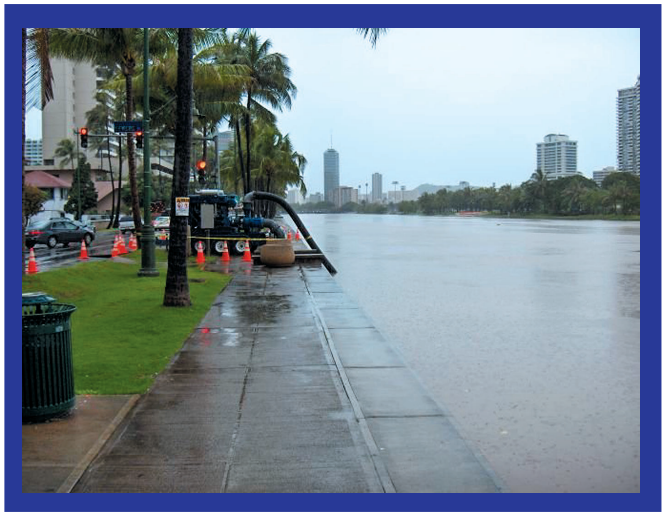
Water Resources Research Center
University of Hawaii at Manoa
October 2006 Bulletin

# WRRC Researcher Looks at March 2006 Ala Wai Canal Sewage Spill

WRRC's Dr. Roger Fujioka is the lead researcher for the Pathogen Project for the Pacific Research Center for Marine Biomedicine (PRCMB), a National Science Foundation and National Institute for Environmental Health Science funded Center at the University of Hawaii. There are three other of these "Centers of Ocean and Human Health" in the nation. Dr. Fujioka used the goals and resources of this project to independently monitor the Ala Wai Canal and Waikiki beaches during the the sewage spill that occurred in March/April of this year.

Dr. Fujioka is a microbiologist who has spent decades examining the issue of bacterial contamination and regulatory standards of recreational waters and the implications for human health of contact with these waters. His work in Hawaii has led the state to adopt *Clostridium perfringens* as a more applicable microbial standard for Hawaii's tropical recreational waters than the federally mandated enterococci. He has recently been examining the utility of enumerating FRNA coliphage (bacterial virus) and bacteroides bacteria (fecal bacteria that cannot be cultured using standard techniques) employing the polymerase chain reaction (PCR) method. These alternative microorganisms are more specific indicators of human sewage.

The Ala Wai canal serves to channel the runoff from several urban Honolulu streams to the ocean. The canal was originally dug in the early 1920s in order to drain the Waikiki area, facilitating it's development into a tourist Mecca. The water and sediment entering the Ala Wai are contaminated with all the usual pollutants that one expects to find in an urban watershed. It is widely recognized by Honolulu residents that the canal is very polluted and unsafe for extensive direct contact. The Hawaii Health Department had previously determined that the canal is unsafe for swimming and had posted signs warning people not to enter.



Emergency pump in place at the Ala Wai end of Kaiolu St. Some 48 million gallons of sewage was discharged into the canal over five days in March/April this year.

Honolulu's Manoa Valley experienced 42 consecutive days of rainfall during the last week of March 2006. After several days of especially intense rain, infiltration of rain water from the saturated ground into the sanitary sewer system contributed to the rupture of a 42" main in the heart of Waikiki on March 24. State officials posted warning signs on the beaches the next day.

In order to avoid the scenario of raw sewage flowing down the streets of Waikiki the City installed pumps to divert the sewage into the canal. The difficult saturated conditions delayed repair work and by the time the City's crews were able to repair the line break - 6 days later - some 48 million gallons of sewage had gone into the Ala Wai. The spill was one of the largest sewage spills in the nation's history. State Health Department and City & County of Honolulu monitoring found enterococci counts as high as 780,000 colony forming units per 100 ml. in the canal and elevated counts were also seen at beaches in Waikiki.

Events took a tragic turn when a Honolulu resident fell into the canal on March 31 and became infected with *Vibrio vulnificus,* a flesh-eating bacteria, native to marine water rather than sewage. Despite the efforts of his doctors he died a few days later. Two less serious infections were reported during this time. One was a lesion on a surfer from which several fecal bacteria were cultured. The other was on a beachcomber, who stated that he had not been in the water but merely walking on the sand. The responsible organism was not identified in this case.

Needless to say, the posting of the beaches along with the tragic loss of life is not the kind of publicity that Hawaii's tourist industry needs. The spill and the infections were reported as far away as the New York Times.

There was an understandable anxiety to get the beaches open to tourists as soon as possible, balanced

**continued on page 3**

# Director's Message - Dr. James Moncur

Jim Moncur

Like thousands of other commuters, my daily trip home to windward Oahu includes passing through one of three fairly long tunnels. Emerging from these tunnels, one is presented with a scene of gloriously lush tropical greenery and, as a bonus, the magnificent blue Pacific Ocean in the background. The greenery, of course, is a result of plentiful rainfall. In 27+ years of living there, I have never had to water the lawn (or rather the weeds that pass for my lawn.) Everywhere on Oahu, our tap water tastes like a four-star restaurant compared to the unsavory flavors pumped out in some places.

Next to some mainland areas, Hawaii is in great shape for water. I was reminded of this at a conference this July in Santa Fe, New Mexico. Water utilities in southwestern states have taken truly drastic measures to keep water flowing through the pipes.

Las Vegas and El Paso, for example, offer homeowners and golf courses $1 per square foot to dig up their lush but thirsty turf, and prohibit having more than half of one's back yard planted in grass. The El Paso water utility replaces urinals with waterless models (chemicals reportedly control odors) and encourages homeowners to trade evaporative swamp coolers for refrigerated air conditioning. Many southwestern cities require or subsidize low-flow toilets and hand out free low-flow shower heads. Albuquerque offers rebates on toilets, landscaping, sprinkler timers, recirculating hot-water systems and washing machines. Lawn watering restrictions are common. Even some traditionally water-rich eastern cities have rebate programs; Dedham, Massachusetts, for example, recently announced a $100 rebate for high-efficiency washing machines.

Contractors must have water sources to accommodate new homes. Since they get credit for water conservation in some places, developers send out door-to-door "salesmen" offering to replace, for free, old toilets with new low-flow units.

Other cities have jumped into desalination, sometimes happily and sometimes not. Singapore has a large new reverse osmosis plant to treat and reuse wastewater at a cost of about $1.70 per thousand gallons (plus distribution, management, planning etc–which typically account for well over half of total costs.) Elsewhere, brackish water desalinating plants report costs as low as $.76/1000 gallons. Tampa, Florida announced in 1998 the largest seawater desalination facility in the U.S. The estimated cost: less than $2/1000 gallons. Six years and three bankrupt contractors later, the City of Tampa plans to pump an additional $26 million into completing construction and replacing (already!) rusted pumps and pipes. The resulting water will cost more than $2.50 per thousand gallons. Some desalination projects are subsidized, but that doesn't make the product water any cheaper, just shifts the burden of costs.

For most consumers, rebates or savings on water bills or both will fall short of justifying the cost of an expensive new toilet or washing machine, at least given the relatively low water rates currently in force. Facing this reality, more and more cities have adopted rate schedules that are intended to promote conservation. Las Vegas, for example, explicitly sets its rates to discourage water use. A steeply-rising usage charge is expected to induce substantial and continuing conservation. My colleague James Roumasset, of the UHM Economics Department and his students (as reported in the WRRC bulletin of March 2005) have devised water rate-setting principles that promise to stretch conventional water sources for many years beyond current projections, and to meet political objections in the process.

Hawaii's municipal water utilities have long encouraged conservation, and probably will have to expand emphasis on conservation in the future. Honolulu consumers face a 60% rate increase by 2010, but this will just finance aging pipes. These higher rates still won't cover the value of leaving water in the ground for future use.

Any decrease in demand induced by higher rates will be a bonus, but achieving sustainability probably requires considerably larger increases to give consumers a solid, continuing, in-your-face reason to conserve. At the same time, we will need expanded information programs to teach people how to conserve and rebate programs to encourage adoption of water-saving appliances and landscaping.

Through all of this, I intend to increase my enjoyment of the rain-fed weeds in my yard.

**Ala Wai Spill** continued from page 1

by a fear of additional cases of infection. The question of how long it takes the environment to clean up after such a spill should therefore be of critical interest to Hawaii's tourist industry and the regulatory agencies that are responsible for protecting the health of swimmers.

On April 4, six days after the flow into the canal was stopped, the warning signs were removed from the beaches based on counts of *C. perfringens* in possibly contaminated waters. However many regular beach-goers and tourists alike stayed away from the beaches for some time after that citing fears about the risk of swimming in possibly contaminated waters.

Paddlers did not return to their regular training in the Ala Wai canal for a couple of months, and swim meets were moved from Waikiki to Hawaii Kai.

Ala Wai Yacht Harbor from Magic Island the day after the end of the spill.

The Ala Wai spill raises questions about the risk posed by going to beaches that have been subjected to sewage spills. When do we know it is safe to return? What factors help determine how quickly the bacteria levels decline to safe levels? Is the sand on the beach contaminated and if so how long does it take for this contamination to clear? (a sand replenishment program at Kuhio Beach was postponed due to the spill). Confusing the issue is the fact that elevated bacterial counts seen at the beaches during storm events may be the result of urban runoff unrelated to sewage spills. Further research is needed to determine the source of the contamination and its associated public health risks.

In order to address the many questions regarding the safety of the water and sand around Waikiki and Ala Moana during and after the spill Dr. Fujioka and his fellow researchers got to work monitoring levels of FRNA coliphage and bacteroides bacteria. The data that the researchers collected supported the decision that the City made to reopen the beaches based on their counts of *C. perfringens.* The UH researchers found no evidence that sand was contaminated with sewage.

The City and State agencies responsible for safeguarding the public health are not equipped to do the research necessary to answer these questions, and are really only able to perform routine monitoring of the water for two of the prescribed indicators. When a spill occurs they can rely only on this limited data to get an idea of whether or not it is safe to keep beaches open. Dr. Fujioka and his colleagues continue to work at getting answers to the questions surrounding the issue of recreational water quality in the state of Hawaii.

This semester the WRRC seminar series is focusing on the Ala Wai spill, and will feature speakers from the City and County of Honolulu, the state Health Department, local medical experts, and microbiologists. For the schedule of seminars please visit http://www.wrrc.hawaii.edu/seminars.html.

# Modeling Streamflows and Flood Delineation of the 2004 Flood Disaster, Manoa, Oahu, Hawaii[1]

*Aly I. El-Kadi[2], and Eric Yamashita[3]*

Abstract:

In October 2004, a flood caused extensive damage to the University of Hawaii (UH) campus and neighboring residential areas in Manoa Valley, Oahu, Hawaii. This modeling study was aimed at streamflow evaluation and flood delineation for the area impacted by the flood. The study concluded that the HEC-1 model of the U.S. Army Corps of Engineers is suitable for simulating storm runoff response for the study area, considering the nature of small Hawaii watersheds, which generate hydrographs with steep rising and falling limbs. The curve number method of the U.S. Soil Conservation Service is also suitable because it predicts reasonably well the main features of streamflow hydrographs, including runoff duration and time of peaks. To improve on accuracy, however, there is a need for better characterization of spatial rainfall distribution through measurements. A flood delineation model, which treats the flood as a hypothetical dam break, was used to predict the flood water pathway, flood zone extent, maximum flood depth, and the time to reach that depth. The model predicted an upper value for storm total flow volume that would not cause flooding on the UH campus. Although not fully validated, the developed models can guide data-collection and decision-making processes. For example, the models demonstrated that it is possible to mitigate the flood through streamflow diversion and stream dredging, realignment, and lining. For efficient management, we recommend defining a new subwatershed of the Ala Wai basin (to be called the West Manoa Watershed) that contains the university campus.

Hawaii's climate is characterized by high rainfall rates. However, due to the high permeability of the rocks and soils, most streams do not flow continuously throughout the year (U.S. Army Corps of Engineers 1998). On the other hand, the

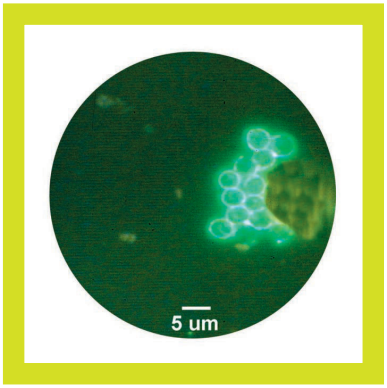
[2] Corresponding author, Department of Geology and Geophysics and Water Resources Research Center, University of Hawai'i at Mânoa.
[3] Office of the Vice Chancellor of Administration, Finance, and Operations, University of Hawai'i at Mânoa.

**continued on page 4**

# Water Center Researcher Awarded USDA Grant to Study Cryptosporidium in Tropical Environment

Dr. Chittaranjan Ray, WRRC and Civil Engineering at Manoa, has recently been awarded a grant to study the fate and transport of the human pathogen Cryptosporidium.

Cryptosporidia are pathogenic protozoa that are present in the digestive tracts of a wide range of vertebrates. Runoff water can carry Cryptosporidium oocysts (a tough dormant form) from manure to source waters (such as rivers and lakes). If this water is not properly treated before drinking, the pathogen can be ingested by humans and cause diarrhea and a variety of other gastrointestinal problems.




Cryptosporidium oocysts (small green spheres) labled with FITC-tagged antibody.

In 1993, a massive outbreak of gastrointestinal illness in Milwaukee, Wisconsin was attributed to poor performance of a drinking water treatment plant and large numbers of protozoa in runoff waters. More than 400,000 cases of stomach illness, and about 120 deaths (primarily among individuals with compromised immune systems) were recorded. Recent US Environmental Protection Agency regulations require surface water treatment plants to remove 99.99% of Cryptosporidium oocysts through sand filtration. This high degree of removal is often not achievable. Therefore watershed management practices to reduce the numbers of Cryptosporidia in runoff waters are needed to prevent their getting into the drinking water source water in the first place.

Although there have been several studies on the fate and transport of Cryptosporidium oocysts in temperate soils, this has not been addressed in tropical soils. The charge of most soils on the US mainland (temperate) does not change with solution pH. However, soil charge varies with pH in tropical soils. In this research, Dr. Ray will examine how soil pH, organic compounds in soil (such as compost, sludge, wastewater), and the salinity of soil pore water affect the attachment of Cryptosporidium oocysts to tropical soils. The study findings will clarify if Cryptosporidium oocysts are a major problem in tropical soils as they are in temperate ones.

**Modeling Streamflows** continued from page 3

steep slope nature of watersheds in Hawaii creates conditions of high peak flows with a sharp rise and recession, increasing the chance of flash floods occurring during storm events. More than 12 major floods have occurred in Manoa Valley, Oahu (see Figure 1), causing damage and fatalities in some cases (HDLNR 1995). On October 30, 2004, the area received about 25 cm of rain in a 10-hour period. According to the National Weather Service Forecast Office, Honolulu, Hawaii (NWS 2006), the unstable atmosphere allowed showers to rapidly develop into a thunderstorm and remain focused over a small area of southeast Oahu (see http://www.prh.noaa.gov/hnl/pages/events/ManoaFlood20041030/). The thunderstorm was locked in place due to the terrain. At the height of the heavy rainfall, around 7 pm, rainfall rates recorded by the gage at the Lyon Arboretum, in the upper portion of Manoa Valley, were over 12 cm/hr. Maximum rainfall accumulations at that site with the respective times were 3.3 cm (15 min), 9.4 cm (1 hr), 11.1 cm (2 hr), 14.5 cm (3 hr), and 22.1 cm (6 hr). These large rainfall rates are estimated to occur with a return rate of almost 50 years. In other words, in any given year, there is only a 2% probability of such a heavy rainfall event like this occurring in upper Manoa Valley.

The storm washed trees and debris into Manoa Stream, creating a dam under the Woodlawn bridge. Flood waters flowed onto the University of Hawaii (UH) campus (Figure 1), causing damage to buildings. Several Manoa Valley neighborhoods also sustained damage.

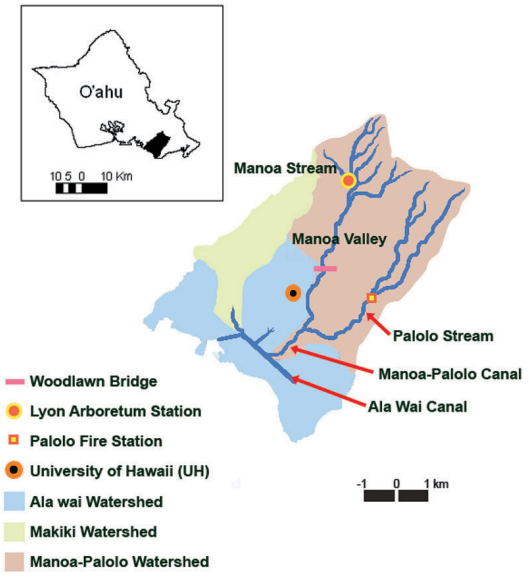



Figure 1, Manoa Valley showing sub-watersheds, points of interest.

**continued on page 5**

# Windmill Desalination Project Wrapping Up

Over the past several years, a WRRC research team led by Dr. Clark Liu has investigated the technical and economic feasibility of natural energy-driven water desalination in Hawaii. A testing facility including a 14-ft Dempster windmill was constructed in 1998 at the Hawaii Institute of Marine Biology (HIMB) facility on Coconut Island, and has been tested ever since. The project has been supported by grants from the UH College of Engineering, the USGS State Water Resources Research Institute Program, the Industrial Technology Research Institute (Taiwan), and the US Bureau of Reclamation. This system is operated entirely by renewable energy, using wind power to drive a reverse osmosis (RO) desalination process and solar photovoltaic (PV) energy to drive the instruments of a control module. The system has proven its capacity to desalinate brackish water and also its utility in removing nitrogenous wastes from aquaculture effluent. The windmill has turned out to be very robust and has required almost no maintenance since it's installation.

Jo-Ann Leong, Director of HIMB addresses the visitors at Coconut Island .

This testing facility will be dismantled in coming weeks. In preparation for the dismantling of the pilot facility WRRC recently invited a group of representatives from the State Health Department, the Commission on Water Resource Management, Department of Land and Natural Resources, the Honolulu Board of Water Supply, and the Kahoolawe Island Reserve Commission to tour the installation and hear a presentation about the feasibility of using natural energy-driven desalination in Hawaii and other small Pacific islands.

Providing fresh water for the restoration effort on Kahoolawe is one potential application of the windmill desalination system. In the long run, water desalination is a viable alternative for providing freshwater supply to meet the demand of an expanding economy in Hawaii. A pilot plant of natural-energy-driven water desalination is also being planned and will be built near Ewa Beach, Oahu, where a State of Hawaii demonstration desalting facility used to be located.

To read an earlier article describing the testing of the Coconut Island system please visit **http://www.wrrc.hawaii.edu/research/project_liu/desalination.html.**

**Modeling Streamflows** continued from page 4

Manoa Stream floods are due to (1) an inadequate capacity of the natural stream channel to accommodate flood flows, (2) a relatively level terrain in some stream reaches which slows down the flow of water, (3) restrictive bridge crossings, and (4) developments along the stream (Townscape, Inc. et al. 2003). Studies of floods in the area include that by the Hawaii Department of Land and Natural Resources (HDLNR 1995), which recommended increasing Manoa Stream's capacity to 300–325 m3/s to accommodate a 100-year storm. That study also recommended implementing a yearly stream maintenance program for embankment areas, especially at bridge openings. For flood control, the study suggested widening and deepening the upstream and downstream approaches to some bridges to increase the capacity of the flow, and establishing a linear park along some reaches to provide for flood plain management.

Although floods in the area are common, damage to the UH campus was not expected, considering that the campus area had not been identified as a flood hazard zone. Thus it is of extreme importance to study the conditions that can cause such a situation. There is also a need to delineate new flood zones, which are essential for land and flood management in the Manoa area.

Models are important tools for assessing hydrological conditions and for predicting system response to alterations based on management decisions. Flood delineation and mitigation should be based on appropriate data collection and on sound scientific principals. For example, stream dredging can be efficient if depths and configurations are estimated through modeling. Models can guide data collection by emphasizing factors of high impact on the watershed's response to rainstorm events. They are also beneficial in assessing suitability of decisions addressing various flood mitigation strategies.

The objective of this study was to develop models for streamflows and for flood delineations in the Manoa area. Suitability of the models for hydrological conditions at this site was examined. The study was also aimed at defining deficiencies in data and in providing recommendations for future actions that can eliminate or reduce flood damage.

This abstract is reprinted here with the permission of Pacific Science, the official journal of the Pacific Science Association in which the article will appear in the April 2007 edition.

# Vibrio/Sunlight Research at WRRC

One group of bacteria of particular interest from the standpoint of public health in Hawaii is Vibrio.

Vibrio are naturally-occurring bacteria in freshwater and saline aquatic environments, and many Vibrio species are to be found in the coastal waters of Hawaii. Usually they are not found in numbers sufficient to cause disease in swimmers but occasionally their numbers can increase due to environmental disruption with an associated increase in risk of infection.

Better knowledge of the behavior of pathogenic Vibrio in the environment can help us to understand the risk posed to recreational water users by this potentially fatal bacterium. One important parameter in bacterial survival is sunlight. UV radiation can destroy bacterial cells through DNA damage. However bacteria are often able to repair themselves after the sun goes down.

In the course of his investigations into the fate and transport of indicator microorganisms in the environment WRRC Researcher Roger Fujioka has found sunlight to be the most important environmental factor in the inactivation of most bacteria, and especially fecal indicator bacteria in seawater. He has also found that sunlight's inactivating efficacy is less in stream water. Fujioka believes that this is most likely due to chlorophyll and other plant degradation materials in stream water which compete to absorb sunlight. These materials are present in seawater at much lower concentrations.

Previous studies have shown that sunlight inactivates vibrio bacteria. However, while some studies indicate that sunlight permanently inactivates vibrio, others show that sunlight inactivated vibrio can revive when removed from the light. Yet other studies show that sunlight converts vibrio to a viable but non-culturable state.

Fig. 1, Experimental setup on the Manoa campus

There are many kinds of vibrio to be found in the marine waters around Hawaii. Dr. Fujioka is interested in determining the fate of these bacteria with special reference to sunlight exposure. Of additional interest is what happens to them during the night-time hours and what happens to them the next day. Since vibrio can be expected to grow in marine waters, their survival and fate in Hawaii's marine waters should differ from those of fecal indicator bacteria such as *E. coli* and enterococci which cannot.

Gayatri Vithanage at the WRRC Microbiology Lab recently conducted an experiment on the front lawn of Holmes Hall. This sunlight experiment was the first in a series of experiments to determine the survival of Vibrio bacteria exposed to sunlight in various types of aquatic environments. The purpose of this first experiment was to determine the survival of *V. vulnificus* in brackish water (1% salinity=~28% seawater) collected from Kaneohe Bay near Heeia Stream on Oahu's eastern shore. For comparison, the survival of *V. vulnificus* was also tested in a 1% salinity phosphate buffered solution (PBS).

Both the brackish water and the PBS were sterilized and seeded with an overnight culture of *V. vulnificus* at a concentration of $10^8$ cells/ml. One liter of each of the seeded waters was put into beakers and set on magnetic stirrers in the sunlight (fig. 1).

A set of "dark controls" were also set up for both the seeded brackish water and PBS. Beakers identical to the first two were covered with foil to prevent sun exposure, and placed alongside the other two beakers in the sunlight. In order to keep the water from getting too hot, all four beakers were immersed in ice water. Temperature was continuously monitored and kept between 25 and 30°C, which is typical of the surface temperature of Hawaii's ocean water during the summer. UV readings were also taken every 15 minutes. Samples were taken from each of the beakers after 0, 30, 60, 120, 180, 240, and 300 minutes exposure to sunlight and assayed by membrane filtration method using ChromAgar Vibrio media.

The survival of *V. vulnificus* in the dark controls was similar for the PBS and brackish water samples. In both cases there was little to no die-off for the duration of the experiment.

In the sun-exposed PBS beaker, there was a dramatic die-off of *V. vulnificus* between 120 and 180 minutes, after which time the bacteria were undetectable in the sample (fig. 2). In contrast, there was a more gradual die-off in the sun-exposed brackish water. Bacteria were still detected at the end of the experiment (fig.3). This result could be due to the presence of chlorophyll and other light-absorbing materials in the brackish water (Heeia stream source).

In future experiments the researchers plan to determine the survival of *V. vulnificus* in seawater and seawater mixed with various amounts of stream water. They also will be working to determine whether this bacteria is capable of inducing dark DNA repair (as many bacteria can) in response to sunlight damage. Finally they are planning to

**Vibrio** continued on page 7

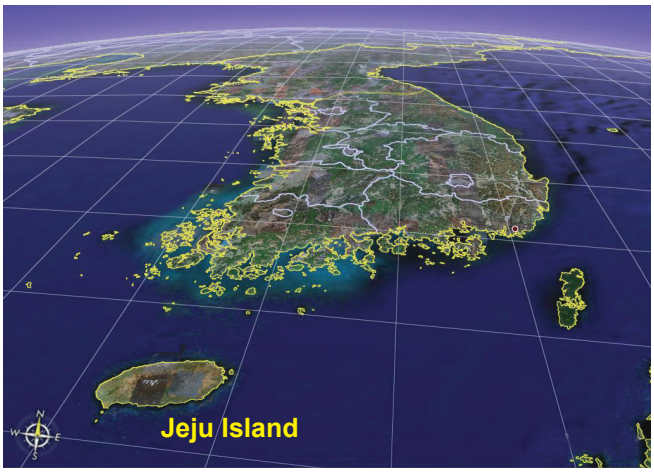
# Water Center Researcher Participates in Jeju Island, Korea Forum

Dr. Aly El-Kadi was invited to represent WRRC in the 2006 Jeju-Hawaii Water Forum, July 21-22, 2006. This was the second forum in a series that emphasizes the hydrological similarities between Oahu and Jeju islands and fosters exchange of information between researchers on both sides. The meeting was strongly supported by the local Jeju government.


The forum delegates

Dr. El-Kadi presented a talk titled "The History of Groundwater Management and Research in Hawaii." He was also interviewed by a local television station. The paper, which he co-authored with Dr. James Moncur, appeared in the forum's proceedings. Other presentations from the Hawaii delegate included: "Formation of the Hawaiian Islands: Influence on Hydrogeology and Groundwater Occurrence in Hawaii" (Kevin T. Johnson, Geology and Geophysics; UH); "State of Hawaii Commission on Water Resource Management" (Peter T. Young, DNLR); and "Island History of Water Management in Honolulu" (Chester Lao, Honolulu Board of Water Supply).

Presentations by the Korean delegate covered: "The Importance of Underground Geological Property on the Occurrence of Groundwater in Jeju Island, Korea"; "History of Water Resource Development on Jeju Island and Relevant Research Studies"; "Hydrogeology and Groundwater Management Systems on Jeju"; and "Fluctuation Factors and Changes of Groundwater Levels in Jeju Island".




Jeju Island is located some 70 miles south of the Korean mainland.

The meeting also included a panel discussion and visits to hydrological sites, including monitoring wells, a deep well drilling site, a water treatment facility, and water catchments. The forum recommended expanding the cooperation including the possibility of joint research and co-sponsoring study visits by Korean students and researchers to the University of Hawaii.

Korean organizations that participated in the forum included: Jeju Provisional Water Resources Management Office, Jeju Special Self-Governing Province, Jeju Development Institute, Korea Institute of Geoscience and Mineral Resources, Jejudo Small & Medium Business Center, Cheju National University, Korea Water Resources Corporation, and the Korea Rural Community & Agricultural Corporation.

**Vibrio** continued from page 6

perform all these experiments on other species of pathogenic Vibrios such as *V. parahaemolyticus*, *V. alginolyticus* and *V. cholerae;* other vibrio species and other non-vibrio marine bacteria found in Hawaii's coastal waters.

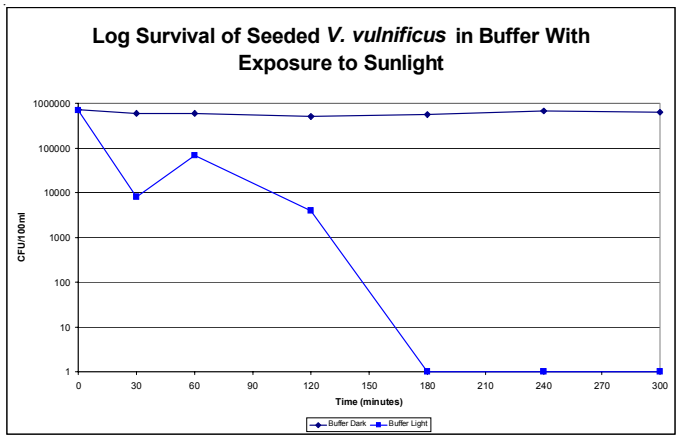



Fig. 2, PBS results

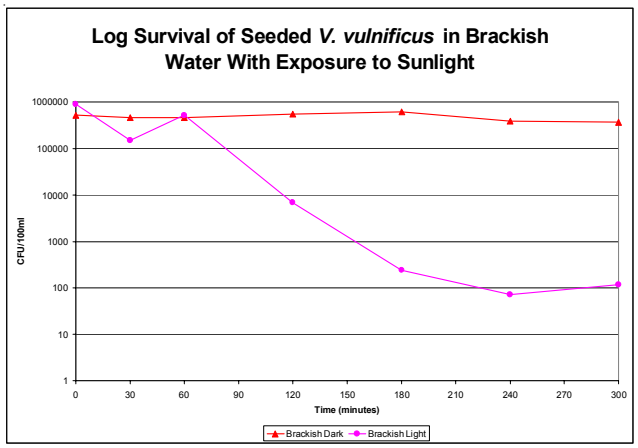



Fig. 3, Brackish water results

# WRRC's Technical Advisory Committee

WRRC benefits from the wisdom of a Technical Advisory Committee with members from water supply and wastewater agencies across our state. The TAC met with WRRC faculty and staff last May 31 at the UH-Manoa Campus Center to advise WRRC on setting priorities for future research directions.

The meeting followed a simplified version of the "nominal group technique." This process allows all members of a group to express and discuss their views, combine them into related categories, and then arrive at a consensus as to priority for research on each issue. The topics identified included (listed here in no particular order or priority):

- Integrated water resource management, hydrology, economics, culture, externalities
- Watershed planning and management, and measurable indicators of success
- Modeling sediment containment
- Natural hazard assessment; floods and droughts
- Updated rainfall recharge data and analysis
- Wastewater reuse over potable aquifers
- Forecasting the hydrologic cycle over a range of time and areal scales
- Risk assessment and management of water quality and quantity
- Water quality standards and regulation for Hawaii
- Asset replacement modeling
- Pipeline forensics

Our thanks go out to the TAC members who took a full morning away from the normal press of business to participate. In addition to WRRC faculty and principal investigators, committee members are:

| | | | |
|---|---|---|---|
| Milton Arakawa, | Maui Dept. of Public Works & Env. Mgmnt. | Laurence Lau, | State Department of Health |
| Clifford Lum, | Honolulu Board of Water Supply | Dean Nakano | Commission on Water Resource Mgmnt. |
| Milton Pavao | Hawaii County Department of Water Supply | Eric Takamura | Honolulu Department of Env. Services |
| George Tengan | Maui County Department of Water | Gordon Tribble | U.S. Geological Service |
| Wynne Ushigome | Kauai Department of Water | Lawrence Yamamoto | Natural Resources Conservation Service |

University of Hawaii at Manoa
Water Resources Research Center
2540 Dole St. Honolulu, HI 96822