Water Resources Research Center
Annual Technical Report
FY 2004

Introduction

Population growth, recovery from a lengthy period of economic stagnation, and growing legal impediments to water transfers have generated a gradual resurgence of interest in issues of water quantity for Hawaii in recent years. Hence WRRC researchers have gravitated toward groundwater flow modeling, recycling, desalination and related membrane issues, and conservation.

A total of 27 research projects were active at some point in the report period, including the nine 104b projects reported below. Other topics dealt with include wastewater treatment (membrane bioreactors, ultraviolet radiation, wind-powered treatment of aquaculture wastewater); assessment of coastal water quality and of drinking water sources; watershed restoration; recreational water quality indicators; goundwater flow modeling; and leaching and transport of various contaminants in Hawaii soils. Past 104b support for computer models of membrane fouling and in the economics of water conservation has also continued.

USGS/WRRIP funds added to support from the University of Hawaii (faculty and staff salaries, lab and office space), the City & County of Honolulu, the State of Hawaii Departments of Health, Land and Natural Resources, and Agriculture; the U.S. Departments of Defense and Interior and several private firms. Members of several other departments joined WRRC faculty in research projects, supplemented with informal contributions from water-related departments across the campus. Research results were disseminated through reports, journal articles, seminars and conference presentations. Training of graduate students has remained a principal focus of WRRC projects.

Research Program

USGS/WRRIP funding for FY2004 allowed the funding of four new research projects in addition to completion of four from previous years and renewal of continuing technology transfer and administration programs. Of the new projects, one (Prevention of Colloidal Fouling...) was a continuation of the previous year's grant. The second (Helium Tracer...) developed a new approach to identifying the source of groundwater contaminants, and the third refined methods of differentiating sewage from non-point-source pollution. The fourth examined connections between culture, ecology and hydrology in reference to alien plant species. In addition, the Hawaii District USGS office funded a student internship.

Prevention of Colloidal Fouling in Crossflow Membrane Filtration: Searching for Optimal Operation Conditions: Year 2

Basic Information

Title:	Prevention of Colloidal Fouling in Crossflow Membrane Filtration: Searching for Optimal Operation Conditions: Year 2
Project Number:	2003HI26B
Start Date:	3/1/2003
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	Hawaii 1st
Research Category:	Water Quality
Focus Category:	Treatment, Solute Transport, Models
Descriptors:	crossflow membrane filtration, colloidal cake layer
Principal Investigators:	Albert Sechurl Kim, Clark C.K. Liu

Publication

1. Chen, Jim C.; Menachem Elimelech; Albert S. Kim, 2005, Monte Carlo simulation of colloidal membrane filtration: Model development with application to characterization of colloid phase transition, Journal of Membrane Science, in press.
2. Kim, Albert S.; Rong Yuan, 2005, Hydrodynamics of an ideal aggregate with quadratically increasing permeability, Journal of Colloid and Interface Science 285, 627-633.
3. Kim, Albert S.; Rong Yuan, 2005, A new model for calculating specific resistance of aggregated colloidal cake layers in membrane filtration processes, Journal of Membrane Science 249, 89-101.
4. Chen, Jim C.; Albert S. Kim, 2004, Brownian dynamics, molecular dynamics, and Monte Carlo modeling of colloidal systems, Advances in Colloid and Interface Science 112, 159-173

Problem and Research Objectives

Colloidal fouling in crossflow membrane filtrations

Reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) are variations of crossflow membrane filtration technology. They have steadily gained importance in environmental engineering separations over the past decade. Recent improvements in the technology—for instance, development of highly selective and permeable membranes, and efficient module designs—and several improvements in peripheral technologies have spurred widespread adaptation of these processes in environmental, chemical, pharmaceutical, and biomedical applications. The level of separation in terms of purification of the solvent, the productivity of yield measured as permeate flux, and the cost of operations have improved to the point where the application of membrane technology is now widespread in the environmental engineering industry. MF and UF, in particular, are widely used to remove suspended solids, colloidal particles, macromolecules, bacteria, and viruses from feed solutions, with particular applications as alternative, substitutional, or supplementary processes for conventional water and wastewater treatment.

A major consideration in membrane filtration operation is the cost associated with fouling of the membrane by colloidal deposition onto the membrane surface. Fouled membranes limit the permeate yield and thereby drive up the cost of operation and maintenance. Membrane fouling involves three different patterns of matter-stacking phenomena on its surface: (1) concentration polarization, (2) (followed by) colloidal cake/gel formation, (3) and aggregate cake formation (i.e., cake of retained aggregates composed of many small primary colloidal particles). All three fouling patterns constrict the permeation rate, and each effect brings out its own permeate flux decline behavior. The most typical fouling pattern that occurs during MF or UF is colloidal cake formation. A deposited cake layer contributes additional hydraulic resistance and thereby reduces the permeate flux. One of the most important governing factors of this type of fouling is cake porosity, which is mainly affected by the combined influences of transmembrane pressure, membrane resistance, solvent (typically water) viscosity, ionic strength, pH, zeta potential, temperature, and particle size. The complexity of these physical, chemical, and operational parameters often makes it difficult to attain higher flux at (possibly simultaneously) less cost. Therefore, one objective of this research is to determine optimal operational conditions by changing a few controllable parameters (among those listed) and then examining the permeate yield that results.

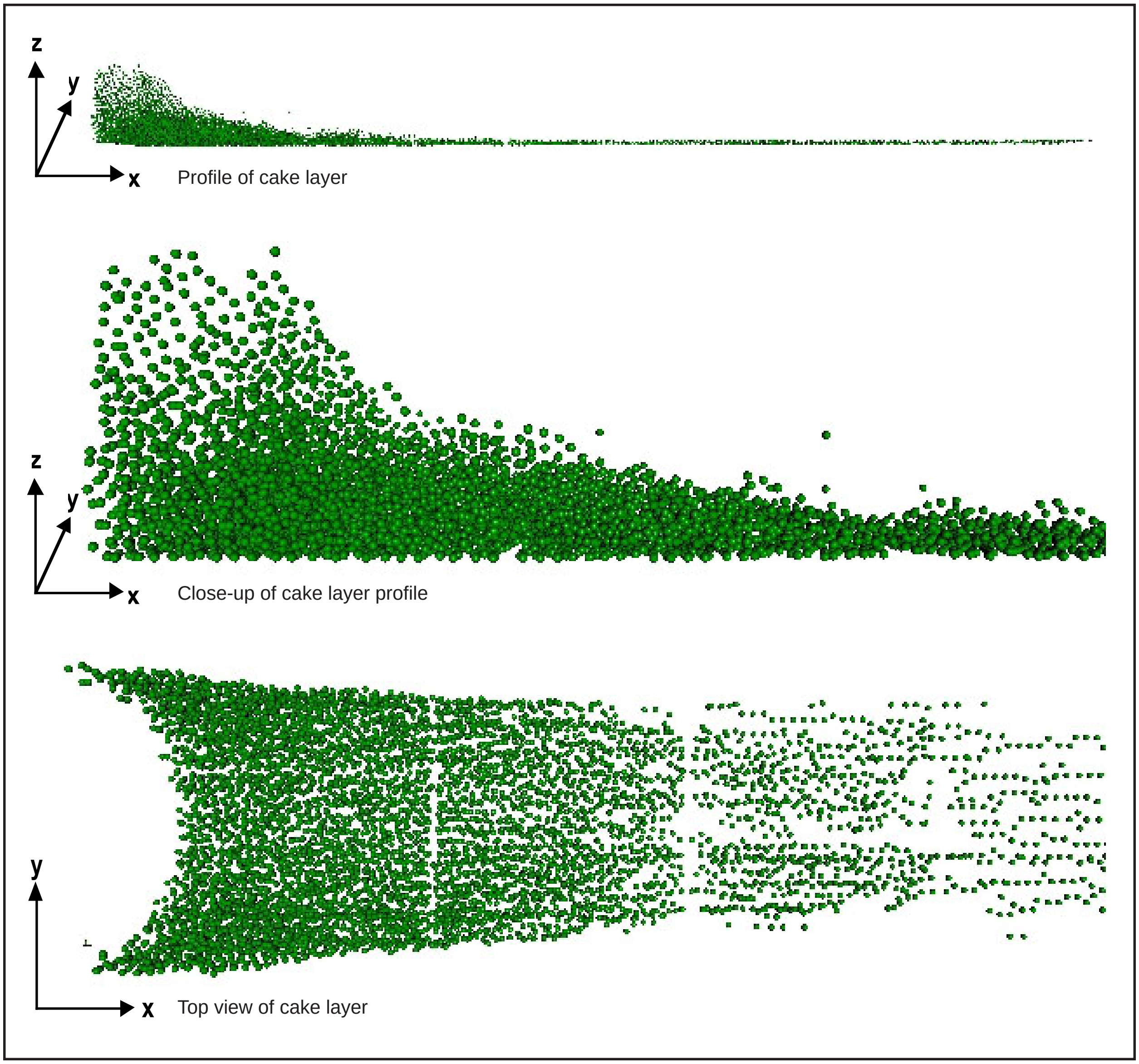
A second objective is to conduct a theoretical investigation of the aggregate cake layer, another type of cake layer that can contribute to membrane fouling, albeit in a different way. In feed water of high ionic strength, aggregation of particles readily occurs in the bulk phase, followed by the formed aggregates depositing on the membrane surface. Due to the high porosity of the aggregates (up to 0.99), this cake layer causes remarkably less flux decline than the colloidal cake layer. Inducing aggregation prior to deposition appears then to be an effective method for enhancing efficiency. Practical utilization of this phenomenon can reduce the operating cost, especially in MF/UF processes used as a pretreatment of RO/NF.

Relevance and importance to Hawaii

Desalination, a process which produces potable water from seawater or brackish water, has become increasingly important due to the paucity of freshwater, especially in the state of Hawaii. Desalination can be accomplished by using either thermal (distillation) or membrane technology. Because of the advancement of membrane technology, most water desalination plants built in the last thirty years have mainly used RO, electrodialysis, and NF. Nevertheless, the use of RO/NF membranes in water treatment processes is hindered by the presence of particulate foulants such as dissolved natural organic matter, small colloids composed of natural silica, clays, organics or biological matter, and ionic constituents, which must be removed in pretreatments of MF/UF. Therefore, this research will enhance our understanding of fouling problems in desalination processes and thus will help in the development of solutions to prevent potential fouling phenomena.

Methodology

The Monte Carlo (MC) simulation is a stochastic modeling method that is especially suitable for problems involving the dynamics of particle motion because of its capability to rigorously evaluate each discrete particle displacement. A classical method for performing MC simulations is the now-standard Metropolis method which uses



Views of cake layer developing in a long crossflow membrane channel

the energy of the system as the criterion to evaluate the acceptance or rejection of an MC step. This research adopts the Metropolis method for performing the MC simulation of the system.

The computational method employed to perform the model simulations is cluster programming by Message Passing Interface (MPI). The principle of MPI leverages the advantage of pooling together the computational power of a network of computer processors. Then the computational demands of modeling the system can be allocated among the network of processors and thus reduce a computationally intensive modeling task to manageable proportions.

We used a computer network composed of a server and many computing nodes (i.e., physical computing processors). One of the processors functions as the server while the remaining processors function as compute nodes. The server performs the tasks of organization and synchronization of the model simulation. It regulates and paces the progress of the remaining nodes which are apportioned the core computations in the model. The server provides each node with the data it requires to carry out its portion of the simulation. Data are sent from the server to each node via a "Send/Receive" communication command. Once the nodes have completed their computations for a given iteration step in the model, their results are returned to the server where they are re-organized to be sent out again for the next step. The nodes then receive the new data from the server to continue. This cycle of communications and computations is repeated throughout the simulation.

As the number of processors increase, bookkeeping of data and their communication becomes an integral component of the overall modeling scheme. Therefore, building a robust cluster-programming algorithm calls for careful evaluation of the logistical processes: data management, task organization, synchronization of nodes, and systematic communication. Improvements to the model can be achieved by ensuring better efficiency and execution of the fundamental logistics of the computing network and their interactions. The computer system used in this research is the University of Hawaii Dell cluster located on the Manoa campus.

Principal Findings and Significance

The simulation results, after 12,000 MC steps using 30 nodes, show excellent portrayal of colloidal membrane filtration at its full physical dimensions (see views of cake layer on previous page). The parameters of the model are particle size (100 μm) and applied pressure (20 psi). The crossflow velocity is 0.1 m/s. The full dimensions of the membrane system are length of 5 cm, width of 0.5 cm, and height of 2 cm. Full-scale modeling of this type has not been previously achieved in the field of colloidal membrane filtration research. Here, the model demonstrates its capability to realistically depict particle deposition in an actual membrane filtration system. Notice that the cake layer begins to form at the entrance of the channel, with a high number of particles accumulating there and then tapering off downward into the channel. The propagation of the cake layer front from the entrance downward to the exit has been theoretically proposed. So, the model results do in fact validate previous theoretical hypotheses. With the model using high-performance cluster computing currently in place, the outlook for future work is auspicious. Cake formation dynamics in colloidal membrane filtration under the influences of inter-particle interaction, hydrodynamics, and solution chemistry can now be modeled as full-scale accurate depictions.

Four journal articles and twelve conference presentations report on the research. Nine of the twelve conference presentations have already been delivered; the remaining three will be presented later this year. The principal investigator received a Certificate of Merit Award for Oral Presentation for his presentation entitled "Hydrodynamic radius of an ideal aggregate with quadratically increasing permeability: An analytic approach" at the American Chemical Society symposium in Philadelphia, Pennsylvania, in August 2004.

Development of a New Technique for the Use of Dissolved Helium as an Environmental Groundwater Tracer

Basic Information

Title:	Development of a New Technique for the Use of Dissolved Helium as an Environmental Groundwater Tracer
Project Number:	2004HI55B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	Hawaii 1st
Research Category:	Ground-water Flow and Transport
Focus Category:	Hydrology, Solute Transport, Models
Descriptors:	
Principal Investigators:	Aly I El-Kadi

Publication

1. Richter, F.; R.B. Whittier; A.I. El-Kadi, Use of dissolved helium as an environmental open-water tracer, Journal of Contaminant Hydrology, to be submitted.

Problem and Research Objectives

Tracer tests are an important method for determining the flow characteristics and patterns of subsurface water (such as groundwater aquifers) and surface water bodies (such as streams and the ocean). In such tests, a constituent is added to the water. The constituent is either non-native to that water or high enough in concentration to be distinguished from the native component in that water. Many of the commonly used tracers have one or more limitations, such as being toxic, being esthetically objectionable, being difficult to be differentiated from the naturally occurring fraction, requiring complex laboratory analysis for their detection and quantification, requiring a high concentration, and reacting with the aquifer matrix. These limitations are not common to helium, however. Thus, if a field method can be developed to detect and quantify the concentration of dissolved helium in surface or groundwater in real time, then helium has great potential for use in certain tracer applications, including its use near drinking water sources or in environmentally sensitive areas such as wetlands and fish farms, its use in areas where esthetics are a concern (e.g., recreational beaches), and its use in conjunction with investigations of the diffusion characteristics of groundwater aquifers.

Helium was successfully tested as a reliable and economical tracer (S.K. Gupta, L.S. Lau, P.S. Moravcik, and A.I. El-Kadi, 1991, Injected helium: A new hydrological tracer, Special Report 06.01.90, Water Resources Research Center, University of Hawaii at Manoa, 94 pp.; L.S. Lau, and P.S. Moravcik, 1994, Ground-water tracing with injected helium, Ground Water 32(1):96–102). Its behavior in open tanks was identical to that of fluorescein dye. Although the system was simple and specific for helium, the small surface area and fragility of the thin quartz window limited its sensitivity and reliability. Moreover, the technique was only suitable for the analysis of discrete samples.

The objective of this project is to develop and demonstrate a new analytical system that substantially improves the precision and utility of the helium tracer analysis techniques for routine use in surface water and groundwater. The work proposed encompasses developing and calibrating the system, and testing the helium tracer in the laboratory against a commonly used tracer.

Methodology

Instrumentation

Compared to the above-mentioned design of Gupta and others, our system, consisting of a gas extraction system and a separate helium analyzer, is somewhat more complex but substantially more sensitive (Figure 1). The new design allows on-site, continuous, real-time monitoring in a completely automated structure. Results of the analysis are automatically recorded on a lap-top computer.

Our system is built around a permeable membrane contactor, which is used commercially to extract dissolved gases from liquids. This contactor is a shell-and-tube device containing thousands of microporous hydrophobic polypropylene hollow fibers woven into a fabric array. To extract dissolved helium, a steady flow of helium-tagged water is maintained through the wet side of the contactor. A constant flow of clean, dry nitrogen through the gas side of the contactor provides a helium concentration gradient and results in the diffusion of helium from water to the gas side of the membrane contactor. Our design includes the use of the 2.5 in. × 8 in. Extra-Flow Membrane from Liqui-Cel. Nitrogen gas is moved inside the hollow fibers at a specified pressure. The rate of helium extraction depends on the partial pressure difference and the flow rate of water. A trial-and-error approach was used to estimate a certain combination of the flow rate and pressure. For example, at 20 psi the optimal flow rate was 600 ml/min.

A vacuum leak detector probe is placed in the discharge path from the gas side of membrane contactor. The leak detector has a helium-based mass spectrometer which generates an electrical signal that is proportional to the helium concentration in the gas discharge from the membrane contactor. This electrical signal is displayed as a leak rate.

A Veeco MS-40 Portable Leak Detector manufactured by Vacuum Instrument Corporation was used in our design. The MS-40 detector is equipped with software that allows communicating with a computer to automatically record output signals. The test port of the MS-40 detector is connected to the gas outlet of the extraction system by polytetrafluoroethylene (PTFE) tubing, which is permeable in regard to the small helium molecules. It is not necessary to use a more gas-tight material, such as copper, considering that the residence time of the molecules is too short for major diffusion processes to occur. In addition, most applications are only concerned with relative concentrations, hence the introduced error can be ignored. The flexibility of PTFE-tubing is an advantage for field

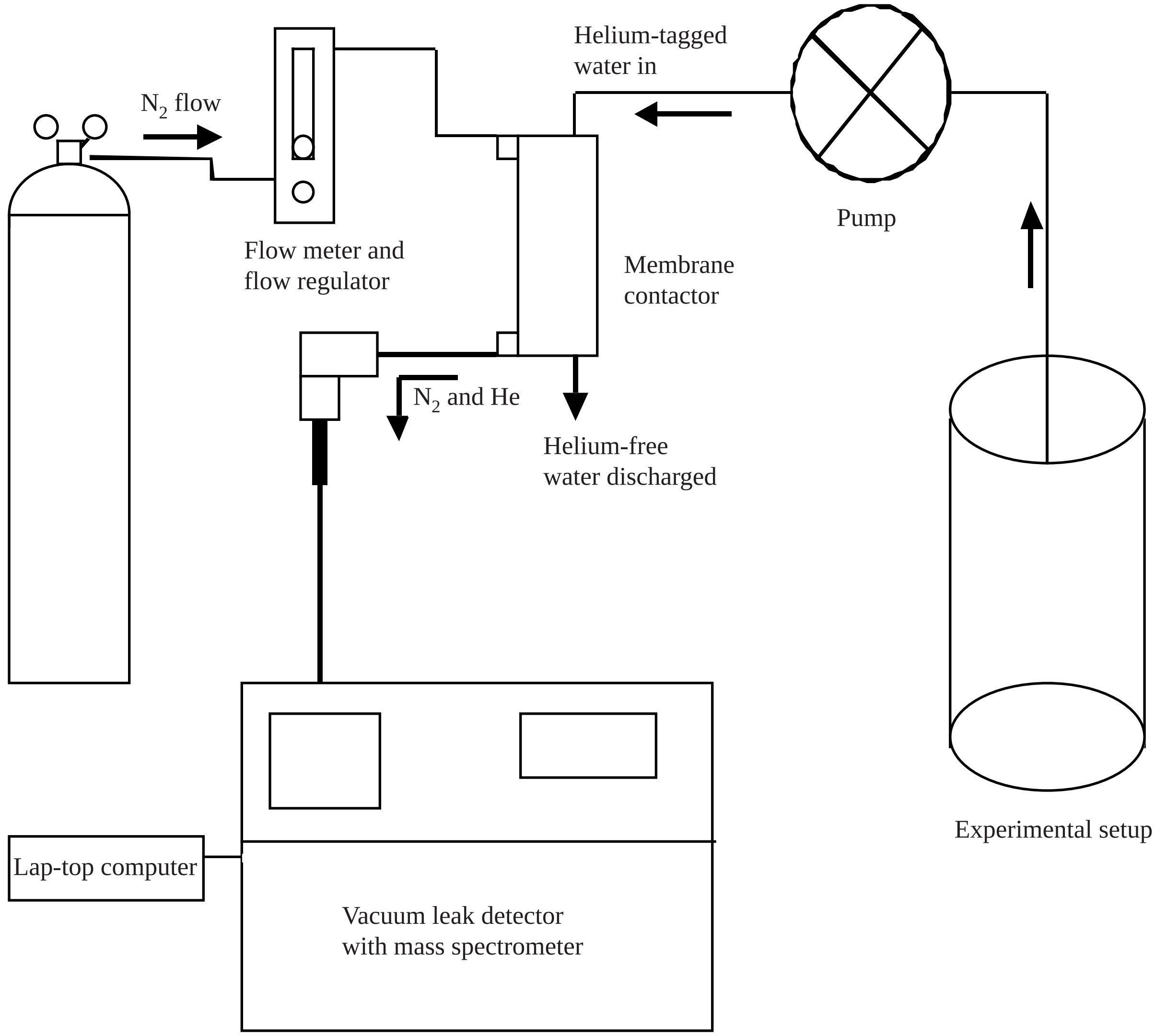


Figure 1. Schematic of the helium tracer system

work. To prevent water vapor from entering the mass spectrometer's high vacuum chamber, a 13 in. × 1 in. PVC cylinder filled with Drierite desiccants (1/4-in. granules) is placed in the flow line between the extraction system outlet port and the mass spectrometer's inlet port.

Instrument calibration

The instrument was calibrated to convert signals from the helium detector to helium concentrations. Helium solutions of known concentrations were prepared based on the solubility of helium in equilibrium with atmospheric air at sea level (i.e., 5.0×10^{-5} ppm) and the maximum solubility at 1 atm of helium (i.e., 8 ppm). The solution with the maximum helium concentration was prepared by bubbling pure helium through a diffuser into a few liters of water at room temperature for at least 15 minutes. This solution was diluted to helium solutions of 10%, 1%, and 0.1%. The helium signal detected by the mass spectrometer is the volume of helium gas that is extracted from the test water per second. In order to estimate the actual helium concentration in the sample, the measured gas volume was divided by the volume of water that passes through the membrane contactor per second, given by the constant water flow rate of 600 ml/min. Figure 2 shows the observed relationship between the concentration based on the helium signal recorded by the mass spectrometer and the directly measured helium concentrations in five helium solutions. A linear relationship exists between the two helium concentrations. However, the detected concentrations were lower than the measured values by an average of 3.13×10^{-3} ppm. The main reason for such an error is likely

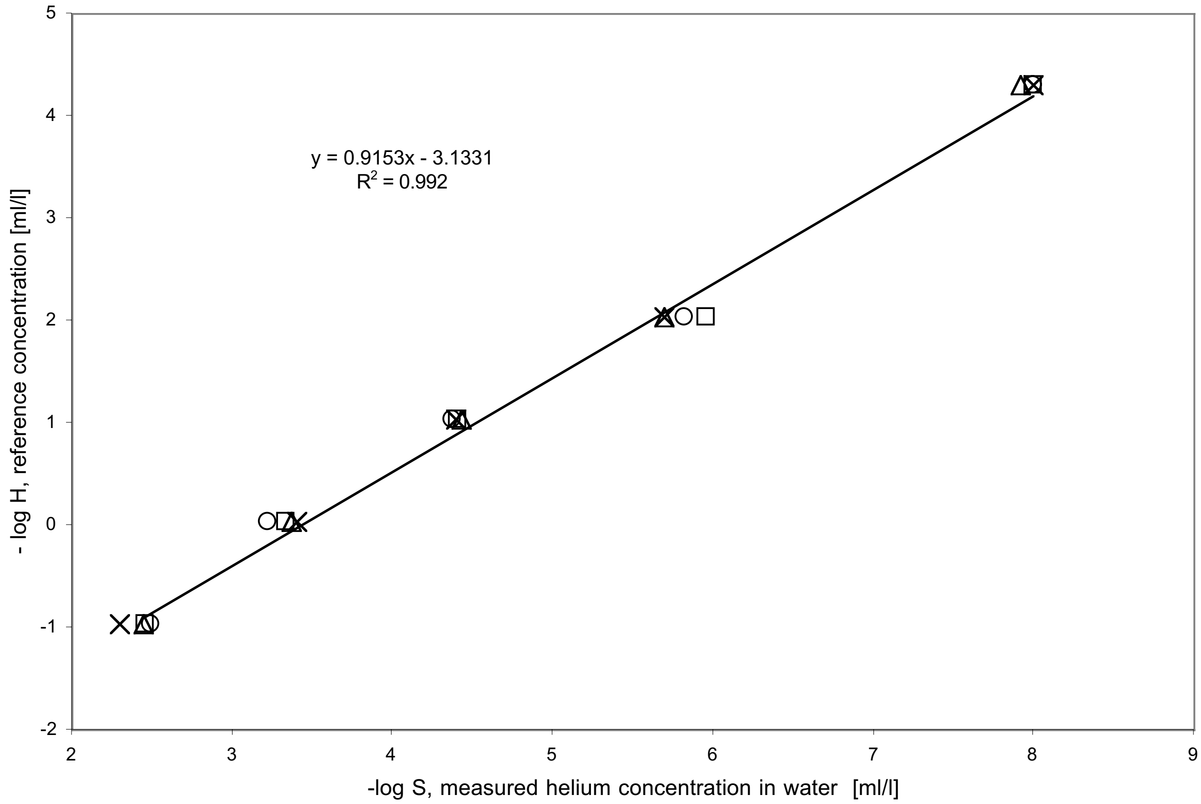


Figure 2. Instrument calibration curve using five different helium solutions. Four test samples were tested for each solution (shown by different symbols)

due to the inability of the contactor membrane to extract all the helium gas from the solution. As mentioned earlier, the helium removal performance of the contactor membranes depends on the water flow rate. The lower the flow rate the higher is the efficiency of the system to extract helium. The flow rate of 600 ml/min used was the lowest possible operable flow rate. Below that value, it was found that air bubbles form in the system due to insufficient water pressure. It is also likely that some helium gas molecules were lost due to diffusion during their passage through the system.

The helium concentration in the sample water can be calculated by the following equation of the least square fit line (Figure 2):

$$-\log(H) = 0.0153[-\log(S)]-3.1331$$

where

H = helium concentration based on detector signal (ppm)
S = actual helium concentration (ppm)

The scatter of the measured data points for the different reference concentrations can be partly explained by the lack of precision in preparing the reference dilutions.

Principal Findings and Significance

A number of bench-scale experiments, including pipe and open-tank experiments, were done to test the instrument. The helium results were compared to a sodium chloride (NaCl) solution to evaluate the suitability of using helium as a tracer.

Pipe Experiment

Tracer experiments were conducted in PVC pipes to test the behavior of dissolved helium as a tracer to that for NaCl. Water was pumped from a reservoir through a 20-ft-long PVC pipe with a 2 in. diameter at a constant flow rate of 1,100 ml/min. Two 10-ft PVC pipes were connected by two 90-degree elbows to fit the experimental setup into the laboratory. An He (~ 66% saturation)/NaCl (66 g/l) solution was injected into the pipes through a 1/4-in. inlet at the same constant flow rate of 1,100 ml/min for one minute. After the tracer injection, pumping from the water reservoir resumed for the remainder of the experiment. The 1/4-in. PVC pipe outlet was connected to the helium extraction and detection unit by 1/4-in. flexible PVC tubing. At the outlet of this unit the conductivity was measured by a conductivity probe. The relative He and NaCl concentration was continuously recorded throughout the experiment.

The results of the helium concentration are compared against NaCl results in Figure 3. Excellent match can be seen regarding the rising limb of the breakthrough curve concerning the first arrival and the slope of the curve. However, fluctuations are evident near the peak concentrations, which are likely due to the high helium concentration in the injected solute. Probably for this reason, some disagreement also exists in the elution of helium. We are currently working on additional test cases to improve on the results and on applying the methodology to longer pipe systems.

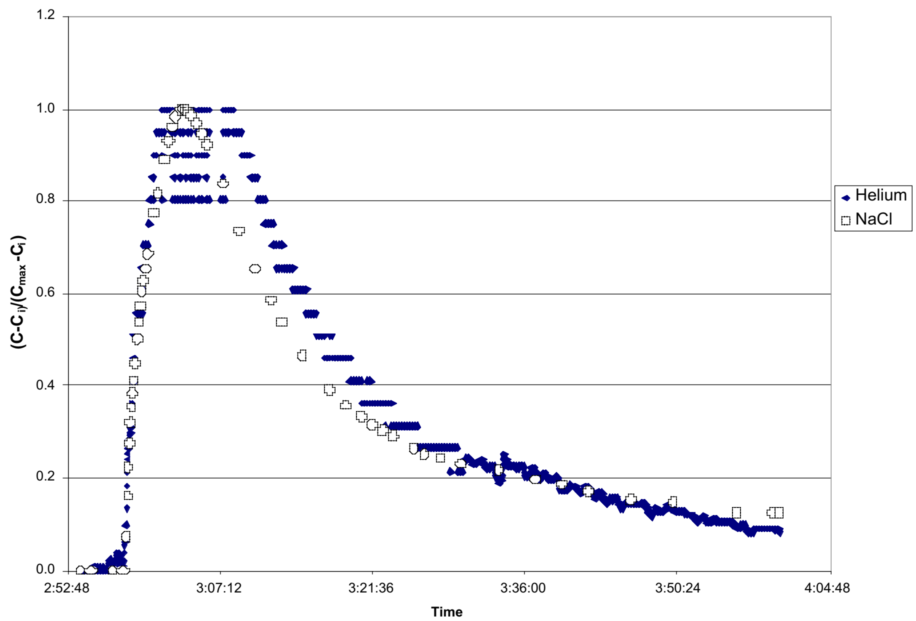


Figure 3. Breakthrough curves for the pipe experiment for NaCl and helium. *C* is the concentration, and C_o and C_i are the peak and initial concentrations, respectively.

Open-Tank Experiment

The experiment involves tracing a plume of dissolved helium and saltwater in an open tank (wedge shape of 244 cm length × 60 cm in the widest part × 25 cm depth). The flow field in this experiment mimics a steady-state radial flow situation. NaCl dissolved in 3 liters of a saturated helium solution was injected instantly at the wider end of the tank. At the opposite end water was continuously pumped out of the tank and into the helium extraction/ detection system at a rate of 600 ml/min. At the outlet of the extraction unit the conductivity of the sample water was continuously measured. Purified tap water was continuously injected into the tank at a recharge rate of 600 ml/min to maintain a steady state between inflow and outflow.

The results of the open-tank experiments (Figure 4) clearly show that the helium-measuring instrument responds instantly to a change of helium concentration in water. The arrival and peak of the NaCl breakthrough curve is delayed by 15 seconds. This can be explained by the different methods used to measure the two solutes. The conductivity probe is mounted in line at the helium extraction unit water outlet. In this case, it seems it takes 15 seconds for a water molecule to travel from the contactor membrane to the conductivity probe.

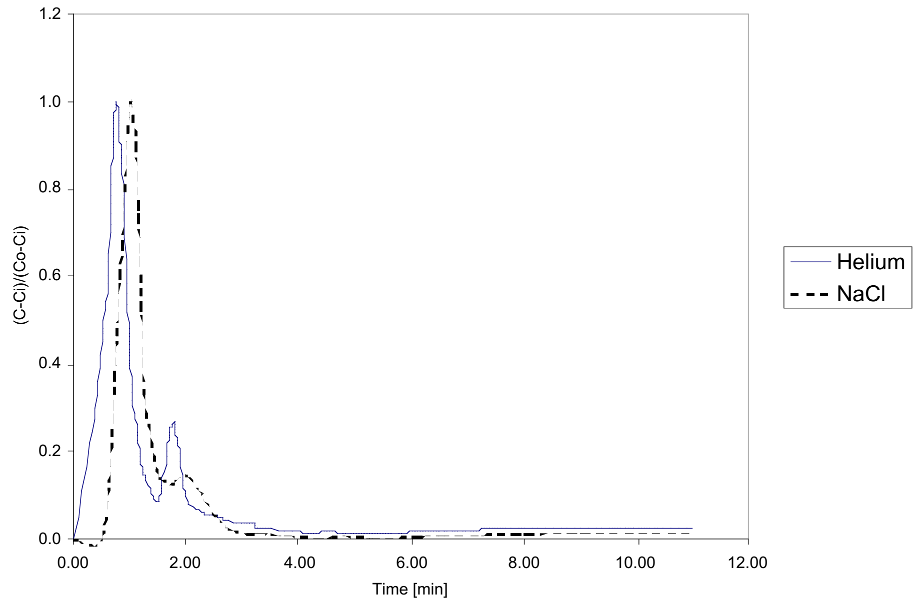


Figure 4. Breakthrough curves for the open-tank experiment for NaCl and helium. *C* is the concentration, and C_o and C_i are the peak and initial concentrations, respectively.

The different transport properties of the two tracers can provide another explanation for the lag of the NaCl breakthrough curve. Advection is presumably the main solute transport process for NaCl, whereas the helium molecules might travel at a higher transport velocity than the water molecules due to molecular diffusion. In larger-scale applications over a long travel time, this lag should not be a serious limitation of the method. As evidence, such an error did not occur in the pipe experiment discussed above due to the longer travel time.

The second peak, which is smaller and which occurs after about 2 minutes, is likely due to the flow condition created by the instant injection of the tracer. Such behavior was confirmed during a second experiment. However, the similar behavior of the two solutes proves the potential success of the helium detection system in responding to multiple injection episodes.

The work completed has demonstrated the success of the new technology in allowing continuous, real-time monitoring in a completely automated structure. Results favorably compare helium as tracer to sodium chloride. The instrument has been successfully calibrated. The drawback of the methodology includes sensitivity of the results to the flow rate and the initial helium concentration of the injected solution. A number of groundwater runs for a sand column and sand tank were completed, but improvements are needed. Groundwater applications will be further addressed in the second year of the project.

The Dynamic Effects of Native Versus Non-native Vegetation on the Ecohydrology of a Hawaiian Stream Valley

Basic Information

Title:	The Dynamic Effects of Native Versus Non-native Vegetation on the Ecohydrology of a Hawaiian Stream Valley
Project Number:	2004HI57B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	Hawaii 1st
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Ecology, Models
Descriptors:	Ecohydrology
Principal Investigators:	Kaeo Duarte

Publication

1. Duarte, T. Kaeo; Charles F. Harvey, 2004, Optimal management of a coastal aquifer hydraulically linked to an inland high-level aquifer through a semi-permeable barrier, Working Paper, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii.
2. Duarte, T. Kaeo; Michela Robba; Charles Harvey, 2005, Optimal pumping strategies for a brackish, coastal pumping well, Working Paper, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii.

Problem and Research Objectives

As populations increase and the demand for natural resources rises, so does the need for informed, sustainable resource management. In Hawai‘i, one particular concern is that land-use change and invasive plant populations may be impacting groundwater recharge and thus freshwater supplies. While parcels of native forest are protected through the designation of water catchment areas, invasive plants threatening these forest parcels are believed to transpire more than their native counterparts or to alter the structure of Hawai‘i's forests in a way that reduces recharge. However, these hypotheses have not been rigorously tested, and the hydrology of the typical Hawaiian watershed accounting for plant water uptake and growth has yet to be modeled. How do native forest communities facilitate infiltration, evapotranspiration, and runoff, and is there a significant difference between the water balance of a watershed dominated by native vegetation and that of a watershed dominated by introduced species? Does a native and perhaps more intact plant community sequester more groundwater than a non-native plant community?

Our research tests the hypothesis that vegetation change alters groundwater recharge by affecting the evapotranspiration (ET) and soil-moisture terms of the fundamental water-balance equation. Underlying this hypothesis is the belief that invasive species are faster-growing and have higher transpiration rates than relatively slow-growing natives. It is also thought that a non-native forest community might lack understory, resulting in increased evaporation due to increased wind speed and less humidity. Over time, this may lead to an overall decrease in ET and a net increase in runoff or leakage.

In order to better manage watersheds, we must understand how ecosystem processes work. Although Hawai‘i's forest should be protected for biodiversity and cultural reasons alone, it should also be protected from the effects of changing forest communities that can have adverse ecohydrological impacts on the watershed. Is invasive species management a worthwhile venture, or should we let invasion run its course? We hope to collect the data and construct a model to rigorously analyze and predict the effects of changing forest communities on water supply in Hawai‘i.

Methodology

To address the question of how different forest communities affect the local water balance, we are collecting data at two sites in South Kona, Hawai‘i, and are constructing models of climate-soil-vegetation dynamics at these sites. Our study involves both ecological and hydrological methodologies. The site at Kahauloa is dominated by native canopy trees and understory, whereas the site at Honaunau is dominated by non-native tropical ash and eucalyptus trees. These two sites were selected to eliminate variation in climate and soil type between sites and to therefore isolate ecohydrological effects due to vegetation differences. They were also chosen for their relatively flat grade and lack of observed surface runoff, which helps simplify the model. Both are located at the same elevation, and preliminary rainfall and radiation data indicate that they are affected by the same climatic factors.

The focus of this study is primarily to determine the effects of vegetation on ET. Both ecological and hydrological methods and equipment are used toward this end. The primary tasks can be summarized as follows:

1. Plots that best represent the average native and non-native forests at the same elevation were chosen for study.
2. Transects were set up around the stations and assessments of local plant species composition made.
3. Evapotranspiration stations were set up at each of the two sites to measure solar radiation, air temperature, relative humidity, rainfall, wind speed, wind direction, and soil moisture. Using this data, potential ET is evaluated with the Penman–Monteith equation, a well-known and established equation in hydrology.
4. Pairs of soil-matric-potential blocks and TDR soil-moisture-content probes were installed at each station. The data will be used to define a soil-moisture-retention curve that can be used to estimate infiltration rates.
5. Studies of xylem sap flow and leaf gas exchange will be independently conducted on the dominant tree species at each of the two sites to estimate transpiration (in FY 2005).
6. Net infiltration into the aquifer will be computed by subtracting ET from rainfall and by using the botanical methods described in task 5 (in FY 2005).
7. Statistical analyses will be done to determine uncertainty in the measurements, and native forest and non-native forest ET and infiltration will be compared (in FY 2005).

Principal Findings and Significance

Data on temperature, humidity, net solar radiation, wind speed and direction, and soil moisture have been collected since May 2004. Although data from more sites are needed to investigate possible spatial heterogeneities, the collected data have yielded interesting preliminary results. The findings are listed below:

1. In agreement with our original hypothesis, wind speeds are higher by 400% in the non-native forest. This result implies that, with all other parameters held constant, evaporation and transpiration in the non-native forest should be much higher.
2. Temperatures are lower in the non-native forest, which agrees with our observation of higher wind speeds and hence more evaporation.
3. Humidity is slightly higher in the native forest.
4. Soil moisture is higher in the native forest, but more measurements need to be taken and more calibration to the local soils needs to be done before any serious conclusion can be reached.
5. Comparative analysis of rainfall and soil-moisture response at the paired native versus non-native sites indicates that the two sites are indeed responding to the same climate regime. This result is critical to our study as it validates our assumption that forest-scale climate and elevation differences have been effectively eliminated between the two sites. This allows us to focus our attention on how two different types of forest affect local soil-moisture and infiltration conditions, if at all.

The next task to be completed is the xylem sap flow and gas exchange work. Once that work is completed we will be able to show (1) how ET varies between a native rainforest and a non-native rainforest in Hawaiʻi and (2) how infiltration differs as a result of the different forest communities.

Application of Innovative Methods and Strategies to Differentiate Sewage from Non-Point Source Pollution in Hawaii

Basic Information

Title:	Application of Innovative Methods and Strategies to Differentiate Sewage from Non-Point Source Pollution in Hawaii
Project Number:	2004HI60B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	Hawaii 1st
Research Category:	Water Quality
Focus Category:	Methods, Non Point Pollution, Water Quality
Descriptors:	water quality, fecal pollution, new methods
Principal Investigators:	Roger Fujioka

Publication

1. Brostrom, K., 2005, A possible alternative chemical indicator of human waste contamination for Hawaii, poster presented at the Hawaii Water Environment Association annual meeting, Hawaii Convention Center, Honolulu, Hawaii.
2. Brostrom, K.; R. Fujioka, 2005, Are fecal sterols an alternative indicator of human waste contamination in Hawaiian recreational waters?, oral presentation with abstract at the American Society for Microbiology, Hawaii Branch annual spring meeting, East-West Center, Honolulu, Hawaii.

Problem and Research Objectives

The basic water quality problem in the state of Hawaii is related to the fact that fecal indicator bacteria (fecal coliform, *E. coli*, and enterococci) are naturally present in all streams and consistently exceed the U.S. Environmental Protection Agency-recommended recreational water quality standards (R.S. Fujioka, K. Tenno, and S. Kansako, 1988, Naturally occurring fecal coliforms and fecal streptococci in Hawaii's freshwater streams, *Toxicity Assessment* 3:613–630). In establishing and implementing recreational water quality standards, USEPA provides the following four guidelines. First, the natural habitat of fecal indicator bacteria is the intestines of mammals and there are no significant environmental sources of these fecal indicator bacteria. Second, these fecal indicator bacteria cannot multiply in the environment. Third, the concentrations of fecal indicator bacteria in environmental waters are directly related to the amount or degree of fecal or sewage contamination and the probability that sewage-borne pathogens are present. Fourth, when *Escherichia coli* and enterococci exceed the current USEPA recreational water quality standards, a predictable and unacceptable number of people who use bodies of water (streams, lakes, coastal beaches) for recreational purposes (swimming, wading) will become ill with diseases associated with diarrhea symptoms. In establishing these guidelines, USEPA relied on data obtained exclusively from the U.S. mainland and supported by data from other temperate regions of the world. USEPA then applied these water quality standards equally to all U.S. jurisdictions, including areas in the tropical and subtropical region of the world (Hawaii, Guam, Samoa, Puerto Rico, Virgin Islands, south Florida). A recent review (R.S. Fujioka and M.N. Byappanahalli, 2003, Tropical Water Quality Indicator Workshop: Proceedings and Report, Special Report SR-2004-01, Water Resources Research Center, University of Hawaii, 95 pp.) of all monitoring data has shown that the four USEPA assumptions are not applicable in these tropical environments where the ambient concentrations of USEPA-recommended fecal indicator bacteria (*E. coli*, enterococci) exceed the recreational water quality standards. These standards are not useful in these tropical environments because the USEPA-recommended fecal indicator bacteria are able to grow and become established in tropical soil environments due to the consistently warm temperature, high humidity, and available nutrients that allow them to become part of the natural microflora (R.S. Fujioka and M.N. Byappanahalli, 2001, Microbial ecology controls the establishment of fecal bacteria in tropical soil environment, *Advances in Water and Wastewater Treatment Technologies*, ed. T. Matsuo, K. Hanaki, S. Takizawa, and H. Satoh, 273–283, Elsevier Science, Amsterdam). In Hawaii (C.M. Hardina and R.S. Fujioka, 1991, Soil: The environmental source of *E. coli* and enterococci in Hawaii's streams, Environ. Toxicol. Water Quality 6:185–195) and Guam (R. Fujioka, C. Sian–Denton, M. Borja, J. Castro, and K. Morphew, 1999, Soil: The environmental source of *Escherichia coli* and enterococci in Guam's streams, J. Appl. Microbiol. 85:83S–89S), rain is the natural mechanism by which these fecal bacteria in soil are transported to streams at concentrations that exceed recreational water standards (in the absence of fecal contamination). Since most fecal-borne pathogens (human enteric viruses, protozoa), cannot multiply in the environment, the concentrations of fecal bacteria in the streams of Hawaii are no longer related to concentrations of sewage-borne pathogens. As a result, because the USEPA-recommended fecal indicators and recreational water quality standards are not reliable in areas such as Hawaii, Guam, and most likely other tropical Pacific islands, there is a need to develop more reliable fecal indicators and water quality standards specifically for these tropical regions.

One solution to the water quality problem in Hawaii was solved by R.S. Fujioka and L.K. Shizumura (1985, Clostridium perfringens, a reliable indicator of stream water quality, *Journal of the Water Pollution Control Federation* 57:986–992) when they showed that monitoring streams of Hawaii for *Clostridium perfringens* rather than the USEPA-recommended fecal indicator bacteria could be used to determine when streams are contaminated with sewage. Several additional studies were conducted using *Clostridium perfringens*, and we (R. Fujioka, B. Roll, and M. Byappanahalli, 1997, Appropriate recreational water quality standards for Hawaii and other tropical regions based on concentrations of Clostridium perfringens, *Proceedings of the Water Environment Federation 70th Annual Conference and Exposition*, Chicago, Illinois, 405–411) concluded that it was superior to any of the USEPA-recommended fecal indicator bacteria in fulfilling six criteria to select an ideal fecal indicator in Hawaii (R. Fujioka, 1997, Indicators of marine recreational water quality, *Manual of Environmental Microbiology*, ed. Hurst, Knudsen, McInerny, Stetezenbach, and Walter, 176–183, American Society for Microbiology Press). Based on ambient concentrations of *C. perfringens*, we (Fujioka et al., 1997) proposed two alternative recreational water quality standards for Hawaii based on geometric mean concentrations. For freshwater, the proposed standard was a geometric mean of 50 CFU/100 ml, whereas for coastal marine waters, the proposed standard was a geometric mean of 5 CFU/100 ml. These standards have proved to be reliable and have been adopted by the Hawaii Department of Health to determine when streams and coastal waters are contaminated with sewage. Some of the reasons why *C.*

perfringens can be reliably used in Hawaii are as follows. First, this bacterium is present in sewage at moderate concentrations (10^4 CFU/100 ml). Second *C. perfringens* is anaerobic and cannot multiply in the soil environment. Third, the method of assay is reliable and feasible. Fourth, the spores of *C. perfringens* are very stable in the environment, making it a more reliable indicator than the USEPA-recommended indicator bacteria, which are inactivated in environmental waters at a faster rate than sewage-borne pathogens. Although monitoring for *C. perfringens* can be reliably used to determine when most streams in Hawaii are contaminated with sewage, there are some conditions when this bacterium may not be reliable indicator of sewage contamination. One condition is when streams and storm drains merge and there is sediment build up in the stream/storm drain system. In this situation, non-sewage sources of *C. perfringens* such as feces of human and animals are discharged from storm drains and the spores accumulate and survive in the muddy sediment. The *C. perfringens* in the sediment are periodically re-suspended and the concentrations in the water column may at times exceed 50 CFU/100 ml. Feces of some animals such as dogs have higher concentrations of *C. perfringens* than human feces. Moreover, cattle and pigs discharge large volumes of feces into the environment. Feces from ducks are a primary aquatic source of *C. perfringens* because ducks live in streams where their feces are directly discharged. Although USEPA has been informed that their recreational water quality standards are not reliable in Hawaii and that the *C. perfringens* standards are much more reliable, USEPA continues to insist that Hawaii monitor its waters for their fecal indicators. The *C. perfringens* standards used in Hawaii has not been approved by USEPA.

The county wastewater departments in Hawaii are most vulnerable to the application of USEPA-recommended recreational water quality standards because whenever concentrations of fecal bacteria in streams or coastal waters exceed the recommended standards, sewage discharge from the wastewater facilities is blamed as the source of contamination. In this regard, the City and County of Honolulu is the agency with greatest vulnerability because it has the largest sewage treatment facilities and serves the greatest population in Hawaii.

The identified need for this study is to develop a monitoring scheme to determine when streams and other environments (stream, stream sediment, ocean, ocean sediment, wastewater) are contaminated with sewage under all conditions. In this regard, the assessment of experts is that no single indicator can be reliable for all conditions. Therefore, the strategy is to develop tests based on measuring other fecal indicators, in addition to *C. perfringens*, to reliably answer the following three basic questions regarding sewage contamination: (1) Is it really sewage contamination? (2) What is the extent of sewage contamination? (3) How recent or how long ago was the sewage contamination? If the answers to three questions can be obtained, all agencies as well as the general public in Hawaii will benefit because it will definitely be an improvement over the current situation, since the current fecal indicators and current recreational water quality standards are unreliable. The wastewater agencies in Hawaii will be a direct beneficiary because they can be assured when a pollution event is their responsibility and can take appropriate action. The regulatory agencies (Hawaii Department of Health, USEPA) will also be major benefactors because it is their responsibility to inform the public whether water is safe or unsafe for use, and these new tests will provide the necessary information to determine the risk to the public. The data obtained can be used to determine real risks from perceived risks to human health. This kind of information will lead to appropriate and effective management decisions.

The objectives of this study is to assess the reliability of monitoring environmental waters in Hawaii for *C. perfringens* in combination with other alternative fecal indicators (F-RNA coliphages, sorbitol-fermenting *Bifidobacteria*, fecal sterols) for the purpose of developing the best combination of test method and environmental monitoring plan to reliably determine when any environment (streams, storm drain, ocean, sediments, soil) is contaminated with sewage and whether the source of contamination is environmental (soil) or due to fecal wastes from non-human sources (e.g., birds, fowl, cattle, dog, cat, and chicken). The strategy of this proposed study is based on the fact that monitoring stream and ocean waters for *C. perfringens* can usually determine when sewage contamination has occurred. However, there are some conditions when the information provided by monitoring alone does not provide enough information to make conclusive decisions, especially regarding the time of contamination and associated health risks to humans. The scope of this research is to evaluate the reliability of determining when sewage contamination has occurred under a variety of conditions by analyzing samples of water or sediments for *C. perfringens* and two other potential alternative fecal indicators (sorbitol-fermenting *Bifidobacteria*, fecal sterols) in situations identified by the City and County of Honolulu as requiring more conclusive information.

Methodology

The design of this study is to monitor streams and coastal waters for one of the USEPA-recommended fecal indicator (enterococci, *E. coli*, fecal coliform), for *C. perfringens*, and for the two new alternative fecal indicators (sorbitol-fermenting *Bifidobacteria* and fecal sterols)

Sorbitol-fermenting *Bifidobacteria*. A recent study indicated that sorbitol-fermenting *Bifidobacteria* are specific to human feces, and although these bacteria are anaerobic, they survive long enough to be cultured (S.C. Long, E.J. Mahar, R. Pei, C. Arango, E. Shafer, and T.H. Schoenberg, 2002, Development of Source-Specific Indicator Organisms for Drinking Water, Technical report, American Water Works Association Research Foundation, Denver, Colorado). Thus, when these bacteria are recovered by a culture method, the results indicate very recent contamination. We will use the methods published by Long et al. (2002) to recover and enumerate sorbitol-fermenting *Bifidobacteria* using the Human Bifid Sorbitol Agar as well as to identify and confirm the presence of these specific bacteria. In this regard, Dr. Long has consented to assist us. Briefly, fecal, sewage, sediment, or water samples are collected in sterile bottles and transported to the laboratory. Using a sterile technique, various concentrations of water are filtered through a membrane. The membranes are then incubated anaerobically at 37ºC for 48 hours. Colonies that appear yellow, domed, and mucoid are presumptive sorbitol-fermenting *Bifidobacteria*. A representative number of presumptive positive colonies are transferred onto two Reinforced Clostridial Agar plates and tested for strict anaerobiosis by incubating one plate anaerobically and one plate aerobically at 37ºC for 48 hours. Strict anaerobes are tested by Gram stain, glucose, lactose and sorbitol fermentation, nitrate reduction, motility, catalase, fructose-6-phosphate phosphoketolase (F6PPK) activity, and nitrate reduction tests for confirmation as sorbitol-fermenting *Bifidobacteria*.

Fecal sterols. Fecal sterols are a class of metabolic by-products of mammals that end up in feces. Since the food and metabolism of animals differ, the fecal sterols differ. The study by P.D. Nichols, R. Leeming, M.S. Rayner, and V. Lathan (1993, Comparison of the abundance of the fecal sterol coprostanol and fecal bacterial groups in inner-shelf waters and sediments near Sydney, Australia, *Journal of Chromatography* 643:189–195) indicated that monitoring environmental waters for different kinds of fecal sterols can be used to determine whether the source of contamination is human or animal feces. Fecal sterols are measured using gas chromatography (GC) to measure coprostanol as a source of human feces. Water or sediment samples are collected and filtered in a manner similar to Standard Methods 9222A. Lipid extraction and fractionation samples are extracted quantitatively using $CHCL_3$ MeOH. After phase separation, the lipids are recovered in the lower $CHCl_3$ layer and are made up to a known volume and stored sealed under nitrogen at -20ºC. Total lipid sterols are obtained following alkaline saponification of an aliquot (10%) of the total lipids. Products are extracted into hexane-$CHCl_3$ and stored at -20ºC. Sterols are converted to their corresponding trimethylsilyl ethers by treatment with bis(trimethylsilyl)trifluoroacetamide. The samples are analyzed by GC using a flame ionization detector and a split/splitless injector.

Principal Findings and Significance

The sorbitol-fermenting *Bifidobacteria* test was evaluated by applying this method to assay sewage, streams and streams contaminated with sewage. The bifidobacteria concentrations were high in sewage but very low in most environmental water samples such as streams. A major limitation of this method is the difficulty in identifying the bacterial colonies as *Bifidobacteria*. As a result, the yellow, presumptive colonies had to be tested using many methods to confirm that the colonies were truly sorbitol-fermenting *Bifidobacteria*. Moreover, these bacteria quickly inactivated in water samples, and therefore their usefulness was limited to only very recent contamination. Based on the low recovery rate, the instability of sorbitol-fermenting *Bifidobacteria* in environmental waters, and the number of tests required to confirm their presence, it was concluded that this test was not feasible or reliable for monitoring environmental waters for fecal contamination.

The fecal sterol test for coprostanol was evaluated for its use in assaying sewage, streams, and streams contaminated with sewage. Using this method, it was shown that sewage contained high concentrations of coprostanol (280,000 ng/L) and high concentrations of fecal indicator bacteria (*E. coli*, enterococci) as well as *C. perfringens*.

When ambient streams were assayed, the concentrations of coprostanol were low (<5 ng/L) but the concentrations of *E. coli* and enterococci exceeded EPA standards, whereas the concentrations of *C. perfringens* was lower than the Hawaii standard of 50 CFU/100 ml. These results confirmed that the source of high concentrations of the USEPA- recommended fecal indicator bacteria (*E. coli*, enterococci) was not from sewage but from environmental soil. The usefulness of this method was shown during a known spillage of sewage into a stream. When tested, the concentrations of coprostanol was high (18,000 ng/L) after 24 hours, but this level dropped to 60 ng/L in 72 hours and down to <10 ng/L after 4 days. These results showed that the chemical assay for fecal sterol in the form of coprostanol was a reliable and feasible independent assay for the presence or absence of sewage contamination in Hawaii stream waters.

Results of this research have been presented at two venues. Kathleen Brostrom presented a poster, entitled "A possible alternative chemical indicator of human waste contamination for Hawaii," at the Hawaii Water Environment Association annual meeting, held in 2005 at the Hawaii Convention Center, Honolulu, Hawaii. She was awarded the second prize of $75. At the 2005 American Society for Microbiology, Hawaii Branch, annual spring meeting at the East–West Center, Honolulu, Hawaii, Kathleen Brostrom and Roger Fujioka's "Are fecal sterols an alternative of human waste contamination in Hawaiian recreation al waters?" was awarded $150 for second place (tied).

An Evaluation of Factors Affecting the Transport of Pharmaceutical Compounds and Pathogens in Selected Hawaii Soils for Land Application of Wastewater

Basic Information

Title:	An Evaluation of Factors Affecting the Transport of Pharmaceutical Compounds and Pathogens in Selected Hawaii Soils for Land Application of Wastewater
Project Number:	2003HI27B
Start Date:	3/1/2003
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	Hawaii 1st
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Focus Category:	Water Quality, Groundwater, Waste Water
Descriptors:	soil physical and chemical parameters, pathogen transport
Principal Investigators:	Chittaranjan Ray, Albert Sechurl Kim

Publication

1. Mohanty, S.; M. Snehota; C. Ray; J. Chen; J. Lichwa, 2005, Transport of selected wastewater contaminants in a tropical soil, poster presentation to the European Geophysical Union General Assembly, April 2429, 2005, Vienna, Austria.
2. Chen, J.; J. Lichwa; C. Ray, A comparison of extraction and analytical methods for hormonal compounds in wastewater, Journal of Chromatography, to be submitted.
3. Snehota, M.; S. Mohanty; C. Ray, Estimating column transport parameters for selected wastewater contaminants for a Hawaii soil, Journal of Hydrology, to be submitted.
4. Mohanty, S.; M. Snehota; C. Ray, An evaluation of transport behavior of wastewater contaminants in a tropical soil, Environmental Science and Technology, to be submitted.

Problem and Research Objectives

Mobility of viruses, bacteria, and other wastewater contaminants (including hormones) in subsurface media and their arrival in groundwater can have public health as well as aesthetic concerns. The sources of human and animal pathogens that may impact groundwater quality include land-applied sludge, manure, and wastewater; storage sites for manure; cesspools and septic tanks; leaky sewers; lagoons for the storage of human and animal wastes; barnyards; and feral animals. Wastewater and manure are also typical sources of hormones and other pharmaceutical compounds. Potential exists for pathogens and hormones/pharmaceuticals and other wastewater contaminants to leach through the soils and to finally reach the drinking water aquifers.

Generally, it is believed that the physical and chemical characteristics of the soil and to some extent the characteristics of the pathogens (as well as hormones) affect transport in subsurface media. If a soil is aggregated, it provides preferential pathways for pathogen- or hormone/pharmaceutical-containing water to pass through the topsoil. Fractures and cracks in subsoil accelerate the movement of this water. The clay and organic matter content of the soil affect the sorption of pathogens, hormones, and pharmaceuticals, while soil pH and the isoelectric point of the pathogens affect their attachment. Also, it is believed that the mineral oxides provide positively charged sites to retain these pathogens in the soil. The degree of saturation of the subsoil media may have some effect on the mobility of pathogens. If the water content is reduced, it is hypothesized that the travel path will be longer and the water film thickness with be smaller. A smaller thickness of the water film around the particles allows greater attachment potential of the pathogens to the particles.

An initial evaluation of a local soil (a tropical Oxisol) showed that it has high potential for retaining a large number of bacteria and viruses in the top three inches of packed soil columns. Oxisols contain a large percentage of clay-size particles and contain significant amounts of the oxides of iron, aluminum, and manganese. For this soil, batch-equilibration sorption experiments conducted for bacteriophage showed a high sorption distribution coefficient. As for bacterial sorption, although methodological problems caused some difficulties in quantitation, the initial results showed higher retention. Although this result has aroused widespread interest locally on the reuse of effluent on land directly overlying potable water aquifers, we strongly believe that additional laboratory and field evaluations are essential prior to undertaking large-scale land application efforts. More remains to be done in characterizing various soils in terms of their physical and chemical properties where land application of wastewater is being or is planned to be practiced. Most soils in temperate climates have fixed charges, whereas many soils in the tropics exhibit variable charges. In addition, quantification of attachment and detachment of the bacteria and viruses through batch-equilibration sorption tests or through flow-through column experiments needs to be evaluated.

The initial goal of this research was to evaluate the transport of pathogens and pharmaceutical compounds as influenced by soil properties, especially under Hawaii conditions. The planned study was proposed to be carried out over a two-year funding cycle. Since funding was provided for just one year, only the transport of selected wastewater contaminants and hormones was considered. Thus the objectives were modified to address the following:

1. How would the wastewater contaminants and hormones move through Hawaii soils?
2. Can the soil properties be manipulated by amendments to affect contaminant transport?
3. Can the existing models be used to quantify contaminant transport in the subsurface?

Methodology

In order to answer the above-outlined questions, the following tasks are being undertaken.

Task 1. How would the wastewater contaminants and hormones move through Hawaii soils?

In a related wastewater reuse project, secondary treated wastewater from the Honouliuli treatment plant on Oahu was characterized (W.M. Muirhead, E.M. Kawata, and R.W. Crites, 2003, “Assessment of recycled water irrigation in central Oahu,” presented at the 2003 WEFTEC Conference, Water Environment Federation, Alexandria, Va.). Table 1 provides a comparison of concentrations of seven chemicals found in groundwater with that found in secondary treated, filtered, and chlorinated effluent (called R1 effluent).

Table 1. Comparison of Concentrations of Trace Organics in Wastewater Prepared for Reuse With That in Central Oahu Groundwater

Constituent	R1 Effluent (ng/l)	Control Groundwater (ng/l)
Atrazine	210–400	<44
17β-estradiol	4.13	0.27
Estrone	224	0.94–3.99
Lindane	16–67	<8
N-nitrosodimethylamine (NDMA)	8.2	0.75
Nonylphenol	12,300	130–216
Octylphenol	15,800–29,600	150–190

Source: W.M. Muirhead, E.M. Kawata, and R.W. Crites, 2003, "Assessment of recycled water irrigation in central Oahu," presented at the 2003 WEFTEC Conference, Water Environment Federation, Alexandria, Va.

The predominant soils in the planned reuse areas of Oahu are the Oxisols. The Wahiawa Oxisol is the most prominent soil in these areas. This soil was retrieved from the Poamoho Experiment Station of the University of Hawaii at two depth ranges: (1) 30 to 60 cm depth, to avoid the influence of surficial organics (referred to as TOP here) and (2) 370 to 390 cm, from the saprolites (referred to as SAP here) where the soil is poorly developed. Table 2 provides the pH measured in water and in KCl, selected ions, and the organic matter of the soil at various depth ranges.

Table 2. Selected Physico-chemical Parameters for the Poamoho Soil of Central Oahu

Sample Depth Range (cm)	Soil Reaction		Ions				Organic Carbon (%)
	H_2O pH	KCl pH	P (mg/g)	K (mg/g)	Ca (mg/g)	Mg (mg/g)	
0 to 15	6.3	6.0	343.0	680.0	1,450.5	382	1.556
15 to 30	6.0	5.5	243.0	358.5	1,326.5	400.5	1.397
30 to 60	6.3	5.8	39.5	92.5	1,023	322	1.064
60 to 90	6.3	5.9	7.8	45.0	879	205	0.475
183 to 213	—	—	—	—	—	—	0.302

Air-dried and sieved (2.33 mm) soils were packed in stainless-steel columns with an internal diameter of 4.75 cm and a length of 7.60 cm to a bulk density of around 1.1 g/cm^3 (typical of that found in the field). Each column had a tensiometer in the mid-section to monitor the pressure. The bottom of the column was exposed to a pressure of around –5 cm . The column was saturated with a background solution from the bottom to expel the air out. The background solution was prepared from deionized water and 0.0005 M $CaCl_2$, resulting in a concentration of Cl^- equal to 36 mg/l. Such a level of Cl^- was found previously in leachate from the TOP soil column leached with deionized water. Using this composition of influent water, an attempt was made to minimize leaching of the Cl^- from the soil to prevent the breakdown of structure. After infiltration of one pore volume of background solution, the leaching solution was switched either to a tracer (bromide at 10 mg/l from KBr, referred to as pilot run here) or to a contaminant solution (in bromide tracer at 5 mg/l with the background leaching solution, known as artificial groundwater [AGW] and the R1 water). The concentrations of the spiked chemicals are presented in Table 3.

Table 3. Concentration of the Compounds in the Influent Water

Experiment	Compound							
	NDMA (mg/l)	Lindane (mg/l)	Nonylphenol (mg/l)	Octylphenol (mg/l)	Atrazine (mg/l)	17β-estradiol (mg/l)	Estrone (mg/l)	Bromide (mg/l)
Pilot run	—	0.4	0.1	0.2	0.008	0.004	0.002	10
AGW	2.5	0.002	0.2	0.4	0.008	5	5	5
R1 water	1	0.002	0.6	0.6	0.008	1	1	5

Note: For the R1 water experiment, the values are for the spiked concentration; actual concentration values can be higher due to background concentration.

After infiltrating the solute pulse at a steady flow rate, the inlet concentration was switched to that of the background solution. Then the experiment was continued to acquire the desorption phase of the breakthrough curve (BTC). Effluent was collected and analyzed regularly to develop the BTC. A schematic of the column setup is shown in Figure 1. The flow rate, column pressure, ambient and the solution temperatures, and the weights of individual columns were recorded electronically.

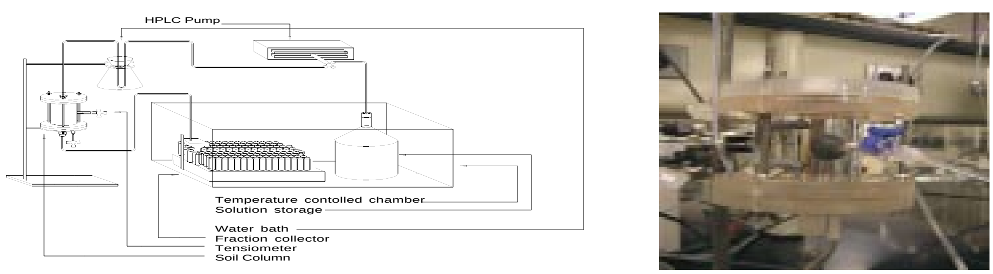

Figure 1. Schematic of experimental setup for conducting BTC experiment (left) and details of the soil-column assembly (right)

Several flow interruptions were made in the column experiments in which the inflow to the column was stopped for various time intervals to examine the degradation of the contaminants in the column. Breakthrough concentrations were prepared by sampling the effluent in a fraction collector and analyzing those using a combination of gas chromatography, high performance liquid chromatography (HPLC) either with a diode array detector or with a mass-selective (MS) detector. Lindane and the two phenols were first extracted with hexane. The hexane extract was directly injected into a gas chromatograph with an electron capture detector for the analysis of lindane. The extract was further evaporated with a stream of nitrogen, redissolved with a mixture of 50:50 acetonitrile and water, and analyzed by HPLC-MS. For estrone and estradiol, 50-ml water samples were lyophilized (freeze-dried) to dryness. The residue was transferred to autosampler vials after multiple rinses with acetone. The acetone solution was then evaporated to dryness under a stream of nitrogen. The residue was redissolved with 0.5 ml of 50:50 acetonitrile and water and analyzed by HPLC-MS. For the analysis of atrazine and NDMA, filtered effluent water samples were directly injected to the HPLC.

Task 2. Can the physical and chemical parameters be manipulated by amendments or by the physical setting of the site to affect contaminant transport?

Soil amendments such as gypsum and lime affect the pH of the soil. This could also shift the zero-point charge on clay surfaces. Addition of manure and other organic waste material can affect the transport behavior of chemicals. For this purpose, we will limit our experiments to the addition of a surfactant and natural organic matter to the soils. Planned experiments are similar to that conducted in the preliminary study (T.P. Wong and C. Ray, 2001, “Effect of polymer and surfactant on bacteria and phage rransport in subsurface,” presented at the World Water and Environmental Conference, Orlando, Florida, May 20–24, 2001, American Society of Civil Engineers, Reston, Va.). Sorption and transport experiments are planned to examine the impact of these additives on contaminant and hormone mobility. At the end, lime and gypsum can be added to two columns as a pH modifier.

Task 3. Can the existing models be used to quantify contaminant transport in the subsurface?

Data from batch and column experiments can be used to estimate sorption parameters for modeling. Estimation of sorption parameters from batch equilibration tests for predicting transport in column experiments has limited use. Apparent equilibration is normally assumed in batch studies, whereas kinetic sorption behavior is needed to describe transport in columns. However, one difficulty arises if no breakthrough of hormones from the column is obtained in a reasonable amount of time. Breakthrough data for wastewater contaminants from soil columns can provide needed transport parameters for simulation.

Principal Findings and Significance

Task 1 is nearly done. However, due to analytical difficulties with some of the compounds, a number of experiments will be repeated. A no-cost extension has been received until February 2006. Tasks 2 and 3 will be undertaken in the remaining period of this project. Below are the principal findings.

As shown in Figure 2, bromide behaved like an ideal tracer with 50% of the feed concentration appearing in the leachate after the passage of one pore volume of leaching solution. Lindane, atrazine, and NDMA were the three other compounds that appeared in the breakthroughs of the TOP and SAP columns. NDMA behaves like a tracer. The BTCs for lindane and atrazine showed certain amounts of retardation in the TOP columns. However, there was negligible retardation of the BTC in the SAP columns. No breakthroughs of estrone and 17β-estradiol were found. The BTCs of octylphenol and nonylphenol showed significant variations. It was later discovered that the standards had significant impurities. A new set of experiments will be conducted for these phenols.

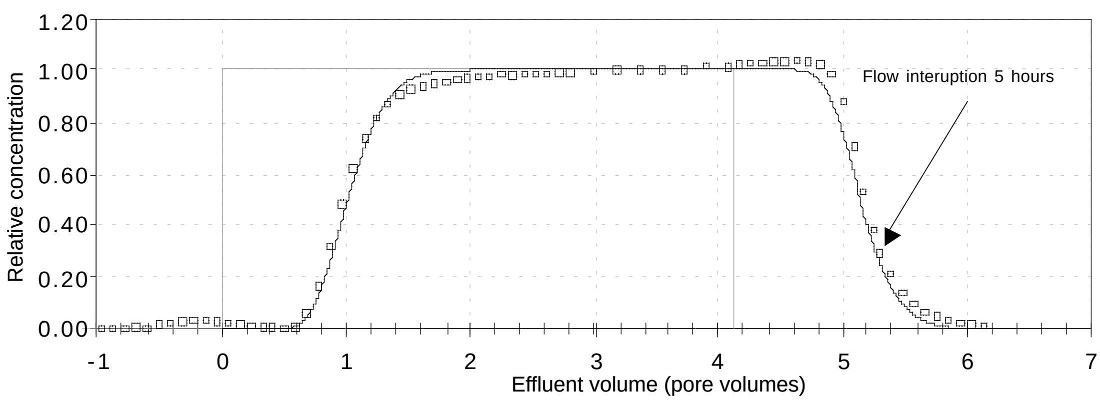

Figure 2. Bromide breakthrough curve from the pilot experiment

Currently, we are conducting inverse numerical modeling to obtain the parameters for the fate and transport of the studied contaminants in the TOP soil columns. Simulations are being conducted using HYDRUS 1D (J. Simunek, M. Sejna, and M.T. van Genuchten, 1998, The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media, version 2.0, IGWMC, Colorado School of Mines, Golden, Colo.). One presentation on the above work was made at the European Geosciences Union conference this year. The poster, entitled “Transport of selected wastewater contaminants in a tropical soil,” by S. Mohanty, M. Snehota, C. Ray, J. Chen, and J. Lichwa, was presented to the European Geophysical Union General Assembly, April 24–29, 2005, Vienna, Austria.

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:	2/28/2005
Funding Source:	104B
Congressional District:	Hawaii 1st
Research Category:	Social Sciences
Focus Category:	Economics, Conservation, Water Supply
Descriptors:	groundwater, optimal control, conservation, water supply
Principal Investigators:	James A. Roumasset, Rodney B.W. Smith

Publication

1. Kaiser, B.; J. Roumasset, 2002, Valuing indirect ecosystem services: The case of tropical watersheds, Environmental Economics and Development 7, 701-714.
2. Kaiser, B.; W. Matsathit; B. Pitafi; J. Roumasset, 2003, Efficient water allocation with win-win conservation surcharges: The case of the Koolau watershed, Working Paper, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii.
3. Pitafi, B.; J. Roumasset, 2005, Integrated water management policies for Oahu, WRRC Bulletin, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii.
4. Pitafi, B.; J. Roumasset, Sequencing watershed conservation and groundwater management reforms, Journal of the American Water Resources Association, forthcoming.
5. Pitafi, B.; J. Roumasset, Pareto-improving water management over space and time: The Honolulu case, American Journal of Agricultural Economics, in revision and resubmission phase.

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. In addition, proposals for efficiency pricing have often been found to be politically infeasible because current users will have to pay a higher price even though future users will be better off. 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 on Oahu. Pricing schemes for achieving efficient use are calculated. We show how efficiency pricing can be rendered politically feasible by compensating the users suffering a loss due to higher prices. Finally, rather than take aquifer recharge rates as exogenous to water management, we incorporate watershed management as one of the policy instruments.

Methodology

We 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 supplemental source as warranted by demand. 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, usage at different elevations with different distribution costs, and different changes in forest recharge levels. The effects of watershed conservation are introduced in the form of probabilistic changes in recharge.

Principal Findings and Significance

We have constructed modeling frameworks, estimated parameters for each aquifer, and conducted pioneer simulations for the cases of Pearl Harbor and Honolulu aquifers.

The Pearl Harbor Case

We investigate the economic benefits of conserving a forested watershed in conjunction with efficiency pricing of the downstream groundwater resource. We find that under a wide range of parameter assumptions, investment in watershed conservation will generate positive benefit-cost ratios, even before accounting for biodiversity and other conservation benefits.

We examine the value of conservation of a forested watershed, assuming that watershed degradation occurs with low probability (between 1% and 20%). We start by describing the impacts of a certain loss of forest quality and associated recharge. If 31% of recharge from the Koolau mountain watershed area on Oahu is lost, this will decrease recharge to the Pearl Harbor aquifer by 15% and decrease the present value of the aquifer by more than $1.2 billion, assuming a 3% social discount rate and efficient resource use.

We then adapt the methodology used to determine this definitive loss in order to calculate the expected loss in social welfare from an uncertain probability of forest quality degradation. Assuming a modest probability of 10% that the resource is degraded, reducing aquifer recharge 15% after 20 years, we find that the expected benefits of conservation are $89 million using a 3% discount rate. This figure is robust to a large number of parameter changes. This estimate assumes that the resource manager optimally solves the problem of water extraction under uncertainty and knows that the optimal price path is discontinuous and jumps up or down after the event or nonevent is realized. In the likely event of mismanagement, inasmuch as water managers are typically unfamiliar with economic optimization even under certainty, the gains of conservation will be larger.

Policymakers have indicated that the costs of successful conservation may be as high as $45 million. Even at such high costs, conservation combined with efficient water management is a win-win-win situation for consumers, taxpayers, and the environment, albeit in the sense that the environmental insurance acquired through conservation costs less than its expected value. Only in cases where the probability of the event is very low do the estimates of expected social loss fall below $45 million.

In addition, we have compared the effects of efficiency pricing and watershed conservation. Efficiency pricing yields a welfare gain of about $900 million in present value, whereas watershed conservation yields only about $43 million without efficiency pricing and $45 million with efficiency pricing. Thus a watershed conservation that costs $45 million may be welfare-reducing if efficiency pricing is not undertaken simultaneously. We also find that if watershed conservation is adopted first, followed by efficiency pricing several years later, the delay can result in major losses (24 % and 44 % for 10- and 20-year delays, respectively).

The Honolulu Case

We analyze two scenarios of water usage/pricing. (a) *Status-quo pricing* — We derive the extraction rates dictated by demand resulting from continuation of the current pricing (equal to cost) and estimate resulting welfare. (b) *Efficiency pricing* — This is a scenario in which insufficient conservation efforts cause the risk of reduced recharge.

We find that if the status-quo policy of pricing water at average (extraction and distribution) cost is continued, consumption will grow quickly and the groundwater aquifer will be depleted fast (in about 57 years), with the head level reaching the minimum allowable (to avoid salinity). After that, extraction of groundwater cannot exceed the recharge rate. Any excess demand at that time and any future growth in demand must be met using the more-expensive desalination technology. Status-quo pricing does not differentiate users by distribution costs and results in subsidies from lower-elevation users (with lower distribution costs) to higher-elevation users. Efficiency pricing requires a slight price increase in the first year. This price rises smoothly over time, but faster than the status-quo price, until the aquifer reaches the minimum allowable head level and desalination has to be used (in year 76). As the efficiency price includes category-specific distribution cost, it avoids distribution-cost subsidies from lower- to higher-elevation users.

The efficiency-pricing regime is compared to status-quo pricing in terms of welfare. Since the efficiency prices are higher than the status-quo prices, initially users lose welfare by switching from status-quo to efficiency pricing. This is not true for the users in the lowest-elevation category who actually gain welfare because they do not have to subsidize the distribution cost of the higher-elevation users. Since most of the consumption occurs at the lowest elevation, these gains are substantial. Over time, however, as the efficiency prices rise, all categories see increasing losses relative to status-quo pricing (the present value of all losses is estimated at $34 million). Later, efficiency pricing becomes welfare-superior to status-quo pricing and remains superior afterwards because the status-quo policy would require the use of expensive desalination technology sooner and would rely on it more heavily than efficiency pricing. Thus efficiency pricing provides greater welfare to users in all elevation categories later on (the present value of the gains is estimated at $441 million).

Switching to efficiency pricing causes some (mostly high-elevation and near-term) users to lose welfare and some (mostly low-elevation and future) users to gain. The resulting political problems can be avoided by actually compensating the losers. This is achieved by proposing a compensation system for welfare-losing users through a free block. The cost of the free block is financed by the users who gain welfare in spite of this reduction. Efficiency pricing is thus made actually Pareto-improving by compensating those who lose welfare due to the switch from status-quo pricing.

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:	2/28/2005
Funding Source:	104B
Congressional District:	Hawaii 1st
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Water Supply, Waste Water
Descriptors:	nitrate Contamination, Water Supply, Waste Water
Principal Investigators:	Clark C.K. Liu

Publication

1. Qin, G; C.C.K. Liu; N.H. Richman; J.E.T. Moncur, 2005, Aquaculture wastewater treatment and reuse by wind-driven reverse osmosis membrane technology: A case study on Coconut Island, Hawaii, Aquaculture Engineering 32:365-378
2. Liu, C.C.K.; J.W. Park, 2002, Water desalination, in McGraw-Hill Encyclopedia of Science & Technology, ninth edition, volume 22, New York, New York, McGraw-Hill, 404-406.
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5. Gang, Q., 2002, Cost-effective aquaculture nitrogen removal by wind-powered reverse osmosis membrane technology, MS thesis, Department of Civil and Environmental Engineering, College of Engineering, University of Hawaii, Honolulu, Hawaii, 186 pages.
6. Liu, C.C.K., 2002, Wastewater reuse, in McGraw-Hill 2002 Yearbook of Science and Technology, New York, New York, McGraw-Hill, 406-409.
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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 for FY 2001 and FY 2002 are (1) to investigate the nitrogen build-up in freshwater aquaculture of tilapia, (2) to develop a wind-powered reverse osmosis (RO) nitrogen removal system, and (3) to evaluate the economic feasibility of the wind-powered RO system for removing nitrogen from aquaculture wastes.

The studies on removal of nitrogenous aquaculture wastes by a wind-powered RO system is followed by a second phase of research on a new pollution issue—namely, the discharged concentrate. The mechanisms of the RO membrane system are such that the discharge concentrate will have a higher nitrogen concentration level than that of the untreated wastewater from the fish tank. Thus the concentrate cannot be recirculated in the system; rather, it must be discharged or further treated before it can be reused. The research objectives for FY 2003 and FY 2004 are (1) to further investigate the nitrogen build-up in discharged concentrate from the RO system and (2) to develop a duckweed-based pond system to remove nitrogen from the concentrate.

Methodology

This began as a two-phase project, with each phase scheduled to last one year. The focus of the first year's research was to study the characteristics of aquaculture waste, especially the concentration of nitrogen at different stages of fish (tilapia) growth. The second year's research was to investigate the performance of nitrogen removal by the reverse osmosis process and to develop a water recirculating system for tilapia production.

The reverse osmosis module of the system separates the wastewater from the fish tank (or feed water) into permeate and concentrate. The high-quality permeate is circulated back to the fish tank and is reused as a freshwater supply. The concentrate is mixed with feed water and is treated again by the reverse osmosis module. As the system operation goes on, the nitrogen concentration in the concentrate becomes higher and must be discharged from the system. As part of the second phase of research, the desirable frequency of concentrate discharge is evaluated, and the process and reuse of waste concentrates by a duckweed-based reactor are investigated.

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 in FY 2001 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 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.

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.

Results of field experiments indicated that the frequency of concentrate discharge is one of the key factors that control the ammonia nitrogen concentration in the concentrate.

Figure 1 shows the changes of ammonia nitrogen concentrations in the feed water, permeate, and concentrate, with a 6-hour concentrate discharge frequency. Comparing the data presented for 4-hour and 8-hour discharging experiments, the peak ammonia nitrogen concentrations in concentrate from 6-hour discharges are 1.09 and 1.49 mg/l, and the peak nitrate concentrations in concentrate are 0.57 and 0.71 mg/l, which proves that the discharging period is a key factor in controlling the concentration levels of the concentrate discharged.

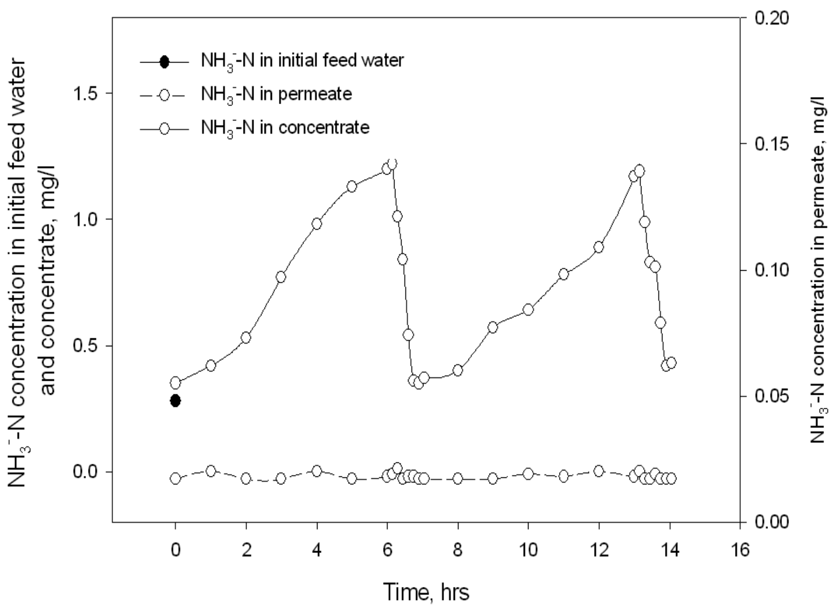

Figure 1. The concentration of ammonia nitrogen in the feed water in the permeate, as well as in the concentrate, with a 6-hour frequency of concentrate discharge and an average ambient wind speed of 5.3 m/s

Results of field experiments also indicated that the freshwater recovery rate would change with the frequency of concentrate discharge and the ambient wind speed (Figure 2).

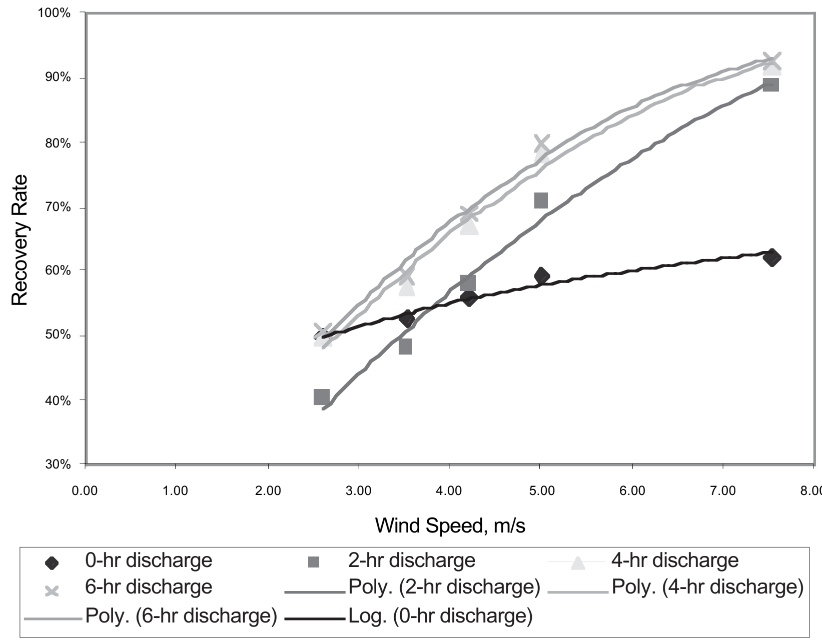

Figure 2. Relationships of freshwater recovery rate and ambient wind speed

A plug-flow bioreactor that was later constructed for the treatment and use of concentrate (brine) from the reverse osmosis process was tested (Figure 3).

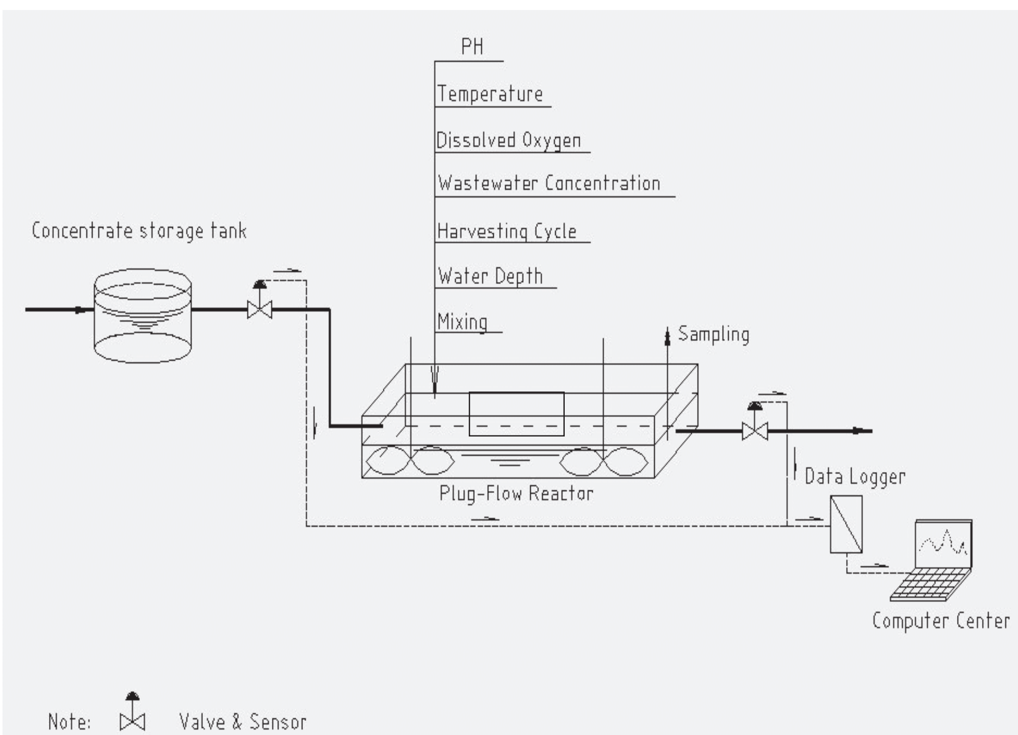

Figure 3. Schematic of plug-flow bioreactor

The system developed by this project can be added to a fishpond to form a closed aquacultural production system with zero waste discharge. The permeate (freshwater) from the system can be used as the freshwater supply for fish culture, while the brine (concentrated wastewater) can be further processed into fish feed by a duckweed-covered reactor.

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:	2/28/2005
Funding Source:	104B
Congressional District:	Hawaii 1st
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, Water Quality, Non Point Pollution
Descriptors:	models, runoff, best management practices, vadose zone, groundwater, infiltration, recharge
Principal Investigators:	Chittaranjan Ray

Publication

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2. Miyasaki, C.; C. Ray, 2004, Evaluation of Hydrologic Balance at an Experimental Landfill Capping Site in Kaneohe Marine Corps Base Hawaii, Research report UHM/CEE/04-04, Department of Civil Engineering, University of Hawaii, Honolulu, Hawaii.
3. Ray, C., Alternative landfill covers for humid tropics?, submitted to Civil Engineering (magazine) in March 2005.
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5. Sanda, M.; C. Miyasaki; C. Ray, Intercode comparison for runoff and leachate production at an experimental landfill cover site, Journal of Hydrology, to be submittted.
6. Ray, C.; I. Stewart; M. Snehota; M. Sanda; T. Hakonson; B. Harre, An alternative cover for landfill cap in a tropical setting: 1. Study site and automated data collection, Water Resources Research, to be submitted.
7. Ray, C.; M. Sanda; C. Miyasaki; T. Hakonson; B. Harre, An alternative cover for landfill cap in a

tropical setting: 2. Evaluation of water balance, Water Resources Research, to be submitted.

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. In addition to some simplifying assumption for water conduction in capping material, 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 the test plots from natural rain and sprinkler-applied water 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 are closely related the previous two years' effort.

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. Since the study is complete now, the site will be dismantled in summer 2005.

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 years' activities)

In order for all instruments to function properly, replacement and recalibrations are continuously needed. Work involves replacement of flow counters, recalibration of pressure transducers, and replacement of level switches and multiplexers. In addition, work involves installing erosion control measures that are needed to prevent sliding of material in various areas of the experimental field and to prevent the material from offsite locations from entering the study area. 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. All these activities were carried out as needed.

Task 2. Additional soil hydraulic, vegetation, and evaporation 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. Altogether, 54 core samples were retrieved from various depths to obtain soil-water retention parameters.

A disc infiltrometer (from Soil Measurement Systems) is used to measure hydraulic conductivity at three locations per plot. Because surface soils are affected by cracks, root channels, and other macropore features, the measured hydraulic parameters at surface can be different from those at deeper depths. Thus, measurements are made first at the soil surface. Then similar measurements are made 15 to 20 cm 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 m2 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 m2 to get the average biomass per unit area.

A Class A Weather Bureau evaporation pan was setup near the meteorological station. A pressure transducer with fine resolution is used to continuously monitor the loss of water.

Duplicate soil cores from four locations outside the plots and from 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 3. Setup of an irrigation system to create artificial rain for water balance measurements

A sprinkler irrigation system was set up on three plots (control, 20% impervious, and 40% impervious) to make artificial rain at a given intensity for desired durations for water balance measurements. Before that, nine automated tensiometers in the three plots were installed to measure soil-water tension as a function of time.

Each plot has a nested tensiometer (at three depths) and four surficial tensiometers. Readings from these tensiometers are taken manually. Also, each plot has four automated (5 to 25 cm) and two manual (5 to 25 and 35 to 55 cm depths) time domain reflectometry (TDR) probes for reading water content. The manual probe readings are to be compared with the automated probe readings.

Task 4. Water balance simulations using a regulatory and two event-based (a runoff and an infiltration/percolation) models

The landfill water balance model (HELP-3, P.R. Schroeder, T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peyton, 1994, The hydrological evaluation of landfill performance (HELP) model: Engineering documentation for version 3, EPA/600/R-94/168b, U.S. Environmental Protection Agency, Washington, D.C.) is used to calculate water balance on a daily basis. For the applied irrigation water or the rain from a natural storm, an infiltration/percolation model (HYDRUS-1D by J. Simunek, M. Sejna, and M. Th. van Genuchten, 1998, The HYDRUS-1D software package for simulating one-dimensional movement of water, heat, and multiple solutes in variably-saturated media, version 2.0, IGWMC-TPS-70, International Ground Water Modeling Center, Colorado School of Mines, Golden, Colo.) and a runoff model (KINEROS2, a modified version of the model by D.A. Woolhiser, R.E. Smith, and D.C. Goodrich, 1991, A kinematic runoff and erosion model: Documentation and user manual, ARS-77, U.S. Dept. of Agriculture, Agricultural Research Service, Washington, D.C.) are used. In the water balance equation, the amount of rain or irrigation water applied is known. In addition, the amount of percolation and runoff are directly measured. Pan evaporation data give an idea about evaporation. Also, the local weather data are used to calculate long-term potential evapotranspiration. Changes in soil-water storage are calculated from the tensiometer/TDR probe readings.

Principal Findings and Significance

Erosion control measures are periodically needed to ensure that water and sediments from offsite do not enter the test site where most of our leachate and runoff measuring devices are sitting in an excavated area adjacent to a slope. In the past, severe erosion resulted in the formation of gullies. After the addition of erosion cloth and riprap, the slope is stable and major erosion is not taking place and; all gullies have since been plugged.

With continuous repair and replacement, all sensors are working properly. Rainfall frequency data are now collected at 1-minute intervals during rain events, as a result of a modification made to the data logging program. During dry periods, rainfall data are collected only at 15-minute intervals (the same frequency as other sensors).

Retention data for more than 48 samples were developed between saturation and 15-bar pressure. 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 (at least one log order) 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 (see the “Methodology” section). The leaf area index varied between 0.96 and 2.08, depending on the plot.

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.

Eight rain and irrigation episodes were closely examined for water balance calculations. Most of the rain episodes were limited to three hours. Leachate and runoff were directly measured. Because of the short duration of the events, evaporation data are less likely to be in error. When we used water content changes, estimated from the responses of automated tensiometers, in the water balance equation, the terms do not balance out. Since the accuracy of measuring rain, runoff, leachate, and ET are better than measuring changes in soil water content, we suspect the conversion of pressure readings to water content using the retention curve could have brought in some errors to the water balance equation. Many fine soils exhibit hysteresis in soil-water retention. The retention curve developed in the laboratory was for the drying of samples. If there is hysteresis, then some discrepancy can be introduced in converting pressure to water content in the rain event using the drying curve.

We found that leachate amounts predicted using HELP-3 were off by as much as 100%. The underprediction of runoff was greatest for the 40% impervious plot. KINEROS-2 predicted surface runoff very well for the control plot. However, the predictions were off (-27% to 122%) for the partially impervious plots. A reason for this discrepancy is the improper accounting of runoff-producing areas in the model. Although the plots were supposed to be 20% and 40% impervious, in reality they were effective in producing on an average 5.3 % and 6.2% runoff (individual events ranged from 0 to 13%), due to interception of overhanging vegetation on the rain gutters. Also, runoff predicted using HELP-3 was lower than the measured runoff values. Leachate production simulation using HYDRUS-1D was better than that with HELP-3. However, the predicted leachate quantities obtained using HYDRUS-1D were still more than the observed values. HYDRUS-1D assumes instantaneous runoff once the rainfall exceeds the simulated infiltration capacity. Measurement errors for soil hydraulic conductivity and soil heterogeneity in the field are other possible types of error.

In 2004, two sets of three control irrigation episodes each were run, with 20 cm of irrigation applied at a constant rate of 1.7 cm/h during each 12-hour episode. For the first set of three episodes, performed between June 28 and July 8, the vegetation cover was completely cut and removed prior to the irrigation runs, which were performed consecutively with approximately 2.5 days between each. For the second set, performed between August 22 and 29 when all of the test plots were abundantly covered with vegetation, each run had a lag period of 1.5 days. During the June/July irrigation episodes, natural rainfall was minimal, with the third episode receiving 1.3 cm. More rainfall occurred during August, when 1.0 to 4.2 cm fell during the episodes, adding to the 20 cm of irrigation applied for each event.

The results of these long-duration irrigation events showed no major difference in leachate production between the non-vegetated (June/July runs) and vegetated (August runs) plots, which coincides with the antecedent soil water having been much lower in June/July than in August. Water was applied to almost dry soil in June, to somewhat wet soil in July, and to more wet soil in August. For the June/July events, leachate varied from 3% to 45% of the rainfall, whereas for the August events, it varied from 20% to 40%. Surface runoff in the initially dry soil was zero for the control plot, 6% for the 20% impervious plot, and 10% for the 40% impervious plot. However, under the subsequently wet conditions, runoff varied between 10% and 40%.

The present design of rain gutters as artificial diversion channels of rainwater does not seem to work effectively during irrigation and natural events. For practical reasons, a small number of wider gutters would work better because they would fill up with less vegetation debris, making them easier to clean. Splash can be minimized by placing some gravel inside these gutters. Another possible setup is to move all the gutters to one or two locations in the plots.

Measurement of water in the soil profile contributes most to the error in water balance, even if TDR probes instead of tensiometers are used over the entire depth of the profile. Soil heterogeneity, especially that for topsoil, contributes to 10% to 30% of the discrepancy. Tensiometers relying on the retention curve relationship can lead to inaccuracy due to hysteresis effects. This inaccuracy can also increase due to swelling of the soil, a phenomenon that was observed during all experiments. Entrapped air in soil could add an additional 10% to the inaccuracy. Errors of balancing outflow and runoff are in a range of a single percentage, due to the high sensitivity of the equipment used. Errors in evaporation can vary, depending on the method used for estimating and the duration of the water balance. However, having an on-site evaporation pan decreases this error to some extent.

Three papers, one project report, one technical report, and one seminar presentation provide the research results of this project. The three papers deal with different aspects of an alternative cover for landfill caps in a tropical setting: one on the general suitability aspects and the other two on the numerical modeling and water balance calculations. The seminar presentation focused on an accurate water balance study for the Kaneohe Marine Corps Base landfill test site.

Information Transfer Program

WRRCs Technology Transfer program continued with a seminar series, project bulletins, newsletters, participation in conferences, assistance to consultants, students of all levels, consultants and the public, participation in school science fairs, direct participation in research projects having an informational component, and an expansion of the Centers web site.

Technology Transfer 2004-05

Basic Information

Title:	Technology Transfer 2004-05
Project Number:	2003HI42B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	First
Research Category:	Not Applicable
Focus Category:	Education, Water Quantity, Groundwater
Descriptors:	
Principal Investigators:	Philip Moravcik

Publication

1. *Bulletin*, Water Resources Research Center, Unviersity of Hawaii at Manoa, December 2003, 8 pp.
2. *Bulletin*, Water Resources Research Center, University of Hawaii at Manoa, May 2004, 8 pp.

Publications

The Technology Transfer program produced 2 newsletters describing research projects and Center activities and news during the subject period.

The Seminar Series is designed to foster communication amongst WRRC researchers, students, and the target audience of government agencies, private sector personnel and members of the public with an interested in water resource issues. A WRRC faculty member is appointed each semester to organize the seminar and recruit speakers on a theme of interest. Topics thus vary depending on the interests of the coordinator and availability of speakers. Typically the seminars include reports on WRRC projects and discussions by government officials of emerging water-related issues. The following is a list of the seminars presented during the reporting period.

Spring 2004 Seminar Coordinator: Dr. Kaeo Duarte

3/18/2004	Brooks Kaiser, Gettysburg College, Asst Professor, **Watershed Conservation and Groundwater Management, An Integrated Perspective**
4/1/2004	Stephen Gingerich, PH.D. Research Hydrologist, USGS, **Effects of Diversions on Streamflow and Native Macrofauna in Northeast Maui**
4/15/2004	Manoj Potapohn, UHM Dept of Natural Resources and Environmental Management, **Modeling Water Use for Hawaii's Diversified Agriculture**
5/6/2004	Kaeo Duatre, UHM Botany and WRRC, **Optimal Management of a Brackish Coastal Pumping Well**
6/28/2004	Steve Anthony, Chip Hunt, Anne Brasher, USGS, **USGS Water Quality Study, Oahu**
7/29/2004	Goloka Behari Sahoo and Sushant Dahl, Dept of Civil & Environmental Engineering and WRRC Graduate Assistants, **Watershed Modeling Using a Physically Distributed Model, MIKE SHE and a Watershed-Scale Moden, AnnAGNPS**

Fall 2004 Seminar Coordinator: Dr. Roger Babcock

9/9/2004	Dennis Livingston, Enviroquip Inc. Austin, Texas, **Design and Operation of an Enviroquip Membrane Bioreactor (MBR)**
9/16/2004	John Kemmerer, Associate Water Director, EPA Region IX, **EPA's Priorities and Activities for the Water Programs**
9/23/2004	Deo, Phagoo, Wastewater Process Manager, Zenon Environmental Inc, **Critical Design Factors for membrane Bioreactors**
10/21/2004	Basharat A Pitafi, Department of Economics, UHM, **Efficient and Politically Feasible Groundwater Management in Honolulu**
11/9/2004	Michael Sparks, Ionics Inc. Watertown Massachusetts, **Design Principles of Ionics MBR and its Positive Impacts on the Environment**
11/16/2004	Roger Babcock, WRRC and Civil & Environmental Engineering, University of Hawaii, **Comparison of Five Different Membrane Bioreactors (MBRs)**
12/2/2004	Jay M. K. Stone P.E., DEE, Oceanic, **Kalaeloa Desalination Plant--Equipment Testing Pilot Facility**

Spring 2005 Seminar Coordinator: Dr. Roger Fujioka

1/20/2005	Roger Fujioka, UH WRRC, **Problems with the Application of EPA Recreational Water Quality Standards in Hawaii: An Assessment of the Scientific Issues and Policy Issues**
1/27/2005	William D. Page, Senior Engineering Geologist, Geosciences Department Pacific Gas and Electric Company, San Francisco, **Pittman Creek Debris Flows, Central Sierra Nevada, California, Performance of 1986/87 and 1997/98 Mitigation**
2/3/2005	Steve Parabicoli, Water Recycling Program Coordinator, County of Maui, **Wastewater Reclamation Division, The Growth of Water Reuse in Hawaii**
2/17/2005	Alan Tice, M.D. (1) and (2) Tonya Fowler, (1) Associate Professor of Medicine, JABSOM, (2) UH Microbiology Grad Student, **Staphylococcus aureus on Land and in the Sea**

WRRC Website 2004-2005

The Center's website has undergone an extensive refashioning over the year to make the home page more accessible and reflective of current activities. The basic arrangement of the site with individual pages detailing the Center's mission, synopses of research activities, detailed descriptions of Center personnel, a comprehensive listing of Center publications including complete abstracts, a description of the Centers's physical facilities, the current semester's seminar schedule, and so on has not changed, but there have been ongoing improvements on all pages. An major focus of the Center's web strategy has been to expand access to the considerable archive of publications that has been produced by our researchers over the years. WRRC's work over the years has been very comprehensive, and increasing awareness of the large body of work that has been done is a priority of the Technology Transfer Office.

Manoa Flood Symposium – February 28, 2005

The Center's Technology Transfer office took the lead role in organizing a day-long workshop to bring the community together to learn about and discuss the devastating flooding that the University's Manoa campus experienced on Halloween Eve 2004. The symposium included scientific presentations by University faculty members with expertise in meteorology, rainfall prediction, peak flow analysis, and stream hydrology as well as presentations by representatives of the US Army Corps of Engineers, State Department of Land and Natural Resources, and the US Geological Survey. The meeting also included the University administration and concerned members of the public. The symposium provided a much-needed forum to discuss and explain the reasons for the flooding.

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	13	0	0	0	13
Ph.D.	6	0	0	0	6
Post-Doc.	1	0	0	0	1
Total	20	0	0	0	20

Notable Awards and Achievements

Dr. Albert Kim, Civil Engineering Professor and WRRC researcher, has been awarded a Faculty Early Career Development Program grant from the National Science Foundation. The grant will allow Dr. Kim to expand work he began with WRRIP funding over the past two years. These projects built computer simulation models to clarify the processes by which contaminant particles tend to foul filtration membranes and impede the movement of water through the membrane. The NSF Early Career grant will fund broader investigations into the micro-scale phenomena on membrane surfaces, and ultimately will facilitate enhanced efficiency of water treatment processes.

Publications from Prior Projects

1. 2001HI14S ("Optimize Aeration, Secondary Clarifier and Disinfection Processes") - Water Resources Research Institute Reports - Schofield Barracks Wastewater Treatment Plant: Optimize Aeration, Secondary Clarifier, and Disinfection Processes, 2004, Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii, 33 pages.
2. 2001HI2082B ("Confirming the Natural Presence of Fecal Indicator Bacteria in Environmental Soil and Water on the Islands of Kauai and Hawaii") - Water Resources Research Institute Reports - El-Kadi, Aly I.; Roger S. Fujioka; Clark C.K. Liu; Kenji Yoshida; Gayatri Vithanage; Yucheng Pan; John Farmer, 2003, Assessment and Protection Plan for the Nawiliwili Watershed: Phase 2Assessment of Contaminant Levels, Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii, 148 pages + appendix.
3. 2001HI2082B ("Confirming the Natural Presence of Fecal Indicator Bacteria in Environmental Soil and Water on the Islands of Kauai and Hawaii") - Water Resources Research Institute Reports - Furness, Monika; Aly I. El-Kadi; Roger S. Fujioka; Philip S. Moravcik, 2002, Assessment and Protection Plan for the Nawiliwili Watershed: Phase 1Validation and Documentation of Existing Environmental Data, Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii, 166 pages.