Water Resources Research Center
Annual Technical Report
FY 2002

Introduction

For the 2002-2003 report period, the University of Hawaii Water Resources Research Center continued with its principal focus on water quality issues and on economic modeling of water allocation over time and space.

WRRC had no faculty turnover during the period, although we recruited an engineer/hydrologist to join the faculty in August 2003. This appointment, joint with the UH Department of Botany, brings the WRRC faculty to nine individuals occupying 6.5 FTE positions. In addition, two affiliate faculty had active WRRC-funded projects. State funding also supports one full time technical assistant, three editorial/graphics persons and three secretarial/clerical positions.

The USGS State Water Institutes grant supported one new and two continuing projects, in addition to technology transfer and directors office activities. The new project, by Economics Professor James Roumasset, will construct a dynamic optimization model integrating economic and hydrological factors to improve the allocation of water on Hawaiis largest island, Oahu. USGS funds were leveraged with $839,000 appropriated by Hawaiis State Legislature.

In addition to the WRRIP grant, ten new projects were supported by grants totaling $1.4 million. New projects were supported by the Honolulu Board of Water Supply, the Honolulu Wastewater Division, the state Department of Agriculture, the US Army Pacific Command, EPA and several private sector firms.

Research Program

Removal of Nitrogenous Aquaculture Wastes by a Wind-Powered Reverse Osmosis System, Year 2

Basic Information

Title:	Removal of Nitrogenous Aquaculture Wastes by a Wind-Powered Reverse Osmosis System, Year 2
Project Number:	2002HI1B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Water Supply, Waste Water
Descriptors:	nitrogen, aquaculture waste, membrane, reverse osmosis, water reuse
Principal Investigators:	Clark C.K. Liu

Publication

Problem and Research Objectives

Advanced treatment must be provided to wastewater used for freshwater aquaculture in order to meet effluent water quality standards. Because such treatment can be expensive and because freshwater is also increasingly in short supply around the world, an attractive management alternative is to develop a closed aquaculture system that supports effluent treatment and reuse while overcoming obstacles of high treatment cost and a short freshwater supply. The research objectives are (1) to investigate the nitrogen build-up in freshwater aquaculture of tilapia, (2) to develop a wind-powered reverse osmosis nitrogen removal system, and (3) to evaluate the economic feasibility of the wind-powered reverse osmosis system for removing nitrogen from aquaculture wastes.

Methodology

This is a two-phase project, with each phase lasting about one year. The focus of the first year's research (activities and findings reported here) is to study the characteristics of aquaculture waste, especially the concentration of nitrogen at different stages of fish (tilapia) growth. The second year's research will be conducted to investigate the performance of nitrogen removal by the reverse osmosis process and to develop a water recirculating system for tilapia production.

Principal Findings and Significance

An experimental system, which consists of an aquaculture subsystem or a fish tank for tilapia culture and a wind-powered reverse osmosis treatment subsystem, was constructed at the research facilities of the Hawaii Institute of Marine Biology on Coconut Island, Oahu, Hawaii.

Water samples were collected from the tilapia culture tank from June 2001 to February 2002. Samples were analyzed in the water quality laboratory of the Water Resources Research Center at the University of Hawaii at Manoa. Table 1 shows the nitrogen concentration data for the aquaculture subsystem. Feedwater is the freshwater provided to the fish tank. Discharge indicates the aquaculture waste flow out of the fish tank. The waste discharge

Table 1. Nitrogen Concentrations of Aquaculture Subsystem Under Normal Conditions

Date	NH_3-N (mg/l)		NO_3-N (mg/l)		NO_2-N (mg/l)	
	Feedwater	Discharge	Feedwater	Discharge	Feedwater	Discharge
06/13/2001	UD*	0.19	0.17	0.14	0.001	0.006
06/14/2001	UD	0.14	0.17	0.14	0	0.001
06/15/2001	UD	0.11	0.21	0.17	0.003	0.004
06/21/2001	UD	0.12	0.20	0.16	0.003	0.002
07/10/2001	UD	0.07	0.15	0.13	0.002	0.001
01/07/2002	UD	0.40	0.17	0.17	0.001	0.001
01/09/2002	UD	0.32	0.17	0.17	0.001	0.003
01/17/2002	UD	0.50	0.16	0.16	0	0
01/22/2002	UD	0.23	0.17	0.20	0	0.001
01/24/2002	UD	0.20	0.17	0.18	0.001	0.002
01/31/2002	UD	0.09	0.17	0.17	0.002	0.001
02/05/2002	UD	0.22	0.14	0.16	0	0.001
02/12/2002	UD	0.26	0.16	0.16	0.001	0.002
02/14/2002	UD	0.06	0.18	0.16	0	0.002
02/21/2002	UD	0.09	0.14	0.14	0	0
02/26/2002	UD	0.25	0.12	0.12	0.004	0.003

*UD = undetectable.

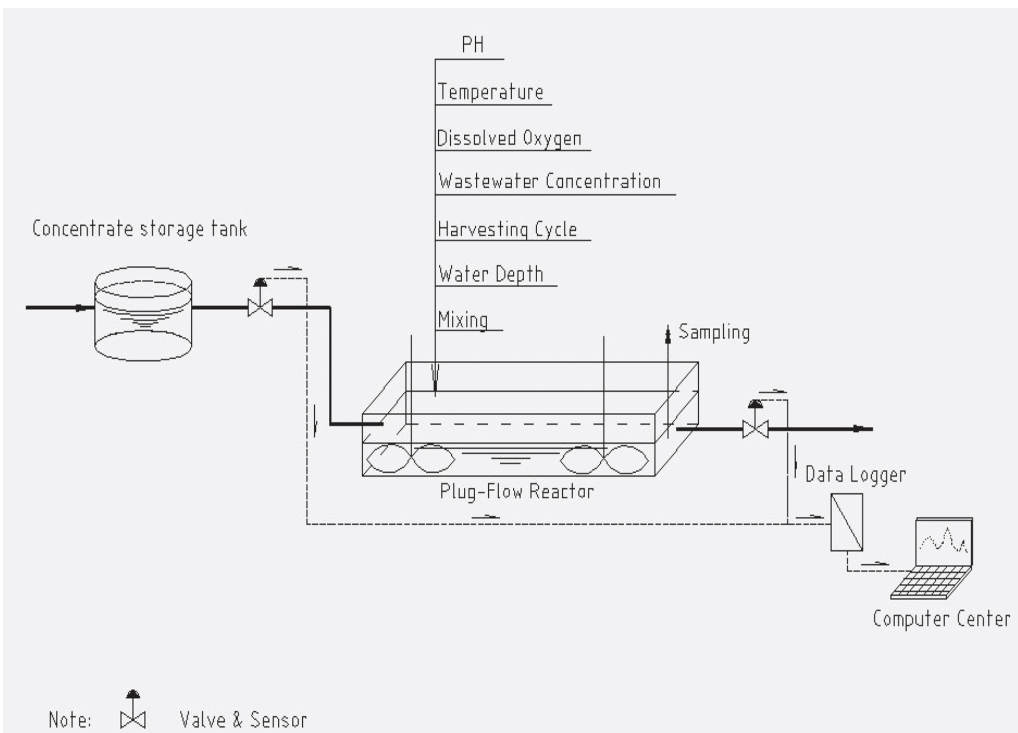
becomes the feedwater for the wind-powered reverse osmosis treatment subsystem. The hydraulic retention time in the aquaculture subsystem or fish tank was about 500 minutes (8.3 hours). During this time, the feedwater and waste discharge rates were both about 73 gal/h (4.6 l/min).

The feedwater provided to the fish tank contained ammonia nitrogen (NH_3-N) at a concentration of less than 0.03 mg/l, whereas the concentration in the aquaculture waste discharge averaged 0.20 mg/l with an unbiased standard deviation of ±0.12 mg/l. The average feedwater nitrate nitrogen (NO_3-N) concentration was 0.17 ± 0.02 mg/l, and the discharge concentration was 0.16 ± 0.02 mg/l. The nitrite nitrogen (NO_2-N) concentration was 0.0012 ± 0.0012 mg/l for the feedwater and 0.0019 ± 0.0015 mg/l for the discharge.

Performance of the reverse osmosis treatment subsystem to remove nitrogen has been evaluated by studying nitrogen concentrations in the feedwater and product water (permeate), as well as by studying the operating flow rate and feed water pressure. Preliminary data indicated that the subsystem removes about 93% of the ammonia and nitrate from the feedwater.

The results of the nitrogen removal research derived by this project are included in a manuscript entitled "Aquaculture Wastewater Treatment and Reuse by Wind-Powered Reverse Osmosis Membrane Technology: A Case Study on Coconut Island, Hawaii" by G. Qin, C.C.K. Liu, H. Richman, and J.E.T. Moncur. The manuscirpt will be submitted to the *Journal of Aquaculture Engineering*.

As part of the continuing research effort, a plug-flow bioreactor is being designed for the treatment and use of concentrate (brine) from the reverse osmosis process (see figure below).



A Win-Win Approach to Water Pricing and Watershed Conservation

Basic Information

Title:	A Win-Win Approach to Water Pricing and Watershed Conservation
Project Number:	2002HI2B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	First
Research Category:	Social Sciences
Focus Category:	Economics, Conservation, Water Supply
Descriptors:	groundwater, optimal control, watershed conservation, block pricing
Principal Investigators:	James A. Roumasset, Rodney B.W. Smith

Publication

1. Kaiser, B.; B. Pitafi; J. Roumasset, 2003, Win-Win Pricing for Watershed Conservation, Working Paper, Water Resources Research Center, University of Hawaii, forthcoming.
2. Pitafi, B.; J. Roumasset, 2003, Efficient Groundwater Pricing and Watershed Conservation Finance: The Honolulu Case, Working Paper, Water Resources Research Center, University of Hawaii, forthcoming.

Problem and Research Objectives

Several studies have documented that inter-temporal water allocation in Hawaii is inefficient. However, the consequences of misallocation, including the economic value lost, are unknown. Moreover, other sources of mismanagement, including spatial misallocation and under-maintenance of watersheds, need to be considered in an integrated framework in order to assess the nature and size of the problem and the potential gains from policy reforms.

The overall objective of the project is to combine existing hydrological, engineering, and economic knowledge in order to estimate efficient water use in Oahu's central corridor (from East Honolulu to Waialua). Rather than take aquifer recharge rates as exogenous to water management, we incorporate watershed management as one of the policy instruments. Alternative pricing schemes for achieving efficient use are calculated. We explore whether conservation surcharges will result in sufficient additional aquifer recharge to cause efficiency prices to fall by more than the original surcharge. This would be a 'win-win-win' solution for water consumers, taxpayers, and environmental stewardship.

Methodology

We wish to estimate optimal groundwater usage with and without the watershed conservation plan. The modeling framework constructed estimates optimal groundwater extraction quantities while avoiding over-extraction that would lead to salinity in existing wells and using desalted water as a supplemental source as warranted by demand. The effects of watershed conservation are introduced in the form of probabilistic changes in recharge.

We divide the central corridor of Oahu into four zones, each with its own groundwater aquifer receiving exogenous recharge from the Koolau watershed and from adjacent zones. The four zones are Honolulu, Pearl Harbor (including part of the Ewa district), Schofield, and North Oahu (Waialua & Kawailoa). Each zone has a distribution network that supplies water to many different elevations. Each zone is divided into a number of elevation categories. Each elevation category has its own demand function. We use parameters estimated from the Honolulu aquifer to solve for optimal extraction, distribution, and marginal valuation.

In year two of the project we will extend the model to include the rest of the central corridor to capture the hydrodynamics of the entire corridor. In that model, inter-zone water trading will also be allowed. When the shadow-price differentials between any two zones exceed the corresponding inter-zone transport costs, water will be transferred from a high shadow-price zone to a low shadow-price zone. This will provide estimates of the effects of conservation and water trade on efficiency prices and groundwater stock.

Principal Findings and Significance

We have constructed modeling frameworks and estimated parameters for each aquifer. We have conducted pioneer simulations for the cases of Pearl Harbor and Honolulu aquifers. The two simulations provide comparable results: the superiority of efficiency pricing with conservation scenario.

Optimal price and head paths for Pearl Harbor — Preliminary analysis was conducted without the minimum head level constraint and without elevation differentiation. A hypothetical social planner chooses the extraction rate of water from the aquifer to maximize the present value of net social surplus. The dynamic of the head level is governed by the amount of water inflow, leakage, and extraction rate. We allow different discount rates, demand growth rates, and different changes in forest recharge level. The welfare gain from conservation and efficient pricing is estimated at around 1 billion dollars.

Optimal price and head paths for Honolulu — The simulation is conducted with head constraint and without elevation differentiation. To include the effects of watershed quality on aquifer recharge, we assume there is a probability that, at a definite time, an *adverse* event will happen. A adverse event is a negative change in forest composition that decreases the amount of water recharge affecting the head level equation of motion. If the adverse event does not occur, the aquifer recharge rate will remain constant. The hypothetical social planner does not know beforehand whether or not the event will occur and has to take into account the event probability while pricing and extracting water from the aquifer.

We analyze three scenarios of water usage/pricing. (a) *Status-quo* — We derive the extraction rates dictated by demand resulting from a continuation of average-cost pricing and estimate the resulting welfare. (b) *Efficient pricing with no watershed conservation* — Insufficient conservation efforts cause the risk of reduced recharge. (c) *Efficient pricing with watershed conservation* — Conservation expenditures are sufficient to prevent depreciation of forest and other vegetative cover.

We found that switching to efficiency prices is welfare enhancing and that expensive desalination technology can be delayed for nearly two decades. Incorporating the risk of decreased aquifer recharge, watershed conservation and efficiency pricing was estimated to increase expected net benefits (consumer surplus) by 8 billion dollars compared to status-quo pricing. We compared the revenue collected under different pricing schemes and showed that the largest revenue is raised under efficiency pricing with conservation. The revenue, generated by the difference between price and cost, can be returned to the consumers (assuming a balanced budget) using a block-pricing scheme. Under efficiency pricing with conservation scenario, the block size of 118 gallons a day can be provided to each consumer for free to recycle the revenue raised in the first period. As the scarcity rent and consumption increase over time, so does the revenue raised. Returning this revenue requires increasing the block size over time. Assuming the number of consumers remains the same in Honolulu (using projections of the Hawaii Department of Business, Economic Development and Tourism), the free block size reaches 945 gallons per consumer per day in 50 years.

An Accurate Evaluation of Water Balance to Predict Surface Runoff and Percolation

Basic Information

Title:	An Accurate Evaluation of Water Balance to Predict Surface Runoff and Percolation
Project Number:	2002HI4B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	First
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, Water Quality, Non Point Pollution
Descriptors:	models, runoff, best management practices, vadose zone, ground water, infiltration, recharge
Principal Investigators:	Chittaranjan Ray

Publication

Problem and Research Objectives

Hawaii, like many other states, has a number of unlined landfills that are potential groundwater contamination sources. Infiltration control is a major means of reducing leachate generation at unlined landfill sites. Use of synthetic materials for the closure of landfills is quite expensive, especially for small rural communities. Use of alternate capping technologies, such as vegetation caps, may not be suitable in humid areas where the annual precipitation exceeds the evapotranspiration demand of growing crops. However, a combination of natural soil caps and runoff-enhancing structures can be a feasible capping method. Local plants growing on natural soil (clay) caps could transpire a large part of the percolating water. Making a portion of the landfill surface impervious (e.g., by use of rain gutters) and diverting the surface runoff offsite could reduce the entry of water through the landfill cap, thus reducing the potential for leachate generation. A recent demonstration by the U.S. Navy showed that, in tropical areas such as Hawaii, it is possible to cap landfills with natural soil cover if 20% to 40% of the surface area can be covered with rain gutters. However, the amount of error in the prediction was high. The model used daily water balance for calculating runoff and infiltration. In reality, rainfall in Hawaii occurs over a relatively short period of time. Higher-intensity rains cause significant surface runoff. Averaging a storm event over a day would significantly reduce the intensity, making it appear as if there is no runoff and all water is infiltrating the ground. For groundwater recharge studies, this overestimation of recharge may provide a false sense of security through modeling by implying that a large part of the rainwater is entering the soil in recharge areas and less water is lost through runoff. It is clear that an accurate estimate of the partitioning of rainwater to surface runoff and infiltration components and the subsequent movement of infiltrated water through subsoil media is quite important for a variety of applications.

The objectives of the study are to measure percolate and runoff at frequent intervals at each of six test plots and to calibrate and test a recharge model and a runoff-producing model against the collected data. These models will provide some insight into the mechanisms of percolate and runoff production in response to specific storm events. They will also indicate if improvements in modeling strategy are needed to better calibrate these models against the collected data. An additional objective is to validate a regulatory model that is commonly used for the closure of landfill caps. The data will also help in the recalibration of the surface runoff and percolate production models and in the study of chemical transport through the soil. Since this is a multi-year study, the activities this year (2002HI4B) are closely related the first year's effort (2001HI2141B).

Methodology

The study site is located at the Marine Corps Base Hawaii in Kaneohe, Hawaii. The site, located near a landfill site, has six test plots—all instrumented to collect surface runoff, percolate at a depth of 2 to 3 feet, and soil moisture data. In addition, weather data such as temperature, relative humidity, wind velocity and direction, solar radiation, and rainfall are measured at the test site. The site is instrumented with pressure transducers, flow meters, soil moisture probes, and other sensors that are connected to data-logging devices to collect data at intervals ranging from a few minutes to twice daily. All collected data from the data loggers are downloaded to a computer (remotely located anywhere) via a modem and a cellular phone daily.

The following four tasks describe the methodology involved in the current study.

Task 1. Repair and replacement of aging and malfunctioning sensors and instruments, and instrument calibration (continuation of the previous year's activities)

Work in the second year involves the replacement of flow counters, recalibration of pressure transducers, and replacement of level switches. In addition, work involves installing erosion control measures that are needed to prevent sliding of material in various areas of the experimental field.

To calibrate the pressure transducer, each tank is first emptied. Then, a known amount of water is introduced into the tank. The transducer response is recorded as a function of the volume of water that is expressed as the depth of water in the tank. Three separate measurements are made. A line of best fit is drawn to get the slope and the intercept to record the calibration constants.

Task 2. Additional soil hydraulic and vegetation data collection

To use computer models for water balance calculations, additional data (not counting the runoff and leachate data) need to be collected. Some examples include data on weather, soil-water retention, hydraulic conductivity, soil moisture, and leaf area index.

Producing water retention curves for soil samples involves taking core samples from the field to the laboratory and measuring the equilibrated pressure and water content of the samples from –5 cm to 15 bars (-15,000 cm) using a combination of tension tables and pressure-plate apparatus.

A disc infiltrometer (from Soil Measurement Systems) is used to measure hydraulic conductivity at three locations per plot. First, these measurements are made at the soil surface. Then, since the surface soils are affected by cracks, root channels, and other macropore features, similar measurements are made 6 to 8 inches below the land surface.

A vegetation survey is conducted using the point-frame method in which a frame, which has a groove at every 10-cm interval, spans the width of the plot. A thin metal rod is dropped in each of the grooves. The type of plants that the rod touches is then recorded. Also recorded is what the tip of the rod hits (e.g., soil, litter, or gutter). Approximately 600 points in each 6 m × 9 m plot is measured.

Leaf area index can be calculated using two methods. The first method is similar to the vegetation survey technique, except that it uses approximately 40 equally spaced points. The same frame and metal rod are used, but instead of recording which plants the rod touches, the number of live plants with which the rod makes contact is recorded. The 40 points are then averaged to get the leaf area index. The second technique involves tossing a 0.1 m × 0.1 m frame randomly onto the plot. All leaves found inside the frame are cut and bagged. The total area of the leaves divided by 0.01 m^2 gives the leaf area index.

Biomass measurements are needed for each plot. By definition, biomass is the amount of living matter; however, for this project, biomass is defined as the amount of living and dead plants. To estimate the biomass, the 0.1 m × 0.1 m frame is randomly tossed onto the plot. All plant material within the frame is trimmed and bagged, leaving the roots behind. Each sample is dried at 70°C in a plant-drying oven and then weighed. The weight of the dried biomass is divided by 0.01 m^2 to get the average biomass per unit area.

Task 3. Soil particle-size distribution

Duplicate soil cores from four locations outside the plots and two locations within the plots are taken for the analysis of soil particle-size distribution. Both the mechanical sieve analysis and the hydrometer settling method are used to get the size distribution of these particles. Particle-size data are then related to soil hydraulic conductivity.

Task 4. Automated measurement of soil-water pressure and additional measurement of water content

We plan to install 12 automated tensiometers in three plots to measure soil-water tension as a function of time. Each plot will have four tensiometers installed at two depths (two per given depth). In addition, we plan to install 24 tensiometers (four per plot) at various depths so that the soil-water tensions can be checked manually. The retention data for the soils will be used to convert pressure readings to water content values. Further, we plan to install six additional time domain reflectometry (TDR) probes in three plots. The soil moisture will be measured manually and then compared against that measured automatically by the existing TDR system.

Principal Findings and Significance

Erosion cloths and ripraps were used to prevent erosion. Our primary effort during the first year was to set up instrumentation and revitalize the site, and we are quite satisfied with the durability of several sensors and instruments. For example, the pressure transducers are still functional after seven years of service, and most of the rain gages are still working nicely. However, we noticed that all sensors and equipment must be serviced at proper intervals for reliable operation. Preliminary data show that all sensors were working well, due in large part to the new wiring done during the second year. All transducers and flow meters are calibrated at least once a year, and this year a total of 12 calibrations were made. The rainfall frequency data were collected at one-minute intervals using instruments that were triggered by the onset of rain. Thus, during dry periods, no rainfall data were collected.

Eighteen soil cores were retrieved from various depths near the plots. Water retention curves for these cores were prepared using data from a combination of experiments with a hanging water table and a pressure-plate apparatus. Most soils appeared to be clayey, and the drainage time for the samples to attain 15 bars of pressure was more than six weeks. Surface hydraulic conductivity, measured using the disk infiltrometer, ranged between 10 and 30 cm/h, with an average of 20 cm/h. The deeper hydraulic conductivity values were close to 5 cm/h. While these values are significantly lower than those measured at the surface, they are much larger than those used by the U.S. Navy in its earlier study based on core samples.

The leaf area index values were calculated using two techniques (as mentioned in the "Methodology" section). The leaf area index varied between 0.96 and 2.04 using the first method and between 0.20 and 0.47 using the second method. It seems that the two methods give significantly different results. We will conduct further investigations into this discrepancy before using the numbers for modeling purposes.

The biomass measurements ranged between 210 and 900 g/m^2. This large range is understandable because of the varied nature of plant growth in each of the plots. Some areas of the plots have denser plant cover than other areas. Also, the presence of gutters reduces biomass in certain plots.

A master's thesis is being written on this research. In addition, we are working on three manuscripts—one describing the site instrumentation, another dealing with water balance using a regulatory model, and a third involving the improved water balance measurements and modeling.

A no-cost extension to complete this research has been granted through February 2004.

Confirming the Natural Presence of Fecal Indicator Bacteria in Environmental Soil and Water on the Islands of Kauai and Hawaii

Basic Information

Title:	Confirming the Natural Presence of Fecal Indicator Bacteria in Environmental Soil and Water on the Islands of Kauai and Hawaii
Project Number:	2001HI2082B
Start Date:	3/1/2001
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Water Quality, Non Point Pollution, Water Use
Descriptors:	fecal indicator bacteria, tropical environment, water quality standards, water pollution
Principal Investigators:	Roger S. Fujioka

Publication

Problem and Research Objectives

Our laboratory at the Water Resources Research Center, University of Hawaii, has been conducting water quality studies in the state of Hawaii for the past 30 years. One of the most significant results of these studies is our conclusion that U.S. Environmental Protection Agency (EPA) hygienic recreational water quality standards are not applicable to the state of Hawaii (R.S. Fujioka et al., 1988, *Toxicity Assessment* 3:613–630; R.S. Fujioka and M.N. Byappanahalli, 1996, WRRC-96-01, Proj. Compl. Rep., 50 pp.). This conclusion is based on years of monitoring data which show that all streams on the island of Oahu consistently exceed the EPA hygienic recreational water quality standards based on concentrations of fecal indicator bacteria (i.e., fecal coliform, *Escherichia coli*, and enterococci) (R.S. Fujioka et al., 1988, *Toxicity Assessment* 3:613–630; C.M. Hardina and R.S. Fujioka, 1991, *Environ. Toxicol. Water Qual.* 6:185–195). This conclusion is also based on our assessment that the two assumptions used by EPA to interpret the public health risks of recreational water quality standards are not applicable to Hawaii. The reason is because environmental conditions in Hawaii differ from environmental conditions in temperate regions of the world where monitoring data were obtained for use in establishing recreational water quality standards.

The first assumption used by EPA is that there are no significant environmental sources of fecal indicator bacteria. Thus, EPA assumes that the source of fecal indicator bacteria in natural environmental waters is sewage or animal feces. Moreover, when the numbers of these fecal indicator bacteria exceed their respective maximum contaminant levels, under EPA guidelines these waters are considered polluted with sewage and the sewage-borne pathogens will pose an unacceptable risk to users of those waters. However, based on our studies, we have determined that soil in Hawaii is a natural habitat for fecal indicator bacteria. Moreover, rain, which is the source of water for all streams, will transport these soil-bound fecal indicator bacteria to all streams (C.M. Hardina and R.S. Fujioka, 1991, *Environ. Toxicol. Water Qual.* 6:185–195). Thus, soil rather than sewage or feces of animals is the major source of fecal indicator bacteria recovered from all streams of Oahu.

The second assumption used by EPA is that fecal indicator bacteria cannot multiply under natural environmental conditions. However, the results of our studies have shown that environmental conditions (temperature, moisture, nutrients) in Hawaii's soil environment allow these bacteria to multiply (R.S. Fujioka and M.N. Byappanahalli, 1998, WRRC-98-04, Proj. Compl. Rep., 85 pp.; M.N. Byappanahalli and R.S. Fujioka, 1998, *Water Sci. Tech.* 38:171–174). This second assumption is of critical importance because many significant sewage-borne pathogens such as human enteric viruses and protozoa (*Giardia*, *Cryptosporidium*) are not able to multiply under environmental conditions. As a result, if fecal indicator bacteria multiply in the environment, their numbers no longer represent the degree of sewage or fecal contamination and no longer represent the same risk for water-borne transmission of sewage-borne pathogens.

Since the two assumptions used by EPA to establish and interpret hygienic water quality standards are not applicable to Hawaii, we concluded that the recreational water quality standards also are not applicable to Hawaii. An important consequence of applying the EPA recreational water quality standards to Hawaii is that all streams will consistently exceed the hygienic water quality standards. Although we have obtained data to show that the source of these fecal indicator bacteria in streams is primarily from a non-sewage source (soil), current monitoring data are not useful because they cannot be used to determine when streams are really contaminated with sewage. To address this need, we have shown that other alternative fecal indicators (*Clostridium perfringens*, FRNA coliphages) can be used to determine when streams are contaminated with sewage because they cannot multiply under environmental conditions and they are consistently present in high concentrations in sewage (R.S. Fujioka and L.K. Shizumura, 1985, *J. Water Poll. Contr. Fed.* 57:986–992; R.S. Fujioka et al., 1997, *Proc. Water Environ. Fed. 70th Ann. Conf. and Expo.*, 405–411; K. Luther and R. Fujioka, 2002, *WEFTEC 2002 Conf. Proc.*, 75th Ann. Tech. Exhib. and Conf., 12 pp. on CD-ROM).

The identified problem is the potential limitation of our studies because most of the data were collected for the island of Oahu and the results are assumed to be similar for all of the other islands of the state of Hawaii. However, it is well known that the soil composition and geology of the various islands of Hawaii differ because the age of the islands differs. In this regard, the islands arose from the eruption of lava from a single hot spot on the ocean floor. Over time, this hot spot moved eastward, leaving a chain of eight islands. Kauai is the oldest island at 4 to 5 millions years old, and Oahu is the second oldest at 2 to 3 million years old. Molokai, Maui, Lanai, and Kahoolawe, the middle islands, follow in age at about a million years old. Hawaii, the youngest island, is reported to be only 0.7 million years old.

The overall goal of this study is to determine whether environmental monitoring data for fecal coliform, *E. coli*, enterococci, *C. perfringens*, and FRNA coliphages, which have been used to assess the hygienic quality of recreational waters for the island of Oahu, are equally applicable to all of the other islands of the state. The objective of Phase I of this study was to determine whether monitoring data obtained from soil and recreational water samples from the island of Oahu are similar to those obtained from similar types of environmental samples from the island of Kauai, which represents the oldest island. The objective of Phase II was to determine whether monitoring data obtained from soil and recreational water samples taken from the island of Oahu are similar to those obtained from similar types of samples taken from the island of Hawaii, which represents the youngest island. It should be noted that Phase II of this study was not funded, and therefore this report is restricted to Phase I or to assessing the quality of water on the island of Kauai. A no-cost extension was granted for the Phase I work.

Methodology

EPA-approved methods (Standard Methods) to assay for fecal coliform, *E. coli,* and enterococci were used to assay the soil and stream water samples obtained from Kauai. These same water samples were also assayed for *C. perfringens* (J.W. Bisson and V.J. Cabelli, 1979, *Appl. Environ. Microbiol.* 37:55–66) and for FRNA coliphages (J. Debartolomeis and V.J. Cabelli, 1991, *J. Appl. Environ. Microbiol.* 57:1301–1305) using methods developed by EPA. During this study, we traveled to Kauai on several occasions to meet with agency personnel and to obtain soil and water samples. Arrangements were made to have water samples sent to us from Kauai on approximately a monthly basis. The Hanalei watershed and the Nawiliwili watershed were the primary study sites.

Principal Findings and Significance

Kauai differs from Oahu in three significant ways. First, it is an older island. Second, there is greater rainfall there, resulting in more and larger streams. Third, Kauai still relies on cesspools to collect and treat wastewater (this method of wastewater collection and treatment is not used throughout most of Oahu). Cesspools are not satisfactory systems, and some of the inadequately treated wastes from cesspools are expected to contaminate the nearby streams and coastal waters. This study focused on the Hanalei and Nawiliwili watersheds. In this regard, we worked closely with the Clean Water Branch of the state of Hawaii and with environmental organizations on Kauai that are responsible for assessing the water quality at these two watersheds. For the Hanalei watershed, we worked closely with and made presentations to members of the Hanalei Heritage River Program. For the Nawiliwili watershed, we worked closely with and made presentations to the Nawiliwili Bay Watershed Council.

The principal findings and significance of this study are as follows. First, as also observed on Oahu, soil samples from Kauai contained high concentrations of fecal indicator bacteria such as fecal coliform, *E. coli*, and enterococci. The significance of this observation is the identification of the same environmental source of fecal indicator bacteria on both Oahu and Kauai. Second, as also observed on Oahu, the streams on Kauai consistently contained fecal coliform, *E. coli*, and enterococci at concentrations that exceeded hygienic water quality standards. The significance of this observation is the impact of the environmental source (soil) of fecal indicator bacteria, which explains the consistently high concentrations of fecal indicator bacteria in the streams on Kauai. Third, as also observed on Oahu, the concentrations of *C. perfringens* in Kauai streams were low but increased when sewage spill was observed. The significance of this observation is the applicability of monitoring for *C. perfringens* as a reliable means of determining when recreational waters are contaminated with sewage. Fourth, as also observed on Oahu, marine coastal water sites that receive land-based discharges (streams, storm drains) contained elevated levels of fecal indicator bacteria. The significance of this observation is the predictable way in which land-based or nonpoint sources of pollution can be expected to increase fecal bacterial contamination at coastal water sites. Fifth, unlike Oahu, many of the streams on Kauai contained elevated levels of FRNA coliphages. The major significance of this observation is that FRNA coliphages may be the best indicator for the contamination of stream water by cesspools. This conclusion is based on the small size and stability of FRNA coliphages, characteristics which enable them to be readily transported through soil to contaminate nearby streams. In summary, the monitoring data for Kauai provided similar results as the monitoring data for Oahu. These results indicate that the conclusions on water quality for Oahu are applicable to Kauai.

Optimize Aeration, Secondary Clarifier and Disinfection Processes

Basic Information

Title:	Optimize Aeration, Secondary Clarifier and Disinfection Processes
Project Number:	2001HI14S
Start Date:	9/1/2000
End Date:	12/31/2003
Funding Source:	Supplemental
Congressional District:	First
Research Category:	Engineering
Focus Category:	, Waste Water, Treatment
Descriptors:	wastewater treatment, aeration, disinfection
Principal Investigators:	Victor D. Moreland

Publication

Problem and Research Objectives

The U.S. Army's Schofield Barracks Wastewater Treatment Plant has a history of not consistently meeting the microbial requirements for discharge into the Waialua Sugar Company irrigation system. The disinfection challenge of reducing the total coliform is that the final effluent quality shall not exceed 23/100 ml for a 30-day median or exceed 240/100 ml in any sample.

The research objectives are (1) to determine whether the chlorine disinfection process is adequate for meeting the microbial requirements and (2) to determine whether the upstream biological process should or can be improved to lessen the burden on the disinfection process.

Methodology

Review existing plant data for process variations that point to a need for process changes. Meet with operating staff, as a team-building effort, to discuss past and current operating guidelines that have been used both successfully and unsuccessfully. Discuss possible changes to the operating guidelines and implement what as a team are felt to be the best testing concepts with the best opportunity for success.

Principle Findings and Significance

The chlorine disinfection process by itself would be inadequate without secondary process improvements.

Control guidance in the past has usually been either mixed liquor suspended solids concentration or mean cell residence time (days). In this effort a somewhat newer approach called total mass (total pounds of suspended solids in the secondary process) was used.

Through experimenting with the process it was found that a far lower than normal dissolved oxygen (0.20 to 0.30 mg/l) was used very successfully, resulting in single-digit effluent total suspended solids (TSS) that has allowed the chlorine disinfection process to meet the disinfection requirements.

In March 2003, we altered the process mode to incorporate an anoxic zone in the first third of each aeration basin, while maintaining the dissolved oxygen (DO) between 0.5 and 1.0 mg/l. The change in DO is in response to increases or decreases in the sludge settling characteristics. The mode has been the most stable used so far, usually generating low single-digit TSS.

Information Transfer Program

WRRCs Technology Transfer specialist, Philip Moravcik, took sabbatical leave between July 2002 and July 2003. In his absence, Peter Rappa of the U.H. Sea Grant staff was hired on a half-time basis.

Technology Transfer

Basic Information

Title:	Technology Transfer
Project Number:	2002HI6B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	Hawaii 1st
Research Category:	Not Applicable
Focus Category:	Education, Water Quantity, Groundwater
Descriptors:	
Principal Investigators:	Philip Moravcik, Philip Moravcik

Publication

WRRC Seminar Series

The Seminar Series is designed to foster communication amongst WRRC researchers, students, and the research audience of government officials, private sector personnel and members of the public interested in water resources. A WRRC faculty member is appointed each semester to draw up and invite a list of speakers. Topics vary depending on interests of the coordinator and availability of speakers. Typically, the seminars include reports of WRRC projects and discussions by government officials of emerging water-related issues. A list of seminars presented during the reporting period follows.

Spring 2002 Seminar Coordinator: Phil Moravcik

3/7/2002	Dr. Edward Laws Human Impacts on the Fluxes of nutrients and Sediment in Waimanalo Stream, Oahu, Hawaiian Islands
3/14/2002	Eric DeCarlo Sediment and Water Quality in Subtropical Watersheds: Focus on the Ala Wai Canal Watershed, Honolulu, HI
3/21/2002	June Harrigan What are Water Quality Standards, and How Have they Been Used and Misused in Water Quality Work?
4/4/2002	Dave Penn Impaired Waters and Total Maximum Daily Loads: Blessing or curse for Hawaii Water Quality?
4/18/2002	Melissa Farinas, Michael McMahon and Maile Bay Community-Based Watershed Planning and Implementation

Fall Semester 2002: Seminar Coordinator: Clark Liu

9/5/2002	Aly El-Kadi Assessment and Protection Plan for the Nawiliwili Watershed (Kauai)
9/19/2002	William Tam Hawaii Water Code
10/3/2002	Lauren Hay Current and Future Prospects in Watershed Modeling
10/17/2002	Alan Murakami Reserved Hawaiian Water Rights
11/7/2002	Keoni Fairbanks Water Issues on Kahoolawe
11/21/2002	Paul Achitoff Waiahole Water Case
12/5/2002	Ezra Kanoho Water Rights Issues at the Legislature

Spring Semester 2003: Seminar Coordinator: James Moncur

01/27/2003	Charles Howe (Special Seminar) Economic Efficiency and Equity Considerations in Regional Water Transfers: A Comparative Analysis of Two Basins in Colorado
2/6/2003	Ka'eo Duarte Long-Term Discounting of Groundwater Resources for Sustainability
3/6/2003	Barry Usugawa Watershed Planning & Management
3/20/2003	Ross Tanimoto Water Treatment and Effluent Disposal
03/28/2003	Joel D. Blum and John D. MacArthur (Special Seminar) Forest Biogeochemistry of Calcium: Acid Rain, Mineral Weathering and a Whole-Watershed Calcium Addition
4/3/2003	James Roumasset Economic Modeling of Water Allocation
4/17/2003	Robert Ward Incorporating Sound Science into Water Quality Monitoring
5/1/2003	Denise DaCosta Water Conservation Education Programs

WRRC Website: 2002-2003

WRRC's website has undergone considerable revision, including changing the URL to www.wrrc.hawaii.edu. However, the site continues to provide current and historical information to people and agencies interested in water issues and problems, as well as water topics in general. The site includes conclusions generated through WRRC research projects, descriptions of current projects, background of faculty and extensive links to related University departments as well as federal, Hawaii and Pacific agencies and organizations.

The website is by nature a work in progress and is updated frequently. Increasingly, WRRC publications are posted on the site and hyperlinks provided to reports or related information. Abstracts of WRRC publications are provided at the website. Seminar announcements are posted on the website, and conference agendas and registration information is available there.

WRRC Conference

WRRC organized and hosted a conference January 15-16, 2003, under the title "Scientific, Regulatory and Cultural Factors Influencing Water and Environmental Issues in Tropical Pacific Islands." Speakers came from Hawaii state and local water and wastewater agencies, from UH faculty and the mainland U.S. and a contingent from the Pacific Water Association, dealing with

Pacific island nations' issues. Sessions were presented on:

- Issues facing drinking water utilities
- Issues facing wastewater management agencies
- Cultural, economic and legal impacts on water issues
- Water issues affected by climate, drought, floods and alternative sources of water
- Issues of groundwater/soil contamination and remediation
- Special water issues for small and remote Pacific islands
- Issues related to environmental water quality and watershed management
- Water issues related to crop and animal production

In addition, UH WRRC organized the March 2003 NIWR conference, held in Washington D.C., handling registration details as well as organizing the meeting presentations.

WRRC Newsletters and Project Bulletins

Researchers need channels of communication to potential users of their results. WRRC needs a means of publicizing its project results and other activities. Newsletters and project bulletins convey this information in an informal, non-technical manner. During the reporting period, one newsletter was produced. It can be viewed at www.wrrc.hawaii.edu.

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	0	0	0	0	0
Masters	4	0	0	0	4
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	5	0	0	0	5

Notable Awards and Achievements

Publications from Prior Projects

1. 2001HI701B ("Removal of Nitrogeous Aquaculture Wastes by a Wind-Powered Reverse Osmosis System") - Articles in Refereed Scientific Journals - Liu, C.C.K.; J.W. Park; J. Migita; G. Qing, 2002, Experiments of a prototype wind-driven reverse osmosis desalination system with feedback control, Desalination 150(3), 277-287
2. 1991HI05B ("System Parameterization and Modeling of Chemical Transport Through Upper Soils") - Book Chapters - Liu, Clark C.K.; Jenny Jing Neill, 2002, Linear systems approach to river water quality analysis, in Haley H. Shen, Alexander H.D. Cheng, Keh-Han Wang, Michelle H. Teng, Clark C.K. Liu, eds, Environmental Fluid Mechanics: Theories and Applications, Reston, Virginia, American Society of Civil Engineers, 421-457.