WATERQ2: UNDERSTANDING WATER QUALITY & QUANTITY IN THE LIMPOPO BASIN

Quarterly Report, 01 October – 31 December 2021

20 January 2022, version 1

Milestone #25

DISCLAIMER: This work was supported by the United States Agency for International Development (USAID), Southern Africa Regional Mission, Fixed Amount Award 72067419FA00001. This work reflects the work of the authors and does not necessarily reflect the views of USAID or the United States Government.

WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin

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Project Information

Project Title	Water Q2: Understanding Water Quality and Quantity in the Limpopo Basin
Geographic Locations	Botswana, Mozambique, South Africa, and Zimbabwe
Award Number	72067419FA00001
Implementation Dates	March 2019 to March 2022

Prepared for:

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USAID/Southern Africa

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USAID/Southern Africa

INTRODUCTION

The transboundary Limpopo River Basin crosses Botswana, Mozambique, South Africa, and Zimbabwe. At over 400,000 km^2, the Limpopo River Basin is home to 18 million people living in both rural and urban areas. Industries in the Basin include businesses in the urban areas and water-intensive uses such as agriculture and mining; industrial water use is growing rapidly. In addition to the human residents, the Basin contains some of the most biodiverse natural areas on the planet.

The rainfall in the Basin is heterogeneous with some sub-basins receiving less than 400 mm on average and other downstream sub-basins in Mozambique receiving over 750 mm annually. Even meteorological stations located in close proximity demonstrate substantial spatial variation within sub-basins. The Basin has experienced severe droughts in the last decade. In addition to the variation in the amount of rainfall, the timing, especially the start of the growing season, has varied significantly. However, there remain many questions about the reliability of rainfall data and other water measurements due in part to the infrequent calibration and validation of field site measurements. **The limited confidence in these data, combined with the substantial variation through time and space necessitates an integrated approach to improve data collection, validation, and overall Basin water resource management in the Basin**.

The goal of this project is to build resilience through the support of Basin stakeholders, including The Limpopo Watercourse Commission (LIMCOM), to improve governance around water resources management and water security in the Basin. A systems approach, such as integrated water resources management (IWRM) is needed to address such complex, large, and interrelated components of water resources. IRWM is recommended by the United States Agency for International Development (USAID) Water and Development Strategy Implementation Guide (2014). This context will be combined with data collection and validation, data sharing, and continuous evaluation of the interrelations that affect water resources.

This project will support water resources monitoring, and the development of methods for water quality and quantity measurement based on *in situ* sensors and satellite measurements. These **measurements** will enable characterization of water resource dynamics at the whole Basin scale and form the foundation for hydrologic **modeling** that can help estimate hard-to-measure parameters and also provide holistic assessments of Basin scale stocks and flows. To support data sharing, the project will use cloud-based, automated data collection and web-based **data sharing**.

The Development of local capacity to maintain water resources and make proactive, scientifically justified management decisions requires a substantial human capital resource that is currently lacking in the Basin. The project will provide training, workshops, and conferences will focus on integrated water resources management (IWRM) and environmental flow analysis.

The results of the water resources and biodiversity studies conducted will be compiled into a report for the Basin stakeholders. Continued high-quality data collection, training, and general logistics depends on dependable physical infrastructure. To support data collection efforts as well as training and collaboration the Limpopo Resilience Lab at the University of Venda will be established. The sustainability of lab activity will continue with the implementation of a small user fee beyond the duration of the project. Annual training workshops and conferences will be located at or nearby the Resilience Lab.

In this report, the collaborators, Duquesne University (Duquesne), University of Venda (Univen), and Rensselaer Polytechnic Institute (RPI) report their activities and progress in the third quarter (Q3) of project year 2021-22 (PY 2021-22).

PROJECT ADMINISTRATION

PROGRESS TOWARDS MILESTONES

Student research has continued during this quarter under the supervision of the PIs. The specific projects will be reported within the module which they support. Water resources monitoring will continue with remote sensing (satellites) and ground-based stations that are equipped with telemetry devices; however, not all instruments are compatible with telemetry or placed in an area that communications are available; these instruments require a physical connection for downloads and the project continues to lose data from those instruments.

This year, project personnel have been busy with presentations based on research supported by this project.

PRESENTATIONS

Bakar, S.A. and Kahler, D.M., (2021). "Hydrologic Modeling with Remote Sensing for Groundwater Resources Management within the Sand River Catchment, South Africa". American Geophysical Union 2021 Fall Meeting. December 13th – 17th, 2021.

Bakar, S.A. and Kahler, D. M., (2021) "Novel Application of Remote Sensing, Geotechnical Measurements, and Groundwater Models for Improved Water Resources Management within the Limpopo River Basin" International Shared Aquifer Resources Management 2021 Conference. December 6th -9th, 2021.

Glines, M. and Rose, K. (October 2021). "Landscape control of seasonality in water clarity across the contiguous United States." GLEON 2021 all-hands meeting. Virtual poster presentation.

Glines, M. and Rose, K. (2021). "Remote sensing of seasonality and long-term trends in Adirondack lake water clarity." Adirondack Research Forum, January 2021.

Kahler, D. M., (2021). "Limpopo Resilience Lab." *Tech Showcase*. UNC Water and Health Conference. 04-08 October 2021.

Treinish, L., Tewari, M., Praino, T., Glines, M., and Moriarty, V. (2021). "Atmospheric drivers for transient harmful algal blooms in a medium-sized oligotrophic lake." American Geophysical Union 2021 Fall Meeting. December 13th – 17th, 2021.

Zuccolotto, G., and Kahler, D. M., (2021). "Monitoring Groundwater Withdrawal and Potential Land Subsidence in The Limpopo River Basin, Mozambique with Remote Sensing." American Geophysical Union 2021 Fall Meeting, H31F-07. December 13th – 17th, 2021.

MODULE 1: WATER MONITORING

HYDROMETEOROLOGICAL STATION NETWORK

Data from stations established in this project continue to be monitored remotely and by staff in South Africa. Data are now available through the project website and hosted on the Development Data Library, (DDL, data.usaid.gov). Data from telemetry sites were updated this quarter.

REMOTE SENSING RIVER GAGE

Researchers have continued to analyze the Planet Labs data and expanded the sites under analysis. These data and results are now being used to inform future projects across the Limpopo.

REMOTE SENSING WATER QUALITY

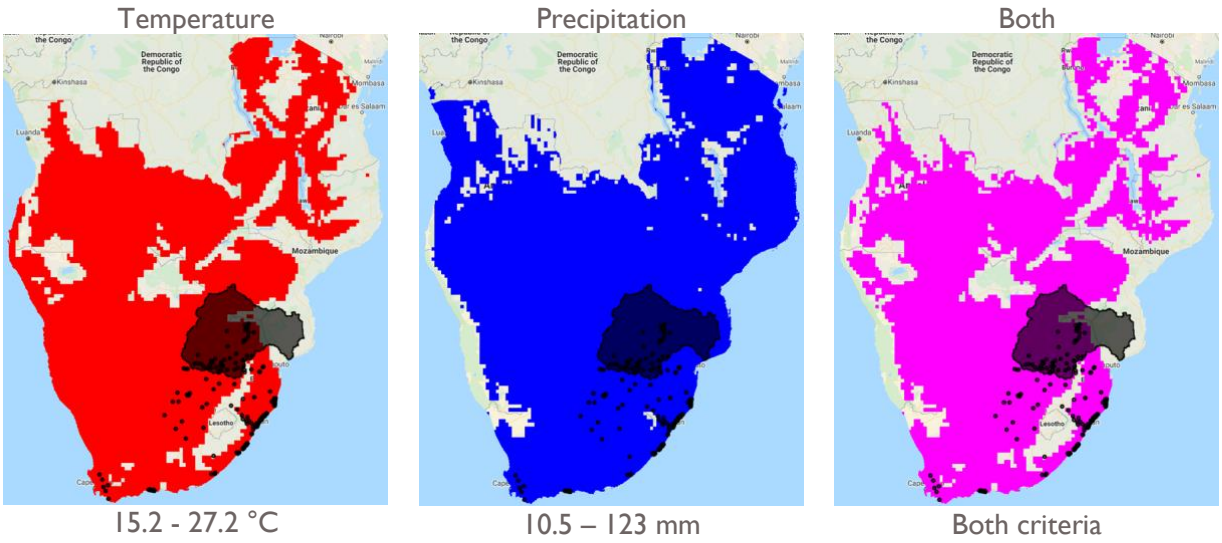

Figure 1: Climate ranges in southern Africa.

The remote sensing of long-term trends in water quality and quantity throughout southern Africa requires the detection and delineation of lakes and reservoirs throughout the region, the acquisition of Landsat reflectance data, the development of a machine learning algorithm using matchups between in-situ observations and Landsat overpasses, and an analysis of estimated trends in relation to climate and land use change. Currently, in-situ validation data has been acquired for 121 waterbodies and shapefiles have been generated for 7,930 lakes and reservoirs throughout southern Africa. Potential lakes and reservoirs were located using the Global Surface Water Dataset raster (Pekel et al., 2016). All waterbodies were clipped to southern Africa (defined as South Africa, Lesotho, eSwatini, Zimbabwe, Botswana, Mozambique, Namibia, Malawi, Zambia, Burundi, Rwanda, Angola, and Tanzania) and interconnected pixels were converted into polygon shapefiles to generate unique waterbodies. Copernicus ERA5 climate data was used to determine the mean and standard deviation for annual temperature and precipitation across the validation sites, and any waterbodies falling outside of one standard deviation were removed to ensure accuracy in satellite-derived estimates (Figure 1). To remove rivers, wetlands, and salt flats from the dataset, waterbodies were removed if the median occurrence of water across all pixels in the shapefile was less than 30%. Following this, any remaining

waterbodies that were obviously not a lake or reservoir were removed manually. Finally, lakes and reservoirs that are either within the Limpopo River basin or are validation sites and were removed due to the climate filtering were added back into the full dataset (Figure 2). Using these shapefiles, optical reflectance and water extent will be downloaded from Landsat 5, Landsat 7, and Landsat 8 imagery from 1984 to 2021.

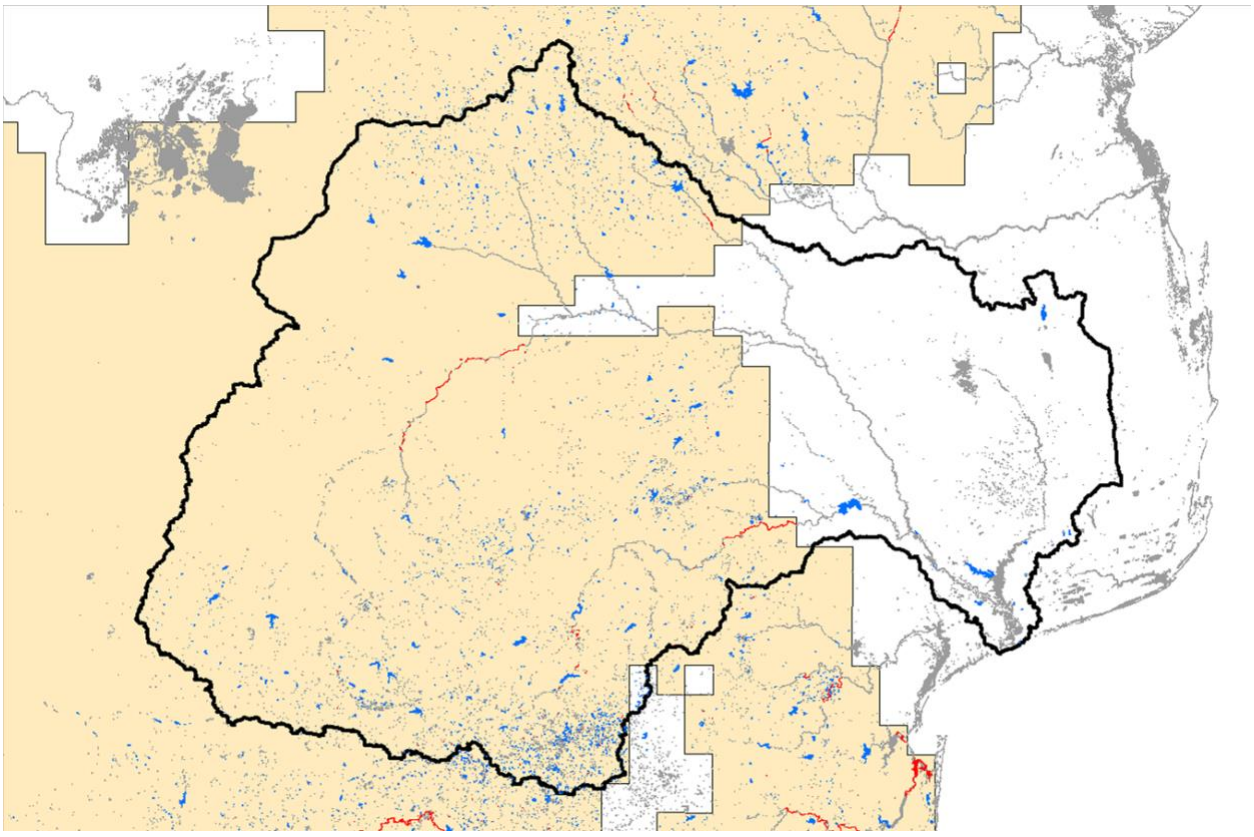

Figure 2: 1,346 waterbodies in Limpopo basin that satisfied the selection criteria (Figure 1) are shown in tan.

GROUNDWATER MEASUREMENTS

The study area was refined to the Sand River Catchment of the Soutpansberg mountains, specifically subbasin 1 (Figure 3). This subbasin was chosen due to the presence of unquantified groundwater resources and an established weather monitoring station at Medike. Data collected and analyzed for model development include precipitation, wind speed, radiation data, river gage data from the Sand River at Waterpoort (SA DWS), GRACE water equivalent thickness data (Landerer 2021, Landerer 2012), GLDAS soil moisture and snowmelt (Rodell 2004), and digital elevation images (Shuttle Radar Topography Mission). The U.S. Army Corps of Engineers HEC-HMS hydrologic modelling software was used for preliminary model development. Parameters utilized in the model include the baseflow recession method, SCS Curve number loss method, and SCS unit hydrograph transform method. GRACE and GLDAS data will be used to supplement canopy, surface, and groundwater loss. Preliminary model results will be from August 2019 to August 2020 based on data availability. The resulting modelled flow will be compared to the observed flow from the gage at Waterpoort.

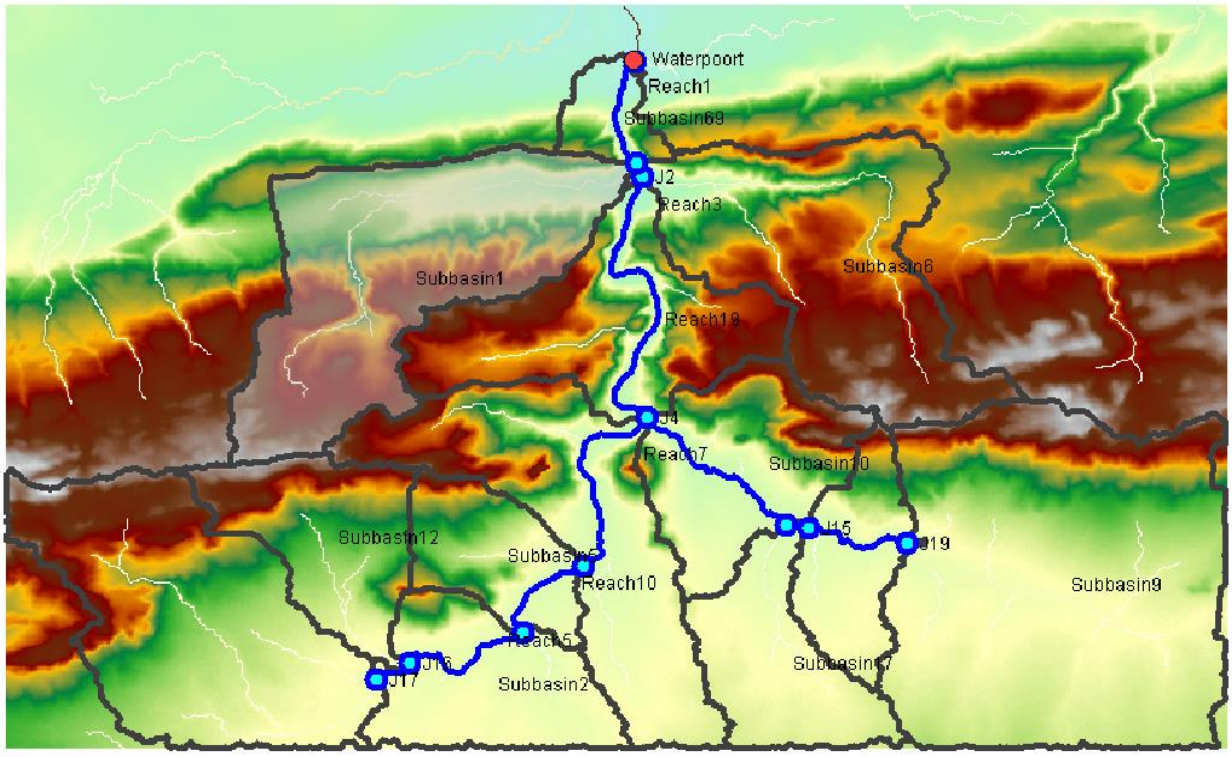

Figure 3: HEC-HMS catchment model of the Sand River delineated at the Soutpansberg Mountains.

South Africa Department of Water and Sanitation. January 19th, 2022. https://www.dws.gov.za/Hydrology/default.aspx

Landerer, F. W., 2021. TELLUS_GRAC_L3_CSR_RL06_LND_v04. Ver. RL06 v04. PO.DAAC, CA, USA. Dataset accessed [2022-01-19] at https://doi.org/10.5067/TELND-3AC64.

Landerer F.W. and S. C. Swenson, Accuracy of scaled GRACE terrestrial water storage estimates. Water Resources Research, Vol 48, W04531, 11 PP, doi:10.1029/2011WR011453, 2012.

Rodell, M., P.R. Houser, U. Jambor, J. Gottschalck, K. Mitchell, C.-J. Meng, K. Arsenault, B. Cosgrove, J. Radakovich, M. Bosilovich, J.K. Entin, J.P. Walker, D. Lohmann, and D. Toll, The Global Land Data Assimilation System, Bull. Amer. Meteor. Soc., 85(3), 381-394, 2004.

Shuttle Radar Topography Mission 1 Arc-Second Global (Digital Object Identifier (DOI) number: /10.5066/F7P Shuttle Radar Topography Mission 1 Arc-Second Global (Digital Object Identifier (DOI) number: /10.5066/F7PR7TFT

COASTAL WATER RESILIENCE

In the coastal city of Xai-Xai, Mozambique, located in the lower part of the Limpopo basin, water security is threatened by reduced surface and groundwater supply, extreme weather events such as drought and cyclones, sea level rise and saltwater intrusion. Here, water is diverted from the Limpopo for irrigation and groundwater is extracted to support Xai-Xai's municipal supply. Reduced river flow and over-pumping of groundwater can result in saltwater intrusion into coastal aquifers and upstream

into the Limpopo, a process which would be detrimental to the extensive agricultural operations near the mouth of the river. This area is also underlain by an unconsolidated alluvium aquifer system, making the city susceptible to groundwater-induced land subsidence. Subsidence of Xai-Xai would exacerbate the effects of cyclones during the rainy season and sea level rise. Insufficient in-situ monitoring of these different hydrologic factors limits our understanding of when and where water is being used in this region and complicates relationships with upstream communities. In this study, we demonstrate how remote sensing can be used to monitor precipitation, river flow, groundwater storage and land subsidence, in order to better understand threats to water security in the lower Limpopo River basin and improve water management. The remote sensing technologies used in this research are outlined below.

- Precipitation is measured via the Global Precipitation Measurement (GPM) mission from October 2003 to September 2020
- Terrestrial water storage data from Gravity Recovery and Climate Experiment (GRACE) is assimilated with GLDAS models to estimate groundwater storage from October 2003 to September 2020
- Sentinel-1 Interferometric Synthetic Aperture Radar (InSAR) is used to monitor land subsidence from October 2017 to September 2020
- Water height data measured by various radar altimeters is used to estimate changes in Limpopo River discharge from October 2008 to September 2020

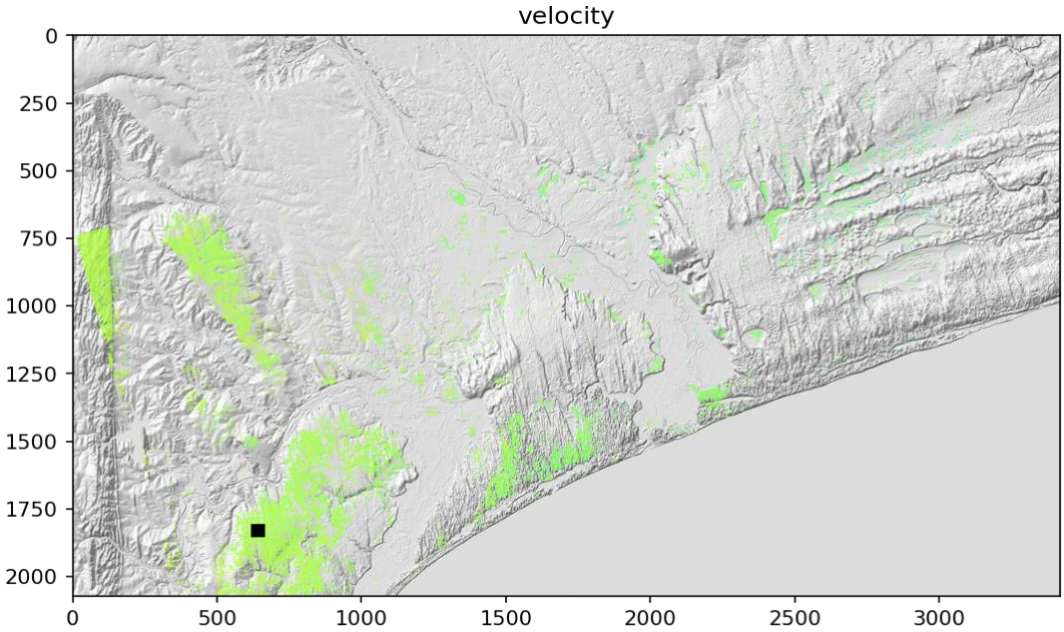

Figure 4: 92 Sentinel-1 single look complex SAR images were generated into 276 interferograms from October 2017-September 2020 using the Alaska Satellite Facility HYP3 tool. Unwrapped and pre-processed interferograms were formed into a stack and analyzed with a short baseline subset technique using the Miami INsar Time-series software in Python (MintPY). Results of the time series analysis show average subsidence of 1.0 – 1.5 cm/year under Xai-Xai, Mozambique.

RIVER HEALTH MONITORING

Researchers continue to monitor water quality in the Levhuvu River as it enters Kruger National Park. The samples were tested for fluoride, chloride, nitrate, nitrite, phosphate, and other ions by ion chromatography and trace metals by induced coupled plasma mass spectroscopy with microwave digestion. The ongoing sampling at these sites will support Mr. Hilton's thesis research.

MODULE 2: TRAINING, WORKSHOPS, AND CONFERENCES

SCIENTIFIC CONFERENCE

PROJECT-SUPPORTED

The project sponsored events and presented at the technology showcase at the University of North Carolina's (UNC) Water Institute's Water and Health Conference, 04-08 October 2021. The project also supported additional participants. The conference was entirely remote. The Limpopo Resilience Lab presentation at the technology showcase can be viewed at the project website: www.duq.edu/limpopo, under conferences.

MODULE 3: BASIN-LEVEL REPORT

The WaterQ2 team has begun to prepare the draft report on water resources management based on our findings during the first year of the project. Currently, the report is being prepared in parallel with a draft of a manuscript that will be prepared for publication in a peer-reviewed journal.

MODULE 4: LIMPOPO RESILIENCE LAB

University of Venda is expanding their analytical water chemistry capabilities and computational resources. The ion chromatograph has been ordered and should be installed in January. The project is prioritizing and budgeting the Limpopo Resilience Lab expansion.

MONITORING AND EVALUATION

MODULES 1 AND 3: WATER MONITORING

There are four primary research activities that have continued in this quarter that are supported through this project. They all fall into USAID category, *Production Systems Research*, as they are a component of natural resources management. The research activities are:

- Remote sensing river gage (*Under field testing*)
- Remote sensing water quality (*Under field testing*)
- Remote sensing and models to estimate groundwater resources (*Under research*)
- Remote sensing to support coastal water resilience (*Under research*)

TABLE 1: MODULES 1&3 INDICATORS

INDICATOR	DISAGGREGATION	CURRENT VALUE	PROJECT TOTAL
Number of technologies, practices, and approaches under various phases of research, development, and uptake as a result of USG assistance	Phase: Under research	2	4
	Under field testing	2	2
	Made available	0	0
	Demonstrated uptake	0	0
Number of peer-reviewed scientific publications resulting from USG support to research and implementation programs	None	0	0
Number of hectares of land under improved technologies or management practices with USG assistance		0	0
Number of datasets shared, which were generated as a result of USG assistance	Downloads: Medike: 91 Mutale: 94 Mbahela: 76 Leshiba: 0	4	4

TECHNOLOGIES

Under research

- Groundwater resources with remote sensing and hydrologic models
- Relative risk for river seawater intrusion based on land subsidence, river discharge, and sea level rise

Under field testing

- Remote sensing of river discharge
- Remote sensing of water quality

PEER-REVIEWED PUBLICATIONS

No manuscripts have been submitted at this time; however, two are nearing submission:

- Remote sensing of river discharge for water resources management
- Remote sensing reveals synchrony in water quality and quantity in the Limpopo River Basin

HECTARES OF LAND UNDER IMPROVED TECHNOLOGIES OR MANAGEMENT PRACTICES

So far, the project has worked with closely with the South African Department of Water and Sanitation and South African National Parks. The researchers hope that this engagement has assisted with technologies and management; however, it would be difficult to provide a specific area at this time.

DATASETS

The Leshiba dataset is currently being collected; however, it has not been uploaded due to COVID-19 travel restrictions.

MODULE 2. IWRM TRAINING, WORKSHOPS, AND CONFERENCES

Module 2 contains two primary components: convene stakeholder workshops and trainings; and convene future collaborators at conferences.

TABLE 2: MODULE 2 INDICATORS

INDICATOR	DISAGGREGATION	CURRENT VALUE		PROJECT TOTAL	
Number of people trained in sustainable natural resources management and/or biodiversity conservation as a result of USG assistance	Sex	Male	Female	Male	Female
		0	0	45	23
Number of water and sanitation sector institutions strengthened to manage water resources of improve water supply and sanitation services as a result of USG assistance	Institutional scale	0		4	

INSTITUTIONS

Previous Institutions

- South African Department of Water and Sanitation
- South African National Space Agency
- South African Weather Service
- South African National Parks

PROJECT PROGRESS

WORK PLAN PROGRESS

Table 3 outlines progress on work plan activities (outlined in the Mobilization Plan) and the ongoing research activities. As specified in the Project Description, the following activities were planned.

TABLE 3: PROJECT ACTIVITIES

#	ACTIVITY	2019			2020				2021				2021
	Project year quarter	1	2	3	4	1	2	3	4	1	2	3	4
	Startup activities: Mobilization Plan, Staffing, EMMP												
1	Establish meteorological, river, and groundwater stations, *Water Monitoring and Algorithm Development* Report		*				*						
1	Groundwater measurements (ERT), to be included in *Water Monitoring* Report		**		**								
1	Develop satellite algorithms												
1	Develop hydrologic and water quality models												
2	Convene stakeholders in workshops												***
2	Scientific conferences					****						❖	
2	Training workshops								†				
3	Publish and present basin report									‡			
4	Launch Limpopo Resilience Lab												
		Completed						In-progress/planned					

Notes:

* Hydrometeorological stations have been installed; however, some stations were scheduled for installation but cancelled due to COVID-19 pandemic travel restrictions. It is unclear if the project will have time to establish these stations and may refocus these resources to Kruger National Park and the Soutpansburg Mountains.

** ERT measurements were delayed at first due to shipping delays with Tazmanian Logistics and then due to COVID-19 pandemic travel restrictions. Project staff is now making routine trips to Kruger National Park to collect data.
*** The stakeholder meeting for PY 2021-22 has been moved to January 2022 to showcase the results of the project and determine how best to integrate these results into water resources management.
**** The project convened a special side event at the Water Institute of Southern Africa conference. The conference was delayed due to COVID-19. The side event was a great success when the conference was held in December 2020.
❖ The PY 2021-22 conference was in conjunction with the University of North Carolina's Water Institute's *Water and Health Conference*, 04-08 October 2021.
‡ The basin report has been delayed.

MILESTONE PLAN

TABLE 4: MILESTONE PLAN

#	MILESTONE	2019			2020				2021				2021
	Project year quarter	1	2	3	4	1	2	3	4	1	2	3	4
1	Mobilization Plan	Apr											
2	Environmental Mitigation and Monitoring Plan	Jun											
3	Quarterly Report	Jul											
4	Water Monitoring and Algorithm Development Report		Dec*										
5	Stakeholder Workshop Report		Nov										
6	Annual Work Plan		Aug										
7	Quarterly Report		Dec*										
8	Quarterly Report			Apr*									
9	Quarterly Report^				Apr								
10	LRL Website and Planning				Apr								
11	Scientific Conference							Dec					
12	Basin Report					Jul							
13	Quarterly Report					Jul							
14	Stakeholder Workshop Report						Sep						
15	Annual Work Plan						Aug						
16	Quarterly Report						Oct						
17	Quarterly Report							Jan					
18	Quarterly Report^								Apr				
19	Scientific Conference									Dec			
20	Quarterly Report									Jul			
21	Stakeholder Workshop Report												Mar

22	Water Monitoring: Two manuscripts	Aug			
23	Annual Work Plan	Aug			
24	Quarterly Report	Sep			
25	Quarterly Report		Jan		
26	Basin Report			Mar	
27	LRL Continuity Report			Mar	
28	Quarterly Report			Apr	

Notes:
Shaded items are completed or pending approval.
Item 10 was delayed to collect more information and await publication of datasets on data.usaid.gov. This report is upcoming.
Item 12, the draft of the basin report, was delayed to address comments from the thesis committee.

FINANCIAL

PRIME RECIPIENT

Duquesne University has used project funds for the expenditures in Table 5.

TABLE 5: PROJECT EXPENDITURES

ITEM	Q3 EXPENDITURE	PROJECT TOTAL
Summer research salary for Dr. Kahler	$0	$14,760.01
GRA Stipend support	$6,930.07	$89,795.97
Tuition	$35,473.00	$82,783.00
Fringe	$0	$2,940.44
Equipment	$15,135.00	$62,320.00
Lab/Research Supplies	$5,433.44	$23,835.00
Travel	$4,980.11	$30,817.41
Subaward: Univen	$0	$122,808.12
Subaward: RPI	$10,713.28	$244,947.88
Indirect to Duquesne University	$20,282.38	$112,316.58
Total	$98,947.28	$787,324.41

APPROVAL

This Quarterly Report has been received and approved by USAID. This satisfies the requirements set forth in the Milestone Plan, item #24: Completion of Quarterly Report (Q2).

Signature: _____

Name: _____
Agreement Officer's Representative

Date: _____

WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin