1. **Award Title**: The Pacific RISA: Supporting Integrated Decision Making Under Climatic Variability and Change in Hawai‘i and the US-Affiliated Pacific Islands

2. **Performance Period:** June 1, 2016 to May 31, 2017

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4. Do you have any **NEW areas of focus or partnership** that have begun this past year? Please provide some context for why you are expanding into this area or partnership. Include any NEW cross-RISA partnerships.

Regional Pacific-Basin Migration: Climate Migration from US-Affiliated Pacific Islands to Hawai'i
Much research and debate has focused on the relationship between climate and migration, but it is widely recognized that a lack of rigor and clarity characterize research on the climate/migration nexus. Climatic changes often act in concert with other socioeconomic factors to drive displacement. Moreover, factors triggering mobility are often intertwined – environmental changes can generate health problems or food insecurity, and may play an even greater role if they emerge in a community characterized by political, social, or economic tension. In 2016, RISA PI Burkett hired a post-doctoral social science researcher and an in-country consultant in the Republic of the Marshall Islands (RMI) to conduct related research and fieldwork.

The key goal of the project is to understand the role of climate change and ecosystem services in the migration decisions of Marshallese Islanders, and the impacts of migration in source and destination areas—by supporting the following in Year 1:

- Hire of a social scientist on a postdoctoral stipend for two years, beginning in October 2016, and providing necessary equipment relevant to the extensive data analysis proposed;
- Support for 40 days of fieldwork in the RMI. Research sites included population center Majuro, as well as more remote Mejit and Malaelop atolls. This also included support for an in-country collaborator and a small team to support the social scientist's work; and
- Support for a Hawai'i-based researcher, Fitzpatrick, who will conduct field research with Marshallese migrant communities situated locally and relevant agencies in Hawai'i during the summer of 2017.

In addition to data analysis, preparation of peer-reviewed publications, and outreach, Year 2 will support:

- Two ground-truthing workshops in the beginning of Year 2 in the RMI and Hawai'i; and
- Two information transfer workshops are planned for the end of Year 2 in Hawai'i and the RMI.

Developing Future Climate Scenarios with the Honolulu Board of Water Supply
The City and County of Honolulu Board of Water Supply (BWS) serves approximately one million customers on the island of O'ahu, Hawai'i with about 145 million gallons per day (mgd) of potable groundwater and 10 mgd of non-potable water. The municipal system supports a large urban center, but the infrastructure (including more than 2,100 miles of pipe, 212 wells and tunnels, and 171 reservoirs) is aging. Following the release of the 2012 PIRCA, the BWS was concerned that changing climate patterns could affect both quality and quantity of the water supply. BWS was aware of Pacific RISA's work developing future climate scenarios for the island of Maui, and wanted to pursue a similar infrastructure-centered process for O'ahu. Even with conservation measures and repairs, freshwater demand on O'ahu is still projected to increase by 5 to 15% by 2040, with the most increases in areas of existing high population density.

In 2015, the BWS partnered with the Pacific RISA, the University of Hawai'i, and Brown & Caldwell consultants to assess projected climate change impacts on their infrastructure and identify vulnerabilities over the next 20 to 70 years using a scenario planning approach to consider a range of plausible future climate and socioeconomic conditions. Two all day meetings have been held at the East-West Center with the entire project team, in September 2016 and March 2017, producing a summary of available data and an initial vulnerability assessment (Figure 1**).** The vulnerability assessment considers extreme heat, coastal erosion, wave, groundwater, storm flooding, annual and seasonal drought patterns, and changes in groundwater recharge impacts. As a project outcome in the next year, BWS will develop a prioritized set

of adaptive actions to minimize the range of climate impacts, including urgent capital improvements and updates to engineering standards.

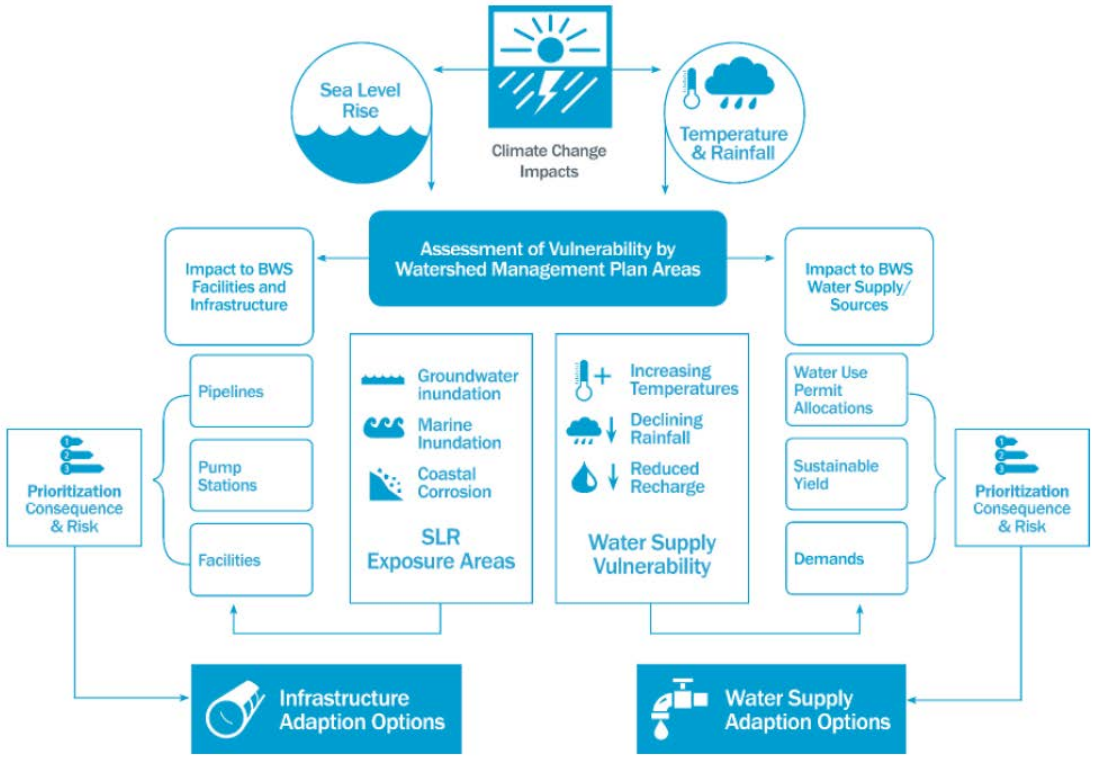

Figure 1. Brown & Caldwell overview of vulnerability assessment framework.

Assessing Sustainability of Groundwater Resources under Future Climate Conditions
This project established a new research collaboration with another State of Hawai‘i Water Resources Research Institute Program (WRRIP) funded research project on stream pesticide and nutrient loads from baseflow, surface runoff, and sediment contributions on Tutuila Island, American Sāmoa, led by Dr. Dulai. The purpose of the collaboration is to share knowledge, experience, and data about the Faga‘alu watershed. In addition, in order to obtain suspended sediment concentration data that was required for the Faga‘alu watershed sediment model calibration and validation processes, the team collaborated with staff from the Department of Geography at San Diego State University. This collaboration provided the available sediment concentration data that enabled the team to calibrate and validate the Soil and Water Assessment Tool (SWAT) for suspended sediment modeling and prediction in the Faga‘alu watershed. Regarding the climate variability impact assessment, two contrasting watersheds have been selected as case studies. These included the Faga‘alu watershed, which is highly disturbed by human activities, and the A‘asu watershed as an example of a pristine watershed. Such studies facilitate the comparison and differentiation of climate variability impacts on the availability of freshwater resources.

5. Please tell us which States or territories in your region are using new or tailored climate services (tools, information, technical assistance, or products) as a result of your interaction with decision makers over the past year. Please describe at least one new/tailored climate service per State/territory that you include.

The PIRCA Sustained Assessment Process and the Fourth National Climate Assessment
In collaboration with the Pacific Islands Climate Science Center (PI-CSC), the NOAA Regional Climate Services Director (RCSD, Marra), the East-West Center, and the Pacific Islands Climate Change Cooperative (PICCC), the Pacific RISA continued to work with the dedicated Sustained Assessment

Specialist (SAS, Grecni) to coordinate activities related to the Fourth National Climate Assessment (NCA4) and Pacific Islands Regional Climate Assessment (PIRCA). The SAS also provided timely and ongoing support for the National Climate Assessment and the Development Advisory Committee. Objectives during the reporting period were to 1) Coordinate activities related to NCA4 drafting and development; 2) Continue assembling a bibliography of peer-reviewed literature on climate change indicators, impacts, and adaptive capacity in the Pacific Islands; and 3) Generate a set of socioeconomic impact climate indicators to correspond to physical climate indicators.

A dedicated PIRCA website (PIRCA.org) now houses and showcases the 2012 PIRCA outputs, NCA4 resources, and upcoming PIRCA products, and serves as a valuable resource for stakeholders on the current status of regional climate and observed and anticipated trends. Resources include a "living bibliography" of published literature specifically relating to the indicators and impacts of climate change in the Pacific Islands, and assessing adaptive capacity. The bibliography has been used and developed by National Climate Assessment authors and other researchers. The SAS, along with NOAA Climate Program Office staff and PIRCA partners, coordinated the development of Pacific Island narratives for the Climate Resilience Toolkit (toolkit.climate.gov), an initiative under the President's Climate Action Plan. The Pacific Islands were one of the first US regions to be featured in the Toolkit in late summer 2016. The SAS also continued to build a set of technical indicators as part of a project with the NOAA RCSD (Marra). The Republic of the Marshall Islands was selected as an initial location, and public health as a priority sector, for determining key indicators. Preliminary contacts and interviews with public health managers were conducted and workshops or focus groups were held with the same health stakeholders later in the project cycle to confirm findings.

Ka Honua Momona

Pacific RISA PI Giambelluca and the statistical downscaling team is working with Ka Honua Momona, a community group on the island of Molokaʻi, to enhance their public outreach and community dialogue activities related to climate change. This interaction included participation in an Earth Day event on Molokaʻi, at which project Pacific RISA project research was explained and preliminary climate modeling results were shown (see ***Statistical Downscaling***, below). Work with Ka Honua Momona has resulted in the development of better contacts with rural stakeholders who can benefit from the results of the RISA project research.

Future Land Cover Maps for Maui

The future land cover maps for Maui island developed by Pacific PIs Brewington and Keener continue to be distributed widely throughout county and state levels of governance and are published on the Pacific RISA webpage. They are being used in an increasing number of policy-relevant and research applications, including ecosystem services valuation for west Maui, the West Maui Ridge to Reef initiative, and an ongoing project on Maui sustainability led by the PICCC. Their utility and broad usage has increased Pacific RISA visibility in Hawaiʻi and a new project investigating water resources on Oʻahu under climate change (see ***New Areas of Focus***, above) is employing a similar explicit land cover-based approach.

6. A. How are you measuring the overall program-level impact of your RISA team? Please provide information on your evaluation model, including metrics or indicators that you use to evaluate your program.

Supporting Hawai'i's Climate Adaptation Efforts: The Role of the Pacific RISA

Over the past year, independent Pacific RISA evaluator Dr. Susi Moser continued her efforts to track the impact that Pacific RISA research has had in the region, producing a final report on the advancements in the action-logic model and evaluation efforts for Phase II of the program (2010-2015). Over the five years

of work, the Pacific RISA was extremely productive, undertaking 17 unique projects, with several of them spanning multiple years or the entire five-year time span.

Each year, for each new or ongoing project, a tracking sheet was completed by the responsible RISA staff, PI or project lead, resulting in 41 individual tracking sheets. Each tracking sheet – in correspondence with the underlying ALM1 – asked the project leads to provide information about:

- The name of the project, lead and performance period (start and end dates)
- The principal focus of the effort (relative to Pacific RISA focal areas)
- The specific objectives of the effort being reported on
- Names of all involved team members
- Assumptions (e.g., available staff, data, resources) at the start of the performance period
- Actual inputs (staff time, resources, stakeholder input etc.) over the performance period
- Intended audiences
- Activities accomplished during the performance period (incl. cross-RISA activities)
- Outputs produced
- Stakeholder interactions and partnerships
- Outcomes achieved
- Future plans

Project information was provided either in the form of multiple-choice survey questions or write-in information. In some instances, project leads provided a narrative in addition to the tracking sheets. The obtained survey-type (quantitative or qualitative) and textual information was transferred from the paper documents into a single excel sheet and coded for analysis. After entering the information into the excel spreadsheet, information was discussed with Pacific RISA PIs Finucane and Keener and carefully cross-checked to ensure accuracy and correct interpretation of the qualitative information. The resulting information was then analyzed using predominantly descriptive statistics.

> B. Please describe your overall program-level impact including (if applicable) a summary of the results from your evaluation efforts.

Through her thorough evaluation of five years of internal tracking sheets, Dr. Moser concluded that since the Phase II launch in 2010, the Pacific RISA has firmly established mechanisms for internal and external tracking and evaluation of its work. Her report found that the Pacific RISA is a boundary organization of remarkable stability and productivity and is also a well-managed program, navigating staff and efforts through staff turnover as well as funding delays and declines – accomplishing much with remarkably little. In its core mainstay projects the Pacific RISA program is well integrated, as is apparent from the mutual dependency of the work being done, the complementarity of the themes, and the evolution of projects over time, as well as through the overlap of staff/team members in various projects. While research clearly dominates the Pacific RISA's work, as evident from a number of indicators, almost all projects involve the wide range of stakeholders they are designed to serve (Figure 2). This deep engagement with stakeholders has maybe contributed most to ensuring that the Pacific RISA is seen as the trusted go-to information source in the region. Despite the heavy emphasis on science, typical scientific outputs – peer-reviewed publications – are not the dominant output. Instead, products for, and encounters with, stakeholders are by far the most prominent outputs of the organization. As such, the Pacific RISA has emerged as a model transdisciplinary program from the evidence at hand. As for the program's outcomes to date, the Pacific RISA is strongest in its achievement of short-term outcomes, with fewer medium-term results, and the lofty long-term goal of "climate resilient communities" may take a little while longer.

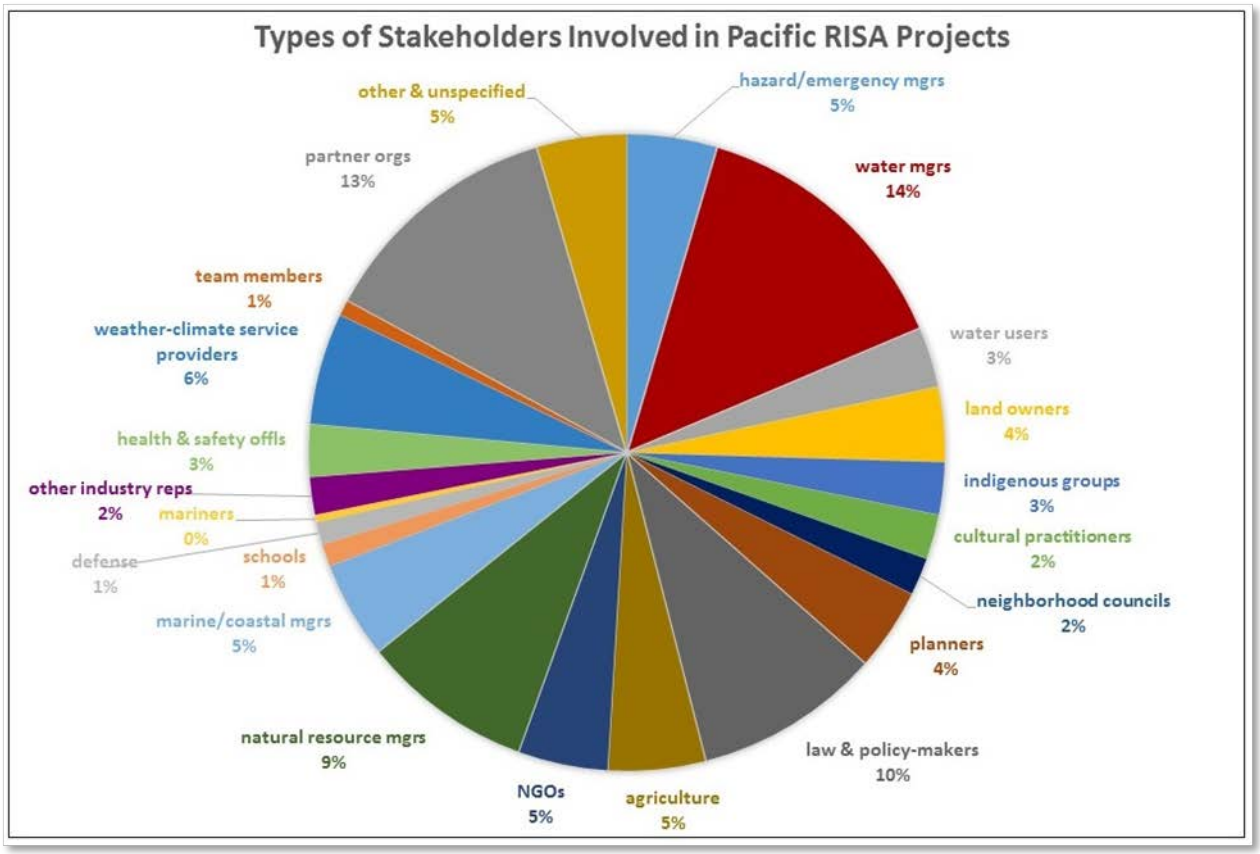

Figure 2. Types of stakeholder groups engaged in Pacific RISA projects.

7. How have you helped to build the expertise and ability of local/regional decision-makers to prepare and adapt to climate variability and change?

Perceptions of Climate Needs and Downscaling Data by Intermediate Modelers in Hawai'i

One of the most consistently confusing issues for decision makers in Hawai'i is how to select and use the most appropriate downscaled climate projections available in specific projects. Available projections are constantly updated with new information and use different spatiotemporal scales or methodologies to create outputs. The Pacific RISA continues to fine-tune the regional understanding of stakeholder needs and interests when it comes to available climate science and information. This research project built on insights and needs generated from the survey completed in 2016 to inform the first Application of Climate Downscaling in Hawaiian Islands workshop. Co-sponsored by the Pacific RISA, the PI-CSC and the PICCC, this project added new research and an associated workshop to that from the previous year, to evaluate how existing efforts to generate downscaled climate projections for Hawai'i were being used by researchers, agencies, and decision makers. Through the survey analysis and workshop, attendees came to the independent conclusion that local "Intermediate Modelers" (IM) were key to the transformation and communication of climate projections for resource management and decision making. For these purposes, IM are defined as scientists who use future climate projections as inputs to local impact models, such as terrestrial ecosystem models (e.g. plant communities, native Hawaiian birds), hydrology models, or economic models, among others.

The objectives of the second downscaling workshop were to focus on gathering climate modelers and IM to: 1) review the downscaled products now available; 2) develop a shared understanding of how uncertainty influences applicability/use of regional climate projections by impact modelers; 3) enable

discussions of how various constraints on climate and impact models affect the products intended to inform resource management decisions; and 4) share lessons learned and insights from experiences of impact modelers communicating impact projections to resource managers. To facilitate this discussion, the Pacific RISA conducted a survey targeting just IM using some of the same set of questions that were previously targeted at climate scientists and resource managers. Supporting the previous year's finding that the IM community was the crucial link to help translate downscaled projections to management, when each group of survey respondents was asked how well they understood the expertise of the other group, the IM group had the most understanding of both kinds of expertise, with 57.1% being "comfortable or very comfortable" with climate science, and 71.5% being "comfortable or very comfortable" with resource policy in Hawai'i (Figure 3).

As an outcome of the workshop, IM and climate modelers decided that non-expert "climate narratives" explaining projections for each Hawaiian island would be a useful product to help ensure that IM could accurately explain the assumptions that generated each set of downscaled projections to resource managers, and how they differ. This would allow managers to make an informed choice about how to use outputs from the different intermediate models, and would ensure consistency across IM about communication of the projections. As an exercise, workshop attendees worked together to create a draft "Climate Narrative" for the island of Maui. The product was said to be the most helpful workshop outcome, and the Pacific RISA will continue to help generate these narratives for IM on all Hawaiian Islands. By increasing the ability of the IM to translate information more easily and consistently from climate scientists to decision makers, the team hopes to see more groups confidently utilizing downscaling results in resource management decisions.

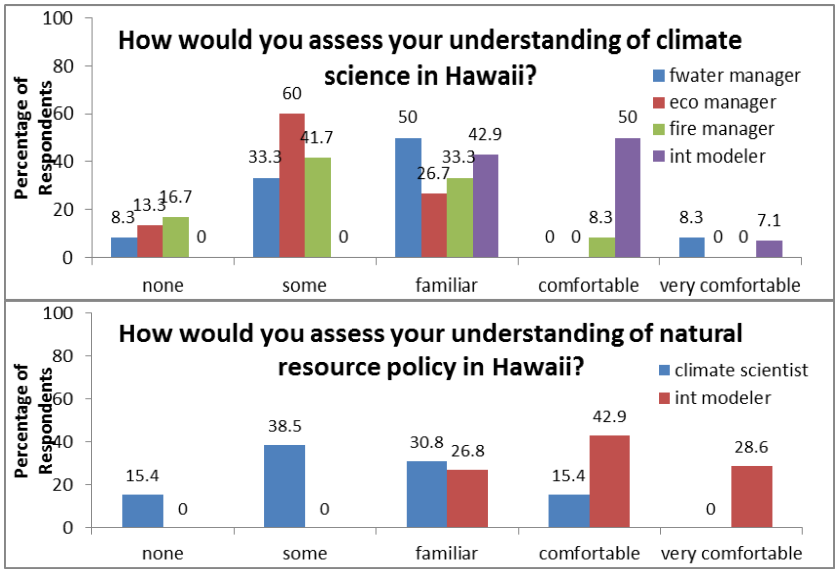

Figure 3. All survey groups' responses to their understanding of others' expertise.

8. What is the accomplishment from this past year of which your team is most proud? Why?

Impact of Future Climate Variability on Freshwater Resources in American Sāmoa
In the past year, the Pacific RISA has been able to grow both research presence and education/communication impact in American Sāmoa with a set of three projects led by Graduate Research Assistant Schuler and Pacific RISA PI El-Kadi. As an unincorporated, unorganized US Territory, American Sāmoa receives less research focus than states, however, with dedicated attention from Schuler and the El-Kadi lab, the team is evaluating how groundwater quality and quantity on the island of Tutuila are influenced by climate variability and change, as well as land use decisions to address

sustainable management of future water and reef resources. This contributes to research in American Sāmoa by 1) modeling drinking water nutrients to quantify human impacts and for partitioning the sources of contamination related to water quality in the mixed-use landscapes of small tropical volcanic islands; 2) modeling anthropogenic nutrient and water-budget characteristics at the island scale to quantify baseflow, runoff, and submarine groundwater discharge; and 3) quantifying groundwater interactions and discharge in a priority watershed. These projects are also closely related to ongoing collaborations and outreach in American Sāmoa (see ***Outreach and Communication***, below).

Drinking Water Nutrient Modeling

On Tutuila, the main island of American Sāmoa, production wells in the most populated region, the Tafuna-Leone Plain, produce most of the island's drinking water. However, much of this water has been deemed unsafe to drink since 2010. Tutuila has three predominant anthropogenic non-point groundwater pollution sources of concern: on-site disposal systems (OSDS), agricultural chemicals, and pig manure. These sources are broadly distributed throughout the landscape and are located near many drinking-water wells. Water quality analyses show a link between elevated levels of total dissolved groundwater nitrogen (TN) and areas with high non-point-source pollution density, suggesting that TN can be used as a tracer of groundwater contamination from these sources. The modeling framework used in this study integrates land use information, hydrological data, and water quality analyses with nitrogen loading and transport models (Figure 4). The approach utilizes a numerical groundwater ow model, a nitrogen-loading model, and a multi-species contaminant transport model. Nitrogen from each source is modeled as an independent component in order to trace the impact from individual land-use activities. Model results are calibrated and validated with dissolved groundwater TN concentrations and inorganic δ15N values, respectively. Results indicate that OSDS contribute significantly more TN to Tutuila's aquifers than other sources, and thus should be prioritized in future water quality management efforts.

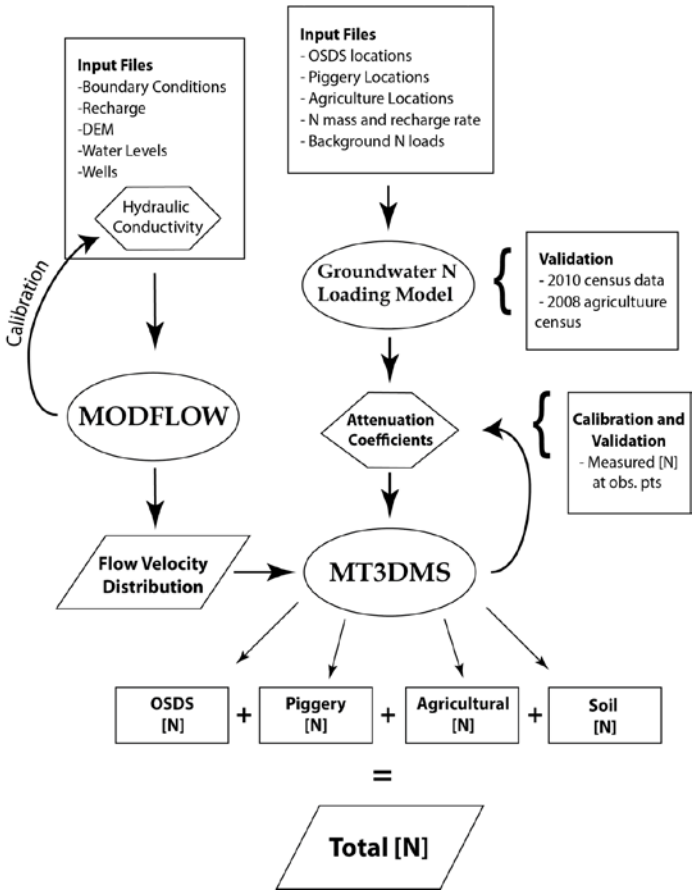

Figure 4. Schematic of the modeling framework used in this study. Anthropogenic impact to groundwater, represented by Total Nitrogen, is evaluated by quantifying N-loading, attenuation, and transport from the four modeled non-point N-sources.

Island-Wide Nutrient and Water-Budget Modeling

This effort is part of the State of Hawai‘i Water Resources Research Institute Program (WRRIP) project, “WRRIP - Likely Hotspots for Algal Blooms: A Multi-Dimensional Analysis to Evaluate Seasonal Impact of Land-Based Sources of Pollution on the Health of American Sāmoa’s Coasts.” Recent studies on tropical islands have indicated that variability in anthropogenic land-use can significantly impact the state of coastal biological communities. Anthropogenic nutrients are delivered to coastal systems by streamflow and surface runoff, and recently, the importance of submarine groundwater discharge (SGD) as a nutrient vector to these environments has been recognized. By quantifying nutrient delivery from coastally discharging streams and groundwater sources, a more complete picture of total nutrient and freshwater inputs to reef ecosystems can be developed. Many biological assessments of reef health use land use factors to assess variability between different regions. Resolving land use inputs at this level allows for improved characterizations of the controlling factors affecting reef health, thereby assisting coastal management efforts aimed at reducing anthropogenic pressures on already distressed nearshore reef ecosystems. For this study, rates of SGD were quantified using a 222Rn box model approach, and were found to vary based on watershed size and geology. Nutrient concentrations from water samples in four watersheds spanning a gradient of human impact were scaled by measured flux rates to estimate total yearly loading to the coastal zone. An island-wide nutrient budget model was then developed by integrating existing datasets such as precipitation, evapotranspiration, runoff, and land use datasets to assess annual rates of watershed-based nutrient loading to each coastal watershed on the island. Uncertainties in nutrient loading estimates, transport dynamics, and environmental attenuation were parameterized and used to calibrate the nutrient budget model with measured nutrient loading rates from field data in selected watersheds. Findings include:

- There is spatial variability in coastal nutrient loading that can be used to assess hot-spots of potential reef ecosystem stress; and
- There is a strong need for special management areas to protect sensitive water resources.

Quantifying Groundwater Discharge

This effort is part of the project, “WRRIP - Quantifying Groundwater Discharge from the Faga‘alu Aquifer, American Sāmoa.” The coastal ecosystems of American Sāmoa contain some of the most pristine and diverse reef communities in the US. Anthropogenic pressures such as land-based sources of pollution, increased sedimentation, and nutrient loading may reduce the reef’s ability for recovery from detrimental events. In Faga‘alu Bay, a small arm of Pago Pago harbor, anthropogenic contaminant sources have been implicated in degraded reef health and reduction of stream water quality as shown by American Sāmoa Environmental Protection Agency. Faga‘alu has also been designated as a Priority Watershed Management Area by the United States Coral Reef Task Force. Long-term reef studies throughout Tutuila indicate that significant groundwater input on the southern coast, may be an explanatory variable in reef health. Although groundwater has been shown to be a potentially significant source of nutrients and other anthropogenic contaminants in similar environments, no studies have yet examined groundwater quality or movement in coastal watersheds on Tutuila. This study explores the mechanics and extent of groundwater-surface water interaction and submarine groundwater discharge (SGD) in and from Faga‘alu watershed, a small drainage that is similar to many other watersheds on the island. Additionally, this work allows quantification of the potential for groundwater to act as a vector for pollutants entering the coastal zone via both stream baseflow and SGD in these environments, thereby informing the efficacy of possible coastal management actions. Results indicate that:

- During baseflow conditions SGD is likely to be more important than the stream as a vector of nutrients to the coastal zone;
- Nearshore groundwater discharge to the stream is a significant source of water (30% at baseflow);
- Around 50% of the coastal N loading to Faga‘alu Bay originates from groundwater with the stream contributing the remainder of the coastal nutrient load primarily during runoff events; and
- Groundwater contributes up to 200% of the coastal N loading to the stream.

9. Please provide a list of up to 5 **research findings**.

Dynamical Seasonal Prediction of Precipitation for the Hawaiian Islands

Because of the small relative size and topographical diversity of Pacific Islands, significant downscaling of global model predictions is needed to make them applicable to island-scale decision making. In Phase II, the Pacific RISA supported the development of the Hawai'i Regional Climate Model (HRCM) by the University of Hawai'i International Pacific Research Center (IPRC). The HRCM is a dynamically downscaled regional model for the Hawaiian Islands at 15 km, 3 km, and 1 km horizontal grid scales, which has been used to perform a 20-year (1990-2009) present-day climate and projected 20-year (2080-2099) simulations for late 21st century conditions (Zhang et al., 2016). One salient result is that both the improved model physics and high model resolutions are needed for realistic simulation of current climate and future projections. Dynamical seasonal prediction of precipitation over the islands is still in its infancy. The skill of both versions of the NOAA operational model (CFSv1 and CFSv2) hindcast experiments were assessed from deterministic (anomaly correlation), probabilistic (rank probability skill score), and categorical (Heidke score) perspectives. Based on these NOAA-recommended metrics, the consensus is that both models are able to capture modest skill when assessed over the Hawaiian archipelago. However, during strong El Niño events (i.e., 1997-1998) the large swings in rainfall and persistence of dryness (from fall through winter and the following spring) are skillfully forecast at longer leads by all ensemble members, primarily attributed to realistic representation of physical processes. This project, led by Pacific RISA PI Annamalai, focused on the dynamical downscaling of rainfall anomalies during the recent intense ENSO cycle (a strong El Niño followed by La Niña during 2015-2016). The forecast data from the "coarse" resolution NOAA prediction model was employed in a "dynamical down-scale setup" (namely, the HRCM) to capture the regional rainfall features over the Hawaiian Islands.

The ENSO evolution of warm conditions (El Niño in 2015) followed by cold conditions (La Niña in 2016) provides a classic test-bed for validating seasonal predictions of precipitation over the Pacific Islands made by the NOAA prediction model. The project team collected station-level rainfall observations for 2015-2016 and are in the process of model validation in different horizontal resolutions (12 and 3 km). Daily forecast data were downloaded from NOAA and archived locally to diagnose the solutions and update the forecast every 10 days. Test runs with HRCM have been performed, and initial results are encouraging. The preliminary tests show the forecasts among the ensemble members can be very different, and justifies the need for an ensemble approach (Figure 5). Further diagnostics are being performed to validate the model predictions of regional features of rainfall over the Hawaiian Islands. Once the above mentioned exercise of testing is over, the team will employ the system in an "experimental" forecast mode and test other past ENSO events. Once a consolidated system is prepared, they will then begin issuing "real-time experimental forecasts" of seasonal precipitation.

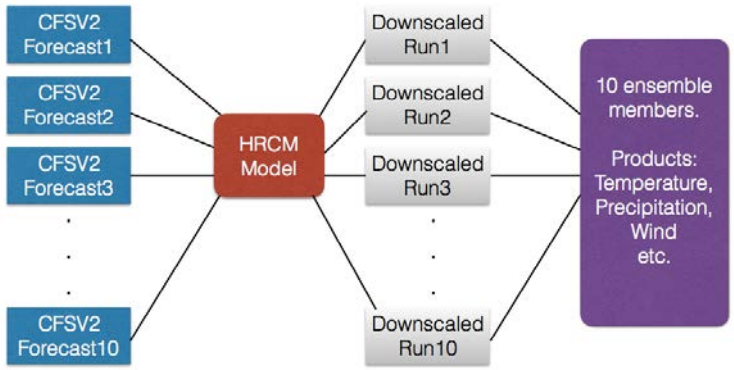

Figure 5. A schematic illustrating the approach for dynamical downscaling of seasonal prediction of precipitation over the Hawaiian Islands.

Evaluating Similarities and Differences between Statistical and Dynamical Downscaling Projections
Future rainfall patterns have been projected for the Hawaiian Islands using statistical and dynamical downscaling methods. 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, which regional stakeholders are grappling with in their efforts to make climate-adaptive decisions. The primary goal that was addressed by Pacific RISA PI Giambelluca was to improve the physical mechanisms behind the statistically downscaled future rainfall change scenarios in Hawai‘i. A first approach was to apply the same downscaling model used in previous projetions and modify the climate change input data. To address this objective, the team tested individual predictor variables, such as the decrease in the atmospheric vertical temperature gradient and the moisture transport, to identify which atmospheric changes produce the projected strong drying trend, and which factors determines the strength of the projected changes in the windward-leeward precipitation contrast. The second main objective deals with the question how the use of a non-linear transformation in the regression analysis would change projected rainfall. Precipitation is known to show a very wide range of variability over the Hawaiian Islands, and linear regression models have problems with projecting physically consistent precipitation anomalies when the circulation changes reach unprecedented large amplitudes (such is the case in the RCP8.5 scenarios). Log-transformation of the precipitation data is a common method to deal with rainfall variations that cover several orders of magnitude (e.g. from 0.3 to 300 inch/year) and the team proposed to apply log-transformed precipitation as the predictant. By comparing both statistical downscaling model results they can identify the robustness of the projected future rainfall scenarios. In particular, the amplitudes of the projected changes are of interest, as well as the regional pattern. Regarding the sensitivity of the projected rainfall change scenarios to the choice of large-scale climate anomalies:

- The team found that higher rates of warming in the mid-atmosphere (500hPa) increase the (dry) static stability of the atmosphere in future scenarios over the subtropics. This pattern results in a strong drying trend. They tested this in the multiple linear regression by leaving out the 1000 hPa minus 500 hPa temperature difference from the large-scale circulation information (this was done by reducing the amplitude to nearly zero);
- The moisture transport at 700 hPA was also tested with this method. It was found that, in particular, moisture transport is responsible for compensating for large drying trend due to changes in atmospheric stability. The transport of moisture increases precipitation in the windward sites; and
- The balance between these two large-scale climate change signals determines most of the future rainfall anomaly pattern with a very strong drying trend in the leeward sides and neutral or slightly enhanced rainfall increases on the windward sites.

Effects of Rainfall Scarcity on SWAT Model Performance
Due to the high spatial rainfall gradients over short distances and lack of rainfall data for Pacific Island watersheds, this study led by Pacific RISA PI El-Kadi and Postdoctoral Fellow Leta compared and assessed the effect of rainfall data scarcity on the Soil and Water Assessment Tool (SWAT) model performance in simulating daily streamflow. This study was carried out in Hawai‘i watersheds that had relatively well spatially distributed rainfall gauging stations within the watershed. The research team collected climate (rainfall, temperature, relative humidity, wind speed, and solar radiation) and geospatial data (DEM, land use, soil type) for the watersheds from various US agencies. Geospatial data, such as DEM, land use, and soil maps were collected from the NOAA Center for Coastal Monitoring and Assessment (CCMA), NOAA’s Coastal Change Analysis Program (CCAP), and Soil Survey Geographic (SSURGO) database of the US Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS), respectively. Daily rainfall, maximum and minimum temperature, wind speed, solar radiation, and relative humidity were obtained from various agencies, including NOAA’s National Climate Data Center (NCDC) and the Western Regional Climate Center (WRCC). Reservoir data, such as storage volume and corresponding area, elevation of middle and upper gates, and pipe inlets and outlets were obtained from the available literature. Statistically downscaled seasonal rainfall anomalies by Elison

Timm et al. (2015) for middle (2041-2070) and late (2071-2100) 21st century under Representative Concentrations Pathways (RCP) 4.5 and 8.5 scenarios were used for climate change impacts assessments. Statistical evaluation criteria were used to assess the accuracy of the model. As an example, streamflow hydrographs for the rain-gauged Kalihi watershed and ungauged He‘eia watershed are shown in Figure 5. Findings include the following:

- As can be seen in Figure 6, for the same time period the observed streamflows in Kalihi watershed were well reproduced by SWAT, but the model missed some peak flow events of He‘eia watershed. Such characterizations suggest the use of rainfall data from outside watershed may not able to capture the local rainfall events. This was also further reflected by statistical evaluation criteria that showed unsatisfactory to satisfactory model performance in simulating daily streamflow for those watersheds that had rainfall data from neighboring areas (e.g. He‘eia);

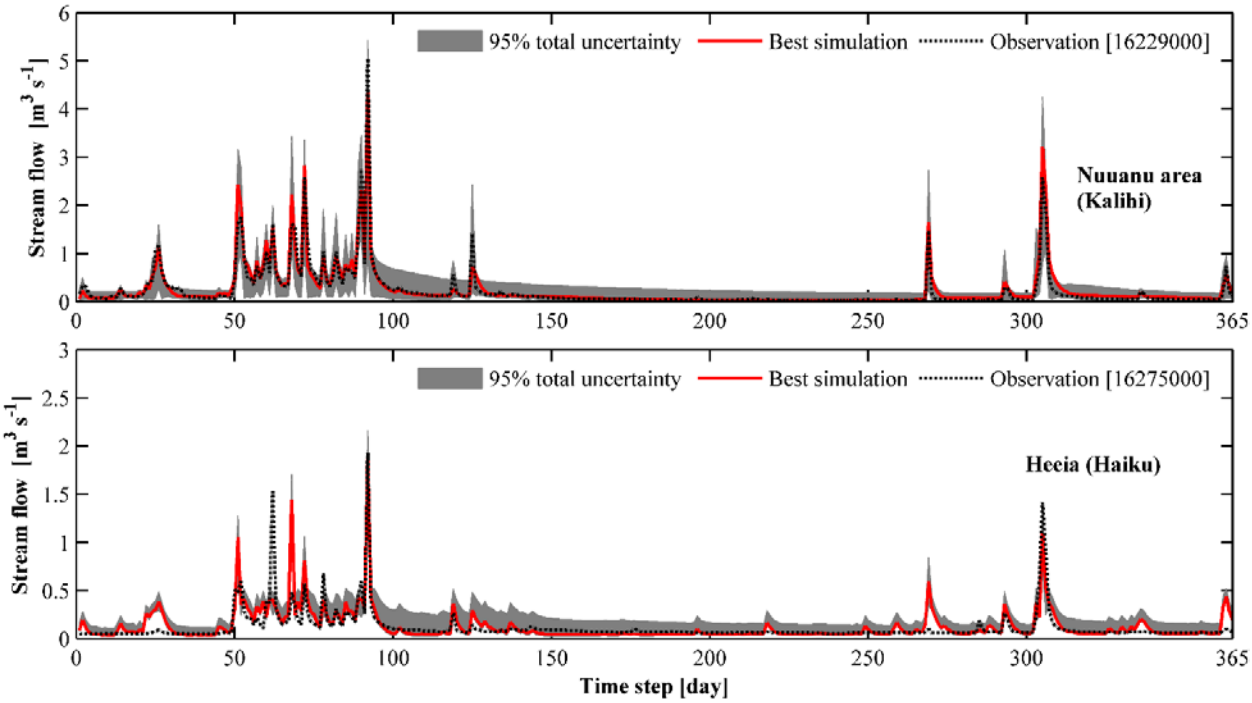

Figure 6. Observed and simulated daily streamflow with 95% prediction uncertainty Kalihi watershed (top) and He‘eia watershed (bottom).

- On the other hand, the model provided good to very good results for those watersheds that had measured rainfall data (e.g. Kalihi). For these watersheds, the percent of observations within a 95% prediction uncertainty was more than twice that of watersheds that had rainfall data from outside, indicating good model representation of observations for watersheds with relatively well-represented rainfall data. Although SWAT performed less well for watersheds without rainfall records, the results from those watersheds were reasonably acceptable; and
- In general, methods to resolve data scarcity and careful statistical evaluation criteria result in the use of rainfall data from neighboring watershed areas being suitable for use in the SWAT model.

Watershed Hydrological Modeling and Climate Change Impacts in He‘eia and Nu‘uanu Areas

Following the suitability and applicability testing of the SWAT model for the Faga‘alu watershed, it was used to estimate the groundwater coverage and amount of water that can be potentially harvested from the He‘eia and Nu‘uanu area watersheds on O‘ahu. The groundwater recharge and reservoir stored water estimated by SWAT will be used as inputs for the groundwater modeling analyses. The watershed modeling process utilizes climate, hydrological, and geospatial data. The team, led by Pacific RISA PI El-

Kadi and Postdoctoral Fellow Leta, collected climate (rainfall, temperature, relative humidity, wind speed, and solar radiation) and geospatial data (DEM, land use, soil type) for the watersheds from various US agencies. After data analysis and quality check, the SWAT model was calibrated and validated using the daily streamflow data monitored at various stations by the US Geological Survey (USGS) Pacific Islands Water Science Center (PIWSC). The model was then used to assess the impact of climate change on water budget components and streamflows for the study areas. The team used the recently statistical downscaled rainfall anomalies reports for the Hawaiian Islands for both Representative Concentration Pathways (RCP) of 4.5 and 8.5. SWAT model performance comparison for daily streamflow simulation was done for both the He‘eia and Nu‘uanu area watersheds. While the He‘eia watershed has scarce hydrological and climate data, the Nu‘uanu area watersheds have relatively good quality data. The findings highlight the importance of using multiple gauging stations within a watershed in order to capture the high climate variability and improve model performance. Findings include the following:

- Extreme low and peak flows analysis indicate that an increase in peak flows of up to 22% is expected for higher return period under the RCP 8.5 scenario, indicating that those events can potentially cause flooding and adverse consequences, such as damages to infrastructure. In contrast, the future extreme low flows are expected to decrease by 56% compared to baseline due to less rainfall availability and high ET during the dry season;
- By the end of the 21st century, more frequent drought periods are expected, which negatively affect agricultural crop productivity, freshwater availability, and ecological functioning of river riparian ecosystem;
- Startlingly, although the temperature is projected to increase, the monthly actual ET is expected to decrease up to 8% in the future. This is most likely due to less rainfall availability (moisture limitation), indicating that rainfall change is the main factor for the general decrease in ET as compared to temperature change;
- Overall, the water budget components such as surface runoff, baseflow, streamflow, ET, soil moisture, and recharge are projected to decrease by the end of 21st century. Compared to the other water budget components, the monthly baseflow values will be consistently lower in the future; and
- The amount of water potentially harvested by Nu‘uanu reservoir is expected to decrease by up to 36%, indicating less freshwater availability in the future with serious implications for sustainability.

Using Ecosystem Service Valuation to Assess Trade-offs and Opportunities from Climate Change

As island-scale projections of future climate variability and change are released and integrated into planning documents, managers still lack detailed information on the value and tradeoffs associated with future climate impacts and the implementation of different adaptation strategies. Limited efforts have attached metrics of value to an island’s natural resources. Policy makers and managers need to have measures of valuation to decide between alternative adaptation options and to weigh the potential costs of inaction. This project builds on the participatory scenario process developed by the Pacific RISA in Phase II to generate a set of rules concerning climate variables, management options, and policy alternatives that will be used to inform ecosystem services valuation and adaptation strategies for Maui. Pacific RISA PI Oleson, Postdoctoral Fellow Fezzi, and Research Assistant Htun are conducting watershed-scale modeling that will be embedded in a decision support tool that quantifies, maps, and values ecosystem services from land to sea. The project, parts of which have been funded by USDA, NOAA, and the PI-CSC, leverages existing models such as InVEST42 and ARIES43, with an aim to guide management by predicting how key ecosystem services will change under alternative management policies and climate change scenarios.

In the past year, the team identified the key ecosystem services that are likely to be impacted by climate change and agro-environmental policies in Maui. They engaged with community members, thought

leaders, and decision-makers to develop scenario elements, identify priority ecosystem services, derive likely management and policy alternatives, and incorporate local knowledge. This process guided the valuation work allowing them to identify priority ecosystem services for integrated assessment work. A list of these services and their main drivers is provided in Table 2. The team then developed a conceptual framework linking four spatially explicit models designed to assess the trade-off and the opportunities arising with climate change and to explore alternative policy scenarios.

Table 2. Priority ecosystem services in Maui.

Ecosystem service	**Main direct drivers**
Crop and livestock	*Land use and development, policy, water availability, climate, soil and land quality, input and output prices*
Wild animals hunting	*Land use and development, crop and livestock decisions climate, policy*
CO_2 emissions and sequestration	*Land use and development, crop and livestock decisions, policy*
Land biodiversity	*Land use and development, climate, crop and livestock decisions, policy*
Drinking water and groundwater recharge	*Land use and development, climate, crop and livestock decisions, water availability, policy*
Cultural and use values from in-stream flow	*Land use and development, climate, crop and livestock decisions, stream flows, policy*
Land recreation, aesthetics and non-use values	*Land use and development, climate, policy, stream flows*
Near shore fishing	*Land use and development, climate change, policy, MPAs, buffer zones*
Marine recreation, aesthetics and non-use values	*Land use and development, climate change, policy, MPAs, buffer zones*
Jobs availability from tourism, agriculture and development	*Land use and development, climate change, stream flow, policy, MPAs*

Notes: Drivers encompass only factors which are likely to change with climate change and the different adaptation options considered in the project

The interdisciplinary system of models was created by analyzing a series of case studies regarding increasingly complex issues, leading to a gradual development of the modeling framework. The first issue being addressed is the impact of climate change and extreme weather events. In particular, the team is estimating the loss in value generated by "brown water" events in Maui and possible adaptation strategies. During brown water events, typically caused by heavy rain, people are advised to stay out of flood and coastal waters due to possible overflowing cesspools, sewer, pesticides, and pathogens. These types of events are common on Maui and are expected to increase if heavy rainfall will become more common with climate change. The team is analyzing the loss of value generated by brown water events and providing a cost-benefit analysis of different strategies designed to mitigate their occurrence. The ecosystem services that are currently being captured include sediment retention, water yield, fisheries, and coastal protection. They will continue to build on this work by expanding the services captured and attaching more explicit valuations to the different adaptation options of interest under future climate scenarios on Maui.

Estimating Changes in Groundwater Recharge under Future Climate Conditions on Maui

In Phase II, the Pacific RISA used a participatory scenario process to identify key stakeholders making short and long-range decisions about freshwater resource management, and defined climate, land use, and development futures for Maui. The Pacific RISA also has existing relationships with a rich set of regional

freshwater decision makers identified through the PIRCA process. During the reporting period, the USGS Pacific Islands Water Science Center (PIWSC) led by Pacific RISA researchers Anthony and Mair corrected an error in the Hawai‘i Water Budget Model (HWBM). It was then used to estimate revised recharge estimates for a baseline condition for the islands of Maui, Kauai, and O‘ahu. The revised HWBM will be used to estimate groundwater recharge for the Pacific RISA project. The team also developed and released a new land-cover map for the island of Maui, circa 2017. The new map was prepared to account for changes mainly related to 1) the cessation of sugarcane cultivation in late 2016; and 2) an updated agricultural land use map for Maui that was published in 2016. As a result, the four future land cover scenarios developed by Pacific RISA PI Brewington are being updated to represent the cessation of sugarcane and modified agricultural dataset. This has added considerable delays to project completion, requiring new model runs for each of the four land cover scenarios and future climate scenarios to account for new input data on rainfall and reference evapotranspiration projections. Comparison between water-budget output using two sets of climate projections that represent “wet” and “dry” future scenarios for a 2010 land cover condition projected the following for the island of Maui:

- Two climate scenarios indicate contrasting effects on estimated recharge across most of Maui; and
- The greatest changes to recharge occur in the west Maui mountains and wet windward areas of Haleakalā.

Island-wide impacts to water budget:

- Mean annual rainfall changes by plus or minus 20%;
- Mean annual ET changes by plus 5% to minus 12%;
- Mean annual direct runoff changes by plus 34% to minus 18%; and
- Mean annual recharge changes by plus or minus 21%.

Pacific RISA PIs Brewington and Keener also completed a manuscript in collaboration with one of the study participants from the Maui Planning Department that details the scenario planning process and future land cover scenario building. During the coming year, the team plans to 1) complete simulations of present-day and future recharge for a set of climate and land-cover change scenarios using the revised water-budget model and the new 2017 land-cover map for Maui; 2) complete USGS report summarizing the modeling results of two climate change scenarios for peer review and release via the USGS publications warehouse; and 3) complete preparation of geospatial datasets summarizing the modeling results for a set of climate/land-cover change scenarios and associated metadata for peer review and release via the USGS water resources node.

10. Please provide a list of up to 5 **outreach or communication activities** that you have undertaken in the past year. OPTIONAL: If applicable, please share the outcomes of these activities. We are particularly interested in measurable or observed changes in areas such as management practices, planning, policy, and behavior.

Coordination of NCA4 and the PIRCA

The Pacific RISA coordinated the development of a regional Hawai‘i and US-Affiliated Pacific Islands chapter for the 4th National Climate Assessment (NCA4). The chapter provides an update to the 2012 Pacific Islands Regional Climate Assessment (PIRCA) and the region’s chapter in the 3rd National Climate Assessment (2014). To collect early stakeholder input for the assessment update, the Sustained Assessment Specialist (SAS) Grecni distributed an informal, online survey (via Survey Gizmo) from September to October 2016. Findings about key communicators in the region from a previous social network analysis were utilized to distribute the survey widely. Pacific RISA received a total of 136 responses from stakeholders in Hawai‘i and all the USAPI jurisdictions. Respondents identified which of the NCA sectors they were most interested in learning about with respect to climate change and suggested

representative case studies. Ultimately, the five top sectors-of-interest identified through the survey were chosen as focal areas for the chapters' five Key Messages. The authors also consulted the relevant literature and held informal discussions with stakeholders to select focal sectors.

The NCA4 authors sought to maximize inclusiveness and represent the key sectoral interests of communities and researchers. To solicit additional participation from potential technical contributors across the region, the SAS held two informational webinars, at times convenient for the range of time zones in the Pacific. The webinars outlined the NCA history and process as well as past regional reports and opportunities to inform the NCA4 process and the development of the next PIRCA. More focused workshops were held in Honolulu and Guam to outline the chapter and engage participants who work in climate-sensitive sectors throughout the region. While developing the NCA4 chapter, the Pacific RISA gathered information to later consider for inclusion in the next PIRCA report or set of products. For example, the PIRCA living bibliography, assembled in the months before and during the preparation of NCA4 (and now containing more than 300 references, the majority published in 2012 or later), will also serve as a literature database for the PIRCA development. Future plans involve convening a committee comprised of potential users of the next PIRCA from each of the USAPI jurisdictions and Hawai'i to advise on the product(s) development, and recruiting a team of lead authors. For more information on Sustained Assessment activities, please see ***Appendix 2***. Finally, to promote a public Hawai'i and Pacific Islands Regional Engagement Workshop for the NCA4, PI Keener gave an interview on Hawai'i Public Radio show The Conversation on March 6, 2017. Dr. Keener explained the importance of the public making their voices heard to represent climate impacts and adaptations in the region at a national scale, and the objectives and history of the National Climate Assessment. (http://Hawai'ipublicradio.org/post/conversation-monday-march-6th-2017)

International Union for the Conservation of Nature World Conservation Congress

Pacific RISA PI Brewington coordinated and prepared a workshop proposal for the International Union for Conservation of Nature (IUCN) World Conservation Congress (WCC) that was held in Honolulu in early September, 2016. Partners on the proposal included the East-West Center, the PICSC, the PICCC, the State of Hawai'i Department of Land and Natural Resources (DLNR), the University of Hawai'i, the IUCN Water Programme, and the IUCN Oceania office. The workshop team was invited to participate in the Hawai'i-Pacific Pavilion series of events that was open to the public on September 3, 2016. The high visibility of the WCC and the open structure of the Pavilions provided the Pacific RISA and collaborators with an extraordinary opportunity to engage with a broad and diverse audience, while exemplifying the Pacific RISA's collaborative strengths. The event highlighted recent initiatives to adapt to climate change in resource management across a variety of sectors and included talks from 1) Chip Fletcher (UH School of Ocean and Earth Science and Technology) and Sam Lemmo (DLNR) on sea level rise and the newly-formed Hawai'i Interagency Climate Adaptation Committee for state planning; 2) Rick Camp (Hawai'i Volcanoes National Park) on vegetation modeling under climate change and targeted restoration areas; 3) Christin Reynolds (Hawai'i Green Growth) on the Aloha+ Challenge; 4) Clay Trauernicht (UH Cooperative Extension) on the Pacific Fire Exchange network; and 5) Zena Grecni (Pacific RISA) on the new PIRCA website and broad climate information access for the region in advance of the National Climate Assessment. Prior to the 2016 IUCN Meeting in Honolulu, Hawai'i, PI Keener was interviewed on national Fox News about climate impacts in the Pacific Islands region, specifically about the effects of climate on conservation and the recent expansion of Papahānaumokuākea Marine National Monument in the Northwest Hawaiian Islands. (http://video.foxnews.com/v/5108378146001/obama-creates-largest-ecologically-protected-area-on-earth/?#sp=show-clips August 29, 2016).

"Climate Matters" for Conservation Documoment

Adding to the series of four short "Climate Matters" documoment videos that were created during Pacific RISA Phase II, PI's Keener and Brewington wrote and directed a new piece called "Climate Matters for Ridge to Reef Ecosystems." The seven minute documoment interviewed two Pacific RISA stakeholders

from the Maui groundwater project, each representing part of the ridge-to-reef climate and ecosystem connection. Starting from the ridge, Chris Brosius of the West Maui Mountain Watershed Partnership discussed conservation of native Hawaiian forests and their importance in maintaining a healthy watershed, and how climate impacts and anthropogenic threats are negatively impacting them. The second half of the documoment focuses on Tova Callendar at the West Maui Ridge-2-Reef program, and the pressures that the West Maui reef faces from both climate impacts like El Niño, and urban development. Both interviewees emphasized the importance of the connection between the ecosystems, and how climate data can help manage them in an integrated way, concluding with a statement about air temperature rise in high-elevation forests and coral reef loss in West Maui. (https://vimeo.com/214577783)

Symposium on Climate Displacement, Migration, and Relocation

To advance Pacific RISA work that explores climate-induced migration, PI Burkett co-chaired a two-day Symposium on Climate Displacement, Migration, and Relocation in December 2016. The Symposium brought together over 100 participants to discuss law and policy options to assist individuals and communities considering relocation as an adaptation response to climate change, in both domestic and international contexts. It was hosted by the Alaska Sea Grant College Program, the Hawai‘i Sea Grant College Program, NOAA Office of Coastal Management, DOI PICSC, University of Hawai‘i William S. Richardson School of Law, and the White House Council on Environmental Quality. The symposium produced several important research findings. First, demonstrating pathways to building successful partnerships around this issue and tangible outcomes from those partnerships can help organize and mobilize at-risk communities and individuals in the future. The Alaska Institute for Justice, for example, is working with 15 Alaska Native communities to create partnerships with federal and state government representatives so that they have access to the financial resources and technical assistance they need to adapt to a rapidly changing climate. The Maldives were also offered as an example of a successful partnership. After the 2004 tsunami, the government made a concerted effort to build resilience to future natural disasters and climate impacts, and brought in a different group of community participants every two weeks to help develop a new community. Affected stakeholders, whether at the community or individual level, need to be at the center of these partnerships, with collaborative governance structures that support affected stakeholders connecting local, regional, state, and Federal agencies and resources, as well as other appropriate partners such as the private sector, academia, or philanthropy.

Second, education and knowledge building are essential to creating processes that protect the livelihoods and well-being of individuals and communities affected by climate change. There also needs to be more integration of traditional knowledge with Western science to help inform the decision-making process of individuals and communities. Education through schools, art, culture, and language should integrate local and traditional knowledge and be transmitted in a way that is accessible and understandable to everyone. Improving the understanding of the complexities of how climate change interacts with geographic, cultural, economic, and environmental specifics can help inform decision-making and lead to the development of more appropriate responses and solutions.

A third essential piece of the puzzle is funding. Resettlement of an entire community is a very costly endeavor, and big gaps remain in identifying how resettlement can be paid for. Even the movement of individuals or families has cost implications. Shifting populations means that receiving communities may need to invest more in infrastructure and social services to meet new demands, while at-risk communities may have a smaller population to draw tax revenue from to help fund ongoing public services. There is also a strong concern that the current funding models, largely based on grants, pit at-risk communities against each other where more positive outcomes could arise from a more collaborative approach. Overall, the symposium advanced knowledge about the complexities of climate-induced migration, fostered cross-cultural story-telling and connections, and sowed the seeds for future, ongoing collaboration.

11. Please provide a list of **key publications** from the past year. We are seeking ~ 5 publications that you wish to highlight, with a brief abstract/description. These can be either non-peer reviewed or peer-reviewed. For peer-reviewed publications, please list either published or in press, but not "in review". For non peer-reviewed publications, please provide a hyperlink or webpage wherever possible. Important: include a comprehensive list of publications as an appendix.

Brewington, L., V. Keener, M. Finucane, and P. Eaton. 2017. Participatory Scenario Planning for Climate Change Adaptation Using Remote Sensing and GIS. In S.J. Walsh (ed). Remote Sensing for Societal Benefits. Amsterdam: Elsevier. doi: http://dx.doi.org/10.1016/B978-0-12-409548-9.10434-8

Leta O.T., A.I. El-Kadi, and H. Dulai. In press. Implications of climate change on water budgets and reservoir water harvesting of Nu'uanu area watersheds, O'ahu, Hawai'i. Journal of Water Resources Planning and Management, doi: http://dx.doi.org/ 10.1061/(ASCE)WR.1943-5452.0000839

Leta O.T., A.I. El-Kadi, H. Dulai, and A.K. Gahzal. 2016. Assessment of climate change impacts on water balance components of Heeia watershed in Hawai'i. J. of Hydrology: Regional Studies. Vol.8 (0), doi: http://dx.doi.org/10.1016/j.ejrh.2016.09.006.

Schuler, C.K., P.R. Eyre, and A.I. El-Kadi. 2016. Groundwater development potential and exploratory drilling recommendations for Tutuila, American Sāmoa. Phase I: Well data and provisional conceptual hydrogeologic model. Honolulu: University of Hawai'i Water Resources Research Center.

Zhang, C., Y. Wang, K. Hamilton, and A. Lauer, 2016: Dynamical downscaling of the climate for the Hawaiian Islands. Part II: Projection for the late twenty-first century. Journal of Climate, 29, 8333-8354.

12. Please provide up to 3 narrative **examples** from the past year of plans, policies, strategies, tools, agreements, etc. that were proposed, adopted, and/or implemented as a result of RISA work. Please describe the role of RISA in achieving the accomplishments described and any associated socio-economic benefits.

Law and Policy Frameworks for Climate Change Adaptation in Water Resource Management

The Pacific RISA aims to assist in information exchange and collaboration between scientists and governments in preparing and adopting laws and policies that facilitate cost-effective, efficient, and equitable adaptation strategies. The law and policy analysis team, led by Pacific RISA Project Specialist Wallsgrove, has found continued evidence of climate change adaptive capacity being enhanced by water law/policy decisions. Recently, the focus has been on developing case studies of water resource management decisions that result in enhanced adaptive capacity, even though they were largely driven by climate change mitigation and other motivations, and not by climate adaptation. One case was the result of a water allocation dispute, resulting from community concerns over the impact of water diversions on watershed ecology, recreational capacity, and traditional and customary practices. Although these community concerns are relevant to both the impacts of climate change and the legal mandate for climate adaptation, neither the dispute nor its resolution was climate adaptation-driven. This illustrates an opportunity to embed adaptive capacity into broader law and policy frameworks. The team is working to identify more generalized principles to maximize the potential scope of this opportunity in the preparation of case studies of enhanced adaptive capacity achieved in water resource management decisions in Hawai'i. They are also preparing a set of island-focused model policies/legislation that would generally address gaps in the adaptive capacity of existing law and policy frameworks. As the Pacific RISA continues to evaluate opportunities to systematically leverage climate mitigation activities (and other activities not focused primarily on adaptation) to increase adaptive capacity, it has also connected the

team with stakeholder not previously involved in law and policy analyses (e.g. Pōʻai Wai Ola/West Kauai Watershed Alliance, Kekaha Agricultural Association, Kauai Island Utility Cooperative).

Product Development in American Sāmoa

In American Sāmoa, opportunities to enhance adaptive capacity continue to grow. The American Sāmoa Water Resources Stakeholders Committee was created in October 2016 to formalize connection and collaboration between University of Hawaiʻi water resources research programs and on-island (Tutuila) stakeholders. The primary tasks and goals for the committee are to:

- Solidify relationships between Hawaiʻi researchers and American Sāmoa stakeholders;
- Provide directory of active personnel and available facilities to enhance networking both ways;
- Keep an up to date list of the territory's water research needs;
- Encourage Tutuila based researchers to be involved with WRRIP projects; and
- Provide stakeholder input in WRRIP grant review process.

These research programs have made significant investments in hydrological monitoring infrastructure and development of relationships with local stakeholders. A collaborative effort with electrical engineers at the University of Hawaiʻi was instigated for the purpose of designing and building a set of instruments intended to collect continuous water level and salinity data at up to 10 production wells on the Tafuna-Leone Plain. Data will be used for parameterizing groundwater models, for basic well operations, and for understanding aquifer response in wells contaminated by surface water. The instruments may be able to replace, or at least reduce the amount of day-to-day operational manual water level and chloride concentration data collection needed at these wells. This project is proceeding with collaborators from the Pacific RISA, the American Sāmoa EPA, the American Sāmoa Power Authority, and the University of Hawaiʻi Water Resources Research Center.

American Sāmoa Making a Visible Difference Hydrological Monitoring Project

The American Sāmoa Tutuila Hydrogeologic Exploration project is sponsored by the US EPA "Making a Visible Difference Program." A groundwater sustainability workshop was held at the American Sāmoa EPA headquarters in Pago Pago, American Sāmoa, on April 10, 2017. The primary objective of this workshop was to disseminate information from the recently completed comprehensive report consisting of existing hydrogeologic information and new hydrologic monitoring data to support the future development of tools such as water availability models, groundwater flow models and surface water models. Communication with local water resources stakeholders was also an important component of this workshop. In order to communicate results and updates to the hydrogeologic conceptual model from phase one of this project, the workshop involved participants from American Sāmoa EPA, American Sāmoa Power Authority, American Sāmoa Community College, US Marine Sanctuaries, and the American Sāmoa Government were in attendance. After a presentation that primed attendees on basic hydrogeology in the context of a high Pacific Island, attendees developed a list of water resources issues, solutions, and other related topics of concern that are relevant to American Sāmoa. Technical Monitoring network and data capture recommendations were presented to American Sāmoa EPA engineers and the Director.

In conjunction with the workshop, a cooperative agreement between the on-island water utility, American Sāmoa Power Authority, and the University of Hawaiʻi Water Resources Research Center has been initiated for the purpose of developing a new weather station, monitoring well, and stream gauging network (Figure 7). This network produces publicly available long-term hydrological datasets for use in water resource management applications. During the reporting period, the following field activities were carried out for improved hydrological monitoring on Tutuila:

- Installed two new wi-fi compatible Campbell Scientific Weather stations, added to the American Sāmoa EPA hydrological monitoring network system;

- Installed a Watchdog Weather station in Fagaitua, expanding monitoring network to Eastern Tutuila;
- Expanded stream gaging network to Eastern Tutuila, with the installation of two new stream gauges in Afono and Fagaitua watersheds;
- Installed or refurbished the following abandoned stilling wells on Vaipito, Afono, and Maloata stream gages;
- Developed and updated stream gage rating curves, provided capacity building and training for American Sāmoa EPA hydrological technicians; and
- Completed logger deployment in available open hole monitoring wells.

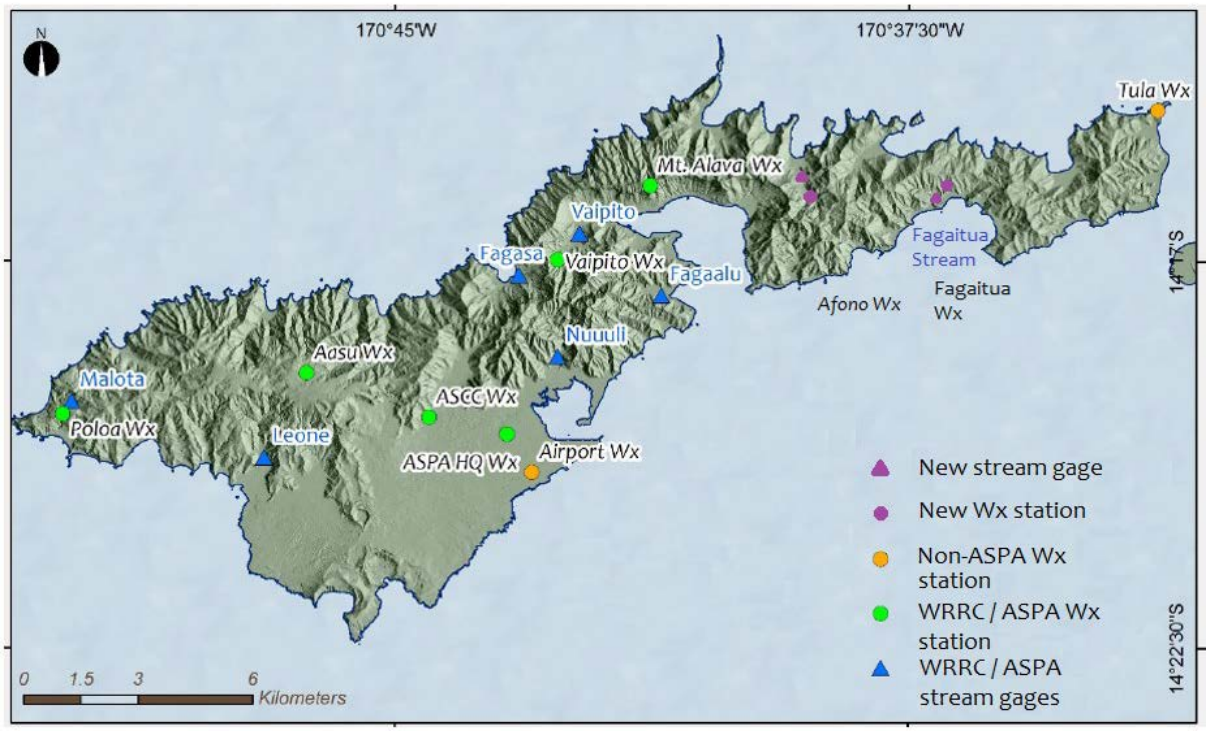

Figure 7. Map of current UH Water Resources Research Center (WRRC) and American Sāmoa Power Authority (ASPA) hydrologic monitoring network system.

Appendix 1: Sustained Assessment Specialist Activities.

1. Regional Chapter for the 4th National Climate Assessment

The Pacific RISA coordinated the development of a regional Hawai‘i and USAPI chapter for the 4th National Climate Assessment (NCA4). The chapter provides an update to the 2012 Pacific Islands Regional Climate Assessment (PIRCA) and the region's chapter in the 3rd National Climate Assessment.

To collect early stakeholder input for the assessment update, the Sustained Assessment Specialist (SAS), Grecni, distributed an informal, online survey (via Survey Gizmo) from September to October 2016. Findings about key communicators in the region from a previous social network analysis were utilized to distribute the survey widely. Pacific RISA received a total of 136 responses from stakeholders in Hawai‘i and all the USAPI jurisdictions. Respondents identified which of the NCA sectors they were most interested in learning about with respect to climate change and suggested representative case studies. Ultimately, the five top sectors-of-interest identified through the survey were chosen as focal areas for the chapters' five Key Messages. Besides the survey results, the authors considered the bodies of literature (peer-reviewed and grey) and informal discussions with stakeholders to select focal sectors.

In October 2016, Pacific RISA PI Keener was named non-federal Regional Chapter Lead for NCA4. Dr. Keener, together with the Coordinating Lead Author, Dr. David Helweg, Director of the DOI Pacific Islands Climate Science Center, invited a total of eight lead authors with expertise in the priority sectors to join the regional team. Two on the author team, Burkett and Giambelluca, currently serve as Pacific RISA investigators. The Pacific RISA core team took the lead on coordinating the chapter development process, with guidance from regional partners at NOAA, USGS, and the US Fish and Wildlife Service. The authors sought to maximize inclusiveness and represent the key sectoral interests of communities and researchers. To solicit additional participation from potential technical contributors across the region, the SAS held two informational webinars to outline the NCA history and process as well as past regional reports and opportunities to inform the NCA4 process and the development of the next PIRCA.

During the Water sectoral workshop, participant Patricia Fifita places adaptation actions on a matrix that helps participants to weigh effectiveness and achievability of potential short-term and mid- or long-term actions

In-person and virtual participants in the Ecosystems, Ecosystem Services, and Biodiversity workshop

Critical to outlining the chapter and gathering literature published since the last NCA were six half-day workshops led by each of the chapter authors and attended by technical experts in the key sectors. Also, one half-day workshop centered on cumulative impacts and adaptation best practices, and was convened with participants from all sectors, as well as regional decision makers. In all, 75 participants, including some virtual, attended the sectoral workshops on March 6 and 13, 2017. In addition, a public National

Climate Assessment Town Hall event was held on March 6 in Honolulu, Hawai‘i, and drew approximately 70 in-person and virtual participants. On April 19, 2017, a second Town Hall was convened in Guam, during the University of Guam’s Island Sustainability Conference. Approximately 30 people who work in climate-sensitive sectors in Guam and other areas of Micronesia participated. The regional NCA4 author team met regularly at the East-West Center and via conference calls from January through May 2017 to collaboratively develop and refine the Key Messages and chapter narrative sections. Authors carefully reviewed evidence and findings in meetings and during the writing phase. Technical contributors were invited to review drafts of the Key Messages and narratives and to respond with comments and suggested edits.

The Chapter Lead Author submitted the first draft regional chapter on June 16, 2017. It contained Key Messages that addressed: water resources; ecosystems, ecosystem services, and biodiversity; coastal systems; oceans and marine resources; indigenous communities; and cumulative impacts and adaptation. Pacific RISA will continue to facilitate collaboration among the authors as they address comments from reviewing bodies and the public over the next year. Further work will also include preparing with the NOAA Technical Support Unit original and redrawn figures to appear in the chapter.

Kalisi Mausio , member of the Polynesian Voyaging Society and a Geospatial Analyst at NOAA, discusses the implications of climate change for island people worldwide at the National Climate Assessment Town Hall.

The NCA4 regional authors take questions from the audience during the National Climate Assessment Town Hall held in Honolulu on March 6, 2017.

2. Pacific Islands Regional Climate Assessment (PIRCA)

Throughout developing the NCA4 chapter, Pacific RISA gathered information to later consider for inclusion in the next PIRCA report or set of products. In communications with stakeholders around NCA4, including the survey and sectoral workshops, the SAS and lead authors emphasized the links between the 2012 PIRCA, the National Climate Assessment, and the next PIRCA. For example, the PIRCA living bibliography, assembled in the months before and during the preparation of the NCA (now containing more than 300 references, the majority published in 2012 or later), will also serve as a literature database for the PIRCA development. Numerous case study ideas gathered will be reviewed and some further developed in digital formats for the assessment. It is likely that the NCA4 chapter’s key focal area also will be central organizing themes for the next PIRCA. Future plans involve convening a committee comprised of potential users of the next PIRCA from each of the USAPI jurisdictions and Hawai‘i to advise on the product(s) development, and recruiting a team of lead authors.

3. PIRCA Website and Climate Resilience Toolkit

In 2016 and 2017, the SAS and the Pacific RISA team have expanded the ability for potential climate information users to find and access online products from Pacific RISA and other groups that participate

in the PIRCA. In August 2016, Pacific RISA launched a dedicated website at PIRCA.org. The website houses the 2012 PIRCA Report and associated publications, and will serve as a platform to distribute future assessment products. It website further bolsters the PIRCA as an umbrella and aggregator for information on the status of climate change and resilience in the Pacific, not being owned by any one organization or agency. The website better enabled partners to announce upcoming events related to the NCA4 chapter development process (with sharable content).

The website converts all figures and graphics contained in the 2012 report to HTML format with download capability and source/credit information. Individual case studies are now also available in HTML format through the PIRCA website. Following its launch, the website received 824 views and 248 unique visitors in September 2016. In particular, users have visited the site to download the 2012 PIRCA report, check out new tools and reports (such as sea-level rise visualizations for O‘ahu and new downscaling fact sheet), and learn about the PIRCA team and partners.

The SAS worked closely with the editors and web developers at NOAA to adapt regional content for the Climate Resilience Toolkit (toolkit.climate.gov). The Hawai‘i and Pacific Islands region is now one of three regions featured on the site. Included in the content are five adapted case studies as well as one new one, written by the SAS in collaboration with the University of Hawai‘i Sea Grant College Program.

4. Marshall Islands Climate and Health Assessment

Research into climate-health interactions in the Republic of the Marshall Islands with the goal to identify a set of climate variable and impact indicators continued this project year; however, it was substantially slowed by the focus on producing a stakeholder-relevant and regionally inclusive chapter for the National Climate Assessment. The methodology for identifying indicators involves interviews with public health managers in the early stages, and workshops or focus groups with expanded groups of health stakeholders later in the project cycle to confirm findings. The list of contacts in the public health sector continues to grow, and five semi-structured interviews have been completed.

Appendix 2: Additional Publications.

Helweg, D.A., V. Keener, and J. Burgett, 2016: Report from the Workshop on Climate Downscaling and its Application in High Hawaiian Islands: U.S. Geological Survey report: Retton.

Mair, A. 2017. Land-cover map for the Island of Maui, Hawai‘i, circa 2017. Vector Digital Data Set (Polygon). Reston: US Geological Survey. https://water.usgs.gov/GIS/metadata/usgswrd/XML/maui_land_cover_map_2017.xml.

Moser, S. 2016. Pacific RISA’s activities and achievements: 2011-2015. An assessment based on internal tracking. Susanne Moser Research & Consulting: Santa Cruz.

Schuler, C. 2016. Source partitioning of anthropogenic groundwater nitrogen in a mixed-use landscape, Tutuila, American Sāmoa. Master’s Thesis. Honolulu: University of Hawai‘i.