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ASSESSING THE MICROBIAL QUALITY OF POTABLE WATER SOURCES ON THE ISLAND OF HAWAII

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CHAPTER ONE

INTRODUCTION AND IDENTIFICATION OF THE PROBLEM

I. Geological Formation of Each Island in Hawaii Determines Quality of Groundwater

Differences in the ages and geologic formations of the various islands of Hawaii affect each island's rainfall patterns, the composition of each island's surface and subsurface soil structure, the groundwater storage capacity and the vulnerability of the groundwater aquifers to contamination with surface sources. The geological differences of the islands can be explained by the "Plate Tectonic and Hawaiian Hot Spot" theory, which states that there has been a progressive movement of the Pacific Plate over a deep immobile "hot spot" in the Pacific Ocean (Macdonald et al., 1983). This slow but continuous movement of the Pacific Plate over the stationary hot spot has resulted in the formation of the various islands of Hawaii, characterized by differences in their ages. Figure 1 shows the islands of Hawaii and the estimated age of each of the islands in millions of years as follows: (a) Kauai: 3.8 to 5.6; (b) Oahu: 2.2 to 3.4; (c) Molokai: 1.3 to 1.8; (d) Maui: 0.8 to 1.3; and (e) Hawaii: <0.7 and still growing. Thus, Kauai is the oldest of the islands followed by Oahu, whereas the island of Hawaii is the youngest. The age, geological formations, climate, time and soil-weathering are factors that determine the surface and subsurface structure of each island. Some of these differences are very apparent. For example, the predominance of surface lava and subsurface lava tubes on the Big Island results in rapid infiltration of rainwater with minimum soil filtration to purify the water. In contrast, on Oahu, the topsoil is comprised of clay-like soil and the subsurface is weathered basalt rock. This allows water to be filtered slowly (e.g., 20-year travel time from the surface to the groundwater aquifer) and is a major reason for the excellent quality of water in Oahu's aquifer. However, the extent to which the quality of the groundwater differs from island to island can only be determined by analyzing groundwater samples for relevant water quality parameters and to compare these measured parameters.

II. Groundwater Hydrology and Quality on Oahu: Model for Hawaiian Islands

Since most of the industries and population (80%) for the state of Hawaii is concentrated on the island of Oahu, the Honolulu Board of Water Supply (HBWS) has always been the state's largest public water utility and over the years has had the resources to characterize the hydrogeology as well as the ambient quality of Oahu's groundwater sources. Today HBWS obtains nearly all of its potable water (150 mgd) from groundwater sources. Many studies have been completed which validate that the quality of potable water sources for the island of Oahu is excellent and readily meets the requirements of drinking water standards established by Environmental Protection Agency (EPA). For example, during the 1980s our laboratory completed two projects (Fujioka et al., 1986, 1989) which showed that based on monitoring potable water sources using standard as well as experimental methods for basic indicator bacteria (total coliform, *Escherichia coli*, heterotrophic bacteria), the quality of potable water sources used by HBWS readily met the EPA drinking water standards at that time. It should be noted that during that time, HBWS did not routinely disinfect their potable water sources. After the 1986 Safe Water Drinking Act (SDWA) was passed, the emphasis was to focus on health effects and pathogens in potable water sources. As a result, monitoring requirements under the SDWA

became more stringent. This prompted HBWS to selectively disinfect more of its groundwater sources. In discussions of pathogens in potable groundwater sources, human enteric viruses were concluded to be the most likely contaminating pathogen. To address this concern, EPA's initial position was that all groundwater sources should be routinely disinfected to obtain a residual of 0.2 mg/l of chlorine. This proposed rule was called the Groundwater Disinfection Rule (Grubbs and Pontius, 1992). This proposed EPA rule resulted in extensive public discussions. These discussions led EPA to conclude that some groundwater sources may not need to be disinfected if it could be shown that the potable groundwater source was not vulnerable to contamination with fecal matter. As a result, the name of the rule was changed to the Groundwater Rule (GWR). To determine if the groundwater sources used by HBWS could obtain a waiver for routine disinfection, our laboratory was contracted by HBWS to complete a monitoring study suggested by EPA. The results of this study (Fujioka and Yoneyama, 1997, 2001) provided evidence that the groundwater sources used by HBWS was not vulnerable to contamination with fecal matter, based on negligible concentrations of fecal indicator bacteria and viruses which infect fecal bacteria (*Escherichia coli*, enterococci, *Clostridium perfringens*, coliphages). Since human enteric viruses were concluded to be the most likely pathogen contaminating groundwater, our laboratory was tasked to monitor groundwater for these viruses. These studies (Fujioka 1987; Fujioka et al., 1999) showed that human enteric viruses were not detected in groundwater sources of Oahu using standard culture method as well as gene probe assays.

In summary, the hydrogeology and the ambient quality of the groundwater aquifers on Oahu have been well characterized. Thus, the water quality data for Oahu's potable water sources can serve as a model system, against which water quality data of the other islands of Hawaii can be compared. These kinds of data will test the working hypothesis that certain characteristics of each island—such as age, geologic formation, climate, soil weathering and anthropogenic pollution—will determine the ambient quality of groundwater for that island. Based on this hypothesis, the groundwater in the older islands (Kauai, Oahu) would be expected to be superior to the quality of groundwater in the younger islands (Maui, Molokai, Lanai) and that the groundwater sources in the youngest island (Hawaii) would be expected to be most susceptible to contamination by surface pollutants, including fecal matter.

III. The Identified Problem: Need for Source Water Quality Data for island of Hawaii

Groundwater is the source of potable water for most of the islands of Hawaii. However, due to the lower population densities on the Neighbor Islands (islands other than Oahu), the public water utilities are relatively small and the resources are limited. Moreover, there are private companies that provide drinking water for limited numbers of people. Thus, unlike the HBWS, the strategy for water utilities on the Neighbor Islands has been to routinely disinfect their groundwater sources of potable water and to routinely measure the quality of the disinfected water entering the distribution system to ensure that potable water meets the coliform standards under the SDWA established by EPA. One limitation of this approach is the lack of data describing the ambient (before disinfection) quality of the potable water sources (groundwater) for each of the Neighbor Islands. Thus, there is insufficient data to assess the vulnerability for contamination of groundwater sources. In summary, the identified need is to obtain monitoring data to assess the ambient (untreated/non-disinfected) quality of groundwater sources on the Neighbor Islands.

This project focuses on determining the quality of potable water sources used by water utilities on the island of Hawaii. As stated earlier, the island of Hawaii is much younger than the island of Oahu. The geological structure of this island is characterized by subsurface lava tubes, which can transport subsurface water for long distances without subjecting water to natural purification by such processes as filtration, adsorption and biotic/abiotic degradation processes as observed in subsurface conditions on Oahu. Moreover, the sanitary practices used on the Big Island differ significantly from that of Oahu. In this regard, most of the sewage for the island of Oahu is collected in pipes and transported to regional wastewater treatment plants. This sanitary practice prevents sewage contamination of groundwater aquifers by not allowing sewage to be discharged into surface streams and soil, thereby limiting opportunities to contaminate groundwater aquifers. Much of the Big Island is still serviced by cesspools and septic tanks that allow sewage to be discharged into the soil environment over existing groundwater aquifers. This sanitary practice increases the possibilities for sewage contamination of groundwater aquifers. Since potable groundwater sources on the island of Hawaii are routinely disinfected, insufficient data are available to determine the ambient microbial quality of groundwater sources to determine whether cesspools and other forms of discharges into the environment is impacting the quality of the groundwater sources on that island. It should be noted that our laboratory (Fujioka and Lau, 1983) monitored groundwater on the Big Island pumped by Haina Well near the town of Honokaa, Hawaii. The primary objective of this study was to determine the presence or absence of human enteric viruses in this well water source because untreated sewage from a hospital was being discharged into a subterranean lava tube approximately 0.25 mile mauka (mountain side/upslope) of the Haina Well. The results of this study showed that human enteric viruses were not recovered from three separate samples (100 gallons/sample). Moreover, this source of groundwater was not contaminated with fecal indicator bacteria such as total coliform, fecal coliform, fecal streptococci, and *Clostridium perfringens*. It was thus concluded that the groundwater source in this area was excellent and not contaminated with fecal matter.

IV. The Quality of Groundwater on the Island of Hawaii Should Address Drinking Water Regulations and Concerns

The recognized need is to determine the ambient quality of the Big Island's groundwater and to assess the quality based on current and up-coming drinking water regulations and guidelines.

A. Primary Need: Meeting the Proposed Monitoring Requirements of the Groundwater Rule

This rule first described in 1992, was called the Groundwater Disinfection Rule (GWDR) because EPA concluded that the best public health practice was to routinely disinfect all potable groundwater sources with chlorine (residual chlorine of 0.2 mg/l) to ensure that any contaminating pathogen would be disinfected (Grubbs and Pontius, 1992). Many water utilities, including the Honolulu Board of Water Supply (HBWS), objected to the first draft of the GWDR because these utilities were able to meet the potable water quality standard based on the Total Coliform Rule without disinfection. Moreover, one of HBWS' mottos was that its water tasted good because it was so pure that chlorination was not necessary. After years of public discussions with the utilities, with the public and with representatives of academia, EPA agreed

that some groundwater systems could obtain a variance to the stringent disinfection requirements if the responsible utility could show that the potable groundwater source was not susceptible to fecal contamination. As a result, the name of the rule was changed to the GWR (Macler and Pontius, 1997). A major controversy with the GWR has been to establish microbial monitoring requirements which can be used to determine whether a groundwater source is or is not vulnerable to contamination with fecal matter.

The final language of the GWR is still being considered and the major issue is the selection of the fecal indicator microorganisms, to be used to monitor the groundwater and to determine which groundwater sources are vulnerable or not vulnerable to contamination with fecal matter (USEPA, 1999). In this regard, EPA initially proposed that groundwater should be monitored for traditional fecal indicator bacteria such as total coliform, *Escherichia coli* and enterococci. However, many research microbiologists believe that monitoring groundwater for only fecal indicator bacteria will be unreliable because convincing data had already been reported to show that human enteric viruses are the pathogens most likely to contaminate groundwater and that traditional fecal indicator bacteria are not reliable indicators of the presence and absence of human enteric viruses in environmental waters. As a result, research microbiologists have proposed that groundwater should be monitored for alternative fecal indicators such as *Clostridium perfringens*, FRNA coliphages, and somatic coliphages, which are characterized by longer survival times than fecal bacteria. Moreover, FRNA coliphages have been reported as having similar transport characteristics through soil as human enteric viruses. In the largest groundwater monitoring research project, Abbaszadegan et al. (1998) detected both FRNA and somatic coliphages in some groundwater samples in the absence of fecal indicator bacteria. In summary, although EPA published a Proposed Groundwater Rule (USEPA, 2000), this rule has not yet been finalized because the monitoring requirements is still being discussed. The monitoring requirement can be expected to greatly affect water utilities, such as those in the state of Hawaii, which use groundwater and which have not monitored their groundwater for the microbial indicators discussed in the GWR. Thus, the primary need of this study is to monitor the potable groundwater sources on the island of Hawaii for traditional fecal bacterial indicators (total coliform, *E. coli*, enterococci) and for selected alternative fecal indicators (*C. perfringens*, FRNA coliphages, somatic coliphages), which are being considered as part of the monitoring requirement under the GWR.

B. Secondary Need: Integration with Source Water Assessment Program (SWAP)

The Safe Drinking Water Act of 1996 established a new program called the Source Water Assessment Program (SWAP). This program mandated that each state develop its own SWAP and assess the susceptibility of each of their drinking water sources to fecal contamination. The state of Hawaii submitted the Hawaii Source Water Assessment Program (HISWAP) to EPA in 1999 (DOH, 1999). One of the stated objectives of HISWAP is to develop linkages to other programs which are involved in monitoring potable water sources to meet drinking water standards as well as to programs involved in the protection of potable water sources. Another objective of HISWAP is to support programs which address upcoming regulation such as the GWR. Thus, the secondary need of this study was to determine general water quality parameters (pH, turbidity, conductivity, total nitrogen, total phosphorus) in the same water samples which were being analyzed for the various fecal microorganisms being considered under the pending GWR.

C. Tertiary Need: Appropriate Water Quality Tests for Bioterrorism Event

After September 1, 2001, potable water systems were identified as potential targets for terrorists to deliver pathogens or toxic chemicals to the public. In assessing the needs of water utilities, it became clear that rapid and reliable tests to detect pathogens and chemical toxins in water were not available. Most tests were complicated and required hours and days to complete. Moreover, tests for many specific pathogens and chemical toxins were not available. In assessing the needs of water utilities, it became clear that under purposeful contamination events, the water monitoring tests must be able to provide results rapidly (few minutes to an hour) in order for the water utility to respond effectively. Since only tests which can provide rapid results can be expected to be useful, traditional and reliable monitoring tests for pathogens and toxic chemicals cannot be relied on. The identified need for water utilities was to develop tests which are rapid and reliable to detect when a water contamination event has occurred. One approach is to develop new, rapid tests. This approach will require a long-term research project. An alternative approach is to select existing rapid tests and determine their usefulness when water supplies are purposely contaminated. The alternative approach was selected for this study.

CHAPTER TWO

GOALS, EXPERIMENTAL DESIGN AND METHODS

I. Prioritized Goals and Objectives of This Study

A. Primary Goal (Phase I)

The primary goal of this study was to determine whether the fecal microbial quality of potable groundwater sources used by the County of Hawaii and by private companies on the island of Hawaii will likely meet the proposed microbial monitoring requirements for the pending GWR and to determine changes in the microbial quality of groundwater as it is stored in reservoir tanks and then distributed to the public via distribution pipes.

B. Secondary Goal (Phase II)

The secondary goal of this study was to determine the general quality (pH, turbidity, conductivity, total phosphorus, total nitrogen) of the same water sources (well, reservoir storage tanks, distribution system) analyzed for fecal microorganisms during Phase I of this study. The secondary goal of this study fulfills the directives of the SWAP for Hawaii.

C. Tertiary Goal (Phase III)

The tertiary goal for this study was to evaluate selected rapid tests and determine their usefulness as a reliable monitoring method in the event of purposeful contamination of potable water sources. For this study, selected samples of all three sources of potable waters (well, reservoir storage tanks, distribution system) used by the County of Hawaii and by private companies were analyzed.

II. Experimental Design

The experimental design of this study was guided by the following six considerations: 1) Obtain representative potable sources of water from island of Hawaii. Water samples were obtained from wells, reservoir tanks, and distribution pipes used by the County of Hawaii and by private companies. 2) Maximize the number of water samples to be analyzed. Water samples were obtained at a frequency of twice a month. 3) Increase the sensitivity of the assay. Larger volumes of water samples (1,000 ml, 500 ml, 200 ml) were analyzed as compared to the minimum volume (100 ml) required by EPA. 4) Analyze water samples for traditional fecal bacteria indicators as well as for the alternative fecal microorganisms, which are being discussed under the pending GWR. 5) Monitor groundwater sources for other traditional chemical tests to determine the general quality of that water and in this way fulfill the directives of the SWAP. 6) Evaluate the feasibility of selected rapid tests and determine if these methods can provide useful data when potable water systems are purposely contaminated with hazardous pollutants. Figure 2 is a diagram of the sampling and assay strategy for microorganisms and general water quality parameters.

III. Methods Used

A. Presence/Absence Method for Total Coliform, *E. coli* and Enterococci

The methods, as described in Standard Methods (APHA, AWWA, WEP, 1999) and modified by

Fujioka and Yoneyama (2001), were used to analyze a large volume (1,000 ml) of water samples for fecal indicator bacteria. Briefly, two 500-ml samples from each of the sampling sites were added to presence/absence broth and incubated at 37°C for up to 5 days as a screening test for the presence/absence of fecal indicator bacteria (total coliform, *Escherichia coli*, enterococci). No change in turbidity or color and absence of gas production in the presence/absence broth indicated that the three groups of fecal indicator bacteria were not present in that volume of water sampled. A change in the color of the presence/absence broth or the presence of turbidity and/or gas production was considered presumptively positive for one or more of the fecal indicator bacteria. To confirm for presence of *E. coli*, the presence/absence broth was streaked onto m-Endo agar. Colonies that formed, which were metallic or magenta-colored, are presumptively positive for total coliform bacteria. These colonies were inoculated into EC broth, streaked onto TSA agar and incubated at 37°C for 24 hours. Turbidity in EC broth and colonies on TSA, which were oxidase positive and catalase negative indicated presence of fecal coliform bacteria. The positive EC sample was then streaked onto Nutrient Agar with MUG reagent and incubated for another 24 hour at 37°C. The development of fluorescing colonies was taken as confirmation that *E. coli* was present in the water sample. To confirm for presence of enterococci, the positive presence/absence broth was streaked onto mE medium. A positive reaction of the colonies on the bile esculin agar indicated presence of enterococci.

B. Assay for Aerobic and Anaerobic Spores

The method to enumerate aerobic and anaerobic spores in water samples was a modification of the method described in Standard Methods and the method reported by Fujioka and Yoneyama (1997). For this method, the water samples were initially pasteurized (heated for 15 minutes at 60°C) to destroy all vegetative bacterial cells but not bacterial spores. Aerobic spores in the water sample belonging to *Bacillus* spp. were enumerated as colony-forming units on TSA agar incubated under aerobic conditions for 24 hour at 37°C. Anaerobic spores in the water samples belonging to *Clostridium* spp. were enumerated as colony forming units on Anaerobic Agar incubated under anaerobic conditions at 41°C. This assay will measure for the presence of *C. perfringens*, the anaerobic bacteria which are used as indicator of fecal contamination. Since aerobic spores are naturally present in soil, the concentrations of total aerobic spores cannot be related to health effects. This assay was included as a control to the anaerobic assay and to provide data on the ambient levels of aerobic spores in potable water sources.

C. The Enrichment Method to Detect for Presence of FRNA Coliphages and Somatic Coliphages

The enrichment method is the most sensitive method to determine the presence or absence of coliphages in water samples. An advantage of this method is that large volumes (100–1,000 ml) of water samples can be analyzed to further increase the sensitivity of the method. The enrichment method as previously described by Fujioka and Yoneyama (1997) was used. Briefly, water samples were seeded with either *E. coli* Famp to specifically support the growth of FRNA coliphages or with *E. coli* CN to support the growth of somatic coliphages. To these water samples, nutrients were added to allow the *E. coli* to multiply for 24 hours at 37°C. Theoretically a single infectious coliphage will specifically infect that strain of *E. coli* and one infected cell will release thousands of coliphages. Each of these coliphages will infect other live *E. coli* cells. As a result, after 24 hours the concentrations of coliphages in the test water sample can be

expected to reach as high as 10^8 PFU/ml of infectious virus. The presence of coliphages in the water sample is confirmed by inoculating a lawn of the specific *Escherichia coli* to form visible plaque forming units.

D. Heterotrophic Bacteria

Isolation and enumeration of heterotrophic bacteria were accomplished using the membrane filtration as described in Standard Methods (APHA, AWWA, WEF, 1999).

E. Identification of Heterotrophic Bacteria Using the Riboprinter™

Heterotrophic bacteria in potable water are not usually identified. However, if these bacteria can be identified, it is possible to characterize that source of potable water based on the variety of identified bacteria. Theoretically, a contamination event can be determined when the bacterial population in that water changes. Methods to feasibly identify the various bacteria in water are not available. The only feasible method for a water monitoring laboratory to characterize the bacteria in water is to use an automated system. The only feasible automated system is the Dupont Riboprinter™, which identifies or characterizes bacteria based on the ribosomal RNA gene sequences in the bacteria. This method is based on previous knowledge that all microorganisms can be identified based on the sequence of nucleotides which code for ribosomal RNA. Methods to identify each of sequence of nucleotide in the DNA that codes for ribosomal RNA is tedious, costly and time consuming. The Riboprinter™ quickly identifies bacteria to its genus and species based on cleaving the DNA sequence that codes for ribosomal RNA and then determining the size and numbers or patterns of the resulting DNA fragments, which becomes specific to that bacteria. This pattern is called a "riboprint". This riboprint is similar to the identification of various products in a supermarket based on a specific barcode. Identification of the bacteria is based on finding the same riboprint in the Dupont Riboprinter™ database of identified bacteria. Even if the bacteria cannot be identified, the riboprint can be used to characterize that bacteria and the resulting riboprint used to compare with those of other isolates in the water sample. By this method, the Riboprinter™ can characterize the bacterial population in that sample of water.

F. Conductivity

Conductivity of water is a measurement of the ability of that water sample to carry an electrical current. The ability of water to conduct an electrical current is directly related to concentrations of various ions or atoms of an element which has a negative or positive charge. Although many elements form ions, the most common elements which form ions in potable water are sodium and chloride ions. Potable water is characterized as having low conductivity and low concentrations of chemical ions. When ambient sources of water are contaminated, the contaminant often contains chemical elements with ions. Thus, contamination of water can be detected by determining a change in the conductivity of water samples. Conductivity measurements are correlated to concentrations of total dissolved salts (TDS) in water samples. For this study, the Model 3200-115 Conductivity Meter, which is manufactured by YSI Environmental (Yellow Springs, OH), was purchased because of the company's reputation and because this model was designed to be used to analyze potable water characterized by low levels of conductivity. Conductivity is measured as μS/cm and this measurement can be obtained instantaneously by the conductivity meter. Most contaminants added to water will have a conductivity higher than potable water. Thus, conductivity is a general measurement which can

be used to detect for the presence of contaminants instantaneously.

G. Assay for Adenosine Triphosphate (ATP)

ATP is produced in every living bacterial cell and this compound can be rapidly measured by an enzymatic reaction. In principle, a sharp increase in ATP concentrations in potable water samples over ambient concentrations of ATP indicate elevated levels of live cells, primarily bacteria and could signal a contamination event. A review of the literature indicated that the ATP assay developed by New Horizon Company (Columbia, MD) was more reliable and applicable to potable water sources (Lee and Deininger, 1999). As a result, the New Horizon method using the 10 X luminometer and reagents supplied by New Horizon were used to assay for ATP in water.

H. InSpectra™ Analyzer

Azur Environmental (Carlsbad, CA) developed a UV absorption method using a specially designed portable spectrophotometer called "Inspectra." It measures UV absorption at selected wavelengths. The patterns of UV absorption at these various wavelengths were correlated to concentrations of biological oxidation demand (BOD), chemical oxidation demand (COD), total organic carbon (TOC), total suspended solids (TSS), nitrates (NO_4), and surfactants (SUR) in natural water samples and water samples contaminated with sewage. These general water quality parameters are often measured to characterize and compare one water sample from another. Each parameter requires a separate and specific test method. The Inspectra method measures the six water quality parameters within a minute, based on measurements of UV absorption at selected UV wavelengths. Because this is a proprietary method, the selected wavelengths used are not reported. This method does not specifically measure the various water quality parameters; rather the patterns by which a given water sample absorbs the selected UV wavelengths are characterized using mathematical models and correlated to actual water samples with specific concentrations of these parameters. In summary, this method indirectly provides concentrations of six common water quality parameters based on measurements made by the manufacturer. Thus, this method uses surrogate measurements for the concentrations. Azur Environmental reported that this method can be applied to a variety of water samples, including natural waters and waters contaminated with sewage. Although there have been some reported success with this method, it is not approved by any agency for actual measurements of the six water quality parameters.

The value of this method is that the instrument is portable, is easy to use, and requires no reagents. Also, it quickly (<1 minute) determines the concentrations of several important water quality parameters. The results obtained are intended to alert the laboratory technician that the ambient quality of a specified source of water has changed. Thus, this method meets the criteria for a simple and rapid test to measure water quality changes that may be related to some purposeful contamination event.

I. Assay for Total Phosphorus and Total Nitrogen

To determine the possibility that nutrients may be contaminating groundwater sources, samples were assayed for total phosphorus and total nitrogen using the methods developed by the Hach Company (Loveland, CO). These methods are EPA-approved and reported to be able to measure at levels ranging from 0 to 3.5 mg/l for total phosphorus and 0 to 25 mg/l for total nitrogen. However, after the testing was over, we determined that the concentrations of both nutrients in potable water samples were higher than expected. Subsequent evaluation of these

methods using phosphorus and nitrogen standards at very low concentrations showed that the Hach methods are not sensitive at low levels. Thus, it was concluded that the measured levels of total phosphorus and total nitrogen using the Hach method for groundwater samples results in slightly elevated readings.

J. Assay for Toxicity Using Microtox Method.

Contaminants may be toxic chemicals. Microtox and Delta Tox are two instruments developed by SDI (Newark, DE) to rapidly detect for the presence of acutely toxic chemicals in water. The principle of this test is based on measurements of light produced by metabolizing marine bacteria (*Vibrio* sp.). Thus, this population of bacteria can be measured based on the amount of light produced. Light production indicates that population is healthy and in a good environment. When this population is added to potable water, any toxic chemicals in that water will inhibit the metabolism of that population and light production will decrease. The amount of light decreased can be correlated to the degree of toxic chemicals in the water sample. This kind of data can be used to quickly signal a water contamination event. The Microtox method has been reported to be able to detect the effective concentration of toxicity for over 1,000 known toxic chemicals and to satisfactorily correlate to whole animal tests such as fish toxicity assays (Qureshi et al., 1982). Thus, this test has a greater data base for many known toxic chemicals than other toxicity assays.

K. Assay to Characterize Particle Sizes in Water using Lasentec Method.

Laser light is used by several companies to measure sizes of particles in water samples. Lasentec Company (Redmond, WA) has developed an instrument (Model M 100 Particle Analyzer) which measure relative particle size distribution in a water samples within a minute. This instrument meets the criteria of a method to quickly determine some ambient water quality parameter.

L. Selection and Collection of Water Samples

The Water Resources Research Center (WRRC), University of Hawaii, prepared all of the sampling bottles for storage in large coolers. These coolers were then sent to island of Hawaii via Hawaiian Airlines or Aloha Airlines or were given to personnel from the Department of Health for transport to the Big Island. The Department of Water, County of Hawaii, selected and collected potable water samples from their system using methods approved by EPA. The Department of Health, State of Hawaii selected and collected water samples from the private water systems on the Big Island using methods approved by EPA. These water samples were transported to either Hawaiian Airlines or Aloha Airlines within 4 hours of collection. In some cases, personnel from the Department of Health transported the samples to Oahu. Arrangements were made for WRRC personnel to obtain the water samples from the airlines cargo area or directly from Department of Health personnel. All assays for microorganisms were completed on the day of sampling, whereas physical and chemical assays on the same day or the next day. The agreed-upon plan was for the water samples to reach Oahu during the early afternoon so the work could be started and completed by 7 P.M. When delays in transporting the samples from Big Island to Oahu occurred, WRRC personnel were required to work late into the night, often to 10 P.M. to process these samples.

IV. Sampling Sites and Characteristics of Water Samples

Figure 3 shows the island of Hawaii and the location of the potable wells and tunnels. The County of Hawaii provides water to the general public throughout the island and therefore it has a large number of sampling sites: wells (47), tunnels and springs (18), reservoir tanks (3), surface source (1), combination of surface/ground (4) and distribution pipes (22). A total of 14 private companies provide potable water for limited numbers of people. Their sampling sites include 34 wells, 2 surface sources, 2 combination of surface/ground/tunnel/spring sources, 3 roof catchments, 2 reservoir tanks and 14 distribution pipes. Water samples were obtained from the County of Kauai and from private companies at the same monthly frequency.

Table 1 lists and identifies each of the sampling sites used by the County of Hawaii as well as sampling sites used by private water utilities on Hawaii. This list contains our numbering and identification system as well as the common names of the sites and the ID number for the sites as previously determined by the County of Hawaii. Our ID system also includes the subscript D to identify those water samples which had been disinfected. The private water utilities did not give their sampling sites a specific ID number. For this study, we used our sampling ID system to identify the sampling sites because it provides information specific to that site. For example, CW stands for County Well, CST for County Spring and Tunnel, CST_D for County disinfected Spring and Tunnel sources, CS for County surface source, CR_D for County disinfected reservoir tanks, CC_D for County disinfected combination of ground/surface/spring/tunnel sources, CD_D for County disinfected distribution sources, PW for private wells, PS for private non-disinfected surface sources, PC_D for private disinfected combination of ground/surface/spring/tunnel sources, PCM for private, non-disinfected catchment sources, PR_D for private disinfected reservoir tanks, PD_D for private disinfected distribution sources. All of the individual assays for each of the sampling sites are listed in the Appendix.

CHAPTER THREE

PHASE I: CHARACTERIZING THE FECAL MICROBIAL QUALITY OF POTABLE WATER SOURCES ON THE ISLAND OF HAWAII TO ADDRESS CONCERNS OF THE PENDING GROUNDWATER RULE

I. Goals and Objectives

There were two primary goals for this study. The first goal was to determine whether the fecal microorganisms (total coliform, *Escherichia coli*, enterococci, *Clostridium perfringens*, somatic coliphages, FRNA coliphages) in potable groundwater sources used by County of Hawaii and by private water utilities on the island of Hawaii will likely meet the fecal microbial monitoring requirements for the pending GWR. The second goal was to determine changes in the microbial quality of potable sources of water as it is stored in reservoir tanks and then distributed to the public via distribution pipes.

To achieve the primary goals of this study, the following objectives were identified:

1. Determine whether the quality of the various potable groundwater sources on the Big Island will likely meet the monitoring requirements under the GWR.

2. Determine whether these potable groundwater sources are vulnerable to contamination with fecal matter, including cesspool wastes, which are common sources of contamination on the Big Island.

3. Compare the quality of groundwater sources used by County of Hawaii with those used by private companies.

4. Compare the quality of potable water as it is pumped from wells, stored in reservoir storage tanks, and distributed to the public via distribution pipes.

II. Relevance of Groundwater Rule (GWR)

The intent of the GWR is to ensure that groundwater sources used for drinking is safe for consumers. Disinfecting (chlorinating) water is one of the basic means to ensure that drinking water is not contaminated with infectious, sewage-borne pathogens. Traditionally, USEPA has required monitoring of all potable water sources for presence of coliform bacteria as an index of whether that source of water is contaminated or not contaminated with fecal matter (sewage). Since surface water sources are vulnerable to contamination with fecal contamination at multiple sites, the Surface Water Rule requires mandatory filtration and disinfection with chlorine. However, groundwater is normally formed by being naturally filtered by subsurface soil and rock matrices. In this regard, many groundwater sources are naturally purified of fecal contamination. These naturally purified groundwater sources do not require additional filtration or disinfection. However, some groundwater sources are susceptible to fecal contamination. Since no one knows which groundwater sources are vulnerable to fecal contamination, a monitoring requirement is needed to determine which groundwater sources are susceptible to contamination with fecal matter. The controversy with the GWR for the past 10 years has been to select those fecal indicator microorganisms for monitoring which will provide reliable data to classify groundwater

sources as vulnerable or not vulnerable to fecal contamination. In this regard, selection of the several proposed fecal microorganisms including the standard fecal indicator bacteria (total coliform, *Escherichia coli*, enterococci) and three alternative fecal microorganisms (*Clostridium perfringens*, somatic coliphages, FRNA coliphages) continues to be discussed.

III. Experimental Design

All water samples collected were analyzed for the two sets of microorganisms being considered under the pending GWR. The first set includes the traditional fecal indicator bacteria (total coliform, *E. coli*, enterococci). These three fecal bacteria have been shown to grow in the soil environment of Hawaii and soil has been reported to be the major source for the high concentrations of these three bacteria in all streams of Hawaii. Since soil is a major environmental source of these fecal bacteria in Hawaii, monitoring data for these three traditional fecal bacteria (total coliform, *E. coli*, enterococci) in groundwater sources in Hawaii cannot be specifically related to sewage or fecal contamination. However, the three alternative fecal microorganisms (*C. perfringens*, somatic coliphages, FRNA coliphages), are present in high concentrations in sewage and are known to survive longer in the environment than fecal bacteria. In addition, they are not able to multiply in the environment and are not present in high concentrations in soil. Thus, the alternative fecal microorganisms are reliable surrogates for the presence of pathogens such as human enteric viruses, especially in Hawaii (WRRC, 2001).

To assess the microbial quality of potable water sources, the percent of samples, which was positive for each of the six groups of selected microorganisms was calculated and compared to existing water quality standards and guidelines. As explained in the methods section, the assay for total anaerobic spores is the assay method for *C. perfringens*. The assay for aerobic spores was included as a control for the assay for total anaerobic spores. Since aerobic bacterial spores are commonly found in soil, their presence in groundwater samples reflects ambient levels of this group of soil bacteria. Since concentrations of total aerobic spores are not related to fecal contamination, these measurements were not included in the summary tables (Tables 2–8) used to determine fecal contamination of groundwater.

IV. Results and Discussion

A. Fecal Microbial Quality of Well Water Samples

Groundwater samples from 47 wells used by County of Hawaii and 34 wells used by private companies were assayed for three traditional fecal bacteria (total coliform, *E. coli*, enterococci) and three alternative fecal microorganism (*C. perfringens*, somatic coliphages, FRNA coliphages). These six fecal indicator microorganisms are being considered for monitoring under the pending GWR. The relative fecal microbial quality of groundwater sources used by County of Hawaii and by private wells was determined by calculating the percent of samples, which was positive for each of the six groups of microorganisms. The monitoring results for traditional fecal bacteria are summarized in Table 2 and show that 15/116 (13%) of non-disinfected well water samples used by the County of Hawaii were positive for total coliform. None of these samples was positive for the more sewage-specific *E. coli* (0/116), and 2% (2/116) samples was positive for enterococci. In comparison, the results of Table 2 show that 12/89 (14%) of the non-disinfected well water samples used by private companies were positive

for total coliform, 3/89 (3%) were positive for *E. coli* and 2/89 (2%) of these same groundwater samples were positive for enterococci. The monitoring results for alternative fecal microorganisms are also summarized in Table 2 and show that none of the non-disinfected well water samples used by County of Hawaii was positive for FRNA coliphages (0/116) and for *Clostridium perfringens* (0/116), while 1/116 (1%) of these samples was positive for somatic coliphages. The non-disinfected wells used by private companies were characterized by undetectable levels of FRNA coliphages (0/89), somatic coliphages (0/89) and *C. perfringens* (0/89).

In summary, the microbial quality of well water samples used by the County of Hawaii and by the private companies was similar based on detection rates for the standard fecal indicator bacteria and for the alternative fecal microorganisms. Both sources of well water samples were characterized by detection rates of 13–14% for total coliform and much lower detection rates for *Escherichia coli* (0–3%) and for enterococci (2%). Both sources of well water samples were characterized by absence of FRNA coliphages and by *C. perfringens*. Somatic coliphages was detected in only one sample (1/116) from well water samples used by County of Hawaii and none from well water samples used by private companies (0/89).

These monitoring data indicate that the well water samples used by the County of Hawaii and by private companies are very good because these well water samples were characterized by low detection rates for the more sewage-specific fecal bacteria (*E. coli*, enterococci) and absence of the most stringent alternative fecal microbial indicators (FRNA coliphage, *C. perfringens*). Moreover, somatic coliphages was detected in only one well water sample used by the County of Hawaii (1/116). These results are especially relevant because FRNA coliphages and *C. perfringens* have been previously determined to be the most reliable indicator of fecal contamination in Hawaii and other tropical environments (WRRC, 2001) and these fecal microorganisms are being considered for monitoring under the pending Groundwater Rule. Based on these results, we conclude that the groundwater sources used by the County of Hawaii and by private companies will likely meet the monitoring requirements of the pending GWR and that these sources of groundwater will be classified as not vulnerable to contamination with fecal matter. These results also indicate that cesspools, and septic tanks, which are commonly used on the island of Hawaii are not measurably contaminating the potable groundwater sources on the Big Island.

B. Fecal Microbial Quality of Spring and Tunnel Water Samples

Water from Tunnels represents shallow groundwater sources and springs are classified as surface water. If water from tunnels is considered groundwater under the influence of surface water, it will be regulated as a surface source rather than a groundwater source. In the state of Hawaii, water from tunnels and springs are often used as potable water sources by water utilities. The County of Hawaii used 11 non-disinfected and 7 disinfected sources from springs and tunnels. The results of analyzing water from the 7 disinfected sources are summarized in Table 3 and show that none (0/19) of the six fecal microorganisms (total coliform, *E. coli*, enterococci, FRNA coliphages, somatic coliphages and *C. perfringens* was detected in the 19 water samples tested. In the non-disinfected sources of springs and tunnels, 72% (23/32) of the samples was positive for total coliform, 38% (12/32) was positive for *E. coli* and 16% (5/32) was positive for enterococci. When these same water samples were assayed for alternative fecal indicators, the

results summarized in Table 3 show undetectable levels of FRNA coliphages (0/32) and *Clostridium perfringens* (0/32). However, somatic coliphages were recovered in 13% (4/32) of these water samples. The sampling sites, which were positive for somatic coliphages were re-sampled and determined to be negative for these coliphages. Thus, contamination events with coliphages appear to be sporadic.

In summary, the microbial quality of non-disinfected spring and tunnel water samples was characterized by high detection rates of total coliform (72%), *Escherichia coli* (38%) and enterococci (16%) but undetectable levels of FRNA coliphages and *C. perfringens*. In contrast the microbial quality of water samples from disinfected spring and tunnel sources was characterized by absence of all six fecal indicator microorganisms.

Several conclusions regarding the microbial quality of spring and tunnel waters can be drawn from the results of Table 3. First, since traditional fecal indicator bacteria were detected in high percentages of non-disinfected spring and tunnel water but were not detected in disinfected spring and tunnel water samples, we conclude that chlorination can effectively reduce the levels of total coliform, *E. coli* and enterococci to undetectable levels. These results support our (Hardina and Fujioka, 1991; WRRC, 2001), previous conclusions that soil in Hawaii supports the growth of traditional fecal indicator bacteria and soil is the source for the naturally high concentrations of standard fecal indicator bacteria in surface water samples. Second, the absence of FRNA coliphages and *C. perfringens* in these water samples indicate that these water sources are not contaminated with sewage. Third, the presence of somatic coliphages in 13% of these water samples cannot be interpreted with confidence. These coliphages, unlike FRNA coliphages, are not as specific to sewage and can multiply under environmental conditions. However, these coliphages have been detected in groundwater sources and are being considered for monitoring under the pending GWR. Fourth, these spring and tunnel sources should be considered as surface water sources.

C. Fecal Microbial Quality of Combination (Ground, Surface, Spring, Tunnel) Sources of Water

Some sources of potable water are some combination of ground, surface, spring and tunnel. These sources of water used by County of Hawaii and by private companies were disinfected and classified as "Combination Sources". A total of four combination sources used by County of Hawaii and two combination sources used by private companies were analyzed for the six fecal microorganisms. The results summarized in Table 4 show that of the 12 water samples from the County of Hawaii sites, only total coliform was detected in 1/12 (8%) water samples. In these samples, the five other fecal microorganisms were not detected in the 12 samples tested (0/12). None of the six fecal indicator microorganisms were detected in the 9 water samples used by private companies. These results indicate that the microbial quality of combination sources of disinfected water used by County of Hawaii and private companies was excellent. These results indicate that chlorination was effective in reducing the concentrations of standard fecal indicator bacteria. The alternative fecal microorganisms (FRNA coliphages, somatic coliphages, *C. perfringens*) are much more resistant to chlorination than fecal indicator bacteria. The absence of these alternative fecal indicators indicate that these combination sources of water are not contaminated with human sewage.

D. Fecal Microbial Quality of Non-Disinfected, Surface Water Samples

Surface water sources are known to be more susceptible to contamination than groundwater sources and to contain higher ambient concentrations of bacteria. The County of Hawaii used 1 non-disinfected surface water source and the private companies used 2 non-disinfected surface water sources for potable water. It should be noted that the 2 surface water sources used by a Private Company had the same name but was listed as filtered and unfiltered. A total of 3 water samples from the surface water source used by County of Hawaii and 5 water samples from the 2 surface water sources used by private companies were assayed for the six fecal microorganisms. The results summarized in Table 5 show that of the 3 surface water samples used by the County of Hawaii, 100% (3/3) was positive for total coliform, and 33% (1/3) was positive for *Escherichia coli* and enterococci. None of these samples (0/3) was positive for FRNA coliphages, somatic coliphages and *Clostridium perfringens*. The results in Table 5 show that 40% (2/5) of the surface water samples used by a private company was positive for total coliform. None of these samples (0/5) was positive for FRNA coliphages, somatic coliphages, and *C. perfringens*. These results indicate that the microbial quality of the surface water sources used by Private Company was excellent and better than the microbial quality of the surface water used by the County of Hawaii. The non-detectable levels of alternative fecal microorganisms (FRNA coliphages, somatic coliphages, *C. perfringens*), from these surface water sources indicate that these surface water sources are not contaminated with fecal matter.

E. Fecal Microbial Quality of Catchment Water Samples

In some areas, especially near the Volcano National Park, roofs of buildings are used as a catchment area to collect rainwater for potable use. Private companies used 3 catchments as sources of potable water. A total of 11 non-disinfected water samples from these 3 catchment sources was analyzed for the six selected fecal microorganisms. The results summarized in Table 6 show that 73% (8/11) was positive for total coliform and 18% (2/11) was positive for enterococci. None of these water samples (0/11) was positive for enterococci, FRNA coliphages, somatic coliphages, *C. pefringens*. Since the catchment area is from the roofs of buildings, these sites are not likely to be contaminated with sewage or human feces but are susceptible to contamination with fecal droppings of birds. The non-detectable levels of alternative fecal microorganisms (FRNA coliphages, somatic coliphages, *C. perfringens*), from these catchment sources indicate that these sources of water are not contaminated with human fecal matter (sewage).

F. Fecal Microbial Quality of Disinfected, Reservoir Water Samples

Reservoir tanks are used to store potable water from various sources to be transported to distribution pipes. Water in reservoir tanks is routinely chlorinated because the tanks are not completely sealed from outside contamination. The County of Hawaii used 3 reservoir tanks and private companies used 2 reservoir tanks. A total of 8 water samples from the 3 reservoir tanks used by County of Hawaii and 4 water samples from the 2 private reservoir tanks were assayed for the six selected fecal microorganisms. The results are summarized in Table 7 and show that none of the six fecal indicator microorganisms was detected in the 8 County of Hawaii reservoir water samples (0/8). Only 1 reservoir water sample used by the private companies was positive for coliform (1/4). The other 5 fecal microorganisms were not detected in these same 4 water samples (0/4). These results indicate that the microbial quality of water in reservoir tanks used by

County of Hawaii and by Private Company was excellent. The results indicate that chlorination was effective in reducing the concentrations of standard fecal indicator bacteria. Since alternative fecal microorganisms (FRNA coliphages, somatic coliphages, *Clostridium perfringens*), are much more resistant to chlorination than fecal indicator bacteria, the results indicate that these reservoir tanks are not contaminated with fecal matter.

G. Fecal Microbial Quality of Disinfected, Distribution Water Samples.

The public obtains their drinking water via distribution pipes. On the island of Hawaii, water in the distribution pipes is routinely chlorinated. The County of Hawaii used 22 different distribution sampling sites and private companies used 14 different distribution sampling sites. A total of 59 water samples from the 22 County of Hawaii distribution sampling sites and 47 water samples from the 14 private companies distribution sampling sites were analyzed for the six selected fecal microorganisms. The results summarized in Table 8 show that only total coliform was detected in 2% of the distribution water samples from the County of Hawaii (1/59) and from the private companies (1/47). The five other fecal microorganisms were not detected from County of Hawaii distribution water samples (0/59) and from Private Company distribution water samples (0/47). These results indicate that the microbial quality of water in distribution systems used by County of Hawaii and by Private Company was excellent. The results indicate that chlorination was effective in reducing the concentrations of standard fecal indicator bacteria. Since alternative fecal microorganisms (FRNA coliphages, somatic coliphages, *C. perfringens*), are much more resistant to chlorination than fecal indicator bacteria, the results indicate that these distribution systems are not contaminated with fecal matter.

V. Conclusions

In this study, we analyzed larger volumes (200 ml, 500 ml, 1,000 ml) of water as compared to 100 ml required by SDWA to increase the sensitivity of the assay. We analyzed these water samples for six selected fecal microorganisms (total coliform, *Escherichia coli*, enterococci, *C. perfringens*, somatic coliphages, FRNA coliphages). Based on the results of the assays for these six fecal microorganisms, the following conclusions can be made regarding the potable sources (well, tunnel/spring, combination, surface, catchment, reservoir, distribution) of water on the Big Island.

1. The microbial quality of non-disinfected potable groundwater used by County of Hawaii and by private companies on the island of Hawaii was similar and was very good. Both sources of groundwater was characterized by detection rate of 13-14% total coliform and 0-3% detection rate for *E. coli* and enterococci. Both sources of groundwater were characterized by absence of alternative fecal microorganisms (*C. perfringens*, FRNA coliphages). Somatic coliphages were detected in only 1% (1/116) of County of Hawaii groundwater samples. These results indicate that the groundwater sources used by County of Hawaii and by private companies on the island of Hawaii will most likely meet the monitoring requirements of the pending GWR.

2. The measured microbial quality of the groundwater sources on Island of Hawaii indicates that these groundwater sources are not vulnerable to contamination with fecal matter. These results provide evidence that cesspools and septic tanks, which are used extensively on the Big Island, are not measurably contaminating groundwater sources.

3. The monitoring data show that water samples characterized as surface sources such as tunnel/springs and surface sources contain detectable levels of standard fecal indicator bacteria such as total coliform, *Escherichia coli* and enterococci but not alternative fecal microorganisms such as FRNA coliphages, somatic coliphages, and *Clostridium perfringens*. When these sources of water are chlorinated, the concentrations of standard fecal indicator bacteria can be effectively reduced to acceptable or non-detectable levels.

4. Non-disinfected rainwater samples collected by roof catchment systems were also characterized as containing detectable levels of total coliform (73%) and *E. coli* (18%) but essentially undetectable levels of alternative fecal microorganisms (FRNA coliphages, somatic coliphages, *C. perfringens*). These results indicate that standard fecal indicator bacteria in this source of water can be effectively disinfected. Moreover, the monitoring results indicate that this source of water is not measurably contaminated with human fecal matter.

5. The potable water samples stored in reservoir tanks and then distributed to the public via distribution pipes is routinely chlorinated. Based on analyzing these samples for the six selected fecal microorganisms, it can be concluded that the microbial quality of the potable water being distributed to the public by County of Hawaii and by private companies should meet current drinking water standards.

CHAPTER FOUR

PHASE II: CHARACTERIZING THE BASIC CHEMICAL AND PHYSICAL QUALITY OF POTABLE WATER SOURCES ON ISLAND OF HAWAII TO ADDRESS GUIDELINES OF SOURCE WATER ASSESSMENT PROGRAM

I. Goals and Objectives

The secondary goal of this study was to determine basic chemical and physical quality (pH, turbidity, conductivity, total phosphorus, total nitrogen) of the same sources of water (well, reservoir tanks, distribution system) previously analyzed for fecal microorganisms. The objective of this secondary goal was to fulfill the guidelines and intent of the SWAP for Hawaii.

II. Relevance of the Hawaii Source Water Assessment Program

The Hawaii Source Water Assessment Program (HISWAP) plan was completed in 1999 with the stated goal "to prepare source water assessments based on sound scientific principles and judgment that will enable the public and our decision makers to make well-founded, fair and reasonable decisions for the protection and preservation of Hawaii's drinking water". This goal, if implemented, with all potable water projects can greatly improve the management of Hawaii's potable water sources. However, since the SWAP is primarily a volunteer program, projects generally must choose to implement the guidelines of HISWAP. This proposed study embraces the goals of HISWAP by assessing the susceptibility of drinking water sources on the island of Hawaii to contamination. Of the three HISWAP technical approaches (delineation, inventory, susceptibility), this project adopts the technical approach to determine the susceptibility of the drinking water sources on the Big Island to contamination from identified potential contaminating activities such as cesspools and septic tanks which are used extensively on island of Hawaii. In this regard, this project focuses primarily on vulnerability of fecal contamination for potable groundwater sources, some of which are under the influence of surface water. In addition, this project also compares the quality of groundwater after the groundwater has been stored in reservoir tanks and distributed to the public via pipes directly to homes and businesses.

III. Experimental Design

For this phase of the study, the general quality of the water samples was determined by analyzing these water samples for the five basic potable water quality parameters (pH, turbidity, conductivity, total nitrogen, total phosphorus). The results of these analyses are summarized in Tables 9, 10, 11, 12, 13, 14, 15.

IV. Results and Discussion

A. General Quality of Water from Wells Used by County of Hawaii and by Private Companies

The general water quality of the 47 wells used by the County of Hawaii and the 34 wells used by private companies was based on the analyses of these water sources for the five selected chemical and physical water quality parameters. The results from 116 well water samples are

summarized in Table 9 and show that the general quality of well water used by County of Hawaii was characterized by average pH of 7.30, turbidity of 1.5 NTU, conductivity of 279 µS/cm, 0.6 mg/l of total phosphorus and 1.6 mg/l of total nitrogen. In comparison, based on analyzing 89 well water samples from 34 wells, the general quality of well water used by private companies was characterized by average pH of 7.25, turbidity of 1.5 NTU, conductivity of 528 µS/cm, 0.7 mg/l total phosphorus and 1.7 mg/l of total nitrogen,. In summary, the general quality of the well water used by the County of Hawaii and private companies was similar and generally within guidelines for potable water.

B. General Quality of Water from Springs andTunnels Used by County of Hawaii Companies

The general quality of non-disinfected water samples and disinfected water samples from 18 spring and tunnels used by the County of Hawaii was determined based on analyses for the five selected chemical and physical water quality parameters. The results of 19 disinfected spring and tunnel water samples are summarized in Table 10 and show that this source of water was characterized by average pH of 7.02, turbidity of 1.6 NTU, conductivity of 222 µS/cm, 0.5 mg/l of total phosphorus and 0.9 mg/l of total nitrogen. Based on analyzing 32 non-disinfected spring/tunnel water samples, the general quality of this source of water was characterized by average pH of 6.62, turbidity of 1.3 NTU, conductivity of 167 µS/cm, 0.3 mg/l total phosphorus and 1.1 mg/l of total nitrogen. In summary, the general quality of the disinfected and non-disinfected spring/tunnel water used by the County of Hawaii was similar and generally within the guidelines for potable water.

C. General Quality of Water in Combination (Ground, Surface, Spring, Tunnel) Sources Used by County of Hawaii and by Private Companies.

The combination water samples used by County of Hawaii and by private companies were disinfected. The general quality of the 4 combination water sources used by the County of Hawaii and the 2 combination water sources used by private companies was determine based on analyzing these water sources for the five selected chemical and physical water quality parameters. The results of 12 combination water samples used by County of Hawaii are summarized in Table 11 and show that the general quality of this source of water was characterized by average pH of 6.83, turbidity of 1.3 NTU, conductivity of 114 µS/cm, 0.7 mg/l of total phosphorus and 1.0 mg/l of total nitrogen. The results of 9 combination water samples used by private companies are summarized in Table 11 and show that the general quality of this source of water was characterized by average pH of 5.87, turbidity of 2.5 NTU, conductivity of 23 µS/cm, 0.4 mg/l total phosphorus and 0.9 mg/l of total nitrogen. The general quality of the combination water used by the County of Hawaii was similar to those of spring/tunnel water samples and was generally within guidelines for potable water. However, the general quality of the combination water samples used by private companies was observed to have a slightly lower pH (5.87), slightly elevated turbidity (2.5 NTU) and lower conductivity (23µS/cm). The elevated turbidity readings most likely reflect the contribution of surface water. The lower conductivity readings most likely reflect the contribution of some sources of water, which had not interacted with soil and other contributors of minerals.

D. General Quality of Surface Water Sources Used by County of Hawaii and by Private Companies

The County of Hawaii used 1 surface source for potable use and private companies used 2 surface sources. The general quality of these non-disinfected surface sources of water was determined based on analyzing these water sources for the five selected chemical and physical water quality parameters. The results of 2 surface water samples used by County of Hawaii are summarized in Table 12 and show that the general quality of this source of water was characterized by average pH of 6.33, turbidity of 3.1 NTU, conductivity of 37 µS/cm, 0.2 mg/l of total phosphorus and 0.5 mg/l of total nitrogen. The results of 5 surface water samples used by private companies are summarized in Table 12 and show that the general quality of this source of water was characterized by average pH of 6.87, turbidity of 2.0 NTU, conductivity of 48 µS/cm, 0.5 mg/l total phosphorus and 1.3 mg/l of total nitrogen. The higher turbidity (2.0–3.1 NTU) of these surface water samples most probably reflect the fact that surface waters, unlike groundwater have not been filtered through soil. These surface water samples also measured unusually low conductivity (37–48 µS/cm) as compared to groundwater samples and probably reflect their truer origin to rainwater, which has low conductivity. In this regard, the conductivity of rainwater increases as salts and minerals are added by interaction with soil.

E. General Quality of Rainwater Catchment Sources of Water Used by Private Companies

Private companies collect rainwater using roofs of building as water catchments area as sources of potable water in some areas of the Big Island such as near Volcano National Park. The private companies use 3 roof catchment sources of water. The general quality of these non-disinfected, catchment sources of water was determined based on analyzing these water samples for the five selected chemical and physical water quality parameters. The results of 11 catchment water samples are summarized in Table 13 and show that the general quality of this source of water was characterized by average pH of 5.48, turbidity of 2.8 NTU, conductivity of 17 µS/cm, 0.4 mg/l of total phosphorus and 0.5 mg/l of total nitrogen. The general quality of this source of water differs from those of groundwater wells. The lower pH (5.48) may reflect acidity due to volcanic gasses in the atmosphere near the Volcano National Park. The elevated turbidity (2.8 NTU) most probably reflect the fact this source of water is not naturally filtered by soil and particles on the roof are mixed with these water samples. The lower conductivity (17 µS/cm) as compared to groundwater samples probably reflect their truer origin to rainwater, which has low conductivity. In this regard, the conductivity of rainwater increases as salts and minerals are added by interaction with soil and other contaminants in the environment.

F. General Quality of Water in Reservoir Tanks Used by County of Hawaii and by Private Companies

The County of Hawaii uses 3 reservoir tanks and private companies use 2 reservoir tanks to store potable water for transport to distribution pipes. Water in these tanks is routinely chlorinated. The general quality of these reservoir sources of water was determined based on analyzing these water samples for the five selected chemical and physical water quality parameters. The results of 8 reservoir tank water samples used by County of Hawaii are summarized in Table 14 and show that the general quality of this source of water was characterized by average pH of 7.29, turbidity of 1.5 NTU, conductivity of 140 µS/cm, 0.6 mg/l of total phosphorus and 2.1 mg/l of total nitrogen. The results of 4 reservoir tank water samples used by private companies are summarized in Table 14 and show that the general quality of this

source of water was characterized by average pH of 7.71, turbidity of 1.5 NTU, conductivity of 351 µS/cm, 0.5 mg/l of total phosphorus and 1.3 mg/l of total nitrogen. The general quality of this source of water is generally within guidelines of potable water and similar to groundwater samples (see Table 9) indicating that drastic changes are not occurring in water samples stored in reservoir tanks.

G. General Quality of Water in Distribution Pipes Used by County of Hawaii and by Private Companies

The County of Hawaii uses 22 sampling sites from their distribution systems whereas the private companies use 14 sampling sites from their distribution systems. These water samples are those distributed to the public. Water in these distribution pipes is routinely chlorinated. The general quality of these distribution sources of water was determined based on analyzing these water samples for the five selected chemical and physical water quality parameters. The results of 59 distribution water samples used by County of Hawaii are summarized in Table 15 and show that the general quality of this source of water was characterized by average pH of 7.30, turbidity of 1.5 NTU, conductivity of 244 µS/cm, 0.6 mg/l of total phosphorus and 1.0 mg/l of total nitrogen. The results of 47 distribution water samples used by private companies are summarized in Table 15 and show that the general quality of this source of water was characterized by average pH of 7.22, turbidity of 1.3 NTU, conductivity of 286 µS/cm, 0.9 mg/l of total phosphorus and 1.6 mg/l of total nitrogen. The general quality of water in the distribution pipes used by the County of Hawaii and by private companies was similar, and were generally within the guidelines for potable water.

V. Conclusions

Samples of several sources of potable water (wells, spring/tunnels, combination, surface, catchment, reservoir, distribution) used by County of Hawaii and by private companies were analyzed for five basic tests (pH, turbidity, conductivity, total phosphorus, total nitrogen) to determine the basic chemical and physical quality of these potable water sources. The results showed that the general quality of water from groundwater, spring/tunnel, reservoir water and water from distribution pipes used by County of Hawaii and private companies were similar and within the guidelines for potable water. With regard to the objectives of the SWAP, these results indicate these sources of water are not susceptible to significant levels of contamination by external sources or by some related activities. However, variations in some water quality parameters such as pH, turbidity and conductivity were observed in surface water samples, catchment water samples and from combination sources of water. These results reflect differences in the sources and interaction history with soil as compared to groundwater sources.

CHAPTER FIVE

PHASE III: ASSESSMENT OF RAPID METHODS TO DETERMINE AMBIENT QUALITIES OF POTABLE WATER SOURCES ON ISLAND OF HAWAII TO ADDRESS CONCERNS OF WATER CONTAMINATION BY TERRORISTS

I. Goal and Objectives

The tertiary goal for this study was to evaluate selected tests as reliable monitoring methods in the event of water contamination by terrorists. The test to be used for this purpose must produce results rapidly (seconds, minutes, few hours). The available tests to detect pathogens and specific toxic chemicals in water are too complicated and time consuming and cannot be used for this purpose. Instead, the test method selected must rapidly measure some ambient water quality parameter, which can be expected to change and signal that water may be contaminated with pathogens or toxic chemicals. To achieve this tertiary goal, the following available tests were evaluated: 1) ATP as surrogate for increased concentrations of bacteria in water samples. 2) Inspecta method as surrogate for increased concentrations of physical and chemical agents in water samples. 3) Microtox as a rapid test to determine for the presence of toxic chemicals in water samples. 4) Particle analysis of water samples.5) Recovery and characterization of heterotrophic bacteria to detect for presence of pathogens or other microorganisms, which may signal that the potable water source is contaminated. In summary, these tests are available but have not been previously used to address contamination by terrorists. The objective of evaluating these rapid methods was to determine whether the ambient water parameters measured by these tests are sensitive and reliable enough to detect purposeful contamination of potable water supplies by terrorists.

II. Relevance of Bioterrorism

Homeland Security has been established as a cabinet level in the Federal Government to deal with terrorists threats. One form of threat has been identified as "Water Terrorism" or the intentional contamination of drinking water sources by pathogens or toxic chemicals with the potential for killing or sickening large numbers of people. In December of 2003, EPA finally published an interim final report called "Response Protocol Toolbox: Planning for and Responding to Drinking Water Contamination Threats and Incidents" (www.epa.gov/safewater/watersecurity). This document contains 6 modules to cover various phases of responsibilities that a water utility must consider to address Water Terrorism. This document is a planning tool, which EPA recommends that water utilities use to effectively manage an actual threat. Module 4 (Analytical Guide) presents an approach in the use of methods to analyze water samples collected from the site of a suspected contamination incident. However, as pointed out in that Module, the purpose of the Analytical Guide is not to provide a detailed protocol. Rather it is a framework for developing an approach for the analysis of water. In this regard, none of the methods described have been verified as being reliable in an actual contamination event. Despite these short comings, all water utilities must begin to evaluate methods which can be useful for their facilities.

III. Experimental Design

This phase of the study was entirely experimental as most of the methods evaluated had not been used as screening tests for drinking water quality and none of these test methods were approved for this use. For this phase of the study, selected samples of potable water sources (well, tunnel/spring, combination, catchment, reservoir tanks, distribution system) used by County of Hawaii and by private companies were used in the evaluation of these selected experimental methods. It was determined that analysis for heterotrophic bacteria concentrations in water samples was required to characterize samples of water, which were assayed for ATP because concentrations of ATP in water is a rapid surrogate test for viable bacteria in water samples. However, since only 0.1% of viable bacteria can be expected to be cultured by the heterotrophic bacterial assay, the concentrations of ATP cannot be expected to predict the culturable levels of heterotrophic bacteria in that water sample. The heterotrophic bacteria assay was also used to isolate viable bacteria from the various water samples using mEndo medium and mHPC agar and to characterize the populations of bacteria in the heterotrophic bacteria assay using the Riboprinter™.

IV. Results and Discussion

A. Analysis of Water for Total ATP

Samples of potable sources of water (wells, tunnels/springs, combination, surface, catchment, reservoir, distribution) were assayed for ATP and for concentrations of heterotrophic bacteria. The results of these assays are summarized on Table 16.

1. *Well water samples*. These water samples are not disinfected. Based on analyzing 62 County of Hawaii well water samples, the geometric mean concentration of ATP was 1977 RLU/100 ml (Range: 32–5,490,240 RLU/100 ml) with corresponding geometric mean concentration of 388 CFU/100 ml of heterotrophic bacteria (Range: 24–6720 CFU/100 ml). Based on analyzing 28 private well water samples, the geometric mean concentration of ATP was 2715 RLU/100 ml (Range: 28–91,596 RLU/100 ml) with corresponding geometric mean concentration of 548 CFU/100 ml of heterotrophic bacteria (Range: 68–17,024 CFU/100 ml). These results show that geometric mean concentrations of ATP and heterotrophic bacteria in the County of Hawaii and private well water samples were similar. However, greater variation in the ATP levels was observed in the well water samples from the County of Hawaii.

2. *Tunnel/Spring water samples (County of Hawaii)*. Some of these sources of water were not disinfected while some were disinfected. Based on analyzing 9 disinfected water samples, the geometric mean concentration of ATP was 203 RLU/100 ml (Range: 0–3348 RLU/100 ml) with corresponding geometric mean concentration of 90 CFU/100 ml of heterotrophic bacteria (Range: 8–1980 CFU/100 ml). Based on analyzing 15 non-disinfected water samples, the geometric mean concentration of ATP was 3106 RLU/100 ml (Range: 56–1,392,552 RLU/100 ml) with corresponding geometric mean concentration of 640 CFU/100 ml (Range: 32–1904 RLU/100 ml). As expected, the disinfected water samples had lower ATP and heterotrophic bacteria readings than the non-disinfected samples because chlorination disinfects bacteria and only viable bacteria produce ATP and CFU (colony forming units) to measure heterotrophic

bacteria. The results of ATP and heterotrophic bacteria for non-disinfected tunnel/spring water samples were slightly higher than the results obtained for well water samples. These results are consistent with the observation that tunnel/spring water samples are generally considered surface water samples and can be expected to have higher ambient concentrations of total bacteria than groundwater samples.

3. *Reservoir water samples*. These water samples are disinfected. Based on analyzing 5 County of Hawaii reservoir water samples, the geometric mean concentration of ATP was 124 RLU/100 ml (Range: 84–160 RLU/100 ml) with corresponding geometric mean concentration of 48 CFU/100 ml of heterotrophic bacteria (Range: 8–264 CFU/100 ml). Only 1 private company reservoir water sample was analyzed. This water sample was shown to have an ATP concentration of 1504 RLU/100 ml and 52 CFU/100 ml of heterotrophic bacteria. The measured concentrations of ATP and heterotrophic bacteria in the disinfected reservoir samples were lower than the corresponding measurements in non-disinfected well water samples and non-disinfected tunnel/spring water samples but similar to disinfected tunnel/spring water samples. These results confirm that chlorination effectively disinfects bacteria in potable water sources and thereby reduces the measurements for ATP and heterotrophic bacteria.

4. *Distribution water samples*. These water samples are disinfected and were obtained from distribution pipes, which provide water to the public. Based on analyzing 29 County of Hawaii distribution water samples, the geometric mean concentration of ATP was 363 RLU/100 ml (Range: 0–3,372,592 RLU/100 ml) with corresponding geometric mean concentration of 110 CFU/100 ml of heterotrophic bacteria (Range: 4–2,416 RLU/100 ml). Based on 16 water samples from private distribution water samples, the geometric mean concentration of ATP was 268 RLU/100 ml (Range: 0–10,640 RLU/100 ml) with corresponding geometric mean concentration of 50 CFU/100 ml of heterotrophic bacteria (Range: 4–2,848 CFU/100 ml). These results show that the concentrations of ATP and heterotrophic bacteria were lower in distribution water samples from private companies as compared to water samples from County of Hawaii. Moreover, there appeared to be much wider variation in ATP levels in County of Hawaii water samples. Two conditions can explain these differences. First, water from County of Hawaii represented more water samples from more distribution sampling sites. Second, disinfection may be more consistent in private distribution pipes as compared to the county distribution pipes.

5. *Surface water samples*. The County of Hawaii uses 1 surface water source and private companies use 2 surface sources for potable use. Based on analyzing 2 County of Hawaii surface water samples, the geometric mean concentration of ATP was 625,546 RLU/100 ml (Range: 252,588–1,100,532 RLU/100 ml) with corresponding geometric mean concentration of 1251 CFU/100 ml of heterotrophic bacteria (Range: 1,008–1,552 RLU/100 ml). Based on 2 private surface water samples, the geometric mean concentration of ATP was 6,726 RLU/100 ml (Range: 4,750-9,184 RLU/100 ml) with corresponding geometric mean concentration of 3279 CFU/100 ml of heterotrophic bacteria (Range: 800–13,440 CFU/100 ml). As expected these results show that the concentrations of ATP and heterotrophic bacteria are higher in surface water than in groundwater. The variations in ATP measurements in County of Hawaii water samples were much greater than the variation in ATP measurement in the private surface water samples.

6. *Combination Water Samples.* The County of Hawaii uses 4 combination water sources and private companies use 2 combination water sources for potable use. These sources of water are disinfected. Based on analyzing 5 County of Hawaii combination water samples, the geometric mean concentration of ATP was 841 RLU/100 ml (Range: 52–653,512 RLU/100 ml) with corresponding geometric mean concentration of 54 CFU/100 ml of heterotrophic bacteria (Range: 0–720 CFU/100 ml). Based on 2 private combination surface water samples, the geometric mean concentration of ATP was 336 RLU/100 ml (Range: 90–1472 RLU/100 ml) with corresponding geometric mean concentration of 12 CFU/100 ml of heterotrophic bacteria (Range: 0–12 CFU/100 ml). The relatively low measurements of ATP and heterotrophic bacteria reflect the fact that these water samples were chlorinated. The results show that the County of Hawaii combination water samples had higher ATP and heterotrophic bacteria than private combination water samples. Moreover, the County of Hawaii combination water samples was characterized by greater variations in measurements of ATP and heterotrophic bacteria. The results of combination water samples are difficult to evaluate as these samples are mixtures of ground, surface, tunnel and spring sources.

7. *Catchment water samples.* Only private companies use 3 roof catchment water sources for potable use. These sources of water were not disinfected. Based on analyzing 2 private catchment water samples, the geometric mean concentration of ATP was 92,031 RLU/100 ml (Range: 79,145–120,850 RLU/100 ml) with corresponding geometric mean concentration of 2142 CFU/100 ml of heterotrophic bacteria (Range: 1280–3584 CFU/100 ml). These results show that catchment water samples are characterized by relatively high concentrations of ATP and heterotrophic bacteria. These results reflect the fact that this source of water was not disinfected and was not naturally filtered. Rainwater samples collected by roof catchments are contaminated with material on the roof and in the gutters.

The ATP measurements in water samples resulted in great variation. As a result, further assessment of the ATP method to measure bacteria were previously reported (Fujioka et al., 2004) and led to the following observations and statements.

1. The concentrations of heterotrophic bacteria recovered from a water sample did not correlate with the levels of ATP measured for that water samples. However, this correlation was not expected because measurement for total heterotrophic bacteria only accounts for 0.1% of the total viable concentrations of bacteria. Since each viable cell can be expected to produce some ATP, the concentrations of heterotrophic bacteria are not expected to correlate with levels of ATP in that water sample.

2. Large variation of ATP levels were observed even when duplicates of the same samples were assayed. These results indicate that the ATP reaction is not stable and is under the control of dynamic changes in water samples. For example, the test is supposed to measures ATP levels in all bacteria. However, production of ATP by each viable bacterium is dependent on the physiological state of that bacteria as well as the species of bacteria. Moreover, there are other viable cells (e.g., protozoa) which may be present in some samples and produce ATP which are not related to bacterial populations.

3. Under control conditions of adding known concentrations of *Escherichia coli* to sterile water, the ATP assay method was not sensitive to detect levels of *E. coli* until more than 500 CFU of *E. coli* was added. Thus, the ATP assay was not sensitive until some threshold concentration of *E. coli* bacteria was reached. The ATP assay method became quantitative after the concentrations of *E. coli* bacteria exceeded 1,000 CFU.

In summary, based on the great variability of the ATP readings, the ATP method used in this study does not provide easily interpretable data. Of significance, the ATP method was not sensitive enough to detect lower levels of *E. coli*, which are of concern. There appears to be too many unknown factors in the use of this method. As a result, the ATP assay method used in this study cannot be relied upon to detect a significant change in the concentrations of bacteria as a signal for a contaminating event. In this regard, the method used in this study was reported to be successfully used to determine changes in bacteria in surface waters used as drinking water source (Lee and Deininger, 1999). However, in that situation, the ambient concentrations of heterotrophic bacteria in surface water was much higher than in the concentrations of heterotrophic bacteria measured in groundwater samples used in this study. Thus, ATP measurement technology must be improved to detect lower levels of bacteria, which are characteristic of most potable water sources, especially groundwater sources. Moreover, interpretation of ATP measurements can be complicated by the fact that some bacteria produce high concentrations of ATP and others produce low concentrations of ATP. In this regard, bacterial spores are characterized by producing very low levels of ATP. Significantly, some pathogens, such as *Bacillus anthracis* and *Clostridium botulinum* are spore forming bacteria and have been identified as candidate for terrorist use. Nevertheless, the potential for use of ATP as a feasible and reliable monitoring method for potable water is good. One can expect improvement in ATP technology to be applied specifically to monitor potable water supplies.

B. Assay for Toxic Chemicals in Water Using Microtox Method

The Microtox method is a feasible method to measure for acutely toxic chemicals in water at levels that are clearly toxic. This conclusion is based on the ability of the Microtox method to reliably detect toxicity in water when many of the known toxic chemicals are added to water samples. We previously used the Microtox method to detect for toxic chemicals in the effluent of the Wahiawa Sewage Treatment Plant (Billingsley, 1990), in storm water samples (Terra McParland, 1991) and in Waimanalo Stream samples (Paulino, 1994). Acutely toxic chemicals were not detected in these samples. For the Wahiawa sewage effluent sample, the presence of chlorine was measured as a toxic chemical. We have used the Microtox method to measure for toxic chemicals added to drinking water samples on a yearly basis in my CE 636/PH 690 class at the University of Hawaii. In those experiments, potable water samples without the addition of the toxic chemical were always used as the negative control. In the use of Microtox for toxicity, loss of light greater than 15–20% must be achieved before reliable results can be obtained. In this regard, groundwater samples from Hawaii have sometimes resulted in increasing the light production of the vibrio bacterial population provided by Microtox. This phenomenon has been observed by users of Microtox method. As a result, toxicity response must be carefully measured based on the light output of the bacterial population in the water to be tested. In this regard, reduction of light much greater than 50% are observed when known toxic chemicals are added to potable water. The usefulness of the Microtox method is that it will measure acutely toxic chemicals in water samples within 15 minutes and many samples can be processed easily. As a

result, each water utility should purchase a Microtox unit in the event of a serious toxic chemical contamination event. For smaller water utilities, the cheaper Delta-Tox unit may be suitable. In the event of any possible contamination event, the Microtox method should be used to analyze the water samples. If the water sample is contaminated with acutely toxic chemicals, the Microtox or Delta-Tox method will detect the presence of these toxic chemicals. If the Microtox test is negative, one can conclude that the potential contaminant is not due to acutely toxic chemicals.

C. Analysis Using the InSpectra™Analyzer

Selected water samples (well, tunnel/spring, combination, surface, reservoir tank, distribution system) used by County of Hawaii and private companies were assayed by the Inspectra method for the six water quality parameters (TSS, COD, BOD, TOC, NO_3, Surfactants). The results are summarized in Table 17 and show variable readings. Many of the readings for specific parameters measured such as COD, BOD were unrealistically high for potable water samples. Some water samples with elevated TOC based on Inspectra readings were measured for TOC using standard chemical assays. It was determined that the readings from the Inspectra did not provide accurate measurements for TOC when measured directly as TOC. It was thus concluded that the six water quality parameters measured indirectly by the Inspectra method are not reliable measurements when applied to potable water sources, especially groundwater sources (Fujioka et al., 2004). It should be noted that the Inspectra uses absorption at selected UV wavelengths to provide an indirect measurements for the five water quality parameters. To determine if this method was measuring for some specific peak at a designated UV wavelength, up to 20 samples were scanned throughout all of the UV wavelengths. No specific UV peaks could be correlated with the same water samples providing elevated levels of some parameters such as BOD, COD or TOC. As a result, it was not possible to interpret the data (Table 17) provided by the Inspectra method.

Since the Inspectra method detect differences in different water samples, the data produced maybe useful data to detect some changes in the ambient physical and chemical composition of that water samples. However, the data base to measure the six water quality parameters were based primarily on sewage effluents and surface waters polluted primarily by sewage. To be useful for potable water sources, this method must be specifically applied to potable water sources and the data-base used to determine the various measured parameters must be obtained only from potable water sources and must include groundwater sources. The advantage of this method is that it will measure some UV absorption response within one minute. However, until this method is specifically adapted to potable water and information is obtained as to what water quality parameter is being measured, this method is not recommended for routine monitoring.

D. Analysis Using the Lasentec Method

The Lasentec Method uses laser light to detect and measure particles in water based on backscattering of the laser light. This method has been used to fingerprint the particles in some manufactured products as a means of quality control. It has also been used to measure the distribution of particles in some kinds of water samples such as sewage effluent to determine the suitability of that water to be disinfected by UV techniques. This method was applied to analyze 7 potable groundwater samples from private wells and 5 potable groundwater samples from County of Hawaii wells. The results of these assays are summarized in Table 18 and show that

this method measures and divides the sizes of particles into fine size (0–16 μm), fine to medium size (16–90 μm), medium to coarse size (90–200 μm) and coarse size (210–1,000 μm). The results in Table 18 show that for most of these well water samples, the majority of the particles are in the fine size range, a minority of the particles are in the fine to medium size range and only a very small percentage of particles are in the medium to coarse and coarse size ranges. Since the sizes of particles in the fine size category ranges from 0–16 μm, the results are not very discriminating. Moreover, when various concentrations of *Escherichia coli* were added to water samples, no detectable difference was observed until 10,000 CFU of *E. coli* was added. Thus, this method cannot be reliably used to detect contamination of potable water by microbial pathogens. In this regard, further analysis of this method reveals that this method cannot measure particles that do not backscatter laser light. A list of materials that do not backscatter laser light included optical grade glass beads, optically clear polystyrene and pure oils in pure water. To this list, we can add bacteria such as *E. coli*. Thus, this method should not be applied to determine water contamination by microorganisms. However, this method can be used to detect water contamination by particles that will backscatter laser light.

E. Analysis Using the Riboprinter™

The Riboprinter™ was used to analyze atypical bacteria recovered from mEndo plates and from heterotrophic bacteria recovered from potable water samples. The results are summarized in Tables 19 and 20. A total of 17 atypical bacteria from mEndo plates were analyzed and determined to contain 16 distinct ribogroups. Two bacteria which could not be identified by the Dupont data base were placed in the same ribogroup (Sample: PW-12) and probably represented the same bacteria. A total of 5/17 or 29% of the bacteria were identified by the Dupont data base. The five identified bacteria were: 1) *Pseudomonas aeruginosa*, 2) *E. coli*, 3) *Citrobacter freundii*, 4) *Serratia marcescens*, 5) *S. marcescens.* One of the atypical bacteria was identified as a true coliform (*E. coli*). The rest of the identified isolates are commonly found in environmental waters. *S. marcescens* was recovered twice from two different sites.

A total of 38 heterotrophic bacteria recovered from several sources of potable water from the island of Hawaii was analyzed by the Riboprinter™. A total of 7/38 (18%) of the samples were identified by the Dupont data base. The seven different identified bacteria were: 1) *Stenotrophomonas maltophilia*, 2) *Terracoccus luteus*, 3) *Staphylococcus xylosus*, 4) *S. marcescens*, 5) *Bacillus megaterium*, 6) *Vibrio cholerae,* and 7) *S. saprophyticus*. One of the identified bacteria with a low similarity index (0.85) was identified as *V. cholerae*. It is unlikely that the isolate identified as *V. cholerae* is actually *V. cholerae* because the habitat of this pathogen is estuarine/marine water rather than fresh water from a well. In this regard, the bacterial population in groundwater has not been identified. It is not surprising that an unknown bacterium in groundwater has ribosomal sequences similar to that of *V. cholerae*.

In summary, 29% of atypical bacteria recovered on mEndo medium could be identified, In contrast only 18% of heterotrophic bacteria recovered on mHPC agar were identified using the Riboprinter™ method. To be useful for potable water samples, many more isolates from all water sites will need to be identified. In assessing the usefulness of the Riboprinter™, the company (Dupont) had indicated that it would include more environmental bacteria in its data base at the time we started this project. However, financial support by Dupont for the Riboprinter™ has been reduced within the past year. Thus, there has been less support for this system and the quality

control of the reagents prepared has suffered. Moreover, the cost of the reagents has increased dramatically. Finally, the software used for the Riboprinter™ is not flexible for use in systems with so many unknown ribogroups as we have detected in drinking water samples. Based on the feasibility of interpreting the data collected, diminishing support from the parent company (Dupont) and the high cost for this method, we do not recommend that water utilities adopt the use of the Riboprinter™ until improvements are made to better analyze unknown bacteria and the cost of operation is significantly reduced.

V. Conclusions

As stated earlier, EPA has not approved a monitoring plan to address bioterroristic contamination of water. States et al. (2003, 2004) were the first to publish their evaluation of some rapid methods such as pH, conductivity, chlorine level, UV absorption, antigen-antibody reactions, enzymatic activity for biological agents or toxicity assays to monitor potable water as a response to bioterrorism. These reports show that selection of appropriate monitoring methods for potable water samples are still in the formative stages. More recently, EPA has finally published a protocol or plans called Toolbox approach (www.epa.gov/safewate/security) and discusses approaches and plans to use before a terroristic event has occurred. Another EPA program called Environmental Testing and Verification or ETV program (www.epa.gov/etv/homeland.index.html) comments on the use of rapid monitoring methods. However, the use of these methods represents on-going research efforts and approved monitoring plans and conclusions on how to interpret the monitoring data are not yet available.

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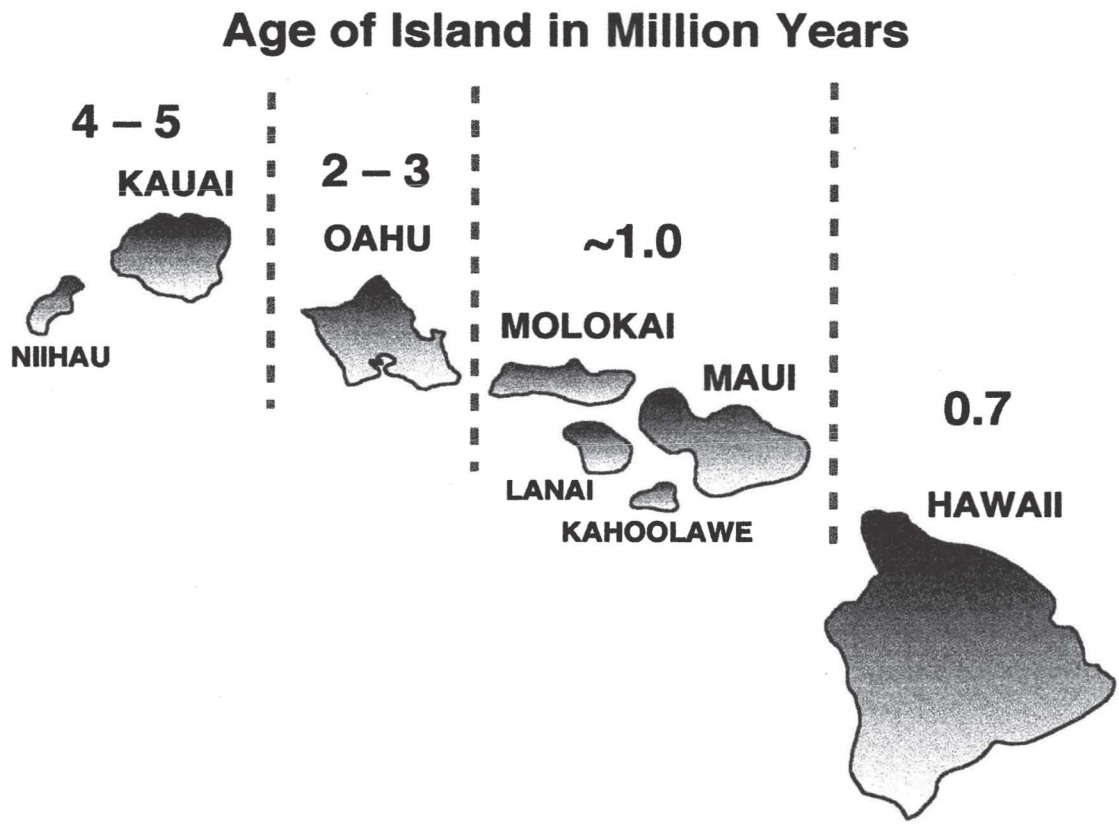
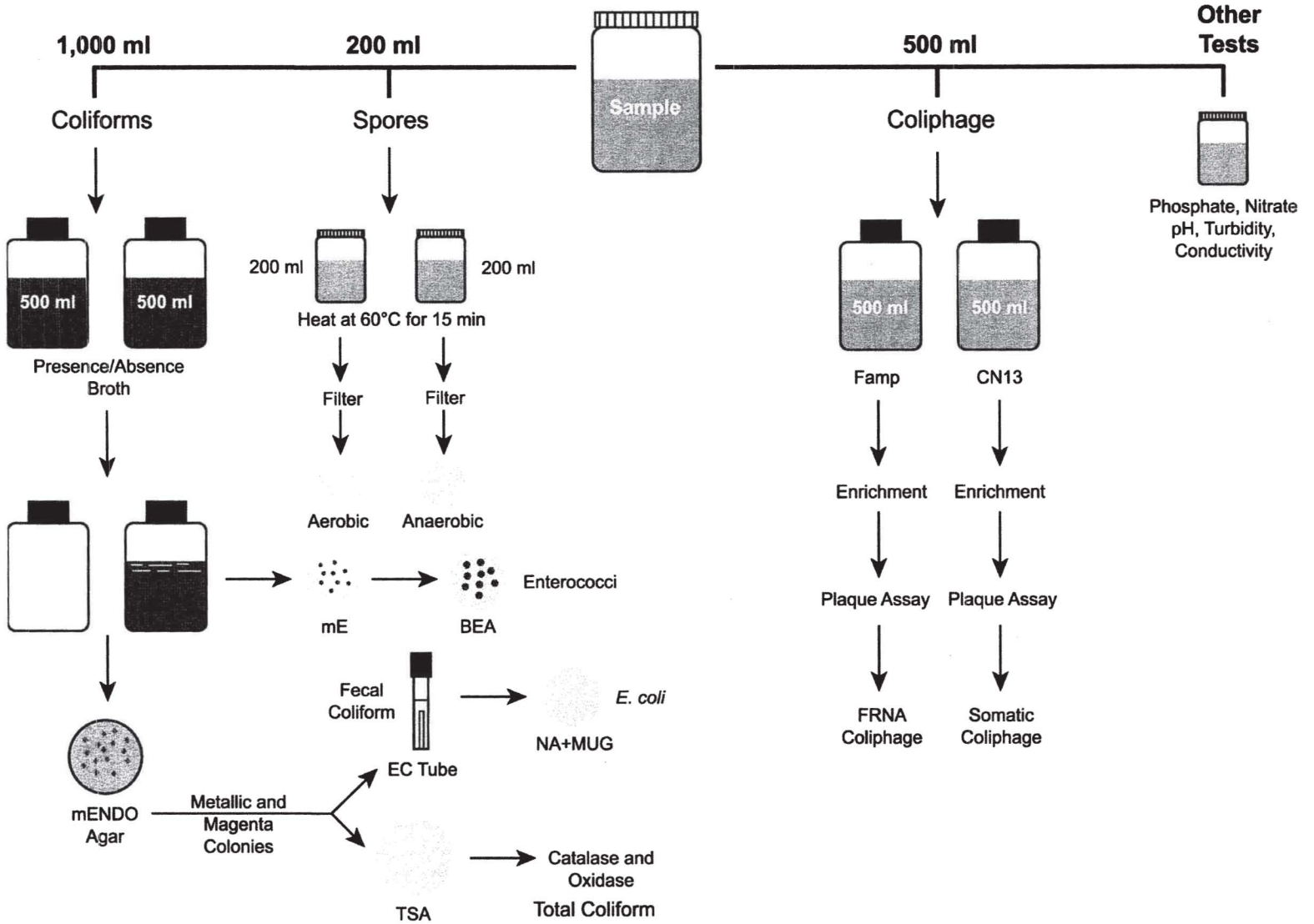
FIGURES



SOURCE: Fujioka et al. (2004).

Figure 1. The estimated ages for each of the islands of Hawaii



SOURCE: Fujioka et al. (2004).

Figure 2. Diagram of procedure to analyze large volumes of water samples for six fecal microorganisms

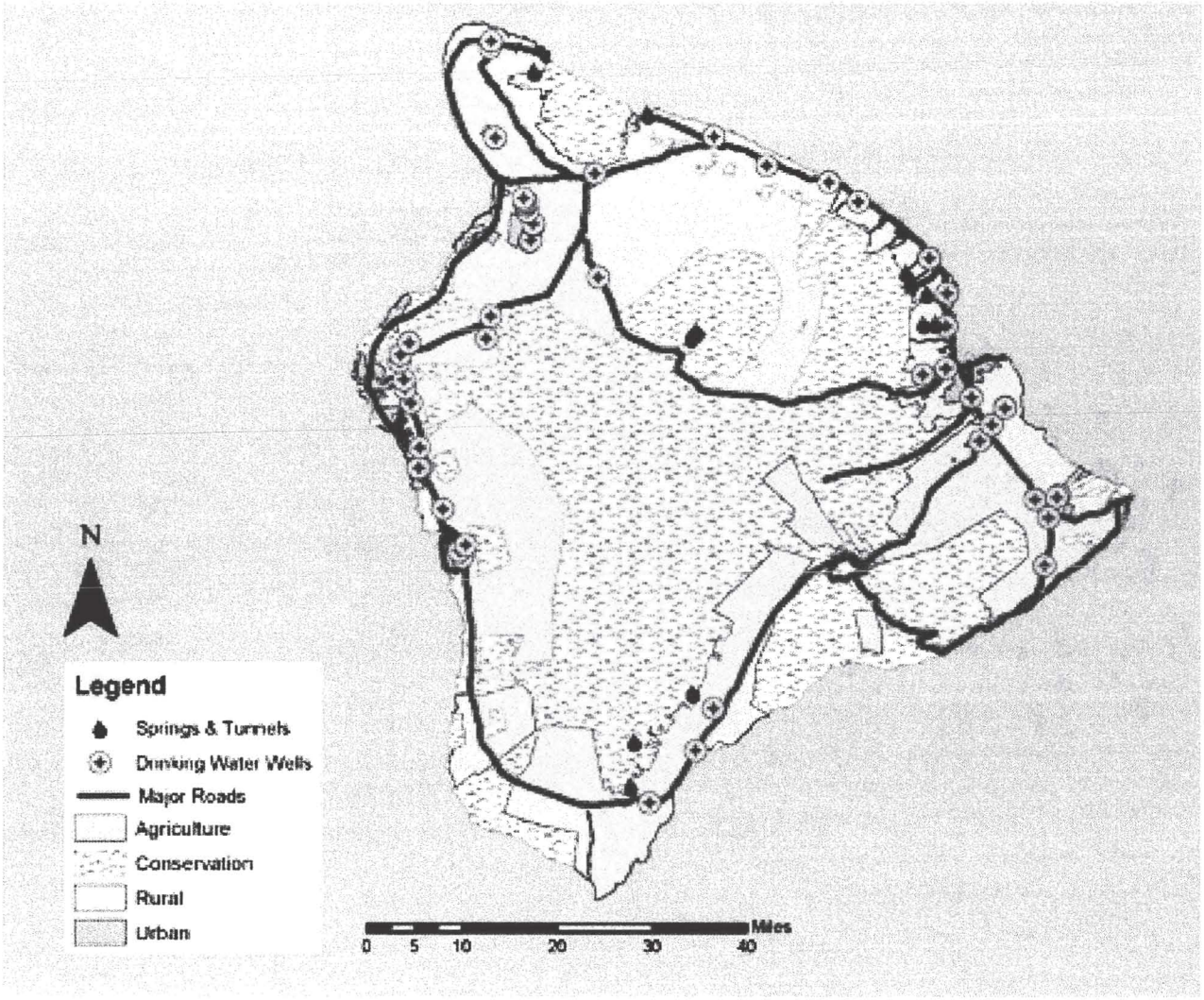


Figure 3. Locations of potable wells and tunnels on island of Hawaii
(map courtesy of R. Whittier)

TABLES

Table 1. List and Identification Number of all Water Sampling Sites Used by County of Hawaii and Private Companies

ID Number	County of Kauai Well Sampling Sites	Hawaii ID
CW-1	Haina Well	161-003
CW-2	Hakalau Well	154-004
CW-3	Halekii Well	131-013
CW-4	Hawi Well 1	129-008
CW-5	Hawi Well 2	129-006
CW-6	Holualoa Well	131-019
CW-7	Honokohau Well	131-010
CW-8	Hualalai Well	131-016
CW-9	Kahaluu A	131-002
CW-10	Kahaluu B	131-003
CW-11	Kahaluu C	131-004
CW-12	Kahaluu D	131-005
CW-13	Kahaluu Shaft	131-006
CW-14	Kalapana Well 1	110-001
CW-15	Kalapana Well 2	110-002
CW-16	Keaau Well #1	112-001
CW-17	Keaau Well #2	112-002
CW-18	Keahuolu Well 1	131-011
CW-19	Keei Well A	132-001
CW-20	Keei Well C	132-006
CW-21	Keei Well D	132-005
CW-22	Keonepokonui Well #1	111-008
CW-23	Keonepokonui Well #2	111-005
CW-24	Kulaimano Deep Well	106-004
CW-25	Lalamilo Well A	160-001
CW-26	Lalamilo Well B	160-002
CW-27	Lalamilo Well C	160-003
CW-28	Laupahoehoe Wells P1	102-002
CW-29	Laupahoehoe Wells P2	102-003
CW-30	Naalehu Well	108-002
CW-31	Olaa Station #3 Well	112-006
CW-32	Ookala Well	104-002
CW-33	Paauilo Well	134-003
CW-34	Pahala Well	109-002
CW-35	Pahoa Well #1	111-002
CW-36	Pahoa Well #2	111-003
CW-37	Panaewa Well 1	101-006
CW-38	Panaewa Well 2	101-007
CW-39	Panaewa Well 3	101-008
CW-40	Papaikou Deep Well	107-004
CW-41	Parker Well #1	160-008
CW-42	Parker Well #2	160-007
CW-43	Parker Ranch Well 1	130-016
CW-44	Piihonua Well A	101-020
CW-45	Piihonua Well B	101-021
CW-46	Piihonua Well C	101-019
CW-47	Saddle Road Well A	101-025

Table 1—*Continued*

ID Number	County of Hawaii Non-Disinfected Spring and Tunnel Sampling Sites	Hawaii ID
CST-1	Akaka Falls Spring	105
CST-2	Alili Tunnel	109-004
CST-3	Chaves Spring	103
CST-4	Haao Spring	108
CST-5	Hakalau Iki Spring	154
CST-6	Kaieie Spring	107
CST-7	Maukaloa Spring	106
CST-8	Mountain House Spring	108
CST-9	Murphy Tunnel	139-002
CST-10	Papaikou Spring	107
CST-11	Waiuliuli Spring	133

ID Number	County of Hawaii Disinfected Spring and Tunnel Sampling Sites	Hawaii ID
CST_D-1	Jan's Store	105-002
CST_D-2	Kaieie Booster Inlet	107-009
CST_D-3	Matsumura Residence	133-012
CST_D-4	Papaikou Hongwanji	107
CST_D-5	Raymond Glory Residence	139-003
CST_D-6	South Point Tank	108-008
CST_D-7	Sueda Residence	103-006

ID Number	County of Hawaii Non-Disinfected Surface Water Sampling Sites	Hawaii ID
CS-1	Waimea Treatment Plant	130

ID Number	County of Hawaii Disinfected Reservoir Tank Sampling Sites	Hawaii ID
CR_D-1	Kalapana 0.5 Mg Tank	110-004
CR_D-2	Kaumana Tank 2	101-062
CR_D-3	Olaa Station 3 Well/Tank #4 Booster C	112-022

ID Number	County of Hawaii Disinfected Combination of Ground, Surface, Spring, Tunnel Sampling Sites	Hawaii ID
CC_D-1	Hakalau Gym	154-003
CC_D-2	Hamakua Federal Credit Union	106-014
CC_D-3	Kau Fire Station	109-005
CC_D-4	Waimea Baseyard	130-014

Table 1—*Continued*

ID Number	County of Hawaii Disinfected Distribution Sampling Sites	Hawaii ID
CD_D-1	Akolea Road	101-068
CD_D-2	Aoki Residence	107
CD_D-3	Dr. Cheng's	131-015
CD_D-4	Hapuna Beach Park	160-018
CD_D-5	Hilo Airport	101-045
CD_D-6	Holualoa School	131-035
CD_D-7	Honaunau School Tap #1	132-034
CD_D-8	Honokaa Public Library	161-010
CD_D-9	Joseph Ah Choy Residence	104-004
CD_D-10	Kau Baseyard	108-004
CD_D-11	Keaau Wells 1&2/Station #2	112-004
CD_D-12	Kealakehe Elementary School	131-076
CD_D-13	King Kamehameha Hotel	131-068
CD_D-14	Kohala Civic Center	129-015
CD_D-15	Kona Acres	131-043
CD_D-16	Kona Health Center	131-082
CD_D-17	Kuwahara Warehouse	111-008
CD_D-18	Laupahoehoe Swimming Pool	102-008
CD_D-19	Lincoln Park	101-080
CD_D-20	Paauilo Ballpark	134-011
CD_D-21	Pahoa School Cafeteria	111-011
CD_D-22	Tsuneo Adachi Residence	107-015

ID Number	Private Well Sampling Sites	Hawaii ID
PW-1	Hawaiian Beaches Well	
PW-2	Hawaiian Natural Water Co. Well	
PW-3	Hawaiian Shores Well	
PW-4	Kaupulehu Well 1	
PW-5	Kaupulehu Well 2	
PW-6	Kaupulehu Well 3	
PW-7	Kaupulehu Well 4	
PW-8	Kohala Joint Venture Well 1	
PW-9	Kohala Joint Venture Well 2	
PW-10	Kohala Ranch Well 1	
PW-11	Kohala Ranch Well 2	
PW-12	Kukio Utility Co. HR Well 1	
PW-13	Kukio Utility Co. HR Well 2	
PW-14	Kukio Utility Co. HR Well 3	
PW-15	Kukio Utility Co. HR Well 4	
PW-16	Kukio Utility Co. HR Well 5	
PW-17	Mauna Loa Macadamia Nut Well 1	
PW-18	Mauna Loa Macadamia Nut Well 2	
PW-19	Ninole Well A	
PW-20	Pahoa Well #1	
PW-21	Pahoa Well #2	

Table 1—*Continued*

ID Number	Private Well Sampling Sites	Hawaii ID
PW-22	Parker Well 4	
PW-23	Parker Well 5	
PW-24	Punaluu Well 1	
PW-25	Punaluu Well 2	
PW-26	Puu Anahulu Well	
PW-27	Puuwaawaa Well	
PW-28	Waiakea Villas Well	
PW-29	Waikii Ranch Well 1	
PW-30	Waikii Ranch Well 2	
PW-31	Waikoloa Well 1	
PW-32	Waikoloa Well 2	
PW-33	Waikoloa Well 3	
PW-34	Wood Valley Well	

ID Number	Private Non-Disinfected Surface Water Sampling Sites	Hawaii ID
PS-1	Mauna Kea State Park (after filter)	
PS-2	Mauna Kea State Park (before filter)	

ID Number	Private Disinfected Combination of Ground, Surface, Spring, Tunnel Sampling Sites	Hawaii ID
PC_D-1	Hawaii Volcanos National Park Distribution	
PC_D-2	Kilauea Military Camp Distribution	

ID Number	Private Non-Disinfected Catchment Sampling Sites	Hawaii ID
PCM-1	Hawaii Volcanos National Park Source	
PCM-2	Kilauea Military Camp Source	
PCM-3	Kulani Correctional Facility Source	

ID Number	Private Disinfected Reservoir Tanks	Hawaii ID
PR_D-1	Olaa Distribution Tank 2	
PR_D-2	Waikii Ranch Distribution	

Table 1—*Continued*

ID Number	Private Disinfected Distribution Water	Hawaii ID
PD_D-1	Hawaiian Beaches Distribution	
PD_D-2	Hawaiian Natural Water Co. Distribution	
PD_D-3	Hawaiian Shores Distribution	
PD_D-4	Kaupulehu Distribution	
PD_D-5	Kohala Joint Venture Distribution	
PD_D-6	Kohala Ranch Distribution	
PD_D-7	Kukio Utility Co Distribution 1	
PD_D-8	Kukio Utility Co Distribution 2	
PD_D-9	Mauna Loa Macadamia Nut Distribution	
PD_D-10	Pahoa Distribution	
PD_D-11	Punaluu Distribution	
PD_D-12	Puuwaawaa Distribution	
PD_D-13	Waikoloa Distribution	
PD_D-14	Wood Valley Distribution	

Table 2. Percent Positive for Various Fecal Indicators From Well Water Samples Used by County of Hawaii and by Private Companies

Fecal Indicators	Non-Disinfected			
	County of Hawaii		Private Companies	
	No. Positive/ No. Tested	% Positive	No. Positive/ No. Tested	% Positive
Total Coliform	15/116	13%	12/89	14%
E. coli	0/116	0%	3/89	3%
Enterococci	2/116	2%	2/89	2%
FRNA Coliphages	0/116	0%	0/89	0%
Somatic Coliphages	1/116	1%	0/89	0%
Anaerobic Spores (*C. perfringens*)	0/116	0%	0/89	0%

NOTE: No. Positive/No. Tested = % Positive.

Table 3. Percent Positive for Fecal Indicators From Springs and Tunnels Used by County of Hawaii

Fecal Indicators	County of Hawaii			
	Disinfected		Non-Disinfected	
	No. Positive/ No. Tested	% Positive	No. Positive/ No. Tested	% Positive
Total Coliform	0/19	0%	23/32	72%
E. coli	0/19	0%	12/32	38%
Enterococci	0/19	0%	5/32	16%
FRNA Coliphages	0/19	0%	0/32	0%
Somatic Coliphages	0/19	0%	4/32	13%
Anaerobic Spores (*C. perfringens*)	0/19	0%	0/32	0%

NOTE: No. Positive/No. Tested = % Positive.

Table 4. Percent Positive for Various Fecal Indicators From Combination Ground, Surface, Spring, Tunnel Water Samples Used by County of Hawaii and by Private Companies

Fecal Indicators	Disinfected			
	County of Hawaii		Private Companies	
	No. Positive/ No. Tested	% Positive	No. Positive/ No. Tested	% Positive
Total Coliform	1/12	8%	0/9	10%
E. coli	0/12	0%	0/9	0%
Enterococci	0/12	0%	0/9	0%
FRNA Coliphages	0/12	0%	0/9	0%
Somatic Coliphages	0/12	0%	0/9	0%
Anaerobic Spores (*C. perfringens*)	0/12	0%	0/9	0%

NOTE: No. Positive/No. Tested = % Positive.

Table 5. Percent Positive for Fecal Indicators From Surface Water Samples Used by County of Hawaii and Private Companies

Fecal Indicators	Non-Disinfected			
	County of Hawaii		Private Companies	
	No. Positive/ No. Tested	% Positive	No. Positive/ No. Tested	% Positive
Total Coliform	3/3	100%	2/5	40%
E. coli	1/3	33%	0/5	0%
Enterococci	1/3	33%	0/5	0%
FRNA Coliphages	0/3	0%	0/5	0%
Somatic Coliphages	0/3	0%	0/5	0%
Anaerobic Spores (*C. perfringens*)	0/3	0%	0/5	0%

NOTE: No. Positive/No. Tested = % Positive.

Table 6. Percent Positive for Fecal Indicators From Catchments Used by Private Companies

Fecal Indicators	Non-Disinfected Private Companies	
	No. Positive/ No. Tested	% Positive
Total Coliform	8/11	73%
E. coli	2/11	18%
Enterococci	0/11	0%
FRNA Coliphages	0/11	0%
Somatic Coliphages	0/11	0%
Anaerobic Spores (*C. perfringens*)	0/11	0%

NOTE: No. Positive/No. Tested = % Positive.

Table 7. Percent Positive for Fecal Indicators From Reservoir Tank Water Samples Used by County of Hawaii and Private Companies

Fecal Indicators	Disinfected			
	County of Hawaii		Private Companies	
	No. Positive/ No. Tested	% Positive	No. Positive/ No. Tested	% Positive
Total Coliform	0/8	0%	1/4	25%
E. coli	0/8	0%	0/4	0%
Enterococci	0/8	0%	0/4	0%
FRNA Coliphages	0/8	0%	0/4	0%
Somatic Coliphages	0/8	0%	0/4	0%
Anaerobic Spores (*C. perfringens*)	0/8	0%	0/4	0%

NOTE: No. Positive/No. Tested = % Positive.

Table 8. Percent Positive for Various Fecal Indicators From Distribution Pipe Water Samples Used by County of Hawaii and by Private Companies

Fecal Indicators	Non-Disinfected			
	County of Hawaii		Private Companies	
	No. Positive/ No. Tested	% Positive	No. Positive/ No. Tested	% Positive
Total Coliform	1/59	2%	1/47	2%
E. coli	0/59	0%	0/47	0%
Enterococci	0/59	0%	0/47	0%
FRNA Coliphages	0/59	0%	0/47	0%
Somatic Coliphages	0/59	0%	0/47	0%
Anaerobic Spores (*C. perfringens*)	0/59	0%	0/47	0%

NOTE: No. Positive/No. Tested = % Positive.

Table 9. Chemical Data for Well Water Samples Used by County of Hawaii and by Private Companies

Selected Chemicals (Unit of Measurement)	Non-Disinfected			
	County of Hawaii		Private Companies	
	Average Concentrations	Range of Concentrations (No. Samples Tested)	Average Concentrations	Range of Concentrations (No. Samples Tested)
pH (pH Units)	7.30	5.59-7.90 (116)	7.25	6.58-7.99 (89)
Turbidity (NTU)	1.5	0-7.6 (116)	1.5	0.2-6.5 (89)
Conductivity (μS/cm)	279	10-1260 (116)	528	25-2570 (89)
Total Nitrogen (mg/L N)	1.6	0-6.8 (116)	1.7	0-5.7 (89)
Total Phosphorous (mg/L P)	0.6	0.2-4.0 (116)	0.7	0.1-4 (89)

Table 10. Chemical Data for Springs and Tunnels Used by County of Hawaii

Selected Chemicals (Unit of Measurement)	County of Hawaii			
	Disinfected		Non-Disinfected	
	Average Concentrations	Range of Concentrations (No. Samples Tested)	Average Concentrations	Range of Concentrations (No. Samples Tested)
pH (pH Units)	7.02	5.70-7.98 (19)	6.62	5.40-9.62 (32)
Turbidity (NTU)	1.6	0.1-7.4 (19)	1.3	0-5.5 (32)
Conductivity (μS/cm)	222	74-360 (19)	167	67-1220 (32)
Total Nitrogen (mg/L N)	0.9	0-5.4 (19)	1.1	0-8.8 (32)
Total Phosphorous (mg/L P)	0.5	0.1-1.5 (19)	0.3	0.1-0.7 (32)

Table 11. Chemical Data for Combination Ground, Surface, Spring, Tunnel Water Samples Used by County of Hawaii and by Private Companies

Selected Chemicals (Unit of Measurement)	Disinfected			
	County of Hawaii		Private Companies	
	Average Concentrations	Range of Concentrations (No. Samples Tested)	Average Concentrations	Range of Concentrations (No. Samples Tested)
pH (pH Units)	6.83	5.90-7.59 (12)	5.87	5.22-6.79 (9)
Turbidity (NTU)	1.3	0.3-5.7 (12)	2.5	0.5-5.5 (9)
Conductivity (μS/cm)	114	55-199 (12)	23	21-25 (9)
Total Nitrogen (mg/L N)	1.0	0-4.1 (12)	0.9	0-3.5 (9)
Total Phosphorous (mg/L P)	0.7	0.1-1.6 (12)	0.4	0.2-1.6 (9)

Table 12. Chemical Data for Surface Water Samples Used by County of Hawaii and Private Companies

Selected Chemicals (Unit of Measurement)	Non-Disinfected			
	County of Hawaii		Private Companies	
	Average Concentrations	Range of Concentrations (No. Samples Tested)	Average Concentrations	Range of Concentrations (No. Samples Tested)
pH (pH Units)	6.33	6.08-6.66 (3)	6.87	6.45-7.10 (5)
Turbidity (NTU)	3.1	0.9-6.0 (3)	2.0	0.5-5.5 (5)
Conductivity (μS/cm)	37	34-40 (3)	48	44-51 (5)
Total Nitrogen (mg/L N)	0.5	0-1.4 (3)	1.3	0-4.8 (5)
Total Phosphorous (mg/L P)	0.2	0.2-0.2 (3)	0.5	0.1-0.7 (5)

Table 13. Percent Positive for Fecal Indicators From Catchments Used by Private Companies

Selected Chemicals (Unit of Measurement)	Non-Disinfected Private Companies	
	Average Concentrations	Range of Concentrations (No. Samples Tested)
pH (pH Units)	5.48	4.30-6.95 (11)
Turbidity (NTU)	2.8	0.7-6.5 (11)
Conductivity (μS/cm)	17	7-50 (11)
Total Nitrogen (mg/L N)	0.5	0-1.6 (11)
Total Phosphorous (mg/L P)	0.4	0.1-1.7 (11)

Table 14. Chemical Data for Reservoir Tank Water Samples Used by County of Hawaii and Private Companies

Selected Chemicals (Unit of Measurement)	Disinfected			
	County of Hawaii		Private Companies	
	Average Concentrations	Range of Concentrations (No. Samples Tested)	Average Concentrations	Range of Concentrations (No. Samples Tested)
pH (pH Units)	7.29	6.90-7.78 (8)	7.71	7.42-7.90 (4)
Turbidity (NTU)	1.5	0.2-5.6 (8)	1.5	0.5-3.7 (4)
Conductivity (μS/cm)	140	76-498 (8)	351	83-467 (4)
Total Nitrogen (mg/L N)	2.1	0-6.1 (8)	1.3	0-2.9 (4)
Total Phosphorous (mg/L P)	0.6	0.2-1.2 (8)	0.5	0.2-0.7 (4)

Table 15. Chemical Data for Distribution Pipe Water Samples Used by County of Hawaii and by Private Companies

Selected Chemicals (Unit of Measurement)	Disinfected			
	County of Hawaii		Private Companies	
	Average Concentrations	Range of Concentrations (No. Samples Tested)	Average Concentrations	Range of Concentrations (No. Samples Tested)
pH (pH Units)	7.30	6.37-7.89 (59)	7.22	6.56-8.20 (47)
Turbidity (NTU)	1.5	0.1-7.6 (59)	1.3	0.2-4.6 (47)
Conductivity (μS/cm)	244	64-892 (59)	286	82-1393 (47)
Total Nitrogen (mg/L N)	1.0	0-4.4 (59)	1.6	0-6.6 (47)
Total Phosphorous (mg/L P)	0.6	0.1-2.0 (59)	0.9	0-4 (47)

Table 16. ATP Data of Potable Water for County of Hawaii and Private Companies with Chemical Hood and Aseptic Technique

	RLU/100 ml		CFU/100 ml	
	Geometric Mean	Range	Geometric Mean	Range
Wells (No. Tested)				
County of Hawaii (62)	1977	32-5490240	388	24-6720
Private (28)	2715	28-91596	548	68-17024
Tunnels and Springs (No. Tested)				
County of Hawaii Disinfected (9)	203	0-3348	90	8-1980
County of Hawaii Non-Disinfected (15)	3106	56-1392552	640	32-1904
Reservoirs (No. Tested)				
County of Hawaii (5)	124	84-160	46	8-264
Private (1)	1504*		52*	
Distribution (No. Tested)				
County of Hawaii (29)	363	0-3372592	110	4-2416
Private (16)	268	0-10640	50	4-2848
Surface Water (No. Tested)				
County of Hawaii (2)	625546	252588-1100532	1251	1008-1552
Private (2)	6726	4750-9184	3279	800-13440
Combination Water (No. Tested)				
County of Hawaii (5)	841	52-653512	54	0-720
Private (2)	336	90-1472	12	0-12
Catchments (No. Tested)				
Private (2)	92031	79145-120850	2142	1280-3584

*Actual measured value.

Table 17. Use of Inspectra Method to Indirectly Determine Average Concentratrions of Selected Chemicals in Water Samples From Wells, Tunnels/Shafts, Reservoirs and Distribution Lines Used by County of Hawaii and Private Companies

Source of Water Sample	TSS	COD	BOD	TOC	NO_3	SUR
	Average Concentrations in mg/L (Range of Concentrations in mg/L)					
Wells (No. Samples Tested)						
County (28)	19.6 (1-58.4)	30.6 (1-127)	23.5 (1-93)	21.8 (1-88)	2.7 (1-15.2)	27.8 (1-109)
Private (41)	58.6 (1-932)	33.8 (1.5-136)	23.4 (1-96)	22 (1-91)	44.7 (1-1602)	26.1 (1-108)
Distributions (No. Samples Tested)						
County (17)	27.7 (1-166)	77.5 (1.7-136)	57.8 (1-100)	55.1 (1-91)	6.7 (1-16.4)	68.9 (1-115)
Private (19)	92 (1-790)	75.2 (1.7-288)	51.1 (1-202)	80.2 (1-665)	5.1 (1-16)	56.8 (1-236)
Reservoirs (No. Samples Tested)						
County (1)	7.3	37	24.8	24.8	1	29.4
Private (3)	9.2 (1-19.2)	132 (4.6-360)	46 (2.7-122)	62.9 (2.3-170)	21.6 (6.3-47.6)	50.3 (2.2-134)
Combination Ground, Surface, Spring, Tunnel Water (No. Samples Tested)						
County (2)	1 (1)	85.7 (29.4-142)	60.1 (24.2-96)	59.2 (22.4-96)	2.6 (1-4.1)	72.3 (29.6-115)
Private (4)	64.7 (1-121)	108.1 (54.5-132)	80 (41-98)	72.3 (32-92)	1 (1)	85.5 (33-112)
County Springs/Tunnels (No. Samples Tested)						
Disinfected (1)	1	860	630	610	21.6	770
Non-disinfected (3)	257.3 (1-770)	81.2 (27.8-122)	51.1 (19.2-99)	46.3 (19-93)	3.1 (1-7.2)	48.3 (1-121)
Private Surface Water (4)	35.5 (12.1-53.5)	21 (12.2-29.8)	17.3 (9.8-25)	14 (8.4-19.6)	1 (1)	16.6 (10.3-22.8)

Table 18. Percentage of Particles in Well Water; Measured by Lasentec and Distributed into Four Sizes

Sample No.	ID #	Sample Date	Fine (0-16 μm)	Fine to Med (16-90 μm)	Med-Coarse (90-200 μm)	Coarse (210-1000 μm)
1	CW-16	3/10/05	1.2	97.9	0.8	0.1
2	CW-23	3/10/05	25.8	34.8	28.7	10.7
3	CW-17	3/10/05	32.7	67.1	0.1	0.01
4	CW-31	3/10/05	43.5	55.9	0.6	0.02
5	CW-38	5/25/04	61.4	38.6	0.04	0.0
6	PW-13	6/15/04	68.4	30.5	0.7	0.3
7	PW-30	6/16/04	72.2	27.8	0.01	0.0
8	PW-29	6/16/04	69.2	30.8	0.02	0.0
9	PW-26	6/16/04	74.7	25.3	0.0	0.0
10	PW-4	6/16/04	67.9	32.1	0.02	0.0
11	PW-7	6/15/04	66.3	33.7	0.01	0.0
12	PW-32	6/16/04	53.9	46.0	0.08	0.0

Table 19. Riboprinted Analysis for Selected Isolates from MENDO Plates

Sample No.	ID No.	Sample Date	Ribogroup	DuPont ID	DuPont ID Label	DID Sim
1	PW-29	6/16/04	277-108-S-1	None	None	None
2	PW-30	6/16/04	277-108-S-2	None	None	None
3	PW-12	6/15/04	277-108-S-3	None	None	None
4	PW-12	6/15/04	277-108-S-3	None	None	None
5	PW-6	6/16/04	277-108-S-6	DUP-16223	Pseudomonas aeruginosa	0.92
6	PW-6	6/16/04	277-108-S-7	None	None	None
7	PW-29	6/16/04	277-108-S-8	None	None	None
8	CW-47	6/29/04	277-116-S-7	None	None	None
9	CW-47	6/29/04	277-116-S-8	None	None	None
10	CNST-6	6/29/04	277-117-S-1	None	None	None
11	CD_D-1	6/29/04	277-117-S-3	DUP-14194	Escherichia coli	0.93
12	CNST-5	6/29/04	277-117-S-4	DUP-15283	Citrobacter freundii	0.89
13	CNST-5	6/29/04	277-117-S-5	DUP-16200	Serratia marcescens	0.89
14	CNST-3	6/29/04	277-117-S-6	None	None	None
15	CNST-7	6/29/04	277-117-S-7	None	None	None
16	CW-24	6/29/04	277-117-S-8	None	None	None
17	PD_D-10	8/3/04	277-152-S-1	DUP-15290	Serratia marcescens	0.89

Table 20. Riboprinted Analysis for Selected Isolates from Heterotrophic Plate Count Plates

Sample No.	ID No.	Sample Date	Ribogroup	DuPont ID	DuPont ID Label	DID Sim
1	PC-1	8/4/04	277-138-S-5	None	None	None
2	PDC-1	8/4/04	277-138-S-4	None	None	None
3	PD_D-1	8/3/04	277-126-S-3	None	None	None
4	PD_D-9	9/7/04	277-153-S-2	None	None	None
5	PD_D-9	9/7/04	277-153-S-3	None	None	None
6	PD_D-10	8/3/04	277-126-S-1	None	None	None
7	PW-18	9/7/04	277-153-S-1	None	None	None
8	CD-39	9/8/04	277-152-S-6	None	None	None
9	CD-39	9/8/04	277-152-S-7	DUP-18547	Stenotrophomonas maltophilia	0.93
10	CD-39	9/8/04	277-153-S-5	None	None	None
11	CD_D-5	9/8/04	277-152-S-4	None	None	None
12	CD_D-10	9/8/04	277-152-S-3	None	None	None
13	CD_D-17	9/7/04	277-152-S-2	None	None	None
14	CD_D-17	9/7/04	277-153-S-4	None	None	None
15	CDR-2	9/8/04	277-152-S-8	None	None	None
16	CDR-2	9/8/04	277-46-S-7	DUP-18429	Terracoccus luteus	0.99
17	CNST-1	8/4/04	277-126-S-5	None	None	None
18	CNST-1	8/4/04	277-126-S-6	DUP-4239	Staphylococcus xylosus	0.87
19	CNST-5	8/3/04	277-126-S-2	None	None	None
20	CNST-8	9/8/04	277-153-S-8	None	None	None
21	CNST-10	8/4/04	277-126-S-7	DUP-15429	Serratia marcescens	0.90
22	CNST-10	8/4/04	277-126-S-8	None	None	None
23	CW-38	9/8/04	277-152-S-5	DUP-4192	Staphylococcus saprophyticus	0.93
24	CW-47	9/8/04	277-153-S-7	None	None	None
25	67ST	8/31/04	277-134-S-5	None	None	None
26	78ST	8/31/04	277-134-S-1	DUP-6054	Bacillus megaterium	0.85
27	78ST	8/31/04	277-134-S-2	None	None	None
28	78ST	8/31/04	277-65-S-4	DUP-6607	Vibrio cholerae	0.85
29	78ST	8/31/04	277-65-S-4	None	None	None
30	78ST	8/31/04	277-138-S-8	None	None	None
31	79ST	8/31/04	277-134-S-8	None	None	None
32	79ST	8/31/04	277-138-S-1	None	None	None
33	81ST	8/31/04	277-138-S-2	None	None	None
34	81ST	8/31/04	277-138-S-6	None	None	None
35	81ST	8/31/04	277-138-S-7	None	None	None
36	81ST	8/31/04	277-65-S-4	None	None	None
37	86ST	8/31/04	277-134-S-3	None	None	None
38	87ST	8/31/04	277-134-S-4	None	None	None

APPENDIX TABLES

Appendix Table 1. Microbial Data for Well Water Samples (County of Hawaii)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	CW-1	7/7/04	-	-	-	-	-	-	1	0
2	CW-1	9/21/04	-	-	-	-	-	-	1	0
3	CW-1	11/9/04	-	-	-	-	-	-	0	0
4	CW-2	8/3/04	+	+	-	-	-	-	7	0
5	CW-2	11/9/04	+/-	-	-	-	-	-	16	0
6	CW-3	8/18/04	-	-	-	-	-	-	0	0
7	CW-3	11/30/04	+/-	-	-	-	-	-	2	0
8	CW-4	9/21/04	+	-	-	+	-	-	1	0
9	CW-4	1/25/05	-	-	-	-	-	-	1	0
10	CW-5	9/21/04	-	-	-	-	-	-	0	0
11	CW-5	1/25/05	-	-	-	-	-	-	0	0
12	CW-6	7/21/04	-	-	-	-	-	-	0	0
13	CW-6	11/30/04	-	-	-	-	-	-	17	0
14	CW-7	7/21/04	-	-	-	-	-	-	0	0
15	CW-7	11/30/04	-	-	-	-	-	-	7	0
16	CW-7	2/9/05	-	-	-	-	-	-	0	0
17	CW-8	7/21/04	-	-	-	-	-	-	0	0
18	CW-8	11/30/04	-	-	-	-	-	-	8	0
19	CW-9	7/21/04	-	-	-	-	-	-	0	0
20	CW-9	11/30/04	-	-	-	-	-	-	58	0
21	CW-10	2/9/05	-	-	-	-	-	-	29	0
22	CW-11	7/21/04	-	-	-	-	-	-	1	0
23	CW-11	11/30/04	+/-	-	-	-	-	-	51	0
24	CW-12	7/21/04	-	-	-	-	-	-	0	0
25	CW-12	11/30/04	-	-	-	-	-	-	3	0
26	CW-13	8/18/04	-	-	-	-	-	-	56	0
27	CW-13	11/30/04	-	-	-	-	-	-	3	0
28	CW-14	10/19/04	+	+	-	-	-	-	1	0
29	CW-15	10/19/04	+	+	-	-	-	-	16	0
30	CW-15	1/11/05	+	+	-	-	-	-	17	0
31	CW-16	3/10/04	-	-	-	-	-	-	1	0
32	CW-16	10/19/04	-	-	-	-	-	-	0	0
33	CW-16	1/11/05	-	-	-	-	-	-	1	0

Appendix Table 1—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
34	CW-17	3/10/04	-	-	-	-	-	-	2	0
35	CW-17	10/19/04	-	-	-	-	-	-	1	0
36	CW-17	1/11/05	-	-	-	-	-	-	2	0
37	CW-18	7/21/04	-	-	-	-	-	-	0	0
38	CW-18	11/30/04	-	-	-	-	-	-	14	0
39	CW-19	8/18/04	-	-	-	-	-	-	0	0
40	CW-20	8/18/04	-	-	-	-	-	-	0	0
41	CW-21	11/30/04	-	-	-	-	-	-	17	0
42	CW-21	2/9/05	+/-	-	-	-	-	-	1	0
43	CW-22	3/10/04	-	-	-	-	-	-	9	0
44	CW-22	10/19/04	+	+	-	+	-	-	0	0
45	CW-23	3/10/04	-	-	-	-	-	-	0	0
46	CW-23	10/19/04	-	-	-	-	-	-	0	0
47	CW-23	1/11/05	-	-	-	-	-	-	3	0
48	CW-24	6/29/04	-	-	-	-	-	-	0	0
49	CW-24	8/4/04	+	-	-	-	-	-	50	0
50	CW-24	10/5/04	-	-	-	-	-	-	0	0
51	CW-25	8/18/04	-	-	-	-	-	-	2	0
52	CW-26	8/18/04	-	-	-	-	-	-	540	0
53	CW-26	1/25/05	+	+	-	-	-	-	2	0
54	CW-27	8/18/04	-	-	-	-	-	-	2	0
55	CW-27	1/25/05	+	+	-	-	-	-	36	0
56	CW-28	7/7/04	+	-	-	-	-	-	12	0
57	CW-28	9/21/04	+	+	-	-	-	+	2	0
58	CW-28	11/9/04	+	+	-	-	-	-	60	0
59	CW-29	7/7/04	+	-	-	-	-	-	16	0
60	CW-30	9/8/04	-	-	-	-	-	-	208	0
61	CW-30	10/19/04	+	-	-	-	-	-	236	0
62	CW-30	1/11/05	+	-	-	-	-	-	184	0
63	CW-31	3/10/04	+	-	-	-	-	-	2	0
64	CW-31	9/7/04	-	-	-	-	-	-	0	0
65	CW-31	10/19/04	-	-	-	-	-	-	0	0
66	CW-31	1/11/05	-	-	-	-	-	-	0	0

Appendix Table 1—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
67	CW-32	7/7/04	+	-	-	-	-	-	0	0
68	CW-32	9/21/04	+	+	-	-	-	-	33	0
69	CW-32	11/9/04	+/-	-	-	-	-	-	2	0
70	CW-33	8/3/04	-	-	-	-	-	-	220	0
71	CW-33	9/21/04	+	-	-	-	-	-	83	0
72	CW-33	11/9/04	-	-	-	-	-	-	76	0
73	CW-34	9/8/04	-	-	-	-	-	-	2	0
74	CW-34	10/19/04	+	-	-	-	-	-	3	0
75	CW-34	1/11/05	-	-	-	-	-	-	0	0
76	CW-35	10/19/04	-	-	-	-	-	-	0	0
77	CW-35	1/11/05	-	-	-	-	-	-	2	0
78	CW-36	10/19/04	+	+	-	-	-	-	40	0
79	CW-36	1/11/05	+	-	-	-	-	-	22	0
80	CW-37	5/25/04	+	-	-	-	-	-	0	0
81	CW-37	7/7/04	-	-	-	-	-	-	0	0
82	CW-37	9/8/04	-	-	-	-	-	-	0	0
83	CW-37	10/5/04	-	-	-	-	-	-	0	0
84	CW-38	5/25/04	+	+	-	-	-	-	3	0
85	CW-38	7/7/04	-	-	-	-	-	-	0	0
86	CW-38	9/8/04	-	-	-	-	-	-	0	0
87	CW-38	10/5/04	-	-	-	-	-	-	3	0
88	CW-39	5/25/04	+	-	-	-	-	-	4	0
89	CW-39	7/7/04	+	-	-	-	-	-	1	0
90	CW-39	9/8/04	-	-	-	-	-	-	0	0
91	CW-39	10/5/04	+	-	-	-	-	-	2	0
92	CW-40	6/29/04	-	-	-	-	-	-	0	0
93	CW-40	8/4/04	+/-	-	-	-	-	-	0	0
94	CW-40	10/5/04	-	-	-	-	-	-	0	0
95	CW-41	8/18/04	-	-	-	-	-	-	4	0
96	CW-41	1/25/05	-	-	-	-	-	-	1	0
97	CW-42	8/18/04	+	-	-	-	-	-	0	0
98	CW-42	1/25/05	-	-	-	-	-	-	0	0
99	CW-43	9/21/04	-	-	-	-	-	-	1	0

Appendix Table 1—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 ml)
100	CW-43	11/6/04	-	-	-	-	-	-	1	0
101	CW-43	1/25/05	-	-	-	-	-	-	0	0
102	CW-44	5/25/04	+	+	-	-	-	-	2	0
103	CW-44	7/7/04	+	-	-	-	-	-	0	0
104	CW-44	9/8/04	+	+	-	-	-	-	1	0
105	CW-44	10/5/04	+	+	-	-	-	-	1	0
106	CW-45	5/25/04	-	-	-	-	-	-	0	0
107	CW-45	7/7/04	-	-	-	-	-	-	0	0
108	CW-45	9/8/04	-	-	-	-	-	-	1	0
109	CW-45	10/5/04	+	-	-	-	-	-	2	0
110	CW-46	6/29/04	-	-	-	-	-	-	1	0
111	CW-46	7/7/04	-	-	-	-	-	-	0	0
112	CW-46	9/8/04	-	-	-	-	-	-	1	0
113	CW-46	10/5/04	-	-	-	-	-	-	0	0
114	CW-47	6/29/04	-	-	-	-	-	-	1	0
115	CW-47	9/8/04	-	-	-	-	-	-	0	0
116	CW-47	10/5/04	-	-	-	-	-	-	2	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 2. Microbial Data for Distribution Water (County of Hawaii)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	CD_D-1	6/29/04	-	-	-	-	-	-	0	0
2	CD_D-1	7/7/04	-	-	-	-	-	-	0	0
3	CD_D-1	9/8/04	-	-	-	-	-	-	1	0
4	CD_D-1	10/5/04	-	-	-	-	-	-	0	0
5	CD_D-2	6/29/04	-	-	-	-	-	-	0	0
6	CD_D-3	7/21/04	-	-	-	-	-	-	0	0
7	CD_D-3	11/30/04	-	-	-	-	-	-	4	0
8	CD_D-4	8/18/04	-	-	-	-	-	-	0	0
9	CD_D-4	1/25/05	-	-	-	-	-	-	2	0
10	CD_D-5	5/25/04	-	-	-	-	-	-	1	0
11	CD_D-5	7/7/04	-	-	-	-	-	-	0	0
12	CD_D-5	9/8/04	-	-	-	-	-	-	0	0
13	CD_D-5	10/5/04	-	-	-	-	-	-	1	0
14	CD_D-6	7/21/04	-	-	-	-	-	-	0	0
15	CD_D-6	11/30/04	-	-	-	-	-	-	4	0
16	CD_D-6	2/9/05	-	-	-	-	-	-	0	0
17	CD_D-7	8/18/04	-	-	-	-	-	-	0	0
18	CD_D-7	11/30/04	+	-	-	-	-	-	32	0
19	CD_D-8	7/7/04	+/-	-	-	-	-	-	0	0
20	CD_D-8	9/21/04	-	-	-	-	-	-	0	0
21	CD_D-8	11/9/04	-	-	-	-	-	-	1	0
22	CD_D-9	7/7/04	-	-	-	-	-	-	0	0
23	CD_D-9	9/21/04	-	-	-	-	-	-	1	0
24	CD_D-9	11/9/04	-	-	-	-	-	-	0	0
25	CD_D-10	9/8/04	-	-	-	-	-	-	1	0
26	CD_D-10	10/19/04	-	-	-	-	-	-	0	0
27	CD_D-10	1/11/05	-	-	-	-	-	-	2	0

Appendix Table 2—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
28	CD_D-11	5/25/04	-	-	-	-	-	-	1	0
29	CD_D-11	10/19/04	-	-	-	-	-	-	1	0
30	CD_D-11	1/11/05	-	-	-	-	-	-	0	0
31	CD_D-12	7/21/04	-	-	-	-	-	-	1	0
32	CD_D-12	11/30/04	+/-	-	-	-	-	-	89	0
33	CD_D-12	2/9/05	-	-	-	-	-	-	1	0
34	CD_D-13	8/18/04	-	-	-	-	-	-	0	0
35	CD_D-13	11/30/04	-	-	-	-	-	-	3	0
36	CD_D-14	9/21/04	-	-	-	-	-	-	2	0
37	CD_D-14	1/25/05	-	-	-	-	-	-	1	0
38	CD_D-15	7/21/04	-	-	-	-	-	-	0	0
39	CD_D-15	11/30/04	-	-	-	-	-	-	1	0
40	CD_D-16	8/18/04	-	-	-	-	-	-	2	0
41	CD_D-16	11/30/04	-	-	-	-	-	-	4	0
42	CD_D-17	5/25/04	-	-	-	-	-	-	0	0
43	CD_D-17	1/11/05	+	-	-	-	-	-	0	0
44	CD_D-17	9/7/04	-	-	-	-	-	-	0	0
45	CD_D-18	7/7/04	-	-	-	-	-	-	2	0
46	CD_D-18	9/21/04	-	-	-	-	-	-	0	0
47	CD_D-18	11/9/04	-	-	-	-	-	-	1	0
48	CD_D-19	5/25/04	-	-	-	-	-	-	2	0
49	CD_D-19	7/7/04	-	-	-	-	-	-	0	0
50	CD_D-19	9/8/04	-	-	-	-	-	-	0	0
51	CD_D-19	10/5/04	-	-	-	-	-	-	0	0
52	CD_D-20	8/3/04	-	-	-	-	-	-	0	0
53	CD_D-20	9/21/04	+	+	-	-	-	-	0	0
54	CD_D-20	11/9/04	-	-	-	-	-	-	3	0

Appendix Table 2—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 ml)
55	CD_D-21	10/19/04	-	-	-	-	-	-	0	0
56	CD_D-21	1/11/05	-	-	-	-	-	-	0	0
57	CD_D-22	6/29/04	-	-	-	-	-	-	0	0
58	CD_D-22	8/4/04	-	-	-	-	-	-	0	0
59	CD_D-22	10/5/04	-	-	-	-	-	-	1	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 3. Microbial Data for Combination Ground, Surface, Spring, Tunnel Water (County of Hawaii)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	CC_D-1	6/29/04	-	-	-	-	-	-	0	0
2	CC_D-1	8/3/04	-	-	-	-	-	-	1	0
3	CC_D-1	11/9/04	-	-	-	-	-	-	5	0
4	CC_D-2	6/29/04	-	-	-	-	-	-	0	0
5	CC_D-2	8/4/04	-	-	-	-	-	-	1	0
6	CC_D-2	10/5/04	-	-	-	-	-	-	0	0
7	CC_D-3	9/8/04	-	-	-	-	-	-	1	0
8	CC_D-3	10/19/04	-	-	-	-	-	-	0	0
9	CC_D-3	1/11/05	-	-	-	-	-	-	2	0
10	CC_D-4	9/21/04	+/-	+	-	-	-	-	1	0
11	CC_D-4	11/9/04	-	-	-	-	-	-	0	0
12	CC_D-4	1/25/05	-	-	-	-	-	-	0	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 4. Microbial Data for Reservoirs (County of Hawaii)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	CR_D-1	10/19/04	-	-	-	-	-	-	0	0
2	CR_D-1	1/11/05	-	-	-	-	-	-	0	0
3	CR_D-2	6/29/04	-	-	-	-	-	-	0	0
4	CR_D-2	9/8/04	-	-	-	-	-	-	1	0
5	CR_D-2	10/5/04	-	-	-	-	-	-	0	0
6	CR_D-3	5/25/04	-	-	-	-	-	-	1	0
7	CR_D-3	9/7/04	-	-	-	-	-	-	0	0
8	CR_D-3	1/11/05	-	-	-	-	-	-	0	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 5. Microbial Data for Surface Water (County of Hawaii)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	CS-1	9/21/04	+	+	-	+	-	-	169	0
2	CS-1	11/9/04	+	+	-	-	-	-	40	0
3	CS-1	1/25/05	+	+	+	-	-	-	109	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 6. Microbial Data for Disinfected Springs and Tunnels (County of Hawaii)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 ml)
1	CST_D-1	6/29/04	-	-	-	-	-	-	0	0
2	CST_D-1	8/4/04	-	-	-	-	-	-	45	0
3	CST_D-1	10/5/04	-	-	-	-	-	-	5	0
4	CST_D-1	11/9/04	-	-	-	-	-	-	0	0
5	CST_D-2	6/29/04	-	-	-	-	-	-	0	0
6	CST_D-2	8/4/04	-	-	-	-	-	-	1	0
7	CST_D-2	10/5/04	-	-	-	-	-	-	7	0
8	CST_D-3	9/21/04	-	-	-	-	-	-	0	0
9	CST_D-3	1/25/05	-	-	-	-	-	-	1	0
10	CST_D-4	8/4/04	-	-	-	-	-	-	0	0
11	CST_D-4	10/5/04	-	-	-	-	-	-	2	0
12	CST_D-5	9/21/04	-	-	-	-	-	-	9	0
13	CST_D-5	1/25/05	-	-	-	-	-	-	0	0
14	CST_D-6	9/8/04	-	-	-	-	-	-	0	0
15	CST_D-6	10/19/04	-	-	-	-	-	-	1	0
16	CST_D-6	1/11/05	-	-	-	-	-	-	0	0
17	CST_D-7	6/29/04	-	-	-	-	-	-	0	0
18	CST_D-7	9/21/04	-	-	-	-	-	-	1	0
19	CST_D-7	11/9/04	-	-	-	-	-	-	2	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 7. Microbial Data for Non-Disinfected Springs and Tunnels (County of Hawaii)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	CST-1	6/29/04	+	-	-	-	-	-	10	0
2	CST-1	8/4/04	+	+	-	-	-	-	78	0
3	CST-1	10/5/04	+	+	+	-	-	+	30	0
4	CST-1	11/9/04	+	+	-	-	-	-	28	0
5	CST-2	9/8/04	+	+	+	-	-	-	0	0
6	CST-2	10/19/04	+	+	+	+	-	-	3	0
7	CST-2	1/11/05	+	+	+	+	-	+	18	0
8	CST-3	6/29/04	+	-	-	-	-	-	18	0
9	CST-3	9/21/04	+	+	-	-	-	-	11	0
10	CST-3	11/9/04	+	-	-	-	-	-	7	0
11	CST-4	9/8/04	+	+	+	-	-	-	6	0
12	CST-4	10/19/04	+	+	-	+	-	-	7	0
13	CST-4	1/11/05	+	+	+	+	-	-	18	0
14	CST-5	6/29/04	+/-	-	-	-	-	-	0	0
15	CST-5	8/3/04	+	-	-	-	-	-	6	0
16	CST-5	11/9/04	+	+	+	+	-	-	2	0
17	CST-6	6/29/04	+	+	-	-	-	-	7	0
18	CST-6	8/4/04	+	+	-	-	-	-	5	0
19	CST-6	10/5/04	-	-	-	-	-	-	2	0
20	CST-7	6/29/04	+/-	-	-	-	-	-	4	0
21	CST-7	8/4/04	+	+	-	-	-	-	1	0
22	CST-7	10/5/04	+	+	+	-	-	+	42	0
23	CST-8	9/8/04	+	-	-	-	-	-	0	0
24	CST-8	10/19/04	+	+	-	-	-	-	0	0
25	CST-8	1/11/05	+	+	+	-	-	-	0	0
26	CST-9	9/21/04	+	+	+	-	-	+	304	0
27	CST-9	1/25/05	+	-	-	-	-	-	5	0
28	CST-10	6/29/04	+	+	-	-	-	-	2	0

Appendix Table 7—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
29	CST-10	8/4/04	+	+	-	-	-	-	24	0
30	CST-10	10/5/04	+/-	+	-	-	-	-	10	0
31	CST-11	9/21/04	+	+	+	-	-	-	84	0
32	CST-11	1/25/05	+	+	+	-	-	-	384	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 8. Microbial Data for Well Water Samples (Private Companies)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	PW-1	5/4/04	-	-	-	-	-	-	2	0
2	PW-1	7/6/04	-	-	-	-	-	-	0	0
3	PW-1	8/3/04	-	-	-	-	-	-	0	0
4	PW-1	9/7/04	-	-	-	-	-	-	0	0
5	PW-1	10/6/04	-	-	-	-	-	-	0	0
6	PW-1	12/7/04	-	-	-	-	-	-	8	0
7	PW-1	2/23/05	-	-	-	-	-	-	2	0
8	PW-2	11/10/04	-	-	-	-	-	-	0	0
9	PW-2	12/7/04	-	-	-	-	-	-	0	0
10	PW-2	2/23/05	+	+	-	-	-	-	2	0
11	PW-3	6/8/04	+	+	-	-	-	-	4	0
12	PW-3	7/6/04	-	-	-	-	-	-	1	0
13	PW-3	8/3/04	-	-	-	-	-	-	0	0
14	PW-3	9/7/04	-	-	-	-	-	-	0	0
15	PW-3	10/6/04	-	-	-	-	-	-	4	0
16	PW-3	12/7/04	-	-	-	-	-	-	0	0
17	PW-3	2/23/05	-	-	-	-	-	-	1	0
18	PW-4	6/16/04	-	-	-	-	-	-	0	0
19	PW-4	12/16/04	-	-	-	-	-	-	2	0
20	PW-5	7/20/04	+	-	-	-	-	-	0	0
21	PW-5	12/16/04	-	-	-	-	-	-	5	0
22	PW-6	6/16/04	-	-	-	-	-	-	1	0
23	PW-7	6/16/04	-	-	-	-	-	-	18	0
24	PW-7	7/20/04	-	-	-	-	-	-	8	0
25	PW-7	12/16/04	-	-	-	-	-	-	0	0
26	PW-8	7/20/04	+	-	-	-	-	-	0	0
27	PW-8	9/22/04	-	-	-	-	-	-	0	0
28	PW-8	2/16/05	-	-	-	-	-	-	2	0
29	PW-9	7/20/04	-	-	-	-	-	-	0	0
30	PW-9	9/22/04	-	-	-	-	-	-	0	0
31	PW-9	2/16/05	-	-	-	-	-	-	1	0
32	PW-10	12/16/04	-	-	-	-	-	-	2	0
33	PW-11	12/16/04	-	-	-	-	-	-	0	0

Appendix Table 8—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
34	PW-12	6/15/04	-	-	-	-	-	-	0	0
35	PW-12	8/17/04	+	-	-	-	-	-	4	0
36	PW-13	6/15/04	-	-	-	-	-	-	0	0
37	PW-13	8/17/04	-	-	-	-	-	-	0	0
38	PW-14	6/15/04	-	-	-	-	-	-	0	0
39	PW-14	8/17/04	-	-	-	-	-	-	2	0
40	PW-15	8/17/04	-	-	-	-	-	-	0	0
41	PW-16	8/17/04	+	-	-	-	-	-	328	0
42	PW-17	6/8/04	+	+	+	-	-	-	1	0
43	PW-17	7/6/04	+	-	-	-	-	-	3	0
44	PW-17	8/3/04	+	-	-	-	-	-	2	0
45	PW-17	9/7/04	+	-	-	-	-	-	3	0
46	PW-17	11/10/04	+	+	-	-	-	-	1	0
47	PW-17	12/7/04	+	-	-	-	-	-	3	0
48	PW-17	2/23/05	-	-	-	-	-	-	1	0
49	PW-18	5/4/04	+	+	+	-	-	-	49	0
50	PW-18	7/6/04	+	-	-	-	-	-	2	0
51	PW-18	8/3/04	+	+	-	-	-	-	14	0
52	PW-18	9/7/04	+	-	-	-	-	-	0	0
53	PW-18	11/10/04	+/-	-	-	-	-	-	1	0
54	PW-18	12/7/04	+	+	-	-	-	-	3	0
55	PW-18	2/23/05	+	+	-	-	-	-	1	0
56	PW-19	12/16/04	-	-	-	-	-	-	0	0
57	PW-20	8/4/04	-	-	-	-	-	-	5	0
58	PW-21	7/6/04	-	-	-	-	-	-	1	0
59	PW-21	8/4/04	-	-	-	-	-	-	113	0
60	PW-22	7/20/04	-	-	-	-	-	-	7	0
61	PW-22	9/22/04	-	-	-	-	-	-	9	0
62	PW-23	7/20/04	-	-	-	-	-	-	28	0
63	PW-23	9/22/04	+	+	-	-	-	-	24	0
64	PW-24	2/24/05	-	-	-	-	-	-	1	1
65	PW-25	2/24/05	+	-	-	-	-	-	0	0
66	PW-26	6/16/04	-	-	-	-	-	-	0	0

Appendix Table 8—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
67	PW-26	8/17/04	-	-	-	-	-	-	17	0
68	PW-26	12/16/04	-	-	-	-	-	-	1	0
69	PW-26	2/16/05	-	-	-	-	-	-	1	0
70	PW-27	6/16/04	-	-	-	-	-	-	1	0
71	PW-27	8/17/04	-	-	-	-	-	-	0	0
72	PW-27	12/16/04	-	-	-	-	-	-	0	0
73	PW-27	2/16/05	-	-	-	-	-	-	0	0
74	PW-28	11/10/04	+	+	+	-	-	-	26	0
75	PW-28	12/7/04	+	+	-	+	-	-	15	0
76	PW-28	2/23/05	+	-	-	+	-	-	14	0
77	PW-29	6/16/04	+	+	-	-	-	-	0	0
78	PW-29	8/18/04	-	-	-	-	-	-	0	0
79	PW-29	2/16/05	-	-	-	-	-	-	0	0
80	PW-30	6/16/04	-	-	-	-	-	-	0	0
81	PW-30	8/18/04	-	-	-	-	-	-	0	0
82	PW-30	2/16/05	-	-	-	-	-	-	1	0
83	PW-31	7/20/04	-	-	-	-	-	-	24	0
84	PW-32	6/15/04	-	-	-	-	-	-	4	0
85	PW-32	9/22/04	-	-	-	-	-	-	24	0
86	PW-33	6/15/04	-	-	-	-	-	-	227	0
87	PW-33	9/22/04	-	-	-	-	-	-	164	0
88	PW-34	12/15/04	-	-	-	-	-	-	1	0
89	PW-34	2/24/05	-	-	-	-	-	-	0	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 9. Microbial Data for Distribution Water (Private Companies)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	PD_D-1	5/4/04	+	-	-	-	-	-	49	0
2	PD_D-1	7/6/04	-	-	-	-	-	-	0	0
3	PD_D-1	8/3/04	-	-	-	-	-	-	0	0
4	PD_D-1	9/7/04	-	-	-	-	-	-	1	0
5	PD_D-1	10/6/04	-	-	-	-	-	-	0	0
6	PD_D-1	12/7/04	-	-	-	-	-	-	3	0
7	PD_D-1	2/23/04	-	-	-	-	-	-	5	0
8	PD_D-2	11/10/04	-	-	-	-	-	-	1	0
9	PD_D-2	12/7/04	+	-	-	-	-	-	4	0
10	PD_D-2	2/23/04	-	-	-	-	-	-	1	0
11	PD_D-3	6/8/04	-	-	-	-	-	-	0	0
12	PD_D-3	7/6/04	+	-	-	-	-	-	0	0
13	PD_D-3	8/3/04	-	-	-	-	-	-	3	0
14	PD_D-3	9/7/04	-	-	-	-	-	-	0	0
15	PD_D-3	10/6/04	-	-	-	-	-	-	1	0
16	PD_D-3	12/7/04	+	+	-	-	-	-	6	0
17	PD_D-3	2/23/05	-	-	-	-	-	-	1	0
18	PD_D-4	6/16/04	-	-	-	-	-	-	6	0
19	PD_D-4	12/16/04	+/-	-	-	-	-	-	0	0
20	PD_D-5	7/20/04	-	-	-	-	-	-	2	0
21	PD_D-5	9/22/04	-	-	-	-	-	-	2	0
22	PD_D-5	2/16/05	-	-	-	-	-	-	0	0
23	PD_D-6	12/16/04	-	-	-	-	-	-	5	0
24	PD_D-7	6/15/04	-	-	-	-	-	-	0	0
25	PD_D-7	8/17/04	-	-	-	-	-	-	0	0
26	PD_D-8	6/15/04	-	-	-	-	-	-	1	0
27	PD_D-8	8/17/04	-	-	-	-	-	-	0	0
28	PD_D-9	6/8/04	-	-	-	-	-	-	2	0
29	PD_D-9	7/6/04	-	-	-	-	-	-	2	0

Appendix Table 9—*Continued*

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
30	PD_D-9	8/3/04	+/-	-	-	-	-	-	1	0
31	PD_D-9	9/7/04	-	-	-	-	-	-	0	0
32	PD_D-9	11/10/04	-	-	-	-	-	-	0	0
33	PD_D-9	12/7/04	+	-	-	-	-	-	3	0
34	PD_D-9	2/23/05	-	-	-	-	-	-	0	0
35	PD_D-10	7/6/04	-	-	-	-	-	-	0	0
36	PD_D-10	8/3/04	-	-	-	-	-	-	2	0
37	PD_D-11	12/15/04	-	-	-	-	-	-	1	0
38	PD_D-11	2/24/05	+	-	-	-	-	-	0	0
39	PD_D-12	6/16/04	-	-	-	-	-	-	1	0
40	PD_D-12	8/17/04	-	-	-	-	-	-	0	0
41	PD_D-12	12/16/04	-	-	-	-	-	-	0	0
42	PD_D-12	2/16/05	-	-	-	-	-	-	0	0
43	PD_D-13	6/15/04	-	-	-	-	-	-	6	0
44	PD_D-13	7/20/04	-	-	-	-	-	-	3	0
45	PD_D-13	9/22/04	-	-	-	-	-	-	8	0
46	PD_D-14	12/15/04	-	-	-	-	-	-	0	0
47	PD_D-14	2/24/05	-	-	-	-	-	-	1	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 10. Microbial Data for Combination Ground, Surface, Spring, Tunnel Water (Private Companies)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	PC_D-1	5/4/04	-	-	-	-	-	-	5	0
2	PC_D-1	6/8/04	-	-	-	-	-	-	0	0
3	PC_D-1	8/4/04	-	-	-	-	-	-	0	0
4	PC_D-1	10/6/04	-	-	-	-	-	-	1	0
5	PC_D-1	2/24/05	-	-	-	-	-	-	1	0
6	PC_D-2	6/8/04	-	-	-	-	-	-	0	0
7	PC_D-2	8/4/04	-	-	-	-	-	-	0	0
8	PC_D-2	10/6/04	-	-	-	-	-	-	2	0
9	PC_D-2	2/24/05	-	-	-	-	-	-	0	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 11. Microbial Data for Reservoirs (Private Companies)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	PR_D-1	7/6/04	-	-	-	-	-	-	0	0
2	PR_D-2	6/16/04	-	-	-	-	-	-	1	0
3	PR_D-2	8/18/04	-	-	-	-	-	-	2	0
4	PR_D-2	2/16/05	+/-	+	-	-	-	-	0	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 12. Microbial Data for Surface Water (Private Companies)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	PS-1	5/5/04	+	+	-	-	-	-	15	0
2	PS-1	6/9/04	-	-	-	-	-	-	0	0
3	PS-1	11/10/04	+/-	+	-	-	-	-	0	0
4	PS-2	6/9/04	+	-	-	-	-	-	18	0
5	PS-2	11/10/04	+	-	-	-	-	-	18	0

*Detection of the Presence or Absence of Coliphage via Enrichment.

Appendix Table 13. Microbial Data for Catchments (Private Companies)

Sample No.	ID #	Sample Date	Presumptive Presence/Absence (1000 ml)	Confirmed			Coliphages (Presence/Absence)*		Spores (CFU)	
				Coliform	*E. coli*	Enterococci	FRNA (500 ml)	Somatic (500 ml)	Aerobic (200 ml)	Anearobic (200 m1)
1	PCM-1	5/4/04	+	+	-	-	-	-	5	0
2	PCM-1	6/8/04	+	+	-	-	-	-	0	0
3	PCM-1	8/4/04	+	+	-	-	-	-	1	0
4	PCM-1	10/6/04	+	-	-	-	-	-	4	0
5	PCM-1	2/24/05	-	-	-	-	-	-	10	0
6	PCM-2	5/5/04	+	+	-	-	-	-	40	0
7	PCM-2	6/8/04	+	+	+	-	-	-	102	0
8	PCM-2	8/4/04	+	+	-	-	-	-	50	0
9	PCM-2	10/6/04	+	-	-	-	-	-	34	0
10	PCM-2	2/24/05	+	+	-	-	-	-	6	0
11	PCM-3	5/4/04	+	+	+	-	-	-	23	0

Appendix Table 14. General Water Quality Data: Well Water (County of Hawaii)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	CW-1	7/7/04	7.80	2.5	444	3.4	0.7
2	CW-1	9/21/04	7.36	0.3	412	1.2	0.4
3	CW-1	11/9/04	7.41	0.7	419	0.5	0.4
4	CW-2	8/3/04	7.47	0.5	162	0.2	0.6
5	CW-2	11/9/04	7.68	0.5	156	2.5	0.4
6	CW-3	8/18/04	7.04	0.4	125	2.9	0.7
7	CW-3	11/30/04	7.38	0.8	122	0.0	0.6
8	CW-4	9/21/04	7.31	0.4	189	0.1	0.6
9	CW-4	1/25/05	7.45	2.7	196	0.0	0.5
10	CW-5	9/21/04	7.52	0.3	193	<0.1	0.6
11	CW-5	1/25/05	7.64	0.8	189	1.6	0.6
12	CW-6	7/21/04	7.02	1.4	224	3.1	0.6
13	CW-6	11/30/04	7.53	0.7	906	0.0	0.6
14	CW-7	7/21/04	7.33	1.8	829	3.8	1.1
15	CW-7	11/30/04	7.52	0.6	201	0.7	0.6
16	CW-7	2/9/05	7.64	0.5	191	0.0	0.3
17	CW-8	7/21/04	7.27	1.6	239	2.5	2.0
18	CW-8	11/30/04	7.47	0.6	224	0.0	0.7
19	CW-9	7/21/04	7.48	1.5	638	0.8	1.4
20	CW-9	11/30/04	7.55	0.9	615	4.5	0.6
21	CW-10	2/9/05	7.23	0.6	449	5.7	0.2
22	CW-11	7/21/04	7.36	2.1	394	1.9	1.2
23	CW-11	11/30/04	7.52	0.7	350	0.0	0.7
24	CW-12	7/21/04	7.51	1.4	657	0.5	0.7
25	CW-12	11/30/04	7.50	0.6	702	3.4	0.7
26	CW-13	8/18/04	7.38	0.3	868	1.8	0.7
27	CW-13	11/30/04	7.55	0.6	903	0.6	0.7
28	CW-14	10/19/04	7.43	0.3	79	0.8	0.7
29	CW-15	10/19/04	7.36	0.3	83	0.0	0.6
30	CW-15	1/11/05	7.19	0.8	500	0.0	0.2
31	CW-16	3/10/04	7.16	4.5	1260	0.0	1.6
32	CW-16	10/19/04	7.10	0.3	1120	0.0	0.4
33	CW-16	1/11/05	7.42	0.7	75	0.0	0.2
34	CW-17	3/10/04	7.04	7.6	86	0.0	0.9
35	CW-17	10/19/04	7.06	0.3	93	0.2	0.4
36	CW-17	1/11/05	7.11	0.5	74	1.9	0.2
37	CW-18	7/21/04	7.88	2.3	184	3.6	1.3
38	CW-18	11/30/04	7.72	0.6	148	2.4	0.7
39	CW-19	8/18/04	7.40	0.4	1170	4.3	0.8
40	CW-20	8/18/04	7.46	0.4	316	3.0	0.6
41	CW-21	11/30/04	7.48	0.6	106	2.8	0.7
42	CW-21	2/9/05	7.35	0.71	108	3.6	0.2
43	CW-22	3/10/04	7.39	3.9	1240	0.9	1.9
44	CW-22	10/19/04	7.02	0.3	1040	0.4	0.7
45	CW-23	3/10/04	7.32	3.9	1210	5.3	>4
46	CW-23	10/19/04	7.20	0.3	983	0.0	0.6
47	CW-23	1/11/05	7.30	0.7	109	1.3	0.2
48	CW-24	6/29/04	6.62	4.1	180	0.0	0.3
49	CW-24	8/4/04	6.23	0.6	178	0.4	0.6
50	CW-24	10/5/04	6.28	0.7	171	0.4	0.4
51	CW-25	8/18/04	7.47	0.3	443	2.6	0.6

Appendix Table 14—*Continued*

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
52	CW-26	8/18/04	7.43	0.3	321	6.5	0.5
53	CW-26	1/25/05	7.77	0.9	300	2.0	0.5
54	CW-27	8/18/04	7.59	0.4	396	6.6	0.5
55	CW-27	1/25/05	7.72	2.7	356	2.4	0.6
56	CW-28	7/7/04	7.14	4.1	350	1.7	0.5
57	CW-28	9/21/04	7.42	0.3	374	0.0	0.6
58	CW-28	11/9/04	7.26	0.8	374	0.0	0.4
59	CW-29	7/7/04	6.90	3.2	236	2.9	0.3
60	CW-30	9/8/04	7.18	4.3	173	0.0	0.5
61	CW-30	10/19/04	7.23	4.0	152	1.9	0.5
62	CW-30	1/11/05	7.23	4.6	206	0.0	0.2
63	CW-31	3/10/04	7.06	3.9	79	0.5	1.1
64	CW-31	9/7/04	7.01	0.5	74	0.0	0.5
65	CW-31	10/19/04	6.86	0.4	85	0.4	0.5
66	CW-31	1/11/05	7.04	0.4	75	0.2	0.2
67	CW-32	7/7/04	7.36	3.0	163	2.3	0.3
68	CW-32	9/21/04	7.52	0.2	150	0.0	0.4
69	CW-32	11/9/04	7.49	0.6	149	0.0	0.3
70	CW-33	8/3/04	7.40	0.4	154	1.4	0.4
71	CW-33	9/21/04	7.43	0.3	142	2.3	0.5
72	CW-33	11/9/04	7.27	0.5	144	0.0	0.5
73	CW-34	9/8/04	7.20	0.7	92	0.9	0.4
74	CW-34	10/19/04	7.32	0.6	92	0.0	0.5
75	CW-34	1/11/05	7.36	0.7	97	5.2	0.2
76	CW-35	10/19/04	7.31	0.4	163	0.0	0.7
77	CW-35	1/11/05	7.34	0.8	127	0.5	0.3
78	CW-36	10/19/04	7.14	0.5	154	4.9	0.8
79	CW-36	1/11/05	7.43	0.5	125	0.3	0.2
80	CW-37	5/25/04	6.94	5.0	80	2.2	1.0
81	CW-37	7/7/04	6.78	2.7	87	1.5	0.8
82	CW-37	9/8/04	7.04	0.3	80	0.0	0.3
83	CW-37	10/5/04	6.89	0.5	79	1.0	0.3
84	CW-38	5/25/04	6.95	2.5	80	1.3	0.5
85	CW-38	7/7/04	6.92	3.0	84	5.0	0.3
86	CW-38	9/8/04	7.15	0.5	77	0.7	0.4
87	CW-38	10/5/04	6.86	0.4	79	0.1	0.4
88	CW-39	5/25/04	6.99	4.5	90	1.2	0.8
89	CW-39	7/7/04	6.97	3.5	92	4.2	0.5
90	CW-39	9/8/04	6.99	0.2	78	0.0	0.4
91	CW-39	10/5/04	7.03	0.3	78	3.4	0.5
92	CW-40	6/29/04	7.08	4.0	120	2.2	0.6
93	CW-40	8/4/04	5.59	1.1	119	1.4	1.1
94	CW-40	10/5/04	7.82	0.2	114	1.6	0.4
95	CW-41	8/18/04	7.82	0.7	422	3.0	0.5
96	CW-41	1/25/05	7.51	0.9	478	1.7	0.5
97	CW-42	8/18/04	7.69	0.3	565	2.8	0.5
98	CW-42	1/25/05	7.68	3	526	0.1	0.5
99	CW-43	9/21/04	7.66	0.3	130	2.6	0.8
100	CW-43	11/6/04	7.22	0.6	130	0.0	0.5
101	CW-43	1/25/05	7.64	7.0	128	2.8	0.6
102	CW-44	5/25/04	7.64	3.5	10	0.5	0.9

Appendix Table 14—*Continued*

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
103	CW-44	7/7/04	6.63	3.4	95	3.4	0.9
104	CW-44	9/8/04	7.44	0.3	88	0.0	0.6
105	CW-44	10/5/04	7.57	0.3	91	1.2	0.5
106	CW-45	5/25/04	7.72	4.5	113	1.4	0.9
107	CW-45	7/7/04	6.88	3.0	93	6.8	0.7
108	CW-45	9/8/04	7.58	0.4	94	0.0	0.6
109	CW-45	10/5/04	7.32	0.3	92	2.4	0.6
110	CW-46	6/29/04	7.42	4.4	103	0.0	0.5
111	CW-46	7/7/04	6.83	4.5	103	4.2	0.5
112	CW-46	9/8/04	7.54	0.3	94	0.0	0.5
113	CW-46	10/5/04	7.42	0.4	100	4.2	0.5
114	CW-47	6/29/04	7.32	6.2	97	0.1	0.6
115	CW-47	9/8/04	7.66	0.2	93	0.0	0.5
116	CW-47	10/5/04	7.07	0.6	93	1.9	0.6

Appendix Table 15. General Water Quality Data: Distribution Water (County of Hawaii)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	CD_D-1	6/29/04	6.86	3.3	64	0.0	0.7
2	CD_D-1	7/7/04	7.25	4.1	73	1.6	0.5
3	CD_D-1	9/8/04	7.54	0.5	77	0.0	0.5
4	CD_D-1	10/5/04	7.22	0.3	80	1.7	0.5
5	CD_D-2	6/29/04	6.37	3.8	82	0.0	0.6
6	CD_D-3	7/21/04	7.37	1.6	82	1.6	0.8
7	CD_D-3	11/30/04	7.61	0.6	83	3.9	0.7
8	CD_D-4	8/18/04	7.49	0.4	89	0.0	0.5
9	CD_D-4	1/25/05	7.78	2.5	90	0.0	0.6
10	CD_D-5	5/25/04	6.76	3.6	91	3.1	2.0
11	CD_D-5	7/7/04	7.60	4.7	93	1.2	0.5
12	CD_D-5	9/8/04	7.10	0.2	93	0.0	0.4
13	CD_D-5	10/5/04	7.17	0.4	93	4.4	0.3
14	CD_D-6	7/21/04	7.45	1.8	95	2.2	1.0
15	CD_D-6	11/30/04	7.51	0.7	96	0.6	0.6
16	CD_D-6	2/9/05	7.45	0.6	97	0.0	0.2
17	CD_D-7	8/18/04	7.17	0.5	98	2.5	0.6
18	CD_D-7	11/30/04	7.37	0.7	99	0.0	0.7
19	CD_D-8	7/7/04	7.17	3.2	100	1.4	1.0
20	CD_D-8	9/21/04	7.52	0.3	104	0.2	0.5
21	CD_D-8	11/9/04	7.36	0.5	104	1.7	0.4
22	CD_D-9	7/7/04	7.24	3.8	107	1.5	0.5
23	CD_D-9	9/21/04	7.63	0.2	108	1.0	0.5
24	CD_D-9	11/9/04	7.49	0.5	108	0.0	0.3
25	CD_D-10	9/8/04	6.62	0.7	110	<0.1	0.3
26	CD_D-10	10/19/04	6.42	0.1	114	0.1	0.2
27	CD_D-10	1/11/05	6.61	0.6	116	1.8	0.1
28	CD_D-11	5/25/04	7.32	7.6	145	0.1	1.9
29	CD_D-11	10/19/04	6.87	0.7	146	0.7	0.4
30	CD_D-11	1/11/05	7.26	0.6	150	1.0	0.2
31	CD_D-12	7/21/04	7.89	1.8	119	2.7	1.3
32	CD_D-12	11/30/04	7.75	0.6	122	0.0	0.7
33	CD_D-12	2/9/05	7.20	0.6	124	0.0	0.2
34	CD_D-13	8/18/04	7.28	0.6	152	0.7	0.6
35	CD_D-13	11/30/04	7.53	0.8	152	3.1	0.6
36	CD_D-14	9/21/04	7.58	0.3	162	0.0	0.7
37	CD_D-14	1/25/05	7.29	2.5	163	1.5	0.5
38	CD_D-15	7/21/04	7.80	2.2	170	3.5	1.5
39	CD_D-15	11/30/04	7.54	0.5	180	0	0.7
40	CD_D-16	8/18/04	7.24	0.7	191	2.7	0.6
41	CD_D-16	11/30/04	7.38	0.7	194	2.6	0.6
42	CD_D-17	5/25/04	7.44	7.0	228	0.2	1.4
43	CD_D-17	1/11/05	7.27	0.6	243	0.9	0.2
44	CD_D-17	9/7/04	7.19	0.2	288	0.0	0.8
45	CD_D-18	7/7/04	7.06	4.5	312	1.5	0.3
46	CD_D-18	9/21/04	7.31	0.4	336	0.0	0.4

Appendix Table 15—*Continued*

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
47	CD_D-18	11/9/04	7.28	0.5	416	0.0	0.4
48	CD_D-19	5/25/04	7.21	2.7	426	0.1	1.2
49	CD_D-19	7/7/04	7.89	3.1	434	0.8	0.8
50	CD_D-19	9/8/04	7.25	0.2	463	0.0	0.9
51	CD_D-19	10/5/04	6.72	0.3	487	2.3	0.9
52	CD_D-20	8/3/04	7.66	0.6	571	1.2	0.8
53	CD_D-20	9/21/04	7.63	0.3	626	0.1	0.4
54	CD_D-20	11/9/04	7.40	0.6	652	0.3	0.3
55	CD_D-21	10/19/04	7.03	0.4	769	1.0	0.6
56	CD_D-21	1/11/05	7.15	0.7	832	1.6	0.2
57	CD_D-22	6/29/04	7.27	4.2	859	0.0	0.3
58	CD_D-22	8/4/04	7.45	0.5	863	0.4	0.8
59	CD_D-22	10/5/04	7.62	0.2	892	1.3	0.3

Appendix Table 16. General Water Quality Data: Combination Ground, Surface, Spring, Tunnel Water (County of Hawaii)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	CC_D-1	6/29/04	7.14	3.6	138	0.0	1.1
2	CC_D-1	8/3/04	6.17	0.7	131	0.1	0.7
3	CC_D-1	11/9/04	7.59	0.9	157	0.8	0.4
4	CC_D-2	6/29/04	7.02	5.7	130	0.0	1.6
5	CC_D-2	8/4/04	5.90	1.6	148	0.7	0.8
6	CC_D-2	10/5/04	6.37	0.5	199	4.0	0.6
7	CC_D-3	9/8/04	6.96	0.8	77	0.0	0.2
8	CC_D-3	10/19/04	6.75	0.3	81	1.9	0.3
9	CC_D-3	1/11/05	7.17	0.5	72	0.1	0.1
10	CC_D-4	9/21/04	7.08	0.3	88	0.0	1.2
11	CC_D-4	11/9/04	6.71	0.5	88	0.0	0.7
12	CC_D-4	1/25/05	7.10	0.8	55	4.1	1.1

Appendix Table 17. General Water Quality Data: Reservoirs (County of Hawaii)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	CR_D-1	10/19/04	7.27	0.6	87	1.6	0.6
2	CR_D-1	1/11/05	7.78	0.6	498	4.6	0.2
3	CR_D-2	6/29/04	7.15	5.6	97	0.0	0.8
4	CR_D-2	9/8/04	7.62	0.5	95	<0.1	0.7
5	CR_D-2	10/5/04	7.43	0.6	96	6.1	0.6
6	CR_D-3	5/25/04	7.12	3.6	85	1.9	1.2
7	CR_D-3	9/7/04	7.03	0.2	85	1.2	0.6
8	CR_D-3	1/11/05	6.90	0.7	76	1.1	0.2

Appendix Table 18. General Water Quality Data: Surface Water (County of Hawaii)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	CS-1	9/21/04	6.66	0.9	37	0.0	0.2
2	CS-1	11/9/04	6.25	2.5	40	0.0	0.2
3	CS-1	1/25/05	6.08	6.0	34	1.4	0.2

Appendix Table 19. General Water Quality Data: Disinfected Springs and Tunnels (County of Hawaii)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	CST_D-1	6/29/04	7.98	7.4	324	0.0	0.3
2	CST_D-1	8/4/04	7.45	1.5	302	1.0	0.6
3	CST_D-1	10/5/04	7.65	0.6	351	5.4	0.3
4	CST_D-1	11/9/04	7.24	0.6	332	0.0	0.2
5	CST_D-2	6/29/04	7.01	3.1	189	0.0	1.5
6	CST_D-2	8/4/04	5.70	0.6	360	2.1	0.9
7	CST_D-2	10/5/04	7.31	0.5	97	0.5	0.7
8	CST_D-3	9/21/04	6.61	0.4	175	0.0	0.4
9	CST_D-3	1/25/05	6.79	0.9	164	1.6	0.4
10	CST_D-4	8/4/04	6.22	1.2	185	0.4	0.5
11	CST_D-4	10/5/04	6.45	0.5	179	0.1	0.5
12	CST_D-5	9/21/04	7.75	0.4	220	<0.1	1.3
13	CST_D-5	1/25/05	7.48	2.6	195	0.0	1.2
14	CST_D-6	9/8/04	6.52	0.4	90	<0.1	0.3
15	CST_D-6	10/19/04	6.12	0.1	74	1.8	0.3
16	CST_D-6	1/11/05	6.50	0.5	97	3.0	0.1
17	CST_D-7	6/29/04	7.80	7.4	329	0.2	0.4
18	CST_D-7	9/21/04	7.87	0.3	302	0.0	0.3
19	CST_D-7	11/9/04	6.88	0.6	260	0.0	0.3

Appendix Table 20. General Water Quality Data: Non-Disinfected Springs and Tunnels (County of Hawaii)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	CST-1	6/29/04	7.55	3.1	104	0.0	0.4
2	CST-1	8/4/04	6.99	0.5	102	0.0	0.6
3	CST-1	10/5/04	5.93	0.4	102	0.0	0.2
4	CST-1	11/9/04	5.99	0.6	99	0.5	0.2
5	CST-2	9/8/04	7.04	0.3	79	0.9	0.3
6	CST-2	10/19/04	6.78	0.2	86	1.3	0.3
7	CST-2	1/11/05	6.67	0.5	67	3.1	0.1
8	CST-3	6/29/04	6.04	3.4	141	0.0	0.7
9	CST-3	9/21/04	6.62	0.3	133	0.0	0.4
10	CST-3	11/9/04	6.08	0.6	132	0.0	0.3
11	CST-4	9/8/04	6.07	0.7	135	0.0	0.4
12	CST-4	10/19/04	6.25	2.3	138	2.3	0.3
13	CST-4	1/11/05	6.12	0.5	135	1.1	0.1
14	CST-5	6/29/04	6.65	4.0	117	0.0	0.2
15	CST-5	8/3/04	6.44	0.4	113	1.0	0.2
16	CST-5	11/9/04	6.10	0.6	108	0.0	0.2
17	CST-6	6/29/04	5.72	3.0	181	0.0	0.4
18	CST-6	8/4/04	6.18	0.4	179	1.4	0.6
19	CST-6	10/5/04	6.76	0.2	176	1.6	0.5
20	CST-7	6/29/04	6.81	4.0	160	0.0	0.3
21	CST-7	8/4/04	5.40	0.3	123	0.1	0.3
22	CST-7	10/5/04	8.71	0.4	524	8.8	0.2
23	CST-8	9/8/04	7.18	0.5	73	<0.1	0.3
24	CST-8	10/19/04	6.59	0.0	81	0.0	0.3
25	CST-8	1/11/05	6.97	0.6	77	0.5	0.1
26	CST-9	9/21/04	6.78	0.4	113	0.0	0.4
27	CST-9	1/25/05	6.27	2.5	115	7.5	0.4
28	CST-10	6/29/04	6.52	5.5	128	0.0	0.4
29	CST-10	8/4/04	9.62	0.6	1220	1.3	0.6
30	CST-10	10/5/04	5.66	0.3	80	1.7	0.3
31	CST-11	9/21/04	6.73	0.3	164	0.6	0.4
32	CST-11	1/25/05	6.65	2.9	161	0.2	0.4

Appendix Table 21. General Water Quality Data: Well Water (Private Companies)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	PW-1	5/4/04	7.02	3.0	1280	0.3	1.2
2	PW-1	7/6/04	7.14	3.0	133	2.8	0.8
3	PW-1	8/3/04	7.01	0.2	135	1.1	0.7
4	PW-1	9/7/04	7.06	0.2	130	1.1	0.7
5	PW-1	10/6/04	7.18	0.3	136	0.5	0.6
6	PW-1	12/7/04	7.01	0.6	133	1.6	0.7
7	PW-1	2/23/05	7.26	0.7	133	2.8	0.7
8	PW-2	11/10/04	6.83	0.7	84	0.0	0.4
9	PW-2	12/7/04	6.93	0.4	83	2.1	0.4
10	PW-2	2/23/05	7.32	0.5	87	0.8	0.4
11	PW-3	6/8/04	7.28	0.9	161	0.4	0.6
12	PW-3	7/6/04	6.95	4.5	174	2.5	0.8
13	PW-3	8/3/04	7.02	0.5	193	0.9	>4
14	PW-3	9/7/04	7.36	0.3	176	0.0	0.7
15	PW-3	10/6/04	7.03	0.4	178	3.2	0.7
16	PW-3	12/7/04	7.05	0.7	172	4.2	0.6
17	PW-3	2/23/05	6.88	0.7	169	2.6	0.6
18	PW-4	6/16/04	7.09	4.0	1370	3.0	0.7
19	PW-4	12/16/04	6.88	0.3	871	2.6	0.8
20	PW-5	7/20/04	7.41	2.0	1480	1.7	1.2
21	PW-5	12/16/04	6.86	0.3	1543	2.5	0.5
22	PW-6	6/16/04	7.10	3.1	1260	3.5	0.5
23	PW-7	6/16/04	7.16	0.7	1260	4.9	0.6
24	PW-7	7/20/04	7.64	1.0	1320	3.8	0.7
25	PW-7	12/16/04	7.07	0.3	1332	4.1	0.5
26	PW-8	7/20/04	7.96	2.2	355	0.9	0.9
27	PW-8	9/22/04	7.05	0.2	350	0.0	0.9
28	PW-8	2/16/05	7.52	0.7	328	1.0	0.1
29	PW-9	7/20/04	7.65	1.8	374	1.4	0.8
30	PW-9	9/22/04	7.43	0.3	376	0.0	0.6
31	PW-9	2/16/05	7.48	0.7	158	1.6	0.2
32	PW-10	12/16/04	7.25	0.3	351	1.5	0.8
33	PW-11	12/16/04	7.27	0.4	374	0.3	0.6
34	PW-12	6/15/04	6.84	0.9	1250	1.2	1.2
35	PW-12	8/17/04	6.99	0.6	1280	3.0	1.3
36	PW-13	6/15/04	6.76	0.9	1010	1.4	1.3
37	PW-13	8/17/04	7.27	0.4	1060	3.3	1.2
38	PW-14	6/15/04	7.05	3.0	862	1.5	1.3
39	PW-14	8/17/04	7.27	0.8	925	2.2	1.3
40	PW-15	8/17/04	6.96	0.4	1250	3.3	1.4
41	PW-16	8/17/04	7.39	1.5	937	0.0	1.0
42	PW-17	6/8/04	7.08	2.8	2480	1.0	0.4
43	PW-17	7/6/04	6.58	3.0	290	5.7	0.4
44	PW-17	8/3/04	6.88	0.2	490	0.8	0.6
45	PW-17	9/7/04	6.95	0.3	435	1.3	0.6
46	PW-17	11/10/04	6.68	0.5	324	0.0	0.4
47	PW-17	12/7/04	6.74	0.4	305	1.7	0.5
48	PW-17	2/23/05	6.90	0.5	325	0.5	0.4
49	PW-18	5/4/04	6.63	6.0	2570	0.3	0.8
50	PW-18	7/6/04	7.14	6.5	277	3.5	0.4
51	PW-18	8/3/04	6.98	4.2	31	0.8	0.7

Appendix Table 21—*Continued*

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
52	PW-18	9/7/04	6.67	5.6	25	0.1	0.4
53	PW-18	11/10/04	7.05	6.0	318	0.0	0.4
54	PW-18	12/7/04	7.19	0.4	305	4.8	0.3
55	PW-18	2/23/05	6.75	5.0	324	0.0	0.2
56	PW-19	12/16/04	7.51	0.3	808	0.6	0.5
57	PW-20	8/4/04	7.90	1.4	151	2.2	1.1
58	PW-21	7/6/04	6.89	3.5	138	1.3	0.9
59	PW-21	8/4/04	7.76	0.7	146	2.7	0.8
60	PW-22	7/20/04	7.84	2.4	281	1.0	0.9
61	PW-22	9/22/04	7.76	0.4	274	0.8	0.5
62	PW-23	7/20/04	7.93	2.4	276	4.8	2.0
63	PW-23	9/22/04	7.33	0.3	272	0.5	0.5
64	PW-24	2/24/05	6.60	2.4	697	1.1	0.5
65	PW-25	2/24/05	6.96	0.5	717	0.8	0.6
66	PW-26	6/16/04	7.96	5.5	366	1.8	0.5
67	PW-26	8/17/04	7.70	0.7	373	4.3	0.5
68	PW-26	12/16/04	7.78	0.3	375	3.0	0.5
69	PW-26	2/16/05	7.81	0.6	373	3.8	0.2
70	PW-27	6/16/04	7.99	4.0	240	0.5	0.4
71	PW-27	8/17/04	7.50	0.4	248	0.0	0.4
72	PW-27	12/16/04	7.62	0.3	246	0.8	0.4
73	PW-27	2/16/05	7.92	2.5	242	3.4	0.1
74	PW-28	11/10/04	6.82	0.6	565	0.0	0.4
75	PW-28	12/7/04	6.72	0.7	453	1.9	0.5
76	PW-28	2/23/05	6.64	0.7	459	0.0	0.5
77	PW-29	6/16/04	7.84	0.8	416	1.9	0.6
78	PW-29	8/18/04	7.67	0.4	439	2.4	0.5
79	PW-29	2/16/05	7.46	0.7	425	4.5	0.2
80	PW-30	6/16/04	7.91	3.4	423	2.3	0.7
81	PW-30	8/18/04	7.58	0.5	441	0.0	0.6
82	PW-30	2/16/05	7.74	0.7	433	0.0	0.2
83	PW-31	7/20/04	7.96	1.8	264	0.3	0.7
84	PW-32	6/15/04	7.94	0.7	624	0.9	0.6
85	PW-32	9/22/04	7.61	0.3	641	0.5	0.5
86	PW-33	6/15/04	7.85	5.5	780	1.5	0.6
87	PW-33	9/22/04	7.51	0.3	486	1.3	0.6
88	PW-34	12/15/04	7.27	0.3	84	0.0	0.3
89	PW-34	2/24/05	6.91	0.4	83	0.0	0.4

Appendix Table 22. General Water Quality Data: Distribution Water (Private Companies)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	PD_D-1	5/4/04	6.83	4.3	82	0.1	1.1
2	PD_D-1	7/6/04	7.10	3.1	84	6.6	0.6
3	PD_D-1	8/3/04	7.11	0.3	84	3.1	0.9
4	PD_D-1	9/7/04	7.31	0.4	84	0.0	0.8
5	PD_D-1	10/6/04	6.91	0.3	87	4.6	0.8
6	PD_D-1	12/7/04	7.02	0.6	104	3.0	0.7
7	PD_D-1	2/23/04	7.09	0.5	112	1.8	0.7
8	PD_D-2	11/10/04	6.79	0.6	114	0.0	0.4
9	PD_D-2	12/7/04	7.04	0.5	132	1.6	0.4
10	PD_D-2	2/23/04	7.25	0.5	133	0.4	0.6
11	PD_D-3	6/8/04	7.39	3.9	133	1.1	0.6
12	PD_D-3	7/6/04	7.05	4.6	134	5.8	0.6
13	PD_D-3	8/3/04	7.12	0.5	134	2.4	1.7
14	PD_D-3	9/7/04	7.50	0.2	137	<0.1	0.6
15	PD_D-3	10/6/04	7.31	0.3	138	0.0	0.7
16	PD_D-3	12/7/04	7.28	0.7	166	2.2	0.6
17	PD_D-3	2/23/05	7.36	0.6	174	2.8	0.0
18	PD_D-4	6/16/04	7.22	4.0	176	1.7	2.6
19	PD_D-4	12/16/04	7.49	0.3	176	1.5	3.7
20	PD_D-5	7/20/04	7.69	2.4	184	3.7	0.7
21	PD_D-5	9/22/04	7.41	0.4	185	0.5	0.6
22	PD_D-5	2/16/05	7.49	0.6	187	0.0	0.2
23	PD_D-6	12/16/04	7.28	0.3	207	0.3	0.7
24	PD_D-7	6/15/04	7.56	3.0	241	0.6	>4
25	PD_D-7	8/17/04	7.51	0.7	250	0.0	>4
26	PD_D-8	6/15/04	6.97	1.0	261	2.3	1.7
27	PD_D-8	8/17/04	6.75	1.5	290	1.6	2.6
28	PD_D-9	6/8/04	6.82	0.8	292	1.7	0.4
29	PD_D-9	7/6/04	6.97	2.8	309	5.7	0.6
30	PD_D-9	8/3/04	6.70	0.3	326	1.4	0.7
31	PD_D-9	9/7/04	6.56	0.8	326	0.3	0.4
32	PD_D-9	11/10/04	6.68	0.5	329	0.0	0.4
33	PD_D-9	12/7/04	6.65	0.3	341	1.4	0.4
34	PD_D-9	2/23/05	6.85	0.7	364	0.4	0.4
35	PD_D-10	7/6/04	7.32	3.7	365	4.5	0.6
36	PD_D-10	8/3/04	7.04	0.3	652	0.5	0.9
37	PD_D-11	12/15/04	7.45	0.2	367	0.0	0.4
38	PD_D-11	2/24/05	6.87	0.5	368	1.7	0.5
39	PD_D-12	6/16/04	8.20	3.6	369	1.2	0.4
40	PD_D-12	8/17/04	7.28	0.3	377	0.4	0.4
41	PD_D-12	12/16/04	7.89	0.4	404	0.8	0.5
42	PD_D-12	2/16/05	8.04	0.7	482	3.0	0.1
43	PD_D-13	6/15/04	7.93	4.5	546	1.9	0.5

Appendix Table 22—*Continued*

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
44	PD_D-13	7/20/04	7.80	1.5	570	0.1	0.8
45	PD_D-13	9/22/04	7.32	0.3	760	0.7	0.5
46	PD_D-14	12/15/04	6.86	0.3	766	0.0	0.3
47	PD_D-14	2/24/05	7.12	0.5	1393	0.6	0.3

Appendix Table 23. General Water Quality Data: Combination Ground, Surface, Spring, Tunnel Water (Private Companies)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	PC_D-1	5/4/04	5.54	5.5	21	0.2	0.4
2	PC_D-1	6/8/04	6.00	0.9	25	0.2	1.6
3	PC_D-1	8/4/04	5.39	1.5	12	0.3	0.3
4	PC_D-1	10/6/04	6.79	5.0	23	3.5	0.2
5	PC_D-1	2/24/05	5.22	0.5	23	0.0	0.3
6	PC_D-2	6/8/04	6.36	4.2	25	0.7	0.2
7	PC_D-2	8/4/04	5.63	2.4	24	0.3	0.3
8	PC_D-2	10/6/04	6.22	1.8	33	3.2	0.3
9	PC_D-2	2/24/05	5.72	0.6	21	0.0	0.4

Appendix Table 24. General Water Quality Data: Reservoirs (Private Companies)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	PR_D-1	7/6/04	7.42	3.7	83	0.5	0.7
2	PR_D-2	6/16/04	7.90	1.0	428	1.7	0.6
3	PR_D-2	8/18/04	7.78	0.5	467	2.9	0.5
4	PR_D-2	2/16/05	7.72	0.8	427	0.0	0.2

Appendix Table 25. General Water Quality Data: Surface Water (Private Companies)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	PS-1	5/5/04	6.72	5.5	47	0.3	0.1
2	PS-1	6/9/04	7.06	0.6	44	1.1	0.6
3	PS-1	11/10/04	7.10	0.5	50	4.8	0.6
4	PS-2	6/9/04	6.45	2.8	47	0.1	0.6
5	PS-2	11/10/04	7.03	0.8	51	0.0	0.7

Appendix Table 26. General Water Quality Data: Catchments (Private Companies)

Sample No.	ID #	Sample Date	pH	Turbidity (NTU)	Conductivity (μS/cm)	Total N (mg/L)	Total P (mg/L)
1	PCM-1	5/4/04	4.70	4.6	15	0.6	0.3
2	PCM-1	6/8/04	4.92	0.8	14	0.5	0.4
3	PCM-1	8/4/04	4.34	0.7	13	0.4	0.1
4	PCM-1	10/6/04	5.93	0.7	14	0.5	0.2
5	PCM-1	2/24/05	5.77	0.9	13	0.0	0.2
6	PCM-2	5/5/04	6.95	5.0	50	0.0	1.7
7	PCM-2	6/8/04	5.93	6.5	16	0.0	0.2
8	PCM-2	8/4/04	5.72	2.0	12	0.8	0.2
9	PCM-2	10/6/04	5.64	1.3	13	1.6	0.2
10	PCM-2	2/24/05	6.05	4.5	20	0.5	0.2
11	PCM-3	5/4/04	4.30	3.3	7	1.0	0.4

Appendix Table 27. Inspectra Data for Well Water Samples (County of Hawaii)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	CW-1	7/7/04	10	1	80	66	62	5.6	81
2	CW-2	8/3/04	10	1	93	88	78	15.2	109
3	CW-6	7/21/04	10	1	2.8	1.3	1.1	1	1
4	CW-7	7/21/04	10	11.7	3.1	1.8	1.4	1	1
5	CW-8	7/21/04	10	1	4.6	2.3	1.5	1	1
6	CW-9	7/21/04	10	7.8	3.4	1.8	1.3	1	1
7	CW-11	7/21/04	10	1	86	62	60.4	1	79
8	CW-12	7/21/04	10	43	5.2	1.9	1.5	1	1
9	CW-16	3/10/04	10	39	4.7	1.7	1.3	1	1
10	CW-17	3/10/04	10	43.5	26.4	18.6	17.2	1	25.9
11	CW-18	7/21/04	10	6.9	2.9	1.2	1	6.4	1
12	CW-22	3/10/04	10	43.5	39	27.6	26	1	31
13	CW-23	3/10/04	10	3.3	28.6	18.8	19	1	22.4
14	CW-28	7/7/04	10	7.5	30.5	20.4	20.2	1	45.6
15	CW-29	7/7/04	10	13	104	77	74	3.4	93
16	CW-31	3/10/04	10	58.4	127	93	88	1	109
17	CW-32	7/7/04	10	16	1.9	1	1	1	1
18	CW-37	7/7/04	10	24.2	2.9	1.1	1	1	5.7
19	CW-38	5/25/04	10	16	1.9	1	1	2.7	1
20	CW-38	7/7/04	10	26.9	2.4	1	1	1.4	1
21	CW-39	5/25/04	10	31.2	3.5	1.3	1	1.7	1
22	CW-39	7/7/04	10	19.6	2.2	1	1	2.5	33
23	CW-44	5/25/04	10	57	97	54	86	14.6	15.9
24	CW-46	6/29/04	10	19.4	2.3	1	1	1	1
25	CW-46	7/7/04	10	2.8	1	1	1	1	1
26	CW-46	9/8/04	10	1	19	18.6	13.3	1	16.4
27	CW-47	6/29/04	10	1	5.2	2.6	2.5	1	2
28	CW-47	9/8/04	10	50	75	90	46.2	3.5	95.3

Appendix Table 28. Inspectra Data for Distribution Water (County of Hawaii)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	CD_D-1	6/29/04	10	148	136	100	24	1	113
2	CD_D-1	7/7/04	10	44.5	17.6	23.6	47	1	12.3
3	CD_D-1	9/8/04	10	166	114	81	72	6.6	90
4	CD_D-2	6/29/04	10	5.1	128	92	90	1	111
5	CD_D-3	7/21/04	10	1	98	71	74	2.6	86
6	CD_D-5	5/25/04	10	14.6	1.7	1	1	1	1
7	CD_D-5	7/7/04	10	35.5	24.6	18.6	25.6	8.1	65.1
8	CD_D-6	7/21/04	10	23.4	3.6	1	45.6	5.2	1
9	CD_D-8	7/7/04	10	14.8	20.4	15.6	1	4.6	1
10	CD_D-9	7/7/04	10	10.2	19	14.6	22.3	12.5	16.6
11	CD_D-9	9/21/04	10	1	51	58	42.6	5.7	61.2
12	CD_D-11	5/25/04	10	1	105	73	70	6.9	89
13	CD_D-12	7/21/04	10	1	129	89	88	9.4	108
14	CD_D-15	7/21/04	10	1	98	75	72	7.2	91
15	CD_D-17	5/25/04	10	1	127	95	91	13.4	115
16	CD_D-19	5/25/04	10	1	123	89	86	16.4	108
17	CD_D-19	7/7/04	10	1	121	85	84	11	102

Appendix Table 29. Inspectra Data for Combination Ground, Surface, Spring, Tunnel Water (County of Hawaii)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	CC_D-2	8/4/04	10	1	29.4	24.2	22.4	4.1	29.6
2	CC_D-1	6/29/04	10	1	142	96	96	1	115

Appendix Table 30. Inspectra Data for Reservoirs (County of Hawaii)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	CR_D-3	5/25/04	10	7.3	37	24.8	24.8	1	29.4

Appendix Table 31. Inspectra Data for Disinfected Springs and Tunnels (County of Hawaii)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	CST_D-7	6/29/04	10	1	860	630	610	21.6	770

Appendix Table 32. Inspectra Data for Non-Disinfected Springs and Tunnels (County of Hawaii)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	CST-5	6/29/04	10	770	93.8	35.2	27	1	1
2	CST-3	6/29/04	10	1	122	99	93	7.2	121
3	CST-6	6/29/04	10	1	27.8	19.2	19	1	23

Appendix Table 33. Inspectra Data for Well Water Samples (Private Companies)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	PW-1	5/4/04	10	19.2	2.3	1	1	7.7	1
2	PW-1	7/6/04	10	23.2	2.8	1	1	1	1
3	PW-1	8/3/04	10	28.6	3.4	1.3	1	3.3	1
4	PW-3	6/8/04	10	9.2	2.8	1.2	1	1	1
5	PW-3	7/6/04	10	6.3	4.7	2.1	1.4	5.5	1
6	PW-3	8/3/04	10	20.8	29.2	24.2	21.8	1.7	28.4
7	PW-3	9/7/04	10	32	4	1.5	1.1	3	1
8	PW-4	6/16/04	10	23	14.5	13	11.2	1	14.8
9	PW-5	7/20/04	10	31.5	3.8	1.4	1.1	6.2	1
10	PW-6	6/16/04	10	16.2	1.9	1	1	3.5	1
11	PW-7	6/16/04	10	25.1	1.5	1	1	14.4	1
12	PW-7	7/20/04	10	27.4	3.3	1.2	1	3.6	1
13	PW-8	7/20/04	10	1	4.9	2.3	1.5	12.9	1
14	PW-9	7/20/04	10	24.2	8.2	3.8	2.5	4.1	1
15	PW-9	9/22/04	10	20.3	5	2.4	1.6	1	1
16	PW-12	6/15/04	10	15.3	4.3	2	1.4	1	1
17	PW-12	8/17/04	10	5.3	6.6	3	2	1.9	1
18	PW-13	6/15/04	10	25.1	3	1	1	2.8	1
19	PW-13	8/17/04	10	41.5	9.9	7.6	6.1	6.2	7.1
20	PW-14	6/15/04	10	54	7.7	3.8	2.9	1	1.6
21	PW-14	8/17/04	10	55	6.1	2.2	1.7	5.2	1
22	PW-15	8/17/04	10	58	7	2.6	2	3.6	1
23	PW-16	8/17/04	10	40.5	4.9	1.8	1.4	1	1
24	PW-17	6/8/04	10	30.5	31	17.8	18.4	4	19.6
25	PW-17	7/6/04	10	51.5	6.2	2.3	1.8	14.7	1
26	PW-17	8/3/04	10	95	89	58.8	56.8	10.4	66
27	PW-17	9/7/04	10	126	81	51.2	49.6	9	54.8
28	PW-18	5/4/04	10	145	132	94	89	11	107
29	PW-18	7/6/04	10	932	73	58.4	50.8	3.8	63
30	PW-18	8/3/04	10	138	110	80	74	6.9	89
31	PW-20	8/4/04	10	143	136	96	91	3.1	108
32	PW-21	7/6/04	10	51.5	19.4	16.8	13.6	12.7	17
33	PW-21	8/4/04	10	1	24.8	19.6	15.4	1	17
34	PW-22	7/20/04	10	33	11.1	7.4	5.6	1	4.8
35	PW-23	7/20/04	10	1	84	57.6	57.2	1602	69
36	PW-26	6/16/04	10	5	87	62	61	12.3	75
37	PW-26	8/17/04	10	5.8	35.5	23.6	23.6	2.5	28
38	PW-27	6/16/04	10	1	103	74	72	16.2	90
39	PW-29	6/16/04	10	11.7	93	67	65	25.4	81
40	PW-30	6/16/04	10	26.5	86	61	60	2.2	73
41	PW-30	8/18/04	10	1	42.5	29	29	1.3	35

Appendix Table 34. Inspectra Data for Distribution Water (Private Companies)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	PD_D-1	38111	10	140	126	87	83	11.8	97
2	PD_D-1	38174	10	85	127	82	81	11.4	94
3	PD_D-3	38146	10	168	288	202	196	1	236
4	PD_D-3	38174	10	113	122	86	82	13	98
5	PD_D-3	38202	10	134	95	62	57.6	7.4	69
6	PD_D-4	38154	10	139	103	75	69	1	84
7	PD_D-7	38153	10	19	21.4	10	5.4	3	1
8	PD_D-7	38216	10	1	15.8	26.1	14.8	1	7
9	PD_D-8	38153	10	1	35	26.8	25.6	1.6	32.5
10	PD_D-8	38216	10	1	34.5	26	25	1.6	31.5
11	PD_D-9	38146	10	1	132	99	95	5.6	120
12	PD_D-9	38174	10	1	18.6	18.8	16.4	6	33.4
13	PD_D-9	38202	10	18	7.3	1.7	1.3	2	10.1
14	PD_D-9	38237	10	22.8	2.7	1	1	1	10.1
15	PD_D-10	38174	10	14.4	1.7	1	1	1.1	1
16	PD_D-10	38202	10	22.8	5.5	8.1	3.5	1	16.5
17	PD_D-12	38154	10	1	88	68	665	16	83
18	PD_D-12	38216	10	790	103.1	36	27.6	1	1
19	PD_D-13	38153	10	66.8	102.5	54.9	72.9	10.3	54.9

Appendix Table 35. Inspectra Data for Combination Ground, Surface, Spring, Tunnel Water (Private Companies)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	PC_D-1	5/4/04	10	89.6	54.5	98	92	1	112
2	PC_D-1	6/8/04	10	121	132	92	86	1	105
3	PC_D-2	6/8/04	10	1	119	89	79	1	92
4	PC_D-2	8/4/04	10	47.2	126.9	41	32	1	33

Appendix Table 36. Inspectra Data for Reservoirs (Private Companies)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	PR_D-2	6/16/04	10	1	360	122	170	47.6	134
2	PR_D-2	8/18/04	10	19.2	4.6	2.7	2.3	6.3	2.2
3	PR_D-2	2/16/05	10	7.3	31.5	13.4	16.4	10.9	14.8

Appendix Table 37. Inspectra Data for Surface Water (Private Companies)

Sample No.	ID #	Sample Date	Path Length	TSS	COD	BOD	TOC	NO_3	SUR
				(mg/L)					
1	PS-1	5/5/04	10	53.5	13.9	11	8.9	1	10.5
2	PS-1	6/9/04	10	45	28	23.4	19	1	22.8
3	PS-1	11/10/04	10	12.1	29.8	25	19.6	1	22.8
4	PS-2	6/9/04	10	31.5	12.2	9.8	8.4	1	10.3

Appendix Table 38. Riboprinter Analysis for Selected Isolates from MENDO Plates

Sample No.	ID No.	Sample Date	Riboprinter Sample No.	Ribogroup	DuPont ID	DuPont ID Label	DID Sim
1	PW-29	6/16/04	277-108-1	277-108-S-1	None	None	None
2	PW-30	6/16/04	277-108-2	277-108-S-2	None	None	None
3	PW-12	6/15/04	277-108-3	277-108-S-3	None	None	None
4	PW-12	6/15/04	277-108-3	277-108-S-3	None	None	None
5	PW-6	6/16/04	277-108-6	277-108-S-6	DUP-16223	Pseudomonas aeruginosa	0.92
6	PW-6	6/16/04	277-108-7	277-108-S-7	None	None	None
7	PW-29	6/16/04	277-108-8	277-108-S-8	None	None	None
8	CW-47	6/29/04	277-116-7	277-116-S-7	None	None	None
9	CW-47	6/29/04	277-116-8	277-116-S-8	None	None	None
10	CNST-6	6/29/04	277-117-1	277-117-S-1	None	None	None
11	CD_D-1	6/29/04	277-117-3	277-117-S-3	DUP-14194	Escherichia coli	0.93
12	CNST-5	6/29/04	277-117-4	277-117-S-4	DUP-15283	Citrobacter freundii	0.89
13	CNST-5	6/29/04	277-117-5	277-117-S-5	DUP-16200	Serratia marcescens	0.89
14	CNST-3	6/29/04	277-117-6	277-117-S-6	None	None	None
15	CNST-7	6/29/04	277-117-7	277-117-S-7	None	None	None
16	CW-24	6/29/04	277-117-8	277-117-S-8	None	None	None
17	PD_D-10	8/3/04	277-152-1	277-152-S-1	DUP-15290	Serratia marcescens	0.89

Appendix Table 39. Riboprinter Analysis for Selected Isolates from Heterotrophic Plate Count Plates

Sample No.	ID No.	Sample Date	Riboprinter Sample No.	Ribogroup	DuPont ID	DuPont ID Label	DID Sim
1	PC-1	8/4/04	277-138-5	277-138-S-5	None	None	None
2	PC_D-1	8/4/04	277-138-4	277-138-S-4	None	None	None
3	PD_D-1	8/3/04	277-126-3	277-126-S-3	None	None	None
4	PD_D-9	9/7/04	277-153-2	277-153-S-2	None	None	None
5	PD_D-9	9/7/04	277-153-3	277-153-S-3	None	None	None
6	PD_D-10	8/3/04	277-126-1	277-126-S-1	None	None	None
7	PW-18	9/7/04	277-153-1	277-153-S-1	None	None	None
8	CD-39	9/8/04	277-152-6	277-152-S-6	None	None	None
9	CD-39	9/8/04	277-152-7	277-152-S-7	DUP-18547	Stenotrophomonas maltophilia	0.93
10	CD-39	9/8/04	277-153-5	277-153-S-5	None	None	None
11	CD_D-5	9/8/04	277-152-4	277-152-S-4	None	None	None
12	CD_D-10	9/8/04	277-152-3	277-152-S-3	None	None	None
13	CD_D-16	8/31/04	277-134-4	277-134-S-4	None	None	None
14	CD_D-17	9/7/04	277-152-2	277-152-S-2	None	None	None
15	CD_D-17	9/7/04	277-153-4	277-153-S-4	None	None	None
16	CR_D-2	9/8/04	277-152-8	277-152-S-8	None	None	None
17	CR_D-2	9/8/04	277-153-6	277-46-S-7	DUP-18429	Terracoccus luteus	0.99
18	CST-1	8/4/04	277-126-5	277-126-S-5	None	None	None
19	CST-1	8/4/04	277-126-6	277-126-S-6	DUP-4239	Staphylococcus xylosus	0.87
20	CST-1	8/31/04	277-134-5	277-134-S-5	None	None	None
21	CST-5	8/3/04	277-126-2	277-126-S-2	None	None	None
22	CST-8	9/8/04	277-153-8	277-153-S-8	None	None	None
23	CST-10	8/4/04	277-126-7	277-126-S-7	DUP-15429	Serratia marcescens	0.9
24	CST-10	8/4/04	277-126-8	277-126-S-8	None	None	None
25	CW-3	8/31/04	277-134-3	277-134-S-3	None	None	None
26	CW-25	8/31/04	277-134-1	277-134-S-1	DUP-6054	Bacillus megaterium	0.85
27	CW-25	8/31/04	277-134-2	277-134-S-2	None	None	None
28	CW-25	8/31/04	277-134-6	277-65-S-4	DUP-6607	Vibrio cholerae	0.85
29	CW-25	8/31/04	277-137-7	277-65-S-4	None	None	None
30	CW-25	8/31/04	277-138-8	277-138-S-8	None	None	None
31	CW-26	8/31/04	277-134-8	277-134-S-8	None	None	None
32	CW-26	8/31/04	277-138-1	277-138-S-1	None	None	None
33	CW-38	9/8/04	277-152-5	277-152-S-5	DUP-4192	Staphylococcus saprophyticus	0.93
34	CW-42	8/31/04	277-138-3	277-65-S-4	None	None	None
35	CW-42	8/31/04	277-138-2	277-138-S-2	None	None	None
36	CW-42	8/31/04	277-138-6	277-138-S-6	None	None	None
37	CW-42	8/31/04	277-138-7	277-138-S-7	None	None	None
38	CW-47	9/8/04	277-153-7	277-153-S-7	None	None	None

Appendix Table 40. Data for ATP and Heterotrophic Bacteria (HB) in Well Water (County of Hawaii)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	CW-1	11/9/04	79	25 ml	90	25 ml
2	CW-2	11/9/04	139	25 ml	52	25 ml
3	CW-3	11/30/04	38736	25 ml	159	25 ml
	CW-3	11/30/04	549024	10 ml		
4	CW-4	1/25/05	752	25 ml	276	25 ml
5	CW-5	1/25/05	29	25 ml	11	25 ml
6	CW-6	11/30/04	250	25 ml	99	25 ml
7	CW-7	11/30/04	47242	25 ml	21	25 ml
	CW-7	11/30/04	60	10 ml		
8	CW-7	2/9/05	74	25 ml	60	25 ml
9	CW-8	11/30/04	569	25 ml	423	25 ml
10	CW-9	11/30/04	6111	25 ml	800	25 ml
	CW-9	11/30/04	2281	10 ml		
11	CW-10	2/9/05	1051	25 ml	568	25 ml
	CW-10	2/9/05	644	10 ml		
12	CW-11	11/30/04	6937	25 ml	832	25 ml
	CW-11	11/30/04	4368	10 ml		
13	CW-12	11/30/04	132	25 ml	528	25 ml
14	CW-13	11/30/04	183	25 ml	41	25 ml
15	CW-14	10/19/04	131	25 ml	196	25 ml
16	CW-15	10/19/04	2556	25 ml	592	25 ml
	CW-15	10/19/04	1580	10 ml		
17	CW-15	1/11/05	6563	25 ml	244	25 ml
	CW-15	1/11/05	2788	10 ml		
18	CW-16	10/19/04	59	25 ml	21	25 ml
19	CW-16	1/11/05	222	25 ml	53	25 ml
20	CW-17	10/19/04	1515	25 ml	124	25 ml
	CW-17	10/19/04	757	10 ml		
21	CW-17	1/11/05	7486	25 ml	139	25 ml
	CW-17	1/11/05	5857	10 ml		
22	CW-18	11/30/04	336	25 ml	16	25 ml
23	CW-21	11/30/04	245	25 ml	89	25 ml
24	CW-21	2/9/05	358	25 ml	42	25 ml
25	CW-22	10/19/04	78	15 ml	85	25 ml
26	CW-23	10/19/04	16	25 ml	109	25 ml
27	CW-23	1/11/05	249	25 ml	57	25 ml
28	CW-24	10/5/04	73	25 ml	50	25 ml
29	CW-26	1/25/05	3916	25 ml	572	25 ml
	CW-26	1/25/05	1884	10 ml		
30	CW-27	1/25/05	9286	25 ml	129	25 ml
	CW-27	1/25/05	3938	10 ml		
31	CW-28	11/9/04	5931	25 ml	608	25 ml
	CW-28	11/9/04	2389	10 ml		
32	CW-30	9/7/04	18802	25 ml	784	25 ml
	CW-30	9/7/04	32836	25 ml		
33	CW-30	10/19/04	16975	25 ml	1344	25 ml
	CW-30	10/19/04	11574	10 ml		
34	CW-31	9/7/04	212	25 ml	369	25 ml
	CW-31	9/7/04	260	25 ml		

Appendix Table 40—*Continued*

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
35	CW-31	10/19/04	251	25 ml	656	25 ml
36	CW-32	11/9/04	42	25 ml	81	25 ml
37	CW-33	11/9/04	1811	25 ml	22	25 ml
	CW-33	11/9/04	312	10 ml		
38	CW-34	9/7/04	465	25 ml	496	25 ml
	CW-34	9/7/04	12	25 ml		
39	CW-34	10/19/04	1293	25 ml	412	25 ml
	CW-34	10/19/04	598	10 ml		
40	CW-35	10/19/04	37	25 ml	39	25 ml
41	CW-35	1/11/05	93	25 ml	83	25 ml
45	CW-36	10/19/04	475	25 ml	544	25 ml
46	CW-36	1/11/05	2396	25 ml	84	25 ml
	CW-36	1/11/05	1047	10 ml		
44	CW-37	9/7/04	12	25 ml	10	25 ml
	CW-37	9/7/04	19	25 ml		
45	CW-37	10/5/04	24	25 ml	6	25 ml
46	CW-38	9/7/04	25	25 ml	26	25 ml
	CW-38	9/7/04	21	25 ml		
47	CW-38	10/5/04	197	25 ml	12	25 ml
48	CW-39	9/7/04	24	25 ml	19	25 ml
	CW-39	9/7/04	27	25 ml		
49	CW-39	10/5/04	8	25 ml	10	25 ml
50	CW-40	10/5/04	20	25 ml	90	25 ml
51	CW-41	1/25/05	643	25 ml	12	25 ml
52	CW-42	1/25/05	1269	25 ml	115	25 ml
	CW-42	1/25/05	336	10 ml		
53	CW-43	11/9/04	1304	25 ml	231	25 ml
	CW-43	11/9/04	901	10 ml		
54	CW-43	1/25/05	1571	25 ml	13	25 ml
	CW-43	1/25/05	1269	10 ml		
55	CW-44	9/7/04	60	25 ml	101	25 ml
	CW-44	9/7/04	39	25 ml		
56	CW-44	10/5/04	23	25 ml	25	25 ml
57	CW-45	9/7/04	496	25 ml	1680	25 ml
	CW-45	9/7/04	617	25 ml		
58	CW-45	10/5/04	146	25 ml	40	25 ml
59	CW-46	9/7/04	21	25 ml	90	25 ml
	CW-46	9/7/04	43	25 ml		
60	CW-46	10/5/04	19	20 ml	98	25 ml
61	CW-47	9/7/04	61	25 ml	14	25 ml
	CW-47	9/7/04	44	25 ml		
62	CW-47	10/5/04	37	25 ml	107	25 ml

Appendix Table 41. Data for ATP and Heterotrophic Bacteria (HB) in Distribution Water (County of Hawaii)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	CD_D-1	9/7/04	120	25 ml	604	25 ml
	CD_D-1	9/7/04	62	25 ml		
2	CD_D-1	10/5/05	102	25 ml	262	25 ml
3	CD_D-3	11/30/04	24	25 ml	61	25 ml
4	CD_D-4	1/25/05	37	25 ml	13	25 ml
5	CD_D-5	9/7/04	29	25 ml	16	25 ml
	CD_D-5	9/7/04	25	25 ml		
6	CD_D-5	10/5/05	60	25 ml	57	25 ml
7	CD_D-6	11/30/04	115	25 ml	143	25 ml
8	CD_D-6	2/9/05	77	25 ml	424	25 ml
9	CD_D-7	11/30/04	142	25 ml	0	25 ml
10	CD_D-8	11/9/04	95	25 ml	23	25 ml
11	CD_D-9	11/9/04	1370	25 ml	66	25 ml
	CD_D-9	11/9/04	761	10 ml		
12	CD_D-10	9/7/04	0	25 ml	3	25 ml
	CD_D-10	9/7/04	2	25 ml		
13	CD_D-10	10/19/05	14	25 ml	5	25 ml
	CD_D-11	10/19/05	266	25 ml	107	25 ml
14	CD_D-11	1/11/05	860	25 ml	262	25 ml
15	CD_D-12	11/30/04	55	25 ml	43	25 ml
16	CD_D-12	2/9/05	26	25 ml	196	25 ml
17	CD_D-13	11/30/04	41	25 ml	1	25 ml
18	CD_D-14	1/25/05	16	10 ml	4	25 ml
	CD_D-14	1/25/05	20	10 ml		
18	CD_D-15	11/30/04	71	25 ml	123	25 ml
20	CD_D-16	11/30/04	30	25 ml	41	25 ml
21	CD_D-17	9/7/04	843148	25 ml	6	25 ml
	CD_D-17	9/7/04	11	25 ml		
22	CD_D-17	1/11/05	296	25 ml	30	25 ml
23	CD_D-18	11/9/04	81	25 ml	6	25 ml
24	CD_D-19	9/7/04	5	25 ml	7	25 ml
	CD_D-19	9/7/04	10	25 ml		
25	CD_D-19	10/5/05	13	25 ml	2	25 ml
26	CD_D-20	11/9/04	7013	25 ml	8	25 ml
	CD_D-20	11/9/04	977	10 ml		
27	CD_D-21	10/19/05	4	25 ml	19	25 ml
28	CD_D-21	1/11/05	693	25 ml	22	25 ml
29	CD_D-22	10/5/05	28	25 ml	13	25 ml

Appendix Table 42. Data for ATP and Heterotrophic Bacteria (HB) in Combination of Ground, Surface, Spring and Tunnel Water (County of Hawaii)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	CC_D-1	11/9/04	125	25 ml	180	25 ml
	CC_D-1	11/9/04	115	10 ml		
2	CC_D-2	10/5/04	13	25 ml	4	25 ml
3	CC_D-3	9/7/04	54	25 ml	0	25 ml
	CC_D-3	9/7/04	75	25 ml		
4	CC_D-3	10/19/04	198	25 ml	5	25 ml
5	CC_D-4	11/9/04	163378	25 ml	9	25 ml
	CC_D-4	11/9/04	25	10 ml		

Appendix Table 43. Data for ATP and Heterotrophic Bacteria (HB) in Reservoir Water (County of Hawaii)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	CR_D-1	10/19/04	34	25 ml	19	25 ml
2	CR_D-1	1/11/05	21	25 ml	26	25 ml
3	CR_D-2	9/7/04	37	25 ml	66	25 ml
	CR_D-2	9/7/04	30	25 ml		
4	CR_D-2	10/5/04	32	25 ml	2	25 ml
5	CR_D-3	9/7/04	40	25 ml	3	25 ml
	CR_D-3	9/7/04	27	25 ml		

Appendix Table 44. Data for ATP and Heterotrophic Bacteria (HB) in Surface Water (County of Hawaii)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	CS-1	11/9/04	20207	8 ml	388	25 ml
	CS-1	11/9/04	10323	2 ml		
2	CS-1	1/25/04	33049	3 ml	252	25 ml
	CS-1	1/25/04	32048	3 ml		

Appendix Table 45. Data for ATP and Heterotrophic Bacteria (HB) in Disinfected Spring and Tunnel Water (County of Hawaii)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	CST_D-6	9/7/04	15	25 ml	6	25 ml
	CST_D-6	9/7/04	8	25 ml		25 ml
2	CST_D-1	10/5/04	28	25 ml	41	25 ml
3	CST_D-4	10/5/04	301	25 ml	31	25 ml
4	CST_D-2	10/5/04	0	25 ml	3	25 ml
5	CST_D-6	10/19/04	11	25 ml	2	25 ml
6	CST_D-7	11/9/04	142	25 ml	16	25 ml
7	CST_D-1	11/9/04	837	25 ml	27	25 ml
8	CST_D-3	1/25/05	29	25 ml	152	25 ml
9	CST_D-5	1/25/05	57	25 ml	495	25 ml

Appendix Table 46. Data for ATP and Heterotrophic Bacteria (HB) in Non-Disinfected Spring and Tunnel Water (County of Hawaii)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	CST-1	10/5/04	1828	25 ml	101	25 ml
	CST-1	10/5/04	632	25 ml		
2	CST-1	11/9/04	950	25 ml	174	25 ml
3	CST-2	9/7/04	152	25 ml	178	25 ml
	CST-2	9/7/04	18	25 ml		
4	CST-2	10/19/04	547	25 ml	188	25 ml
5	CST-3	11/9/04	348138	25 ml	268	25 ml
	CST-3	11/9/04	74612	10 ml		
6	CST-4	9/7/04	908	25 ml	384	25 ml
	CST-4	9/7/04	467	25 ml		
7	CST-4	10/19/04	2245	25 ml	242	25 ml
	CST-4	10/19/04	651	10 ml		
8	CST-5	11/9/04	265	25 ml	374	25 ml
9	CST-6	10/5/04	14	25 ml	8	25 ml
10	CST-7	10/5/04	552	25 ml	476	25 ml
11	CST-8	9/7/04	103	25 ml	202	25 ml
	CST-8	9/7/04	905	25 ml		
12	CST-8	10/19/04	105	25 ml	115	25 ml
13	CST-9	1/25/05	389	25 ml	50	25 ml
14	CST-10	10/5/04	378	25 ml	166	25 ml
15	CST-11	1/25/05	1712	25 ml	284	25 ml
	CST-11	1/25/05	1840	10 ml		

Appendix Table 47. Data for ATP and Heterotrophic Bacteria (HB) in Well Water (Private Companies)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	PW-1	9/7/04	14	25 ml	35	25 ml
	PW-1	9/7/04	7	25 ml		
2	PW-1	10/5/04	77	25 ml	53	25 ml
3	PW-2	11/9/04	234	25 ml	135	25 ml
4	PW-3	9/7/04	324	25 ml	369	25 ml
	PW-3	9/7/04	330	25 ml		
5	PW-3	10/5/04	225	25 ml	102	25 ml
6	PW-4	12/15/04	1834	25 ml	111	25 ml
	PW-4	12/15/04	419	10 ml		
7	PW-5	12/15/04	4724	25 ml	25	25 ml
	PW-5	12/15/04	4729	10 ml		
8	PW-7	12/15/04	362	25 ml	17	25 ml
9	PW-8	2/16/05	621	25 ml	161	25 ml
10	PW-9	2/16/05	13075	25 ml	2240	25 ml
11	PW-10	12/15/04	185	25 ml	27	25 ml
12	PW-11	12/15/04	22899	25 ml	456	25 ml
	PW-11	12/15/04	7700	10 ml		
13	PW-17	9/7/04	3241	25 ml	4256	25 ml
	PW-17	9/7/04	5952	25 ml		
14	PW-17	11/9/04	520	25 ml	1120	25 ml
15	PW-18	9/7/04	4433	25 ml	744	25 ml
	PW-18	9/7/04	3314	25 ml		
16	PW-18	11/9/04	4646	25 ml	180	25 ml
	PW-18	11/9/04	1605	10 ml		
17	PW-19	12/15/04	73	25 ml	35	25 ml
18	PW-24	2/23/05	250	25 ml	136	25 ml
	PW-24	2/23/05	141	10 ml		
19	PW-25	2/23/05	9500	25 ml	43	25 ml
	PW-25	2/23/05	23	10 ml		
20	PW-26	12/15/04	3111	25 ml	56	25 ml
	PW-26	12/15/04	1243	10 ml		
21	PW-26	2/16/05	8753	25 ml	1120	25 ml
22	PW-27	12/15/04	215	25 ml	32	25 ml
23	PW-27	2/16/05	259	25 ml	492	25 ml
24	PW-28	11/9/04	325	25 ml	121	25 ml
25	PW-29	2/16/05	793	25 ml	77	25 ml
26	PW-30	2/16/05	286	25 ml	560	25 ml
27	PW-34	12/15/04	25	25 ml	21	25 ml
28	PW-34	2/23/05	26	25 ml	24	25 ml
	PW-34	2/23/05	31	10 ml		

Appendix Table 48. Data for ATP and Heterotrophic Bacteria (HB) in Distribution Water (Private Companies)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	PD_D-1	9/7/04	10	25 ml	6	25 ml
	PD_D-1	9/7/04	7	25 ml		
2	PD_D-1	10/5/04	11	25 ml	3	25 ml
3	PD_D-2	11/9/04	158	25 ml	78	25 ml
4	PD_D-3	9/7/04	22	25 ml	7	25 ml
	PD_D-3	9/7/04	45	25 ml		
5	PD_D-3	10/5/04	29	25 ml	73	25 ml
6	PD_D-4	12/15/04	220	25 ml	41	25 ml
7	PD_D-5	2/16/05	225	25 ml	7	25 ml
8	PD_D-6	12/15/04	1171	25 ml	4	25 ml
	PD_D-6	12/15/04	304	10 ml		
9	PD_D-9	9/7/04	16	25 ml	1	25 ml
	PD_D-9	9/7/04	21	25 ml		
10	PD_D-9	11/9/04	2660	25 ml	8	25 ml
11	PD_D-11	12/15/04	0	25 ml	1	25 ml
12	PD_D-11	2/23/05	34	25 ml	18	25 ml
13	PD_D-12	12/15/04	37	25 ml	3	25 ml
14	PD_D-12	2/16/05	132	25 ml	712	25 ml
15	PD_D-14	12/15/04	25	25 ml	21	25 ml
16	PD_D-14	2/23/05	105	25 ml	69	25 ml
	PD_D-14	2/23/05	22	10 ml		

Appendix Table 49. Data for ATP and Heterotrophic Bacteria (HB) in Combination of Ground, Surface, Spring and Tunnel Water (Private Companies)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	PC_D-1	10/5/04	368	25 ml	3	25 ml
	PC_D-1	10/5/04	9	10 ml		
2	PC_D-2	10/5/04	59	25 ml	0	25 ml
	PC_D-2	10/5/04	41	10 ml		

Appendix Table 50. Data for ATP and Heterotrophic Bacteria (HB) in Reservoir Water (Private Companies)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	PR_D-2	2/16/04	376	25 ml	13	25 ml

Appendix Table 51. Data for ATP and Heterotrophic Bacteria (HB) in Surface Water (Private Companies)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	PS-1	11/9/04	1425	25 ml	200	25 ml
	PS-1	11/9/04	475	10 ml		
2	PS-2	11/9/04	2296	25 ml	3360	25 ml
	PS-2	11/9/04	823	10 ml		

Appendix Table 52. Data for ATP and Heterotrophic Bacteria (HB) in Catchment Water (Private Companies)

Sample No.	ID #	Sample Date	ATP (RLU)	Volume	HB (CFU)	Volume
1	PCM-1	10/5/04	15829	20 ml	896	25 ml
	PCM-1	10/5/04	9865	10 ml		
2	PCM-2	10/5/04	19007	25 ml	320	25 ml
	PCM-2	10/5/04	12085	10 ml		

Appendix Table 53. Lasentec Results for Well Water (County of Hawaii and Private Companies)

Sample No.	ID #	Sample Date	Fine (0-16 μm)	Fine to Med (16-90 μm)	Med-Coarse (90-200 μm)	Coarse (210-1000 μm)	Total No. Particles
1	CW-16	3/10/05	21.2	1747.3	13.5	1.9	1783.9
2	CW-23	3/10/05	4.6	6.2	5.1	1.9	17.8
3	CW-17	3/10/05	7779.4	15930.6	26.5	2.0	23738.5
4	CW-31	3/10/05	8494.7	10898.2	113.2	4.3	19510.4
5	CW-38	5/25/04	36166.2	22731.2	23.2	1.0	58921.6
6	PW-13	6/15/04	18559.9	8284.4	197.4	77.6	27119.3
7	PW-30	6/16/04	17354.0	6673.8	2.3	0.0	24030.1
8	PW-29	6/16/04	14610.4	6499.0	4.3	0.0	21113.7
9	PW-26	6/16/04	17464.6	5915.4	0.7	0.0	23380.7
10	PW-4	6/16/04	15076.4	7132.0	4.0	0.7	22213.0
11	PW-7	6/15/04	13635.6	6922.8	2.3	0.0	20560.6
12	PW-32	6/16/04	9106.2	7764.6	13.5	1.0	16885.2