Water Resources Research Center Annual Technical Report FY 2007

Introduction

In the FY2007 reporting period, The University of Hawaii Water Resources Research Center initiated two new projects under the 104(b) program, and continued two others into their second (and final) year. In addition, work progressed on a 104(g) award, begun under the FY 2005 appropriation (and due to end August 2008). One project, sponsored by the U.S. Army using intergovernmental transfer of funds to USGS, was completed, and another was begun. About 7% of the grant was allocated to information transfer activities (principally newsletters). A like amount went to the administration program, which mainly funds faculty travel, an important function given Hawaii's isolated location.

In order to continue funding four rather modest research projects, UH WRRC has allocated other funds to supplement the 104(b) money. Just this spring, the University announced significant increases in GA salaries, which constitute a large fraction of WRRIP project costs. In the future, if salaries continue to increase, it will be necessary to fund fewer projects or to rethink the type of grants made under this program–partial rather than full RA support, less ambitious projects, perhaps more community outreach and less actual research.

Aside from the USGS/WRRI Program, nine new or continued projects were funded through WRRC in this fiscal year. These projects allowed WRRC to leverage each dollar of USGS/WRRIP funding in FY2007 into about $26 of other funding, including allocations from the University budget. Projects thus supported included investigations into phytoremediation and biodegradation of certain contaminants in a tropical environment; evaluation of landfill microcosms; Hawaii's registration procedures for termiticides; unexploded ordinance chemicals; antibiotics and hormones in animal wastes; and cryptosporidium mobility in tropical soils, among other topics.

Research Program Introduction

Water use on Oahu as well as other Hawaiian islands is approaching the sustainable capacity of our underground aquifers, and freshwater surface flows are few and generally small. The squeeze on water sources has led to modeling for efficient exploitation of aquifers; experiments into alternative sources such as desalination and water reuse; methods to extend and protect conventional sources, among other topics.

One WRRIP project has developed genetic fingerprinting methods to identify and control organisms that foul membrane bioreactors used in wastewater treatment processes. Another examined hydrological models for flood control and water quality management.

Other projects continue lines of work begun earlier, recognizing that before the island undertakes the massive investment necessary for desalination or reuse, much can be done to rationalize current water use. To this end, researchers have investigated the economics of pricing reform as an inducement to water conservation. In the process, this research has integrated hydrology into economic models, notably in considering multiple, interconnected aquifers. One study combines botanical information into a hydrologic−economic model to study efficient exploitation of subsurface groundwater flows into the near−shore ocean.

WRRC continues its long−term support for City and State agencies in implementing various EPA requirements related to water and wastewater regulations. Related projects study methods of ultra−violet purification of wastewater, and methods of improving membrane bioreactor processes.

We have also continued investigations into fate and transport of veterinary antibiotics, hormones and pathogens through tropical soils. Identification and testing methods for water quality indicator organisms remains an important line of research in Hawaii, as the EPA−mandated E. coli and enterococci tests give mainly false positive results in warm semi−tropical areas like Hawaii.

Coastal Groundwater Management in the Presence of Positive Stock Externalities

Basic Information

Title:	Coastal Groundwater Management in the Presence of Positive Stock Externalities
Project Number:	2005HI125G
Start Date:	9/1/2005
End Date:	8/31/2008
Funding Source:	104G
Congressional District:	HI 1st
Research Category:	Social Sciences
Focus Category:	Economics, Hydrology, Ecology
Descriptors:	groundwater management, externalities
Principal Investigators:	James A. Roumasset, Kaeo Duarte

Publication

1. Pongkijvorasin, Sittidaj, and James Roumasset. 2007. "Optimal conjunctive use of surface and groundwater with recharge and return flows: Dynamic and spatial patterns." *Review of Agricultural Economics* 29(3), pp. 531−539.
2. Pongkijvorasin, S., and J.A. Roumasset. Under review. Optimal conjunctive water use over space and time. *Journal of Environmental Economics and Management.*
3. Pongkijvorasin, S., J.A. Roumasset, and B.A. Pitafi. 2006. How to Stop Worrying and Learn to Love Bathtub Economics. Paper presented at the First Occasional Giannini Retreat on Water Economics, University of California, Davis.

Problem and Research Objectives

The nearshore marine environment of Hawai‘i is a major recreational and ecological resource that supports indigenous fish and marine vegetation. Freshwater discharge from groundwater aquifers mixes with seawater along the coast to create an ecological system with salinity less than that of the ocean water. Extraction of freshwater affects the salinity of the nearshore ecosystem since lower aquifer-head levels produce less freshwater discharge into the ocean. In other words, the state of the aquifer is directly linked to the cultural, recreational, and economic values of the community.

Thus our research objective was to determine the optimal management scheme in Hawai‘i for groundwater resources—taking into consideration both the benefits of water consumption and the environmental consequences of freshwater extraction.

Understanding the environmental consequences of freshwater extraction requires an assessment of the linkages between submarine discharge and the nearshore ecosystem. Native marine algae, identified by the Hawaiian word *limu,* play an important role as primary producers in a food web of endemic and other organisms. They can therefore serve as an appropriate indicator of the surrounding environment’s overall health.

To gain a better understanding of how groundwater discharge affects the nearshore marine environment we monitored, in a controlled laboratory environment, the physiological response of a selected species of *limu* to varied levels of salinity and nutrients. We chose to use the edible endemic species of marine algae *Gracilaria coronopifolia* for our study.

Methodology

Our research agenda is inter-disciplinary and involves two sub-programs. The first uses a bio-hydro-economic model to solve for optimal levels of groundwater use and *G. coronopifolia* production. The second is a laboratory study of the relationship between salinity and the biological productivity of *G. coronopifolia.*

Bio-hydro-economic Model

The model is an application of optimal control theory and follows the framework laid out in Krulce, Roumasset, and Wilson's (1997) study of the Pearl Harbor aquifer. The objective is to choose the paths over time of groundwater extraction and desalinated-water production to maximize the present value of net social surplus from water. For this purpose social surplus includes both traditional water-use benefits as well as external benefits (or costs) of freshwater extraction on the nearshore ecosystem. Our particular study focuses on *G. coronopifolia* as the nearshore resource affected by submarine discharge but the model is general and can therefore be applied to any other nearshore resource.

Mathematically, the problem is to

$$\max_{q_t, b_t} \int_0^{\infty} e^{-rt} [\int_0^{q_t + b_t} p(x)dx + \int_0^{m_t} p_m(y)dy - c(h_t)q_t - \bar{p}b_t - c_m(S_t)m_t]dt$$

subject to $\dot{h}_t = a[R - l(h_t) - q_t]$

$$\dot{S}_t = g(S_t, h_t) - m_t$$

where the social surplus is defined as the consumer surplus associated with water and *G. coronopifolia* consumption (the first two terms) less the producer costs of freshwater extraction and ocean-water desalination as well as the cost of harvesting *G. coronopifolia* (the last three terms). The aquifer-head level evolves over time according to changes in natural inflow, leakage, and extraction. The evolution of the *G. coronopifolia* stock depends on harvesting and on the resource's intrinsic growth function (which is itself dependent on the stock and on freshwater discharge).

Manipulation of the first-order conditions for this problem yields the following expression for price:

$$p = c(h) + \frac{\dot{p} - a(R - l(h))c'(h)}{r + al'(h)} + \frac{ag_h(S,h)\theta}{r + al'(h)}$$

The usual expression for the efficient price of a renewable resource includes the first two terms on the right hand side of the equation; price is equal to extraction cost plus marginal user cost. There is a third term, however, when a stock externality exists. In this case the term captures how the stock of groundwater (and hence discharge) affects the growth rate of *G. coronopifolia.*

Botanical Laboratory Study

G. coronopifolia was chosen for this investigation in order to assess the impact of varied levels of submarine groundwater discharge on the nearshore environment. The physiological parameters measured in this investigation include growth rate, branch development, and in vivo pigment absorption. Growth rate is measured as changes in wet-tissue mass over time and branch development is measured by quantifying the rate at which new growing tips are formed in reference to the initial tips and initial mass. To accurately measure these physiological responses to isolated variables a digital growth chamber was modified to support a unidirectional flow-through saltwater system.

In order to quantify changes in wet weight and morphology, three variables were calculated. The specific growth rate was calculated [(final wet mass – initial wet mass) / initial wet mass] / sixteen days. The percent change in apical-tip number relative to initial-tip number was calculated in a similar manner: 100*[(final apical-tip number – initial apical-tip number) / initial apical-tip number] / sixteen days. In order to quantify the number of apical tips in reference to initial weight, apical-tip number / mass is calculated as the tip score. The change in tip score can then be calculated [(final tip score – initial tip score) / initial tip score] / sixteen days.

Principal Findings and Significance

Bio-hydro-economic Model

We use data from the Kūkiʻo area located along the North Kona Coast of the island of Hawaiʻi to numerically solve for the optimal groundwater-management program. *G. coronopifolia* is incorporated into the model in two different ways. The first approach uses the market value of *G. coronopifolia* and the second imposes a "safe minimum-standard" level on the *G. coronopifolia* stock. The results presented here are based on theoretical assumptions of the relationships between submarine discharge, nutrients, salinity, and *G. coronopifolia.* In the next stage of our research we modify these assumptions to include actual results from the botanical lab study.

Optimal water extraction for the market-value approach is less than extraction when *G. coronopifolia* is ignored, although the difference is slight. This is likely due to the fact that the value of *G. coronopifolia* is relatively insignificant compared to the value of water. However it should be emphasized that the market value accounts for only the consumption value and ignores other potentially significant cultural or ecological values.

When a "safe minimum-standard" level is imposed as a constraint on *G. coronopifolia* stock, the optimal paths of water extraction, aquifer-head level, and price for water are non-monotonic. Efficiency requires depleting the aquifer below the steady-state level and then building it back up to the steady-state level in the period that follows. In addition, while the backstop technology (desalination) is never required in the market value scenario, it is implemented for all stock constraints that meet or exceed 75% of the current stock. Policy implications of these results will be articulated.

Botanical Laboratory Study

In order to simulate submarine discharge in a controlled environment, we ran trials with four levels of salinity (11‰, 19‰, 27‰, and 35‰) and corresponding levels of other nutrients, the proportional relationship of which others have estimated for the North Kona Coast. The mean growth rate, percentage change in apical-tip number, and apical-tip number/mass were calculated for each level of salinity. Only the 11‰ treatment differed significantly in both mean specific growth rate (lower than the others) and in vivo pigment absorption (higher than the others). Nearly half of the samples in the 11‰ treatment group died rapidly while the other half grew at rates similar to the other treatment groups. Therefore it is likely that the lower salinity concentration threshold for the viability of *G. coronopifolia* is close to 11‰.

Significant results were obtained for both measures of tip development. The 27‰ salinity-level treatment showed at least twice the branching rate of any of the other treatments. Since most growth of marine algae occurs at the apical tips, it is clear that those samples with more tips per mass will have higher growth rates.

This study may be the first to show that the calculation of tip scores as well as the percent of new apical tips are valid and useful methods for quantifying changes in morphology of marine algae. In summary, water chemistry conditions which simulate moderate amounts of freshwater discharge maximize the growth rate of *G. coronopifolia* when compared to ambient ocean-water controls.

Ongoing research

Our current research involves incorporating the laboratory results into the bio-hydro-economic model.

In the botanical experiment, within the 11‰–27‰ salinity range, maximal *G. coronopifolia* growth rate increased with increasing salinity. Specifically within the 27‰–35‰ salinity range, however, maximal *G. coronopifolia* growth rate actually decreased with increasing salinity from 3% per day for the 27‰ treatment to 1% per day for the 35‰ treatment (ocean salinity), i.e. the growth rate declined by about 67%.

A *G. coronopifolia* growth curve was estimated as a function of simulated freshwater discharge. The challenge is to translate this curve into a constraint for the economic model. One possibility is to constrain the growth rate itself and another is to constrain the reduction in growth rate. Results from preliminary simulations using a growth constraint indicate that *G. coronopifolia* reaches its carrying capacity extremely quickly. This is likely because the controlled laboratory environment abstracts from predators and competition for space, both of which exist in actual nearshore marine environments. One way to address this issue would be to adjust the initial growth rate downward to account for competition and also allow the adjustment to decline with the stock of *G. coronopifolia* to account for the drag on the competitors' populations.

Publications Cited in the Synopsis

Krulce, D.L., J.A. Roumasset, and T. Wilson. 1997. Optimal management of a renewable and replaceable resource: The case of coastal groundwater. *American Journal of Agricultural Economics* 79(4): 1218–1228.

Grant No. 05HQGR0171 – Stormwater Education on US Army Installations on Oahu

Basic Information

Title:	Grant No. 05HQGR0171 – Stormwater Education on US Army Installations on Oahu
Project Number:	2005HI172S
Start Date:	9/15/2005
End Date:	9/14/2007
Funding Source:	Supplemental
Congressional District:	HI 1st
Research Category:	Ground−water Flow and Transport
Focus Category:	Education, Water Quality, Surface Water
Descriptors:	Environmental education, Watersheds, Stormwater
Principal Investigators:	John Cusick

Publication

1. Cusick, J. 2007. Stormwater education on US Army installations on Oahu: Final Report. Honolulu: University of Hawai‘i at Mânoa Environmental Center. (September) 38 pp.

Problem and Research Objectives

Public education and outreach are required elements of the Army's Environmental Protection Agency MS4 permit to operate "small municipal separate storm sewer systems" in Hawaiʻi. One way the Army has attempted to meet these requirements in Hawaiʻi was to develop an educational program addressing stormwater-related problems in watersheds associated with military installations within the state. Working with specific public schools located on Army installations, the goal of this project was to introduce the students, their families, and their teachers to stormwater-related problems. The two-year project successfully culminated with the presentation of a "WaterWorks Festival" incorporating reusable science-education exhibits developed by Bishop Museum specifically for this project.

The exhibits were designed to increase awareness of drainage-basin processes and stormwater-related environmental concerns. They identify activities with negative impacts and display ways the public can mitigate these negative impacts to improve water quality. The exhibits introduced concepts related to best-management stormwater-related practices to the students, their families, and their teachers.

The project's primary objective was to provide education intended to help ameliorate negative impacts originating on Army installations while introducing best-management practices to public school students, their families, and their teachers living on these military bases.

A secondary goal was to increase awareness and understanding of other stormwater-related problems affecting the watersheds of central Oʻahu. Of particular concern was the Waikele Stream, identified as an "at-risk" watershed by the state of Hawaiʻi, which is located, in part, on Army installations.

Principal Findings and Significance

The project developed a "Water Works Festival" that was presented to elementary and secondary school students, their families, and their teachers at Wheeler Army Airfield. Bishop Museum science and cultural education specialists prepared exhibits for an event held at Wheeler Elementary School on 10 March 2007. Approximately 60 students and their families from public elementary and middle schools located on Wheeler Army Airfield and Schofield Barracks attended the festival. The schools involved included Wheeler Middle School and its three feeder schools: Wheeler, Hale Kula, and Solomon Elementary Schools.

The Festival was a three-hour event in an "open house" format (drop-in; self-exploration). It was held in the Wheeler Middle School cafeteria and engaged visitors in a diverse array of hands-on science, engineering, and cultural activities designed for multi-generational, interactive learning. The topics presented in the Festival include watershed boundaries and topography, the water cycle, aquatic ecosystems and biota, soil erosion, water quality and management, stormwater and wastewater infrastructure, stormwater and drinking water systems, avoidance of pollution, and cultural resources.

As indicated, the objective of this project was to develop stormwater education materials targeted for elementary and middle public school students, their families, and staff living and working at Wheeler Army Airfield and Schofield Barracks. The initial challenge was considered to be curriculum development, but instead became a matter of addressing school administrator and teacher concerns as how to accommodate the addition of stormwater-related concepts into existing curriculum. The original intent was to develop content that would be incorporated into existing curriculum during the course of the school year. However, the evident reluctance on the part of school administrators to overload their teaching staff indicated that a compromise solution was necessary to achieve the project objective. The compromise was to conduct the Festival and to develop the exhibits for continued use by Bishop Museum.

Publications Cited in the Synopsis

N/A

Fate and Transport of Contaminants in a Stream−Aquifer System

Basic Information

Title:	Fate and Transport of Contaminants in a Stream−Aquifer System
Project Number:	2006HI138B
Start Date:	3/1/2006
End Date:	2/28/2008
Funding Source:	104B
Congressional District:	HI 1st
Research Category:	Ground−water Flow and Transport
Focus Category:	Geochemical Processes, Solute Transport, Sediments
Descriptors:	Surface−groundwater interaction
Principal Investigators:	Chittaranjan Ray

Publication

1. Kim, S.H., K.H. Ahn, and C. Ray. Revised manuscript under review. Distribution of discharge intensity along small−diameter collector−well laterals in a riverbed−filtration model. *Journal of Irrigation and Drainage Engineering* ASCE.
2. Kim, S.H., and C. Ray. 2007. Extending the design velocity of axial flow from the lab−scale horizontal well to practical scales in riverbed filtration. Poster presented at ISMAR6: The Sixth Annual International Symposium on Managed Aquifer Recharge, October 28–November 2, 2007, Phoenix, Arizona, USA.
3. Sharma, L., H. Prommer, P. Eckert, and C. Ray. In process. Clogging−induced water−quality changes at a riverbank filtration site along the Rhine River at Dusseldorf, Germany. For submittal to the *Journal of Hydrology*.

Problem and Research Objectives

Streams and rivers transport sediments, natural organic matter, and, frequently, land-applied chemicals.

Many drinking-water wells located on streambanks and riverbanks induce a portion of the stream or river water to flow through the aquifer to well screens. The pumped well water is then a mixture of groundwater and induced infiltration water and is of a better quality than the stream or river water. This process is known as "riverbank filtration."

Stream- and river-water contaminants are removed through straining, colloidal filtration, chemical precipitation, sorption, and microbial degradation. Also dilution is possible if the respective contaminants in the surface water are lower in concentration than in the groundwater. Riverbank filtration is a viable and low-cost water-treatment technology for water utilities.

As this natural filtration process works somewhat differently than engineered filtration systems, knowledge of the dynamic behavior of the system for various flow regimes of the stream or river is important for safe and sustainable operation. Advance understanding of the expected changes in water quality generated by scouring or bed clogging enables water utilities to better address filtrate quality during periods of flooding or heavy sedimentation.

Scouring and clogging of the stream or river bottom affect the rate of infiltration and the fate of the soil-resident or percolating contaminants. Scouring during floods can destroy the clogging layer and introduce oxygen-rich water into the aquifer, disturbing the previously established redox conditions. Conversely, a clogged streambed or riverbed would have a slower infiltration rate and a reduced flow compared to a normal streambed or riverbed.

It is not easy to study these processes in field settings because of high velocity in streams or rivers during high-flow events and our inability to accurately measure clogging and redox processes.

The research objectives were as follows:

(a) To retrofit a recirculating flume to serve as a model stream or river channel and attach a column to the channel bottom to simulate conditions in an aquifer under a streambed or riverbed;
(b) To study the impact of velocity profile on the scouring and deposition processes of particles;
(c) To study the redox conditions in the column as a function of stream velocity, particle-deposition rate, natural-organic-matter content of the recirculating water, and the travel distance;
(d) To examine the effect of channel-bed scouring on the change in the redox conditions of the upper portions of the column and its impact on water quality.

Methodology

Retrofitting of flume/column: A small recirculating flume (15-cm wide, 3.5-m long), available in the Hydraulics Laboratory of the University of Hawaiʻi at Mānoa Civil & Environmental Engineering Department, was retrofitted for this research and extended by 2.0 m.

This recirculating flume could be tilted to change the bed slope. A mechanically-controlled flap made it possible to control the water level on the bed. A 10-cm diameter column attached to the bed of the flume channel simulated the porous media typically present between the stream or river and the well screen. A layer of silica sand simulated the streambed or riverbed. A peristaltic pump drew water at a set rate from the bottom of the column.

Piezometers were placed in the sand bed and the column at 2.7 cm, 10.3 cm, and 12.8 cm below the bed to observe the head loss that occurred as water was pumped from the column. Water flowing out of the flume was collected in a tank and recirculated by another pump to provide water at the upstream end of the flume. Clogging of the bed was simulated by adding fine particles, such as streambed sediments and kaolinite, into the flow stream. Scouring was simulated by increasing the flow rate of the water being pumped into the flume to simulate a flood event.

Velocity impact on scour/deposition: The sediment composition and flow velocity in the recirculation system were adjusted to have distinct particle distributions in the flow systems. For each set of experiments, the corresponding heads in piezometers at various depths below the channel were examined. A series of experiments were conducted in which the velocity of flow was varied from 0.18 m/s to 0.27 m/s. These changes resulted in a concurrent rise in water depth in the flume from 13.3 cm to 16.7 cm at a bed slope of 1.15%.

When the flow velocity was increased from 0.18 m/s to 0.27 m/s the hydraulic heads measured at the piezometers rapidly decreased with the flow showing increased head losses in the column. (Figure 1). This is contrary to the general understanding that a higher flow in the channel would decrease head loss in the column packed with the porous media.

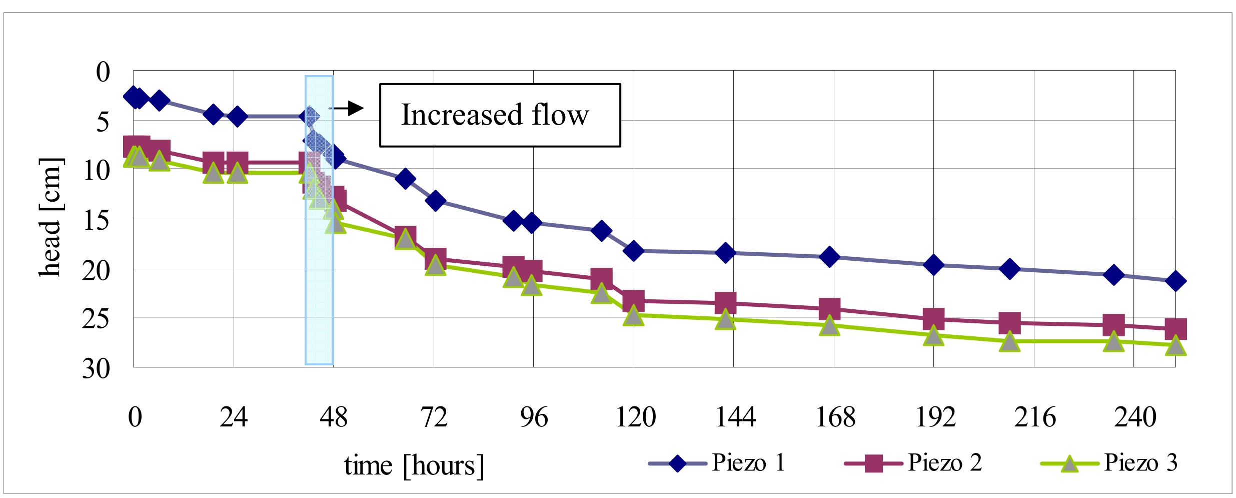

Figure 1: Head loss along the column for a 5-hour increased flow in the flume.
(The blue-shaded segment represents the 5 hours during which the flow was increased.)

Increasing the flow velocity beyond 0.3 m/s resulted in unstable flows and the formation of undulating sand bars on the bed.

It was found that, within the test limits of 0.18 m/s to 0.27 m/s, as the flow was increased the head loss in the top 2.7 cm sand layer above the first piezometer rapidly increased (see the shaded area in Figure 1). The simulated flow was not sufficient to cause scouring of the bed so attrition of the clogging layer was not evident, rather it further increased clogging.

Resumption of the original flow velocity did not reduce the head loss, so the clogging appeared to be nonreversible under the flow conditions prevailing in the flume throughout the observed time. No external sediments were added into the flume. The bed material was made up of well-sorted sand of mean diameter, d_{50} = 0.25 mm, coefficient of uniformity, C_u = 1.8, and particle density of 2.63.

Another run of the experiment was done to investigate the effect of the introduction of suspended sediment in the flowing water. Stream-bed sediment from Honolulu’s Mānoa Stream was obtained from under the East Mānoa Road bridge and wet sieved to separate the material passing through 60 mesh sieve (sieve passing 250 µm). This fine sediment was periodically added to the flowing water in the flume to maintain a turbidity of 175 Nephelometric Turbidity Units (NTU). The heads observed in the piezometers are shown in Figure 2.

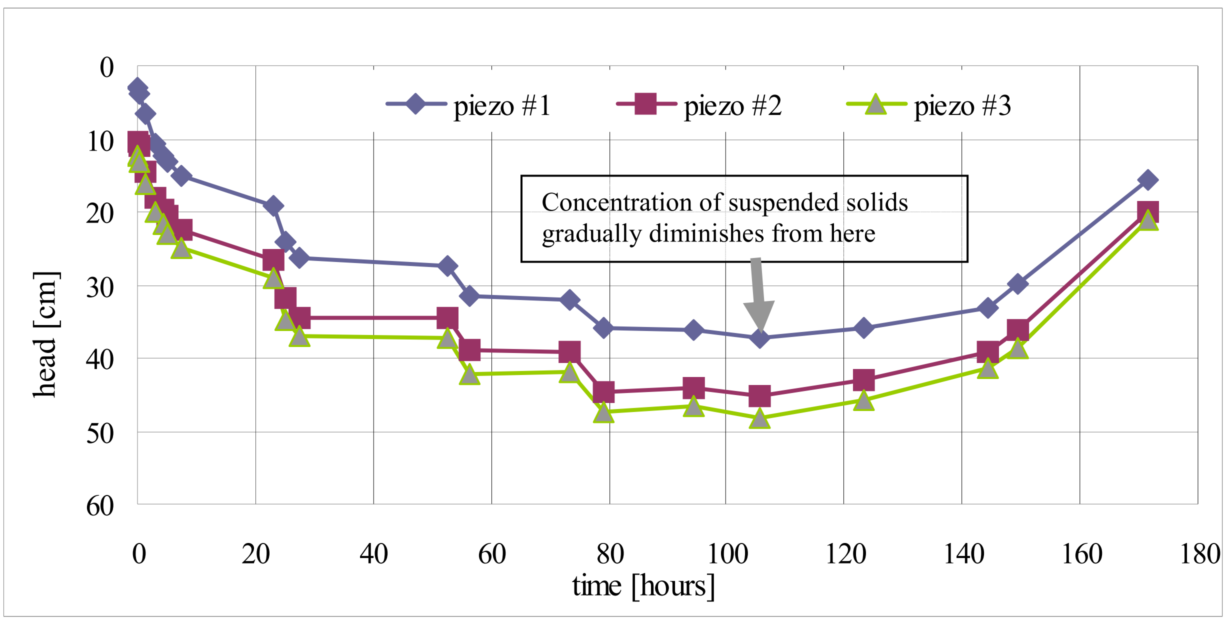

Figure 2: Head loss along the column for channel flow with additional sediments.

Regular additions of the sediments were required to keep the turbidity near a constant value. It was seen that the hydraulic heads in the piezometers dropped sharply every time sediment was added to the flowing water. After about 100 hours of running the experiment no more additional sediments were added and the flowing water gradually cleared up. This also resulted in a gradual recovery of the piezometric heads. So the head losses were seen to be reversible for the case of addition of external sediments.

It was further observed that the addition of sediments expedited the drop in hydraulic heads. It took about 24 hours for the head to drop 5 cm in the first piezometers (Figure 1), shown as Head #1, while it dropped about 20 cm in the first 24 hours with the sediment-laden flow (Figure 2).

The effect of the hydraulic head loss was also used to investigate the distribution of hydraulic conductivity (K) along the depth of the column during the addition of sediments to the flowing water. Three peizomteric measurements were used to divide the column into three layers. The top layer was 2.7 cm thick above the first piezometer, then the second layer was 2.7 cm to 10.3 cm above the second piezometer, and the third layer was 10.3 cm to 12.3 cm above the third piezometer.

It was found, as shown in Figure 3, that the reduction in hydraulic conductivity occurred entirely in the top layer of 2.7 cm, where the hydraulic conductivity reduced by an order of magnitude from 0.03 cm/s to about 0.003 cm/s. The hydraulic conductivities in the subsequent layers remained almost the same at above 0.03 cm/s.

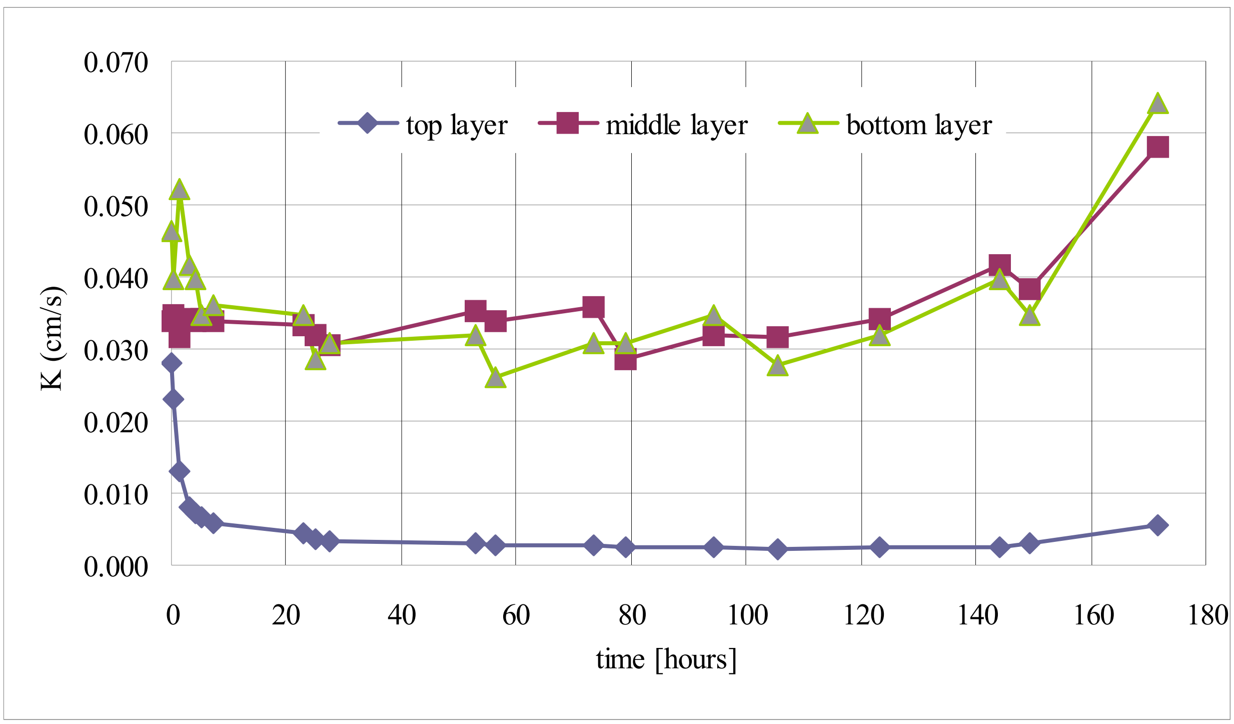

Figure 3: Variation of hydraulic conductivity (K) with time in different layers of the column

Redox dynamics: In further experiments to be conducted next year, redox parameters that will be measured include dissolved oxygen, oxidation-reduction potential, dissolved organic carbon (DOC), and selected redox-sensitive compounds or elements such as nitrates, nitrites, ammonium, iron, and manganese.

Frequent measurements of the velocity profile and the size distribution of the flowing particles should provide a good indication of the small-particle load in the flow stream. Head loss due to particle clogging of the column surface will be correlated with the sizes of the flowing particles. Redox parameters of the flowing water and the sampled water will be correlated with the velocity profile in the channel, particle-size distribution, DOC in the channel water, and water extraction rate through the column.

Scouring effects on redox: In additional further experiments to be conducted next year, once a redox regime (based on a flow regime in the channel, DOC content of the water, and the sediment load in the channel water) in the column is established, conditions in the channels will be changed to that of incipient scour. Head loss in the column will be examined and selected redox parameters in the column will be monitored. Following a given period of disturbance (i.e., simulation of a flood passage), the time needed to re-establish a redox condition that is conducive for denitrification and the degradation of other chemicals will be examined.

Principal Findings and Significance

Retrofitting of the flume/column and studies of velocity impact on scour/deposition are nearly complete. A no-cost extension has been requested to complete the studies of redox dynamics and of scouring effects on redox during the next reporting period.

Findings indicate that the clogging layer is developed in the sand bed in a very thin top layer only. Reduction in the hydraulic conductivity of the top layer of the column by an order of magnitude was observed. Clogging developed with the addition of fine sediments (higher turbidity) was found to be reversible. Head losses decreased as the turbidity was reduced.

Head loss also increased in the top layer when the flow rate in the flume was increased—however these losses were not recovered when the flow reverted to the lesser discharge. This warrants a closer look at the different processes of bed clogging and a more detailed study of the mechanisms of clogging.

Publications Cited in the Synopsis

n/a

Hydrologic Analysis of Hawaii Watersheds for Flood Control and Water Quality Management

Basic Information

Title:	Hydrologic Analysis of Hawaii Watersheds for Flood Control and Water Quality Management
Project Number:	2006HI144B
Start Date:	3/1/2006
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	HI 1st
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Floods, Non Point Pollution
Descriptors:	Watershed hydrograph, Flood, TMDL
Principal Investigators:	Clark Liu

Publication

1. Fernandes, K., and C.C.K. Liu. 2005. Flood hydrograph analysis for Manoa watershed, Oahu, Hawaii. Proceedings of AWRA Summer Specialty Conference, June 27–29, 2005, Honolulu, Hawaii. Middleburg, VA: American Water Resources Association. CD−ROM.
2. Liu, C.C.K., C. Ice, J.K. Levy, and J. Moncur. 2005. Institution, policies, and technologies for sustainable watershed management in the Asia−Pacific, Water Resources Impact Vol.7, No.2, 6–9.

Problem and Research Objectives

The establishment of the rainfall-runoff relationship of a watershed is an important and difficult problem in applied hydrology. The rainfall-runoff relationships of Hawai‘i watersheds are even more difficult to establish than most because Hawai‘i watersheds tend to have steep slopes, small drainage areas, and a high infiltration rate. Currently the simple *rational formula* is used for urban drainage design in Hawai‘i and the more sophisticated *unit-hydrograph method* is used for the design of large flood-control facilities.

The unit-hydrograph method is based on linear systems theory (Dooge 1973). The system impulse response function of a linear system describes the overall system characteristics which affect the input-output relationship. The determination of the system response function of a particular system is called system identification. By the unit-hydrograph method a watershed is taken as a linear system. Its input function is effective rainfall, its output function is direct runoff, and its system response function is called instantaneous unit hydrograph (IUH), which is the direct runoff generated by the watershed system when it receive an input of unit-pulse-effective rainfall. After the IUH of a watershed is identified, direct runoff generated by future rainstorms in the watershed can be calculated by a convolution integration of IUH and rainfall input.

Similarly for waste-loading simulation, the impulse-response function can be called the instantaneous pollutograph (IPG), which is the temporal variation of pollutant concentration at the watershed outlet generated by the watershed system when it receives an input of unit-pulse-effective rainfall. The waste loading at the watershed outlet can then be readily calculated as a product of direct runoff and pollutant concentration.

The principal objectives of this research were to 1) demonstrate the applicability of a linear-systems approach for flood and water-quality analysis for Hawaiian watersheds and 2) develop techniques for deriving IUH and IPG.

Methodology

The modern unit-hydrograph method, the most popular analytical tool for flood hydrograph analysis, can be formulated based on linear systems theory. By this method direct runoff produced by a rain storm over a watershed system can be calculated by a convolution integration of effective rainfall and instantaneous unit hydrograph (IUH). Direct runoff or system input is the measured stream flow minus groundwater contribution or base flow. System output or effective rainfall is the rate of rainfall after subtracting the rate of infiltration and other "losses." System impulse response function, or IUH for a linear watershed system, is the direct runoff produced by a watershed when it receives a unit-instantaneous-effective rainfall.

The linear systems approach has been successfully used in watershed hydrology to relate rainfall to runoff (Liu and Brutsaert 1978). This type of approach has also been used recently in river-water-quality analysis (Liu and Neill 2002) and in chemical transport in soils (Liu 1988). In this project the linear systems approach is also applied to watershed water-quality analysis to simulate waste loadings generated by a watershed receiving heavy storm.

Following the linear systems approach, storm runoff from a watershed at any time can be calculated by a simple convolution of the instantaneous unit hydrograph (IUH) and the effective rainfall. The IUH of a particular watershed is usually derived by performing an inverse operation based on one set of historical rainfall-runoff data. For watersheds that have no historical rainfall-runoff data, a method of synthetic IUH or "grey method" (Liu 1988) can be used. Using the grey method the linear systems model of a watershed rainfall-waste loading can be formulated as,

$$Y(t) = \int_0^t g(\tau)\, f(t-\tau)\, d\tau$$

Where $Y(t)$ = the system output or contaminant concentration

$g(t)$ = the system input or effective rainfall

$f(t)$ = IPG in terms of a particular probability density functions.

Principal Findings and Significance

The modern unit-hydrograph method is theoretically sound. However its application is often limited by difficulties in determining the IUH which characterizes a particular watershed system.

In this study techniques were developed to combine the modern unit-hydrograph method with a geographic information system (GIS). An empirical formula was derived during this study to more accurately estimate effective rainfall working from storm rainfall data by considering the soil-moisture content. These techniques and the empirical formula were applied to flood hydrology analysis for a Hawaiian watershed. Research results of this study indicate that these techniques alleviate the limitations of the application of the modern unit-hydrograph method and make it a useful analytical tool.

The initial point of the infiltration rate prior to the 30 October 2004 storm was estimated to be about 1.5 in/hr from the given previous one-day rainfall volume which was estimated to be about 0.95 inches. This numerical value was used, together with the other two parameters of the Horton model, to calculate the time series of the infiltration rate during the 30 October 2004 storm event. Figure 1 shows the actual infiltration process, actual loss, and the effective rainfall during the storm. Figure 2 shows effective rainfall (input) and flow (output) from the Waikeakua watershed during the October 2004 flood.

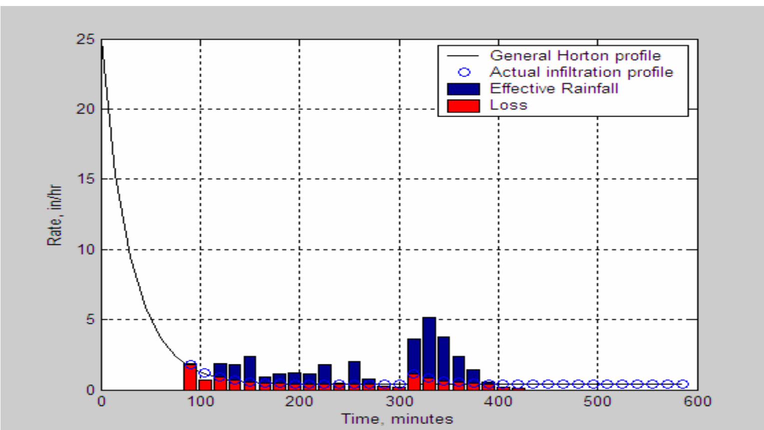

Figure 1. Infiltration profile and actual infiltration in Waikeakua watershed on 30 October 2004

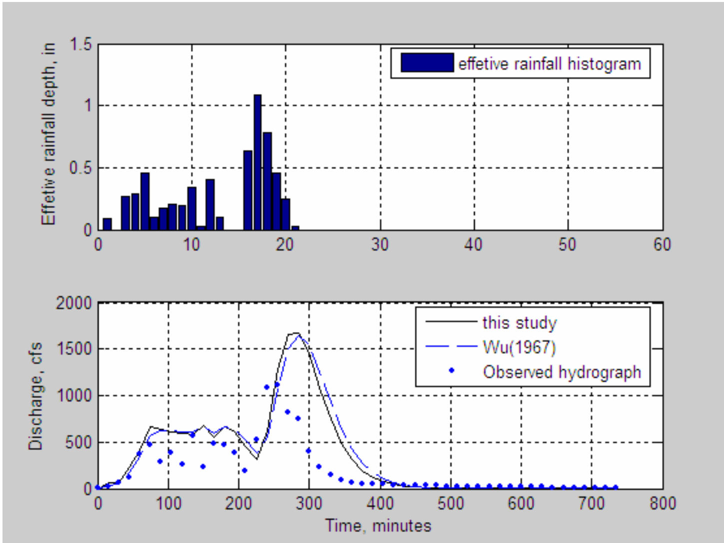

Figure 2. Predicted flood hydrograph from Waikeakua watershed on 30 October 2004

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Identification and control of membrane bioreactor biofouling organisms using genetic fingerprinting

Basic Information

Title:	Identification and control of membrane bioreactor biofouling organisms using genetic fingerprinting
Project Number:	2006HI159B
Start Date:	3/1/2006
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	HI 1st
Research Category:	Engineering
Focus Category:	Water Supply, Treatment, Economics
Descriptors:	Membrane bioreactor, Biofouling, Genetic fingerprinting, Economics
Principal Investigators:	Roger Babcock

Publication

1. Babcock, R.W., Jr.; T. Huang; Y. Chanthawornsawat, 2006, Characterizing biofouling in membrane bioreactors, in Proceedings of the 21st Annual WateReuse Symposium, Hollywood, California.
2. Babcock, R.W. Jr., and T. Huang. 2007. Understanding and controlling fouling in MBRs. Paper presented at the 29th Annual Hawai‘i Water Environment Association Conference, Honolulu, Hawai‘i
3. Babcock, R.W. Jr. 2007. Characterizing biofouling in different membrane bioreactor configurations. Proceedings of the 80th annual conference of the Water Environment Federation, San Diego, California.

Problem and Research Objectives

Membrane bioreactors (MBRs) are relatively new wastewater-treatment technologies promising exceptional treatment efficiency with a reduced surface-area footprint compared to conventional-treatment-process trains (Gander et al. 2000). A MBR uses an activated-sludge process in which the conventional secondary clarifiers are replaced by a membrane-separation process (either microfiltration or ultrafiltration).

Like other membrane systems—but to an even greater degree—MBRs are susceptible to biofouling (Chang et al. 2002). Biofouling is not a well-understood process but its effects increase operating pressures, reduce maximum flux (water passed through the membrane), increase recovery-cleaning requirements, and possibly reduce total membrane life (Cicek et al. 2001, LeClech et al. 2003). All of these effects of biofouling have adverse effects on either initial capital cost or ongoing operation-and-maintenance costs for MBRs. Because MBRs are quickly becoming the process of choice for water recycling there is a need to improve their cost efficiency by controlling the biofouling.

The primary research objectives were to 1) identify the microbial species present in MBRs under different operating conditions and 2) correlate the microbial species make-up in MBRs with biofouling conditions and water-quality parameters.

Methodology

This study included long-term operation of two different bench-scale MBRs. One MBR used a flat-sheet membrane technology provided by Enviroquip, Inc., utilizing Kubota membranes with 0.4 µm pore size. A second MBR used hollow-fiber technology provided by Ionics Corp. utilizing Mitsubishi membranes also with 0.4 µm pore size.

These bench-scale MBRs were operated using raw sewage pretreated only by passage through a 3mm-fine screen. Operating parameters that were varied include flux rate (flow per unit area of membrane, in this case 10 and 15 gallons per square foot of membrane per day [GFD]), solids retention time (SRT, in this case 5, 10, 20, and 40 days), organic/nutrient loading (raw sewage with/without supplemental organics), and state of oxygenation (high, low, or anoxic).

Steady-state operation was achieved under each set of conditions prior to proceeding to the next set of conditions. Operating and water-quality parameters that were monitored included trans-membrane pressure (TMP, continuous on-line measurement), soluble microbial products/extracellular polymeric substances (SMP/EPS) carbohydrate and protein fractions (cation exchange resin extraction, carbohydrates, and proteins), viscosity, particle size distribution (PSD), and soluble chemical oxygen demand (COD).

Microbial consortium samples from both mixed liquor and attached biofilms (cake layers) were collected from the bench-scale MBRs under various conditions. Samples of microbial populations in full-scale conventional activated-sludge systems and pilot-scale MBR systems were collected for comparisons. Genomic DNA for the total community was extracted en mass (using a culture-independent method which also yields unculturable organisms). Polymerase chain reaction (PCR) was used to produce 16S rRNA V3 region gene-amplification products. Denaturing gradient gel electrophoresis (DGGE) was used to separate the 16S rRNA V3 region gene-amplification products to characterize the microbial community and monitor the dominant population.

The total number of DGGE bands provides an estimate of the microbial diversity within a given environment (a "genetic fingerprint"). The dominant microbial species were determined by DNA sequencing of genetic material taken from the DGGE bands. The sequenced DGGE bands were compared with the GeneBANK database to identify the bacteria responsible for biofouling.

Principal Findings and Significance

Total membrane flux resistance is easily calculated given the operating flux, viscosity, and TMP. Figures 1 and 2 show the total flux resistance during the various phases of the bench study for the Enviroquip, Inc., and Ionics Corp. MBRs, respectively. The slope of the total-resistance line can be considered the fouling rate.

For the Enviroquip, Inc., bench-scale MBR several observations can be made. First, at 10 GFD the fouling rate was essentially zero during the period of observation (meaning that the resistance held constant and fouling was minimal). Second, at 15 GFD there appear to be several different fouling rates. The fouling rate starts out low (about 2.8E10 $m^{-1}d^{-1}$), then apparently increases rapidly (to about 2.3E11 $m^{-1}d^{-1}$), slows down for a period (to about 2.9E10 $m^{-1}d^{-1}$), and then again rapidly increases (to about 2.3E11 $m^{-1}d^{-1}$). This phenomenon will require further investigation prior to reaching any possible conclusions. Third, when supplemental glucose was added to increase the feed strength by 50% for 7 days (with flux held at 15 GFD) the fouling rate did not appear to increase appreciably (to about 3.0E10 $m^{-1}d^{-1}$). Fourth, when the system was modified to eliminate the anoxic zone (with flux held at 15 GFD) the initial fouling rate seemed to decrease (to 6.4E09 $m^{-1}d^{-1}$).

For the Ionics Corp. bench-scale MBR the fouling rate at 15 GFD (about 4.2E10 $m^{-1}d^{-1}$) was about three times as rapid as that at 10 GFD (about 1.4E10 $m^{-1}d^{-1}$). These fouling rates are all at SRT = 20 days.

During the relatively rapid increase in total resistance observed for the Enviroquip, Inc., bench-scale MBR at 15 GFD, the protein EPS and SMP in the mixed liquor were fairly steady but the permeate SMP showed an interesting trend (Figure 3). Figure 3 shows that the permeate SMP was fairly steady until a certain point (30–35 days into the 49-day run) when the value dropped off suddenly (meaning all SMP was retained). This is apparently an indication of severe fouling. No trends in the protein fraction of EPS or mixed-liquor SMP that could be useful for predicting fouling were apparent in this data set.

Figures 4, 5, and 6 show the type of data obtained in the biofouling-genetics study. Each vertical lane represents a different sample of community DNA, each horizontal band represents a different bacteria, and brighter bands indicate larger numbers of biomass (dominant species).

In Figure 4 it can be observed that there are differences in the dominant species of bacteria in the Huber MBR as compared to the Ionics Corp. MBR and that speciation changes over time in the MBRs.

Figure 5 shows the bench-scale Enviroquip, Inc., MBR under non-fouling conditions when the SRT was 20 days, the flux was 10 GFD, and no anoxic zone was included. In this case it can be observed that one dominant bacterium seems to wash out (upper band) and other bacteria either fluctuate, appear, or disappear. The biofilm sample (lane #6) taken at the end of this phase of experiments may be the most interesting since we can see that the dominant bacteria species are almost completely different from those in the mixed liquor, that there are fewer species present, and that three bacteria are highly concentrated (dominant).

Figure 6 shows the bench-scale Enviroquip, Inc., MBR under high-fouling conditions when the SRT was 20 days and the flux was 15 GFD. In this case there appears to be about three types of bacteria that are more dominant at the end when fouling was severe that were either less prevalent or were not present at the beginning. These bacteria, therefore, may be associated with fouling.

These bands were cut out for sequencing to identify the bacteria species. The data obtained from the sequencing was queried with GeneBANK to identify the bacteria. The results are shown in Figures 7 and 8.

Future work is necessary to further study these and other identified fouling bacteria species by reviewing their physiological/morphological characteristics to see if they can be biologically or chemically controlled to reduce their biofouling potential.

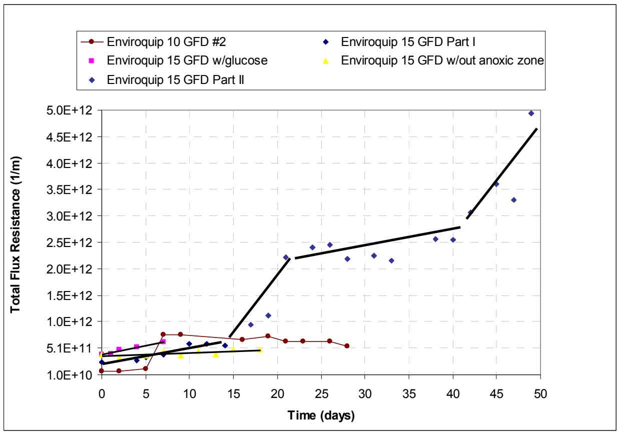

Figure 1. Fouling rates during operation of bench-scale Enviroquip, Inc., MBR

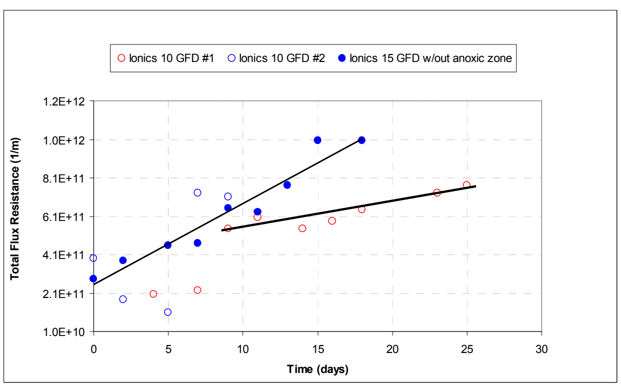

Figure 2. Fouling rates during operation of bench-scale Ionics Corp. MBR

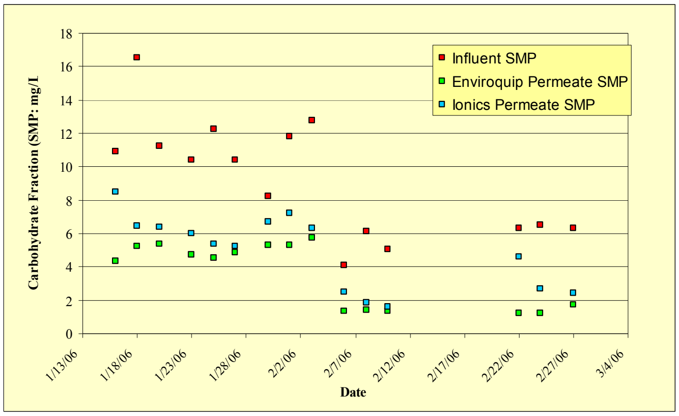

Figure 3. Comparison of permeate carbohydrate SMP from bench-scale MBRs

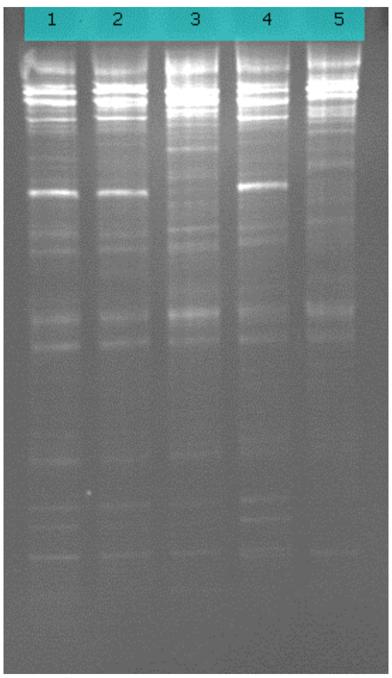

Figure 4. DGGE analyses of pilot MBR mixed-liquor samples. Lane 1: Huber 6/29/07, lane 2: Huber 7/6/07, lane 3: Ionics 6/29/07, lane 4: Huber 7/20/07, lane 5: Ionics 7/20/07

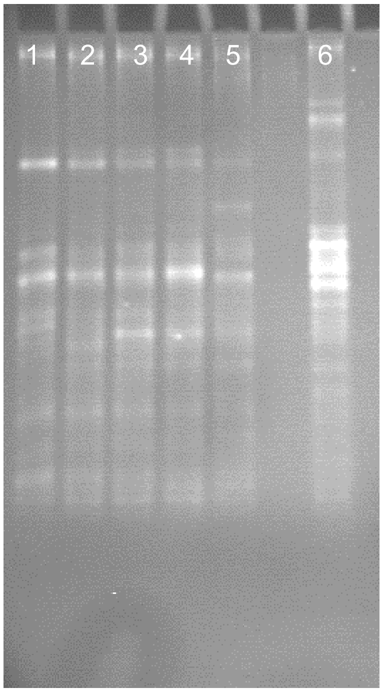

Figure 5. DGGE analyses of bench-scale Enviroquip, Inc., MBR mixed-liquor samples under non-fouling conditions. Lane 1: 5/24/07, lane 2: 5/31/07, lane 3: 6/7/07, lane 4: 6/14/07, lane 5: 6/21/07, lane 6: biofilm 6/28/07

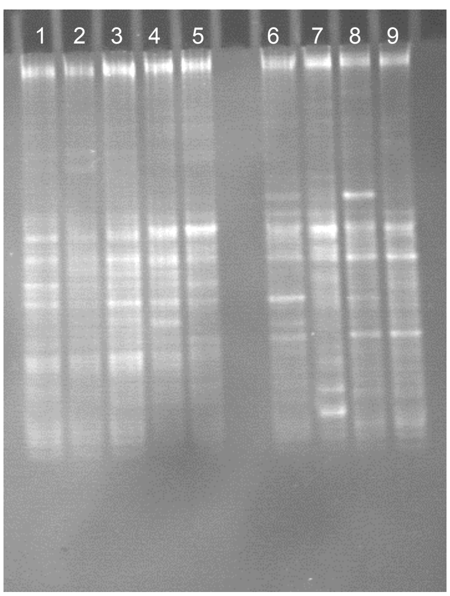

Figure 6. DGGE analyses of bench-scale Enviroquip, Inc., MBR mixed-liquor samples under high-fouling conditions. Lane 1: 3/8/07, lane 2: 3/15/07, lane 3: 3/22/07, lane 4: 3/29/07, lane 5: 4/5/07, lane 6: 4/19/07, lane 7: 4/26/07, lane 8: 5/3/07, lane 9: 5/10/07

```
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gene,
partial sequence
Length=1450

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 Identities = 163/163 (100%), Gaps = 0/163 (0%)
 Strand=Plus/Plus

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  ORGANISM  uncultured bacterium
            Bacteria; environmental samples.AGCCGCGGTAAT  168
REFERENCE   1  (bases 1 to 1450) ||||||||||||||||||||||
  AUTHORS   Ginige,M.P., Keller,J. and Blackall,L.L.TAAT  499
  TITLE     The analysis of a methanol denitrifying microbial community by
            stable isotope probing, full cycle rRNA analysis and fluorescence
            in situ hybridization-microautoradiography
  JOURNAL   Unpublished
REFERENCE   2  (bases 1 to 1450)
  AUTHORS   Ginige,M.P., Keller,J. and Blackall,L.L.
  TITLE     Direct Submission
  JOURNAL   Submitted (18-MAY-2003) Advanced Wastewater Management Centre,
            The University of Queensland, Ritchie Building (64A), Research
            Road, St Lucia, Brisbane, QLD 4072, Australia
```

Figure 7. Denitrifying biofouling organism identified

```
>dbj|AB205887.1|  Uncultured bacterium gene for 16S rRNA, partial sequence
clone:12C-M49
Length=578

 Score =  323 bits (163),  Expect = 1e-85
 Identities = 163/163 (100%), Gaps = 0/163 (0%)
 Strand=Plus/Plus

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ACCESSION   AB205887    TGGATGGGGCGAAAAAACGGGATTTATCCTGGACTGACGGTACCAT  125
VERSION     AB205887.1  GI:73912549CGAAAAAACGGGATTTATCCTGGACTGACGGTACCAT  146
KEYWORDS    ENV.
SOURCE      uncultured bacteriumTCCGTGCCAGCAGCCGCGGTAAT  168
  ORGANISM  uncultured bacterium||||||||||||||||||||||
            Bacteria; environmental samples.GCCGCGGTAAT  189
REFERENCE   1
  AUTHORS   Osaka,T., Yoshie,S., Tsuneda,S., Hirata,A., Iwami,N. and
            Inamori,Y.
  TITLE     Identification of Acetate- or Methanol-Assimilating Bacteria
            under Nitrate-Reducing Conditions by Stable-Isotope Probing
  JOURNAL   Microb. Ecol. 52 (2), 253-266 (2006)
   PUBMED   16897304
REFERENCE   2  (bases 1 to 578)
  AUTHORS   Osaka,T., Yoshie,S., Tsuneda,S., Hirata,A. and Inamori,Y.
  TITLE     Direct Submission
  JOURNAL   Submitted (01-MAR-2005) Toshifumi Osaka, Waseda University,
            Department of Chemical Engineering; 3-4-1 Ohkubo, Shinjyuku-ku,
            Tokyo 169-8555, Japan (E-mail:toshifumi-oggy@suou.waseda.jp,
            Tel:81-3-5286-3210, Fax:81-3-3209-3680)
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Figure 8. Nitrate-reducing biofouling organism identified

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Cicek, N., J. Macomber, J. Davel, M.T. Suidan, J. Audic, and P. Genestet. 2001. Effect of solids retention time on the performance and biological characteristics of a membrane bioreactor. *Water Sci. Technol*., **43**, 43.

Gander, M., B. Jefferson, and S. Judd. 2000. Aerobic MBRs for domestic wastewater treatment: a review with cost considerations. *Sep. Purif. Technol*., **18**, 119.

LeClech, P., B. Jefferson, and S.J. Judd. 2003. Impact of aeration, solids concentration and membrane characteristics on the hydraulic performance of a membrane bioreactor. *J. Membr. Sci*., **218**, 117.

Estimating Hydraulic Properties for Volcanic Island Aquifers using Wave Setup

Basic Information

Title:	Estimating Hydraulic Properties for Volcanic Island Aquifers using Wave Setup
Project Number:	2007HI177B
Start Date:	3/1/2007
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	HI 1st
Research Category:	Ground−water Flow and Transport
Focus Category:	Groundwater, Models, None
Descriptors:	Aquifer parameters, Wave Setup
Principal Investigators:	Aly I El−Kadi, Ali Fares

Publication

1. Rotzell, K. and A. I. El−Kadi. 2007. Estimating hydraulic properties of coastal aquifers using wave setup. *Eos Trans. AGU* 88(52): Fall Meet. Suppl., Abstract H21C−0696.
2. Rotzoll, K., and A.I. El−Kadi. 2008. Estimating hydraulic properties of coastal aquifers using wave setup. *Journal of Hyudrology* 353(2): 201−213.

Problem and Research Objectives

As is the case in many parts of the United States and elsewhere in the world, water problems in Hawaiʻi are related to the availability of potable freshwater and to its contamination by organic or inorganic chemicals associated with land-use activities. In Hawaiʻi groundwater provides about 99% of domestic-water use and about 50% of other freshwater uses (Gingerich and Oki 2000). Although all the main islands have large amounts of groundwater contained in volcanic rock aquifers, the quality of some of this groundwater may not be suitable for all uses. While there is a great need to identify new sources for potable water, better management of the existing resources is equally important.

Aquifer management in Hawaiʻi is based on the concept of "aquifer sustainable yield," which is defined as the maximum allowable total daily pumping without compromising storage and water quality. When the sustainable yield is exceeded over periods of time the reduction in water storage can cause an increase in salinity (Meyer and Presley 2000, Oki 2005).

In fact, water-quality profiles in the Honolulu area show that the salinity of water in the aquifer has increased over the years and that the transition zone is undergoing a steady upward movement (Visher and Mink 1964, Oki 2005). The resident population has increased tremendously on all main islands in the last three decades and existing development plans will only further extend this trend. Hence, better management of the aquifers is essential to ensure sustainability of Hawaiʻi groundwater resources.

Aquifer sustainable yield and management are studied by applying analytical and numerical models. Accurate values of hydrogeologic parameters, including hydraulic conductivity and storage, are needed for correct solutions. Uncertainty in correctly identifying the aquifer parameters may be reflected in erroneous model estimates—consequently leading to the potential mismanagement of drinking-water supplies.

Classic aquifer tests are accepted techniques for small-scale aquifer-parameter estimation. In such tests an aquifer is subjected to pumping and the water-table elevation level is recorded at the pumping well and in one or more monitoring wells. In Hawaiʻi studies using aquifer tests to estimate hydraulic parameters include Williams and Soroos (1973), Gingerich (1999), and Rotzoll et al. (2007). However quantifying and removing all "background noise" (i.e., perturbations not directly related to pumping) from the water-level records is critical for accurate aquifer-test analysis.

Ocean processes can also have a significant influence on water-table elevations for unconfined coastal aquifers. Overlooking ocean influences when making groundwater assessments in near-shore aquifers can lead to unacceptable errors. Ocean tides, for example, represent a periodic high-frequency forcing affecting groundwater levels in coastal aquifers. The harmonic signal decays as it propagates through the aquifer as functions of transmissivity, storage coefficient, and distance from the shoreline (Jacob 1950, Ferris 1951).

Waves are another factor in near-shore water-table changes. The interaction between waves and the groundwater table below beaches and in the littoral zone is well known. Wave run-up on a sloping beach is characterized by an instantaneous swash infiltration resulting in groundwater responses in the beach zone (Li and Barry 2000). This drives a groundwater circulation where water infiltrates at the upper part of the beach and exfiltrates at the lower, submerged, part of the beach. Swashes that extend beyond the mean groundwater level cause the groundwater table to rise directly proportional to the amplitude of the wave run-up (Hegge and Masselink 1991). The amplitude becomes increasingly damped inland (Li et al. 1997) and is hardly detectable at distances greater than tens of meters away from the shoreline.

As with waves, periods of large ocean swells result in an elevated mean-water level at the shoreline. This condition is identified as "wave setup" (Longuet-Higgins and Stewart 1963). The super-elevation occurs from the effects of transferring wave-related momentum to the water column in the surf zone. The duration of such periods of large ocean swells is generally one to two days but can be longer. Existing studies relating wave-setup and groundwater-table variations were previously limited to beaches (Gourlay 1992, Turner et al. 1997, and Massel 2001). Investigations including aquifers further than 150 meters from the shoreline were previously unavailable.

Available data from Maui indicates that wave setup inside the Kahului Harbor, measured at the Kahului tide gauge, is less than that outside the harbor. Wave setup is a localized phenomenon greatly influenced by the bathymetry of the near-shore area (Holman and Sallenger 1985). Broad low-sloping beaches result in greater wave setup. On the other hand coastal areas fronted by pronounced channels generate less wave action. The presence of one or more channels allows water to flow back to the deeper ocean. In such areas the effects of wave setup are less intense.

The geometry of Kahului Harbor with its protecting breakwalls and its deep channel through the narrow entrance provides an example of the effects noted above. Waves do not generally break inside the harbor or in the channel. Thus less energy is transferred into the water column in the harbor and therefore the water level in the harbor is generally not substantially affected by wave setup.

The effects of ocean tides are commonly used in aquifer-parameter estimation (Merritt 2004, Trefry and Bekele 2004, and Rotzoll et al. 2008). However wave-setup responses have not previously been used in such endeavors.

Similar to addressing the effects of tidal responses, using data generated by wave setup in aquifer-parameter estimation offers an advantage over small-scale aquifer tests by providing information on greater length scales. In addition the use of wave-setup responses is appealing due to the lower costs and simpler logistics involved. The required observation period for groundwater-table fluctuations generated by wave setup is much shorter than that needed for observations of tidal variations. However wave-setup analysis requires a reliable swell forecast. Recognizing that usually accurate forecasts of large-swell events are generated five-to-seven days in advance of the event, it is generally possible to schedule wave-setup analysis during such an event.

The primary research objective of this study was to investigate the influence of large ocean swells and the resulting wave setup on low-frequency water-table variations in a coastal aquifer and to utilize wave setup in hydraulic-parameter estimation. The approach is expected to be beneficial to many high-permeability coastal environments such as volcanic islands and atolls. The technique will also provide a practical approach for aquifer-parameter estimation as an important step towards more efficiently managing valuable groundwater resources.

Methodology

A three-month period, starting on 11 December 2004, was chosen for the analysis because of the occurrence of high-energy swells observed in available data. Water-level data at four observation points in central Maui, located approximately one, two, four, and five kilometers inland from the island's north coast near Kahului, had been collected at five-minute intervals by the U.S. Geological Survey.

Hourly-recorded climatologic data (barometric pressure and rainfall) were also available from the nearby Kahului airport. Available Kahului tide-gauge data provided tide readings every six minutes and available Waimea buoy data recorded significant wave height, dominant wave period, and swell direction every thirty minutes. Since the Waimea buoy is about 200 km away from the Kahului area a time shift between the arrival of the waves at the Waimea buoy and the study area was included in the analysis. For large waves traveling in deep water with a typical wave period of seventeen seconds, the time lag was approximately four hours (Brown et al. 1989).

To isolate and quantify the influence of wave setup on low-frequency water-table fluctuations we used different techniques of signal processing including low-pass filtering, spectral analysis, cross-correlation, and single- and multi-variable regression. Signal processing of the wave-setup data is required to filter out other environmental impacts, such as barometric and tidal influences, to limit the water-table fluctuation data recorded to that specifically generated by wave setup.

The effects of wave setup were correlated with observed inland transient-head changes. The water-table rise at the coast can be quantified by empirical formulae for wave setup controlled by the significant wave height, wave length outside the surf zone, and beach steepness (Stockdon et al. 2006). This allows relating the wave setup to the observed water-table rise in the aquifer and determining the efficiency of such measurements at each observation point as related to swells. Previously developed analytical solutions for tides were used to estimate aquifer hydraulic parameters (Jacob 1950 and Ferris 1951). The solution for the transient case, which assumes a vertical boundary between land and ocean, can be written as:

$$h = h_0 e^{-x\sqrt{\frac{\pi S}{t_0 T}}} \sin\left(\omega t - x\sqrt{\frac{\pi S}{t_0 T}}\right) \tag{1}$$

where h = water level in coastal aquifer (m), h_0 = amplitude of the tidal harmonic oscillation (m), x = distance to coast (m), S = storativity (dimensionless), t_0 = period of the harmonic oscillation (d), T = transmissivity (m^2/d), ω = angular frequency of the harmonic oscillation or $\omega = 2\pi/t_0$ (d^{-1}), and t = time (d). This equation can be used to estimate aquifer diffusivity (T/S) based on either time lag or on attenuation of the signal.

The main contrast between tides and wave-setup is that the wave-setup pulse is neither sinusoidal nor periodic. However during the data-collecting period a forty-one-day-long series of storm events occurred. This allowed the use of simple harmonics to describe the forcing. Spectral analysis identified the matching frequencies in wave-setup and groundwater responses. The aquifer parameters estimated from wave-setup propagation were compared with aquifer-parameter estimates from the same study area using aquifer tests (Rotzoll et al. 2007) and tides (Rotzoll et al. 2008).

Numerical modeling of the transient head using MODFLOW 2000 (Harbaugh et al. 2000) was applied to evaluate the accuracy of the analytical solution. A simple one-dimensional groundwater-flow model was developed including a wave-setup forcing at the boundary. The results of the numerical model were compared with those of the analytical model.

Principal Findings and Significance

The influence of wave setup on coastal-groundwater elevations and the possibility of using the propagating wave-setup signal in aquifer-parameter estimation were investigated for central Maui. The wave-setup signal is detectable at observation points as far away as five kilometers from the coast. Regression analysis shows that correlation coefficients between wave setup and groundwater fluctuations are as high as 0.73. The observation period was split into two sections, termed SWELL and BARO, to investigate the effects of wave setup and barometric pressure on groundwater levels. Observation of SWELL started on 12 December 2004 and lasted for 41 days and that of BARO started on 30 January 2005 and lasted for 35 days. The SWELL subset contains nine swell events, of which four were major storm events producing waves above 4 m. The SWELL subset was characterized by modest barometric fluctuations. In contrast the BARO subset shows more significant atmospheric pressure variations while wave setup is relatively uniform.

Barometric influence is insignificant (correlations <0.1) in the SWELL subset. However the correlation coefficients improve using setup and barometric changes together. In contrast, in the BARO subset, correlations with wave setup are weak and the influence of barometric-pressure variations is strong, reaching correlations up to 0.81. Therefore wave setup can significantly affect groundwater elevations in costal aquifers and can overshadow barometric influence in times of large swell events. At other times the barometric loading dominates.

Wave-setup propagation through the aquifer is similar to that for tides with exponentially decreasing amplitudes and linearly increasing time lags between wave-setup and observed groundwater responses. The average duration of swell events in the SWELL subset was approximately 6 days and spectral analysis shows matching peak periods at 6.8 and 3.2 days in wave-setup and groundwater observations. The longer periods explain the milder amplitude attenuation and milder phase-lag gradients of wave-setup compared to tidal propagation. This can be very useful because wave-setup signals propagate deeper into the aquifer (about 10 km in central Maui) than diurnal tides (5 km) and can therefore provide information on greater length scales.

Aquifer parameters were estimated from wave-setup attenuation using the analytical solutions from tidal propagation. The results are consistent with parameters estimated from aquifer tests and tides in the same study area. Mean hydraulic diffusivity from wave-setup attenuation is identical based on the wave-setup estimates by Vetter (2007) and Stockdon et al. (2006) and is estimated as $2.3 \cdot 10^7$ m^2/d. Assuming that the wave-setup signal travels through the entire aquifer thickness of 1.8 km and the specific yield is 0.04, the hydraulic conductivity is 520 m/d.

A one-dimensional numerical model reproduced the results of the analytical solution. The best fit was achieved with hydraulic-conductivity values of 650 or 460 m/d, based on the respective approaches by Vetter (2007) and Stockdon et al. (2006). The model successfully simulated groundwater responses that match the transient head at observation points reflecting the amplitude attenuation and the time lag of wave-setup pulses. The mean correlation coefficient is 0.84 for all observation points.

Wave-setup signal propagation was successfully used to estimate hydraulic parameters. The technique is expected to be beneficial to many high-permeability coastal environments, such as volcanic islands and atolls, and will provide a practical approach for aquifer-parameter estimation as an important step toward managing valuable groundwater resources.

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Efficient Water Management and Block Pricing for Integrated Aquifers: Lessons from Southern Oahu

Basic Information

Title:	Efficient Water Management and Block Pricing for Integrated Aquifers: Lessons from Southern Oahu
Project Number:	2007HI183B
Start Date:	3/1/2007
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	HI 1st
Research Category:	Social Sciences
Focus Category:	Economics, Management and Planning, Groundwater
Descriptors:	Conservation pricing, efficient extraction, multiple aquifers
Principal Investigators:	James A. Roumasset

Publication

1. Pitafi, B., and J.A. Roumasset. Forthcoming. Pareto−improving water management over space and time: The Honolulu case. *American Journal of Agricultural Economics*.

Problem and Research Objectives

Most previous studies on the topic of groundwater management have limited their attention to the case of a single aquifer. However one can identify situations where multiple sources of groundwater are accessible to a single city or a dense cluster of cities. For example, the Honolulu Board of Water Supply (HBWS) on the island of O‘ahu, Hawai‘i, currently extracts water from both the Honolulu and Pearl Harbor aquifers and pumps this water into an interconnected pipeline that serves both consumption districts. Water is being imported from Pearl Harbor to meet the large and growing demand in Honolulu.

Thus the problem requires an integrated analytical model that determines optimal groundwater use when water can be extracted from two sources.

Methodology

Following the theoretical framework laid out by Pitafi and Roumasset (2008) we applied an optimal control model to the Honolulu and Pearl Harbor aquifers independently and identified the efficient paths of water extraction for each. The purpose of this exercise was both to update previous estimates for Honolulu (Pitafi and Roumasset, forthcoming) and Pearl Harbor (Krulce, Roumasset, and Wilson 1997) and to provide a benchmark for comparison with the joint-management scenario.

Our methodology differed from previous studies in several ways. Most notably we attempted to incorporate spatial aspects into our extraction cost functions by considering well placements and depths. Low ground-surface elevation wells near the coast tend to have lower extraction costs but they are also first to face the effects of saltwater intrusion.

As the aquifer is drawn down the saltwater interface rises to the well bottoms—at which point a decision must be made. The managing authority may 1) abandon low-elevation wells and increase extraction at high-cost higher-elevation wells; 2) impose a constraint on extraction so that the hydraulic head does not fall further in order to protect the lower-elevation wells; or 3) abandon the coastal wells and drill new and expensive higher-elevation wells. In our simulations we examined the first two possibilities and found that the results differed significantly.

The multiple-aquifer model is an extension of the optimal control model for the single-aquifer case. The objective is to choose time paths for groundwater extraction and desalinated-water production to maximize the present value of the net social surplus from water use (consumer surplus less producer costs):

$$\underset{q_t^1, q_t^2, b_t}{Max}\, PV\ ,\ PV = \int_0^\infty e^{-rt}\left(\int_0^{q_t^1+q_t^2+b_t} D^{-1}(x,t)dx - q_t^1 \cdot c_1(h_t^1) - q_t^2 \cdot c_2(h_t^2) - b_t \cdot c_b \right)dt$$

$$\text{subject to} \quad \dot{h}_t^1 = n_1(h_t^1) - q_t^1$$

$$\dot{h}_t^2 = n_2(h_t^2) - q_t^2$$

$$q_t^1 \geq 0,\ \ q_t^2 \geq 0,\ \ b_t \geq 0$$

$$h_t^1 \geq h_{\min}^1\ ,\ h_t^2 \geq h_{\min}^2\ ,\ h_0^1 \text{ and } h_0^2 \text{ given}$$

Manipulation of the Pontryagin conditions for this dynamic optimization problem gives an expression for the efficiency price:

$$p_t^i = c_i(h_t^i) + \frac{\dot{p}_t^i - c_i'(h_t^i)\cdot n_i(h_t^i)}{r - n_i'(h_t^i)} \qquad \text{for } i = 1,2$$

This is the usual expression for the efficiency price of a renewable resource; price is equal to the extraction cost plus a marginal user cost. However only one price is effective at any given point in time so we also have the condition that:

$$p_t \le c_1(h_t^1) + \lambda_t^1, \qquad \text{if } <, \text{ then } q_t^1 = 0$$
$$p_t \le c_2(h_t^2) + \lambda_t^2, \qquad \text{if } <, \text{ then } q_t^2 = 0$$
$$p_t \le c_b, \qquad \text{if } <, \text{ then } b_t = 0$$

In other words, water is extracted from the resource with the lowest extraction cost plus in situ shadow value. When the efficiency prices are equal, water is extracted from both aquifers simultaneously.

We used pumping and cost data provided by HBWS to estimate the parameters required for numerical simulations of our model. A computer algorithm written in *Mathematica* was then used to estimate the optimal time paths of the efficiency price and hydraulic-head levels.

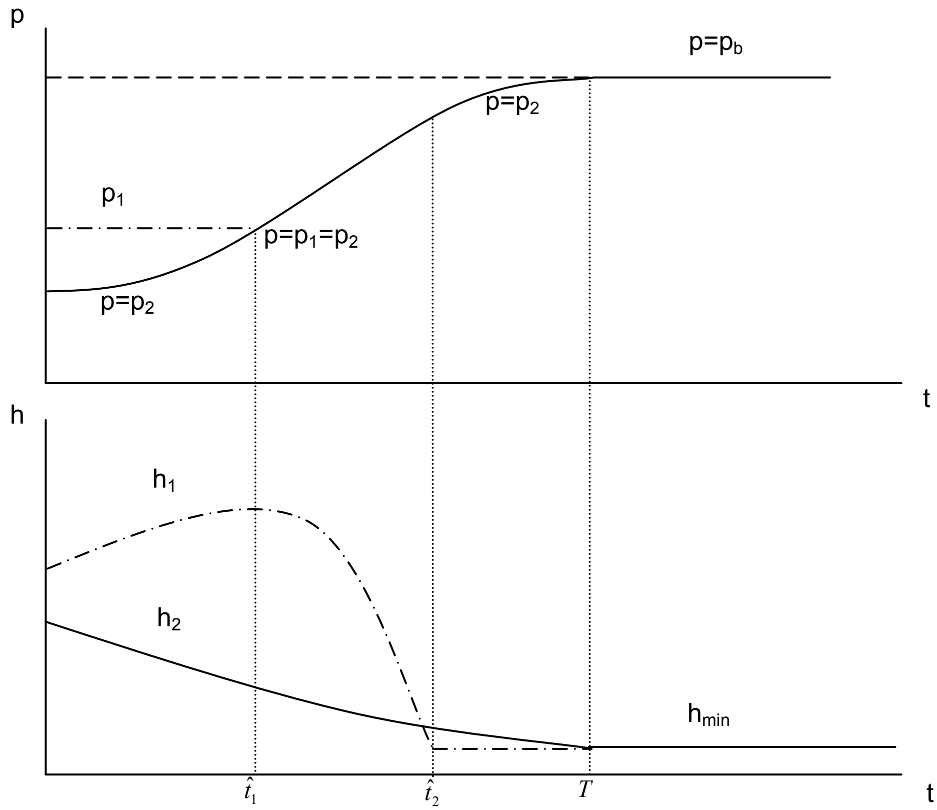
Principle Findings and Significance

For comparative purposes we ran numerical simulations for the independent management of Honolulu and Pearl Harbor aquifers. The results indicate that in both cases, switching from status quo to efficiency pricing can extend the useful life of the aquifer for up to twenty years. Economic efficiency requires switching to desalination after 148 and 167 years for Honolulu and Pearl Harbor respectively, much later than was calculated in previous studies. This is largely due to the fact that the previous Honolulu study did not consider that a large percentage of the water consumed in Honolulu is actually being imported from Pearl Harbor and that total draft for Pearl Harbor has declined over the past twenty years. The welfare gain from switching pricing structures is on the order of tens of millions of dollars for Honolulu and hundreds of millions of dollars for Pearl Harbor, or 1–2% of the status quo welfare.

When a constraint is placed on the hydraulic-head level to ensure that coastal wells remain usable for freshwater extraction, the results change drastically. For the case of Honolulu, a hydraulic-head constraint of 22.4 feet was imposed in order to protect the deepest wells. The resulting optimal efficiency price path rises drastically and the switch to desalination occurs after about twenty-five years, less than 1/6th of the time it takes for the “abandon as you go” strategy.

Aside from spatial issues on the demand side, our joint-aquifer analysis indicates that Pearl Harbor should be used exclusively for a period of time, after which both aquifers are used simultaneously. Eventually the Honolulu aquifer is depleted and the Pearl Harbor aquifer is again used exclusively until it, too, is exhausted.

At that point extraction from both aquifers is limited to natural recharge and the remainder is supplied by desalination. The stages of extraction are illustrated in the figure below.



Preliminary analysis suggests that welfare gains associated with switching from the status quo pricing structure to integrated management are larger in both absolute and percentage terms than the gains from switching to efficient but independent management of the Honolulu and Pearl Harbor districts.

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USGS Grant No. 07HQAG0162 Assessing Effects of Intraborehole Flow in Deep Monitoring Wells on Estimates of Aquifer Salinity Profiles

Basic Information

Title:	USGS Grant No. 07HQAG0162 Assessing Effects of Intraborehole Flow in Deep Monitoring Wells on Estimates of Aquifer Salinity Profiles
Project Number:	2007HI241S
Start Date:	9/1/2007
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Funding Source:	Supplemental
Congressional District:	HI 1st
Research Category:	Ground−water Flow and Transport
Focus Category:	Groundwater, Water Quality, Water Supply
Descriptors:	Salinity encroachment; groundwater modelling; intraborehole flow
Principal Investigators:	Aly I El−Kadi

Publication

Problem and Research Objectives

Regulation of groundwater withdrawals at some aquifer locations in Hawai‘i is based principally on salinity-versus-depth profiles from adjacent deep-monitoring wells. Salinity profiles are being used to monitor the midpoint of the transition zone between freshwater and saltwater as a proxy to track the thickness of the overlying freshwater lens (Meyer and Presley 2001; Gingerich and Voss 2005).

This information is being used by the Hawai‘i Commission on Water Resource Management for sustainable-yield estimates utilizing the RAM2 model (Mink 1980; Mink 1981; Liu 2006; Liu 2008). Salinity profiles are being used, as well, for calibrating regional density-dependent groundwater-flow models (Souza and Voss 1987; Oki, Souza et al. 1996). These models provide insights into groundwater availability under different recharge-and-withdrawal scenarios (Oki 2005; Gingerich in preparation).

Borehole geophysical logging in Hawai‘i has shown some evidence of subtle vertical borehole flow in some cases (Paillet and Hess 1995; Paillet, Williams et al. 2002). Because of possible borehole-flow effects, salinity profiles from deep-monitor wells may not accurately reflect the salinity distribution in the surrounding aquifer with changing depth.

The definitive questions then become: “Is this subtle borehole flow sufficient to invalidate the depth-salinity profiles that are being observed?” Or: “Is the borehole flow great enough that the observed salinity profile in the borehole is substantially different from that in the adjacent aquifer?”

A final question concerns the use of and management intent for these deep-monitoring wells: “Are salinity profiles from deep-monitoring wells sufficiently invalid that they cannot be used to monitor long-term changes in the adjacent aquifers over time periods ranging from years to decades?”

“Years-to-decades” is currently the anticipated timescale in response to pumping for saltwater intrusion into the aquifers in Hawai‘i (Visher and Mink 1964). Thus far this topic has not been comprehensively addressed in published literature.

The objective of this research is to evaluate the potential for vertical borehole flow in deep-monitor wells that may result in inaccurate or misleading information being used for groundwater management in Hawai‘i.

Methodology

Two approaches will be used: 1) evaluating and summarizing existing work to date, and 2) consulting with experts in borehole geophysical logging to design a strategy for further fieldwork.

Case Studies —Field data and studies in Hawaiʻi on borehole flow by Paillet and Hess (1995) and Paillet et al. (2002) will be reviewed. Existing geophysical logs and salinity profiles will be inspected for evidence of vertical flow and profile disturbance. Some deep-monitor wells are currently suspected of having such significant borehole flow that salinity profiles from these wells are probably invalid measurements of the salinity distribution in the adjacent aquifers.

One indicator of possible vertical borehole flow sometimes evident in salinity profiles is a step-like change in electrical-conductivity data. These "kinks" are evident where significant quantities of water may be either entering or exiting the uncased part of the borehole. Salinity profiles frequently show multiple step-like changes in electrical conductivity. This makes it difficult to accurately determine the principal direction of borehole flow and whether or not the measured conductivity accurately estimates the salinity in the adjacent aquifer (Oki and Presley 2008).

On the island of Oʻahu, Hawaiʻi, there is a classic case where a fully-open deep-monitor well has been sited too close to large-capacity water-supply wells. At this site the drawdown from the pumping wells appears to draw brackish water up the bore of the monitor well. For wells away from obvious pumping disturbances much less evidence for salinity-profile disturbance exists.

In a second example vertical borehole flow is likely to occur in a deep-monitoring well which taps a degraded irrigation-return groundwater layer. A well fitting this description is located at the discharge end of the central Oʻahu flow system where upward vertical-head gradients are expected. A deep-monitor well in this area has lower nitrate than surrounding shallower observation wells and this may indicate upward flow of "fresher" water from intermediate depths. Considerable chemical and tracer data are available for the deep-monitor well which, if carefully evaluated, may provide insights into quantifying the amount of vertical borehole flow. The possible presence of seasonal effects currently "hidden" in the data in existing salinity logs will be examined by differentiating log data from various dates to see if differences follow the expected trend.

Strategy for Further Fieldwork—Results of the case studies above will be used to design a strategy for fieldwork on Oʻahu, Hawaiʻi.

Separately, it is likely that new data logging will be proposed for the Waiehu deep-monitor well in the ʻIao Valley area of the island of Maui, Hawaiʻi. This well is particularly important to the management of ongoing pumping activities at this location as, under the sustainable-yield concept, the midpoint of the transition zone in the salinity profile of this deep-monitor shows a steady rise over the last three decades.

Geophysical specialists in borehole logging will be asked to propose methods not to simply demonstrate that there is borehole flow but to definitively answer the critical question: Can it be demonstrated that, in certain cases, the borehole-salinity reference profile differs substantially from the adjacent aquifer-salinity profile?

Proposed strategies may include induction tools that "look outside" the borehole and into the formation (Keys 1990). The use of such tools would require adequate measurements of formation porosity and of the bulk resistivity of the solid-basalt matrix and the application of Archie's Law. It would be essential that the geophysical logging methodology be able to differentiate between resistivity measured for the fluid and that measured for the surrounding formation.

Other deep-monitor wells on various Hawaiian islands may also be proposed for additional work. Approaches may include salinity profiling under ambient and pumped conditions or repeat profiling at seasonal intervals (to take advantage of naturally-imposed vertical-head gradients).

One example of a naturally-imposed vertical-head gradient is the seven-foot rise in the regional water table on Oʻahu that has accompanied a recent recharge event after five dry years. Repeat sampling data may be accessed through ongoing logging programs of the Hawaiʻi Commission on Water Resource Management and county water department records.

Challenges—Local stakeholders believe that salinity profiles from open boreholes are a reasonable indicator of adjacent aquifer salinity. Well owners may not be enthusiastic in their support of uncompensated geophysical research in their wells considering unexpected high costs associated with rehabilitating any wells damaged by logging tools.

Finally, valuable information can be obtained through a network of short-screened or point-piezometer measurements to define vertical-head gradients or the true-salinity distribution in the adjacent aquifer. High costs, however, would limit such efforts—especially for wells exceeding a depth of one thousand feet.

Preliminary Findings and Significance

Step-like changes in conductivity are evident in almost all available salinity profiles. A regional trend, supported by basin-wide groundwater-flow dynamics, is prominent as major downward flow components that occur in recharge areas and major upward flow components that are seen in discharge areas towards the coast. Several salinity profiles in deep-monitor wells indicate large kinks as signs of vertical borehole flow. The largest deviation from theoretical aquifer salinity occurs in deep-monitor wells located in area extending from east Pearl Harbor to Kalihi on Oʻahu. However no significant correlation exists between proximity to pumping centers and the magnitude of kinks in the profiles.

Is the vertical borehole flow so great that salinity-profile data are invalid measurements of adjacent aquifer salinity? We can not answer this yet for all deep-monitor wells but, in tracking for the midpoint of the transition zone between freshwater and saltwater, the Beretania deep-monitor well case study shows depth displacements caused either by barometric pressure and tidal fluctuations or by nearby withdrawal from pumping centers to be inconsequential.

The 1 mS/cm concentration is indicative for the top of the transition zone between freshwater and saltwater. Contrary to the midpoint, several salinity profiles indicate 100 to 400 ft depth displacements of the 1 mS/cm concentration in deep-monitor wells near pumping centers.

In many cases studied in this project, poor quality control of salinity profiles is hindering data interpretation. It can be concluded, however, that this continuing research is an important step towards assessing the significance of the problem.

Should the results from this project indicate significant unreliability of the salinity-profile data from deep-monitoring wells in determining adjacent aquifer salinity, local stakeholders are likely to become more interested in funding further fieldwork.

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Information Transfer Program Introduction

A small state like Hawaii allows many opportunities for researchers to interact with administrators and policy makers. In hopes of broadening knowledge of and appreciation for Hawaii's water resources, WRRC's technology transfer program produces newsletters, arranges and advertises seminars, workshops and conferences, assists in producing posters and other materials for presentations, and maintains a website. A particular pleasure during this reporting period was to organize a one−day symposium occasioned by the publication of *Hydrology of the Hawaiian Islands*, written by former WRRC director L. Stephen Lau and former researcher John Mink. The conference, as with the book itself, covered every major aspect of Hawaiian hydrology through presentations from some of the state's most experienced and respected hydrologists and water engineers.

Technology Transfer

Basic Information

Title:	Technology Transfer
Project Number:	2007HI192B
Start Date:	3/1/2007
End Date:	2/28/2008
Funding Source:	104B
Congressional District:	HI 1st
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	
Principal Investigators:	Philip Moravcik

Publication

1. Moravcik, Philip. 2007. *Bulletin*, Water Resources Research Center, University of Hawaii at Manoa (August), 8 pp.
2. Moravcik, Philip. 2008. *Bulletin*, Water Resources Research Center, University of Hawaii at Manoa (March), 8 pp.

Problem and Research Objectives

The mandate of the Water Resources Research Center (WRRC) includes an obligation to broadly disseminate the results of its research activities to audiences of local water and wastewater agencies, environmental engineering consultants, other academic researchers, and interested members of the public.

Methodology

WRRC bulletins; other publications; web site; workshops, meetings, and conferences; and regular bi-weekly seminars all served to aid the center in transferring to its multiple audiences timely and critical information concerning water-resource research and issues.

Principal Findings and Significance

N/A

Publications Cited in the Synopsis

N/A

Technology Transfer Program

WRRC's Technology Transfer Program activities for the report period included: organization of multiple seminars; production of project bulletins and newsletters; participation in meetings and conferences; and providing water-resources-research information to consultants, students of all levels, and the general public. The program PI also participated in school science fairs, WRRC research projects having an informational component, and refinement of the center's web site. During this current reporting period the Technology Transfer Program produced one newsletter describing research projects and center activities and news. During this reporting period the Technology Transfer PI made extensive use of the center's large-format printer/plotter, producing posters for display at local, national, and international meetings and conferences. Three of these posters, illustrating the work of graduate student researchers, won awards at conferences.

The Technology Transfer Program organizes biweekly seminar series designed to foster communication among WRRC researchers, students, and the organizational target audience of government agencies, private-sector researchers, and members of the general public with an interest in water-resource issues. Each semester one WRRC faculty member is appointed to organize the seminars and recruit speakers from university faculty, visiting scientists, government agencies, and private-sector firms. 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 on emerging water-related issues. The seminars are generally well attended and provide one of the few public forums in the state for the discussion of water issues. The following is a list of the eighteen seminars presented during the reporting period.

Seminar Coordinator: Dr. Clark Liu

3/1/07	Chester Lao, Honolulu Board of Water Supply, Honolulu, HI **A Review of Oahu Hydrogeology**
3/15/07	Lynne Lewis, Professor of Economics, Bates College, Lewiston, ME **Dams, Dam Removal, and River Restoration: A Hedonic Property-Value Analysis**
3/16/07	Sally Logsdon, National Soil Tilth Laboratory, Ames, IA **Soil Dielectric Spectra from Vector Network Analyzer Data**
3/23/07	Shaleen Jain, Department of Civil and Environmental Engineering, University of Maine, Orono, ME **Sustainable Water Resources Management in a Changing Climate**
4/5/07	Jim Butler, Senior Scientist, Geohydrology Section, Kansas Geological Survey, University of Kansas, Lawrence, KS **Getting the Information Ground-Water Modelers Need: A Report from the Field**
4/19/07	David Penn, Hawaii Department of Health, Environmental Planning Branch, Honolulu, HI **Total Maximum Daily Loads for Sustainable Water Resource Management?**
4/26/07	Michael Robotham/Katina Hanson, USDA-NRCS Pacific Islands Area, Honolulu, HI **Strengths and Weaknesses of USLE-based Models for Watershed Assessment in Tropical Island Environments**
5/22/07	Dharni Vasudevan, Associate Professor of Environmental Chemistry, Bowdoin College, Brunswick ME **Environmental Fate of Veterinary Antibiotics: Sorption to Soils and Soil Components**

Seminar Coordinator: Philip Moravcik

7/10/07	Donna Ferguson, Microbiologist, Southern California Coastal Water Research Project, Costa Mesa, CA	**Growth of *E. coli* and Enterococci in Storm-Drain Biofilm and an Update on the Doheny Epidemiology Study**
9/6/07	Jamil Rima, Professor, The Lebanese University, Beirut, Lebanon	**Oxy-Nanoparticle Technology to Mineralize all Organic Compounds and Disinfect Microorganisms for Water Treatment**
9/20/07	Victor Moreland, WRRC Researcher	**Sand Island WWTP: Primary Effluent Ultraviolet (UV) Disinfection**
10/4/07	Chittaranjan Ray, University of Hawaii WRRC and Civil Engineering	**Mobility of Pathogen Indicators and Chemicals in Selected Soils of Hawaii**
10/18/07	Kolja Rotzoll, University of Hawaii WRRC and Geology and Geophysics	**Hydraulic-parameter estimation using aquifer tests, specific capacity, ocean tides, and wave setup for Hawaii aquifers**
10/25/07	Kevin Brannan, Research Associate, Biological Systems Engineering, Center for TMDL and Watershed Studies, Virginia Tech, Blacksburg, VA	**Watershed-Modeling Approaches for TMDL Development: the Virginia Experience**
11/1/07	Ali Fares, Associate Professor of Hydrology, University of Hawaii Natural Resources and Environmental Management Department	**Impact of Invasive Species (Animals and Plants) on Hawaii Coastal Watersheds: A Modeling Approach**
11/15/07	James Paul, Attorney, Paul Johnson Park & Niles, Honolulu, HI	**The Waiahole Ditch Case Seven Years Later: "With Utmost Haste and Purpose"? What Role for "Science"?**

Spring 2007 Seminar Coordinator: Dr. James Moncur

1/17/08 Tom Sale, Director, Center for Contaminant Hydrology, Civil Engineering, Colorado State University, Fort Collins, CO.

Non-Aqueous Phase Liquids (NAPLs)— Emerging Issues and Solutions

2/7/08 Victor Moreland, WRRC Researcher

White Paper Recommending Approval of the City and County of Honolulu's Honouliuli Wastewater Treatment Plant's Application for a Modified NPDES Permit under Section 301(h) of the Clean Water Act

Special Hydrology Symposium—13 August 2007

The Technology Transfer Program organized a special symposium for Monday 13 August 2007 on "The State of Hydrological Sciences in Hawaii." The symposium followed on the October 2006 publication by the University of Hawai'i Press of *Hydrology of the Hawaiian Islands*, authored by former WRRC Director L. Stephen Lau and Hawaii/Pacific hydrology consultant John F. Mink.

The symposium sought to bring together individuals in Hawaii working or studying in all of the aspects of hydrology to discuss the current state of water research in Hawaii.

Topics were organized around the natural divisions of atmospheric, surface, soil, ground, and coastal-water hydrologies. WRRC invited individuals with particular expertise in each area to deliver short talks, followed by discussion sessions involving all attendees.

The symposium was well attended with more than 110 participants. It served as an opportunity for those either working in or otherwise interested in Hawaiian hydrology to network with WRRC faculty and other water experts from around the state.

WRRC Website

The website (www.wrrc.hawaii.edu) is continually updated with new information about WRRC researchers' activities, seminars, reports, meetings, grant announcements, and the center's L. Stephen Lau scholarship fund. The site provides information about center facilities and personnel as well as a database of WRRC publications. A web-site search function provides easy access to the available information.

Poster Production

The Technology Transfer Program PI assisted numerous center faculty and graduate research assistants in the design and production of posters illustrating research projects for display at meetings and conferences. Three graduate-research-assistant posters were recognized by conference awards.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR−USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	3	2	0	0	5
Ph.D.	5	4	0	1	10
Post−Doc.	0	0	0	1	1
Total	10	6	0	2	18

Notable Awards and Achievements

Marcus Solderlund, a microbiology student of WRRC Researcher Dr. Roger Fujioka, won first prize at the Hawaii Water Environment Federation Conference in February 2008. His poster described new methods for identifying human fecal contamination, used to detect a leak of human sewage into a local stream.

Krishna Lamichhane won third prize at the Hawaii Water Environment Federation Conference, February 2008. Mr. Lamichhane is a student of WRRC Researcher Dr. Roger Babcock. His poster presentation described a closed−loop waste disposal system that minimizes water and energy use and allows for retrieval of valuable nutrients for soil improvement.

Publications from Prior Years

1. 2005HI114B ("Diffusive Tortuosity of Reactive Porous Media: Application to Colloidal Fouling and Biofouling During Membrane Filtration") − Articles in Refereed Scientific Journals − Ng, Aileen N. L. and Albert S. Kim, 2007, A Mini−Review of Modeling Studies on Membrane Bioreactor (MBR) Treatment for Municipal Wastewaters, Desalination, 212, pp. 261−281.
2. 2003HI26B ("Prevention of Colloidal Fouling in Crossflow Membrane Filtration: Searching for Optimal Operation Conditions") − Articles in Refereed Scientific Journals − Kim, Albert S. and Aileen N.L. Ng, 2007. Hydraulic Permeability of Poly−dispersed Cake Layers: An Analytic Approach, Desalination, 207 pp. 261−281.
3. 2002HI2B ("A win−win approach to water pricing and watershed conservation") − Articles in Refereed Scientific Journals − Pitafi, B. and J. Roumasset. 2008. "Pareto−Improving Water Management over Space and Time: The Honolulu Case," American Journal of Agricultural Economics (forthcoming).