WATERQ2: UNDERSTANDING WATER
QUALITY & QUANTITY IN THE LIMPOPO BASIN

FY2021-2022 Work Plan

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Milestone #23

WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin

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Cover photo: High-elevation wetland in the Soutpansburg Mountains. Photo credit: David M. Kahler

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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
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INTRODUCTION

The transboundary Limpopo River Basin crosses Botswana, Mozambique, South Africa, and Zimbabwe. At over 400,000 km², 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), Rensselaer Polytechnic Institute (RPI), and University of Venda (Univen), establish their work plan for the fiscal year 2021-2022 (this is in reference to the United States Government fiscal year that begins 01 Oct).

OVERVIEW

This work plan is for the period 01 October 2021 – 27 March 2022. This year is the conclusion of our project; however, we have requested an extension from USAID and are awaiting a response. The primary delay in the work is due to COVID-19 travel restrictions.

PROJECT ADMINISTRATION

PERSONNEL

At all partner universities, graduate students continue to work on research identified within the relevant modules in this report. Current students include:

- Duquesne University
    - Sophia Bakar (project-supported)
    - Gabriella Zucolotto (university-supported)
    - Mackenzie Martin (graduating)
- University of Venda
    - Hilton Thivhonali Shimbabu
    - Masingi Collen
    - Ntwanano Mutaleni (graduating)
- Rensselaer Polytechnic Institute
    - Max Glines
    - Jenna Robinson (partial university supported)

VACCINATION STATUS

As the project is classified as assistance, it is unclear if President Biden's requirement for vaccines applies to project personnel. Nevertheless, all project personnel have and will comply with the policies of the universities, which require vaccinations in the United States and support vaccination once widely available in South Africa.

- Duquesne University: https://www.duq.edu/life-at-duquesne/health-recreation-and-counseling/health-services/covid-planning-and-information/news-and-updates/covid-19-vaccine-will-be-required-for-all-students-at-duquesne-university
- University of Venda: https://www.univen.ac.za/news/the-university-of-venda-is-a-vaccination-site-for-staff-students-and-the-surrounding-communities/
- Rensselaer Polytechnic Institute: https://covid19.rpi.edu/vaccinations

REQUESTED COVID-19-RELATED EXTENSION

COVID-19 has significantly reduced the ability for the project to perform the planned activities of the project. With an extension, the project staff could significantly improve several of the outputs and outcomes of the project. Specifically:

- Milestone #26: Basin Report (final draft)
- Milestone #27: Limpopo Resilience Lab (continuity report)

FINANCES

Project management will include the verification of all finances incurred under the project and is the responsibility of Dr. Kahler as set forth by the previous Work Plan. All invoices will be verified by Dr. Kahler and paid by Duquesne on a reimbursement basis. All monitoring, verification, and coordination procedures set forth in the previous Work Plan.

METEOROLOGICAL, RIVER, AND GROUNDWATER MONITORING (MODULE 1)

HYDROMETEOROLOGICAL STATIONS

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). A range of API and analysis tools are now available at the Limpopo Resilience Lab page on GitHub: https://github.com/LimpopoLab. Data will continue to be collected and additional sensors will be deployed based on need and accessibility.
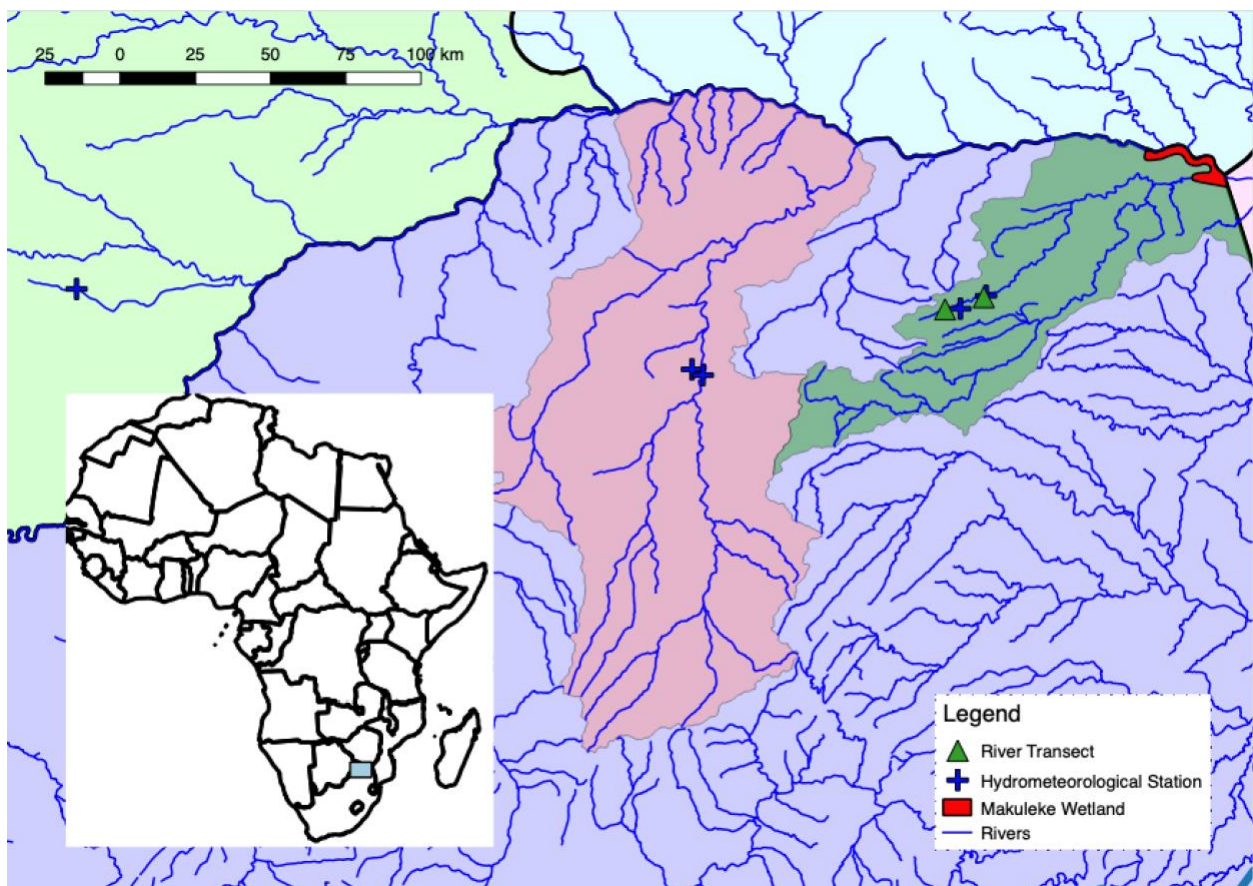
Figure 1: The Limpopo River Basin and Sand River catchment (pink) and Levuvhu/Mutale River catchment (dark green). The Basin spans Botswana (light green), Mozambique (light pink), South Africa (lavender), and Zimbabwe (light blue). Locations of installed stations and transect locations (and planned Botswana location). The Leshiba Wetlands are located near the station in the Sand River. A dynamic map is available at www.duq.edu/limpopo under the data page.

REMOTE SENSING RIVER GAGE

Research staff has continued to obtain data from Planet Labs satellites for discharge research for several sites in South Africa where continuous monitoring is available and one site in the United States for contrast. Planet data were made available through Planet Labs' Education and Research Program. Ms. Martin has made progress on an algorithm to identify the edge of water values Planet Labs' images and measure the width of a river along a transect perpendicular to the mean flow. The algorithm is being developed in the open-source platform, R, and will be released publicly following testing and peer-review. A manuscript and MS thesis is currently in preparation.

REMOTE SENSING WATER QUALITY

Staff has used Landsat for water quality through Google Earth Engine. Mr. Glines has sought the target parameters of water clarity, chlorophyll, and turbidity. Calibration data were obtained through collaborations with the Department of Water and Sanitation, South Africa.

GROUNDWATER MEASUREMENTS

Fortunately, South Africa lifted some restrictions on travel and Univen scientists were able to collaborate with scientists from Kruger National Park for surface and groundwater investigations in November. This included use of electrical resistivity tomography (ERT) to profile the water table at the confluence of the Levuvhu and Limpopo Rivers at Makuleke Contractual Park, which includes the Makulek wetlands, a Ramsar-recognized wetland of importance. The results of this work will be made available as an appendix in the next report and data will be available through the Kruger National Park data repository and the Development Data Library (USAID).

Staff is also examining groundwater recharge zones and precipitation patterns throughout the region. Satellite-based measurements include water data from NASA's Gravity Recovery and Climate Experiment (GRACE). The GRACE satellites measure changes in gravity based on monthly changes in mass. The mass changes are measured in terms of "water-equivalent thickness" changes that occur in a concentrated layer of water near the Earth's surface. Most of the monthly gravity changes are caused by changes in water storage, moving ocean, atmospheric and land ice masses, and by mass exchanges between these. By tracking water equivalent thickness at different points on Earth's surface, GRACE data can provide a picture of what groundwater storage may look like at a specific location. The Global Land Data Assimilation System (GLDAS) combines satellite and ground-based observational data via land surface modeling and data assimilation techniques to generate a model of land surface states and fluxes in order to support proposed weather and climate prediction. Ground-based measurements include precipitation data and aquifer location and characteristics from electrical resistivity tomography (ERT). The data collected will aid in the development of a groundwater model of the Limpopo River Basin using HEC-HMS hydrologic modeling software. The developed model will identify key recharge zones for water resources in the Limpopo River Basin.

COASTAL WATER RESILIENCE

In various regions around the world (e.g. the Central Valley of California, the North China Plain and Mexico City), excessive groundwater extraction has resulted in aquifer depletion and land subsidence. Along with damage to infrastructure, land subsidence can be especially devastating to coastal regions

where rising sea levels can submerge coastlines and saltwater can intrude into important freshwater sources. Groundwater availability and subsidence have historically been monitored using networks of boreholes and GPS stations. In southern Mozambique, groundwater extraction is insufficiently monitored, and the aquifer is unconsolidated, sedimentary; furthermore, increased demand for freshwater during the dry season could make this region susceptible to depletion and subsidence. Such effects would be devastating to those residing in the region, as 60% of the country's population relies on groundwater for domestic use and agriculture according to the Census of 2007. In this study, changes in groundwater storage in southern Mozambique are monitored using NASA's Gravity Recovery and Climate Experiment (GRACE) satellite. To assess the potential effects of groundwater withdrawal, differential interferometry from ESA's Sentinel-1 Synthetic Aperture Radar is used to monitor changes in ground deformation over three major coastal cities in Mozambique: Maputo, Xai Xai and Inhambane. This study serves as the first attempt to quantify changes in groundwater availability using remote sensing techniques in southern Mozambique - an approach which may prove to be useful for future water management decisions in a country where in situ monitoring is limited.

RIVER HEALTH MONITORING

Water samples were obtained along 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.

CITIZEN SCIENCE

The RPI student team has continued to work on the citizen science project for water resources monitoring. Most code is available: https://github.com/CSSAW. The original project team attempted to find images for use in a training algorithm for a neural network; an adequate number of training images is not available. At this time, the image-based program will not be continued. A text-based data collection is available.

STAKEHOLDER WORKSHOP AND TRAINING (MODULE 2)

TRAINING

R FOR DATA ANALYSIS

The project has hosted two training workshops on R for data anaylsis. The first in March 2021 was so successful, the South African Department of Water and Sanitation requested an additional workshop that focused on their hydrology staff, which was held in August 2021. Such a request is encouraging for the sustainability of the Limpopo Resilience Lab. This course may be offered again if there is demand.

SCIENTIFIC CONFERENCES

WATER AND HEALTH CONFERENCE

The Scientific Conference for this project year has been selected. The project will sponsor a side-event and have presentations at the University of North Carolina's (UNC) Water Institute's Water and Health Conference. This will be held in October 2021. The project is also supporting attendance of participants from the Limpopo River Basin.

WATER INSTITUTE OF SOUTHERN AFRICA

The Water Institute of Southern Africa 2020 Conference in Johannesburg was postponed to December 2020. The project hosted a side event with a keynote from South African National Parks and presentations on ongoing research activities. Results of some of our activities were presented in the scientific program of the conference. Unfortunately, WISA's bank processing errors delayed much of the planning for the conference and the project decided not to continue work with WISA.

STAKEHOLDER ENGAGEMENT MEETING

This first two stakeholder meetings were a complete success. The first meeting was held at the Council for Scientific and Industrial Research (CSIR) in Pretoria. The second meeting was held virtually via Zoom® with online interpretation for Portuguese speakers due to Covid-19 restrictions.

At this time, we cannot determine if in-person meetings will be possible this coming year. Continued stakeholder meetings will be held either in-person or virtually. The plan for the final stakeholder meeting, tentatively scheduled for January 2022, will be a series of targeted meetings with a final plenary meeting to showcase the results of the research projects conducted in this project and communicate with stakeholders the ongoing Limpopo Resilience Lab activities, which will include:

- Training, especially on data management and analysis;
- Citizen science; and
- Water quality and quantity testing at Univen.

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. Quotes have been obtained for an ion chromatograph and several computer resources. The project is prioritizing and budgeting the Limpopo Resilience Lab expansion.

Training will continue to be a part of the project's sustainability. Most training will be in computational resources for data management and analysis.

TIMELINE

TABLE 1: WORK PLAN			
OBJECTIVES	**ACTIVITIES**	**RESULTS**	**TIMELINE**
Water monitoring and algorithm development (Module 1)	Finalize research projects: • Remote sensing river gage* • Remote sensing water quality* • Groundwater monitoring • Coastal water resources • River Health monitoring Continue data monitoring and uploads	Remote sensing manuscript prepared and submitted. * projects should be submitted for publication by the end of 2021.	Fall semester 2021
Stakeholder workshops (Module 2)	Stakeholder Meeting	Stakeholders engaged, post-meeting report	January 2022
Training workshops (Module 2)	Data Analysis and Quality Control in R	Training delivered, report	March, August 2021
Scientific conference (Module 2)	UNC Water and Health Conference	Side event, post-conference report	October 2021
Limpopo Basin Report (Module 3)	Development of report contents with stakeholders, building on stakeholder meetings	First edition of the report	Fall semester 2021
		Project edition of the report	March 2022
Website developed (Module 4)	www.duq.edu/limpopo	Website guide and analytics provided in report	Ongoing
Quarterly Reports			Due 30 October 2021
			Due 30 January 2022
			Due 30 April 2022

Note: Academic terms refer to the United States conventional terminology; fall semester is September to December and spring semester is January to May.

DATA, KNOWLEDGE MANAGEMENT, AND COMMUNICATIONS

The data collected by the project will be uploaded to the USAID Development Data Library (DDL). The project PI, Dr. Kahler, has received a Partner Account with the DDL under the e-mail address, david.m.kahler@gmail.com. After the performance period, if use of the DDL is no longer available, the Limpopo Resilience Lab will be place data in public research repositories such as Mendeley Data.

The data and reports generated by this project will be submitted to USAID and be made available on the project website: www.duq.edu/limpopo. Additional results will be posted to this website as the long-term home of the Limpopo Resilience Lab.

In addition to the reports and data for USAID, the project is planning on the following manuscripts to be submitted to peer-reviewed journals:

- Manuscript-in-progress: *Novel algorithm for river discharge*, M. Martin (based on thesis, target journal: *Water Resources Research*)
- Manuscript-in-progress: *Hydrologic modeling based on remote sensing of water resources in the Sand River, South Africa*, S. Bakar (based on thesis)
- Manuscript-in-progress: *Water clarity with remote sensing*, M. Glines (based on dissertation chapter)
- Manuscript-in-progress: *Land use change, river turbidity, and groundwater change*, G. Sharp (target journal: *Ecology and Society*)
- Research (proposals and manuscripts to follow): Groundwater quality, microbial contamination of groundwater with PCR, N. Mutileni
- Research (proposals and manuscripts to follow): Impact of land use (e.g., mining) on water quality (e.g,. heavy metals) in the Olifants River, T. Hilton

APPROVAL

This Work Plan has been received and approved by USAID. This satisfies the requirements set forth in the Milestone Plan, item #23: Completion of Annual Work Plan.

Signature: _____

Name: _____

Agreement Officer's Representative

Date: _____

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