WATERQ2: UNDERSTANDING WATER QUALITY & QUANTITY IN THE LIMPOPO BASIN

FY2020-2021 Work Plan

01 October 2020, version 1

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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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Implementation Dates	March 2019 to March 2022

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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), Rensselaer Polytechnic Institute (RPI), and University of Venda (Univen), establish their work plan for the fiscal year 2020-2021 (this is in reference to the United States Government fiscal year that begins 01 Oct 2020).

WORK PLAN

This work plan is for the period 01 October 2020 – 30 September 2021. This work plan introduces the planed work during the fiscal year 2021.

PROJECT ADMINISTRATION

PERSONNEL

At Duquesne University, graduate research assistant (GRA) 1 plans to submit a thesis in partial completion of the degree of Master of Science. This work is based on research supported by this project. GRA 2 will continue studies and work on a research thesis that will support this project; the progress on this project is detailed under Module 1, Satellite River Gage. Duquesne has accepted one graduate student for the USAID-supported GRA 3 starting who has recently begun studies at the university. The planned research led by this student is detailed under Module 1, Groundwater Monitoring and Modeling.

University of Venda (Univen) will continue to support two graduate students on activities to support this project. The research conducted will focus on contaminants in the Levuvhu River as the result of differences in lands adjacent to the river. The project is detailed under Module 1.

Rensselaer Polytechnic Institute (RPI) has transitioned support from one postdoctoral research associate to a graduate research assistant. This student will continue the work started by the supported RPI associate in the use of remote sensing to detect changes in water quality. Additionally, the student will use remote sensing methods to examine changes in land cover, such as forest extent, in the basin.

COVID-19 PLANS

At the start of this fiscal year, the world continues to confront issues related to Covid-19 (also, SARS-Cov-2). This pandemic has presented unique challenges to this program as many of the researchers are located in the United States and have faced significant travel restrictions; it is unclear when it will be practical to plan to travel again. The United States Department of State lists Botswana and South Africa as a *Level 3: Reconsider Travel* with Mozambique as *Level 3* with areas of *Higher Security Risk*. These restrictions will make travel, especially with students highly unlikely for the near future.

South Africa is moving to *Level 1* Covid-19 restrictions on 01 October 2020, which will allow our collaborators in South Africa to travel within the country and perform some fieldwork. These restrictions will also permit visitors from outside of South Africa; however, proof of recent negative Covid-19 test or quarantine until the visitor obtains a negative test.

The University of Venda is opening consistent with national guidance. As of the start of October, Univen will permit fieldwork by faculty and students. Trips have already been planned to visit field sites at the Mutale River and Levuvhu River within Kruger National Park. These trips will allow researchers to visit established sites, collect samples, perform field tests, and evaluate sites for extended sensor placement.

At the close of the previous fiscal year, the project held our second Stakeholder Meeting completely virtually. This, along with several other meetings with multiple parties, demonstrated that meetings and other interactions can be done via the internet. This will be the primary modality for meetings and trainings for the first half of the fiscal year.

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

The hydrometeorological stations monitor the water resources and are used to calibrate models (Figure 1). The data are routinely uploaded to the Development Data Library.

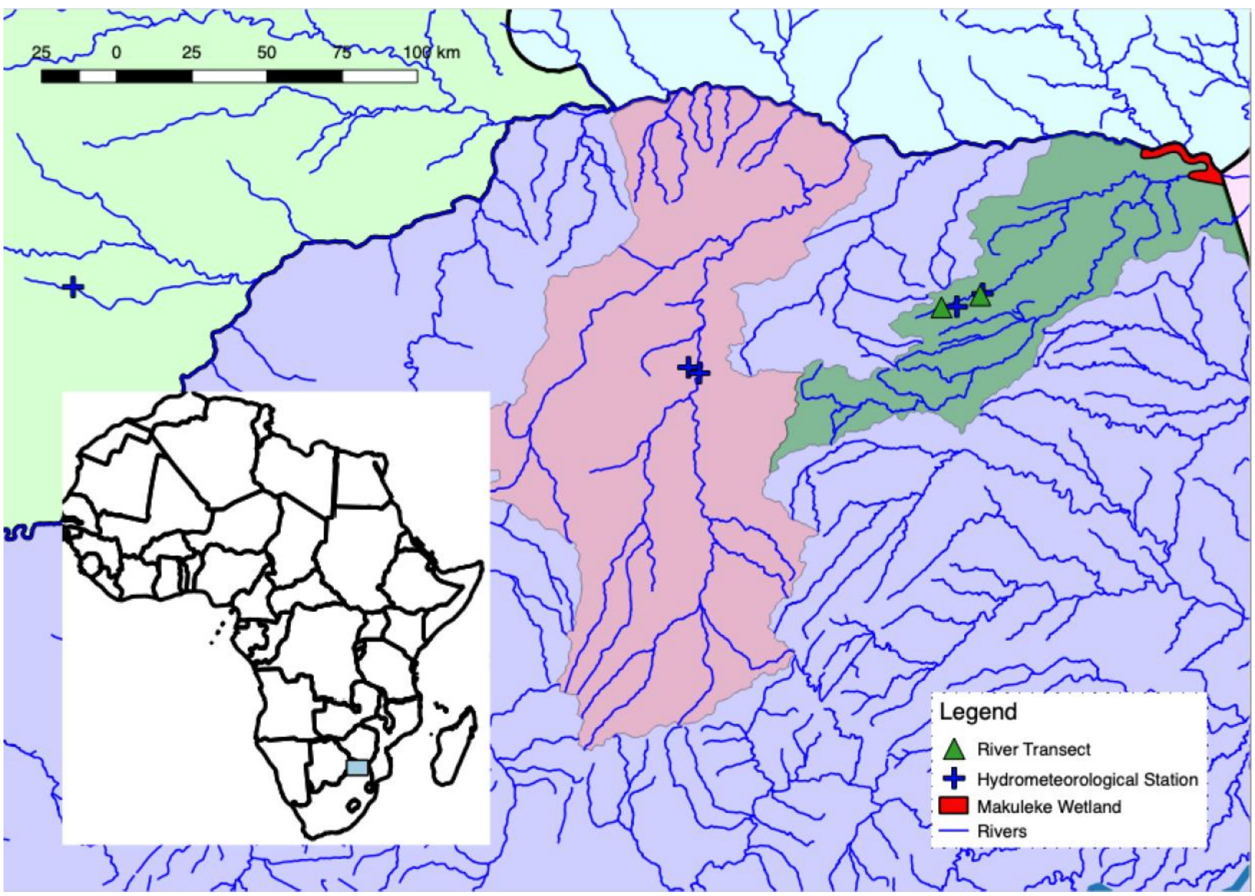

Figure 1: The Limpopo River Basin and Sand River catchment (pink) and Levuvhu/Mutale River catchment (dark green). The Basin spans Botswana (light green), Mozambique (light pink), South Africa (lavender), and Zimbabwe (light blue). Locations of installed stations and transect locations (and planned Botswana 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.

In addition to the hydrometeorological stations listed above (and Figure 1), routine surveillance of water quantity and quality will be made by the collaborators. Periodic measurements of river stage/discharge, and water temperature, conductivity, dissolved oxygen, turbidity, and chlorophyll will be made. The areas of primary interest for water quality are (Figure 2):

- Soutpansberg
  - Sand River near Medike Nature Reserve
  - Sand River near Waterpoort
  - Mutale River, Mutale weir (for quality control)
  - Levubu River near Louis Trichardt/Albasini Dam
  - Levubu River near Thohoyandou/Nandoni Dam
  - Levubu River near the Mutale River confluence
  - Levubu River near Makuleke wetland in Kruger National Park (a Ramsar-recognized wetland)

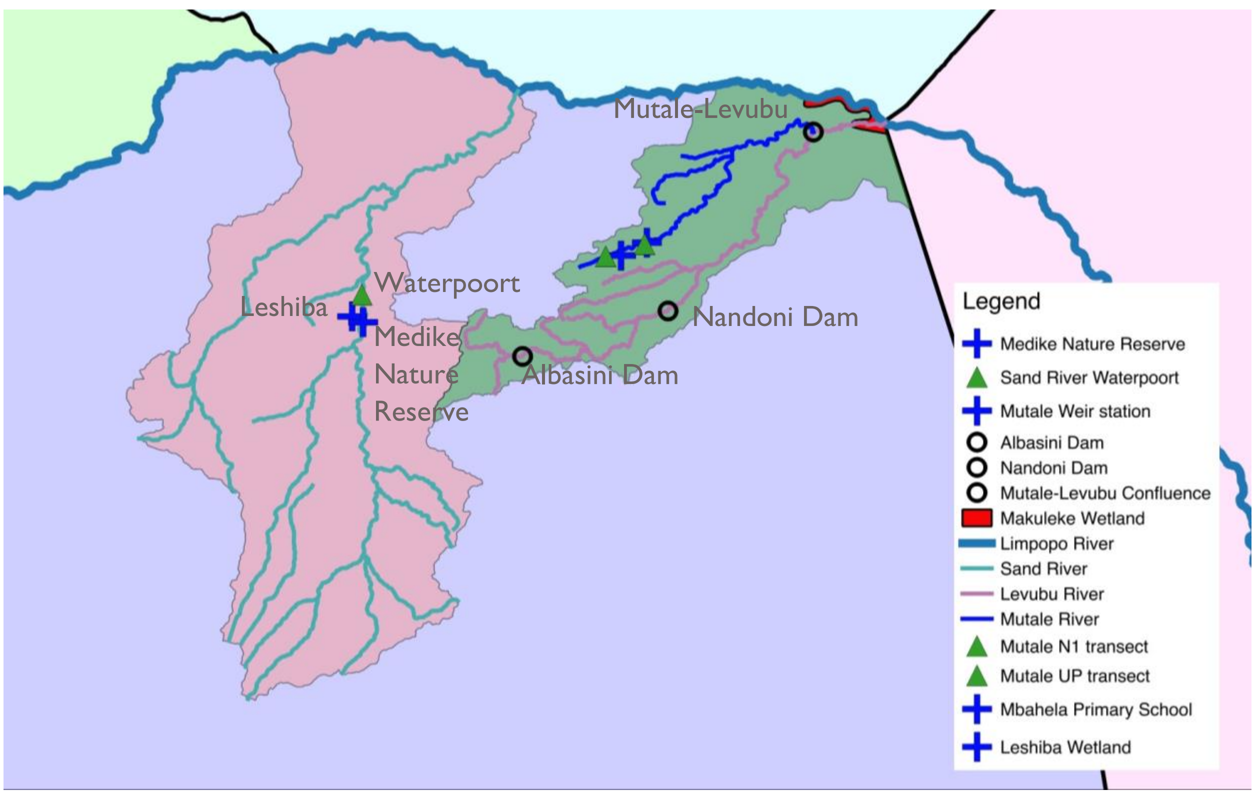

Figure 2: The Limpopo River Basin and Sand River catchment (pink) and Levuvhu/Mutale River catchment (dark green). The Basin spans Botswana (light green), Mozambique (light pink), South Africa (lavender), and Zimbabwe (light blue). Locations of proposed stations, transect locations, and proposed groundwater investigation locations. Location of key established stations are also shown.

This work was scheduled for the July/August fieldwork. Unfortunately, this will have to be postponed by a full year due to Covid-19 related travel restrictions.

SATELLITE RIVER GAGE ALGORITHMS

This year, GRA #2 at Duquesne University will complete the computer program that will detect the edge of the water in the normalized difference water index (NDWI) given knowledge of the pixels in the satellite image and measure the cross-river width with sub-pixel river estimates. The goal of this proposal is to develop a new method of monitoring river discharge in small rivers (≲30m in width). These data will hopefully be used by resource managers to benefit the community and transboundary management. Furthermore, there is currently broad preparatory research on future remote sensing missions specifically designed to monitor hydrological quantities (Durand et al., 2016). So far, methods have relied solely on data able to be measured with remote sensing techniques without the potential use of ground-based measurements. While a panacea, this goal is beyond what is currently feasible in smaller rivers and does not provide reliable historical river flow.

Satellites

Water flow data are lacking. In areas where data were rich, systems are being retired without replacements typically due to lack of funding; globally, water flow data are below where they are needed for adequate resource management, especially in Africa (IAHS Ad Hoc Committee, 2001). Development of monitoring practices that take advantage of remote sensing capabilities have become prevalent in the field of hydrology. Some relevant techniques include multiparameter functions using a range of satellite variables and riverbed slope (Bjerklie et al., 2003, 2005), but the satellite altimetry does not have sufficient resolution to apply to smaller rivers. A technique using satellite measured river width as a "gage" to follow the relationships used in traditional ground-based gaging to generate a width-based rating curve has also been developed, but this technique requires an initial calibration phase when river flow is known and spans all reasonable discharges, which would likely take at least one full transition from dry to wet season in tropical regions (Pavelsky, 2014). This method could be used on rivers that have historical data but are no longer actively monitored. These practices have been relatively successful for their monitoring purposes, but still a gap in the field exists for rivers that are considered small (<30m river width) and without a historical discharge record. Despite their size, these rivers are still necessary components of the community water resources. One method to attempt to broach this gap has been by taking many satellite river widths along a river reach of reasonable length so flow can be approximately constant, developing a width-based rating curve to satisfy the physical relationships of river width and flow, which does not include any ground based data. However, this method shows errors up to 1000% in arid regions and has only been tested in rivers larger than 30m in mean annual width (Durand et al., 2016; Gleason et al., 2014; Gleason & Smith, 2014). This method loses strength when considering accuracy or historical data for the purposes of climate monitoring and drought and flood prevention and control.

The algorithm that will be released under this work plan is a new technique to monitor discharge of small rivers remotely, which can also be applied retrospectively to recover historical discharge records. The method uses Manning's equation for open channel flow parameterized by ground measurement of cross-river depth profile and river slope coupled with width measurements from satellites; a direct discharge measurement is taken to calibrate Manning's n (friction coefficient), which should agree with tabulated values (Chow et al., 1988). Satellite images with 3m-resolution were used to calculate the Normalized Difference Water Index (NDWI), whose value was used to delineate the edge of water (McFeeters, 2007). This method may be used as an additional tool in river flow monitoring for water resource management.

Images were obtained by Planet Labs' PlanetScope satellites. These cubesats (Bouwmeester & Guo, 2010; Woellert et al., 2011) gather images approximately daily in blue (λ = 455-515 nm), green (λ = 500-590 nm), red (λ = 590-670 nm), and near-infrared (λ = 790-860 nm) bands, at a resolution of about 3 m, and which are available as orthorectified images.

To determine the width of the river from satellite images the normalized difference water index (NDWI) was calculated from the green (G) and near-infrared (NIR) bands (1) of the image (McFeeters, 2007) after the top of atmosphere radiance has been corrected.

$$NDWI = \frac{G - NIR}{G + NIR} \tag{1}$$

Hydrologic Relationships

The relationship developed by Manning for discharge, Q, of an open-channel as a function of the friction slope, S, the hydraulic radius, R, the cross-sectional area, A, and the friction factor, Manning's n (2), which is valid for turbulent flow (Katul et al., 2002) such that (3) is satisfied, both which are dimensional equations in SI units (Chow et al., 1988). An equation for hydraulic geometry (4) is also provided, where w is the width, Q is the discharge in cubic feet per second, and a, b are numerical constants (Turnipseed & Sauer, 2010). The hydraulic geometry equation relates quantitative characteristics of steam channels to discharge in a cross-section of a river, which may also yield useful relationships.

$$Q = \frac{AR^{2/3}S^{1/2}}{n} \tag{2}$$

$$1.1 \times 10^{-13} \leq n^6\sqrt{R\,S} \tag{3}$$

$$w = aQ^b \tag{4}$$

At a given time and section of river, *A*, *R*, *S*, *n*, and *Q* can be measured. While *S* and *n* will remain mostly constant under a range of flows, *A* and *R* are functions of the size of the river, which is to say, there is a function that relates width to *A* and *R*.

A cross river depth profile was measured along a transect free of overhead trees and branches that can interfere with the satellite-based width measurements with an automatic level (Nikon® AC-2S Automatic Level, Forestry Suppliers, Inc., Jackson, MS, USA). Transect locations were also selected for accessibility on foot by researchers for ground-truth measurements. Calibration discharge was measured at the time of bathymetry measurements as a reference point for this data method. Water velocity measurements were taken at regular distances along the transect by an acoustic Doppler velocimeter current meter (FlowTracker 2, Sontek, San Diego, CA, USA). Velocity was measured at 60% of the water depth if the depth was less than 0.02 m or at 20% and 80% of the water depth if the depth was greater than or equal to 0.02m and integrated with cross-sectional area by the mean-section method (method ISO 748). The friction slope, *S*, was approximated as the slope of the top of the water surface in the area of the transect. To determine the slope of the water surface, an automatic level was setup on a tripod and leveled. A level rod was placed in the water in the middle of the transect and the vertical distance from the datum (from the level) to the water surface was recorded. Such measurements were taken at middle of the transect itself and at least 20m upstream and downstream from the transect, measured along the center with a fiberglass measuring tape. The average slope of the water was estimated by the change in height divided by the distance along the bank. Since water surface slope can change along the river course, the upstream and downstream distances were kept as short as reasonable while still maintaining accuracy in the measurement; in cases where waterfalls or roughness would drastically affect the slope, note of those occurrences was taken and the distance from the transect was adjusted to just above or below those interruptions for down- and up-stream slope points. The precise coordinates of the center of the transect (Garmin eTrex 10 GSP plus GLONASS, Olathe, KS, USA, and FlowTracker2 built-in GPS) were imported into each image file in the geographical information system used.

GROUNDWATER MONITORING

GRA #3 at Duquesne University will examine groundwater resources in the Limpopo Basin with two geophysical techniques: electrical resistivity tomography (ERT), and data from the Gravity Recovery and Climate Experiment (GRACE), with data from 2002 to 2017, and GRACE follow-on (GRACE-FO), with data from 2018 to present. These two techniques will allow researchers to assess changes in the groundwater levels in key areas within the basin. The Southern African Development Community Groundwater Management Institute (SADC-GMI) has collected massive amounts of data from groundwater wells throughout the region. The primary limitation of these data is that they are static. ERT and the GRACE mission data will allow observations over time.

Groundwater surveys with ERT will commence in October 2020 and continue every three months. The areas of greatest significance are the high-elevation catchments identified measurements have been previously identified. In particular:

- Wetlands within the Sand River catchment near Medike Nature Reserve
- Makuleke wetland along the Levubu River near in Kruger National Park (a Ramsar-recognized wetland)
- Mutale River near Tshilamba and upstream through Dzimauli and Lake Fundudzi
- Tswapong Hills, when available

Rationale

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; meteorological stations located in close proximity demonstrate substantial spatial variation within sub-basins (Petrie et al., 2014). 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 (Edokpayi et al., 2018). Investigation will help us understand the greater water resources in the transboundary Limpopo River Basin and the role of water resources management for ecosystem services including biodiversity conservation, domestic, agricultural, and industrial uses.

This research focuses on the use of specialized measurement techniques for groundwater and traditional surface water monitoring; these data will be used in hydrologic models to enhance our overall understanding of the hydrology in the area and improve basin-wide water management. The investigation in the Makuleke wetlands and surrounding areas provide a protected natural setting where groundwater and surface water interact in unique ways (Figure 3). The 22,000 ha Makuleke area (Fabricius & Collins, 2007) is known for the community that inhabits it and the waterbodies that comprise the Makwadzi Pan, which has shown variations in paleoclimate (Ekblom et al., 2012).

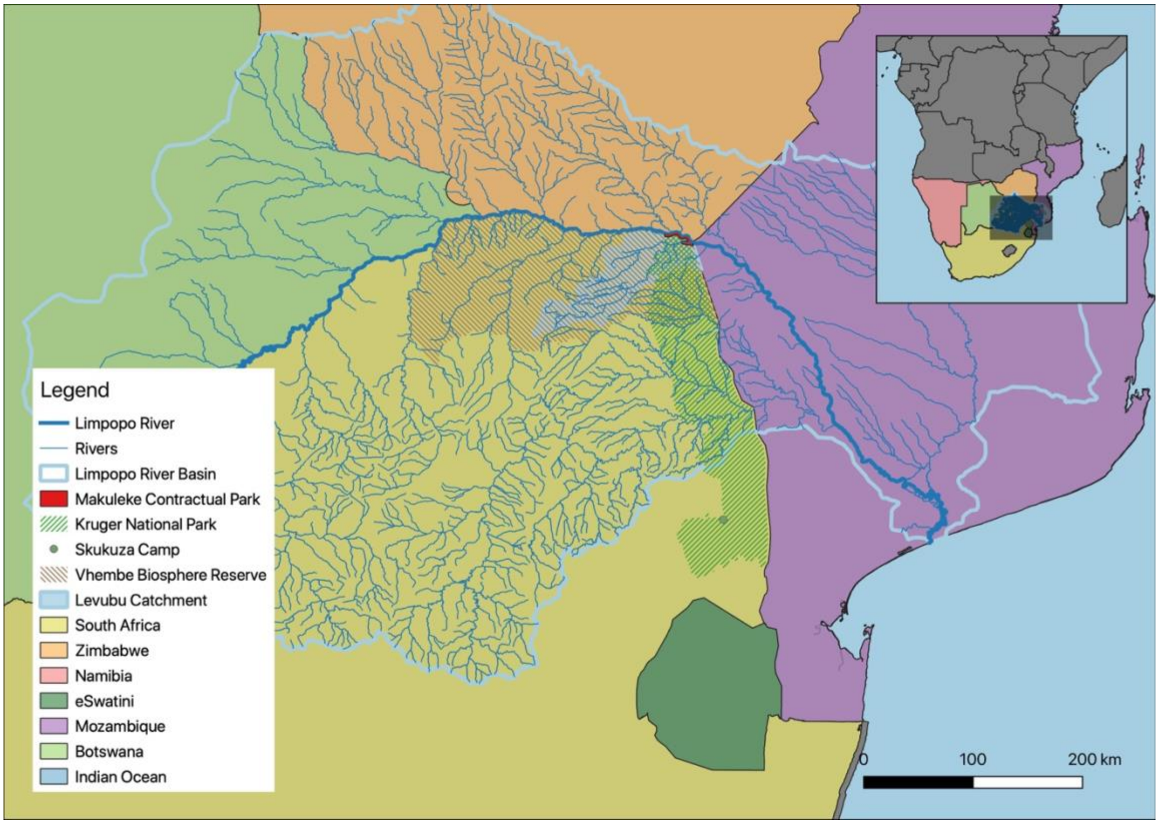

Figure 3: Location of the Makuleke Contractual Park within Kruger National Park in South Africa.

Methods

We plan to use electrical resistivity tomography (ERT) to resolve the shape of the water table over time (Hubbard et al., 1999) and estimate the parameters for groundwater flow (Vanderborght et al., 2005). We will use induced polarization (IP) to further estimate the aquifer parameters (Slater, 2007), specifically porosity and permeability. Measurements will be taken along multiple transects throughout the area both parallel and perpendicular to the land surface gradient as a surrogate for the aquifer (Figure 4). Measurements will also be made near perennial and annual surface water bodies.

We plan to configure the instrument to sample electrical resistivity based on a Wenner array and a Schlumberger array; based on our experience, we expect that our linear 48 electrode, 240 m array will sense approximately 80 m in depth. Water has a significantly higher conductivity than the air-water mixture present in the vadose (unsaturated) zone; this allows the instrument to sense an abrupt decrease in resistivity at the piezometric surface (water table). The depth of the water table will indicate the amount of aquifer water storage and the gradient of the water table, with other parameters, will indicate the transport of water through the aquifer. These measurements over time will allow us to monitor the groundwater component of the local water balance.

In the saturated aquifer, solid particles, which have an intrinsic charge, have bound layer (called the Stern layer) and a diffuse layer of ions in the water that surround the solid particle called an electrical double layer (EDL). This layer is subject to polarization during the imposed signal from the instrument (Figure 5), which is called induced polarization (IP). When the emitted signal is turned off, the receiver continues to monitor for changes and detects the relaxation of the EDL. The signal, measured as resistivity, is related to the permeability of the soil (Dahlin et al., 2002) in that thin EDL due to smaller individual water channels are more similar to clay (Leroy & Revil, 2009) compared to larger individual water channels, which are more similar to sandy deposits (Revil, 2012).

Darcy's Law (Freeze & Cherry, 1979) relates the specific discharge of an aquifer to the hydraulic conductivity and the pressure gradient, typically taken as the slope of the piezometric surface.

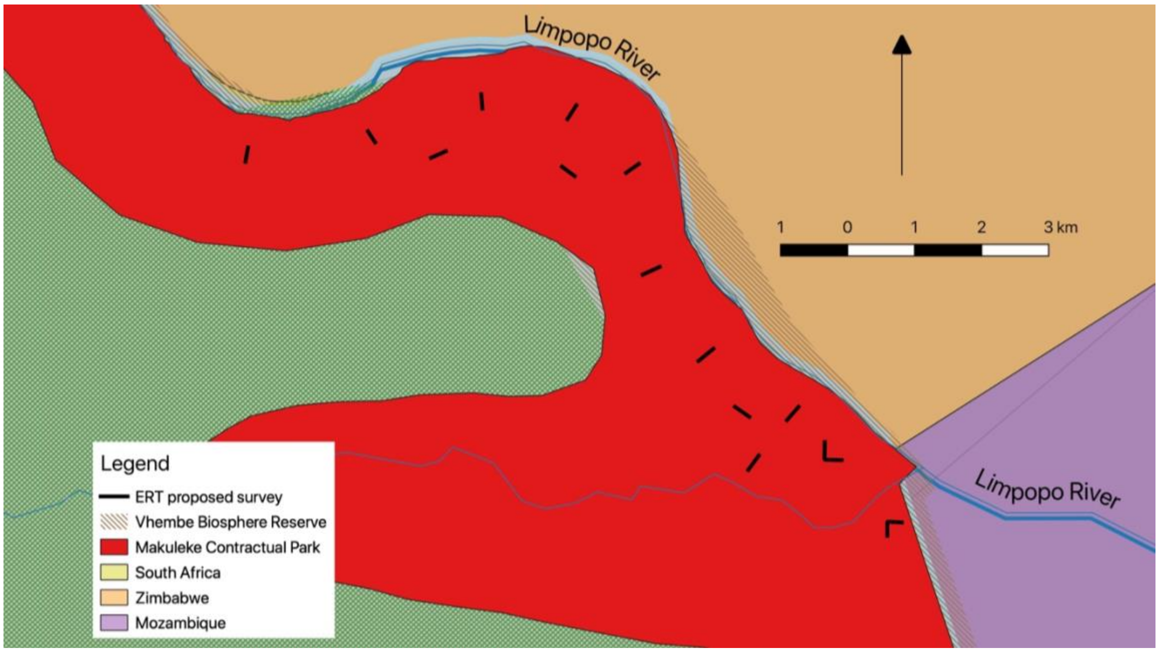

Figure 4: Proposed ERT survey locations surrounding the Luvuvhu-Limpopo confluence. These survey transects were selected by examination of satellite images and may be adjusted based on the hydraulic measurements and consultation with Park scientific staff and other stakeholders to minimize disturbances to environmentally or culturally sensitive areas.

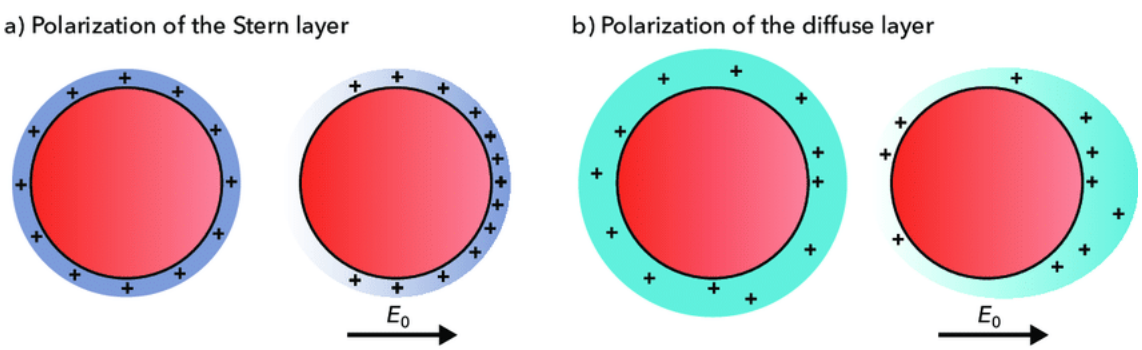

Figure 5: EDL from charged dielectric material, from (Pesch, 2019). Both the fixed (a) and diffuse (b) layers are diagramed. IP measures the response from the polarized (right of each layer) to return to a normal distributed layer.

We will use ERT data collected from this project to construct hydrologic models of groundwater-surface water interactions in MODFLOW (U.S. Geological Survey) (Brunner et al., 2010; Guevara Ochoa et al., 2020). Additionally, for basin-scale monitoring, we will use the U.S. Army Corps of Engineers, Hydrologic Engineering Center software suite: Hydrologic Modeling System (HEC-HMS) and River Analysis System (HEC-RAS). Specifically, HEC-HMS will be used to estimate the general baseflow contributions based on the flow and precipitation data available in the area. These models will be used to determine the groundwater flow into the Limpopo River. We will also consider observations made by satellite gravity anomaly from GRACE data (Richey et al., 2015).

Objectives

Our objective in this project is to collect water table height and gradient, and induced polarity data that can be used in hydrologic models. These data and models will be used to measure the groundwater resources, volume and flow, and help elucidate the groundwater-surface water interactions in the Makuleke area. Multiple samples taken across seasons through multiple years will help to determine the role of the groundwater flow in the Levuvhu catchment.

This supports the goals of our overall program through the estimation of the groundwater flow into the Limpopo River and elucidate the groundwater-surface water interactions in the Makuleke wetlands and surrounding water bodies. We hope that this will support the conservation work by Kruger with increased groundwater monitoring.

Groundwater in southern Africa is an important resource especially in the context of climate change. Groundwater in the Limpopo Basin holds great potential for increased water access; however, groundwater measurement data are currently insufficient to calculate sustainable total withdrawal rates (Petrie et al., 2014).

Our objective is that resource managers will have an improved basis for scientifically based decisions and may be able to utilize groundwater resources more effectively to increase (e.g., agricultural) productivity and conserve biodiversity with improved data collection, validation, and sharing of these data.

WATER QUALITY AND LAND USE CHANGE

Rationale

Investigation in rivers as they cross different ecosystems and levels of urbanization or industrialization will help us understand the greater water resources in the transboundary Limpopo River Basin and the role of water resources management in biodiversity conservation. Assessing the Luvuvhu River, as it flows from the settled regions across Limpopo Provence into Kruger National Park, will help us to determine contamination load into the great Limpopo River and the dynamics of heavy metal contaminants from agricultural and thickly settled regions as the river passes through a protected environment.

Our research focuses on the use of conventional and novel measurement techniques for surface water monitoring. The goal of these data tools is to enhance water management. We would like to scale up our instrumentation and modeling efforts in Kruger National Park to better understand the water resources in the Park.

Methods

The research will involve the collection of water and sediment samples at different sites in the Luvuvhu River Catchment for water and sediment quality assessment for a period of two years (2020-2022). The basis of the research will be water quality assessment mainly focusing on heavy metals (Cu, Pb, Zn, Hg, Cd, Cr, Ni, Al, Fe, Ag, As, and Mn) and physicochemical parameters in water and sediments. We will also investigate the influence of different land use activities on water quality. Furthermore, various indices such as potential ecological risk index (RI) (Hakanson, 1980), pollution load index (PLI)

(Tomlinson et al., 1980), enrichment factor (EF) (Rubio et al., 2000), index of geo-accumulation (Rubio et al., 2000), and hazard quotient (Yi et al., 2011) will be applied to determine potential ecological and human health risks of heavy metals contamination due to land use activities (wastewater treatment plants, tree plantations, sand mining, settlements, transport and agricultural activities i.e. crop and fruits farming). Total load will be estimated with river discharge measurements.

Certain physicochemical properties will be measured in situ (pH, conductivity, temperature, dissolved oxygen, YSI Professional Plus multimeter, YSI, Yellow Springs, OH, USA); In situ sensors will also be deployed in some points for physicochemical measurements. This will aid in understanding water quality patterns and their variation throughout different seasons. Water samples will be collected and preserved for water quality analysis (Edokpayi et al., 2018). Samples will be analysed for metals with induced coupled plasma mass spectrometry (ICP-MS) (USAPA Method 200.8) and for anions and cations with ion chromatography (IC) (USEPA Method 300.1). Samples will be obtained along the reach of the river. Each sample will be surveyed throughout the project period to assess trends.

We will use a range of statistical methods, which may include principal component analysis (PCA), spatial correlation analysis, and transport models to determine possible sources for metals. Data in this study will be statistically analysed by using the statistical package IBM SPSS statistics 25. The results of this study will be tallied against the DWAF guidelines for the protection of the aquatic ecosystem and SANS standard guidelines for safe drinking water as a reference for metals.

Objectives

- To determine physiochemical parameters (pH, Temperature, Total dissolved solids, Turbidity, Salinity, Electrical Conductivity, Biological Oxygen Demand, Chemical Oxygen Demand, Dissolved oxygen), heavy metals, and major ions (anions and cations) in Luvuvhu river water and sediments.
- To evaluate the potential ecological and human health risks of heavy metals in river water and sediments.
- To determine the river discharge.
- To develop land use map of the Luvuvhu River catchment.

Outcomes and/or Management Implications

In our research, we will focus on temporal river quantity and quality data. In Kruger, we will expand our data collection on water quality and quantity. Our focus will be in unique hydrologic regions, specifically, the Luvuvhu River and the Makuleke Wetlands. Our current work includes the hydrodynamics and water quality of the Luvuvhu/Mutale system. The Luvuvhu River joins the Limpopo River in Kruger with the Makuleke Wetlands at their confluence. The results may help identify human health hazards and potential contaminant sources in the Luvuvhu catchment.

STAKEHOLDER WORKSHOP AND TRAINING (MODULE 2)

STAKEHOLDER ENGAGEMENT MEETINGS

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. Additional meetings last work plan period were also successful; however, the staff was not able to confirm meetings in Maputo in January 2020 as planned. Consequently, the WaterQ2 staff will continue to hold meetings with stakeholders who were not able to attend the Stakeholder Meeting. These parties include, but are not limited to:

- Limpopo Watercourse Commission (LIMCOM)
- Mozambique Department of Water and Sanitation
- Mozambique Ministry of the Sea, Interior Water, and Fisheries
- Limpopo Transfrontier Conservation Area
- Other Limpopo-focused projects

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. One lesson learned from this past Stakeholder Meeting is that it is even easier in the virtual environment for participants to remain quiet. To avoid this in future virtual meetings, we plan to use both open, large-attendee format meetings with targeted semi-structured interview meetings scheduled with participant groups.

TECHNICAL TRAINING

Due to Covid-19 restrictions, in-person training is not possible. As such, the WaterQ2 staff is planning to develop and hold computer-based training on data management using R (Wickham & Grolemund, 2017). This training will be held with synchronous and asynchronous lessons to allow students to work at their own pace while still having virtual real-time engagement with instructors. Asynchronous teaching will also allow students with unstable internet connections to keep up with the training. Specifically, the R training will include (planned):

- Introduction to R programming
- Data acquisition and manipulation
- Data quality control
- Data visualization
- Basic statistics
- Geographical information manipulations in R
- Hints and tips for teaching R in classes (target audience: university instructors)

The collaborators will track all participants of training activities in USAID's Training Results and Information Network, TraiNet. The participants will be host-country (that is, a Limpopo Basin country) nationals. Training that occurs outside of the Milestone Plan will be reported on in the appropriate Quarterly Report.

For Dr. Edokpayi's and Univen GRAs' professional development, Univen's budget includes travel to international professional conferences. These exchange visitors, as defined in RAA9 of the award agreement, will also be tracked in Trainet. Furthermore, the exchange visitors will comply with the terms of the J-1 exchange visitor.

CONFERENCES

The Water Institute of Southern Africa 2020 Conference in Johannesburg was postponed until December 2020. This remains the ideal meeting to hold a side event with a keynote speaker and networking opportunities for scientists from the Limpopo River Basin (https://wisa2020.org.za/). WaterQ2 has requested Thursday 10 December for the side event and will confirm keynote speakers shortly. Coincident with this event, the project will present an introduction to the first edition of the basin report based on the work done thus far on water resources in the basin.

LIMPOPO RESILIENCE LAB (MODULE 4)

There has been increasing excitement of the role that the Limpopo Resilience Lab will play at Univen. Dr. Edokpayi has begun the process of seeking additional space and agreements for computing resources. This year, as the Lab becomes a reality, the project will finalize the goals for additional instrumentation needed for the lab. Univen plans to apply for additional funding to build up additional resources. Post-project cost recovery will be an issue of capacity building for Univen. The project will work with Univen's finance personnel during this year to ensure that a sustainable cost model will be in place after this project has ended.

TIMELINE

TABLE 3: WORK PLAN

OBJECTIVES	ACTIVITIES	RESULTS	TIMELINE
Water monitoring and algorithm development (Module 1)	Sensors placed in key catchments; algorithm development underway	Maintain data loggers	Ongoing
		Algorithm parameterization and data analysis	Fall semester 2020
		Remote sensing manuscript prepared and submitted.	April 2021
Groundwater investigations (Module 1)	ERT surveys	Site map, data acquired	Starting in January 2020
		Hydrologic models parameterized, groundwater models training developed (see Module 2)	Academic year 2020-21
		Measurements of Leshiba and Makuleke wetlands	Starting in November 2020 and ongoing.
Stakeholder workshops (Module 2)	Maputo Stakeholder Meeting	Stakeholders engaged, post-meeting report	Online, Spring 2021
	Gaborone Stakeholder Meeting		July/August 2021
Training workshops (Module 2)	Data Analysis and Quality Control in R	Training delivered, report	March 2021

Scientific conference (Module 2)	WISA 2020 Conference	Side event, post-conference report	December 2020
Limpopo Basin Report (Module 3)	Development of report contents with stakeholders, building on stakeholder meetings	Format of report	Fall semester 2020
	Buy-in from LIMCOM, exploration of how this project can assist LIMCOM in their work	Specific tools introduced in the report (e.g., comprehensive repository of data and reports from the Limpopo Basin	Spring 2021
	Draft report developed and presented at the WISA Conference	First edition of the report	December 2020
Website developed (Module 4)	www.duq.edu/limpopo	Website guide and analytics provided in report	Ongoing
Quarterly Reports			Due 30 October 2020
			Due 30 January 2021
			Due 30 April 2021
			Due 30 July 2021
Annual Work Plan			Due 31 August 2021

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.

Some meteorological stations will automatically upload data to a cloud computing resource. This project plans to use Meter stations that use a proprietary service called Zentra Cloud (https://www.metergroup.com/environment/zentra-cloud/). These data will be downloaded by the collaborators and uploaded to the DDL.

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.

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: *Riverine turbidity with remote sensing*, M. Mlotha

- 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 #16: Completion of Annual Work Plan.

Signature: ____

Name: ____

Agreement Officer's Representative

Date: ____

WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin