STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
COMMISSION ON WATER RESOURCE MANAGEMENT
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STAFF SUBMITTAL

COMMISSION ON WATER RESOURCE MANAGEMENT

June 16, 2020
Honolulu, Hawai‘i

Authorize the Chairperson to Enter Into a Joint Funding Agreement with the U.S. Geological Survey for a Water Budget Sensitivity Study, Island of Maui, Hawai‘i

SUMMARY OF REQUEST

That the Commission on Water Resource Management (Commission) authorize the Chairperson to enter into a Joint Funding Agreement with the U.S. Geological Survey (USGS) to conduct a water budget sensitivity study for the island of Maui.

BACKGROUND

In 1903, the Governor of the Territory of Hawai‘i approved Act 44, enacted by the territorial legislature, to designate forest reserves and extend the reserve system to protect ground water supplies. Extensive cattle grazing in native forests during the 1800s had resulted in significant deforestation. Public and private concerns about water supply and quality were the impetus for placing the forests into reserves and undertaking massive reforestation projects at the turn of the century. Through Act 44, the Territory of Hawai‘i established one of the first forestry agencies in the nation, with the authority to establish forest reserves for the protection of springs, streams, and other water supply sources. This policy of watershed protection resulted in dramatic improvements from the degraded conditions due to overgrazing that prevailed at the turn of the century.

The intent of Act 44 is implemented today through the enabling statutes for the Division of Forestry and Wildlife (DOFAW), which states that Department of Land and Natural Resources (DLNR) shall "*devise ways and means of protecting, extending, increasing, and utilizing the forests and forest reserves, more particularly for protecting and developing the springs, streams, and sources of water supply to increase and make that water supply available for use*." Hawaii Revised Statutes (HRS) §183-1.5(4)

DOFAW carries out this mission through programs such as the Natural Area Reserves System, the Natural Area Partnership Program, and the Watershed Partnership Program.

Although these programs excel at managing the forest resources of the mauka watersheds, the impact of management on water resources is not well understood. Limited data exists to link watershed management programs with changes in ground and surface water resources. There needs to be a better understanding of the regional impacts of native and non-native plant species on freshwater availability.

The Commission appreciates this need for research and data and supports the missions of DOFAW and other watershed management organizations through several program areas. One of these is the cooperative hydrologic monitoring program with the USGS. This long-term monitoring program collects rainfall, ground water, and surface water data from monitoring stations throughout the State. The data from this program allows managers to observe trends in Hawai‘i’s water resources that are associated with land use change, seasonal climate variability, and climate change. This program currently funds monitoring stations in several watersheds on O‘ahu as a means to observe hydrologic responses to watershed management activities.

The Commission also funds research that is vital to understanding the impacts of watershed management on water supplies. These include the regular updates of ground water recharge estimates and development of numerical ground water models by the USGS, and updates of the Rainfall Atlas of Hawai‘i and statewide estimates of evapotranspiration rates by the University of Hawai‘i. Despite these ongoing efforts, gaps in the understanding of the hydrologic processes that occur in the watershed still exist. The high cost of protecting mauka watershed areas underscores the importance of the need to support research that helps water resource managers determine how watershed protection efforts impact the sustainability of fresh water supplies.

To address this need, in 2016, the U.S. Geological Survey (USGS) proposed a study to collect information that will lead to a better understanding of the hydrologic impacts of native and non-native plant species on freshwater availability on Maui and throughout the State of Hawai‘i. The overall objective of the study is to provide valuable information for (1) assessing species-specific impacts on freshwater availability and (2) reducing uncertainty in regional recharge estimates associated with forested areas.

The study was developed as an outcome of a series of three workshops with stakeholders such as the Maui watershed partnerships and the Maui Department of Water Supply (MDWS). To accomplish the overall objective, intensive field investigation needs to be conducted to quantify plot-scale rates of rainfall, net precipitation, cloud-water interception, evapotranspiration (ET), infiltration, and groundwater recharge for different plant species. The selection of plant species and suitable study sites is a necessary and critical first step towards achieving the overall study objective. Therefore, to ensure the implementation of the study with existing fiscal resources, the effort was divided into two phases: Phase 1A, a species-evaluation and site-selection phase, and Phase 1B, an intensive field data-collection phase.

PHASE 1A: SPECIES EVALUATION AND SITE SELECTION

On April 19, 2016, the Commission authorized the Chairperson to enter into a Joint Funding Agreement (JFA) with the USGS for the first phase (Phase 1A) of the study to quantify the impacts of high-priority non-native and dominant native plant species on freshwater availability on Maui and throughout the State of Hawai‘i.

The total cost of Phase 1A was $302,000. The Commission shared the cost of the effort with MDWS and the USGS with the Commission's contribution totaling $50,000.

Contributions from each participant were as follows:

USGS	$55,000
CWRM	$50,000
MDWS	$197,000
TOTAL	$302,000

The study was subsequently expanded to include the islands of Kauaʻi, Oʻahu, Molokaʻi, and Hawaiʻi through the participation of other funding partners and collaborators.

The objectives of Phase 1A were to: (1) determine how transpiration rates are dependent on species type within forested areas; (2) determine how understory and overstory forest species influence stand-level transpiration rates; (3) determine how infiltration rates and soil hydrophobicity are dependent on species type; and (4) develop a detailed study plan and proposal for Phase 1B. Phase 1B was to involve field monitoring to quantify plot-scale rates of rainfall, net precipitation, cloud-water interception, ET, and groundwater recharge for different plant species.

Phase 1A consisted of the following five (5) tasks:
1. candidate site review and reconnaissance,
2. data collection to measure transpiration and infiltration rates for selected species and study sites,
3. data processing and analysis to accomplish Phase 1A objectives,
4. proposal development for Phase 1B, and
5. stakeholder/cooperator engagement to present Phase 1A results and a proposal for Phase 1B.

The results of the Phase 1A study revealed that it was difficult to determine which species have greatest potential for water-resource impacts without data collection (evapotranspiration (ET) measurements, infiltration measurements, and species distribution information or maps). Furthermore, there were significant challenges with paired-plot design for data collection, including the inability to find paired plots for many target species and to find paired plots in a range of conditions related to aspect (windward and leeward) and elevation (above and below cloud base). Plot vegetation is often mixed making it difficult to isolate monotypic stands for target species.

The Phase 1A study found that the results from infiltration testing are equivocal and concluded that the results from site reconnaissance do not support paired-plot design for all species. As a result, it is recommended that a shift be made from a sequential approach with a large field investigation component (Phase 1B) to an iterative approach with focused studies. This would allow the management objectives of multiple stakeholders to be addressed and inform priorities for future work to quantify the impacts of non-native species on freshwater resources.

A summary of the results of the Phase 1A study and proposed next steps are summarized in a presentation prepared by USGS and attached as Exhibit 1.

PROPOSAL FOR WATER BUDGET SENSITIVITY STUDY

This study replaces Phase 1B which initially envisioned intensive field data collection. The Phase 1A effort revealed the difficulties and costs associated with such an effort, so USGS decided to shift their initial approach and conduct a sensitivity analysis first on the vegetation parameters to better prioritize what data should be collected. This study is one of several proposed next steps to complete the objectives of the overall study to address the need to better understand regional impacts of native and non-native plant species on freshwater availability. Other proposed next steps include species distribution mapping, continued data collection, and groundwater modelling.

The water budget sensitivity study will help to identify the areas of greatest uncertainty, determine which aquifer systems are most affected, determine what types of additional data are most needed and where they should be collected, and inform future ground water modeling efforts. The proposal is attached as Exhibit 2.

The proposed study aims to:

- estimate the sensitivity of recharge estimates to selected model parameters that might be impacted by land-cover changes associated with watershed management or lack of watershed management,
- determine which of the selected model parameters are most critical for quantifying recharge within selected regions in Maui, and
- identify and summarize the types of information that could be collected for each selected parameter and region on Maui.

FUNDING

The total cost of this 1.5-year study is $100,000. USGS will fully fund the study. This JFA covers the first $50,000 of available federal funding. USGS plans to amend the JFA to add another $50,000 in the next federal fiscal year starting October 1, 2020 to complete the study.

Should additional federal funds or cost-share opportunity become available in the future, the study could be expanded to other islands. The Commission has identified completion of the overall study as a priority task in its 2019 Water Resource Protection Plan. The Commission had allocated $50,000 in FY 2020 to match the USGS' available funding. However, due to the economic fallout associated with the COVID19 virus, use of Commission funds has been restricted. Therefore, the USGS is now proposing to solely fund this water budget sensitivity study.

LEGAL AUTHORITY

Under its general powers and duties, the Commission has the authority to plan and coordinate programs for the conservation of water and to contract with private persons to assist with these programs. Under

Section §174C-5 (4), HRS, the Commission "*[m]ay contract and cooperate with the various agencies of the federal government and with state and local administrative and governmental agencies or private persons".* Section §174C-5 (13), HRS, further provides that the Commission *"[s]hall plan and coordinate programs for the development, conservation, protection, control, and regulation of water resources based upon the best available information, and in cooperation with federal agencies, other state agencies, county or other local governmental organizations and other public and private agencies created for the utilization and conservation of water"*.

ENVIRONMENTAL REVIEW CHAPTER 343, HAWAII REVISED STATUTES

This planning study is exempt from the application of HRS Chapter 343 pursuant to HRS §343-5(b) and Hawaii Administrative Rule §11-200.1-8(a). This is a planning-level study that will not involve testing or other actions that may have a significant impact on the environment.

RECOMMENDATIONS

Staff recommends that the Commission:

1. Authorize the Chairperson to enter into a Joint Funding Agreement with the USGS to conduct a water budget sensitivity study for the island of Maui.

2. Delegate authority to the Chairperson to amend or modify the Joint Funding Agreement as may be necessary to accomplish the goals described in the attached proposal, including the addition of the second increment of $50,000 in federal funding, provided that any amendment or modification does not require any Commission funding.

Ola i ka wai,

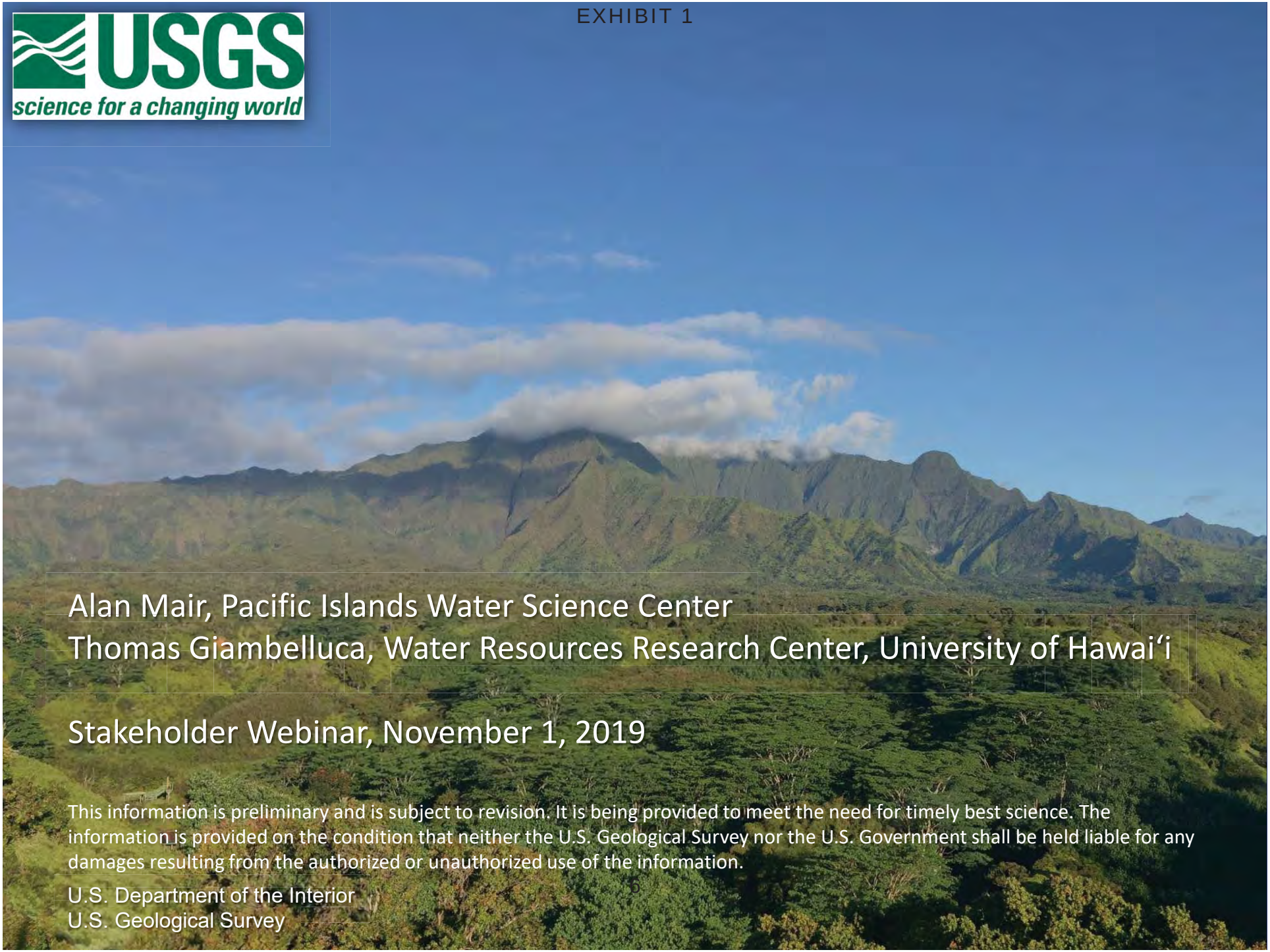
M. KALEO MANUEL
Deputy Director

Exhibits
1. Impacts of Non-Native Forest Species on Freshwater Resources in the State of Hawai'i: Proposed Next Steps
2. USGS Proposal to Identify Critical Information Needed to More Accurately Assess Potential Effects of Land-Cover Change on Groundwater Resources and Availability, Island of Maui, Hawai'i, May, 2020

APPROVED FOR SUBMITTAL:

SUZANNE D. CASE
Chairperson

EXHIBIT 1



Alan Mair, Pacific Islands Water Science Center
Thomas Giambelluca, Water Resources Research Center, University of Hawai‘i

Stakeholder Webinar, November 1, 2019

U.S. Department of the Interior
U.S. Geological Survey

EXHIBIT 1

Study Location

Species Identification, Site Selection, and Data Collection, Maui

Species Identification and Site Selection
Kaua‘i, O‘ahu, Moloka‘i, and Hawai‘i

Species Selection and Site Identification

- Total of 33 high-priority non-native species identified statewide
  - Difficult to find paired plots for many of the high-priority non-native species
  - Prioritization criteria did not focus on water-availability factors

Infiltration Measurements

- Infiltration measurements collected from paired plots at 5 study sites on Maui
  - Plot comparisons
    - Equivocal differences between native and non-native forests
    - Significant differences between native forest and grassland
  - Landscape comparisons
    - No significant differences between native and non-native forests
    - Significant differences between non-native forest and grassland

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Proposed Next Steps

- Modify paired-plot study design
- Shift from sequential approach with large field investigation component to iterative approach with focused studies
  - Addresses stakeholder management objectives
  - Informs priorities for future work to quantify impacts of non-native species on freshwater resources

Presentation Outline

- Purpose of overall study
- Completed study results
- Implications of results
- Proposed next steps

Goals and Benefits of Study

Goals

Provide information to

- Assess species-specific impacts on freshwater resources
- Reduce uncertainty in regional recharge estimates
- Assist in prioritizing watershed management

Benefits

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Study Objectives

- Identify high-priority forest species and possible study sites (statewide)
- Data collection (Maui):
  - Transpiration rates
  - Total leaf area
  - Infiltration rates
- Develop a statewide study design

Total Leaf Area

Infiltration Rates

Study Highlights

Infiltrometer testing

Leaf-level measurements

Candidate site reviews

Leaf-area measurements

Summary
Target Species Identification

- Total of 33 high-priority non-native species identified by stakeholders on 5 islands
- Identified species were not prioritized on water-resource considerations
- Difficult to determine which species have greatest potential for water-resource impacts without data collection
  - Evapotranspiration (ET) measurements
  - Infiltration measurements
  - Species distribution information or maps

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High-Priority Non-Native Species

Species Group	Common Name	Scientific Name
Group 1 Species identified on three or more islands	Strawberry guava	*Psidium cattleianum*
	Himalayan ginger	*Hedychium gardnerianum*
	Albizia	*Falcataria moluccana*
	Black wattle	*Acacia mearnsii*
	Pine species (Monterey, Maritime, Mexican weeping)	*Pinus radiata, P. pinaster, P. patula*
	Tropical ash	*Fraxinus uhdei*
	Christmas berry	*Schinus terebinthifolius*
	Silk oak	*Grevillea robusta*
	African tulip tree	*Spathodea campanulata*
	Eucalyptus species (Swamp mahogany, Saligna, Blue gum)	*Eucalyptus robusta, E. saligna, E. globulus*
	Ironwood	*Casuarina equisetifolia*
	Firetree	*Morella faya*
Group 2 Species identified on two islands	Gorse	*Ulex europaeus*
	Java Plum	*Syzygium cumini*
	Tree poppy	*Bocconia frutescens*
	Banana poka	*Passiflora mollissima*
Group 3 Species identified on one island	Australian Red Cedar	*Toona ciliata*
	Paperbark tree	*Melaleuca quinquenervia*
	Shoebutton ardisia	*Ardisia elliptica*
	Kukui	*Aleurites moluccana*
	Octopus tree	*Schefflera actinophylla*
	Haole koa	*Leucaena leucocephala*
Group 4 Pasture/grassland species	Guinea grass	*Megathyrsus maximus*
	Buffle grass	*Cenchrus ciliaris*
	Broomsedge, Barbas de indio, Bush beardgrass, Tufted beardgrass	*Andropogon virginicus, A. bicornis, A. glomeratus, Schizachyrium condensatum*
	Fountain grass	*Cenchrus setaceum*
	Kikuyu grass	*Pennisetum clandestinum*
Group 5 Shrub, substory, or poor paired-plot potential	Koster's curse	*Clidemia hirta*
	Australian tree fern	*Sphaeropteris cooperi*
	Miconia	*Miconia calvescens*
	Rubus species	*Rubus ellipticus, R. niveus*
	Daisy fleabane	*Erigeron karvinskisanus*
	Lantana	*Lantana camara*

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Candidate Paired-Plot Study Sites

Explanation

- Acacia confusa
- African tulip
- Albizia
- Albizia/S. guava
- Black Wattle
- Bocconia/Pine
- C. berry/A. confusa
- Christmas berry
- Clidemia
- Eucalyptus
- Eucalyptus/S. guava
- Ginger/T. ash
- Gorse
- Grass species
- Guava/Clidemia
- Guava/Ironwood
- Himalayan ginger
- Ironwood
- Kikuyu grass
- Kukui
- Paperbark
- Paperbark/Eucalyptus
- Pasture grasses
- Pine
- S. guava/C. berry/Silk oak
- Silk oak/ C. berry
- Slash pine
- Strawberry guava
- Tropical ash

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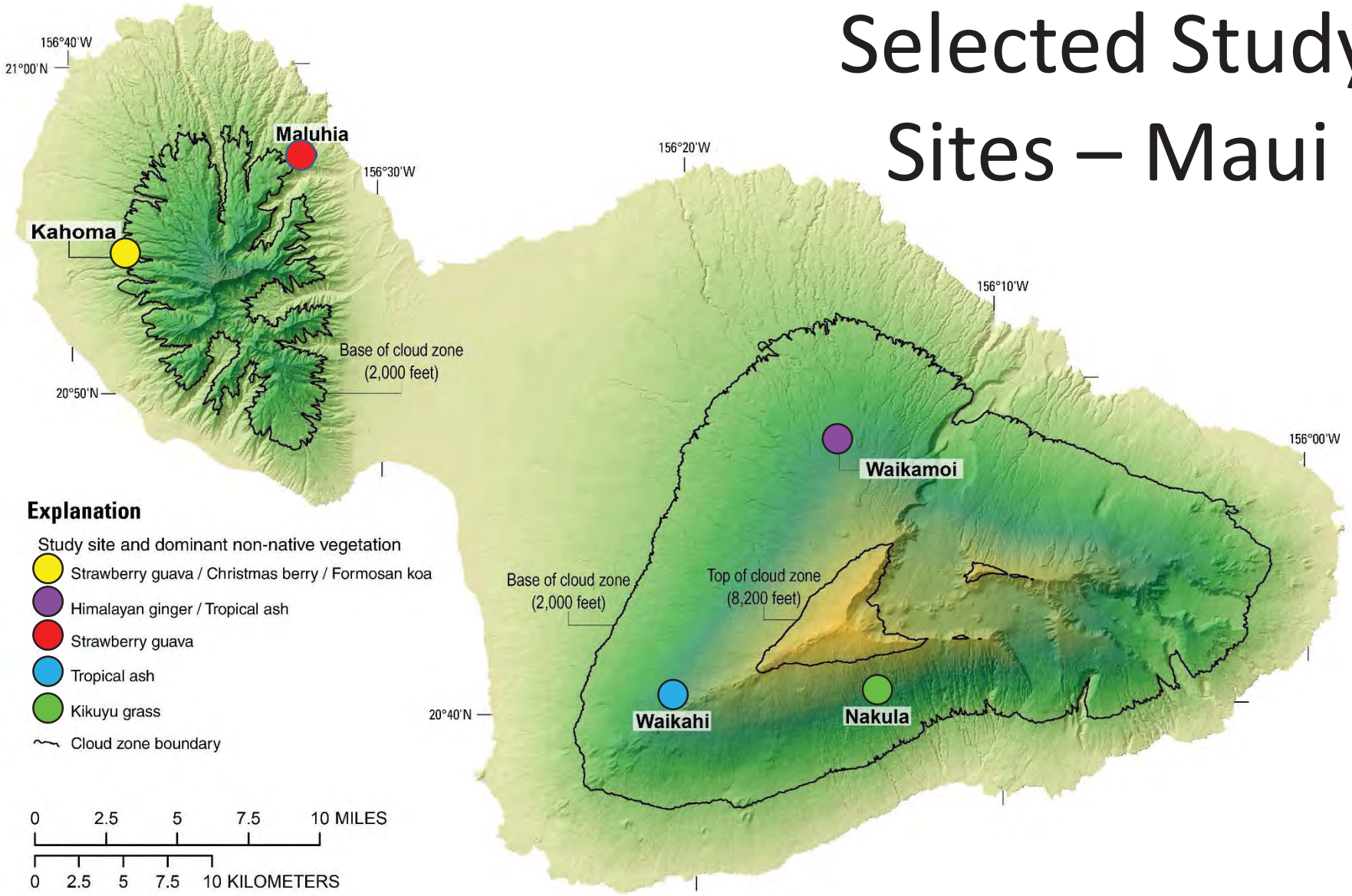
Summary
Candidate Site Reconnaissance

- Significant challenges with paired-plot design for data collection:
  - Unable to find paired plots for many target species
  - Unable to find paired plots in range of conditions related to aspect (windward and leeward) and elevation (above and below cloud base)
  - Plot vegetation is often mixed making it difficult to isolate monotypic stands for target species
- Results from site reconnaissance do not support paired-plot design for all species

Selected Study Sites – Maui



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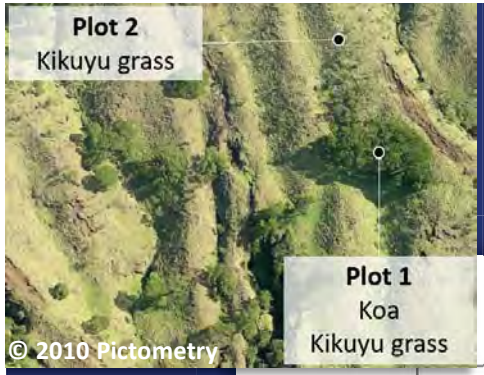
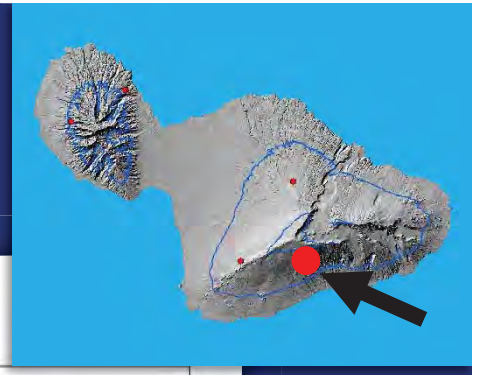
Infiltration Measurements Maui Data Collection

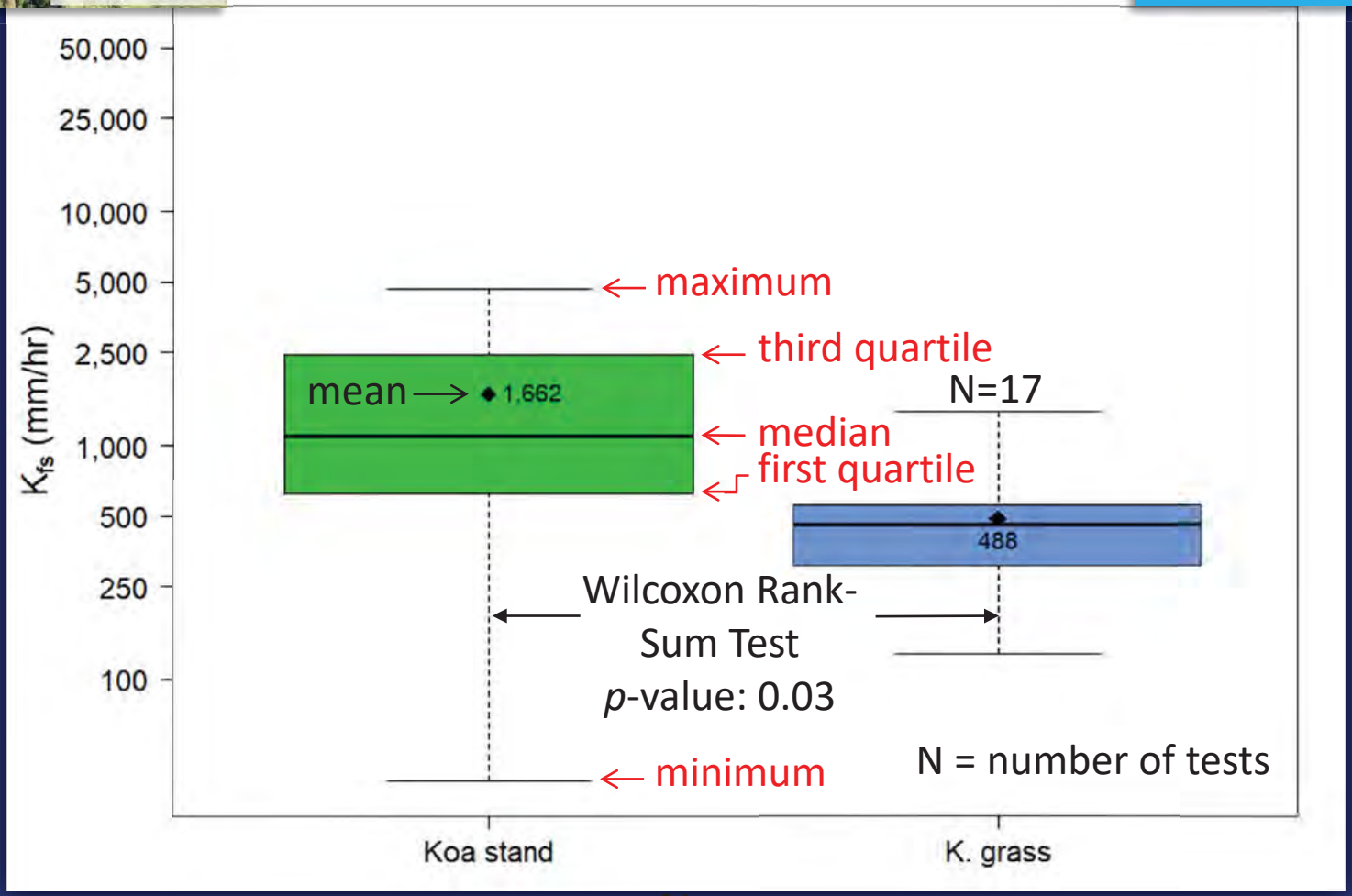
Paired-plot comparisons

- Field-saturated hydraulic conductivity (K_{fs})
- Soil hydrophobicity
- Preferential-flow assessment
- Soil particle-size analysis

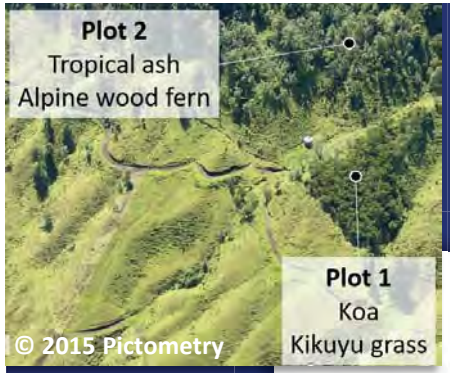
Nakula: K_{fs}

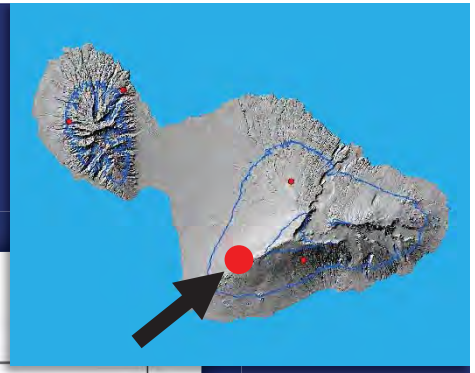


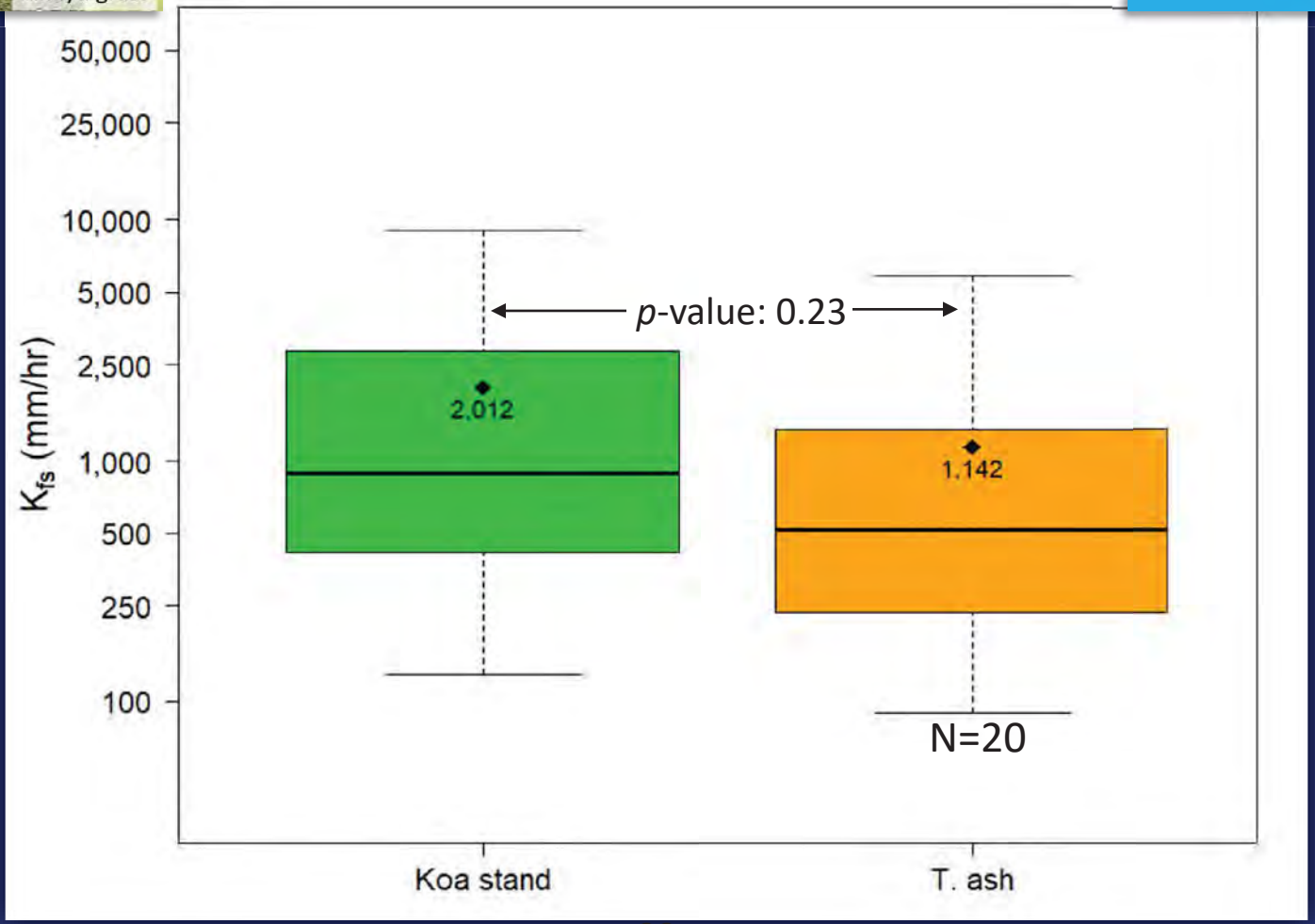




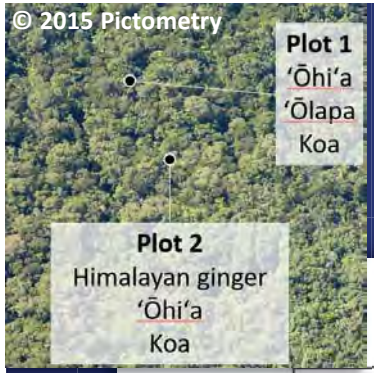
Waikahi: K_{fs}

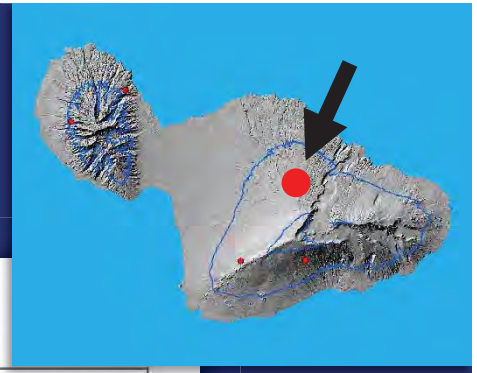


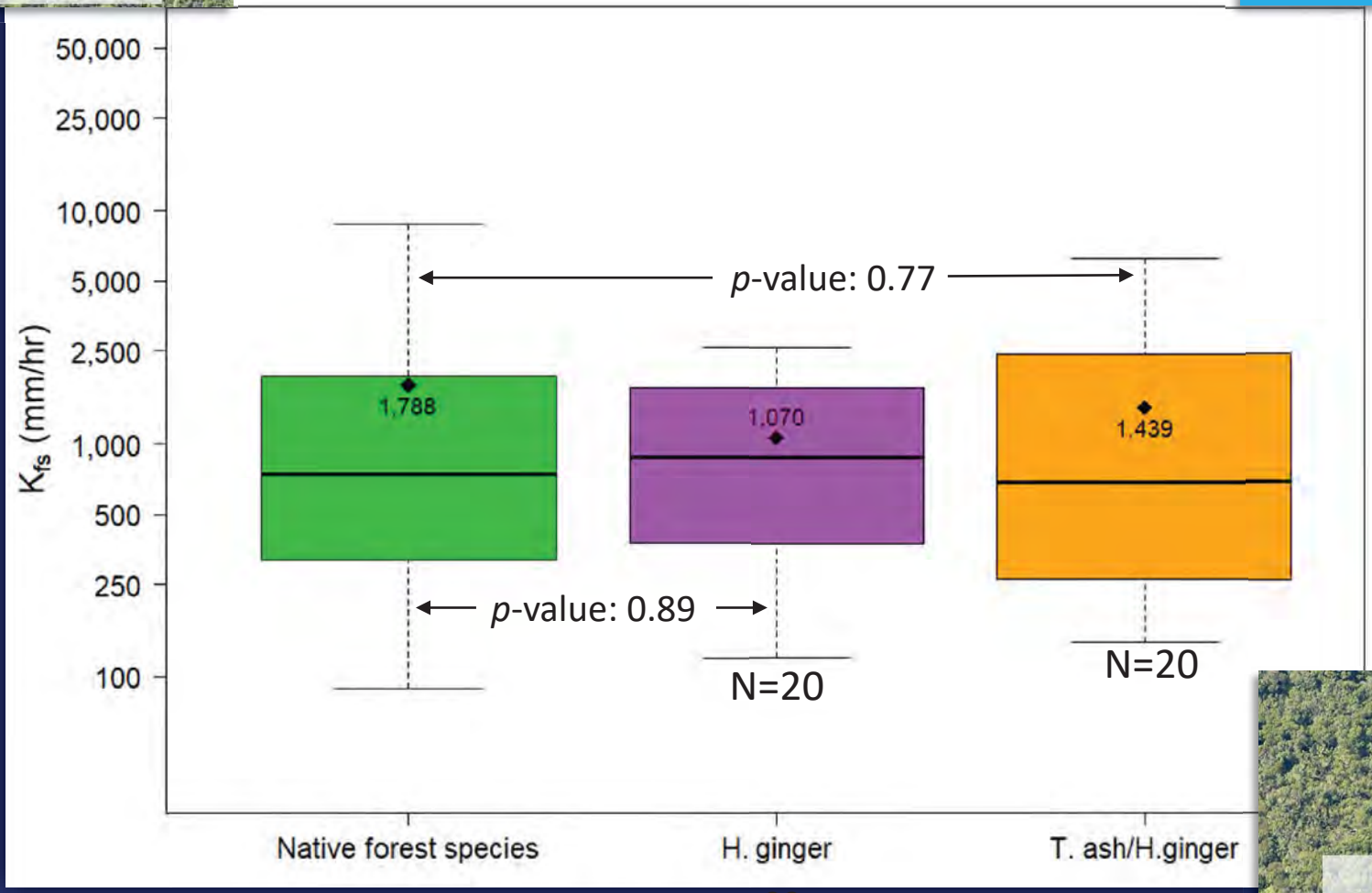




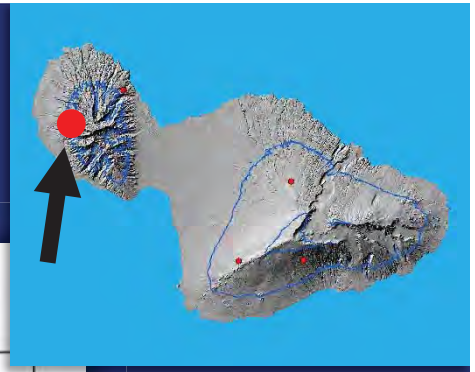
Waikamoi: K_{fs}

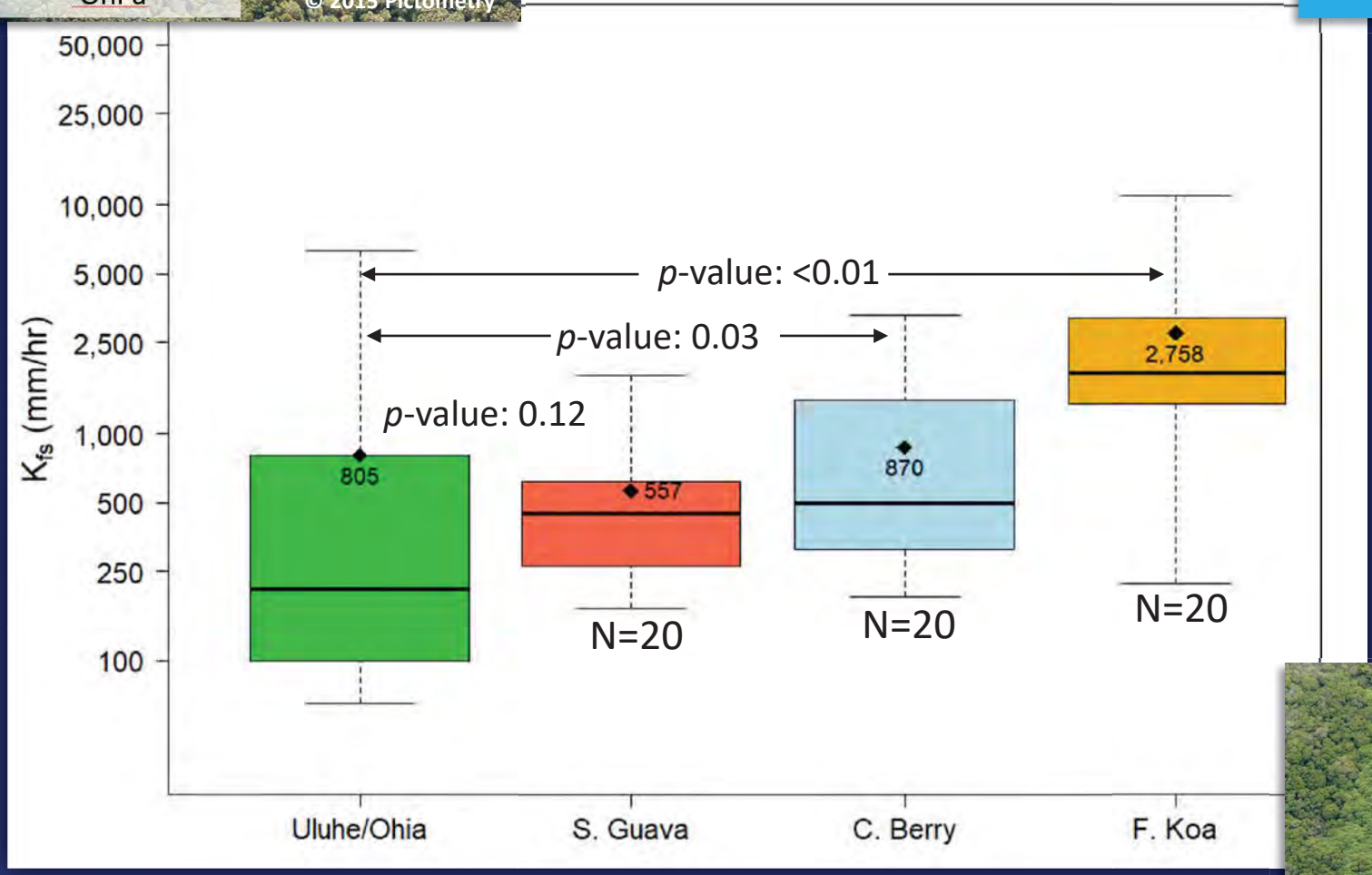


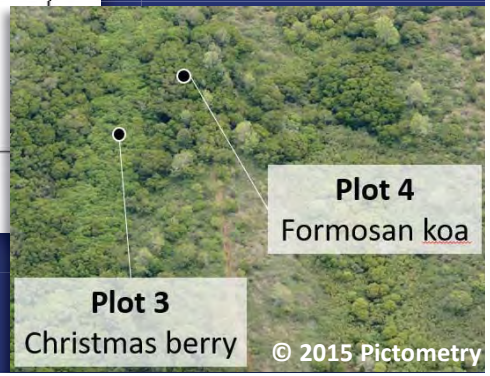




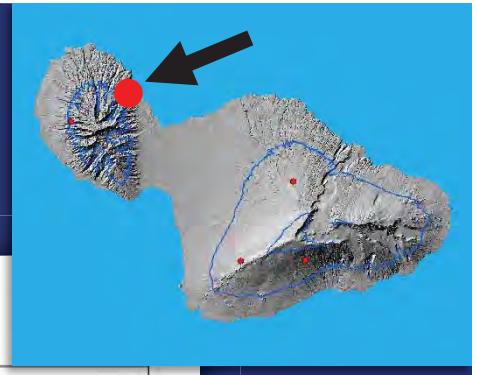
Kahoma: K_{fs}

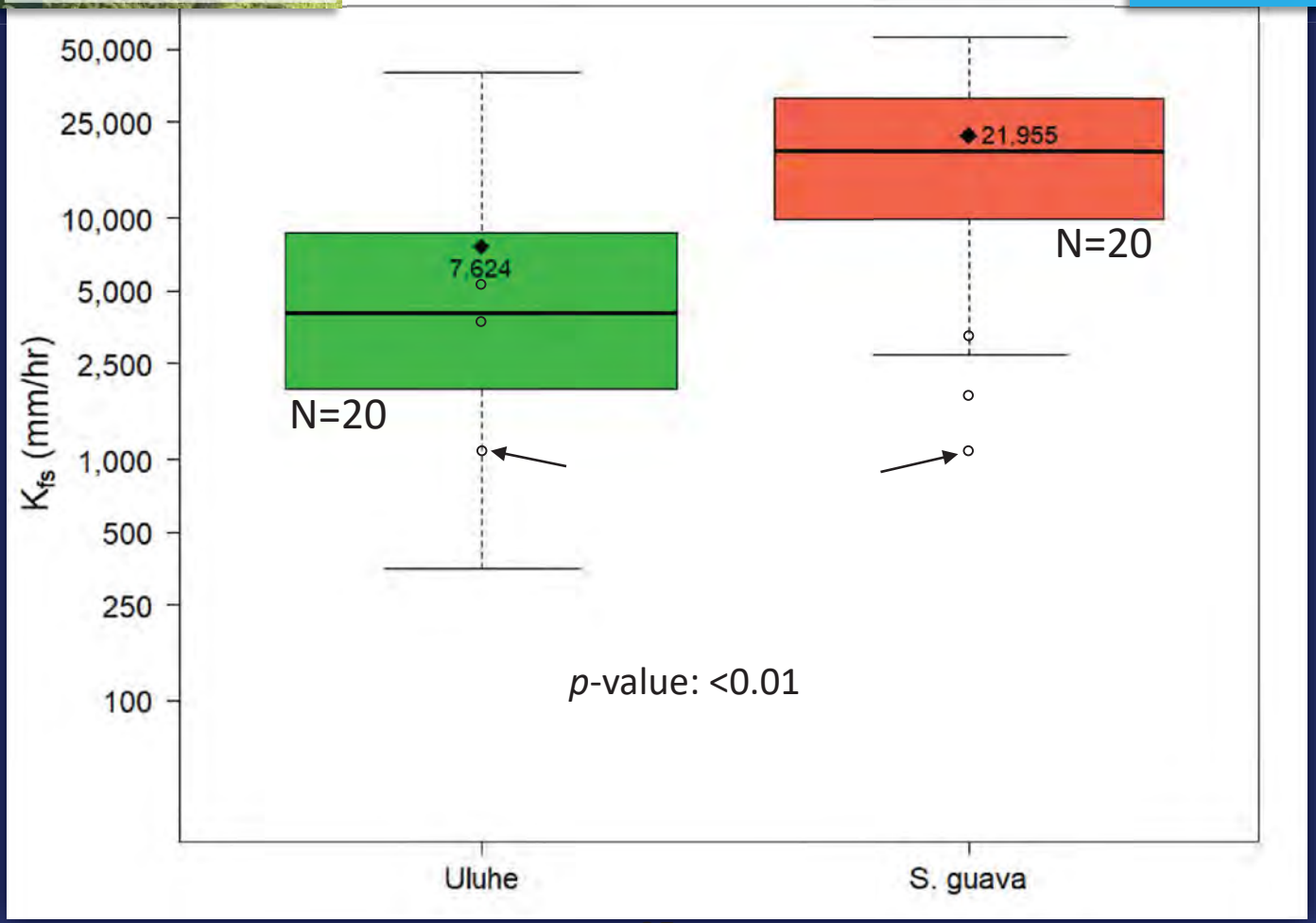






Maluhia: K_{fs}





Test site T-10
K_{fs} = 3,600 mm/hr

Test site T-03
K_{fs} = 24,000 mm/hr

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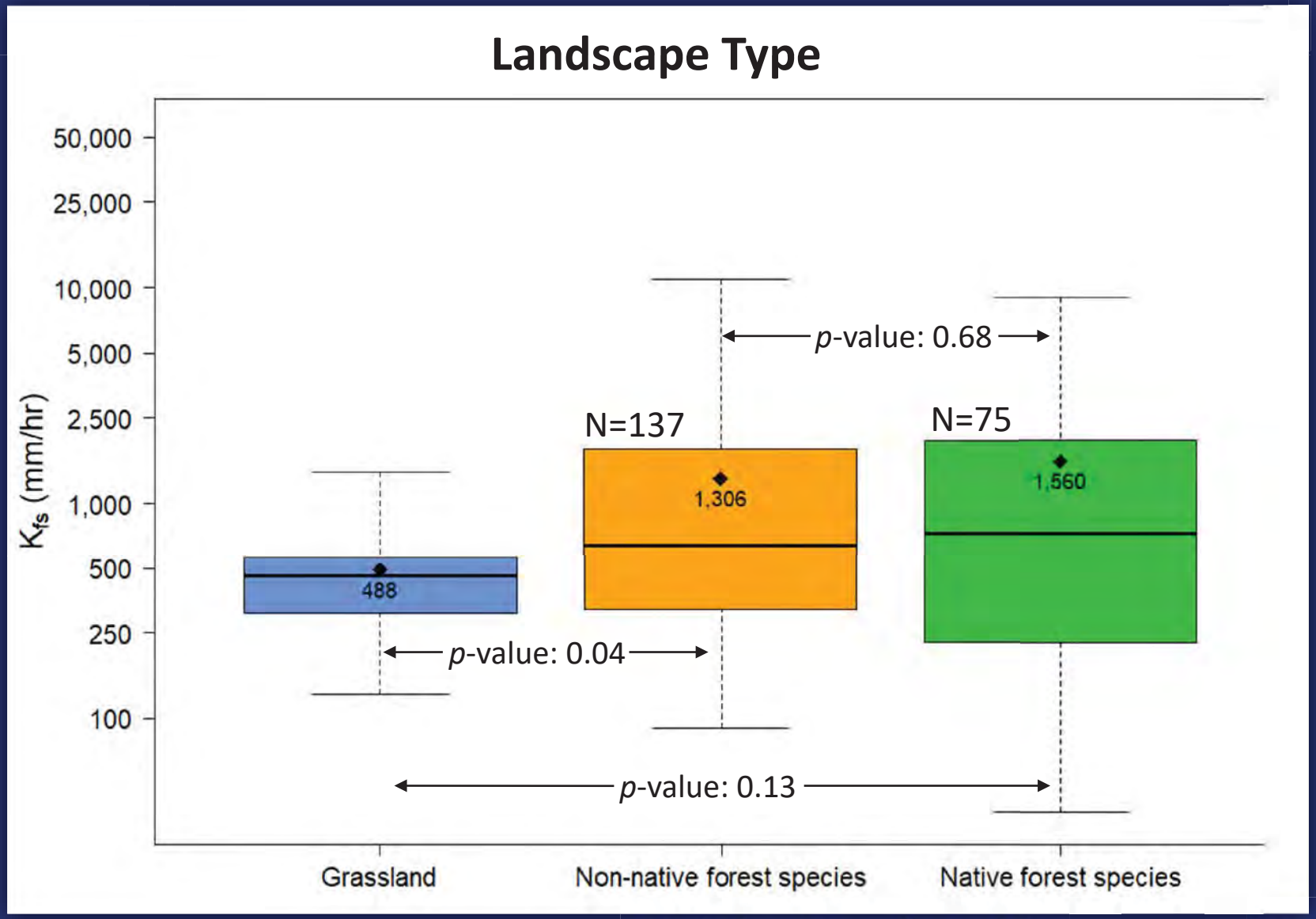
Field-Saturated Hydraulic Conductivity (K_{fs})



Excludes data collected from Maluhia plots

Summary – Infiltration Measurements Maui Data Collection

Plot comparisons

- Significantly higher K_{fs} values in native species plot at Nakula (Koa)
- Significantly higher K_{fs} values in plots with non-native species at Maluhia (S. guava) and Kahoma (C. berry, F. koa)
  - Horizontal or lateral flow likely cause of high K_{fs} values in S. guava plot at Maluhia

Landscape comparisons

- Mean and median native forest K_{fs} values are higher than those for grassland and non-native forest
- Non-native forest K_{fs} values are significantly higher than those for grassland
- Non-native and native forests K_{fs} values have greater range of variability than those for grassland

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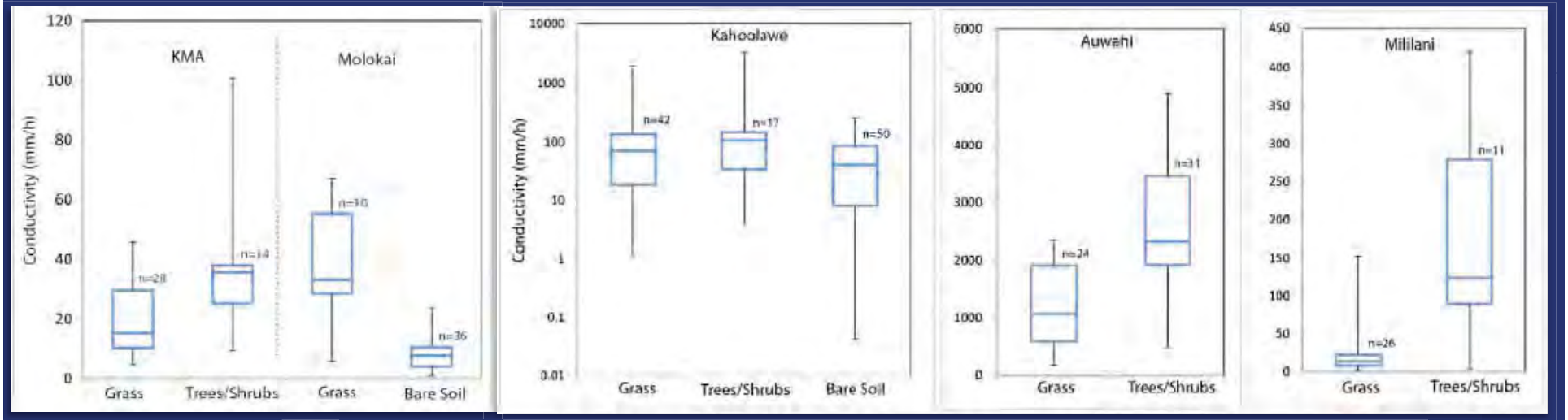
Ecohydrology

RESEARCH ARTICLE | Full Access

Vegetation influences on infiltration in Hawaiian soils

Kim S. Perkins, Jonathan D. Stock, John R. Nimmo

First published: 08 March 2018 | https://doi.org/10.1002/eco.1973



- K_{fs} measured at 290 locations across plot sites of forest, shrublands, grasslands, and bare soil
- Mean values: K_{fs} (trees/shrubs) > K_{fs} (grassland) > K_{fs} (bare soil)

Summary – Infiltration Measurements Comparison with Other Studies

- Measured K_{fs} values at Nakula are comparable to Auwahi
- Significant difference in measured K_{fs} values between grassland and native forest at Nakula, which is consistent with other studies
- Measured K_{fs} values at the other four sites are higher than values in other studies
- Mixed results in comparisons between native and non-native forest species

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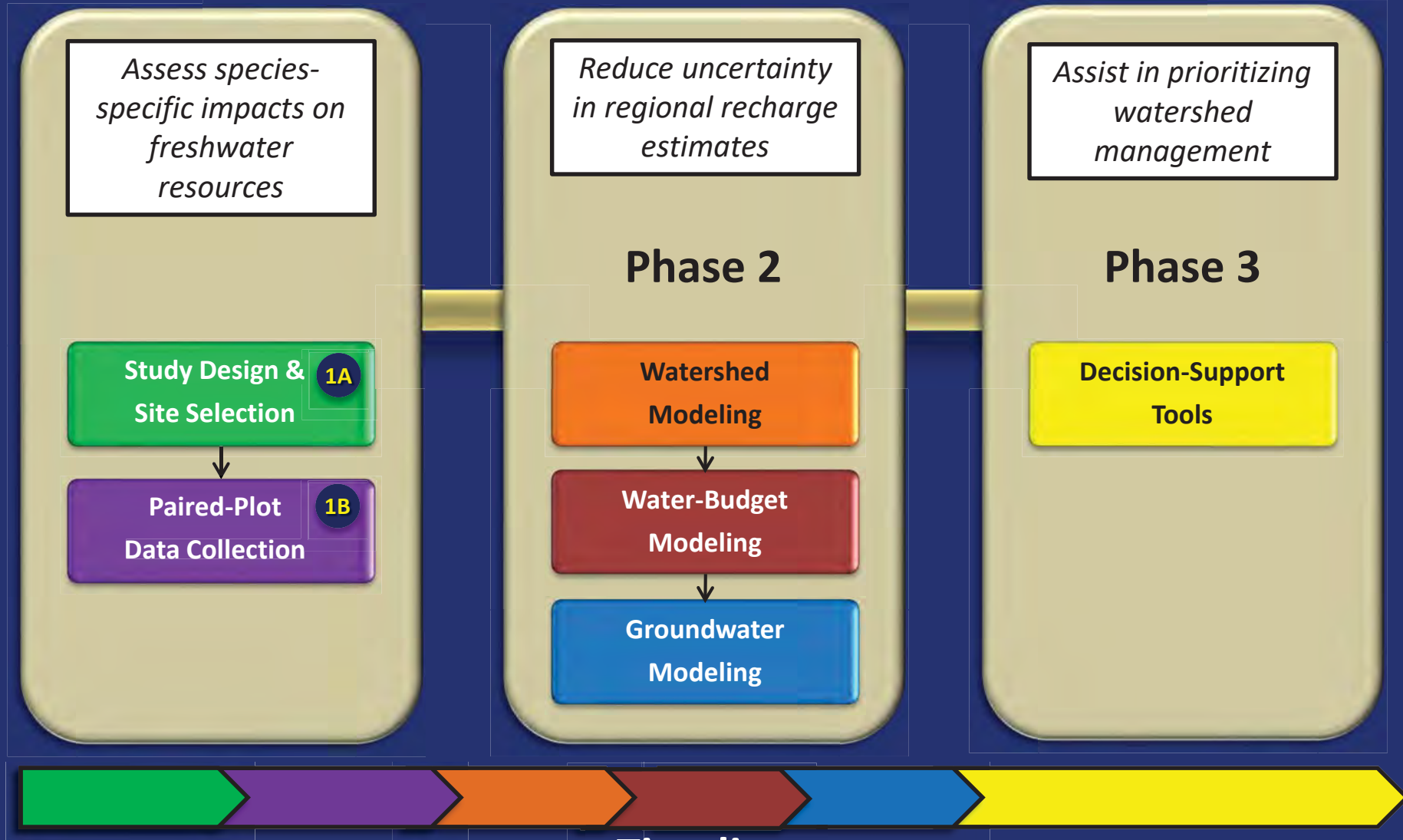
IMPLICATIONS OF RESULTS

Implications of Results Infiltration

- Need to modify paired-plot study design
- Results from infiltration testing are equivocal
- Shift from sequential approach with large field investigation component to iterative approach with focused studies
  - Addresses stakeholder management objectives
  - Informs priorities for future work to quantify impacts of non-native species on freshwater resources

Original Study Approach



Challenges with Original Approach

- Data collected do not provide clear basis for statewide study design
- Sequential approach requires extended timeline
- Potential data-collection costs may be high
- Difficult to identify monitoring strategy
  - By island?
  - By species?
  - By setting?
  - One comprehensively instrumented pilot site?

Updated Study Approach

Better understanding of species impacts on freshwater resources

Iteratively refined study design

Better watershed management for source water protection and enhancement

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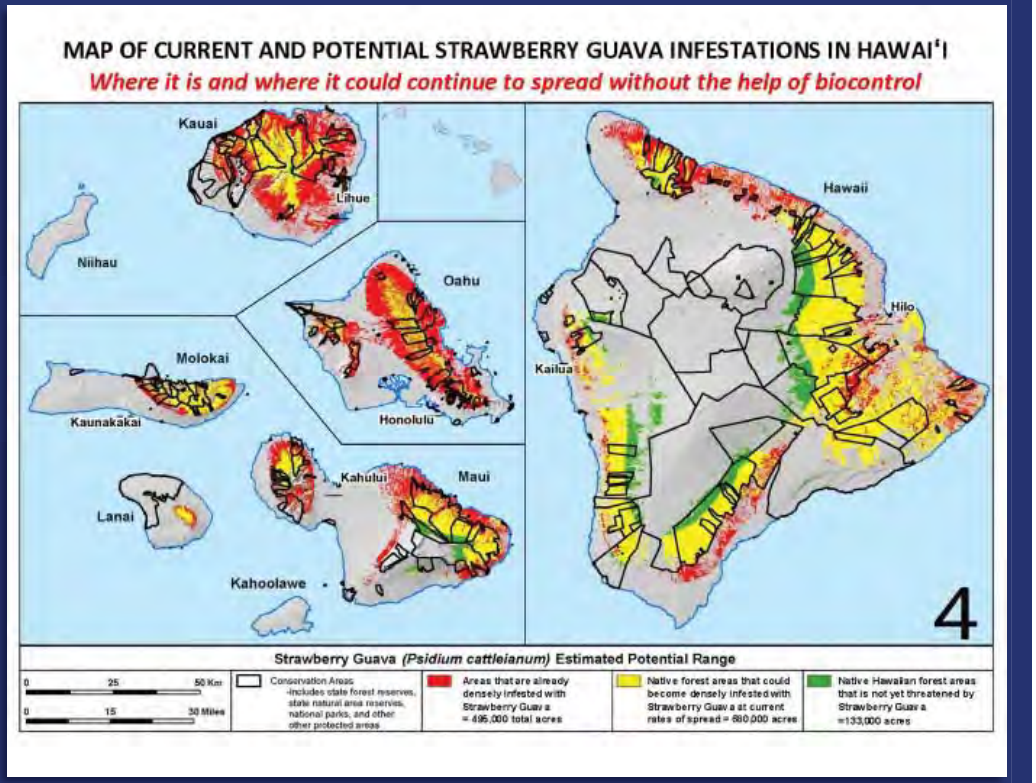
Proposed Next Steps

- Species distribution mapping (USGS-PIERC)
- Data collection (UH)
  - Leaf-level evaluation
  - Continuous monitoring at “anchor” stations
  - Statistical analyses to estimate transpiration
- Water-budget modeling (USGS-PIWSC)
- Groundwater modeling (USGS-PIWSC)

Invasive Species Distribution Mapping

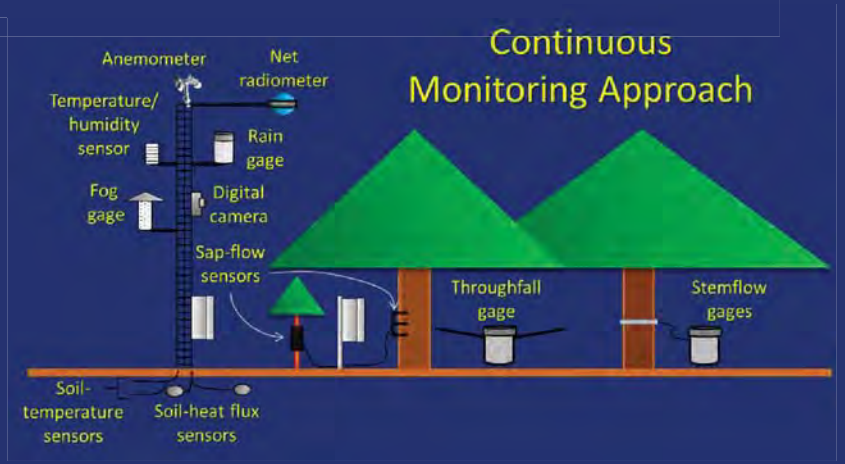
- Develop maps of the current and potential range of target species/forest communities to inform managers and assist with identifying data-collection needs and areas for modeling impacts to freshwater availability

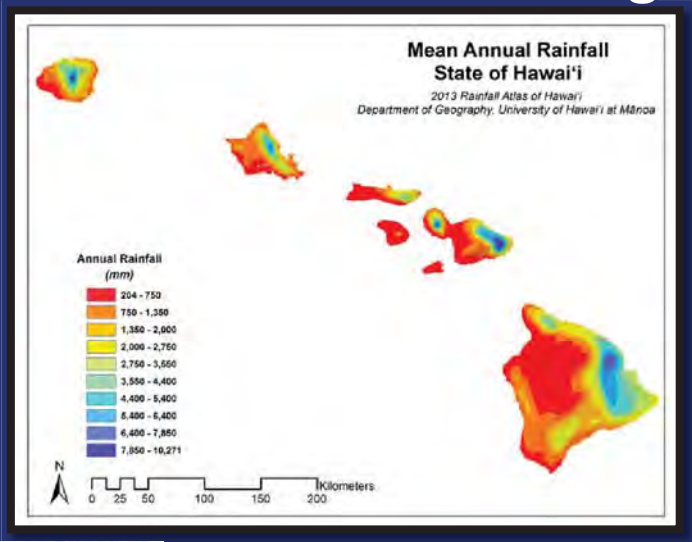


Data Collection: Field-Based Water Use Measurements and Modeling

Overall Study Objectives

- To understand how non-native species in Hawai‘i change ecosystem fluxes of water and impact water resources
- Support Water Budget and Groundwater Modeling





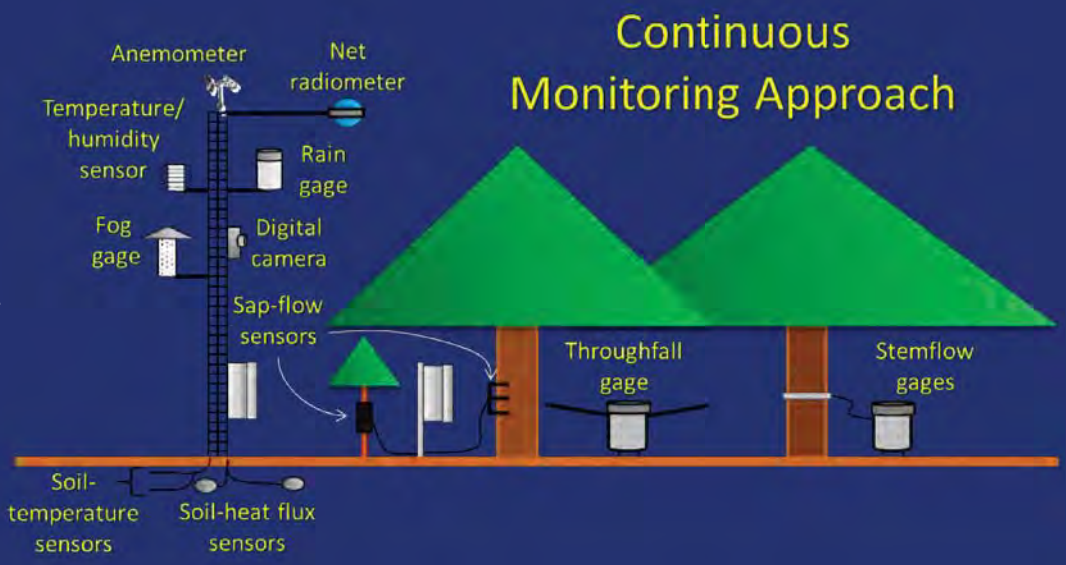
USGS science for a changing world

Data Collection: Field-Based Water Use Measurements and Modeling

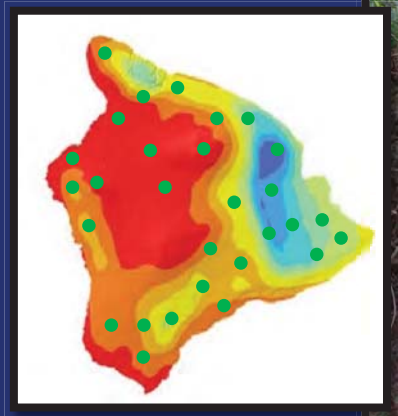
Continuous Monitoring at "Anchor" Stations

Approach

- Establish comprehensive water flux monitoring in carefully selected paired plots
- Measure all water fluxes through ecosystem including rainfall, wet canopy evaporation, transpiration, and soil evaporation



Data Collection: Field-Based Water Use Measurements and Modeling



Approach

- Obtain basic information about ecosystem exchanges of water vapor (transpiration) and carbon dioxide (photosynthesis) across broad range of conditions for each selected target species

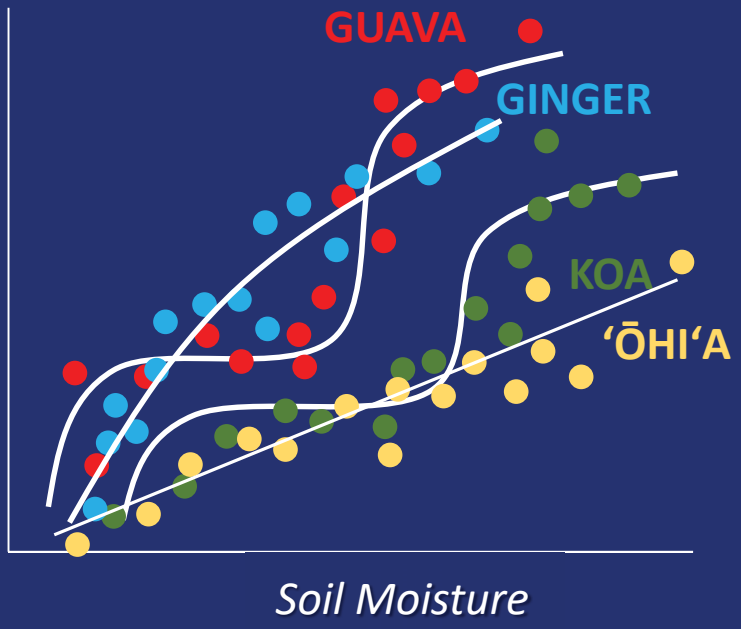
Data Collection: Field-Based Water Use Measurements and Modeling

Use Machine Learning Techniques to Create Statistical Model of Transpiration for Each Major Species

$Transp_{species} = f[Solar\ radiation, Temperature, Humidity, Soil\ Moisture, LAI, Soil\ Age, Stand\ Age, \ldots]$

Approach

- To develop a tool for estimating transpiration rates for a variety of conditions for each target species

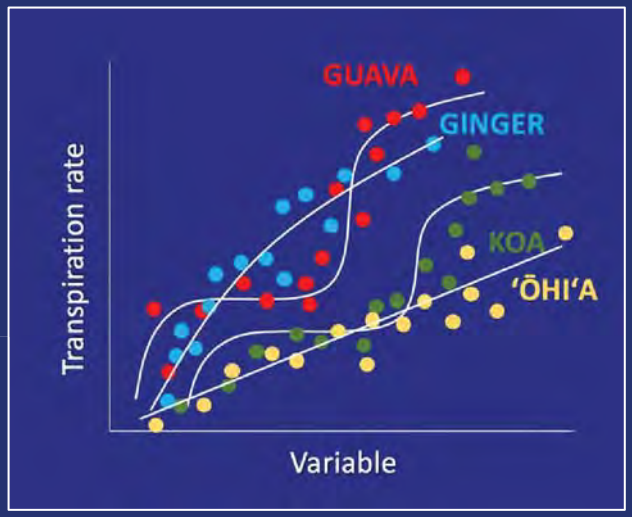


Data Collection: Field-Based Water Use Measurements and Modeling

Map Transpiration for Each Species and Provide Critically Important Input for Water Balance and Groundwater Modeling

Approach:

- Combine field-based statistical models with species distribution maps and LAI maps to get transpiration maps for each species



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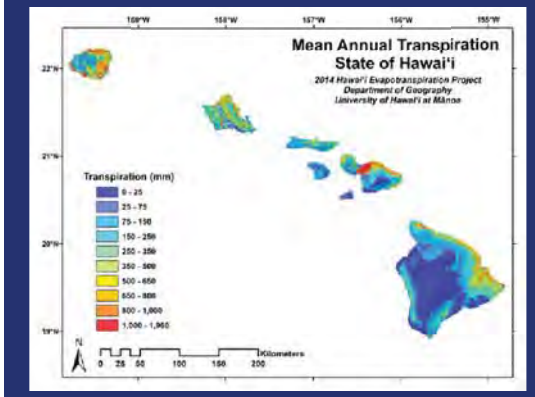
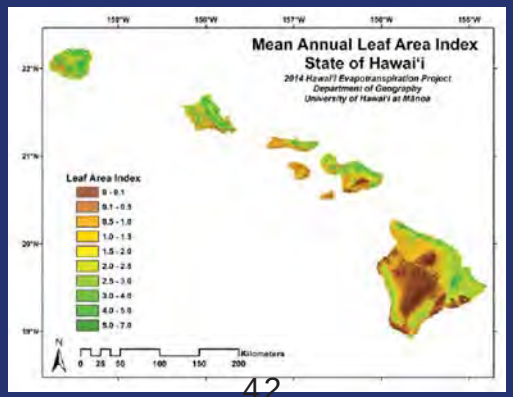
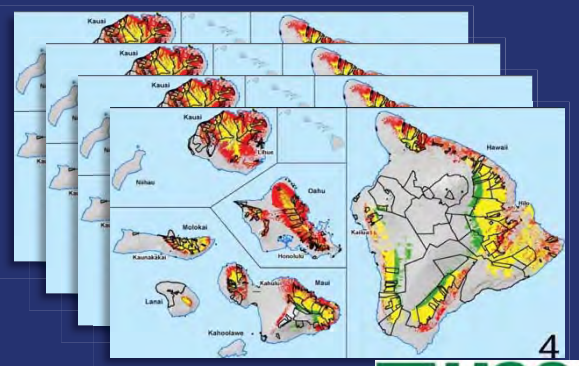






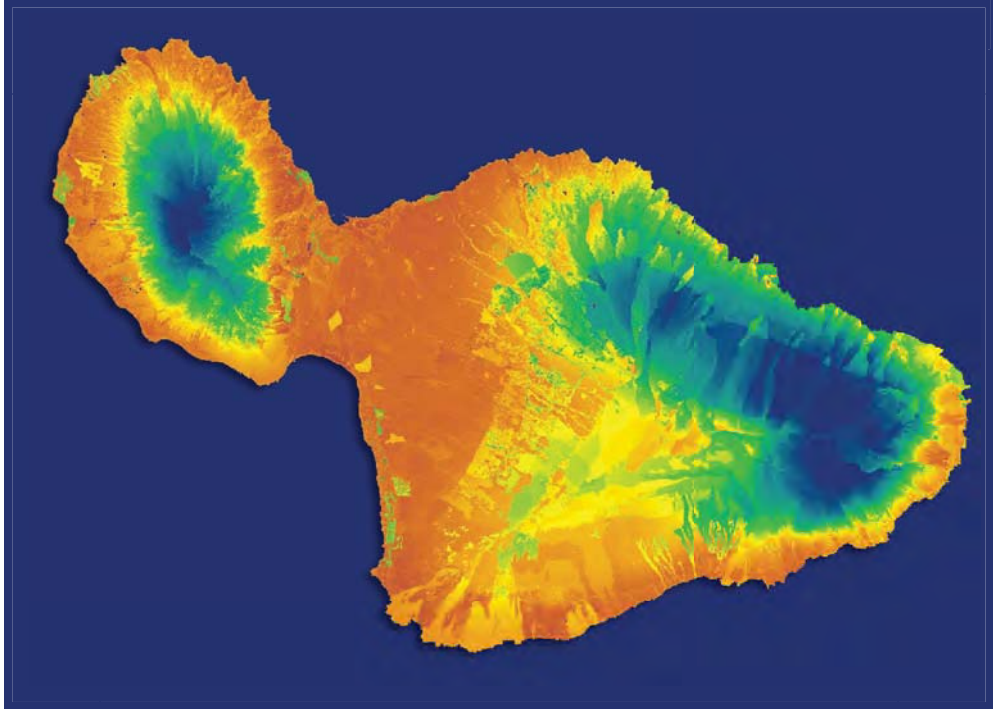
USGS science for a changing world

Data Collection: Field-Based Water Use Measurements and Modeling

Benefits:

- Critically important input data and parameters relevant to native & non-native species for water balance and groundwater modeling
- Comprehensive understanding of the effects of species invasion on evapotranspiration and (together with USGS modeling) consequent impacts on water resources
- Identification of the non-native species that cause the largest increases in evapotranspiration
- Enabling more efficient ecosystem conservation efforts, targeting the species and locations that will provide the large benefits to water resources

Water-Budget Modeling



Objective

- Evaluate water-budget component (ET) uncertainty on groundwater recharge in watershed management areas and sustainable-yield estimates by the State of Hawai‘i Commission on Water Resource Management

USGS science for a changing world

Water-Budget Modeling

Approach

- Use existing water-budget models
- Identify critical management areas for assessing impacts to recharge
  - Watershed partnership management areas
- Vary model inputs related to ET and fog interception
  - Reference ET
  - Crop coefficient
  - E/R ratio
  - Root depth
  - Canopy and trunk storage capacities
  - Fog-interception rates

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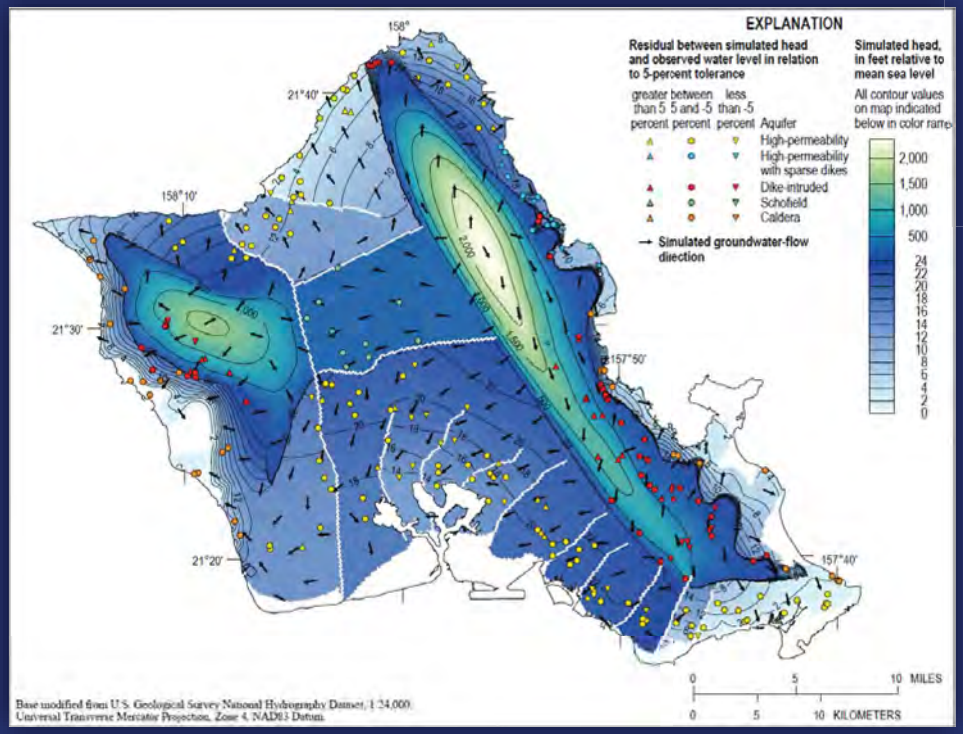
Water-Budget Modeling

Benefits

- Identify areas of greatest uncertainty
- Determine which aquifer systems are most affected
- Determine what types of additional data are most needed and where they should be collected

Groundwater Modeling



Objective

- To evaluate impact of changes in recharge on groundwater availability and critical infrastructure

Groundwater Modeling

Approach

- Use existing island-wide groundwater models to assess changes
  - Water levels
  - Freshwater-saltwater interface
  - Impact to existing wells

Groundwater Modeling

Benefits

- For cases of enhanced recharge, determine increased withdrawal capacity of existing infrastructure to maintain reference conditions
- For cases of reduced recharge, determine which wells might be impacted by a rise in the freshwater-saltwater interface
- Potential development of unit-response function for translating how changes in recharge affect water levels

Projects Way Forward

Phasing	Project	Project Lead	Funding Partners
Ongoing	Pauoa Flats anchor site	UH-Mānoa	HBWS
Proposed Next Step	**Species mapping**	**USGS-PIERC and UH-Hilo, others?**	
Proposed Next Step	**Data collection (Leaf-level measurements, anchor sites, and statistical analyses)**	**UH-Mānoa**	
Proposed Next Step	**Water-budget modeling**	**USGS-PIWSC**	
Proposed Next Step	**Groundwater modeling**	**USGS-PIWSC**	
Future Step	Additional anchor sites	UH-Mānoa and USGS-PIWSC	
Future Step	Additional data collection	USGS-PIWSC	

Acknowledgments

Current Funding Partners

- State of Hawai‘i, Commission on Water Resource Management
- State of Hawai‘i, Division of Forestry and Wildlife
- County of Maui Department of Water Supply
- U.S. Department of the Interior Pacific Islands Climate Adaptation Science Center

Current Collaborators

- University of Hawai‘i at Mānoa
- Hawai‘i Community Foundation
- The Nature Conservancy
- Hawai‘i Association of Watershed Partnerships
  - Islands of Kaua‘i, O‘ahu, Moloka‘i, Maui, Hawai‘i

United States Department of the Interior

U.S. Geological Survey
Pacific Islands Water Science Center
Inouye Regional Center
1845 Wasp Blvd., Bldg 176
Phone: (808) 690-9600 Fax: (808) 690-9599

June 9, 2020

Mr. Kaleo Manuel, Deputy Director
State of Hawai‘i
Department of Land and Natural Resources
Commission on Water Resource Management
P.O. Box 621
Honolulu, Hawai‘i 96809

Attn.: Lenore Ohye

Dear Mr. Manuel:

Subject: Joint Funding Agreement between the State of Hawai‘i Department of Land and Natural Resources Commission on Water Resource Management (CWRM) and the U.S. Geological Survey (USGS) for a cooperative water-budget sensitivity study, during the period July 1, 2020 to December 31, 2021

Enclosed is a Joint Funding Agreement between the State of Hawai‘i Department of Land and Natural Resources Commission on Water Resource Management (CWRM) and the U.S. Geological Survey (USGS) for a cooperative water-budget sensitivity study, during the period July 1, 2020 to December 31, 2021. The total cost of the agreement is $100,000, which will be fully borne by the USGS. The attached agreement is shared by the CWRM ($0) and the USGS ($50,000). This agreement will be amended after October 2020 when a second installment of $50,000 becomes available from the USGS.

The scope of work for this study is attached to the enclosed Joint Funding Agreement. If you wish to initiate this study, please sign and return a copy of the enclosed Joint Funding Agreement.

The objective of the proposed study is to identify which types of data are most critical for quantification of the effects of watershed management on groundwater recharge on Maui. This information is essential for efficient data collection. Specifically, this study aims to:

1. estimate the sensitivity of recharge estimates to selected model parameters that might be impacted by land-cover changes associated with watershed management or lack of watershed management;

2. determine which of the selected model parameters are most critical for quantifying recharge within selected regions on Maui; and

3. identify and summarize the types of information that could be collected for each selected parameter and region on Maui.

If you have any questions or concerns, please feel free to contact me at 690-9602 or by e-mail at jphoffma@usgs.gov. Thank you for your continued interest in working with the USGS to provide water-resource information for the State of Hawai‘i.

Sincerely,

John P. Hoffmann

John P. Hoffmann
Acting Center Director

Enclosures

Form 9-1366
(May 2018)

U.S. Department of the Interior
U.S. Geological Survey
Joint Funding Agreement
FOR
Water Resource Investigations

Customer #: 6000001189
Agreement #: 20ZHJFA00000074
Project #: ZH00TW3
TIN #: 99-0266119

Fixed Cost Agreement YES[X] NO[ ]

THIS AGREEMENT is entered into as of the July 1, 2020, by the U.S. GEOLOGICAL SURVEY, Pacific Islands Water Science Center, UNITED STATES DEPARTMENT OF THE INTERIOR, party of the first part, and the COMMISSION ON WATER RESOURCE MANAGEMENT, DEPARTMENT OF LAND AND NATURAL RESOURCES, STATE OF HAWAII party of the second part.

1. The parties hereto agree that subject to the availability of appropriations and in accordance with their respective authorities there shall be maintained in cooperation a water-budget sensitivity study according to the attached scope of work, herein called the program. The USGS legal authority is 43 USC 36C; 43 USC 50, and 43 USC 50b.

2. The following amounts shall be contributed to cover all of the cost of the necessary field and analytical work directly related to this program. 2(b) include In-Kind-Services in the amount of $0.00

(a) $50,000 by the party of the first part during the period July 1, 2020 to December 31, 2021

(b) $0 by the party of the second part during the period July 1, 2020 to December 31, 2021

(c) Contributions are provided by the party of the first part through other USGS regional or national programs, in the amount of: $0

Description of the USGS regional/national program:

(d) Additional or reduced amounts by each party during the above period or succeeding periods as may be determined by mutual agreement and set forth in an exchange of letters between the parties.

(e) The performance period may be changed by mutual agreement and set forth in an exchange of letters between the parties.

3. The costs of this program may be paid by either party in conformity with the laws and regulations respectively governing each party.

4. The field and analytical work pertaining to this program shall be under the direction of or subject to periodic review by an authorized representative of the party of the first part.

5. The areas to be included in the program shall be determined by mutual agreement between the parties hereto or their authorized representatives. The methods employed in the field and office shall be those adopted by the party of the first part to insure the required standards of accuracy subject to modification by mutual agreement.

6. During the course of this program, all field and analytical work of either party pertaining to this program shall be open to the inspection of the other party, and if the work is not being carried on in a mutually satisfactory manner, either party may terminate this agreement upon 60 days written notice to the other party.

7. The original records resulting from this program will be deposited in the office of origin of those records. Upon request, copies of the original records will be provided to the office of the other party.

8. The maps, records or reports resulting from this program shall be made available to the public as promptly as possible. The maps, records or reports normally will be published by the party of the first part. However, the party of the second part reserves the right to publish the results of this program, and if already published by the party of the first part shall, upon request, be furnished by the party of the first part, at cost, impressions suitable for purposes of reproduction similar to that for which the original copy was prepared. The maps, records or reports published by either party shall contain a statement of the cooperative relations between the parties. The Parties acknowledge that scientific information and data developed as a result of the Scope of Work (SOW) are subject to applicable USGS review, approval, and release requirements, which are available on the USGS Fundamental Science Practices website (https://www.usgs.gov/about/organization/science-support/science-quality-and-integrity/fundamental-science-practices).

Form 9-1366
(May 2018)

U.S. Department of the Interior
U.S. Geological Survey
Joint Funding Agreement
FOR
Water Resource Investigations

Customer #: 6000001189
Agreement #: IWAA CMF agreement
Project #:
TIN #: 99-0266119

9. Billing for this agreement will be rendered **quarterly**. Invoices not paid within 60 days from the billing date will bear Interest, Penalties, and Administrative cost at the annual rate pursuant the Debt Collection Act of 1982, (codified at 31 U.S.C. § 3717) established by the U.S. Treasury.

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Hydrologist
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U.S. Geological Survey
United States
Department of Interior

Signature

By John P. Hoffmann **Date: 06/05/2020**
Name: John P. Hoffmann
Title: Acting Center Director

State of Hawaii
Commission on Water Resource Management

Signatures

By_____ **Date:** _____
Name:
Title:

By_____ **Date:** _____
Name:
Title:

By_____ **Date:** _____
Name:
Title:

Identification of Critical Information Needed to More Accurately Assess Potential Effects of Land-Cover Change on Groundwater Recharge and Availability, Island of Maui, Hawai‘i

U.S. Geological Survey
Pacific Islands Water Science Center
Proposal, May 2020

SUMMARY

Watershed management activities potentially can improve groundwater availability through enhancement of groundwater recharge. State and County agencies of Hawai‘i have committed substantial resources to Watershed Partnerships for managing watershed areas with the intent of improving water-resource availability, among other effects. However, the state of knowledge on the hydrologic effectiveness of watershed management in Hawai‘i is limited. Thus, quantitative estimates of the efficacy of watershed management for improving groundwater recharge and groundwater availability are uncertain.

Water-budget models developed for Hawaiian Islands, including the Island of Maui, are one of the best available tools for assessing how regional-scale recharge in Hawai‘i is affected by land-cover changes associated with watershed management or lack of management. These assessments, however, have substantial uncertainty that can be reduced by the collection of additional hydrologic information. To guide the efficient collection of additional information, analysis is needed to identify and prioritize the types of additional hydrologic information that should be collected in different ecologic and climatologic regions.

The objective of the proposed study is to identify which types of data are most critical for quantification of the effects of watershed management on groundwater recharge on Maui. This information is essential for efficient data collection. The objectives of the proposed study will be accomplished by conducting a sensitivity analysis of selected model parameters for an existing water-budget model for Maui. Results of the sensitivity analysis will identify the most influential model parameters and the types of information to collect for regions on Maui and similar regions on other Hawaiian Islands.

Results of the proposed study are needed to guide the efficient collection of information that is crucial for improving the utility of existing island-wide water-budget models and groundwater models developed for Maui and other Hawaiian Islands. The improvement of water-budget and groundwater models is needed to reduce uncertainty in regional-scale assessments of potential changes to water-resource availability for humans and ecosystems in Hawai‘i in response to anthropogenic and natural disturbances to forested watersheds. The proposed study is consistent with the Department of Interior (DOI) Strategic Plan for 2018–2022 and the USGS mission to provide information to better manage the Nation’s water resources.

The study methods and results will be documented in a USGS Scientific Investigation Report. The proposed study is estimated to cost $100,000 and take 1.5 years to complete.

INTRODUCTION

Watershed management activities potentially can improve groundwater availability through enhancement of groundwater recharge. The concept of watershed management for the enhancement of water resources in Hawai‘i has been recognized for over a century. For example, Bailey (1851) stated that “it is a well established fact that rains are more frequent and copious where trees abound, than where they are wanting.” More recently, as part of its “The rain follows the forest” plan, the State of Hawai‘i declared that “immediate action is needed to secure Hawai‘i’s water supply… Protecting forest watersheds is the most cost effective and efficient way to absorb rainwater and replenish ground water” (State of Hawai‘i, 2011).

State and County agencies of Hawai‘i have committed substantial resources to Watershed Partnerships for managing watershed areas with the intent of improving water-resource availability, among other effects. For example, Maui County has invested more than 20 million dollars in watershed management since 1997. In general, watershed management in upland areas involves protecting native trees and vegetation from invasion of non-native trees and vegetation, constructing and maintaining fences to reduce the impacts of ungulates, and replacing non-native trees and vegetation with native trees and vegetation. Watershed-partnership areas on the Island of Maui, Hawai‘i, include upland, forested parts of watersheds (fig. 1).

PROBLEM

Although watershed management in Hawai‘i is a longstanding strategy intended to enhance groundwater recharge, the state of knowledge on the hydrologic effectiveness of watershed management in Hawai‘i is limited. Thus, quantitative estimates of the efficacy of watershed management for improving groundwater recharge and groundwater availability are uncertain. The uncertainty is partly related to the fact that regional groundwater recharge cannot be directly measured easily or with confidence.

One of the most widely used approaches to estimate groundwater recharge on a regional or island-wide scale is the water-budget approach. Thus, models that use the water-budget approach are the best available tools for quantifying potential effects of watershed management or lack of watershed management on recharge in Hawai‘i.

Water-budget models capable of estimating the spatial distribution of recharge for Maui and other Hawaiian Islands have been developed by the U.S. Geological Survey (USGS) (Engott and others, 2017; Izuka and others, 2018, Johnson and others, 2018; Oki and others, 2020). The water-budget models compute recharge by calculating daily inputs and outputs of water to the forest canopy and plant-soil system. The water inputs and outputs are calculated on the basis of model parameter values that are process and land-cover dependent. For example, the water-budget models must calculate actual evapotranspiration to estimate recharge, and the calculation of actual evapotranspiration (ET) in forested areas requires, at a minimum, reliable estimates of canopy evaporation rate, canopy and trunk interception capacity values, root depths of vegetation, reference-grass ET, and potential ET by vegetation type (crop coefficient).

Hydrologists assign numerical values to model parameters using calibration techniques and the best available information. For example, to estimate recharge for Kauaʻi, Oʻahu, and Maui during recent conditions, Izuka and others (2018) used island-wide maps of mean transpiration and soil evaporation during recent conditions (Giambelluca and others, 2014) to derive the numerical values assigned to an ET-related parameter (crop coefficient) for native forests and non-native forests. In general, hydrologists can use a water-budget model to assess the effects of watershed management on recharge by changing the values assigned to model parameters that are assumed to be affected by land-cover change.

Even though water-budget models are widely used for assessing how regional-scale recharge in Hawaiʻi is affected by watershed management or lack of management, these assessments have substantial uncertainty owing to a number of limitations. These limitations include uncertainties related to (1) which model parameters are affected by land-cover change, (2) appropriate parameter values for different types of native and non-native vegetation, and (3) how much vegetation-related parameter values vary from one region to another, given the diversity of ecologic and climatic settings in Hawaiʻi.

The aforementioned limitations can be addressed by the collection of additional hydrologic information that reduces uncertainty in regional recharge estimates. The collection of hydrologic information, however, can be expensive, especially if several types of information are collected in multiple regions. Some types of information may be more important than others, in terms of reducing uncertainty in assessments of recharge and groundwater availability. To reduce

the cost of data collection, analysis is needed to identify and prioritize the types of additional hydrologic information that should be collected in different ecologic and climatologic regions.

OBJECTIVES and SCOPE

The objective of the proposed study is to identify which types of data are most critical for quantification of the effects of watershed management on groundwater recharge on Maui. This information is essential for efficient data collection. Specifically, this study aims to:

1. estimate the sensitivity of recharge estimates to selected model parameters that might be impacted by land-cover changes associated with watershed management or lack of watershed management;
2. determine which of the selected model parameters are most critical for quantifying recharge within selected regions on Maui; and
3. identify and summarize the types of information that could be collected for each selected parameter and region on Maui.

For example, results of the proposed study may indicate that recharge estimates for one region are most sensitive to the depth of vegetation roots. Therefore, the most critical information to collect in the region could be measurements of root depths for (1) the most widespread species of native vegetation and (2) each species of non-native vegetation that has a considerable potential to invade large areas predominantly vegetated by native species. Regions will be delineated by the proposed study as specific areas on Maui and will include parts of watershed-management and forested areas (fig. 1). The proposed study aims to delineate regions on Maui in a manner that produces regions that can be easily understood.

The scope of analysis will be limited to the Island of Maui. Study results, however, may inform the collection of data on other Hawaiian Islands. The scope of analysis will be limited to selected model parameters of an existing water-budget model for Maui (Johnson and others, 2018) that might be affected by land-cover changes. The selected model parameters are fraction of canopy cover, canopy-interception capacity, fraction of rainfall that passes through the canopy and is intercepted by trunks, trunk-interception capacity, root depth, crop coefficient, and fog-catch efficiency. The runoff computation method in the existing water-budget model uses runoff-to-rainfall ratios and does not include or consider parameters related to land-cover or forest-

understory characteristics or processes. Therefore, runoff-to-rainfall ratios, which are likely land-cover dependent, will not be included in the proposed sensitivity analysis. Existing water-budget sensitivity analyses of runoff on water budgets indicate that runoff is an important factor controlling the water budget in Hawai‘i (Engott and others, 2017; Izuka and others, 2018; Johnson and others, 2018; Oki and others, 2020). The hydrologic effect of watershed management on runoff, which is recognized as an important information need, can be addressed separately using watershed modeling that is beyond the scope of the proposed study.

RELEVANCE and BENEFITS

The sensitivity analysis in the proposed study will explore and identify the most influential model parameters controlling the accuracy of estimates of how future recharge and water-resource availability in Hawai‘i might be affected by widespread invasion of non-native vegetation. Results of the proposed study are needed to guide the efficient collection of information that is crucial for improving the utility of existing island-wide water-budget models (Engott and others, 2017; Izuka and others, 2018; Johnson and others, 2018) and groundwater models (Oki and others, 2020; Izuka and Rotzoll, in preparation) developed for Hawai‘i. The improvement of water-budget models is needed to reduce uncertainty in regional-scale assessments of potential changes to water-resource availability for humans and ecosystems in Hawai‘i in response to anthropogenic and natural disturbances to forested watersheds. Hawai‘i is one of the principal aquifers in the United States (Reilly and others, 2008) and is part of the USGS Water Availability and Use Science Program (WAUSP) Regional Groundwater Availability Assessments. Because Maui includes many of Hawai‘i’s ecologic and climatic settings, results of the proposed study will inform data collection on other Hawaiian Islands.

Results of the proposed study will directly benefit the Nation by helping the State of Hawai‘i Commission on Water Resource Management (CWRM) fulfill its mission to protect and manage the waters of the State of Hawai‘i for present and future generations. The proposed study is an intermediate step toward the overall goal to more accurately quantify how water-resource availability in Hawai‘i is affected by watershed management.

Results of this study will enable resource managers and researchers to identify and prioritize the critical types of field data to collect by region on Maui to maximize the utility of data collected. Data collected by resource managers and researchers could then be used to better

quantify the potential effects of land-cover changes associated with watershed management on groundwater recharge in forested watersheds and groundwater availability for Maui. For example, this study may determine that recharge in one forested region on Maui is particularly sensitive to crop coefficients. Water managers and researchers working in that region could collect field data needed to derive crop coefficients for several species of non-native vegetation in the region. The crop coefficients derived from the field data could ultimately be applied in water-budget and groundwater-modeling analyses that estimate how recharge and water-resource availability could be preserved by effective watershed management that prevents widespread invasion of each species of non-native vegetation in the region.

The proposed study is consistent with the Department of Interior (DOI) Strategic Plan for 2018–2022 (Department of Interior, 2018) through DOI Mission Area 1 (*Conserving Our Land and Water*); Goal 1, (*Utilize science in land, water, species, and habitat management supporting decisions and activities*); Strategy 1, (*Apply science to land, water, and species management*). Specifically, the proposed study aligns with Strategy 1 because the (1) USGS will conduct a research assessment that can be used to support the development of management strategies that address the impacts of land use on the sustainability of water resources, and (2) USGS will work with land and water-resource managers to help them make informed decisions for effectively managing the resources with which they are entrusted.

The proposed study also addresses several of the goals, objectives, and strategic actions of the USGS Water Science Strategy (Evenson and others, 2013), including:

- *Strategic action 12*— Conduct …modeling activities, in coordination with various water-related management actions, to improve understanding of benefits, limitation, and adaptive strategies;
- *Goal 5*— Deliver timely hydrologic data, analyses, and decision-support tools seamlessly across the Nation to support water-resource decisions.

APPROACH

The objectives of the proposed study will be accomplished by conducting a sensitivity analysis of selected model parameters for an existing water-budget model (Johnson and others, 2018) with the capacity to compute the spatial distribution of recharge for Maui. A sensitivity

analysis allows analysts to identify model parameters that exert the most influence on model results (Hamby, 1994). First, for each selected water-budget parameter, a range of values to test in water-budget simulations will be determined based on existing information. The existing water-budget model will be used to estimate the spatial distribution of recharge on Maui for multiple scenarios. Each scenario will use one of the values identified for a selected parameter and baseline values (Johnson and others, 2018) for all remaining parameters. In other words, the proposed study will evaluate parameter sensitivity using the one-at-a-time approach, in which one parameter value is varied at a time while the remaining parameter values are held fixed (Hamby, 1994).

Next, the Island of Maui will be subdivided into regions for the purpose of summarizing study results. Regions will be delineated using various methods to be determined by the study. Delineation methods will be limited to those that produce regions that are straightforward and applicable to other Hawaiian Islands. For example, regions could be delineated on the basis of climate, elevation, aspect (leeward or windward), or some combination of features.

Next, mean annual recharge for each region and scenario will be computed from the water-budget results. A sensitivity index will be computed for each selected parameter and region using the region's recharge values and the approach described in Lenhart and others (2002). The relative sensitivity of the selected parameters for each region will be determined on the basis of sensitivity index values. In other words, for each region, the selected parameters will be sorted from most influential to least influential, in terms of the amount influence each has on the model's recharge estimates for the region.

Last, the types of information to collect in order to reduce uncertainty of values assigned to the most influential parameters will be identified and summarized for each region. The summary of information to collect will be reported in a way that guides water managers, researchers, and stakeholders on Maui and other Hawaiian Islands.

HOW THE PROPOSED STUDY COMPLEMENTS RECENT AND ONGOING USGS STUDIES

The proposed study is an outgrowth of a recently completed USGS study–conducted in cooperation with the Maui Department of Water Supply, the Hawai‘i Division of Forestry and Wildlife, and CWRM–for identifying approaches and sites to evaluate the hydrologic effects of watershed management. Although a number of field sites for additional study were identified on

Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi, information collected as part of that study indicated that further analysis was needed to help prioritize, for cost-efficiency purposes, the types of data that should be collected in different ecologic and climatologic settings.

The proposed study complements an ongoing USGS study, conducted in cooperation with CWRM, that is using water-budget models to estimate future groundwater recharge statewide on the basis of published climate projections. Results of the ongoing study will enable CWRM to evaluate how groundwater availability may be affected by *climate change* over a water-resources planning horizon and potentially adjust sustainable-yield values. Results of the proposed study will guide efforts to collect hydrologic data that are most critical for quantifying potential changes to groundwater recharge from *land-cover change* associated with watershed management or lack of watershed management in Hawaiʻi.

QUALITY ASSURANCE/QUALITY CONTROL

No new data will be collected for the proposed study. USGS Fundamental Science Practices (https://www2.usgs.gov/fsp/) will be followed to provide unbiased, objective, and impartial scientific information. The product of the proposed study will be created, reviewed, and approved according to USGS Fundamental Science Practices Procedures and Guidelines (https://www.usgs.gov/about/organization/science-support/office-science-quality-and-integrity/information-product-use-case).

PRODUCTS

The study methods and findings will be documented in a USGS Scientific Investigation Report made available online to the public.

TIMELINE

The general tasks and associated timeline for the proposed study are provided in Table 1.

Table 1. General tasks and timeline for the proposed study.

	FY20	FY21				FY22
General task	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
Sensitivity Analysis	■	■				
Write report and edit after reviews		■	■	■	■	
Publish report						■

PERSONNEL

This study will require the equivalent of a GS-12 hydrologist for about 15 percent of full time in fiscal year 2020 and about 30 percent of full time in fiscal year 2021. Required personnel are available in the USGS Pacific Islands Water Science Center.

BUDGET SUMMARY

This proposed 1.5-year study is estimated to cost $100,000. A cost breakdown is provided in Table 2.

Table 2. Budget for the proposed study.

Category	Total
Labor	$60,036
Science support	$12,007
Total net funds	$72,043
DOTSC	$27,957
Total gross funds	**$100,000**

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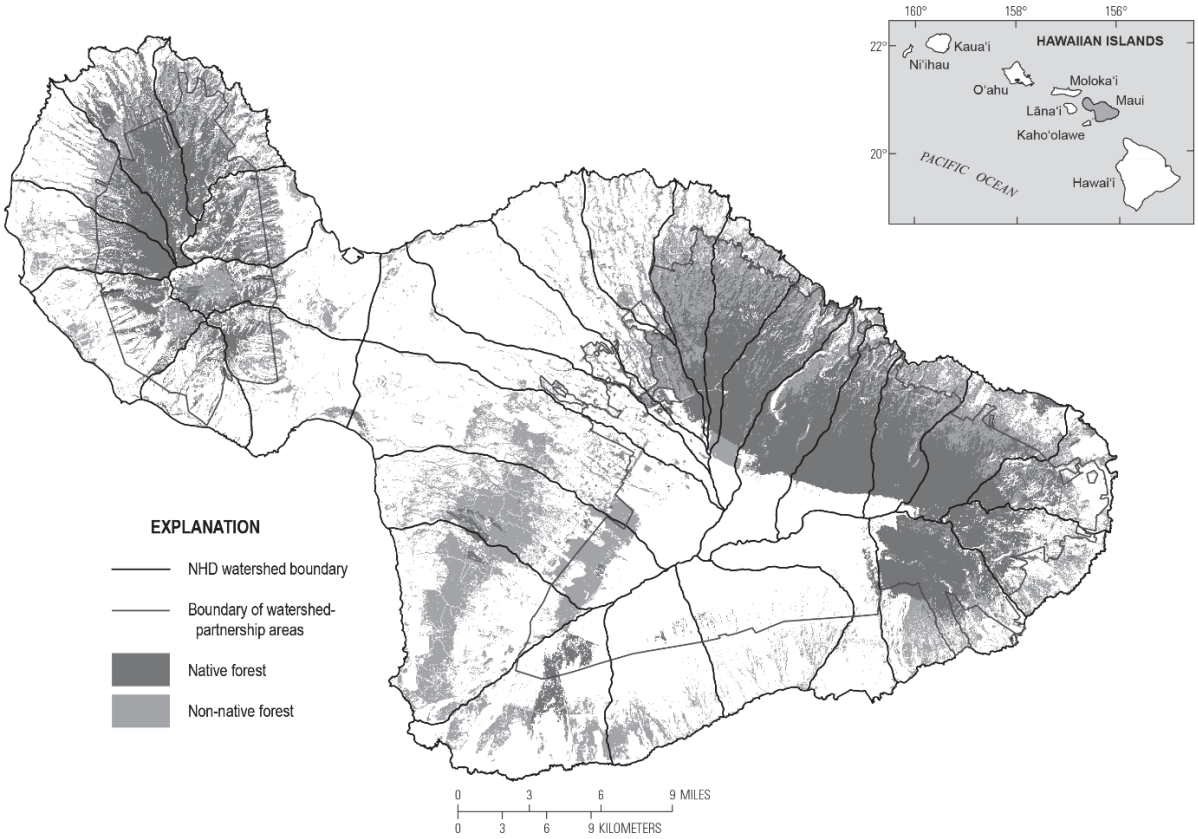

Figure 1. Forested areas, boundaries of watershed-partnership areas, and boundaries of selected watersheds from the U.S. Geological Survey National Hydrography Dataset (NHD) Plus High Resolution, Island of Maui, Hawai‘i (modified from U.S. Geological Survey 2016; 2020).