**American Samoa Water Resources**

*Evaluating the Impacts of Land Cover and Water Quality Changes in American Samoa to Improve Watershed Management*

**VPS Title:** Water-Shedding Light on Coral Reef Decline

**Project Team**

***Project Team:***

Marshall Worsham (Project Lead)

Melissa Collin

Eric Davis

Arev Markarian

***Advisors & Mentors:***

Dr. Juan Torres-Pérez (Bay Area Environmental Research Institute, NASA Ames Research Center)

Dr. John Olson (California State University Monterey Bay)

Tomoko Acoba (Joint Institute for Marine and Atmospheric Research, University of Hawai’i at Manoa)

**Project Overview**

***Project Synopsis:*** The watersheds and coral reefs of American Samoa represent inimitable biodiversity hotspots. However, they have suffered from deteriorating water quality as a result of land use and land cover change (LULCC) and insufficient watershed management practices. The NASA DEVELOP American Samoa Water Resources Team applied NASA Earth observations to produce a time series analysis of LULCC and water quality change on the island of Tutuila between 2012 and 2019. The results of this effort support the conservation planning work of the US Coral Reef Task Force Watershed Partnership Initiative and the American Samoa Department of Marine and Wildlife Resources Coral Reef Advisory Group.

***Abstract:***

For at least the past two decades, the coral reefs and coastal ecosystems of the American Samoan island of Tutuila have experienced deteriorating water quality. Increased levels of sedimentation, nutrients, and other land-based sources of pollution (LBSP) have negatively impacted these systems and the local fishery-based economy. Traditional efforts to monitor these systems, such as *in situ* water quality sampling studies and field surveys of piggery operations, have proven insufficient, prompting the US Coral Reef Task Force (CRTF) Watershed Partnership Initiative (WPI) and the American Samoa Department of Marine and Wildlife Resources (DMWR) Coral Reef Advisory Group (CRAG) to seek new strategies. This project provided the partners with maps and geospatial data products to support management interventions designed to mitigate the impacts of land use and land cover change. A time series analysis deployed Earth observations from Landsat 8 Operational Land Imager (OLI) to analyze changes in land cover and chlorophyll-a (Chl-a) concentrations—a proxy for water quality—from 2013 to 2019 at an island-wide scale. Ancillary data products from the United States Department of Agriculture Natural Resources Conservation Service were used to depict change patterns in land cover at a more granular scale, using the Tafuna Plain, Nu’uuli watershed, and Faga’itua watershed as sample sites because of the biodiversity and vulnerability of their marine ecosystems. The end products supplied project partners with knowledge and tangible decision-support tools to maintain the structure and function of vital coastal ecosystems.

***Keywords:***

remote sensing, Landsat, land use and land cover change (LULCC), coastal ecosystems, chlorophyll-a, coral reefs, management

***National Application Area Addressed:*** Water Resources

***Study Location:*** Tutuila, American Samoa

***Study Period:*** 2012 to 2019 (April to October)

***Community Concerns:***

* Coral reefs and marine environments on the American Samoan island of Tutuila have been deteriorating. This degradation negatively affects biodiversity, coastal protection, recreation, and the local fishery-based economy.
* In recent years, sedimentation, high nutrient loads, and land-based sources of pollution (LBSP) have directly harmed coastal ecosystems. Key non-point sources of pollution include LULCC, agriculture, and poorly maintained septic, sewage, and stormwater management systems. The primary point sources are piggeries, quarries, former military dump sites, and wastewater treatment plants.
* Resource limitations have hampered monitoring and management efforts. There is an identified need for research aimed at prioritizing areas of vulnerability to better inform future watershed conservation strategies.

***Project Objectives:***

* Quantify the magnitude of LULCC on Tutuila and identify “hotspot” areas of significant change
* Discern trends in water quality and potential correlation with LULCC in adjacent watersheds
* Produce maps and geospatial analyses that enable partners to optimize watershed management strategies and protect coastal ecosystems in the future
* Provide end users with effective outreach and communication materials to better inform community-based conservation efforts

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **US Coral Reef Task Force, Watershed Partnership Initiative** | Va’amua Henry Sesepasara, Director, American Samoa Department of Marine and Wildlife Resources | End User | No |
| **American Samoa Department of Marine and Wildlife Resources, Coral Reef Advisory Group** | Fa’asalafa Diana Kitiona, Watershed Coordinator; Alice Lawrence, Reef Fish Ecologist | End User | Yes |

***Decision-Making Practices & Policies:***

The Watershed Coordinator works with scientists and community groups to manage conservation practices and conduct research aimed at improving the condition of coastal habitats and coral reefs in American Samoa. Currently, the Watershed Coordinator has limited personnel and resources to monitor and manage water quality. The Coral Reef Advisory Group (CRAG) develops and implements watershed and reef management plans in partnership with local communities. Additionally, the department conducts community workshops, creates communication materials to support management interventions, and ensures compliance with fishery and wildlife regulations. The Watershed Partnership Initiative (WPI), CRAG, and other agencies have completed baseline water quality studies and created point-in-time land cover maps in several priority watersheds, including Faga’alu, Nu’uuli, Vatia, and Aunu’u. However, there is a gap in the geospatial monitoring and evaluation of changes over time. Consequently, the effects of LULCC on coastal water quality across the study area are not yet well understood.

***Project Benefit to End User:***

The American Samoa Water Resources project improved the capacities of the WPI and CRAG to apply remote sensing methods to monitor and evaluate coastal watersheds across the island of Tutuila. Island-wide time series data both qualified and quantified how land cover and water quality have changed from ridge to reef between 2012 and 2019. Annual land classification images and change maps from the past seven years provided important communication and decision-support materials to inform future policymaking, particularly concerning the construction, management, and regulation of piggery and quarry operations around Tutuila. The results of a random forest (RF) model equipped partners with clear inferences about the strength of the relationship between land use change and coastal water quality. In sum, these analyses provided the partners with geospatial products to enhance future community-centered coastal watershed management.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Landsat 8 OLI** | Remote sensing reflectance (Rrs), chlorophyll-a (Chl-a) | Bands 2 (blue), 3 (green), and 4 (red) were processed to analyze changes in land use and land cover on Tutuila from 2013 to 2019. Bands 2 (blue) and 3 (green) were used to produce estimates of chlorophyll-a concentrations in the near-shore ocean. |

***Ancillary Datasets:***

* USDA Natural Resources Conservation Service, US Pacific Basin Islands orthoimagery (2012 and 2017) – conduct watershed-scale land classification and LULCC analysis
* American Samoa Department of Commerce, shapefile of Tutuila Island landform – clip island landform for land cover classifications
* NOAA Pacific Islands Fisheries Science Center, Pacific Islands Benthic Habitat Mapping Center, mosaic of the bathymetry of Tutuila Island – create a buffer zone to extract land and seafloor pixels from water quality images
* American Samoa Department of Commerce, Coastal Management Program, shapefile of major watersheds of Tutuila – clip NRCS orthoimages for watershed-scale land classification; divide near-shore water for zonal water quality analysis
* American Samoa Department of Marine and Wildlife Resources 2012 habitat classification map – validate Landsat and Natural Resources Conservation Service orthoimagery-derived land cover classifications
* NOAA, National Center for Environmental Information, Southern Oscillation Index – generate temporal variables representing El Niño and La Niña oscillations for random forest modeling
* NOAA, National Data Buoy Center, Pacific Islands Ocean Observing System, Station NSTP 6, (2013 to 2019) – quantify wind behavior for random forest modeling
* NOAA, National Center for Environmental Information, Global Surface Summary of the Day, Pago Pago Airport Station – quantify and validate wind behavior for random forest modeling
* NOAA, National Weather Service Forecast Office, NOAA Online Weather Data (NOWData), (2013 to 2019) – document precipitation and air temperature readings for random forest modeling
* NOAA, National Centers for Environmental Information, Storm Events Database – create variables representing presence or absence of storms for random forest modeling

***Software & Scripting:***

* Esri ArcMap 10.6 – manipulate raster datasets, produce and manage shapefiles, produce land classifications at island and watershed scales on Tutuila, and generate map products
* Google Earth Engine API – generate cloud mask pixel composites at island scale on Tutuila
* ACOLITE Python 20190326.0 – calculate Chl-a concentrations in coastal water from Landsat 8 OLI data
* RStudio 1.2.1335 – develop a random forest model to test for strength of relationships between water quality trends, LULCC variables, and ancillary climatological and hydrogeological factors; convert ACOLITE outputs into geotiff raster files
* Adobe Photoshop Creative Cloud 2019 – generate GIF animations from static images of land cover and water quality

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **Annual Land Classification Maps (2013 to 2019)** | Landsat 8 OLI | These maps will enable the partners to visualize the percent cover of four land cover classes for each year during the study period. | I |
| **Island-Scale Land Use and Land Cover Change Map** | Landsat 8 OLI | LULCC maps identified the locations that experienced the greatest changes in land cover across the island between 2013 and 2019. Detecting patterns of change can enable partners to prioritize conservation efforts in areas heavily impacted by human activities. | I |
| **Watershed-Scale Land Use and Land Cover Change Map** | N/A | The watershed-scale LULCC map depicted pixel differences in land cover classes derived from two high-resolution images from the USDA Natural Resources Conservation Service. This product provided partners with additional insight into LULCC in two sample watersheds that experienced the greatest changes in land use and land cover between 2012 and 2017. | N/A |
| **Annual Water Quality Maps (2013 to 2019)** | Landsat 8 OLI | Annual water quality maps highlighted hotspots in the near-shore ocean that showed high Chl-a concentrations between 2013 and 2019, allowing resource managers to pinpoint areas of consistently poor water quality. | I |
| **LULCC Impact on Water Quality** | Landsat 8 OLI | The output of the impact analysis was a table of coefficients quantifying the explanatory power that LULCC and other ancillary variables have over changes in water quality. These results equipped partners with reliable inferences about the consequences of LULCC, which could be applied to inform conservation interventions. | I |
| **GIF Animations of LULCC and Water Quality Change (2013 to 2019)** | Landsat 8 OLI | GIF animations provided communication tools that show the broad trends in LULCC and Chl-a concentration over the study period. Partners will be able to use these visually compelling products in presentations and community outreach to enhance watershed conservation. | N/A |

**Project Handoff Package**

***Transition Plan:*** The American Samoa Water Resources Team formally presented the finalized deliverables to the partners by video conference during the week of August 5, 2019. The final deliverables, listed in the “Handoff Package” section below, were handed off virtually using the NASA Large File Transfer (LFT) platform following the conclusion of the term.

***Team POC:*** Marshall Worsham, marshallworsham@berkeley.edu

***Partner POCs:*** Va’amua Henry Sesepasara, hsesepasara@gmail.com

Fa’asalafa Diana Kitiona, faasalafa.kitiona@crag.as

Alice Lawrence, alicelawrence.mpa@gmail.com

***Handoff Package:***

* Poster
* Presentation
* Project Video
* Technical Paper
* Annual Land Classification Maps (2013 to 2019)
* Island-Scale Land Use and Land Cover Change Map
* Watershed-Scale Land Use and Land Cover Change Map
* Annual Water Quality Maps (2013 to 2019)
* LULCC Impact on Water Quality
* GIF Animations of LULCC and Water Quality Change (2013 to 2019)
* Handoff Package README document

**References**

Birkeland, C., Craig, P., Fenner, D., Smith, L., Kiene, W. E., & Riegl, B. (2008). Geologic setting and ecological functioning of coral reefs in American Samoa. In B. M. Riegl, & R. E. Dodge (Eds.), *Coral reefs of the USA* (pp. 741-764). London: Springer. Retrieved from http://www.botany.hawaii.edu/basch/uhnpscesu/pdfs/sam/Birkeland2007ageolAS.pdf

Comeros-Raynal, M., Lawrence, T., Sudek, A., Vaeoso, M., McGuire, K., Regis, J., & Houk, P. (2019). Applying a ridge-to-reef framework to support watershed, water quality, and community-based fisheries management in American Samoa. *Coral Reefs*, *38*(3), 505-520.

https://doi.org/10.1007/s00338-019-01806-8

Craig, P., DiDonato, G., Fenner, D., & Hawkins, C. (2005). The state of coral reefs of American Samoa. In J. Waddell (ed.), *The state of coral reef ecosystems of the United States and Pacific Freely Associated States: 2005*. (NOAA Technical Memorandum NOS NCCOS 11 pp. 312-334). Silver Spring, MD: NOAA/NCCOS Center for Coastal Monitoring and Assessment’s Biogeography Team. Retrieved from https://repository.library.noaa.gov/view/noaa/17792