Submarine Groundwater Discharge and Corresponding Nutrient Fluxes in Kaneohe Bay, Oahu

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Geochemical tracer studies suggest that globally, submarine groundwater discharge (SGD) is responsible for 3 to 4 times the water discharge delivered to the oceans by rivers. In the Pacific Ocean large islands contribute a disproportionately larger fraction of SGD compared to the continents. SGD is therefore important on tropical islands not just because of its volume, but because it is a pathway for land-sourced pollution that directly affects coastal water quality.

To demonstrate the significance of SGD as a terrestrial nutrient pathway we compare stream and submarine groundwater discharge rates in a watershed on the windward side of Oahu, one of the major islands of the Hawaiian Archipelago. SGD is measured using multiple techniques that include the application of radon and radium isotopes. Our analysis of Kaneohe Bay, which hosts the largest coral reefs on the island, reveals that SGD in the form of total groundwater discharge is 2 to 4 times larger than surface inputs. Corresponding DIN and silicate fluxes are dominated by SGD, while DIP is delivered mostly via streams.

This study confirms that Oahu fits in the global SGD trend and demonstrates the need to consider SGD in land-sourced coastal nutrient and pollution fluxes.

Keywords

Submarine groundwater discharge, Hawaii Islands, radon, radium, coastal water quality

Coupling Aerial Infrared Imaging from Aircraft and Drone with Radon Time Series for Mapping and Quantifying Groundwater and Nutrient Discharge from Coastal Aquifers

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Submarine groundwater discharge (SGD) is a principal conduit for huge volumes of fresh groundwater loss and is a key transport mechanism for nutrient and contaminant pollution to coastal zones worldwide. However, the volumes and spatially and temporally variable nature of SGD is poorly known and requires rapid and high-resolution data acquisition at the scales in which it is commonly observed.

Airborne thermal infrared (TIR) remote sensing, using high-altitude manned aircraft and low-altitude remote-controlled unmanned aerial vehicles (UAVs or "Drones") are uniquely qualified for this task, and applicable wherever 0.1°C temperature contrasts exist between discharging and receiving waters. This presentation will discuss the use of these technologies in combination with in situ radon model studies of SGD volume and nutrient flux from three of the largest Hawaiian Islands. High altitude manned TIR-aircraft results produce regional (~300 m wide × 100s km coastline) 0.5 to 3.2-m-resolution sea-surface temperature maps accurate to 0.7 °C that show point-source and diffuse flow in exquisite detail. TIR-UAV mapping offers advantages of much higher spatial and temporal resolution with instantaneous detection and mapping of dispersal that can be coordinated simultaneously with any ground-based quantification, including site-specific groundwater/pollutant flux.

This report demonstrates how aircraft and UAV TIR-mapped groundwater discharge may be correlated to in situ groundwater flux. We also illustrate how in situ nutrient data can be incorporated into infrared imagery to produce nutrient dispersal maps. Our results further illustrate the potential for volumetric quantification and up-scaling or down-scaling of small- and regional-scale SGD. These methodologies provide tremendous advantage for identifying and differentiating spring-fed, point-sourced, and/or diffuse groundwater discharge into oceans, estuaries, and streams. These integrative techniques are also important precursors for developing best-use and cost-effective strategies for otherwise time-consuming field studies, and represent a substantial new asset for land use and coastal zone research and management.

Keywords

Submarine groundwater discharge, coastal zone, nutrients, pollution, resource management

Dieldrin: An Unregulated Drinking Water Contaminant of Potential Concern in Guam's Groundwater

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Dieldrin was widely used for pest control in the US between 1950 and the late 1980s. It is currently listed as an unregulated contaminant under the Safe Drinking Water Act, and has been monitored in the Nation's drinking water resources since 1993. Data thus far collected generally indicate low dieldrin detections and concentrations in groundwater. This is especially true in major aquifers where detection frequencies are typically <1% and maximum levels are rarely >0.03 μg/L. Karst limestone aquifer systems may be the notable exception here, especially in tropical monsoonal regions where overlying soils are normally shallow and organic matter depleted. For example, in Guam dieldrin has been detected in ~80% of the island's drinking water production wells with levels >0.03 μg/L in the majority examined by the Guam Waterworks Authority (GWA) since 1996.

The dieldrin data from this 20-year old survey were examined and weighed against established health advisories and benchmarks. Spatial differences and temporal trends in well profiles were also scrutinized. Dieldrin concentrations throughout the aquifer ranged from <0.005 to 1.70 μg/L and were log normally distributed. Individual well profiles varied appreciably, although similarities often existed between sister wells. Both long- and short-term temporal trends were evident suggesting rapid turnover rates of dieldrin under certain conditions. Exceedances of the USGS Cancer Health-Based Screening Level of 0.20 μg/L (10^{-4} excess cancer risk) were noted at least once in 11 of 123 GWA wells examined.

This study highlights the vulnerability of Guam's aquifer to dieldrin and other persistent pollutants with predictably low soil mobilities. Well profiles for dieldrin also imply that diverse and complex hydrological pathways facilitate contaminant transport through the highly fractured vadose zone. In the absence of an enforceable drinking water standard for dieldrin, some Guam residents continue to be exposed to relatively high levels of this contaminant in their drinking water.

Keywords

Dieldrin, Guam, karst-limestone aquifers, health advisories, well profiles

Use of an Automated Device Based on Zero Angle Photon-Spectroscopy (ZAPS) for Real-Time Monitoring of Biological and Chemical Pollutants of the Ala Wai Marina, Honolulu, Hawaii

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Concerns regarding water quality exist in most urbanized settings. Honolulu, Hawaii is no exception, and the Ala Wai Canal and marina represent a water body that often appears on the EPA list of water quality limited segments. Heavy metal, nutrient, and bacterial contamination have been well documented through studies carried out over the past few decades. More recent efforts have also used multiparameter sondes to measure properties of these waters in real time but, prior to this study there has been no successful effort to monitor, in real time, the chemical, physical, and biological water quality of the Ala Wai Canal or marina.

We describe the applicability of the LiquID (LID) station developed by ZAPS Technologies to environmental monitoring. The utility of the LID, which uses zero angle photon spectroscopy, has been demonstrated in wastewater applications for a number of years. However, our study represents the first deployment of the LID in a heavily used public water body in tropical waters, for environmental monitoring. Because the water properties of the Ala Wai Marina, an urban estuary, are naturally dynamic, the LID is an ideal tool to detect changes and permit immediate response by users. The LID station deployed at the Hawaii Yacht Club samples surface water of the marina immediately downstream from the Ala Moana Bridge and has recorded rapid changes in parameters that are potentially important to human health in response to a variety of weather events.

Changes in the concentration of fluorescent dissolved organic matter (FDOM), suspended sediments, nutrients (N+N), refined hydrocarbons, and *E. coli* observed during diurnal and tidal cycles, as well as in response to heavy rain induced runoff and spills, will be presented and interpreted in the context of other parameters measured at the same location with more traditional multiparameter sondes.

Keywords

Water quality, bacteria, real time monitoring

High-Volume Ultrafiltration: Going Beyond Indicator Bacteria

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Globally, microbial water quality is still evaluated by analyzing samples, typically not exceeding 100 ml, for indicator bacteria such as *E. coli* and enterococci. This is a concern as (1) distribution of microbes is patchy; hence, typical water samples do not provide adequate representation of microbial water quality, and (2) these indicator bacteria can grow in the environment outside the host and may have limited relevance to human health. Therefore, collecting larger sample volumes to analyze for indicator bacteria, as well as more sewage specific microbial markers with reliable links to human health, must be considered.

The UHM WRRC laboratory recently acquired a novel dead-end hollow fiber based ultrafiltration device, which can collect water samples exceeding 100 L volume and recover all bacteria and viruses in a final concentrate. This device was developed, extensively tested, and validated by Dr. Daniel Lim and his team at the University of South Florida (USF). WRRC and the Hawaii Department of Health staff were trained to use this instrument by the USF team in two workshops. Currently, in partnership with the Hawaii Department of Health, this device is being used in several water quality studies in Hawaii. As the sampling process is automated, high consistency between the samples is achieved.

Our preliminary data indicates that this device is extremely well suited for the detection and quantification of a wide array of microbial targets, which cannot be detected in 100 ml samples. More specifically, by using this large volume sampling device, bacteria and viruses that are more specific to sewage than indicator bacteria can be measured. The resulting data are more reliable for determining when recreational water sites are contaminated with sewage and when these sites are cleared of sewage contamination. We expect this device to have a high impact on the State's recreational and groundwater quality monitoring programs.

Keywords

Microbial water quality, ultrafiltration, indicator bacteria, human pathogens

Evaluating Hydrologic Ecosystem Services Models for Use in Hawaii

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Water is critical for supporting life, and fundamental for provisioning, regulating, cultural and supporting ecosystem services that support human wellbeing. However, freshwater resources are projected to become scarcer in Hawaii due to a growing population, a changing climate, and altered land use and land cover. In order to support management of hydrologic ecosystem services, our project focused on identifying Hawaii-compatible hydrological models to estimate water yield, a process which underpins multiple hydrologic ecosystem services, including water filtration, groundwater recharge, flood control, habitat, and cultural values.

Due to Hawaii's unique hydrogeological conditions, including steep topography and rainfall gradients, most "off the shelf" hydrological models poorly represent eco-hydrologic processes, and thus fail to accurately quantify services. We identified a suite of models (potentially) applicable to Hawaii that quantify water yield either directly or via post-processing, developed and used a set of criteria to select candidate models, and evaluated candidate model performance in selected leeward and windward watersheds under climate and land use change impacts. Here, we assessed existing hydrological (both surface and groundwater) model capabilities using specific Hawaii ecosystem services dependent criteria (i.e., one that is based on biotic, abiotic as well as technical aspects).

This study identified Hawaii-compatible models that can simulate land-use and climate change impacts to inform management of hydrologic ecosystem services. Hydrologic ecosystem service modeling can enable managers to explore the impacts and trade-offs inherent to managing small yet diverse watersheds in Hawaii.

Keywords
Criteria, Hawaii, hydrologic ecosystem service, modeling

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Quantifying Effects of Humans and Climate on Groundwater Resources Through Modeling of Volcanic-Rock Aquifers of Hawaii

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The volcanic-rock aquifers of Kauai, Oahu, and Maui are heavily developed, leading to concerns related to the effects of groundwater withdrawals on saltwater intrusion and streamflow. A numerical modeling analysis using the most recently available data (e.g., information on recharge, withdrawals, hydrogeologic framework, and conceptual models of groundwater flow) will substantially advance current understanding of groundwater flow and provide insight into the effects of human activity and climate change on Hawaii's water resources.

Three island-wide groundwater-flow models were constructed using MODFLOW 2005 coupled with the Seawater-Intrusion Package (SWI2), which simulates the transition between saltwater and freshwater in the aquifer as a sharp interface. This approach allowed relatively fast model run times without ignoring the freshwater-saltwater system at the regional scale. Model construction ($FloPy_3$), automated-parameter estimation (PEST), and analysis of results were streamlined using Python scripts. Model simulations included pre-development (1870) and current (average of 2001–2010) scenarios for each island. Additionally, scenarios for future withdrawals and climate change were simulated for Oahu.

We present our streamlined approach and preliminary results showing the estimated effects of human activity on the groundwater resource by quantifying the decline in water levels, reduction in stream base flow, and the rise of the freshwater-saltwater interface.

Keywords
Groundwater, modeling, open-source scripting, climate change

Using a Geographic Information System to Predict Flow Duration Curves at Ungaged Stream Sites in Guam

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In order to properly manage a region's water resources, it is important for water managers to know the long-term time variability of flow in the streams of that region. Studies such as those for water supply, hydropower, and those involving sediment transport depend on this kind of long-term flow variability data in order to develop the best management practices for a region's water resources. The flow duration curve provides a means of representing the long-term flow variability at a study site in a concise graphical fashion. The problem in Guam, as in most locations, is that the stream-flow information required to directly compute flow duration curves is not available for all possible sites where information is required. The main objective of this project was to develop a mean of predicting flow duration curves at ungaged sites in South Guam using geographic information system analysis techniques

The first step in the project was to develop a set of parametric flow duration curves based on average flow and known flow duration values at gaged sites. These curves were used to predict duration curves at ungaged sites. Next, various geographic information system analysis techniques were applied to the parametric flow duration curves along with digitized maps of normal annual precipitation and a digital elevation model of South Guam in order to predict average flows and flow duration values for the streams. In addition, maps resulting from this study show drainage area and average annual precipitation upstream and average annual flow for all of the streams in South Guam.

This study has filled an important gap in defining stream-flow variability at ungaged sites along South Guam streams. The techniques developed in this study can be applied to other steams in the region where flow variability is required.

Keywords
Streamflow, flow variability, flow duration curves, geographic information system

Water Resource Challenges and the Updated Conceptual Hydrological Model of Tutuila Island, American Samoa

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Groundwater is the primary source of drinking water on the island of Tutuila in American Samoa. However, the sustainability of this resource is currently in question. The island's most productive aquifers are highly permeable making them vulnerable to direct contamination from surface waters and anthropogenic pollutants. Furthermore, a number of very productive wells have shown elevated turbidity and bacterial counts, indicating that these wells are under the influence of surface water. This rise in bacterial counts has subjected much of the island's municipal water to a "boil water notice" since 2009. Results of the EPA mandated studies show surface water is reaching wells during heavy rain events; however, the mechanisms of this rapid recharge remain unknown. In addition to acute contamination during rain events, Tutuila's groundwater has chronically shown elevated levels of nitrogen in aquifers underlying populated areas.

This study's objective is to address these problems using a quantitative analysis that combines stable isotope and nutrient geochemistry with numerical groundwater modeling to determine the degree of influence that primary polluting activities have on the island's groundwater quality. This study also presents recent updates to the conceptual hydrological model of the island, which is foundational to the numerical modeling presented here.

To better constrain recharge timescales in surface-water influenced wells, time-series δD and $\delta^{18}O$ measurements of precipitation and groundwater were analyzed over multiple seasons. To quantify the degree and primary sources of chronic anthropogenic impact, historical water quality data, nutrient levels and $\delta^{15}N$ of nitrate and $\delta^{13}C$ of dissolved inorganic carbon from wells and springs were compared to land-use data within the context of the updated conceptual hydrological model. Our results suggest that wastewater sources of nitrate have a greater impact than agriculture or livestock operations, a finding that has strong implications for water resource management.

Keywords
Groundwater, water quality, isotopes, modeling, water resources management

Water Resource Sustainability Issues—Puerto Rico and U.S. Virgin Islands

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Puerto Rico and the U.S. Virgin Islands face challenges to water resource sustainability both common to and distinct from other tropical islands. Comparing and contrasting these challenges in the American Caribbean with those elsewhere can provide perspective for sustainable water resources management. The objectives of this presentation are to describe the threats to water resources sustainability in Puerto Rico and the U.S. Virgin Islands, and the role of the USGS Caribbean-Florida Water Science Center in providing the scientific data and analysis in support of optimal decision-making.

Water resource sustainability is subject to both anthropogenic and natural threats, exacerbated by socioeconomic problems. Productive aquifers are available only in relatively small areas of these islands. Over-exploitation of these aquifers in this very densely populated part of the world has led to long-term loss of subsurface storage and groundwater-quality degradation. The quantity of surface water resources is often a case of feast or famine—intense storm events leading to life- and property-threatening floods alternate with droughts that have led to recurring water shortages amplified by long-term loss of reservoir storage. An aging distribution infrastructure contributes to large losses of water. Scarce water resources in the U.S. Virgin Islands have led to the prevalence of expensive and storm-vulnerable desalinization for water supply. Climate change, accompanied by sea level rise and a drier climate punctuated with more intense storms, is projected to bring further challenges to the existing precarious situation in the islands.

The USGS Caribbean-Florida Water Science Center provides objective, non-regulatory science in support of sustainable water resource management. Hydrologic conditions including streamflow, rainfall, groundwater levels, reservoir storage, and water quality are monitored; all data are subject to national standards of collection, review and archival. Interpretive studies are provided in the disciplines of groundwater, surface water, water use, evapotranspiration, and water quality.

Keywords
Puerto Rico, Virgin Islands, USGS, sustainability, water resources

Developing a Unified Soil-Water-Balance Model for Tropical and Continental Settings

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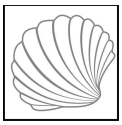

Soil-water-balance models commonly are used to estimate potential groundwater recharge and other components of the hydrologic budget. However, a unified soil-water-balance model that represents relevant hydrologic processes for both continental and tropical settings is not readily available. The U.S. Geological Survey Groundwater Resources Program currently is funding the development of a new soil-water-balance model, SWB2, that incorporates aspects of existing models and that will be broadly applicable to both continental and tropical settings.

Hydrologic processes that are important in tropical settings (and some continental settings) and that will be represented in SWB2 include the capabilities to (1) account for fog interception; (2) vary potential evapotranspiration by land-cover type; (3) estimate canopy interception from tropical forests; (4) include water inputs from septic systems, leaking water mains, cesspools, and reservoirs; and (5) estimate irrigation and evapotranspiration for tropical crops, including sugarcane and pineapple. SWB2 uses gridded input and output in NetCDF format, which is useful for working with climate and land-cover datasets and groundwater-model grids. However, using gridded input and output can be less precise than using a polygon format, and potential recharge results can be sensitive to model-grid resolution. Initial SWB2 testing results for the island of Maui, Hawaii, during 1978 to 2007, indicate potential recharge estimates from SWB2, using a model-grid resolution of 15 meters, differ from the published estimates generated using a polygon format by less than 1% both islandwide and for most land-cover types.

SWB2 can be an effective tool for estimating potential recharge on tropical islands and is user-friendly. This effort will be documented and published in a U.S. Geological Survey report, and the SWB2 code will be made available through the internet.

Keywords
Groundwater, recharge, tropical islands, modeling, soil-water balance

USGS Water Availability and Use Science Program

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A key part of achieving the U.S. Department of the Interior's (DOI) sustainability goals is informing the public and decision makers about the status and changes over time of the Nation's freshwater resources. To achieve these goals, the USGS has implemented a National Water Census (NWC) to provide a more accurate picture of the quantity of the Nation's water resources and improve forecasting of water availability for future economic, energy production, and environmental uses. In fiscal year 2016, to streamline water sustainability activities, the USGS realigned all water availability and use oriented research, including the NWC, within a new Program—the Water Availability and Use Science Program (WAUSP).

WAUSP supports producing a current, comprehensive scientific assessment of the factors that influence water availability by developing nationally consistent datasets reflecting the status and trends of major water budget components (precipitation, streamflow, groundwater, and evapotranspiration), as well as human water use for the Nation; improving the current understanding of flow requirements for ecological purposes; and evaluating water-resource conditions in selected river basins, or Focus Area Studies, where competition for water is a local concern.

In addition to efforts at the national level, the WAUSP also supports water sustainability activities that are locally relevant in tropical basins. Currently, the WAUSP is evaluating groundwater resources as part of the National Brackish Groundwater Assessment and the Hawaiian Volcanic-Rock aquifers study. In the future, WAUSP will expand methods to refine water budget components developed in the conterminous U.S. (ungaged streamflow, evapotranspiration, water use) to both the U.S. Pacific and Caribbean Islands. Additionally, the WAUSP collaborates with DOI Climate Science Centers, and others, to evaluate drought impacts regionally. Finally, the WAUSP coordinates the new Water Use Data and Research program, which provides assistance to State Water Resource Agencies to improve water use data collection and estimation activities.

Keywords
Streamflow, evapotranspiration, groundwater, water use, drought

Southern Guam Watershed Model: Current and Potential Applications

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The southern Guam watershed model provides a physically based tool to estimate runoff and determine the effects of climate change on southern Guam surface-water availability. The southern Guam watershed model was constructed by updating the 2005 rainfall-runoff model for the Fena Valley Reservoir (FVR), and expanding the modeled area to include all of southern Guam. The updated version of the U.S. Geological Survey's Precipitation Runoff Modeling System, PRMS-IV, was used to construct the updated watershed model. PRMS-IV simulates different parts of the hydrological cycle based on a set of user-defined modules. Model development requires the delineation of watersheds and hydrologic response units and the selection of appropriate PRMS-IV modules suitable for simulating the southern Guam environment.

One location the southern Guam PRMS-IV model is being applied to is the FVR, which is the largest surface-water reservoir on Guam and an important water source for the U.S Navy and citizens of Guam. The U.S. Geological Survey currently uses a calibrated PRMS and water-balance model of the FVR to provide 6-month forecasts of FVR water availability to the Guam Navy Public Works. An updated PRMS-IV model and PRMS-IV estimates of future runoff are needed so they can be used in conjunction with the updated FVR capacity curves and the existing FVR water-balance model to evaluate how changes in streamflow and sedimentation will affect reservoir water levels.

The southern Guam PRMS-IV model will be used to evaluate changes in runoff and recharge due to climate change once data from the International Pacific Research Center is available. Other potential uses of the Southern Guam PRMS-IV model include evaluating changes in runoff and recharge under different land-cover change scenarios or coupling the model to a sediment or solute-transport model to estimate the amount of sediment or solutes transported to the nearshore reef environment.

Keywords
Watershed, modeling, management, climate change

Historical Episodes of Water Sustainability in Hawai‘i

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Chinese scholar Yu Xin (513–581 A.D.) once wrote, “when drinking water, trace to its source.” Where and what is the source of the water you drink today? What is the state of the law and what is the level of science. Water sustainability has been a major public health concern throughout Hawai‘i’s history.

In the islands, all resources within the confines of each island must meet the water demands. The fundamental constraint encouraged the application of relatively sophisticated scientific and engineering principles to water investigation in Hawai‘i long before this approach had become common in most other regions of the world. Many hydrogeologic processes in tropic islands are profoundly different from those of continents and other climatic zones. Hawai‘i’s humid tropical climate, the surrounding ocean, its volcanic earth, and high mountains govern hydrogeologic phenomena and analysis. The management of water, land, and environments face great uncertainties and often may be at risk of potential failure without full understanding of the nature of water.

This paper divides Hawai‘i’s water sustainability into four major periods: (1) by royal decree (Ahupua‘a as both a legal regime and hydrogeologic system), (2) without any governance (unrestricted production and use of Artesian Wells), (3) by market forces (water ownership, negotiation, and litigation; groundwater resources and water treated as a commodity), and (4) by government regulation (the executive branch administration under the Statewide Water Commission, with legislation setting appropriate use and preservation; groundwater and surface water as state property held in public trust).

In Hawai‘i, it is a constant challenge to have sustainable water resources within the confines of each island. Despite the largess of water resources in the major Hawaiian Islands, these resources need to be managed wisely, taking into account many unique hydrogeologic systems, and the changing forms of governance in Hawai’i.

Sustainable Water Supply Expansion Using Satellite Reclamation of Wastewater in Honolulu

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A study was conducted to examine possible applications of membrane bioreactors (MBRs) for decentralized production of recycled water on the Island of Oahu. The objectives of this study were to identify potential reuse and treatment facility sites and to develop costs to build and operate these facilities. Eight sites were preliminarily identified from the top 100 water users list as potential locations for MBR water recycling facilities (WRF):

- Central Oahu Regional Park
- Public Bath Wastewater Pump Station and Ala Wai Golf Course (AWGC)
- Sand Island Wastewater Treatment Plant
- Moana Park Wastewater Pump Station
- Kailua Beach Park
- Kamehameha Highway Wastewater Pump Station
- Fort DeRussy Wastewater Pump Station
- University of Hawaii at Manoa (UHM)

Cost estimates were developed for 0.1, 0.25, 0.5, and 1.0 million gallons per day (MGD) installations to help bracket anticipated flow rates. These estimates include capital and operational costs for the MBR process and UV disinfection. For the decentralized systems, the facilities are strategically located near the wastewater source, and the sludge is returned to the sewer. Therefore, cost for conveyance piping and sludge disposal are not included. For two of the facilities, UHM and AWGC, additional preliminary design work has been completed as UH student design projects. The results of these studies and design work will be presented as well as information on progress with respect to getting these projects off the ground. One of these projects is currently in final design and additional projects will move forward pending funding.

Keywords
Water reuse, satellite reclamation, membrane bioreactor

Toward an Understanding of Residential Water Conservation Behaviors on Oahu

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A better understanding of water conservation behaviors can provide decision makers and policy-makers valuable information about water demand management strategies. In this study we investigate the extent to which household characteristics and attitudes are associated with water conserving actions among a cross section of residential households on Oahu. Using a household survey that we merge with billing data from the Honolulu Board of Water Supply, we consider how socio-economic, attitudinal, behavioral, and climate factors are associated with water consumption patterns. We address several research questions: (1) Do more informed and water-conscientious households actually use less water? (2) Are households in more arid environments more concerned about conserving water than households in wetter climates? (3) Do households that have taken water-conserving actions, like installing low-flow toilets, actually use less water? If so, how much?

An online survey was administered to 400 residential households across Oahu. The survey asked households about water use practices both inside the home and outside the home, and differentiated these practices by housing type (single-family vs. multi-family units) and tenure type (ownership vs. rental). The survey asked questions about efforts to conserve water (e.g., installing low-flow toilets and drought tolerant landscaping), awareness of conservation programs and policies, and attitudes about more sustainable consumption practices that could be undertaken to encourage households to reduce water consumption. Monthly water consumption patterns will be estimated from historical billing data obtained from the Honolulu Board of Water Supply.

Ultimately the project goal is to link water consumption patterns with socio-economic information of each household, housing characteristics, water use behaviors, environmental attitudes and attitudes to conserving water. This will allow us to evaluate determinants of water use and conservation behaviors across households that vary across socio-economic, household, and building characteristics.

Keywords
Residential water use, conservation, demand management, Oahu

Tradeoffs of Water Use and Carbon Sequestration in Incentivized Reforestation in the Seasonally Dry Tropics

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Ecosystem service policies that incentivize reforestation for carbon sequestration may be at odds with the conservation of water supplies in seasonally dry regions and impact human welfare. This presentation assesses the water to carbon tradeoff in reforestation strategies sponsored by the Payments for Ecosystem Services scheme in the Nicoya Peninsula in seasonally dry Costa Rica. This scheme currently incentivizes landowners of lands covered by natural secondary forest and teak plantations managed for timber.

Comparisons were made of stand level water use, carbon fixation, and water use efficiency in adjacent secondary forests and teak plantations across six paired sites by estimating individual tree water use via sap flux and scaling to the stand level. Neither water use or carbon fixation was significantly different between paired secondary forests and teak plantations. However, water use efficiency was significantly higher in teak plantations (mean = 1.7 kg C / Mg H_2O, SE = 0.34) compared to secondary forests (mean = 0.50 kg C / Mg H_2O, SE = 0.062). Contrary to expectation, water use efficiency of secondary forests was positively related to a gradient of increasing elevation associated to higher rainfall, and no relationship was found in teak plantations.

These results show that, at an annual time scale, secondary forests are not any better than managed teak plantations at conserving water in seasonally dry tropical Costa Rica, with teak plantations fixing significantly more carbon into biomass per volume of water used than native secondary forests. This can be applicable to similar regions, including islands, where water resources are scarce and there is interest in engaging similar policies that promote reforestation for multiple purposes such as carbon sequestration and economic development. In the case of teak, carbon sequestration and timber production are not at odds with water conservation compared to other tree species, as was suggested by previous greenhouse studies.

Keywords

Ecosystem services, timber plantations, tree transpiration, tropical secondary forests, water scarcity

Damaging Typhoons and Major Drought: The Ongoing and Forecast Effects of the 2015 El Niño in the Tropical Pacific

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During the first half of 2015, substantial warming of the equatorial Pacific sea surface and sub-surface waters clearly and unambiguously signaled the arrival of El Niño. The 2015 El Niño is now considered to be strong, rivaling the epic events of 1982 to 1983 and 1997 to 1998. Wild weather patterns typical of El Niño onset were observed across the tropical Pacific. These include noteworthy extremes of rainfall and an abundance of tropical cyclones. All of the tropical North Pacific is now at high risk of a major drought.

The author's of this report are members of the Pacific ENSO Applications Climate Center (PEAC Center). Headquatered at the University of Hawaii, the PEAC provides long-lead time (up to one year) forecasts of typhoon distribution, rainfall, and sea level for the U.S.-affiliated Pacfic Islands (U.S.-API). Activities include outreach, research and forecasts of Pacific climate vis-à-vis El Niño and other seasonal and inter-annual modes of Pacific climate variability. Early in 2015, the PEAC provided accurate advance warning of three El Niño-related Pacific climate anomalies: a high risk of damaging typhoons, the occurrences of extreme heavy rain events, and a lowering of the mean sea level. One more threat of El Niño is yet to come: severe prolonged widespread drought across all the U.S.-API.

The authors are now active in helping PEAC to craft and provide advance warnings of impending severe Pacific-wide drought. The Guam team, with support from NOAA and the USGS, have been working to establish criteria for the severity of tropical island drought. Two recent milestones include the inclusion of the U.S.-API in the U.S. Drought Monitor, and the upgrade of the PEAC outlooks to the status of an official operational forecast product of NOAA. This presentation highlights the nature of the 2015 El Niño and discusses the latest outlook for anticipated hazards.

Keywords
El Niño, drought, typhoon, climate forecasts

Hydrological Modeling and Climate Change Impact Assessment for Heeia (Hawaii) Watershed

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Hydrological models can be used for assessing the impact of climate change, but their applicability needs to be evaluated before they are used for scenario analysis. This study evaluates the applicability of the SWAT model for hydrological modeling of Heeia watershed and assesses the impact of climate change on water budget.

We developed and calibrated the SWAT based on the available geo-spatial and hydro-meteorological data within Heeia and neighboring watersheds. The simulated and observed streamflow showed an agreement with a satisfactory model performance, indicating the applicability of the model with a modification to reflect typical watershed characteristics. Overall, SWAT is suitable for modeling the Heeia Watershed. However, the model did not show sensitivity to the surface runoff lag parameter, which is commonly identified as a sensitive parameter; while curve number, channel hydraulic conductivity and baseflow alpha parameters are the most sensitive. Furthermore, the calibrated curve number values with the streamflow data are relatively low compared to reported values. The calibrated model was used to assess the impact of rainfall and temperature changes on the water balance of the watershed. Findings revealed that the decrease in rainfall during wet season and marginal increase in dry season will generally cause a decrease in water balance components. More importantly, the groundwater flow component will be adversely affected by the combined change in rainfall and temperature in comparison to the other components. For example, the expected change of monthly streamflow ranges from -15% to 6% while a maximum decrease of -19% in groundwater recharge is predicted compared to the baseline.

Our results suggest that climate change will negatively impact streamflow and groundwater reservoirs, affecting the groundwater sustainability and the riparian ecological functioning of the watershed in the future. The developed SWAT model, together with the applied climate change scenarios, can provide useful information for evaluating the future freshwater availability and designing mitigation measures.

Keywords
Streamflow, SWAT modeling and calibration, water budget, climate change, Heeia

Sea Level Rise Induced Groundwater Inundation and Soil Accommodation Space Narrowing in Honolulu, Hawaii

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The National Research Council has projected a rise in global mean sea level of 0.18 to 0.48 m by mid-century and 0.5 to 1.4 m by 2100. A rise of this magnitude will produce both direct marine and groundwater inundation into low-lying areas. Sitting less than 2 m above mean sea level, the economically valuable coastal zone of Honolulu, Hawaii, faces elevated risk of such flooding.

We use a 3-dimensional hydrologic flow model (MODFLOW) populated with over 150 groundwater level observations to simulate sea level rise induced soil accommodation space narrowing and groundwater inundation in Honolulu. Our model simulations reveal regions at elevated flood risk induced by 33 cm, 66 cm, and 1 m increments of sea level rise. One quarter of the study area presently has a narrow soil accommodation space of <1 m; sea level rise of 1 m triples this areal extent and produces flooding over 20% of a 1 km wide coastal zone.

A rise in sea level of 1 m will produce both continuous and episodic flooding within coastal Honolulu, prompting repercussions throughout the entire state of Hawaii owing to the economic contribution of this area. Expected impacts include increased flooding, drainage problems, salinization of buried infrastructure, and storm damage during periods when rainfall and high tide are coeval.

Keywords

Coastal groundwater, modeling, inundation, sea level rise

Impact Assessment of a Freshwater Lens on Atoll Islands Using Numerical Modeling

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Fresh groundwater is a scarce resource on atoll islands and faces short-term threats from increasing demand, extreme weather conditions, pollution, as well as long-term climate change and sea level rise. On the atoll of Tarawa in the Republic of Kiribati, salinization of the Bonriki Island freshwater lens, driven by increased pumping to meet the rising demand caused by population growth, is a key concern.

In this study, published literature and analysis of historical records of salinity and water level measurements were used to develop a conceptual model of the Bonriki freshwater lens. A numerical groundwater model of the variable-density groundwater flow system was built using SEAWAT. This model was used to assess the impacts from groundwater abstraction, climate variability, inundation from storm surge overtopping events and sea level rise.

The model results highlight the strong control of rainfall variability on the temporal dynamics of the freshwater lens. The numerical model scenarios further showed that abstraction is one of the most significant parameters influencing the modelled salinity. The longevity of the adverse effects of inundation is strongly dependent on the recharge conditions after the flooding event.

Keywords
Atoll hydrogeology, modeling, freshwater lens, climate variability, groundwater abstraction

Sediment Export with Changing Land Use in Leeward Hawaiian Watersheds

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Land-based sediments are a key threat to shallow coral reef ecosystems in Hawaii, yet notably hard to predict with modeling. Estimating sediment export is a critical step to being able to connect future land use changes with changes in sediment released to the coastal zone. However, empirically- and process-based hydrological models have proven difficult to adapt to Hawaii, adding significant uncertainty to using available decision support tools.

We compared two models for their ability to predict sediment export: Soil Water Assessment Tool (SWAT) and the InVEST Sediment Delivery model. We compiled data including precipitation, flow discharge, and suspended sediment concentration for four leeward watersheds in the Hawaiian Islands. These were combined with the most recently available GIS data on soils, rainfall, land use, and 10-m elevation. Results show that annual sediment export is typically underpredicted by an order of magnitude in the models. Moreover, soil loss predictions are spatially incongruent with field observations. Model results overestimate soil loss in the steep forested zones, where field observations show source material to be limited, and are not able to adequately capture human- and animal-disturbed material that connects hydrologically with the stream network.

We suggest that the differences stem from a mismatch of processes that source sediments, including stream channel erosion and storage and shallow landslides, which are not included in all the models that are typically used for decision support. Moreover, different modeling platforms use different transport equations, which have not been validated for steep, mountainous watersheds. Changes in land use, such as new developments or cover crops, are obscured by models that consider steeply-sloped areas to be the primary source of sediment. The comparison suggests that decision support tools for Hawaii need a different approach for predicting sediment export with changing land use.

Keywords
Watershed modeling, water quality, sediments, InVEST, SWAT

Potential Use of Halophytes in Conservation Buffers Near Coastal Areas

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The United States Coral Reef Task Force identified the need to increase protection of coral reefs from land and marine pollution. Poorly managed land-use practices cause excessive discharge of sediments, nutrients and contaminants into the coastal environment through runoff or riverine discharge. Conservation buffers are strips of permanent vegetation, designed to slow water movement and trap nutrients, sediments, and other contaminants generated from upland agricultural activities. Effectiveness of these buffers depends on appropriate selection of plant species, site characteristics, plant adaptability and plant attributes. This project evaluated the potential use of salt tolerant species to be used as conservation buffers in coastal zones

Three species of halophytes: *Sesuvium portulacastrum, Batis marítima and Paspalum vaginatum* were tested in table plots (4′ × 8′) and field plots (10′ × 20′) located in the DNER Boquerón Wildlife Refuge in southwestern Puerto Rico. The control plots consisted of bare soil. Variables evaluated in the field plots included halophytes naturally growing on-site and commercially propagated plants. Rainfall simulators installed in tables and field plots and experiments simulated rainfall events with intensities ranging from 2.71 in/h to 5.49 in/h. Grain size distribution, soil moisture, runoff, sediment concentration, and the amount of soil erosion were measured.

Most of the experiments showed a linear relationship between soil erosion and time; however, erosion rates varied according to the individual species sediment trap efficiency. Results from table plots showed a reduction in soil erosion higher than 94% for all species. *Paspalum vaginatum* resulted in the higher soil loss reduction. Field experiments showed soil loss reductions between 88% and 98% with halophytes vegetative cover between 67% and 95%. Experimental observations suggest that the evaluated halophytes species could be effectively used as vegetative buffers for erosion control and sustainability of coastal environments.

Keywords
Erosion protection, sediment control, halophytes, coral reef protection

Poster PRESENTATION

SESSION P-1: Sustainability

POSTER SESSION
Session Chair: Philip Moravcik

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Optimum Turf Irrigation Management Minimizes Irrigation Water, Saves Energy, and Reduces CO_2 Emission: Case of O'ahu Public Schools

Ripendra Awal[1], **Ali Fares**[1], Samira Fares[1], Hector Valenzuela[2], and Rosslyn Harris[2]

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As demand for water increases with urban growth and renewed interest in local agriculture production, there is a need for optimum irrigation water management. Such an approach requires a strong outreach/educational program on irrigation Best Management Practices (BMPs) for urban and agriculture production settings in Hawaii. The goal of this work is (1) to demonstrate BMPs for optimum water and nutrient use efficiencies for turf grass at three public schools on Oahu and (2) to estimate optimum irrigation water requirement for turf grass and corresponding energy saving and CO_2 emission reduction at different public high schools of Oahu based on soil and historical climate data using the Irrigation Water Requirement Estimation Decision Support System (IWREDSS 2.0). Experimental plots were developed at three selected schools installing weather station/rain gauge, sprinkler irrigation system, soil moisture sensors and soil solution sampling cups within and below the rootzone. Different irrigation lengths and frequencies were tested (e.g., every night for 15, 30, 45, and 60 minutes). We found differing irrigation requirements at each of the three schools. Field demonstrations with hands on experience for K–12 students conducted as part of this project were well received and the curiosity displayed by the students encourage the use of such outreach activities in educating future potential decision makers and private citizens on conserving natural resources and protecting our environment. By inputting the school's particular weather and soil data into the IWREDSS, a yearly irrigation schedule was developed for all public high schools of Oahu. We also estimated the annual volume of water requirement considering 30% of the school area as a turf grass. Optimum irrigation management based on IWREDSS estimations would result in an annual irrigation saving of about 431 million gallons of water, which is equivalent to 785 MWh of energy savings and 591 metric tons in CO_2 reduction.

Keywords
Irrigation water requirement, turf grass, IWREDSS, energy saving, CO_2 reduction

Reusing Wastewater Effluent for Agricultural Irrigation: Proposed Lahaina Application

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Domestic wastewater effluent is a largely untapped source of water that can be treated and used for a variety of beneficial uses. Treatment of domestic wastewater can be done in a safe, cost-effective manner, and using it for non-potable purposes could greatly increase the water resources available for drinking water. In water short regions such as the western United States, non-potable reuse of domestic wastewater is increasingly utilized to supplement other sources for multiple purposes. The research team assembled is specifically looking at treatment and reuse of oilfield wastewater for agricultural irrigation, with many of the same issues similar to applying reused domestic wastewater for the irrigation on the island of Maui, specifically at the Lahaina Wastewater Reclamation Facility.

Project director Jim Mothersbaugh has been discussing the application of wastewater reuse with Maui and Lahaina officials since a settlement was reached on a federal lawsuit over the Clean Water Act violations related to the treatment facility's effluent injection wells. Watertectonics, in conjunction with Colorado State University (CSU), will provide treatment testing and results to prove the efficacy and economic viability of converting existing plant effluent to irrigation water. University of Hawaii water reuse expertise will also be leveraged to assure the treatment meets local condition and cultural goals. A key aspect of the project is determining suitable crops to be grown and biophysical water limitations for each. Experts from both the University of Hawaii's and CSU's agricultural colleges and extension will be utilized to design and monitor this aspect of the project.

The results of the project will be consequential since a new irrigation water source will be developed using an approach that protects the pristine ocean environment of the Lahaina coast.

Keywords
Domestic wastewater reuse, Lahaina Wastewater Reclamation Facility, irrigation, reuse

RAM, RAM2, and What's Next?

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Basal aquifers provide the major water supply for the Hawaiian Islands, in which freshwater lens floats on underlying saltwater from sea. The practical determination of the sustainable yield of aquifers are made based on Mink's Robust Analytical Model (RAM) and improved by Liu's RAM2, both of which are user-friendly. In this study, an analytical approach RAM3 is preliminarily derived to provide a possible next step towards better understanding the behavior of freshwater lens, and the further accuracy for sustainable yield estimate.

RAM is an actual zero-dimensional (0-D) tank on the sharp interface between freshwater and seawater. RAM2 is a combination of the two tanks: a 0-D freshwater tank sitting over the one-dimensional (1-D) transport tank of the mixing water of the seawater into the freshwater as the transition zone (TZ). The current preliminary derivation of the further modified analytical groundwater model RAM3 is the combination of a 1-D freshwater flow in-and-out tank sitting over the 1-D transport tank as the TZ. For the RAM3, one of the key issues is to analyze the coastal groundwater head before the seepage of freshwater lens, along the shoreline, qualitatively and quantitatively. That head is affected by the scales of cap-rocks and/or other porous media through which the freshwater leaking into sea. It affects the thickness of the freshwater lens. RAM3 may be simplified back to RAM2 for thick freshwater lens with similar accuracies.

RAM3 demonstrates that analytically, with well-developed cap-rocks, the basal groundwater lens is thick, and behaves like a water tank. Thus, RAM and RAM2 have been successfully applied to Hawaiian basal aquifers with cap rocks, such as the Pearl Harbor Aquifer. RAM3 may also be properly applied to aquifers of the Big Island, where the cap rocks might not be well-developed

Keywords

Groundwater modeling, basal aquifer, seawater intrusion, sustainable yield, transition zone, analytical model

Assessment of CMIP5 Ensemble's Initial Conditions Used for Dynamical Downscaling over Oahu, Hawaii

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Understanding long-term changes of rainfall is important for water resources planning and development. Global Circulation Models (GCMs) such as CMIP5 have undergone significant improvements since the early development of Numerical Weather Prediction. However, due to coarse spatial resolutions and simple parameterization schemes of GCMs, the current rainfall estimates and future rainfall projections are often unrealistic, especially for small islands with complex terrains such as the Hawaiian Islands. Recent advancements in mesoscale meteorology have helped develop the limited area Regional Climate Models (RCMs) such as WRF-ARW that are used to perform dynamical downscaling. These RCMs have the ability to estimate and project high-resolution rainfall at smaller scales, in our case down to 1.1 km.

Since the RCM output is forced by lateral boundary conditions from a GCM, we see significant variations in estimated and future projected rainfall depending on which GCM is chosen to force the RCM. In this study, we assess an ensemble of ten CMIP5 models in their ability to represent the monthly mean vertical mass-weighted atmospheric total energy over the Hawaiian Region (170ºW–150ºW, 13ºN–28ºN) for the time period of 1950 to 2005 derived from a global reanalysis product. The single best performing ensemble member based on three metrics over the 55-year period is GFDL-CM3. The GFDL model is then used to force the limited area RCM, and provides 1.1 km high-resolution model projections for the wet season 2030, 2040, and 2050 under the RCP8.5 global warming scenario, for the island of Oahu.

Output from dynamical downscaling is highly dependent on the initial conditions used to force the RCM. Although, RCMs can produce high-resolution model output from the GCM initial conditions, using the initial conditions that are unrealistic to the Hawaiian Region will not provide skillful high-resolution projections of future climate change. Therefore, by first assessing an ensemble of GCM initial conditions compared to the observations, we find the model that best captures the current climate and perform dynamical downscaling of future projected climate change under the RCP8.5 global warming scenario.

Keywords

Future rainfall projections, dynamical downscaling, climate change, CMIP5

Reducing Irrigation Overuse Through Research Into Precision Irrigation

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Monsanto Hawaii is committed to sustainable farming practices and the careful stewardship of essential resources. Ongoing efforts to keep these commitments include improved water resource management, which has reduced the overall amount of water used to produce our seed crop. This achievement has been accomplished through a series of incremental advances based upon the evaluations of irrigation durations and frequencies, end of cycle shut-off times and precision application methods in consideration of yield and seed quality. In this presentation, these key improvements will be expanded to provide support for how we derived our main objective—to improve water resource management and foster responsible irrigation practices for our farms in Hawaii.

Initially, research was conducted to explore irrigation volume and frequency combinations. It was found that one acre-inch per week was enough to produce the seed we needed without affecting yield or seed quality. This was a major improvement over multiple short irrigation events. When combined with diligent shut-off practices, we reduced water use by more than 40% annually. Currently, Monsanto Hawaii is researching methods of "precision irrigation" based on evapotranspiration models that direct when and how much water is used, based on the growth stage of the plant and weather data. With recent investments into irrigation infrastructure and valve automation, precision irrigation has enormous potential to further reduce annual water use.

While this research is ongoing, we can conclude that we can generate the amount of seed that we need and at the same time conserve water resources and repurpose their use to support other sustainability initiatives such as the establishment of rotating cover crop systems and beneficial insect sanctuaries. These results are significant because managing water efficiently and demonstrating responsible resource stewardship is fundamental to sustainable crop production.

Keywords
Irrigation, sustainability, evapotranspiration, irrigation practices, precision irrigation, resource management

Hydrology of the Hawaiian Islands

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The poster introduces the book by L. Stephen Lau and John F. Mink entitled *Hydrology of the Hawaiian Islands* published by University of Hawaii Press with a book description, three critical book reviews, and an abridged table of contents. A publisher's flyer is available for tear-off to go. The book is about groundwater, surface water, their sustainability and water quality, and more water resource issues in the Hawaiian Islands. It is the first book written on the subject and is intended for use by a wide audience: professionals, academics, and the general public. The book reviews are cited in full in the poster and are independently done by a professional journal (American Society of Civil Engineers Journal 77 (4): 67), an academic book review (Current Review for Academic Libraries Choice Magazine 44 (9): May 2007), and a lay public news media (Honolulu Advertiser April 23, 2007). Lau is professor emeritus of civil engineering at the University of Hawaii. Mink was a practicing geologist-hydrologist with Mink and Yuen, Inc. Honolulu. They have been research collaborators and co-authors on numerous studies and journal articles for nearly fifty years. All royalties generated from the sale of the book have been donated to L. Stephen Lau Water Research Endowed Scholarship, University of Hawaii Foundation, and to Patsy Takemoto Mink Education Foundation for Low Income Women and Children.

Keywords
Hydrology, Hawaiian Islands, book, reviews

Evaluating the Performance of SWAT Model for Simulating Daily Streamflow in Selected Watersheds of Oahu Island (Hawaii)

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Watershed hydrological models are a useful tool for estimating water resources availability under changing climate and land use, which can help the decision makers in the design of appropriate mitigation measures. Evaluating hydrological models performance is important particularly for tropical islands that usually experience highly variable climate conditions, unique hydrological properties, and scarcity of freshwater resources. This study evaluates and compares the performance of the Soil and Water Assessment Tool (SWAT) model for the leeward Nuuanu area and windward Heeia watersheds of Oahu Island. The leeward Nuuanu area watersheds had relatively spatially well distributed hydro-meteorological data within the watersheds, in contrast to the Heeia watershed where the majority of data sets were based on those obtained from the surrounding watersheds.

Based on the available geospatial and hydro-meteorological data of the selected watersheds, the modified SWAT model, which reflects typical volcanic soil properties, was used and calibrated for daily streamflow modeling. We evaluated the performance of SWAT by consistently using six statistical criteria. We found that the daily performance of SWAT was very good for the leeward watersheds, while satisfactory results were obtained for the windward watershed. When the Nash-Sutcliffe Efficiency (NSE) was considered, all the leeward watersheds showed NSE ranges of 0.58 to 0.87 for both calibration and validation periods. However, a lower NSE of 0.35 to 0.64 was achieved for the Heeia watershed. Additionally, the percent of observations covered by 95% confidence interval was considerably increased for the leeward watersheds in comparison to Heeia. Finally, the calibrated curve number values with the observed daily streamflows were relatively low for all the watersheds as compared to the reported values for continental watersheds.

Our findings highlight the importance of using multiple gauging stations within the watershed in order to capture the high spatial variability of the climate and improve model performance. As should be expected, further improvement can be achieved if good quality and well-represented climate data are used for the Heeia watershed.

Keywords
Streamflow, SWAT modeling and calibration, model performance, Oahu Island

Advances in Game-Theoretic Modeling for Disaster Risk Reduction Under Conditions of Climate Change in the Pacific Island Region

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Pacific Island communities are faced with pressing and complex conflicts related to climate change and the sustainable management of water resources. Fresh water resources are under threat on many Pacific islands as the result of overuse, pollution and climate change. Global sea level is rising, with the highest rates in the world recorded in the tropical Pacific Ocean where many low-lying carbonate reef-lined atoll islands are located. These atoll islands are particularly vulnerable for a number of reasons: many have maximum elevations less than four meters above the present sea level, there is limited land and water available for human survival, and ecosystems are vulnerable to inundation from sea-level rise. Restoring, preserving, and protecting watersheds on Pacific Islands goes beyond technology-based solutions and includes participatory negotiation and conflict resolution.

This presentation proposes powerful new non-quantitative decision and negotiation approaches (meta-game analyses) for the resolution of water resources conflicts and disaster risk reduction. While a traditional operations research approach to structuring, analyzing, and modeling complex sustainable water resources problems is taken, decision makers, options, and preferences are not assumed to be fixed. This helps players interact to design the game they eventually play (by communicating with each other prior to a game) while simultaneously selecting a focal equilibrium set in that game.

It is shown that advances in meta-game analyses are valuable for analyzing "wicked" water-related problems on Pacific Islands and for modeling the uncertainties associated with climate-change impacts. It is shown that traditional models for effective community participation include the Hawaiian *'aha* council, in which all stakeholders can collaborate to overcome water sustainability crises through dialogue, negotiation, and shared decision-making. A thorough discussion and mathematical treatment of key meta-game concepts (i.e., positions, intentions, doubts and dilemmas) are provided.

Keywords
Conflict resolution, environmental decision and negotiation, climate change, game-theory

Interdisciplinary Hydro-Meteorological Disaster Resilience Education: The Disaster Preparedness and Emergency Management Program

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There have been several major coastal storms to affect Pacific Islands in recent decades including Hurricane Iniki, which hit the island of Kaua‘i, Hawai‘i in 1992, resulting in $2.5 billion in physical damages. The strong winds, heavy rains, and storm surge that accompany these water-related disaster events pose a direct threat to the well-being of Pacific Island communities. In particular, climate-related sea-level rise is an ongoing and accelerating process that may cause catastrophic inundation, erosion, and involuntary relocation in some Pacific Island nations. Under the conditions of climate change, an interdisciplinary approach to disaster resilience education is needed.

A unique and interdisciplinary certificate in Disaster Preparedness and Emergency Management at the University of Hawai‘i-West O‘ahu was approved by the University of Hawai‘i Board of Regents in Fall 2002. A federally designated indigenous-serving institution, the campus has one of the highest percentages of Native Hawaiian students (28.5%) of all 4-year universities in the country. Sample partners of the certificate include the U.S. Army Corps of Engineers (Honolulu District), the Hawaii Emergency Management Agency, and the Pacific Tsunami Warning Center.

Interdisciplinary methodologies for disaster risk reduction education are used to reduce disaster risk and socio-economic vulnerabilities by shifting the disaster management paradigm in the Pacific Island region from crisis management to a community based disaster resilience approach. This emerging and holistic concept of planning for disaster resilience with the “whole community” emphasizes that lives can be saved through sustainable local pre- and post-disaster planning. It is shown that building hydro-climatic disaster resilience in Pacific Island communities requires innovative collaborations among institutions of higher education, governments, and the private sector in order to manage the unexpected and cascading impacts of water resources hazards that cross policy domains, geographic, political, and sectoral boundaries.

Keywords
Hydro-meterological hazards, disaster resilience, higher education, climate change

Recycled Tire Crumb Rubber to Remove Emerging Contaminants and Halogenated Organic Compounds from Water

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There is a growing need for the development of low cost adsorbent materials to remove organic contaminants from dilute aqueous solutions. From a materials engineering viewpoint, low-cost waste tire crumb rubber (TCR) can be considered as a polymer-carbon black nanocomposite capable of removing emerging contaminants such as triclosan (TCS), trichloroethylene (TCE) and perchloroethylene (PCE). Besides, the reuse of TCR as a multifunctional sorbent will present two big challenges: expanding recycling options and developing a simple and cost-effective route to clean up polluted waters.

The effectiveness of TCR for the removal of the contaminants mentioned above was evaluated through controlled batch experiments. Carbon black (CB) and styrene-butadiene polymer (SBP), which are the main components in TCR, were evaluated as well to assess their contribution in the sorption process. The experiment results were better explained by the Langmuir adsorption isotherm models. The maximum removal of TCS onto TCR, CB, and SBP were around 89%, 95%, and 92%, respectively; and did not change significantly in the evaluated pH range (3–7). Likewise, TCE and PCE removal was independent of the initial concentration of the organics and were around 80% and 95%, respectively. The desorption of TCS, TCE and PCE from TCR was also evaluated; a maximum desorption of TCS from TCR was ~89% using methanol as extracting solution. For TCS, TCE, and PCE the corresponding desorption efficiencies were 94%, 93%, and 86%, respectively. The results from cyclic sorption/desorption experiments indicate that TCR can be used for at least 5 cycles without a significant decrease of the adsorption and desorption efficiencies.

These results demonstrate the feasibility of using TCR as a low-cost, green alternative to remove different organic contaminants from water systems. It represents a viable option for the removal of these contaminants from contaminated waters.

Keywords
Triclosan, trichloroethylene, perchloroethylene, waste-tire-crumb-rubber, water-remediation

Determining the Effect of Large-Scale Climate on Rainfall Variability of the Main Hawaiian Island

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Understanding the cause of a long-term decline in Hawaiian rainfall is complicated by high temporal and spatial variation in rainfall, which is difficult to predict. Rainfall variability arises from the dynamics involving two predominant sources (trade winds and synoptic disturbances) and the influence of large-scale climate on these dynamics. Understanding the relationships between large-scale climate and rainfall may help understand the long term decline and enhance seasonal predictability.

These relationships are examined by correlating regional variables and basin-scale climate indices of the Pacific with both Empirical Orthogonal Functions of Hawaiian rainfall and the Hawai'i Rainfall Index. Two time series were studied, 1905 to 2000 and 1950 to 2000 with the latter showing generally stronger correlations (possibly due to better rainfall and/or climate data). Seasonal composites of wet season rainfall (November–April) and dry season (May–October) showed stronger relationships with climate indices than running time series, particularly for wet season rainfall. The strongest relationships were observed between wet season Hawaiian rainfall and extra-tropical atmospheric indices (the Pacific North American Pattern and the North Pacific Index) during the 1950 to 2000 time period. However, wet season rainfall from 1905 to 2000 had a higher relationship with the Southern Oscillation Index.

Variability in Hawaiian rainfall is more strongly coupled with atmospheric dynamics of the Aleutian Low and Southern Oscillation (which are strongly correlated with one another), particularly during the wet season (winter), when the Aleutian Low is more active. However, in these years, less wet season rainfall results from reduced trade winds due to a more well developed Aleutian Low. In contrast, there is greater dry season rainfall in these years, probably due to more tropical storms. Regional or basin-scale SST patterns (e.g., PDO) are less efficient in describing the relationship with large-scale climate. Other influences and potential causes of the rainfall decline are also discussed.

Keywords

Hawaiian rainfall, El Niño, PDO

Modeling Stream Flow at a Leeward Watershed in Hawaii: Application to Water Resource Management Under the Threat of Wildfire

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Streams systems in the Hawaiian Islands are unique compared to other systems in the world. Aside from the fact that their geological and topographical features contribute to the flashiness of stream flow, the prevalent trade winds deliver disproportionate amounts of rain to watersheds on their windward (wet) and leeward (dry) sides. All above factors present the challenges when trying to understand the mechanisms driving stream flow formation in Hawaii. In this study, we used a hydrological model to help understand (1) Hawaiian Island hydrology, (2) how natural and anthropogenic disturbances alter stream flow paths and water budgets within Hawaiian watersheds, and (3) how these alterations might ultimately impact water quantity and water quality of intrinsic freshwater resources.

We used a semi-distributed model, Soil and Water Assessment Tool (SWAT), to simulate the stream flow of the Makaha watershed at the leeward side of Oahu Island. We obtained elevation, land use, soil, and weather data to serve as input in SWAT model. Ten years of daily flow records (2005–2014) from stream gage (USGS 16211600) were used to calibrate stream flow. This SWAT model was then applied to evaluate water quantity and quality when land use changed due to natural or anthropogenic disturbance. In particular, the high risk of wildfire in western leeward side of Oahu becomes an emerging concern. We designed three scenarios to describe different degrees of losing forest due to wildfire. The difference results in the flow quantity and quality were described and compared with intact condition.

Through simulation, we modeled the likely outcomes of wildfire impact on water quantity and quality. This provides information to managers when design adaptive management practices and other approaches for protecting island surface and groundwater. The successful building SWAT model at Makaha could be applied to leeward watersheds of other islands.

Keywords
Watersheds, modeling, management, SWAT

Assessing Water Availability in the Conterminous United States with the USGS Soil-Water-Balance Model

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The United States Geological Survey (USGS) Soil-Water-Balance (SWB) model was designed as a tool to estimate potential groundwater recharge relatively quickly and painlessly. SWB estimates recharge on a daily time step and computes all major water budget components above the bottom of the root zone over a gridded model domain. Although written as a faithful implementation of the Thornthwaite-Mather water balance method, the application of SWB to various projects revealed the need to enhance the code by adding alternate hydrologic processes and data handling modules.

In response to specific project needs, capabilities have been added to the code in order to make it more generally applicable. A water availability project for the Lake Michigan Basin required SWB to ingest gridded precipitation and air temperature data, as well as simulate the effects of frozen ground on runoff. Another water availability project for the High Plains illustrated the need to include irrigation as a component of the water budget. Yet another water availability project involving the glacial aquifer systems of the conterminous United States demonstrated the need to improve methods for the ingestion of gridded data where different map projections and grid cell sizes have been used.

Since its initial release in 2010, SWB has been used in support of USGS water availability projects covering close to 50% of the landmass of the conterminous United States. Application of SWB to JeJu Island in South Korea was successful, but also highlighted the need for further modifications to make SWB more broadly useful to tropical island settings. The USGS Groundwater Resources Program is currently underwriting the effort to implement these needed modifications. Modifications include the addition of mechanisms to simulate fog and canopy interception, as well as a module capable of simulating sugarcane and pineapple plant growth. The modified code will be released as SWB 2.0 along with the updated documentation in 2016.

Keywords
Water balance, irrigation water requirements, potential recharge, Thornthwaite-Mather method

GIS and Semiparametric Analysis of the Effects of Wetland on Property Values in Oahu, Hawaii

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Sustainable water management in Hawaii is a complex, multi-disciplinary field. There may be hundreds of conflicting criteria that must be considered, including tangible factors (monetary costs, infrastructure damage, etc.), intangibles (such as socio-psychological variables) and geospatial variables as well as demographic, energy, and technologic and climatic trends. This requires the use of the Decision Support Systems, which incorporates the diverse interests, priorities and values of all stakeholders including accountability, profitability, transparency, equity and market power. Moral and ethical values held by the stakeholders may be as important as technical issues, placing high demands on the decision making process: Hawaiian sustainability values, including Auamo Kuleana (collective transformation through individual excellence), ʻIke ʻĀina (knowledge learned from connection to land), and Aloha ʻĀina (love and commitment to land) are used to drive sustainability decisions on Oahu.

The field of Multiple Criteria Decision Making (MCDM) has long been applied to the planning and management of complex sustainability problems involving strategic uncertainty at the "wicked" level of decision making. MCDM techniques are widely used to identify alternatives that are dominated by at least one other alternative. The rapid growth of MCDM for water sustainability issues is due to a number of factors, including dissatisfaction with conventional "single criterion" methods and the emergence of more powerful processors and new software and algorithms.

Real-time MCDM Decision Support System (DSS) architecture is presented that integrates advances in MCDM, remote sensing, GIS, environmental models, spatial statistics and real-time information systems for sustainability issues on Oahu, Hawaii. It shows that DSS and MCDM can improve sustainable water resources planning and management under uncertainty by providing data displays, analytical results, and model output to summarize critical information.

Keywords
Multiple Criteria Decision Making (MCDM), sustainability, GIS, and climate change

Monitoring of Hawai'i's Beaches Water Quality Using Enteric Viruses as Alternative Indicators

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Recreational waters contaminated with human fecal pollution are a public health concern and ensuring the safety of recreational waters for public use is a priority of both the Environmental Protection Agency and the Centers for Disease Control and Prevention. Current recreational water standards rely on fecal indicator bacteria levels as indicators of human disease risk. However, present evidence indicates that levels of FIB do not always correspond to the presence of other potentially harmful organisms, such as viruses. Thus, enteric viruses are currently tested as water quality indicators, but have yet to be successfully implemented in routine monitoring of water quality.

This study utilized enteric viruses as possible alternative indicators of water quality to examine 18 different fresh and offshore recreational waters on O'ahu, Hawai'i, by using newly established laboratory techniques including highly optimized polymerase chain reaction (PCR), real time PCR, and viral infectivity assays. All sample sites were detected positive for all four viruses tested in this study by PCR, including enterovirus, norovirus genogroups I and II, and male specific FRNA coliphage. A six time-point seasonal study of enteric virus presence indicated significant variation in virus detection between the rainy and dry seasons. Quantitative PCR detected the presence of norovirus genogroup II at levels at which disease risk may occur, and there was no correlation found between enteric virus presence and FIB counts. Under the present laboratory conditions, no infectious viruses were detected from the samples PCR-positive for enteric viruses.

These data emphasize the need for improved monitoring of Hawaii recreational water quality for safe use, and support the notion of using human enteric viruses as potential alternative indicators.

Keywords
Human enteric virus, indicator, recreational water quality, PCR

Detecting Hot Spots for Algal Blooms in Shallow Waters Around Tutuila, American Samoa

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Land-based sources of pollution (LBSP) drive coastal algal blooms, growth of opportunistic seaweeds that can persist for years and in many parts of the world. In tropical regions, blooms often have negative ecological and economic impacts, and are exacerbated by declines in grazers or loss of habitat. Using American Samoa as comparison for on-going studies of the main Hawaiian Islands, we employed the first multi-dimensional assessment integrating geochemistry, nutrient measurements, and microbial community analysis with submarine groundwater discharge, to examine the potential for LBSP to impact reefs in Tutuila.

Our objective was to identify areas vulnerable to blooms. We selected coastal sites along a human use gradient ranging from pristine to heavily impacted. Pristine sites had no residents within the watershed, little LBSP, few obstructions to water movement and sparse run-off. Impacted sites were downstream of dense residential areas and had substantial sediment loads and slowed water movement—pre-conditions for an algal bloom. At each site, we collected surface water for inorganic nutrients, ∂^{15}N, and planktonic microbial community, tissues of indicator algae, and characterized the benthic community.

Sample analyses are underway but much can be gained by examination of the sites on our gradient. Microbial community analysis will be performed using high throughput Illumina sequencing. Algal tissues will be characterized by ∂^{15}N and %N analysis. We anticipate our results from pristine sites will show diverse benthic-plant communities, a microbial community that is indicative of a healthy watershed and low ∂^{15}N and %N in tissues of indicator algae. We anticipate our results from impacted sites will show declines in species numbers for the benthic communities, a shift in microbial communities with detection of pathogens, as well as elevated ∂^{15}N and % N in tissues of indicator algae. These data should help inform resource managers as to the threats to coastal regions.

Keywords
Algal blooms, coral reefs, nutrient pollution, tropical watersheds

Keauhou Aquifer Hydrologic Monitoring

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Beginning in the 1980s, the Kailua-Kona region in West Hawaii has experienced tremendous growth. Associated with the increased urbanization is increased demand on water supplies and competition among large landowners and developers for new water sources in the Keauhou Aquifer System Area. Exploratory well drilling since 1990 revealed both high-level water in the mauka areas and the occurrence of very deep fresh water below salt water underlying the basal aquifer in makai areas. The relationship between these two geohydrologic regimes and their connectivity to basal ground waters is not well understood. It is critical to obtain better information to refine our conceptual understanding of the ground water resources, especially the impacts of high-level pumpage on the makai basal aquifer, and to ensure sustainable supplies into the future.

Urban growth pressures combined with the complexity of the geohydrologic regime compelled the Commission on Water Resource Management to establish a ground water monitoring network in 1990. Existing unused wells located in strategic locations were converted to water-level observation wells, and two deep monitor wells were constructed to track the ground water response to increasing pumpage to help validate estimated sustainable yields. Results of the long-term monitoring indicate a slow decline in the water levels of high-level wells is occurring while some basal wells have experienced chloride increases as a result of climatic changes, localized pumping patterns, and perhaps vertical cross-connections between aquifers.

These and other major findings to be presented have greatly increased our understanding of the ground water regime. The data has been and can be used as calibration targets for current and future numerical ground water models to further facilitate our understanding of the geohydrology and water resource sustainability and aid in the site selection for new water supply wells.

Keywords

Ground water monitoring, hydrologic data collection, water resource management, deep monitor well, water level measurement, water sustainability

Hydrology of Warm Anchialine Ponds at Kapoho, Hawaii

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In August 2014, after flooding from Tropical Storm Iselle caused household hazardous wastes to spill into anchialine ponds at Vacationland, Kapoho, Hawaii, the community requested more information about the local hydrology. Anchialine ponds (brackish water ponds with tidal fluctuations but no surface connection to the sea) provide a unique opportunity to examine small-scale hydrology of a fractured basalt aquifer, where tides, seawater, and at Kapoho, geothermal water can be used as tracers.

Field surveys and satellite image analysis identified 64 ponds, isolated to an older (1000 yr) lava flow in the southern half of Vacationland. The environmental variability of 20 ponds was examined using continuous data loggers. The warmest nighttime temperatures (32 °C at salinity of 8.0‰) were found in the north-central part of the neighborhood, and spread out towards the east and south, consistent with the location of warm groundwater springs at the shoreline. Daily salinity variability driven by tides did not simply decrease with distance from shore and instead likely varied with fresh groundwater input. Daily minimum salinity fluctuated with the tidal range, with the highest salinity measured during spring tides, and lowest during neap tides. Oxygen was generally abundant at the shoreline and at ponds on the uphill side. However, 47% of ponds experienced hypoxia, and ponds that were not maintained, and had rotting organic matter, experienced occasional anoxia.

A marine mass mortality event (MMM) in November 2014 occurred in a several shoreline tidepools. Two days after the MMM, anoxic seawater was observed during high tide in a pond 137 m from the shoreline, providing the only evidence of anoxia. Recirculated seawater must have entered the aquifer near the shoreline where the MMM occurred and had a flow rate of 45 m/d. It was concluded that coastal water quality is just as important as fresh groundwater in these anchialine ponds.

Keywords
Anchialine ponds, anoxic, recirculated seawater, geothermal

Staphylococcus aureus in Hilo Bay: Investigating Potential Associations with Water Quality Parameters

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Staphylococcus aureus is an opportunistic pathogenic bacteria responsible for a variety of human illnesses. Infections resulting from this pathogen are found to be associated with exposure to the marine environment. Presently, the State of Hawai'i has the highest rates of methicillin-resistant *S. aureus* infections in the United States, possibly due to the high use of marine resources for sustenance, cultural and recreational purposes. The objectives of this study were to determine the abundance of *S. aureus* in surface waters of Hilo Bay, and to investigate relationships between *S. aureus* and water quality parameters.

To assess the threat of marine based *S. aureus* infections in Hawai'i, a study was conducted on Hawai'i Island, in Hilo Bay. Culture-based methods using chromogenic media were employed to determine *S. aureus* abundance within the bay. Analyses of fecal indicator bacteria (*Enterococcus* and *Clostridium perfringens*), nutrients, and basic water quality parameters were also conducted. During dry periods, *S. aureus* was most abundant at the mouths of the Wailuku and Wailoa Rivers; however, abundance increased across Hilo Bay during rain events. Salinity, turbidity, total dissolved phosphorus and fecal indicator bacteria showed significant correlations with *S. aureus* abundance.

Significant correlations between *S. aureus* abundance and water quality parameters provide the potential to create a model to predict this pathogen in the environment. Using data from the Hilo Bay water quality buoy, such a model could lead to faster public notification of potentially hazardous water quality conditions. Additionally, this study provides the foundation for future investigations on sources of this pathogen to coastal waters, which will support public health and water quality management solutions for Hawai'i's marine environment.

Keywords
Water quality, estuaries, pathogens, *Staphylococcus aureus*, fecal indicator bacteria

Wastewater Injection, Biogeochemical Reactions, and Resultant Groundwater N Flux to Coastal Waters: Kā‘anapali, Maui, Hawai‘i

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Treated wastewater effluent disposal via deep injection wells at Lahaina Wastewater Reclamation Facility (LWRF), located in Kā‘anapali on the island of Maui, Hawai‘i, has been long thought to contribute excess N and other pollutants to nearby coastal waters, resulting in invasive macroalgal blooms, coral mortality, and general ecosystem degradation. Recent studies (e.g., Hunt and Rosa, 2009; Glenn et al., 2012, 2013) have shown that treated wastewater effluent injected at LWRF enters the coastal ocean at several submarine spring sites along a nearby stretch of coastline and that wastewater effluent comprises the majority of the submarine spring discharge. These studies have also shown that a significant but temporally variable portion of N in the injected effluent is removed prior to its discharge, resulting in temporally variable fluxes of N to the coastal ocean via submarine groundwater discharge (SGD).

We utilized wastewater injectate and submarine spring N and C species data along with $\delta^{15}N$ values of dissolved NO_3^- and $\delta^{13}C$ values of DIC to evaluate the stoichiometry of biogeochemical reactions occurring along the effluent plume flowpath. Additionally, we compared LWRF N species time series data, injection rates, and treatment history with submarine spring N species times series data to assess the correlation between these input and output variables.

We found that NO_3^- reduction using organic C as an electron donor is the primary mechanism of N attenuation within the effluent plume and that chlorination of injected effluent for disinfection purposes may suppress the activity of bacteria responsible for this N attenuation, resulting in the adverse trade off of increased N loading to the coastal ocean. The use of non-persistent UV disinfection may result in the restoration of strongly N-attenuating conditions in the effluent plume, reducing the flux of injected wastewater N to coastal waters.

Keywords
Wastewater treatment, underground injection, nitrogen cycle, denitrification, anammox, submarine groundwater discharge

Modified Leachfield Design for Highly Conductive Volcanic Substrates

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A large portion of the American Samoan population relies on onsite wastewater systems for handling sanitary waste. In order to provide better sanitary treatment and protect groundwater resources that are the main source of drinking water, the islands are transitioning from cess pools to septic systems. The installation of septic leach fields within the highly conductive local substrate does not allow adequate retention times for treatment to occur within the leachfield trench media before it enters local aquifers. In many cases percolation tests result are 0 minutes per inch and water well sampling results have found *Escherichia coli* in nine operating wells. In order to provide better treatment, the American Samoa Power Authority has performed a series of percolation tests using the most readily available fill material to determine how to obtain slower percolation rates and create a leachfield design suitable to the local geology.

Four percolation tests were conducted using locally mined very fine black sand. Each test consisted of varying depths of sand and compaction. Due to local residential restraints, formal compaction tests were not utilized and compaction was tracked by the number of passes with the compactor. The tests revealed that a 12-inch base of black sand with three passes from the compactor achieved the targeted percolation rates of 6 to 7 minutes per inch. A base layer of compacted fine black sand is now utilized beneath the entire leachfield bed during installations in highly conductive areas. Upon the installation of each base layer a percolation test is completed to confirm that the appropriate percolation rate has been achieved.

The use of this modified design will allow better treatment to occur within the leachfield trench media. By utilizing onsite systems which function better the contamination of local aquifers from septic effluent can be reduced.

Keywords
Onsite, leachfield, percolation, design

Assessing Subsurface Vulnerability Potential to Pharmaceuticals Using a Geo-Processing Tool

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Pharmaceuticals have recently received considerable attention due to their occurrence in the Nation's streams, groundwater, and drinking water supplies. The mass emission of pharmaceuticals to the environment is difficult to quantify due to a multitude of sources from both point and diffuse sources. As concern grows on the possible impacts of pharmaceuticals, a reliable and valid assessment method for delineating soil and groundwater vulnerability needs to be provided for federal and state agencies as well as the local public.

The main objectives of this study are (1) to collect important chemical characteristics of pharmaceuticals from appropriate databases and lab experiments, (2) to develop an emission inventory for wastewater treatment facilities to quantify their impact on surrounding areas, (3) to conduct laboratory experiments to evaluate the fate and transport behavior of pharmaceuticals in the selected soils in Hawaii, (4) to compare the accuracy between the new geo-processing tool (namely, CLERS) and numerical model to determine the suitability of the CLERS for vulnerability analysis of pharmaceuticals, and (5) to implement the leachability of pharmaceutical compounds to a digital map with other relevant contamination activities.

The results of inter-model comparison between the CLERS and HYDRUS-1D showed that the CLERS correctly assessed the relative leachability of pharmaceuticals at various soils in Hawaii. However, there was disagreement in the leaching prediction between two models for the sampled soils in the Big Island, which was probably attributed to inaccurate estimation of the unsaturated soil hydraulic properties. Therefore, we recommend further work on characterizing the intrinsic properties for these soils in more detail. The aggregate leaching for pharmaceuticals was evaluated with the leaching map (assessed by the CLERS) and additional GIS data layers (i.e., SWAP and PCA layers). This will help determine if HDOH will be pursuing sampling of a particular pharmaceutical at any specific areas.

Keywords
Customized tool, pharmaceuticals, Comprehensive Leaching Risk Assessment System (CLERS), Source Water Assessment Program (SWAP), Potential Contaminating Activities (PCA), Hawaii State Department of Health (HDOH)

Survey and Modeling Analysis of HDOT MS4 Highway Storm Runoff on Oahu, Hawaii

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Under Section 303(d) of the US Clean Water Act, the total maximum daily load (TMDL) must be established by states for water-quality-limited streams in which established water quality standards cannot be met even after mandatory minimum treatment facilities have already been constructed and put in operation. TMDL is the pollutant load a water body can receive and still meet water quality standards. It must be established by considering point-source, nonpoint source, and natural background pollutions.

The TMDL for the Ala Wai Canal on Oahu was established in 2002, without an analysis of canal's waste assimilative capacity. In this study, intensive water quality surveys and modeling were conducted for the development of a receiving water quality model of Ala Wai Canal as well as the watershed models to estimate storm runoff and nonpoint source waste loadings. The Ala Wai model was formulated by taking the canal as a series of four completely stirred tank reactors (CSTR). The hydrodynamic characteristics of each segment was represented by its flushing time which is the length of time required to replace existing fresh water in a tidal river at a rate equal to river discharge.

This study is the first major survey and modeling efforts relative to the establishment of TMDL in Hawaii. The results indicated that the existing limit of 25 kg/day for total nitrogen in the Ala Wai Canal was exceeded in three of the four canal segments, and that a major portion of storm runoff and pollutant loads received by the Ala Wai Canal were from upper watershed areas of steep topography and high rainfall. The results also indicated that best management practice for water quality management must be implemented by considering quality and quantity issues.

Keywords
Water quality, runoff, tidal river, modeling, flushing time

Spatial and Temporal Variability in Urban Water Quality on a Tropical Island

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Protection of water quality is particularly important on montane tropical islands, which frequently have limited availability of fresh water and close connections between upland watersheds and nutrient-sensitive coastal ecosystems. Urbanization is one of the most significant sources of water quality degradation in many regions, and is particularly important in Puerto Rico. The primary objective of this study was to relate spatial variability in the water quality of the Rio Piedras basin and its sub-watersheds in San Juan, Puerto Rico to watershed attributes such as population density and density of urban infrastructure. The secondary objective was to determine the effect of season, storms, and long-term trends on water quality over a 7-year period of record.

Results show a surprisingly strong relationship between many indicators of urbanization and spatial variability among sub-watersheds, despite the fact that the entire watershed is served by municipal water supply and waste water treatment that should minimize effects of urbanization. Wide variation in ammonium and phosphate concentrations was associated with the human footprint in the watersheds, especially the volume of sewer pipes. Nitrate was not correlated with urbanization intensity, contrary to global patterns. Chemistry of the main stem showed no consistent temporal trends, but was highly variable from week to week, suggesting sources that are ephemeral in nature.

Management and maintenance of urban infrastructure is critically important in minimizing water quality impacts. The data presented show that one aspect of urban evolution, the failure of sanitary sewer systems that can degrade over time, is particularly important in driving environmental degradation and impairing ecosystem integrity in the coastal study watershed.

Keywords
Watersheds, water quality, management

What's a Clean Beach Worth: Recreational Willingness to Pay for Coastal Water Quality

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Like many places across the world, coastal waters in Hawaii are under threat from anthropogenic degradation, which carries significant economic costs to human welfare. To understand the economic implications of water quality events and environmental degradation of Hawaii's coastal waters, we undertook a non-market valuation.

We used a discrete choice experiment to capture recreationalists' preferences for coastal water attributes, including beach closures due to bacteriological exceedance, water clarity, coral cover, and fish diversity. Each attribute had three levels (low, medium, and high). We conducted in-person surveys with 263 beach users from June to November 2014 across a representative sample of Oahu's beaches staffed by lifeguards. For each beach visit, analysis of a mixed logit model suggests an individual is 'willing to pay' (WTP) approximately $17.17 to reduce days of bacterial exceedance from 11 to 5 per year, and an additional $19.76 to reduce it to no bacterial exceedances at all. WTP to move from 15 ft to 30 ft of underwater visibility was $29.99, and an additional $9.85 to increase from 30 ft to 60 ft. Respondents were willing to pay $13.97 to improve coral reef cover from 10% to 25%, and an additional $3.75 to improve to 45% cover. WTP for moving from 9 species in the environment to 18 species in terms of fish diversity was $11.79, and an additional $0.82 to increase that to 27 fish species.

This study represents an important contribution to the environmental valuation literature in Hawaii. Our results provide critical information for resource managers and policy makers about the economic costs of water quality and coastal resource decline, and illustrate the importance of investing in resource management. While dollar amounts may not fully represent the richness of natural resources and the diversity of ecosystems, valuation can help ensure environmental goods are considered alongside other interests.

Keywords
Non-market valuation, discrete choice experiment, water quality, coral reefs

A Multi-Tracer Approach for Determining the Sources and Spatial Variability of Groundwater-Delivered Nutrients to Coastal Waters: Maunalua Bay, O'ahu, Hawai'i

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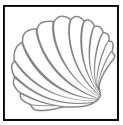

Elevated nutrient loading of submarine groundwater discharge (SGD) has been documented in the western edge of Maunalua Bay, Oahu, an area with known high on-site disposal system (OSDS) density. SGD and nearshore marine water quality were examined in two adjacent aquifers (Waialae East and Waialae West) within Maunalua Bay, Oahu, Hawai'i to decipher the spatial variability of SGD nutrient and water fluxes. Nutrient concentrations and nitrate stable isotope ratios were measured in coastal and terrestrial groundwater as well as nearshore marine water and integrated with SGD flux, land-use, and recharge data to examine potential nutrient sources in each aquifer.

Regionally-elevated nitrate concentrations (166–171 μM) and δ15N-NO3- values (10.4–10.9‰) were apparent in SGD in the Waialae West Aquifer, an area with high OSDS. Coastal sites sampled in the neighboring Waialae East Aquifer exhibited significantly lower values for these parameters, with δ15N-NO3- values ranging from 5.7 to 5.9‰ and nitrate concentrations from 43 to 69 μM. The isotopic composition of nitrate in SGD originating from the Waialae West Aquifer was primarily influenced by mixing of a wastewater source, with wastewater effluent accounting for nearly 4.4% of total recharge and 54 to 95% of total N and P loads, respectively.

These findings illustrate the utility of synthesizing nutrient concentrations and stable isotope parameters together with SGD flux determination and aquifer-scale land-use and recharge data in determining the contribution of terrestrial sources to coastal nutrient loading via SGD. In addition to exploring nutrient dynamics and quantifying SGD nutrient fluxes for each study site, we demonstrated that OSDS leachate is likely responsible for the elevated SGD N fluxes observed at Black Point. These findings should aid in restoration efforts aimed at curbing nutrient pollution of these coastal waters by providing regulators with compelling source determination information.

Keywords
Submarine groundwater discharge, wastewater, water quality

Meeting the Criteria: Linking Biofilter Design to Fecal Indicator Bacteria (FIB) Removal and Our Sustainable Water Future

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Capture, treatment, and reuse of stormwater is a win-win proposition that can improve human water security and ecosystem health. Although not all treatment technologies facilitate capture and reuse of water, biofilters do. Biofilters are engineered analogues of natural systems that treat stormwater using natural processes. Their design is closely linked to treatment efficiency. As such, specific design components, such as submerged zones (SZ; saturated layers near the biofilter base), can significantly effect contaminant removal. Of particular interest, is the utility of SZ biofilter designs for removing indicators of pathogens, the so-called fecal indicator bacteria (FIB). FIB exist at high concentrations in stormwater, and have been identified as a primary barrier to stormwater reuse.

A meta-analysis evaluating $\log_{10}$ FIB removal across biofilter designs was performed to compare the efficacy of standard vs SZ biofilters. Thirteen studies were evaluated, resulting in a dataset including 349 biofilter experiments; 89 SZ and 269 standard designs. A nonparametric bootstrap analysis of these data revealed significant effects of SZ on biofilter performance (~10 fold higher FIB removal). Subsequently, structural equation modeling was used to determine the importance of SZ relative to other design features (e.g., vegetation and filter media % fines). SZ and fines were found to effect FIB removal similarly (and more than vegetation) during dry periods (antecedent dry period > 10 days), and less than vegetation during wet periods.

Overall, biofilters with SZ were comparable/superior to non-SZ designs for FIB removal. This bodes well for our ability to maintain existing biofilter functionality (e.g., nitrate removal; also enhanced by SZ) while maximizing FIB removal, which is requisite for the acceptance of biofilters as stormwater treatment technologies. However, SZ alone do not always improve biofilter performance to the maximum extent possible. Thus, other design components must be considered in addition to SZ, especially in wet climates.

Keywords
Stormwater, biofilter, water security, fecal bacteria

Impact from Current Wastewater Management on Water Resources of Small Islands

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Domestic wastewater is generated from the toilet, kitchen, bathroom, and cloth washing machines. Wastewater from the toilet (black water) contains human waste, band associated bacteria, viruses and pathogens. Wastewater from other sources (grey water) is generally free of these potential health hazards. Current wastewater collection, treatment and disposal practices put very high pressure on water and energy resources and the environment making it unsustainable especially for small island communities. This paper analyzes the current collection, treatment and disposal of domestic wastewater and explores opportunities of managing wastewater in a more sustainable way.

This effort is focused on existing domestic water allocations, and collection, treatment, and disposal of treated water in to the environment. Current design daily per capita water allocation is about 100 gallons, of which about eighty percent is collected for treatment. Black water contribution to wastewater is about five percent. However, this small fraction is combined with the grey water eventually making eighty gallons of black water per person per day. Keeping the black and grey water in separate trains from collection to treatment to disposal will result in energy savings, more sustainable water reuse and greatly reduces discharges to the environment.

Analysis of existing information and comparing with other less water using systems show that separate collection and treatment of domestic black water and grey water result in great benefits to small island communities. This combined with alternate transport systems and altering existing treatment processes will greatly reduce the pressure on water resources, energy cost and environmental degradation in the face of anticipated climate change.

Keywords
Wastewater, environment, management, low pressure systems, sustainability, climate change