**Panama Water Resources**

*Characterizing Vegetation Water Use in the Panama Canal Watershed to Inform Water Management in the Panama Canal*

**Project Team**

***Project Team:***

Roger Ly (Project Lead)

Max Dunsker

Erica Carcelen

Camille Pawlak

***Advisors & Mentors:***

Erika Podest (Jet Propulsion Laboratory, California Institute of Technology)

Kyle McDonald (City College of New York; Jet Propulsion Laboratory, California Institute of Technology)

**Project Overview**

***Project Synopsis:*** This project partnered with the Smithsonian Tropical Research Institute and Panama’s Ministerio de Ambiente (MiAmbiente) to use NASA Earth observations, synthetic aperture radar (SAR), and *in situ* data to assess the impacts of vegetation structure and moisture regimes on vegetation water use in the Panama Canal River Basin during extreme wet and dry seasons. Evapotranspiration rates, used as an indicator for water resource availability, were obtained through Terra Moderate Resolution Imaging Spectroradiometer (MODIS) data and compared to land cover maps produced from NASA Gulfstream III Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR), Advanced Land Observing Satellite (ALOS) Phased Array L-band Synthetic Aperture Radar (PALSAR), and Sentinel-1 radar data. The data were used to create water use maps of different land cover types within Agua Salud and Barro Colorado Island in the Panama Canal Watershed (PCW).

***Abstract:***

The Panama Canal Watershed (PCW) is a major socioeconomic resource. The PCW provides potable water to surrounding cities and ensures the Panama Canal remains fully operational throughout each year. Over one million residents in Panama City, Colón, and San Miguelito rely on the PCW for electricity and potable water. Around three percent of global maritime shipping passes through the Panama Canal annually, which is dependent on water from the PCW to power and fill the locks for ships’ passage. The PCW must be carefully managed to maintain community water needs and operation of the Panama Canal during the dry season. Land cover in the PCW varies from pasture to secondary and old-growth forests. This project used NASA Earth observations and Synthetic Aperture Radar datasets in collaboration with data provided by the Smithsonian Tropical Research Institute to assess the vegetation structure and moisture regimes of different land cover types in the PCW during extreme wet and dry seasons. The team observed evapotranspiration in the PCW using data from Terra Moderate Resolution Imaging Spectroradiometer (MODIS). Using NASA Gulfstream III Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) and Advanced Land Observing Satellite (ALOS) Phased Array L-band Synthetic Aperture Radar (PALSAR), the team interpreted backscatter values to create land cover classifications. Measurements of evapotranspiration and land cover type classifications between 2007 and 2019, in both the wet and dry seasons, indicated that forests were the most effective land cover in maximizing water availability during the dry season.

***Keywords:***

remote sensing, hydrology, synthetic aperture radar, MODIS, evapotranspiration

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

***Study Location:*** Agua Salud and Barro Colorado Island in the Panama Canal Watershed, Panama

***Study Period:*** August 2007 to December 2017

***Community Concerns:***

* The Panama Canal depends on sufficient water supply to function. During the dry season, water scarcity threatens continuous operation. Climatic and anthropogenic interventions, such as stronger El Niño events, the construction of larger locks, and a growing population, add pressure to the amount of water needed from the PCW to fulfill the water needs of the Panama Canal and the people living nearby.
* Water resources must be sustainably managed in order to keep the Panama Canal fully operational as a major transportation route for global maritime commerce.
* The Republic of Panama’s Ministry of the Environment, MiAmbiente, stated that Goal Two of their National Plan for Water Security is the use of water for inclusive socioeconomic growth. In order to assure the equal distribution of water among the population, MiAmbiente promotes the sustainable use of water resources, construction of water infrastructure, and examination of ecosystem dynamics to maximize water availability across Panama.

***Project Objectives:***

* Create land cover water use maps and develop a workflow to relate evapotranspiration and land cover type
* Create land cover maps using SAR data
* Validate classifications and climatology data with *in situ* measurements
* Compare MODIS evapotranspiration across land cover types and between years

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Panama Ministerio de Ambiente** | Francisco Abre, Departamento de Áreas Protegidas | End User | No |
| **Smithsonian Tropical Research Institute** | Jefferson S. Hall, Staff Scientist | Collaborator | No |

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

The Ministerio de Ambiente (MiAmbiente) is in charge of managing the land and water resources of the PCW. The organization has a national water safety plan, in which 20 other organizations participate, which outlines goals relating to sustainable socioeconomic development and water management in Panama. The organizations involved are completing projects of varying lengths related to water resource management. MiAmbiente has a GIS team capable of using remote sensing information to aid the projects related to water resource management. The Smithsonian Tropical Research Institute (STRI) helps inform water resource management through longitudinal studies in the fields of hydrology, biology, and biogeochemistry.

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

MiAmbiente was interested in better understanding how land cover impacts water resources, particularly during the dry season. Our study sites, Agua Salud and Barro Colorado in the PCW, represent many land cover types and have historical *in situ* datasets, making them excellent case study sites to address vegetation water usage in the dry season. MiAmbiente would like to understand how to perform similar studies in areas of Panama outside of the PCW. Our project established and documented a scientifically rigorous methodology for evaluating the evapotranspiration of different land uses, enabling MiAmbiente to scale up the feasibility study for different watersheds. The results of this study suggested which types of land cover would be most beneficial for conserving water in the PCW.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **NASA Gulfstream III - UAVSAR** | L-Band Polarimetric Radar Backscatter | The UAVSAR L-Band was used to characterize land cover types. |
| **Sentinel-1 C-SAR** | C-Band Dual Polarization Radar Backscatter | The Sentinel-1 C-Band SAR was used to characterize land cover types. |
| **ALOS PALSAR** | L-Band Dual Polarization  Radar Backscatter | The PALSAR L-Band was used to characterize land cover types. |
| **Terra MODIS** | Evapotranspiration (ET) | MODIS was used to observe rates of evapotranspiration. |

***Ancillary Datasets:***

* Smithsonian Tropical Research Institute GIS Portal – *In situ* observations and various GIS datasets in the Panama Canal Watershed for validation

***Software & Scripting:***

* Esri ArcGIS 10.6 – Used for image processing and analysis
* L3 Harris Geospatial ENVI – Used for image processing and analysis
* Brockmann Consult, Array Systems Computing and C-S Sentinel Application Platform (SNAP) – Used for image processing and classification
* Python 3.7 – Used for data acquisition
* R – Used for running statistical analysis and creating graphs

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **Land Cover Water Use Maps** | Terra MODIS  NASA Gulfstream III - UAVSAR  ALOS PALSAR  Sentinel-1 C-SAR | This product informed the end user about which types of land cover were the most beneficial for conserving water during extreme dry seasons. | N/A |
| **Standard Operating Procedure** | N/A | This document allowed the end user to scale our feasibility study to additional watersheds in Panama. | N/A |

**Project Handoff Package**

***Transition Plan:*** At the end of the term, the team handed off the land cover water use maps, standard operating procedure, and deliverables to MiAmbiente through Google Drive. A video conference call was conducted to present project accomplishments and to answer partner questions.

***Team POC:*** Roger Ly, roger.ly@ssaihq.com

***Partner POC:*** Francisco Abre, fabre@miambiente.gob.pa; Jefferson Hall, HallJe@si.edu

***Handoff Package:***

* Land Cover Water Use Maps
* Standard Operating Procedure (English and Spanish)
* Technical Paper (English and Spanish)
* Presentation (English and Spanish)

**References**

Bretfeld, M., Ewers, B. E., & Hall, J. S. (2018). Plant water use responses along secondary forest succession during the 2015-2016 El Niño drought in Panama. *New Phytologist*, *219*(3), 885–899. https://doi.org/10.1111/nph.15071

Harmon, R. S. (2005). An Introduction to the Panama Canal Watershed. In R. S. Harmon (Ed.), *The Río Chagres, Panama,* *52*, 19–28. https://doi.org/10.1007/1-4020-3297-8\_2

Hassler, S. K., Zimmermann, B., van Breugel, M., Hall, J. S., & Elsenbeer, H. (2011). Recovery of saturated hydraulic conductivity under secondary succession on former pasture in the humid tropics. *Forest Ecology and Management*, *261*(10), 1634–1642. https://doi.org/10.1016/j.foreco.2010.06.031

Stallard, R. F., Ogden, F. L., Elsenbeer, H., & Hall, J. (2010). *PANAMA CANAL WATERSHED EXPERIMENT: AGUA SALUD PROJECT*. *12*(4), 4. Retrieved from [http://ctfs.si.edu/Public/pdfs/ToDelete/2010\_3Q\_Ogden\_et\_al\_AWRA\_Proc.pdf]

van Breugel, M., Hall, J. S., Craven, D., Bailon, M., Hernandez, A., Abbene, M., & van Breugel, P. (2013). Succession of Ephemeral Secondary Forests and Their Limited Role for the Conservation of Floristic Diversity in a Human-Modified Tropical Landscape. *PLoS ONE*, *8*(12), e82433. https://doi.org/10.1371/journal.pone.0082433