**Tonlé Sap Food & Agriculture**

*Evaluating the Effects of Land Use and Hydrological Change on Ecosystem Vitality using Remotely-Sensed Data in the Tonlé Sap Lake Basin*

**Project Team**

***Project Team:***

Marco Vallejos (Project Lead)

Jenna Johnston

Sonnet Phelps

Joseph Scarmuzza

***Advisors & Mentors:***

Dr. Venkataraman Lakshmi (University of Virginia, Department of Engineering Systems and the Environment)

Dr. Kenton Ross (NASA Langley Research Center)

Dr. Derek Vollmer (Conservation International)

***Team POC:*** Marco Vallejos, vallejosma97@gmail.com

***Partner POC:*** Dr. Derek Vollmer, dvollmer@conservation.org

**Project Overview**

***Project Synopsis:***

Tonlé Sap Lake, known as “the heart of Cambodia,” is a tightly linked social-ecological system facing hydrological challenges due to increased irrigation demand, deforestation, dam construction, and changing climate patterns. To augment end users’ *in situ* measurements of changing ecosystem vitality, we used NASA Earth observations as inputs into a Freshwater Heath Index (FHI) analysis for the Tonlé Sap Lake Basin. Designed to be replicable in other inland water bodies, our research leverages open-source data and processing to provide a remotely-sensed snapshot of water quality and ecosystem health that will inform development and conservation decisions.

***Abstract:***

Tonlé Sap Lake, the largest lake in Southeast Asia, is a critical source of fish and freshwater resources for the region. The health of this freshwater system is under pressure from accelerating dam construction, intensifying agriculture, deforestation, and changing climate patterns, forcing tradeoffs between immediate food security and the long-term vitality and productivity of the ecosystem. Efficient freshwater system monitoring is crucial to navigating these challenges. In collaboration with Conservation International, the Cambodian Ministry of Water Resources and Meteorology, and the Tonlé Sap Authority, we developed and tested remotely-sensed proxies for sub-indicators of the Freshwater Health Index (FHI), which is typically calculated using *in situ* datasets. We used landcover datasets derived from Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Landsat 8 Operational Land Imager (OLI), PROBA-V Vegetation sensor (VGT), Sentinel-2 Multispectral Imager (MSI), Advanced Very High Resolution Radiometer (AVHRR), and Envisat Medium Resolution Imaging Spectrometer (MERIS) as inputs to calculate land cover naturalness and bank modification. Additionally, we created a lake-level time series using a collection of altimetry data sources to estimate deviation from natural flow. We observed a decrease in landcover naturalness and a breakdown in the volume and regularity of annual lake levels from 2000-2020, reflecting increased pressure on water supply and agricultural productivity. At least 8% of forested areas in the basin were lost and rice harvest intensity increased over the course of the study period. These results will help our partners make informed decisions regarding freshwater management. Furthermore, our remotely-sensed FHI analysis can be replicated in other regions, providing decision makers with a snapshot of freshwater health in data-scarce environments.

***Key Terms:***

 Freshwater Health Index, conservation, inland water body, remote sensing, land use/landcover, lake level change, altimetry, irrigation, Google Earth Engine

***National Application Areas Addressed:*** Food Security & Agriculture, Water Resources

***Study Location:*** Tonlé Sap Lake and River Basin, Cambodia

***Study Period:*** 2000 - 2020

***Community Concerns:***

* The Tonlé Sap Lake Basin has one of the fastest rates of deforestation in the world, primarily due to agricultural expansion and flooded forest fire, which threatens water quality and system health.
* Annual water level fluctuations have become more extreme and less reliable in the lake system, due to hydrologic dam construction, increased irrigation, land use change, and shifting regional weather patterns, exemplified by the fact that the Mekong River flow reversal was several months late in both 2019 and 2020, which impacted fish catch, agriculture, and livelihoods.
* Decision-makers in Cambodia work to monitor and mediate the tension between developing infrastructure to support economic development, and preserving ecosystem health to protect ecosystem services in the future.

***Project Objectives:***

* Identify and prototype remotely-sensed proxies for FHI sub-indicators
* Create annual land cover naturalness maps for 2000 – 2020 for drainage basin sub-indicators
* Calibrate a lake level altimetry time series alongside gauge data to calculate deviation from natural flow sub-indicator
* Design a Google Earth Engine (GEE) tool for remotely-sensed FHI analysis for application in data-scarce regions
* Integrate local *in situ* data into the tool’s flexible framework

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Conservation International**  | Derek Vollmer, Freshwater Science Program Senior Director; Nicholas Souter, Freshwater Research Manager | End User | Yes |
| **Ministry of Water Resources and Meteorology (Cambodia)** | Mr. Im Soursdey, Deputy Director of FWUC; Mr. Keo Sovathapheap, Deputy Director of FWUC; Mr. Pol Saren, Deputy Director of Irrigated Agriculture's Department; Mr. Nourn Chamnap, Deputy Director of Irrigated Agriculture Department; Mr. Hear Meng Director of Engineering Department; His Excellency Mr. Watt Botkosal, Cambodia National Mekong Committee | End User | No |
| **Tonlé Sap Authority** | His Excellency Mr. Tony Hell | End User | No |
| **Asian Development Bank** | Mr. Alvin Lopez, NRM Lead | Collaborator | No |
| **World Bank** | Mr. Maurice Rawlins, NRM Specialist | Collaborator | No |

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

Conservation International (CI) has worked in the Tonlé Sap region since 2008, linking technical expertise and products to government agencies and local communities in order to guide research that is responsive to end users’ needs. They have begun to conduct an FHI analysis based on *in situ* data for the Tonlé Sap region, which will be enhanced by our remotely-sensed analysis. Cambodia’s Ministry of Water Resources and Meteorology (MoWRaM) is broadly focused on developing policy and strategy for maintaining the country’s water resources. They monitor, collect, and disseminate hydrologic and meteorological data from *in situ* measurements as well as remotely-sensed sources. MoWRaM has collaborated with NASA SERVIR-Mekong for surface water distribution mapping and other datasets to create decision support tools. The Tonlé Sap Authority (TSA) specifically coordinates the management, conservation, and development of the river basins surrounding the Tonlé Sap Lake. Most of their expertise is based on *in situ* data collection, management, and dissemination. Both TSA and MoWRaM have an opportunity to build internal capacity and gain exposure to Earth observation products related to their decision making. Additionally, the World Bank has created a framework to assess the economic value of forest ecosystem services, and believes improving hydrologic data products and modeling throughout the lake basin could inform ecosystem accounting. The Asian Development Bank supports the creation of a water resources information system and is interested in assessing how it could relate to ongoing projects.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Landsat 5 TM** | Surface reflectance | Landsat 5 TM imagery was used to map land use / land cover in the Tonlé Sap Basin from 2000 – 2013. Landsat 5 TM-derived NDWI and NDVI were used to map agricultural areas in the Tonlé Sap Basin from 2013 – 2020. |
| **Landsat 7 ETM+** | Surface reflectance | Landsat 7 ETM+ imagery was used to map land use / land cover in the Tonlé Sap Basin from 2000 – 2003. |
| **Landsat 8 OLI** | Surface reflectance, NDVI, NDWI | Landsat 8 OLI surface reflectance was used to map land use / land cover in the Tonlé Sap Basin from 2013 – 2020. Landsat 8 OLI-derived NDWI and NDVI were used to map agricultural areas in the Tonlé Sap Basin from 2013 – 2020. |
| **AVHRR** | Surface reflectance | AVHRR HRPT surface reflectance was used to map land use / land cover in the Tonlé Sap Lake Basin from 2000-2015. |
| **PROBA-V** | Surface reflectance | PROBA-V surface reflectance was used to map land use / land cover in the Tonlé Sap Lake Basin from 2013-2019. |
| **Envisat** | Surface reflectance  | Envisat MERIS surface reflectance was used to map land use / land cover in the Tonlé Sap Lake Basin from 2002-2012. |
| **Terra MODIS** | Surface reflectance, Enhanced Vegetation Index (EVI), NDVI, NDWI, land surface temperature | Terra MODIS EVI, NDVI, NDWI, and LST were used to map agricultural areas in the Tonlé Sap Basin from 2000 – 2020. Terra MODIS surface reflectance was used to map agricultural intensity in reference datasets. |
| **Aqua MODIS** | Surface reflectance, EVI, NDVI, NDWI, land surface temperature | Aqua MODIS EVI, NDVI, NDWI, and LST were used to map agricultural areas in the Tonlé Sap Basin from 2002 – 2020. Aqua MODIS surface reflectance was used to map agricultural intensity in reference datasets. |
| **SRTM** | Digital Elevation Model (DEM) | The SRTM DEM was used to map agricultural areas in the Tonlé Sap Basin 2000 – 2020. |

***Ancillary Datasets:***

* Conservation International Tonle Sap Lake Level Gauges – In *situ* ground truth data, provided by Nick Souter, were used to calibrate relative altimetry data and derive absolute lake levels.
* DAHITI Aggregated Altimetry Water Level Time Series – This dataset was used to visualize, process, and produce our water level time series. DAHITI performs algorithmic processing to aggregate and normalize datasets from the following altimetry missions:
	+ Envisat RA-2 Altimeter, 2002 – 2010
	+ OSTM/Jason-2 Poseidon-3 Altimeter, 2008 – 2016
	+ IGDR/Jason-3 Poseidon-3B Altimeter, 2016 – present
	+ SARAL AltiKa Altimeter, 2013 – 2016
	+ Sentinel-3A & 3B Altimeters, 2016 – present
* NASA SERVIR Mekong’s Cambodia Land Use Land Cover Maps – Landcover classifications from 2000-2018 were used to derive land cover naturalness and bank modification for Tonlé Sap.
* ESA Copernicus Global Land Cover Layers – Annual classifications 2015 – 2019 were used to derive baseline landcover naturalness indices globally and to validate landcover naturalness for Tonlé Sap.
* ESA Climate Change Initiative Land Cover – Annual classifications 2000 – 2019 were used to derive baseline landcover naturalness indices globally and to validate landcover naturalness for Tonlé Sap.
* Cambodian Ministry of the Environment 2016 Land Cover – This map, produced in collaboration with the Food and Agriculture Organization, was used to validate landcover naturalness for Tonlé Sap and to make comparisons across datasets.
* Joint Research Center, Global Surface Water (JRC GSW) Layers - This dataset was used to validate land cover and surface water assessments, visualized through the GSW Explorer.
* World Wildlife Fund HydroSHEDS – This dataset, available in Google Earth Engine, was used for water body and watershed extents in classification analysis.
* University of Virginia, Vietnam Mekong Delta Land Cover Maps – Layers including rice harvest intensity were used as reference to map agricultural areas from 2000 – 2018.
* University of Maryland, Hansen Global Forest Change v7 – This global map was used to assess forest change in land cover classifications.
* CHIRPS Precipitation data – This dataset was used to map agricultural areas and land use / land cover in the Tonlé Sap Basin from 2000-2020.

***Modeling:***

* Freshwater Health Index (FHI) (POC: Dr. Derek Vollmer Conservation International) – This conceptual framework was used to build the FHI tool structured around earth observations to allow for quick evaluation of inland water ecosystem health

***Software & Scripting:***

* Esri ArcGIS Pro 2.7.1 – Data analysis and visualization
* Esri ArcMap 10.8 – Data visualization
* Google Earth Engine 0.1.250 JavaScript Code Editor – Raster processing and analysis
* Python 3.9.0 – Data processing and analysis

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Product** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Tonlé Sap Water Level Time Series** | Envisat FMR v3, OSTM/Jason-2 Poseidon-3, IGDR/Jason-3 Poseidon-3B, SARAL/AltiKa, Sentinel-3A, Sentinel-3B Altimeters | Partners will use this comprehensive time series of water levels in the lake to understand the impacts of irrigation, climate change, and land use change on lake water levels and inform future decisions around development and conservation in the region.  | N/A |
| **Tonlé Sap Watershed Weighted Land-Cover Naturalness Maps** | Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI, Terra MODIS, Aqua MODIS, STRM, CHIRPS | Land use and land cover change maps will provide context for hydrological changes over the last several decades and help partners anticipate the effects of future changes in land use. The ability to incorporate additional FHI-oriented land cover classes allow for investigation of topics of hydrological importance for more realistic class weights and naturalness estimates.  | N/A |
| **Preliminary GEE Tool/ Framework for Remote Sensing of FHI** | Landsat, Sentinel-2, Terra MODIS, GPM IMERG, TOPEX/Poseidon, Jason | This package of scripts will allow partners to calculate FHI sub-indicators for the Tonlé Sap Lake basin using remotely-sensed data. With flexibility in data flow, the tool can be adapted to incorporate other inputs available locally for validation and improved accuracy. This tool can also be repurposed in other under-observed watersheds to gain a remotely sensed baseline assessment of the ecological health of inland waters. Weighting of the index is also adjustable, based on values or concerns of local experts. | N/A |

***Product Benefit to End User:***

The impacts of irrigation on the lake’s hydrology are currently an information gap for the MoWRaM and the Tonlé Sap Authority. This project serves to help fill that gap and support decision making around safeguarding the lake’s fisheries and biodiversity while still supporting agricultural development. Understanding the recent changes in freshwater system health can help local decision makers anticipate the impacts of development, and will allow them to make choices which preserve natural resources while fostering local livelihoods around Tonlé Sap Lake. The development of the FHI tool based on Earth observations will make assessing hydrology and its disturbance on the lake faster and easier for Conservation International and other partners in data-scarce watersheds around the globe.

***Project Continuation Plan:***

The aim of the second term will be to validate that the designed framework addresses partner needs, deliver created products and tools with documentation, and iterate with partners on the performance of the global FHI tool in GEE. Other sub-indicators, such as water quality, flow connectivity, and biodiversity, will be incorporated into the FHI tool using Earth observation datasets and GEE. Inputs to the Tonlé Sap Lake FHI will be refined and integrated within the framework, making it flexible for varying levels of *in situ* data availability.

**References**

Freshwater Health Index (2018). Sekong, Sesan and Srepok Basin: An assessment of freshwater ecosystem health in the Lower Mekong, December 2016. Version 1.0. Available from

www.freshwaterhealthindex.org/sites/default/files/3S%20Basin%20Technical%20Report.pdf.

Poortinga, A., Nguyen, Q., Tenneson, K., Troy, A., Saah, D., Bhandari, B., . . . Chishtie, F. (2019). Linking Earth observations for assessing the food security situation in Vietnam: A landscape approach. *Frontiers in Environmental Science, 7*(186). doi:10.3389/fenvs.2019.00186

Rawlins, M., Pagiola, S., Shaad, K., Alam, M., Portela, R., Roy, S., . . . Vollmer, D. (2020). Valuing the Ecosystem Services Provided by Forests in Pursat Basin, Cambodia. World Bank, Washington, DC. <https://openknowledge.worldbank.org/handle/10986/34323>

Uk, S., Yoshimura, C., Siev, S., Try, S., Yang, H., Oeurng, C., . . . Hul, S. (2018). Tonle Sap Lake: Current status and important research directions for environmental management. *Lakes & Reservoirs:*  *Research*

*& Management, 23*(3), 177-189. doi:10.1111/lre.12222

Vollmer, D., Shaad, K., Souter, N. J., Farrell, T., Dudgeon, D., Sullivan, C. A., . . . Regan, H. M. (2018).

Integrating the social, hydrological and ecological dimensions of freshwater health: The Freshwater Health Index. *Science of The Total Environment, 627*, 304-313. doi:10.1016/j.scitotenv.2018.01.040