



Supporting Integrated Decision Making  
Under Climatic Variability and Change in  
Hawai'i and the US-Affiliated Pacific Islands

Annual Report 2019 – 2020

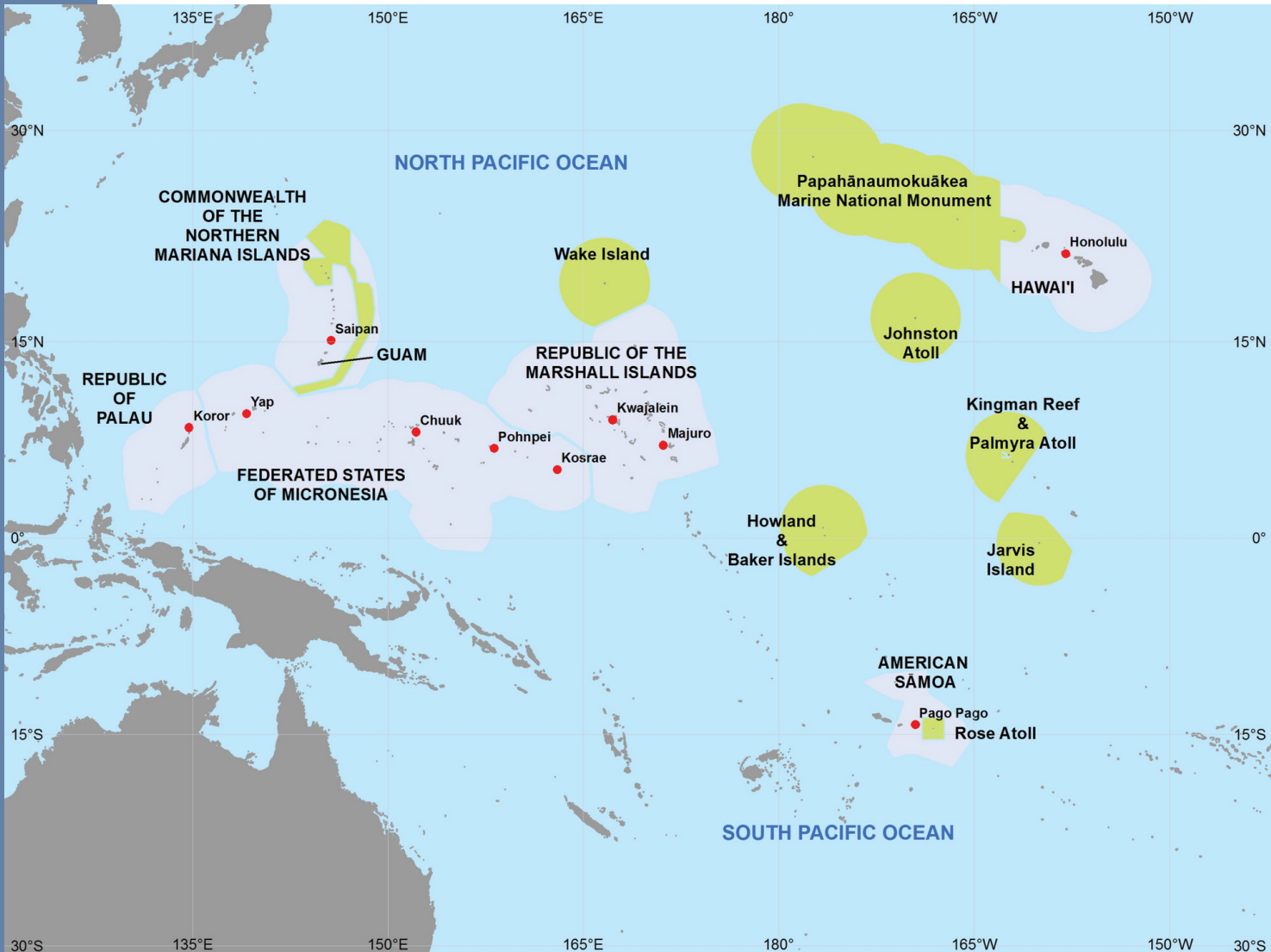


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## Table of Contents

Introduction to Pacific RISA	2
Pacific RISA Team Members	2
Proudest Accomplishment This Reporting Period	4
New Partnerships and Focus Areas	4
Selected Climate Services and Outputs	7
Outreach and Engagement Highlights	9
Next Steps and Future Plans	13
Evaluating Pacific RISA's Progress	13
Evidence of Societal Impact	14
Case Studies of Pacific RISA's Contributions	16
Publications with Highlights	18



*Pacific RISA serves the U.S. Pacific Islands region, which includes Hawai'i, Guam, American Sāmoa, Commonwealth of the Northern Mariana Islands (CNMI), Republic of Palau, Federated States of Micronesia (FSM), and the Republic of the Marshall Islands (RMI).*

## Introduction to Pacific RISA

The Pacific Regional Integrated Sciences and Assessments (Pacific RISA, [www.pacificrisa.org](http://www.pacificrisa.org)) program supports Pacific island and coastal communities in adapting to the impacts of climate variability and change. We strive to enhance Pacific communities' abilities to understand, plan for, and respond to changing climate conditions. Our work is conducted through interdisciplinary research and partnerships with local, national, and regional stakeholders. As one of eleven RISA programs, Pacific RISA emphasizes the engagement of communities, governments, and businesses in developing effective policies to build resilience in key sectors such as water resource management, coastal and marine resources, fisheries, agriculture, tourism, disaster management and public health.

**Vision** – Resilient and sustainable Pacific Island communities using climate information to manage risks and support practical decision-making about climate variability and change.

### Mission Objectives

- Meet critical climate information needs in the Pacific Region through multidisciplinary climate research, assessment, education, and training;
- Provide integrated, locally relevant climate information to decision-makers and communities;
- Enhance regional and local capabilities to manage climate risks, build resilience in key sectors, and support sustainable development;
- Promote collaboration among Pacific regional, U.S. national, and international institutions and programs providing climate information products and services.

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*Attendees of RMI's first National Climate Change and Health Dialogue, held January 30–31, 2020 in Majuro.*

## **Proudest Accomplishment This Reporting Period**

### **Analyzing the Causes & Impacts of Climate-Induced Migration in the Marshall Islands**

Pacific RISA investigators are leading two highly collaborative research initiatives on climate change, migration, and health in the Pacific Islands. The “Marshall Islands Climate and Migration Project” (MICMP) examines how climate change affects the ecosystems and wellbeing of Marshallese migrants and communities in the Republic of the Marshall Islands (RMI) and in destinations in the US. In the past year the MICMP team published a series of policy briefs available on their [new website](#). These products have been cited in publications of the UNFCCC, shared by the UN humanitarian information service ReliefWeb, and reported by Marshall Islands-based journalists. At COP25, Kees van der Geest gave a [press briefing](#) on sea level rise and climate migration in RMI. Laura Brewington leads the “Climate, Health, and Migration in the Pacific Islands” NOAA International Research and Applications Project, which complements MICMP’s work. This initiative was designed in collaboration with the RMI Ministry of Health and Human Services, NOAA, and the UH Sea Level Center, and aims to both improve climate information delivery to the health sector in RMI, and inform health service providers in Hawai‘i about migration, health, and environmental change in the region. In January 2020, Pacific RISA PIs led RMI’s first National Climate Change and Health Dialog, which received extensive [online](#) media coverage. Inputs received during this national dialog were synthesized into a list of climate indicator variables and timelines for RMI’s health sector, designed to inform a future climate services delivery system.

## **New Partnerships and Focus Areas**

### **Pacific RISCC (Regional Invasive Species and Climate Change)**

The Pacific RISA is collaborating with the Pacific Islands Climate Adaptation Science Center, Hawai‘i Department of Land and Natural Resources, Hawai‘i Invasive Species Council (HISC), US Fish and Wildlife Service, and Hawai‘i Coordinating Group on Alien Pest Species (CGAPS) to create a new working group at the intersection of climate change and invasive species in Pacific Islands, known as the Pacific Regional Invasive Species and Climate Change (RISCC) management network.



A new webinar series was initiated in May 2020 in response to a survey that was submitted to natural resource managers in Hawai'i between December 2019 and January 2020, which found that most managers want more tailored climate information specific to particular temporal and spatial scales, and that this information is largely absent from the peer-reviewed literature. Pacific RISCC's goal is to link climate and invasive species scientists with invasive species managers and policy makers from the Pacific Islands region to promote a two-way dialogue to 1) Share regional knowledge about current management strategies and scientific insights; and 2) Identify and address planning and information needs of managers related to invasive species and climate change.

As an extension of the Hawai'i Working Group, Dr. Brewington is leading the preparation for a Pacific Ecological Security Conference in late 2020 that will convene leaders and government representatives from Pacific Island nations and territories, international experts, and invasive species managers in Palau or virtually. Coordinating partners include the Government of Palau, the US Department of Agriculture, New Zealand Department of Conservation, Australia's Commonwealth Scientific and Industrial Research Organization, the European Union, Sasakawa Peace Foundation, and other regional and national entities. The conference will demonstrate existing biosecurity partnerships and commitments in the region (e.g., the Regional Biosecurity Plan for Micronesia and Hawai'i), identify the top Pacific-wide priorities for invasive species management (e.g., climate change, species-specific targets, maritime transport, port facilities), and conclude with the development of a coordinating mechanism for ongoing collaboration, training, and financial support. Note that while the Summit activities are being funded by the US State Department, these are considered to be part of the Pacific RISA's goal to increase international scope and impact.

The Climate Strong Islands Dialogue was held in New York City during UN Climate Week, September 23–27, 2019. Islands from across the world came together to model aggressive climate adaptation and mitigation strategies as well as promote transitioning to a circular economy.

*L to R: Makale'a Dudoit Ane, Environmental Coordinator, Mayors Office of Economic Development at the County of Maui; Dana Okano, Program Director at Hawai'i Community Foundation; Rebecca Shute-Villegas, Hawai'i County Council; Victoria Keener, Pacific RISA and the East-West Center; Celeste Connors, CEO and Executive Director, Hawai'i Green Growth. (Image: Hawai'i Green Growth)*



## Hawai'i Green Growth & the UN Local2020 Islands Hub

This year Pacific RISA became an official member of the Hawai'i Green Growth (HGG) network and is supporting their new role as the United Nations Local2020 Islands Hub. Victoria Keener is representing the RISA on HGG's Voluntary Local Review Committee and the Metrics Working Group. We plan to deepen our partnership in Fall 2020 with new State Department funding and a new hire targeted at doing more in-depth indicators work in the Freely Associated States (FAS), which may be able to link to the Local2020 Islands Hub's expansion of the Aloha+ Dashboard. This partnership is strategic as we broaden our regional collaborations with both the FAS and other Pacific Islands.





*Dr. Victoria Keener and the Pacific RISA team present their work to President David Panuelo of the Federated States of Micronesia, Palau Vice President Raynold Oilouch, and the Marshall Islands Minister and Assistant to the President David Paul. (Image: Shayne Hasegawa)*

## Pacific Islands Development Program & the Micronesian Conference of Leaders

In partnership with the East-West Center Pacific Islands Development Program (PIDP), the inaugural Micronesian Conference of Leaders was held on October 14, 2019. Delegations from the Republic of the Marshall Islands, Federated States of Micronesia, and Palau gathered at the Center. Those in attendance included FSM President David Panuelo, Palau Vice President Raynold Oilouch, and the Marshall Islands Minister and Assistant to the President David Paul. Pacific RISA was invited to join the convening, and Victoria Keener briefed Pacific Island leaders on Pacific RISA's use-inspired research on climate change, while the whole team took questions. The growing potential PIDP collaboration is of note because it is the sole US and northern hemisphere member of the Council of Regional Organizations of the Pacific (CROP) established by Pacific Island Forum Leaders in 1988 to improve cooperation, coordination, and collaboration among Pacific inter-governmental organizations.

## Climate Change and National Security

Climate change has potential ramifications for US national security. The new Strategic Environmental Defense Research Program (SERDP) project "Advancing Best Practices for the Analysis of the Vulnerability of Military Installations in the Pacific Basin to Flooding under a Changing Climate" involving Pacific RISA PIs John Marra (Lead) and Laura Brewington (Spatial Analyst) is funded by the US Department of Defense (DoD), and aims to develop methodologies for assessing the vulnerability of coastal military installations to increases in sea level over the next century. Potential climate change impacts on coastal installations include loss or damage to mission-essential infrastructure, loss of training lands and testing areas, loss of transportation corridors and facilities, loss of natural habitat and natural resources, increased risk of storm damage, and increased risk of loss of life. The approach is being tested at a set of DoD sites in the Pacific Basin. Training areas, waterways, coastal structure, and buildings will be assessed for their vulnerability to flooding, inundation, erosion, saltwater intrusion, and shifting tidal flows. The methodologies and outputs from this project are expected to serve future uses, particularly in low-lying coastal US military installations and similar locations in the Pacific Islands region. Efforts thus far have focused on integrating the geographic, biophysical, and infrastructure data for analysis within a GIS modeling environment and testing them using the sea level rise scenarios. Model outputs will show the potential impacts of sea level rise on infrastructure, allowing for a comprehensive assessment of vulnerability. Meanwhile, the modeling framework will capture nonlinearities within the climate and the additive processes causing coastal flooding, and provide estimates of event magnitude and frequency that will assist DoD managers in assessing and responding to anticipated impacts. The approach is first being developed for US Naval Base Coronado and will subsequently be applied to US Army Garrison Kwajalein Atoll (RMI), Marine Corps Base Hawai'i, and Naval Base Guam.



# Selected Climate Services and Outputs

## Hawai'i

- ▶ The Hawai'i Revised Statutes (HRS), Chapter 205A, authorizes the City to establish and revise as appropriate a coastal setback. Mayor Caldwell, in correspondence dated June 25, 2019, requested that the Honolulu Climate Change Commission provide guidance on new shoreline regulations and rules. In response, Victoria Keener and other commissioners provided a December 2019 [guidance document](#) for amending Revised Ordinance of Honolulu Chapter 23 "Shoreline Setbacks." These eight recommendations were developed in collaboration with the Honolulu Office of Planning, and suggest using multiple criteria including place-appropriate and future-climate considerations to create dynamic setbacks across the island. Honolulu Chapter 23 on shoreline setbacks is currently being revised.
- ▶ The Hawai'i Division of Aquatic Resources and The Nature Conservancy are using the recreational value concept and maps developed by Dr. Kirsten Oleson's lab in their marine spatial planning.
- ▶ Maps and associated geospatial data layers produced during the Maui Groundwater Project have been used by UH researchers and graduate students, Maui County officials, and state offices to visualize and understand the trade-offs between different land management types under different climate futures. In addition, this project has led the Hawai'i Commission on Water Resources Management to fund climate and groundwater recharge modeling and projections for all of the main Hawaiian Islands. This is evidence of the value of the RISA-pioneered approach to scenario planning in Hawai'i and its effectiveness in reaching stakeholders at multiple levels.

## Republic of the Marshall Islands

- ▶ Proceedings and associated "climate stories" documents from the First RMI National Climate Change and Health Dialog in January 2020 are being used by stakeholders and Ministry of Health officials to craft the National Adaptation Plan for climate change adaptation. They are also being used to craft funding proposals that emphasize the need for climate-ready healthcare systems in Pacific Islands that are resilient to multiple environmental threats (storms, drought, etc.).

## Guam

- ▶ Stakeholders in Guam requested simple, short summaries of findings based on the report, [Water resources on Guam—Potential impacts of and adaptive response to climate change](#), co-authored by Melissa Finucane and Victoria Keener. In response, Pacific RISA developed [briefing sheets](#) addressing the impacts of future climate on freshwater resources in Guam, and a [webpage](#) collecting project resources and data from the project. These products have been used in creating both the regional PIRCA Climate Science report for Guam and informing the newly crafted Guam Climate Commission.

**Guam's Water Resources**  
How do climate and humans impact freshwater resources, and how can we plan for change?

**Where does freshwater come from on Guam?**

- Recharge occurs naturally into the soil and "recharge" the aquifer, most often in mountainous areas, or occurs in the mountains by way of evaporation and plant transpiration.
- High groundwater and surface water supplies depend on all-weather rainfall, which averages from 80 to 100 inches a year, mostly falling during the wet season from July through September. About 12% of annual rainfall is absorbed by the system.
- There are two main sources of freshwater on the island of Guam: surface water on the north half of the island (Tinson's, Agaña (NGIA) to the north (pumped wells).
- Groundwater provides about 80% of the drinking water for the island's 160,000 residents and 1 million visitors a year. Groundwater is contained in a freshwater lens that floats on saltwater, separated by a brackish transition zone.
- The Guam Waterworks Authority (GWA) pumps fresh groundwater from the NGIA and surface water from the Ugnan River into pipes that provide water to residents and visitors.

**Why do we have to manage freshwater differently in the future?**

- Up to 30% of total annual rainfall is retained in the atmosphere by evaporation and transpiration and does not recharge the aquifer. A hotter environment will generally increase that percentage.
- The reversal of 80 groundwater wells in the NGIA area is necessary to pump and distribute drinking water.
- The NGIA produces about 40 million gallons of freshwater per day. That means that daily per capita consumption is about 20 gallons. The US daily per capita use is 63 gallons.
- More pumping requires more energy. Guam already pays 2.3 times more for energy than the mandated US due to the cost of shipping fuel.

**Future climate projections for Guam.**

- In this document, climate and hydrologic projections are for the future period 2050-59, and change are expressed relative to historic conditions (1970-2000), unless stated otherwise.
- Average annual air temperature in Guam is projected to be 5.8°F warmer in the future (Fig. 3).
- The number of "very hot days" (days when the air temperature exceeds 95°F) increased from one day a year in the 1970s to 20 days in 2050. In the future, the number of very hot days is projected to increase further to 27 days a year, or 70% of the year.
- Projected average annual rainfall will be about 7% lower (Fig. 3).
- Average rainfall during the wet season (July to December) is projected to be 12% less, whereas average rainfall during the dry season (January to June) is projected to be 10% more.
- Drought conditions are projected to be more frequent, occurring 4 years out of every 10 years, instead of the historic rate of

**Figure 3:** This cross-section of the NGIA shows how freshwater recharges by rain and extracts to the coast. Wells need to be designed carefully to minimize the risk of saltwater contamination (adapted from Keener 2009).

**Freshwater Availability in Guam With Projected Changes in Climate**

Guam receives 80 to 100 inches of rain a year, two-thirds of which historically falls during the wet season. On average, three tropical storms and one typhoon pass within 80 nautical miles of Guam each year, generally during the rainy season. Both drought and flooding can impact freshwater supply and the associated infrastructure. Department of Defense (DoD) installations and non-military populations on Guam face freshwater stresses, which will be impacted by changes in demographics, freshwater demand, and climate. This DoD Strategic Environmental Research and Development Program (SERDP) funded study evaluated potential climate impacts on freshwater supplies in Guam, and identified methods of increasing the water distribution system's resilience.

Climate models were designed for Guam's location and topography to estimate climate and water use scenarios at the end of the century (2050-59). Future climate scenarios help managers plan a range of adaptive strategies depending on their risk tolerance. This study used the warming scenario RCP8.5, which describes a "high greenhouse gas emissions" and "business-as-usual" future to provide an upper limit for adaptation needs that are relevant to a high-risk system.

**Future climate projections for Guam.**

- Guam is within one of the most active tropical storm regions in the world. In the future, typhoons will be less frequent, but stronger. The decrease in rainfall may be due to the projected decrease in the number of storms.
- Southern Guam is dependent on surface freshwater supplies from rivers and the Fena Valley Reservoir (FVR).**
- Future annual streamflow will be about 10% lower in southern Guam, ranging from 12 to 16% lower in different watersheds.
- Future annual evapotranspiration will be about 14% higher in southern Guam, and up to 29% higher in some areas, which is partly related to higher temperatures.
- Operational costs of the Ugnan River treatment plant for water supply have increased because of high turbidity of the river during high-dry events.
- The FVR is the DoD's primary water source for the Naval Base and nearby facilities. Its water storage capacity is reduced over time by sediment buildup. The sediment load to FVR

**Change in Annual Temperature (°F)**

**Change in Annual Rainfall (in)**

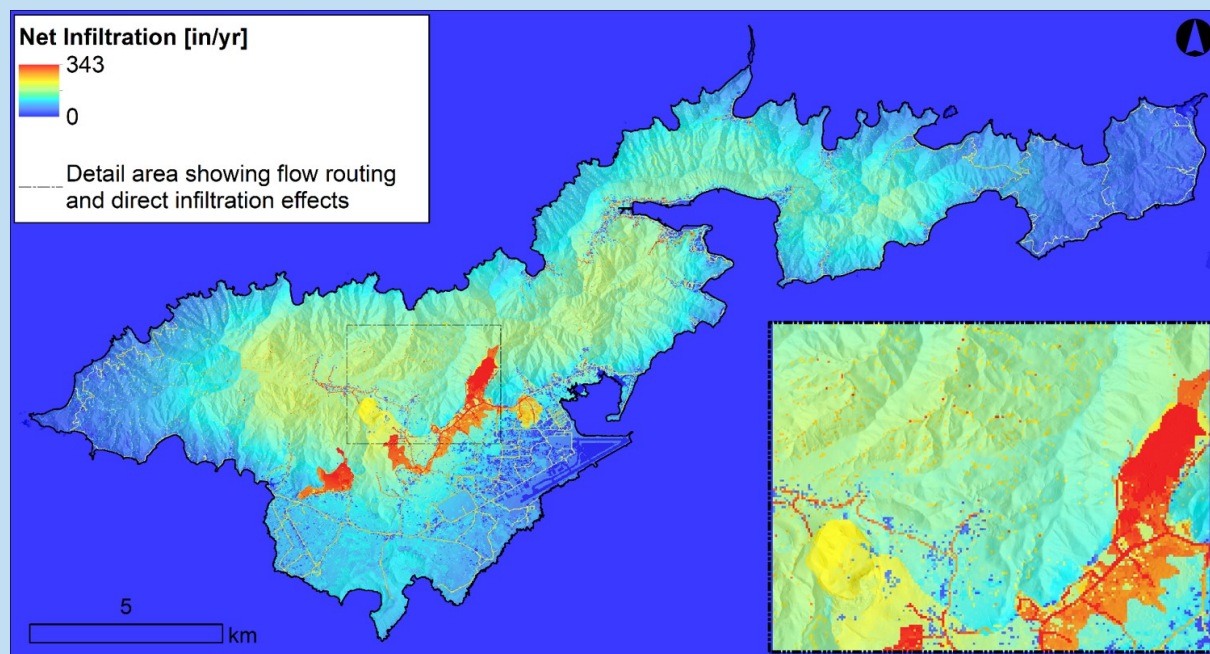
**Figure 4:** Projected changes in average annual (a) temperature (°F) and (b) rainfall (in) (%) change in 2050-59 using warming scenario RCP8.5. Changes are relative to a comparison to the 1970-2000 baseline.

Informational briefs were designed in response to stakeholder requests for short policy-relevant summaries on the findings of new report, [Water Resources in Guam: Potential Impacts and Adaptive Response to Climate Change](#). These resources are available at: <http://www.pacificrisa.org/projects/>



## American Sāmoa

- ▶ The American Samoa Power Authority (ASPA) is using weather station [data from the hydrologic monitoring network](#) developed by UH WRRC, ASPA, and Pacific RISA for their own engineering project designs, for example to assess expected rainfall intensities when designing drainage ditches.
- ▶ Ongoing initiatives led by the American Samoa EPA to establish local Dissolved Inorganic Nitrogen thresholds are looking to utilize the open-source [nutrient loading tool](#) developed by Dr. Chris Shuler.
- ▶ ASPA is applying [criteria](#) developed through test installations of monitoring well instruments to design their next generation SCADA operational well control and data logging system (see WRRC-ASPA's [Hydrological Monitoring Network Handbook](#)). ASPA also intends to use [hydrologic modeling products](#) (e.g., water budget model, groundwater modeling framework) developed through this research collaboration for water management decision making.
- ▶ A water budget model that estimates groundwater recharge across the Island of Tutuila was developed. This recharge model is designed to assess different future scenarios of climate and possible land uses, simulated for the end of the century. It was developed as an open-source package ([https://github.com/cshuler/SWB2-Participatory\\_Scenarios](https://github.com/cshuler/SWB2-Participatory_Scenarios)), which significantly increases reproducibility and transparency.



*Final map of present day model calculated average-annual groundwater recharge at 20 m cell-size resolution. Inset map shows detail of 1) flow routing effects, seen as higher recharge squares at the bottom of drainage channels, 2) direct infiltration from leaking water lines, seen as linear zones of higher infiltration, and 3) MFR zones seen as larger areas of high-infiltration. (Credit: Chris Shuler)*

## Pacific Islands Region

- ▶ Dr. Laura Brewington provided a literature summary of climate change and invasive species impacts, interactions, and future risks in Pacific Islands to the members present at the 2018 Pacific Invasives Partnership meeting in June. This informed a Global Climate Fund proposal developed by the Secretariat of the Pacific Regional Environment Programme (SPREP) targeting invasive species removal in Niue and Tonga. The literature summary is also being used to update the Regional Biosecurity Plan for Micronesia and Hawai'i, and will serve as a springboard for the Hawai'i Climate Change and Invasive Species Working Group webinar series anticipated to begin in Summer 2020.





*Volunteers from Kupu's Hawai'i Youth Conservation Corps were a vital part of the State of Hawai'i Climate Conference's success. (Image: S. Hasegawa)*

## **Outreach & Engagement Highlights**

### **2020 Hawai'i Climate Conference: Hā O Ke Kai**

For the second year, our collaborators at the Hawai'i Department of Land and Natural Resources asked the Pacific RISA and East-West Center to co-organize and host the [State of Hawai'i Climate Conference](#). Building off of the success of last year, this year's free conference was expanded to two days, January 13–14, 2020, and took place at the EWC Imin Center. Just as equity set the tone for last year's conference, Year 2 emphasized the communications aspect of climate change action. Governor David Ige and DLNR Chair Suzanne Case gave the opening remarks. The first day featured Keynote speaker David Wallace-Wells, author of *The Uninhabitable Earth*, and two panels that highlighted work being done in Hawai'i and lessons from other states and cities. The second day featured lightning talks by researchers working at the cutting edge of climate change issues—including Kirsten Oleson, Matthew Widlansky, and Dan Ervin from Pacific RISA—as well as three media workshops led by communications experts and science professionals to help participants fine-tune their climate change messages. Pacific RISA's Victoria Keener, Krista Jaspers, and John Marra each played important roles in ensuring the success of the conference.

### **Humanism, Empathy, Social Justice, and Global Health Symposium**

As a part of “Humanism Week” at the University of Hawai'i John A. Burns School of Medicine, Pacific RISA Project Specialist Dan Ervin partnered with the University of Hawai'i System Global Health and Social Justice Work Group and the School of Medicine to co-organize the 2020 Humanism, Empathy, Social Justice, and Global Health Symposium in Honolulu in February 2020. The meeting featured a specialty panel on social justice and Micronesian health in Hawai'i with a keynote address by Dr. Sheldon Ricklon, one of only two US-certified medical doctors from the RMI. Addressing issues such as health equity, justice, and inclusion is central to ensuring Micronesian communities in the USA have access to quality healthcare and safe housing, and the Symposium shed light on the need to integrate local and regional politics and health. Health equity and justice for marginalized populations are now more crucial than ever in the COVID-19 pandemic.

### **National Climate Assessment–PIRCA Workshops in the USAPI**

Pacific RISA was widely engaged with stakeholder groups in American Samoa, Guam, CNMI, and Palau during 2019–2020 through the National Climate Assessment–PIRCA workshops held in each jurisdiction as part of the 2020 PIRCA climate assessment process. In June 2019, Pacific RISA Principal Investigator Victoria Keener and former graduate student Chris Shuler met with approximately 25 decision-makers from government and natural resource management sectors. Those gathered learned about the findings of the Fourth National Climate Assessment, with specific attention to local research findings. Participants contributed local sectoral knowledge toward this assessment product. Key knowledge shared included, for example, impacts on specific cultural sites and challenges faced in managing risks to coastal infrastructure under the current land-use regulatory system.





*Technical contributors at the National Climate Assessment-Pacific Islands Regional Climate Assessment Workshop for Palau on July 23, 2019.*

In July 2019, workshops were held in Palau and the Commonwealth of the Northern Mariana Islands. At these workshops, over 70 representatives from a range of sectors gave their input on how climate variability and change is affecting local sectors such as tourism, ecosystems, fisheries, health, agriculture, disaster management, infrastructure planning, cultural resources, and the economy. In Palau, the country's Office of Climate Change partnered with Pacific RISA to host the National Climate Assessment PIRCA Workshop on July 23, 2019 at the Palau National Marine Sanctuary headquarters. As part of the workshop, Pacific RISA Program Manager Wendy Miles and Sustained Assessment Specialist Zena Grecni facilitated detailed discussions on the draft climate science summary for Palau with technical contributors from Palau's various sectors. In Saipan, Pacific RISA presented a summary of the most recent climate science research for the Northern Mariana Islands and facilitated working sessions to gain feedback on the CNMI climate assessment summary at the 2-day NOAA "Adaptation Planning for Coastal Communities" workshop (July 30–31, 2019). Additional meetings were held with representatives from government agencies and non-profit organizations in CNMI to gain further feedback that will inform this effort.

In Guam, Pacific RISA partnered with the Guam Climate Change Resiliency Commission to host a Town Hall Forum and NCA-PIRCA Workshop, organized in partnership with the Pacific Islands Climate Adaptation Science Center, the Guam Bureau of Statistics and Plans, and the University of Guam. Lieutenant Governor Joshua Franquez Tenorio welcomed Pacific RISA to Guam, speaking to the gathered press about the importance of Guam's newly established Climate Change Resiliency Commission. The Town Hall Forum was held on October 29th, at which the findings of national and regional climate assessments were shared to raise awareness on the potential impacts of climate change to Guam. The following day, over 30 local experts and managers from an array of agencies and organizations gathered for the Guam NCA4/PIRCA Workshop. Feedback provided by attendees in all workshops informed the climate assessment summaries that will be published in late 2020.

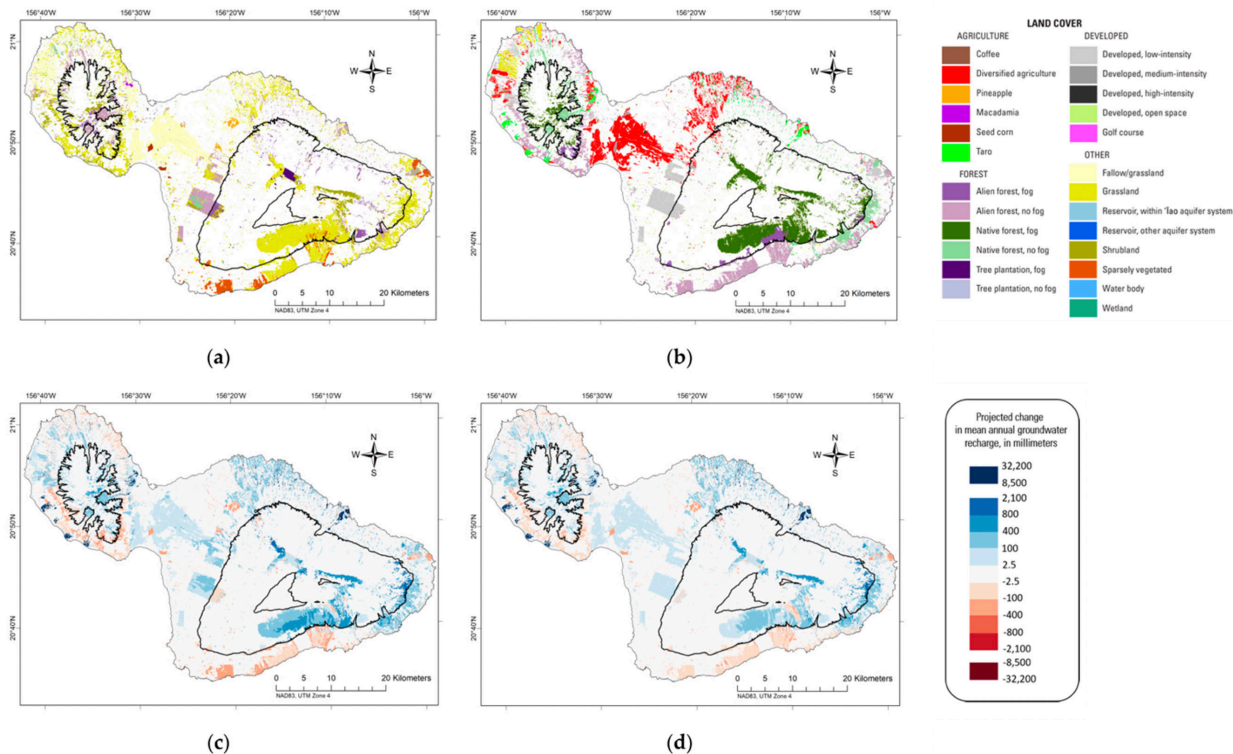


*Lieutenant Governor Tenorio welcomes Pacific RISA team members Wendy Miles and Zena Grecni to Guam and announces the new Climate Change Resiliency Commission, which partnered with Pacific RISA to host the Guam Pacific Islands Regional Climate Assessment Workshop in October 2019.*



## Maui Groundwater Project Demos and Discussions

Laura Brewington and Victoria Keener held multiple seminars and workshops highlighting the results of the Maui Groundwater Project. These were designed to inform stakeholders on Maui and at the State level of the utility of the findings, such as targeted areas for investment in water-saving or reclamation techniques, regions of high conservation priority with impacts on groundwater recharge, and vulnerable coastal areas with limited groundwater resources under future land cover and climate scenarios. The future land cover scenario inputs to this project, which were co-produced with Maui stakeholders and have been available to planners, policy makers, and researchers, are now accompanied by the outputs of the water-budget model and associated geospatial data layers that clearly demonstrate the tradeoffs between urban development, watershed conservation, agricultural practices, and water resources under a changing climate.



The figure above shows (a) 2017 baseline land cover for Maui. Only areas that were subject to change under the Conservation-focused land cover scenario are shown; (b) Conservation-focused land cover change from 2017 baseline land cover conditions. Change in mean annual recharge for Conservation-focused land cover and (c) Wet future climate; (d) Dry future climate. The solid contour lines represent the base (610 m) or top (2500 m) of the cloud zone. Recharge increased where grassland converted to any type of forest above the cloud zone, where new diversified agriculture appeared, and where taro cultivation was introduced. Recharge decreased under both future climates in areas where grassland changed to alien forest below the cloud zone, seen along the leeward areas of west and east Maui.

## Incorporating ecosystem goods and services into planning in Hawai'i

Pacific RISA PI Kirsten Oleson has continued to support the State of Hawai'i's efforts in coastal management, often bringing a unique perspective to consider ecosystem goods and services in planning. In 2019–2020 she participated in multiple stakeholder meetings convened by the State of Hawai'i's Department of Aquatic Resources, developing socio-economic, cultural, and governance indicators for effective management. Dr. Oleson's team worked with the State of Hawai'i's Commission on Water Resource Management, Board of Water Supply, and USGS to develop their water accounts system. Dr. Oleson presented preliminary results to Ulupono Initiative, broad stakeholders at the 'Ike Wai Wai WRRC workshop, and peers and the public at the Pacific Technical Water Conference.



*Edith Adkins, habitat conservation manager, shows researchers seedlings of endangered native trees used in ecosystem restoration at Pu'u Wa'awa'a Forest Reserve. (Image: Abby Frazier)*

## Hawai'i Drought Exchange

The Pacific Islands Climate Adaptation Science Center is supporting a “Hawai'i Drought Exchange” project in collaboration with the Pacific RISA, to improve drought information delivery and uptake among Hawai'i's natural resource managers, focusing on three pilot sites: Hawai'i Volcanoes National Park and Pu'u Wa'awa'a Forest Reserve on Hawai'i Island, and the West Maui Mountains Watershed Partnership on Maui Island. This work will build out the drought-management and stakeholder component that Pacific RISA has already done by conducting manager site interviews and a statewide survey. The objective is to demonstrate how managers can take a more active role in the drought research process, and how drought-related research can be more effectively used to inform management planning on different time scales, including preparing for an accentuated dry season or long-term baseline change. PIs Keener and Oleson are leading the social science component with Masters student Melissa Kunz, while Drs. Abby Frazier and Ryan Longman are simultaneously conducting spatial analysis and creating the resulting products. Field visits are conducted with both social and physical science teams present.

## Cross-Regional Dialogues on Climate Change, Health, and Migration

Pacific RISA team members continue to engage with a wide range of stakeholders both in the Pacific Islands region and elsewhere on the inter-related challenges of climate change, human health, and migration. In 2019–2020 these activities have included:

- ▶ The Association of State and Territorial Health Officials (ASTHO) held its annual meeting in Honolulu in June 2019. Participants included Ministry-level health representatives from the USAPI, Puerto Rico, and the US Virgin Islands. Laura Brewington was an invited panelist and discussant on climate change, health, and migration. She described the NOAA Pacific Climate Services Dialog process and presented the output from prior work with the Marshall Islands agroforestry sector, and is in discussion with ASTHO officials to replicate the process for the health sector beyond the Marshall Islands IRAP project work to other locations within the USAPI.
- ▶ Dan Ervin attended the 2nd Symposium on Climate Change Adaptation in the Pacific Region in Lautoka, Fiji (August 2019). This multi-day conference convened researchers from all over the Pacific to discuss climate change and share the Pacific RISA's work on climate, health, and migration with participants. The climate and health topic in particular was approached through a range of lenses, including academic theory, youth education, healthcare management, information connectivity, religious faith, and local knowledge. Related to migration, concrete examples of research and development projects were discussed, which included planned relocation, environmental migration, information sharing networks, school lesson plans, and local food projects.



- ▶ Dr. Brewington organized a special session at the RISA Annual Meeting in Honolulu on climate-induced migration to enable the exchange of lessons across regions. Speakers from ACCAP, CCRUN, Pacific RISA, and Hawai'i SeaGrant described multi-sector efforts to plan for climate impacts on coastal communities in Alaska, the Northeast, and Hawai'i.

## Next Steps and Future Plans

### Climate Synthesis Reports for the US-Affiliated Pacific Islands

In 2019–2020 PIRCA Sustained Assessment Specialist Zena Grecni, Dr. Wendy Miles, Dr. Victoria Keener, and Dr. Chris Shuler collaborated with partners in the region to hold a series of workshops that provide stakeholders and technical experts the opportunity to inform the development of PIRCA reports for American Samoa, Palau, the Commonwealth of the Northern Mariana Islands, and Guam. Although similar meetings in the Federated States of Micronesia, and the Republic of the Marshall Islands were in the early planning stages when the COVID-19 pandemic started, those convenings were indefinitely postponed. Nonetheless, the project team identified key partners in national governments of the two countries, and are developing a PIRCA summary for RMI in close collaboration with a point-of-contact within the RMI National Disaster Management Office. Work on these reports will continue, with publication anticipated in late 2020. When released, the PIRCA reports will be used in funding proposals for adaptation projects, to inform National Adaptation Plans, and in governments' communications with the public and decision makers at local, national, and international scales.

### Evaluating similarities & differences between statistical & dynamical downscaling

Future rainfall patterns have been projected for the Hawaiian Islands using statistical downscaling and for Maui Island using dynamical. However, more work needs to be done to test and refine methods in order to produce reliable results. Both statistical and dynamical downscaling methods have inherent uncertainties. The statistical downscaling approach is based on statistical relationships between local weather conditions and large-scale atmospheric circulation patterns. Stakeholders in policy and management positions need to know both how and why the downscaled projections differ. Pacific RISA PI Thomas Giambelluca and his team will be applying the optimized statistical downscaling model to project near-term and end of 21st century climate change scenarios and develop case scenarios for specific locations on the Hawaiian Islands that can inform the general public about the potential impacts of future climate change. In the upcoming year, a significant part of the effort will go into product development (including preparation of open-access data sets and code sharing, metadata data, description of data and code, and writing a peer-reviewed article).

### Economic Impacts of the RISA Network

Dr. Kirsten Oleson recently joined a cross-RISA effort to develop a methodology to help quantify the economic impacts of RISA. This initiative will examine how coral restoration, coastal protection, and watershed management in strategic locations could generate high economic benefits in terms of non-market ecosystem services returns.

### Evaluating Pacific RISA's Progress

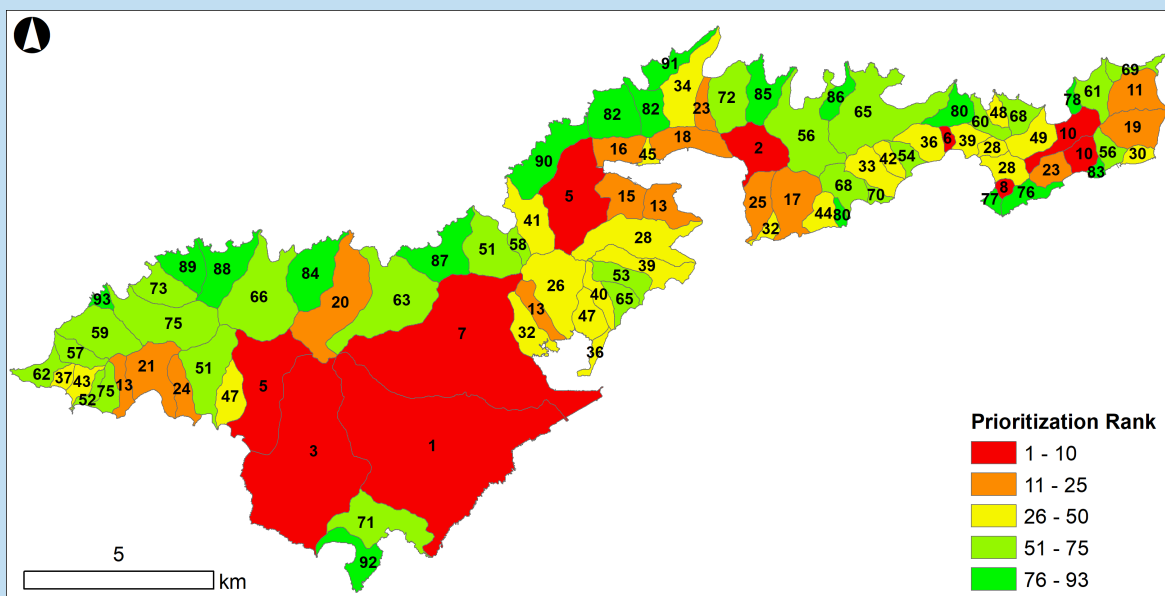
Pacific RISA's evaluation component encompasses internal and external efforts to learn from Pacific RISA's efforts in advancing adaptation science and planning in the Pacific Islands. This research helps us to assess the value of the program in supporting decision-makers with climate information and services that are unique yet coordinated with other regional programs, and adaptively improve the climate services we develop. This ongoing learning process informs Pacific RISA's evolving "Theory of Impact."

In the past year, Pacific RISA’s annual reporting data collection process has been re-designed into a two-part online survey that more effectively and efficiently tracks team progress through time. In August 2019, Pacific RISA reflected on the progress they have made since inception, and articulated this in the “Evolution of the Pacific RISA Program” poster presented at the RISA Annual Meeting in Honolulu. This poster includes a timeline of major milestones from 2003–present, team statistics for 2015–2020, and a new figure on the functions of Pacific RISA from the perspective of stakeholders. Building on past evaluative research on Pacific RISA, Finucane, Moser, Miles, and Keener are drafting a paper on the functions of boundary organizations from the perspective of stakeholders, and the importance of engaging end users from project outset to identify theories of impact, appropriate tracking methods, and useful indicators and metrics. In Spring 2020, Pacific RISA and Moser developed the design parameters of an upcoming evaluation of the PIRCA, which will provide valuable insights for NCA5 and future PIRCA climate information products and services.

## Evidence of Societal Impact

### Development of an Open-Source Dissolved Inorganic Nitrogen Loading Model in American Sāmoa

In the past, the only watershed scale impact classification available to local management agencies in American Samoa was developed with a basic assessment of population density within each 'major' watershed. In contrast, the initiative led by Pacific RISA’s Chris Shuler and Aly El-Kadi in collaboration with the American Samoa Power Authority incorporates direct metrics, such as assessing loading directly from the numbers of mapped nitrogen sources island-wide, and also provides a prioritization scheme to coastal water quality managers at a higher ‘minor’ watershed resolution. Ongoing initiatives led by AS-EPA such as the establishment of local dissolved inorganic nitrogen (DIN) thresholds are incorporating available resources including our open-source tool into their decision making. Other researchers working in American Samoa are now examining the utility of this DIN loading model to help inform impacts of terrestrial run-off on important reef fishes, and some are incorporating the new DIN loading model in a consolidated data collection and presentation effort to visualize the drivers of coastal ecosystem health with the ocean tipping points project (e.g., <https://www.pacioos.hawaii.edu/projects/oceantippingpoints/#data>).



The above map showing impact prioritization ranking for each watershed on Tutuila, American Sāmoa. The measure of impact uses coastal loading of dissolved inorganic nitrogen (DIN) rates as a proxy. Impact in each watershed is calculated as an index score, which is a function of 1) the amount of DIN released by all known anthropogenic sources in each watershed, 2) the area of each watershed, and 3) the coastline length of each watershed. Each of the 93 watersheds are then sequentially ranked based on their impact score with the highest ranked watersheds (1 to 10) being those with the greatest amount of anthropogenic impacts, according to the information analyzed by this study.

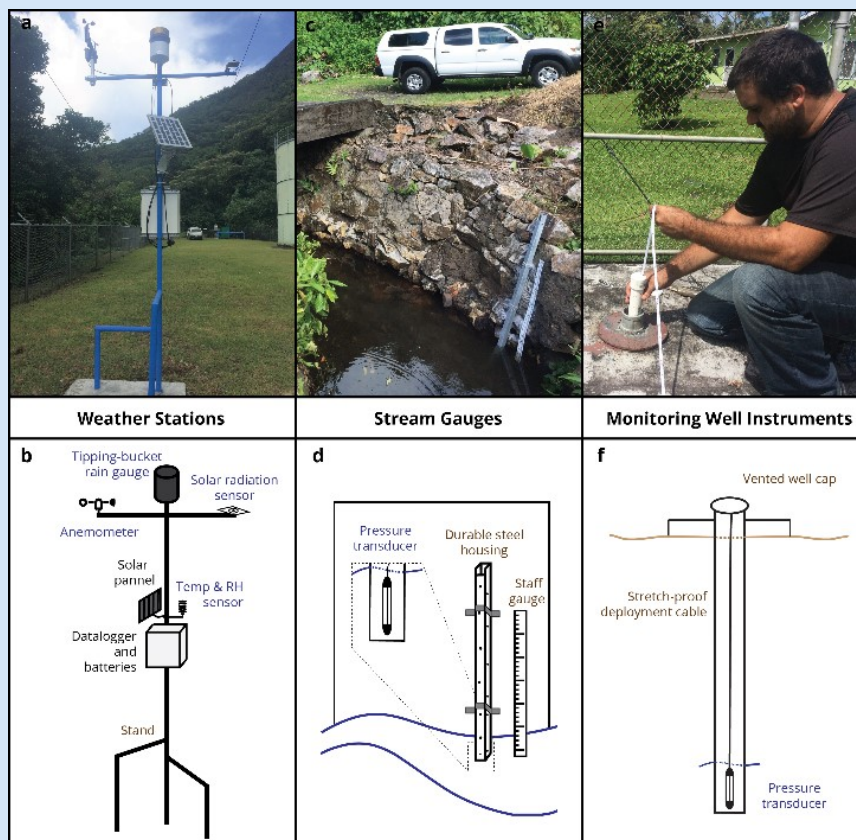


## Groundwater modeling work in American Sāmoa

Pacific RISA PI Aly El-Kadi and Dr. Chris Shuler’s groundwater modeling work with the American Samoa Power Authority directly supports their mission in managing and providing a sustainable supply of water to the territory. Their new water budget modeling work produced projections of groundwater recharge availability at the turn of the century in consideration of climate change effects as projected by Wang and Zhang (2016) using a dynamical global climate model. Groundwater recharge estimates during 2080–2099 under the RCP4.5 and RCP8.5 future climate scenarios were produced and delivered to multiple agency stakeholders during a field visit in June 2019.

## UH-ASPA Hydrologic Monitoring Network

On Tutuila, American Samoa, weather monitoring and stream gauging operations were initiated by the United States Geological Survey in the 1950s. However, as of 2008, all USGS monitoring activity on Tutuila had ceased. Although this legacy data remains as a valuable tool, climate change and variability continues to reduce its viability as time passes. Because this information is a critical component of sustainable water management, the UH Water Resources Research Center and the territory’s sole water utility, American Samoa Power Authority, have entered into a cooperative agreement for the purpose of developing a new weather station, stream gauging, and aquifer monitoring network. The instruments used in this network are intended to be simple, robust, and easily maintained to ensure longevity and continuity of data.



Example photos of ASPA-UHWRRRC weather station, stream gauge, and monitoring well network instruments with schematics. Campbell Scientific weather stations are shown in panels a and b, stream gauges are shown in panels c and d and the monitoring well instruments are shown in panels e and f. Blue text on schematics indicates sensors and brown text indicates infrastructure used.

## Assessing Economic Impacts of Natural Resource Management Decisions in Hawai'i

Pacific RISA PI Oleson and Dr. Carlo Fezzi worked with the State of Hawai'i Division of Aquatic Resources and partners—including NOAA, The Nature Conservancy, and others—to build economic considerations into ongoing marine spatial planning efforts. The goal of this effort has been to improve the return on investment of marine management actions. Instead of focusing just on areas that have high ecological value, the economic dimension ensures that marine conservation is also steered by where society will benefit, i.e., from experiencing restored reefs or fishing. Dr. Oleson's team has forged tight partnerships with key water management agencies in the state to evaluate the water system and the resilience of the water-energy-food nexus. In addition to multiple public presentations that drew broad interest, Dr. Oleson and her team held a well-attended workshop on water accounting for O'ahu.

## Pacific Islands Regional Climate Assessment (PIRCA)

External evaluation has shown that Pacific RISA stakeholders want assessments to reflect more inclusively the needs and input of decision makers from across the region. By developing a PIRCA report for each USAPI country and territory, with the involvement of more than 125 in the NCA-PIRCA workshops, the 2020 PIRCA will be strongly focused on climate-related issues of importance to the wider Pacific Islands beyond Hawai'i. When these PIRCA reports are released for Palau, Guam, CNMI, and American Samoa in late 2020, they will address the need for locally specific information on how climate is changing and the risks and impacts in key sectors, and will highlight key research and information gaps. These reports will be used in funding proposals for adaptation projects, to inform National Adaptation Plans, and in governments' communications with the public and decision-makers at local, national, and international scales. For example, local partners advised Pacific RISA that the PIRCA has informed draft territorial legislation in Guam and American Samoa and is currently being used as the scientific basis for a funding proposal for developing Palau's National Adaptation Plan.

## Further evidence of the societal impact of Pacific RISA

- ◆ The Marshall Islands National Adaptation Plan is being developed with input from the IRAP project and the Pacific Islands Regional Climate Assessment country report. This collaboration would not be possible without engagement with the Ministry of Health and the Office of Environmental Planning and Policy Coordination during the climate change and health dialog organized by Laura Brewington and held in Majuro in January 2020.
- ◆ Regional and international priorities for invasive species continue to be guided by input from the Pacific Invasives Partnership, which Dr. Laura Brewington has provided climate change expertise for since 2017. A Regional Invasive Species Coordination Office is currently being stood up in Palau under guidance from the most recent Micronesian Island Forum, at which Laura Brewington successfully advocated for a direct relationship with the Palau Office of Climate Change.
- ◆ The Maui Groundwater Project has proved so useful to stakeholders across multiple sectors on Maui that the Hawai'i Commission on Water Resources Management has committed to funding a similar scenario-based approach to predict future groundwater resources on all the main Hawaiian Islands in partnership with the USGS.

## Case Studies of Pacific RISA's Contributions

### Guidance for Revising O'ahu's Shoreline Setbacks

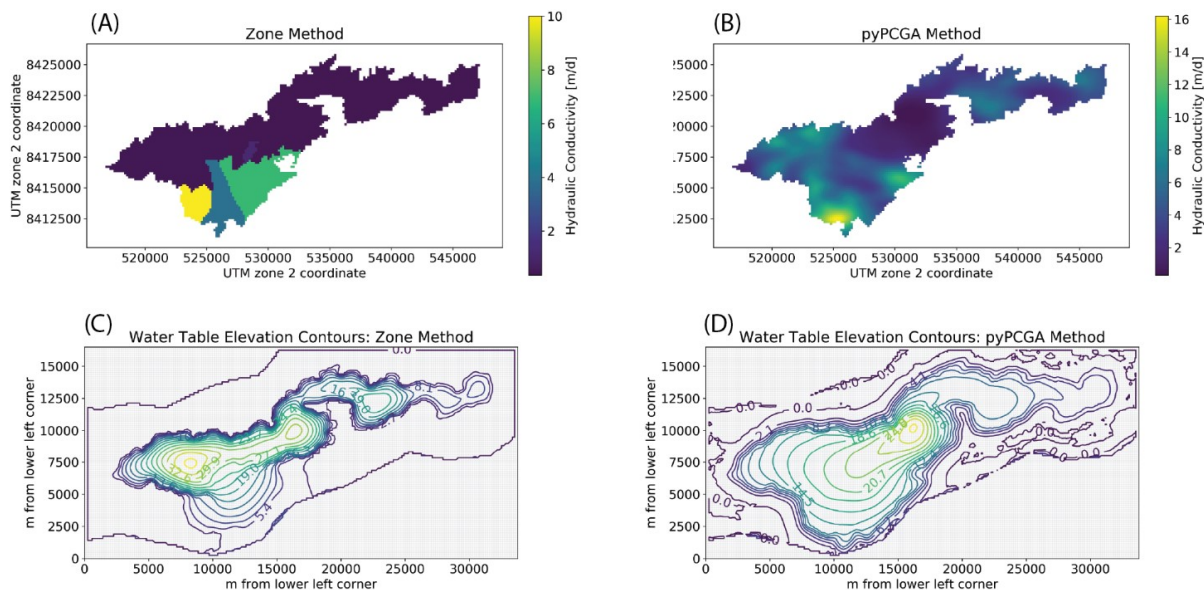
The 2017 Hawai'i Sea Level Rise Vulnerability and Adaptation Report assessed that with only 1 foot of sea level rise, O'ahu's land and building value exposed to high seasonal waves, coastal erosion, and groundwater inundation would surpass \$4.1 billion, and would result in over 2,000 residents being



displaced. These estimates increase to \$12.9 billion in land and building value and 13,300 O‘ahu residents displaced with 3.2 feet of sea level rise. The Hawai‘i Revised Statutes (HRS), Chapter 205A, authorizes the City to establish and revise as appropriate a coastal setback. Mayor Caldwell, in correspondence dated June 25, 2019, requested that the City and County of Honolulu Climate Change Commission provide guidance on new shoreline regulations and rules. In response, Dr. Victoria Keener and other commissioners provided a December 2019 guidance document for amending Revised Ordinance of Honolulu (ROH) Chapter 23 “Shoreline Setbacks.” These eight recommendations were developed in collaboration with the Honolulu Office of Planning, and suggest using multiple criteria including place-appropriate and future-climate considerations to create dynamic setbacks across the island. ROH Chapter 23 on shoreline setbacks is currently being revised.

### ASPA-UH WRRRC Integrated Groundwater Modeling Framework

In American Samoa, groundwater resources supply over 90% of domestic, and nearly 100% of industrial water use. However, these resources are afflicted by multiple threats to their long-term sustainability. Since 2009, portions of the public water supply system have been unsafe to drink, necessitating one of the longest standing boil-water-advisories in U.S. history. This is partly caused by the vulnerability of Tutuila’s young and highly-permeable aquifers to anthropogenic and surface water contamination. Other aquifers on Tutuila produce high salinity water, presumably caused by salt-water intrusion. In some cases, the island's wells produce water with Cl<sup>-</sup> concentrations exceeding the US EPA drinking water standards by four to five times. Multiple local stakeholders see groundwater models as a tool that will greatly facilitate management of these issues. While development of groundwater models has been a long standing priority for ASPA, the island’s only water utility, limitation of financial and personnel resources has precluded realization of that goal. The static nature of typical models also restricts their ability to be modified, and by nature, most small-scale water utilities do not have the time or resources needed to support building and maintaining the technical capacity necessary for maintaining active modeling projects. However, the ASPA-UHWRRRC Integrated Groundwater Modeling Framework facilitates the collaborative model development process and delivers seamless integration of multiple computational components into a dynamic cloud-based workflow that is immediately accessible by stakeholders and resource managers. Additionally, this modeling framework will serve as a foundational resource for Pacific RISA work planned for 2020–2021, enabling the examination and identification of critical buried utility infrastructure that is most at risk to sea level rise effects.



Examples of calibrated hydraulic conductivity ( $K$ ) distributions and resulting water table elevation contours. Figure (a) shows zone-based  $K$  calibration based on simplified geologic units from Stearns (1944). Figure (b) shows grid-based  $K$  calibration developed using the pyPCGA optimization technique. Figures (c) and (d) show water table elevation contours computed using the zone-based and the pyPCGA methods, respectively. Note that results are shown only for demonstration purposes as the model calibration remains, as of this writing, in an oversimplified state.

## Publications with Highlights

### Most Significant Publications of the Reporting Period

**Brewington, L., Keener, V., and Mair, A. (2019). Simulating land cover change impacts on groundwater recharge under selected climate projections, Maui, Hawai'i. *Remote Sensing*, 11 (24): 3048, <https://doi.org/10.3390/rs11243048>.**

This publication was years in the making and relied on collaboration between Pacific RISA/East-West Center, University of Hawai'i International Pacific Research Center, and USGS Pacific Islands Water Science Center researchers to develop an integrated land cover/hydrological modeling framework using remote sensing and geographic information systems (GIS) data, stakeholder input, climate information and projections, and empirical data to estimate future groundwater recharge on the Island of Maui. End-of-century mean annual groundwater recharge was estimated under four future land cover scenarios and two downscaled climate projections representing a dry future and a wet future. The study demonstrated that a spatially-explicit scenario planning process and modeling framework can communicate the possible consequences and tradeoffs of land cover change under a changing climate, and the outputs from this study serve as relevant tools for landscape-level management and interventions.

**van der Geest, K., Burkett, M., Fitzpatrick, J., Stege, M. and Wheeler, B. (2019). Marshallese perspectives on migration in the context of climate change. International Organization for Migration (IOM) Migration: Environment and Climate Change: *Policy Brief Series*, <https://environmentalmigration.iom.int/policy-brief-series-issue-1-vol-5-marshall-islands>.**

This policy brief on Marshallese perspectives on migration in the context of climate change highlights key findings on migration patterns, drivers and impacts, and discusses the tension between being prepared to move and fortifying to stay in place. This research has been cited in publications of the UNFCCC, shared by the UN humanitarian information service ReliefWeb, and reported by Marshall Islands-based journalists.

**Shuler, C. K., and Mariner, M. (2020). Collaborative Groundwater Modeling: Open-Source, Cloud-Based, Applied Science at a Small-Island Water Utility Scale. *Environmental Modeling and Software*, 127: 104693, [doi.org/10.1016/j.envsoft.2020.104693](https://doi.org/10.1016/j.envsoft.2020.104693).**

This case study demonstrates how the groundwater modeling field is well positioned to benefit from advances in cloud-computing and social networking. Pacific RISA researcher Dr. Chris Shuler used cloud-based methods to collaborate with remote stakeholders in American Samoa, and applied open-source tools to develop a collaborative hydrologic modeling framework that integrated multiple data collection and modeling components including the monitoring network, a water budget model, and a groundwater modeling framework. The open-source framework allows for seamless integration of multiple computational components into a dynamic cloud-based workflow that is immediately accessible to stakeholders, resource managers, or anyone with an internet connection.



# Complete List of Publications for the Annual Reporting Period

\* Most significant Pacific RISA publications of the past year have an asterisk.

- [Alegado, R., Coffman, M., Fletcher, C., Keener, V., & Mehnert, B.] City and County of Honolulu Climate Change Commission, (Adopted: December 23, 2019). Shoreline Setback Guidance. <https://www.resilientoahu.org/guidance-and-publications>
- Brewington, L. (In press). Transitions and drivers of land use/land cover change in Hawai'i: A case study of Maui. In *Land Cover/Land Use Change on Islands: Social & Ecological Threats to Sustainability*. Heidelberg: Springer.
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