser discharges, near shore and offshore stations is related to the fact that priority pollutants, like all the constituents in the discharges, are diluted by factors ranging from 400 to 1600 following passage through the dischargers, and would be unmeasurable in most instances. Estimation of the concentrations of priority pollutants and other toxicants in Mamala Bay is accomplished by the use of mathematical modeling of diffusion, mixing, and transport in the system.

Data Gaps: There are no substantive gaps in the data for chemical pollutants as related to the waters of Mamala Bay that are influenced directly by WWTP diffuser

discharges. There exist significant gaps in the data on chemical pollutants in the waters of Mamala Bay that are influenced by nonpoint sources (surface runoff and urban runoff) that enter the Bay with discharge from the major sub-embayments. As shown by Stevenson (1994), in his special studies of discharges from the Ala Wai Canal, the quantities of chemical (and bacteriological) contaminants entering the near shore waters of Mamala Bay from nonpoint sources can be substantial.

Recommendations for Future Monitoring: Careful evaluation of the existing data and the development of new estimates of initial dilution of wastes from the diffuser discharges in Mamala Bay show no negative impact on the system in the immediate vicinity of the diffuser discharges and the zones of mixing. No data exist relative to pollutant concentrations in shoreline waters under the influence of land side nonpoint sources (streams and stormwater conduits. Future monitoring for chemical pollutants, as indicated by conventional measures of pollution, should be modified so that the scale of coverage is changed from local (focussing on the diffuser discharges) to regional (encompassing the Bay as a whole).

We recommend a reduction in the number of stations occupied for the taking of samples for chemical pollutants at the diffuser discharges in Mamala Bay. Samples adjacent to the diffuser discharges (in the zone of initial dilution an in the zone of mixing) should be reduced to a total of three for each discharge (one at the diffuser, and one, each, at the eastern and western end of the zone of mixing). We recommend that the area covered by offshore and near shore sampling stations be increased to cover the entirety of Mamala Bay; for example, a series of eight stations located along the 70 meter depth contour (the depth of the diffusers), and a series of eight stations located along the 20 meter contour (equivalent to near shore stations). The data for the six diffuser stations, in combination with the data from the 16 regional stations, sampled on a quarterly basis, will provide sufficient data for comparison with existing data, and will serve as "ground truth" for verification and validation of model predictions of the fate and transport of chemical pollutants throughout Mamala Bay. Depending upon the degree of concordance between field data and model predictions over the next five years, consideration should be given to increasing, or decreasing, the number of

analyzed on an annual basis. The National Mussel Watch Program maintains a program for the collection of Hawaiian oysters (*Ostrea sandvicensis*) from Barber's Point and from Keehi Lagoon/Honolulu Harbor.

Status: Regular chemical monitoring of fishes in Mamala Bay is carried out on an annual basis in the vicinity of the diffuser discharges from Sand Island and Honouliuli WWTPs. Hawaiian oysters from Barber's Point and Keehi Lagoon are sampled and analyzed for chemical contaminants on an annual or semi-annual basis. Fish and invertebrates from the Ala Wai Canal are sampled and analyzed for chemical contaminants on a sporadic basis.

Data Gaps: The analytical methods applied to fishes collected in the annual surveys at and adjacent to the diffuser discharges in Mamala Bay are not sufficiently sensitive to detect and measure chemical contaminants. We recommend that more sensitive methods be applied to these survey samples. Sampling and analysis of oysters in the National Mussel Watch program, and fish and invertebrates from the Ala Wai Canal provide only local coverage. The potential for bioaccumulation of pollutants by biota throughout Mamala Bay has not been evaluated.

Recommendations for Future Monitoring: We recommend establishing a regional "Mussel Watch" program in Mamala Bay wherein Hawaiian oysters are harvested from pristine areas and implanted or suspended at selected sites throughout Mamala Bay. Suggested sites for deployment of the oysters would be at the sites of the diffuser discharges, and at approximately five additional sites throughout Mamala Bay. At least two of those sites should be 1) at the mouth of Pearl Harbor, and 2) at the mouth of the Ala Wai Canal. Oysters should be deployed once, yearly, and should remain in place for a period greater than 30 days, but not exceeding 90 days. At the end of deployment, the oysters should be harvested, composited, and analyzed for a full suite of chemical contaminants, including metals, base-neutral organic compounds, and specialty chemicals such as diazinon and dioxins.

4.0 Physical Monitoring

Physical monitoring in Mamala Bay at the present time entails the measurement of

currents and various oceanographic data that are used in making predictions of diffuser discharge plume surfacing and movement to beaches. Monitoring of physical parameters at and in the vicinity of the diffuser discharges should be maintained at their current level of intensity.

5.0 Biological Monitoring

Biological monitoring is carried out in the immediate vicinity of the diffuser discharges from the Sand Island and the Honouliuli WWTPs as part of the required NPDES permits for these plants. Biological monitoring includes benthic infauna analyses, fish and megainvertebrate analysis, and coral reef surveys. One aspect of the biological monitoring for fish includes the analyses of fishes consumed by humans for pollutant body burdens (see above).

5.1 Benthic Infauna Analyses

Status: Benthic infaunal analyses in Mamala Bay presently focus on localized regions adjacent to the diffuser discharges from the Sand Island and Honouliuli WWTPs. As noted in the reports describing the outcome of five years' analysis of benthic populations adjacent to the diffuser discharges in Mamala bay, there is no evidence to suggest that the diffuser discharges have had any negative impact on the benthic infaunal community.

Data Gaps: Data gaps in the benthic infauna analyses in Mamala Bay may be described as both temporal and spatial. The temporal data gap arises because the benthic infauna sampling for the two WWTP diffuser discharges are specified in the NPDES permits for different times of the year; January/February for Honouliuli, and August/September for Sand Island. The spatial data gap arises because the benthic infauna sampling is highly localized, and does not cover Mamala Bay except in the areas adjacent to the diffuser discharges.

Recommendations for Future Monitoring: Mamala Bay Study investigators recommended in their summary reports that future monitoring of the benthic infauna in

Mamala Bay should take into account the full extent of the Bay, and should not be limited to the areas near the diffuser discharges. We concur fully in that recommendation. Further, we recommend that benthic infauna analysis should be standardized as to the time of year that samples are taken. Thus, we recommend a benthic infauna monitoring program that is carried out once per year, covering the entirety of Mamala Bay, and that benthic infauna monitoring should proceed with fewer stations located immediately adjacent to the diffuser discharges.

Monitoring of benthic infauna is recommended at 15 stations in Mamala Bay, comprising eight stations at the 30 m depth contour, spanning the distance between Diamond Head and Barber's Point, and seven stations at the 70 m depth contour and spanning the distance between Diamond Head and Barber's Point. At least four of the stations at the 70 m depth contour should coincide with stations that are currently occupied for benthic infauna analysis under the provisions of the existing NPDES permits for the Sand Island and Honouliuli WWTPs. All sampling and analysis for benthic infauna should proceed according to techniques outlined in the NPDES permit conditions, or modifications of methods approved by the Hawaii Dept. Of Health and the US EPA Region IX staff.

5.2 Fish and Megainvertebrate Analysis

Status: Fish and megainvertebrate analyses focus on localized regions at the site of the diffuser discharges from the Sand Island and Honouliuli WWTPs, as well as at inshore locations at the 9 m depth contour. As noted in the reports describing the outcome of five years' analysis of fish and megainvertebrate populations adjacent to the diffuser discharges in Mamala bay, there is no evidence to suggest that the diffuser discharges have had any negative impact on the fish or megainvertebrate community.

Data Gaps: We consider the coverage of fish and megainvertebrate populations in Mamala Bay to be adequate.

Recommendations for Future Monitoring: Monitoring for fish and megainvertebrate population in Mamala Bay should be maintained at current levels with the proviso that fish and megainvertebrate population surveys should be carried out in a single season, rather than

at different seasons as specified in the NPDES permit conditions for the Sand Island and the Honouliuli WWTPs.

5.3 Coral Reef Surveys

Coral reef surveys are carried out according to specifications laid out in the NPDES permits for the diffuser discharges from the Sand Island and the Honouliuli WWTPs. The available data suggest that the coral reef communities in Mamala Bay are thriving and in the process of recovery from recent storm damage. Coral reef surveys should be maintained at their current level of intensity.

6.0 Microbiological Monitoring

Bacteriological monitoring is carried out on a regular basis throughout Mamala Bay, including in the near shore areas and on bathing beaches. The bacteriological monitoring is carried out according to specifications set forth in the NPDES permits for the Sand Island and the Honouliuli WWTPs.

Status: Bacteriological monitoring in Mamala Bay includes the measurement of concentrations of fecal coliforms and *Clostridium perfringens*. Measurements of Clostridium were a recent addition to the program.

Data Gaps: Historical data using concentrations of fecal coliforms as an indicator of sewage contamination are probably of little use. The recent addition of Clostridium measurements to the bacteriological monitoring effort assures an increased value of bacteriological monitoring as a measure of potential sewage contamination. At present there are no assays that allow the direct measure of bacterial, viral, and protozoan pathogens in the Mamala Bay system.

Recommendations for Future Monitoring: Future monitoring of bacteria population in the Mamala Bay watershed must include measurement of Clostridium perfringens as an indicator organism. Further studies are recommended for the development of direct measurements of pathogenic organisms in the Mamala Bay system

7.0 Bioassays

Bioassays are currently employed only for the evaluation of the toxicity of effluent from the Sand Island and the Honouliuli WWTPs. The bioassay tests performed are those specified in the NPDES permits, and include whole effluent toxicity measurements using *Ceriodaphnia dubia* and a Hawaiian sea urchin species, and chronic toxicity evaluations using the water flea (*C. dubia*), fish (either *Tilapia mossambica* or *Corypheana hippurus*), and shrimp (either *Penaeus vannamei* or *P. monodon*). Additional bioassay studies are also specified in the NPDES permit as related to performance of toxicity reduction evaluations.

There are no bioassay studies carried out to determine the potential toxicity of any other whole effluents or diluted discharges on the biota of Mamala Bay.

Status: Effluent toxicity monitoring is a critical aspect of evaluating the potential for treated effluent to cause harm to the biota in the vicinity of the discharge. We recommend that whole effluent toxicity and chronic bioassay studies be continued at the current frequency using the current species of choice.

Data Gaps: There are no data with which to evaluate the potential for nonpoint source waste water to cause toxicity in the biota of Mamala Bay or its contiguous waters. Such data may be irrelevant in the context of the fact that most nonpoint waste from the Mamala Bay watershed enters sub-embayments and is subject to some settling prior to the discharge of the waste to the open waters of Mamala Bay. Nonetheless, NPDES nonpoint source discharge permits generally require the evaluation of nonpoint source waste waters for toxicity prior to discharge into receiving water bodies. We assume that this requirement is part of the Mamala Bay nonpoint source discharge permit, and that such studies will be needed in the future.

Recommendations for Future Monitoring: Future monitoring in Mamala Bay should include bioassay testing of nonpoint source waste discharges for chronic toxicity using the EPA-approved tests for at least one species, *Ceriodaphnia dubia*. In those instances where chronic toxicity of raw stormwater discharge is detected, further tests following the protocols for Toxicity Identification Evaluations should be conducted.

8.0 Conclusions

The results of the Mamala Bay Study are only now being finalized. It is abundantly clear from the results of the Mamala Bay Study that the ecosystem remains healthy and productive despite an ever-increasing load of pollutants and chemical contaminants. The complexity of the system itself, and the human-induced influences on the system, suggest that future management of Mamala Bay is best performed on a watershed basis. The monitoring program suggested herein, therefore, comprises a regional, rather than local program, with an emphasis on accumulation of data from throughout the watershed as well as throughout Mamala Bay proper.