Using LiDAR Measurements of Canopy Structure to Estimate Rainfall Interception

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Hawaii continues to experience increasing demand for water resources, putting pressure on existing sources and increasing the need for better estimates of resource capacity. For ground-water sources, in particular, reliable estimates of sustainable yield limits are critically important. Groundwater recharge estimates, in turn, are needed to determine accurate safe yield limits. Recharge is highly spatially variable in Hawaii, because of extreme gradients in precipitation and evapotranspiration (ET).

The accuracy of recharge estimates in Hawaii has been limited by a lack of direct measurements of ET within forested recharge areas. Recent research has improved our knowledge of stand-level ET in Hawaii and pointed to the need to better understand interception loss, the amount of rainfall intercepted by leaves and stems and subsequently evaporated. The amount of interception loss, which can vary from 10 to 50% of incoming precipitation, is strongly influenced by canopy structure, especially canopy gap fraction, leaf, stem and epiphyte storage capacity, and branch angle, and hence is highly variable across the forested landscape.

Alien trees, some of which such as *Psidium cattleianum* (strawberry guava) are highly invasive, are markedly different in structure from native trees, such as *Metrosideros polymorpha* (ohia). Very little is known about the rate and spatial variability of interception loss and the effects of alien tree introductions on interception in Hawaii. Better estimates of interception are needed to improve water resource assessments. Such improvements would be highly valuable to water supply purveyors of the various counties and State water planners.

The traditional method for measuring interception, based on canopy water balance, is difficult and very limited in spatial coverage. But, recent advances in ground-based and airborne LiDAR technology offer the promise of spatially-distributed estimates of interception using a physically-based approach.

This project will allow the researchers to better characterize canopy properties that control the partitioning of rainfall. This work will lead to improved estimates of canopy rainfall interception in Hawaiian forests. Better estimates of canopy rainfall interception will have direct benefits in the form of more accurate water resource assessments in Hawaii.
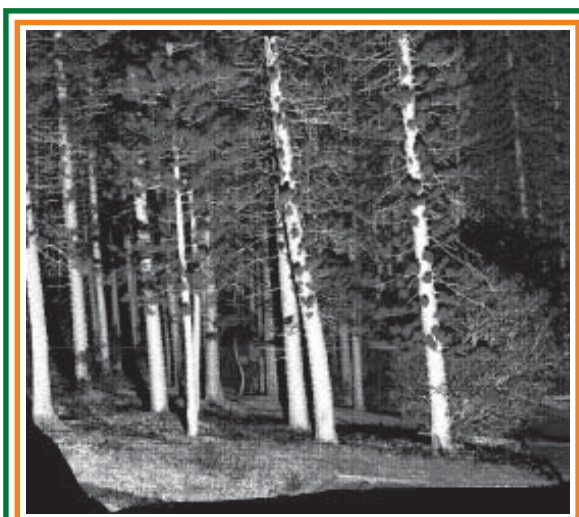

Image derived from high-resolution LiDAR scan made on Wa'ahila Ridge, Oahu

While the evaluation and testing of LiDAR-derived parameters for estimating interception at two study sites will make a valuable original contribution, the ultimate goal is to couple these results with airborne LiDAR data to estimate interception loss over large areas in Hawaii. The researchers currently collaborate on related research with Dr. Gregory Asner of Carnegie Institution, who is a leader in the use of airborne LiDAR and hyperspectral data to investigate ecological processes in tropical forests.

For the next step in their study the researchers will team with Dr. Asner to seek extramural support from the NSF Hydrology Program. Using the results obtained with the pilot study described here, they will develop a proposal to combine wet-canopy water balance measurements, and ground-based and airborne LiDAR to derive the spatial distribution of interception loss rates over the important recharge areas in Hawaii.

Canopy water storage has been shown to be highly variable from place to place in Hawaii's forests due to the diversity of structural characteristics related to morphological variability in native species and to the influences of

canopy structural variables that control the amount and disposition of rainfall deposited on plant leaves and stems. This newly available technology facilitates for the first time the use of mechanistic models to fully describe the partitioning of rainfall into throughfall (TF), stemflow (SF), canopy storage capacity (S), and interception evaporation (I).

The objective of this project is to utilize a newly-acquired LiDAR system and existing state-of-the-art field measurement facilities to develop and test a new method for estimating interception in Hawaii's native and invaded forests.
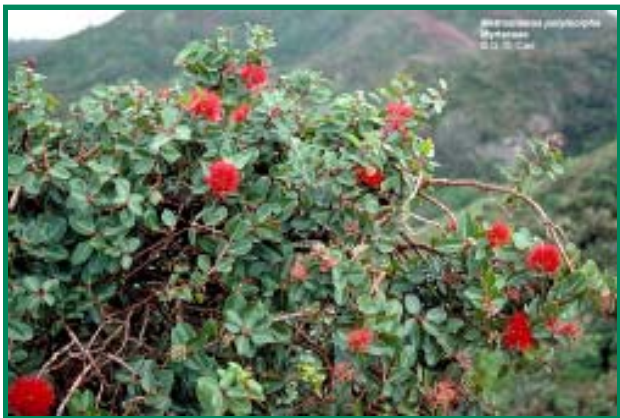
Metrosideros polymorpha, 'ohi'a-lehua. A common native forest tree in Hawaii.

The researchers will use this ground-based LiDAR system to map the 3-dimensional above-ground biomass distribution at two existing study sites within Hawaii Volcanoes National Park. The two sites represent intact native *M. polymorpha* forest and a *P. cattleianum*-dominated invaded forest.

At each site, they are operating state-of-the-art instrumentation to measure the exchanges of water vapor, carbon dioxide, and energy between the forest and the atmosphere, and to observe the pathways of water entering the forest canopy as rainfall or fog interception. With the newly purchased LiDAR, the researchers will acquire high-resolution scans of each stand, over an area of 0.36 ha surrounding each tower. These data will be used to determine the following canopy structural parameters: canopy gap fraction, tree density, leaf area index, tree height, lower crown limit, basal area, canopy biomass, canopy area index, stem diameter, branch diameter, and branch inclination angle. This information is needed to set parameter values (canopy capacity, canopy cover fraction, trunk storage

Ground-based LiDAR instrument

What is LiDAR?

LiDAR (Light Detection and Ranging) is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevalent method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves instead of light, using LiDAR the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. LiDAR employs laser light which typically has a very narrow beam allowing the mapping of physical features with very high resolution compared with radar.

capacity, free throughfall coefficient, and fraction of water diverted to stemflow) in the revised analytical interception model developed by Gash (1995). Drs. Giambelluca and Chen will use this model to estimate TF, SF, and I, and compare the results against their measurements of TF and SF at each site.

The researchers are setting up 4 x 4 grid plots (grid size = 20 m) at the sites and will scan the trees from each grid node. With a total of 16 scans at each site, they will be able to fully characterize trees from different views within an area of 60 by 60 m².

The raw LiDAR data will be registered into a common coordinate system using the InnovMetric© point cloud software and/or common feature matching methods. With the registered point cloud, they will then apply a morphological filtering algorithm to separate ground and canopy returns. The researchers will use ground and canopy returns to generate a digital elevation model (DEM) and a canopy height model (CHM), based upon which they will further delineate individual tree crown polygons. Once the trees are isolated, individual tree height, crown size, and lower crown limit can be extracted by analyzing the laser points within each crown polygon. The tree density can be summarized using the spatially-explicit individual tree map.

Gash, JHC., Lloyd, C.R., Lachaud, G. 1995. Estimating sparse forest rainfall interception with an analytical model. *Journal of Hydrology* 170:79-86

The Strawberry Guava Threat to Hawaii's Native Forests

"The strawberry guava, or waiawi-, is a Brazilian tree that was brought to Hawai'i in the 1820s. People in Hawai'i today are most familiar with the plant because of the popular jellies and sauces made from the strawberry guava fruit. Since its introduction nearly 200 years ago, strawberry guava has encroached steadily into Hawaii's native wet forests, entirely taking over vast swaths of the landscape and threatening the continued survival of native 'o-hi'a and koa forest ecosystems. As strawberry guava encroaches further and further into Hawaii's forests, native trees and plants are crowded out by the dense thickets and cannot reestablish themselves, which in turn means that natural habitat and food for native birds and insects are destroyed.

The strawberry guava fruit also poses a problem as it leads to an increase in fruit flies (which threaten local agriculture) and facilitates the spread of avian malaria that is a major threat to the survival of Hawaiian native forest birds (the fruit attracts feral pigs that in turn create holes and wallows that mosquitoes use for breeding; it is the mosquitoes that infect birds with malaria).

Additionally, Hawaii's water supply is put at risk by strawberry guava. Research at Hawai'i Volcanoes National Park conducted by University of Hawaii's Professor Thomas Giambelluca shows that strawberry guava evapotranspires 27% more water than trees and plants native to Hawai'i. What this means is, as native forests are replaced by strawberry guava thickets, less water is entering into our stream and groundwater systems, which translates into less water for human uses such as drinking water and irrigation of agricultural crops."

http://hawaiiconservation.org/strawberryguava.asp

Hilo Landfill Leachate Treatability Study

WRRC researcher and Civil Engineering professor Roger Babcock, Jr. has been working on a landfill leachate study for the Hilo Municipal Landfill. Hawaii County is considering an expansion of the existing landfill. The current landfill has no underliner system, and therefore precipitation that infiltrates through the waste pile discharges to the underlying aquifer system. In order to be in compliance with State and Federal regulations, any newly constructed landfill cell at the site would have to include an underliner system to allow collection and removal of infiltrating water (leachate). Due to the high precipitation rates in the Hilo area, the generation of a substantial volume of leachate is anticipated. The leachate is likely to include dissolved metals and organic compounds.

Installation of a leachate collection pipe in a lined landfill

Several alternatives are available for leachate management, and these fall into two broad categories: 1) on-site treatment and discharge and 2) transport to a local wastewater treatment facility for treatment and discharge. On-site treatment and discharge often proves to be the most cost-effective approach, especially if the leachate contains relatively low concentrations of contaminant compounds. Dr. Babcock has been evaluating on-site leachate treatment technologies in advance of more formal landfill design efforts that have not yet been initiated. The results of his study are intended to provide guidance to the selection of leachate management technologies and future design efforts.

This research project is a collaboration involving personnel and other resources from the Honolulu office of ERM and Integral (environmental consulting firms) and the University of Hawaii. The scope of work being conducted by Dr. Babcock is as follows:

1. Leachate characterization:

Leachate collected from the current waste pile is being characterized for various chemical constituents including: Biochemical oxygen demand (BOD5), chemical oxygen demand, total organic carbon, total nitrogen, total phosphorus, pH, alkalinity, and total dissolved solids.

2. Technology screening and treatability studies:

A suite of proven and innovative technologies is being screened for inclusion in treatability tests. Approximately 3-4 of the most promising technologies will be selected for more detailed evaluation using a formal technology screening process. Possible technologies to be screened include: wetlands treatment, biological oxidation and membrane filtration (among others). For one or more of the candidate technologies selected through the screening process, treatability studies will be conducted with

Hilo Landfill Leachate Treatability Study continued...

actual leachate to determine treatment efficiencies and general design parameters.

Upon completion of the technology screening process and focused treatability studies, UH will work with Integral on conducting an Alternatives Analysis based on the Feasibility Study Guidance developed by the U.S. EPA's CERCLA (Superfund) program. A comparative analysis of technologies will consider treatment effectiveness, implementability and cost. The findings of this Alternatives Analysis will be presented in a Final Report, to include results of the technology screening and treatability study work.

USGS Scientist Visits WRRC

Former WRRC Researcher Dr. Muruleedhara Byappanahalli recently paid the Water Center a visit. Dr. Byappanahalli is currently working as a Research Microbiologist with the Ecosystem Health and Restoration Branch of the Public Lands Section at the Lake Michigan Ecological Research Station in Porter, IN. Dr. Byappanahalli returned to Hawaii with several objectives. One was to meet with and advise WRRC's Dr. Roger Fujioka's research team regarding his recent research findings.

Dr. Byappananhalli

Another was to make a presentation and hold discussions with the Hawaii wastewater scientific group at the Hawaii Water Environment Association Annual Conference, held on Feb. 4, 2009. Here he informed the group about his recent research results, obtained in the Great Lakes region, which support the findings of studies conducted in Hawaii. Dr. Byappanahalli also presented a seminar to the research group at the University of Hawaii and the Honolulu USGS Office about the USGS Ocean Research Priorities Plan and his research group's implementation project. This seminar was sponsored by Water Resources Research Center and Pacific Research Center for Marine Biomedicine. Dr. Byappanahalli also met individually with a number of Hawaii-based researchers to discuss his current research. Dr. Byappanahalli's visit was extremely busy and well-spent. We were pleased to welcome him "home" to Hawaii and are proud of his accomplishments and success as a leading research microbiologist since he left us in 2001.