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# WATERQ2: UNDERSTANDING WATER QUALITY & QUANTITY IN THE LIMPOPO BASIN

## Hydrometeorological Station Network

12 December 2019, version 2

Milestone 4

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## WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin

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Cover photo: Mutale Weir Hydrometeorological Station, credit: Mackenzie L. Martin.

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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  |

|  |  |
|--|--|
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| Agreement Officer's Technical Representative | Alternate Agreement Officer's Technical Representative |
| USAID/Southern Africa                        | USAID/Southern Africa                                  |

## INTRODUCTION

The transboundary Limpopo River Basin crosses Botswana, Mozambique, South Africa, and Zimbabwe. At over 400,000 km<sup>2</sup>, 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 (LBPTC, 2010). In addition to the human residents, the Basin contains some of the most biodiverse natural areas on the planet (Kahinda et al., 2016).

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 (LBPTC, 2010). Even meteorological stations located in close proximity demonstrate substantial spatial variation within sub-basins. The Basin has experienced severe droughts in the last decade (LBPTC, 2010). 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). 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. IWRM 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. For example, surface water quality will affect ecosystem biodiversity and those who depend on those ecosystems for drinking water or fish as a food protein source. Another example is groundwater; Petrie et al. (2014) found that 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. With improved data collection, validation, and sharing of these data, managers will have a basis for scientifically-based decisions and may be able to utilize groundwater

resources more effectively to increase (e.g., agricultural) productivity. These same resource managers need monitoring and surveillance tools to measure water consumption by users within the basin, how demand and use changes through time, and to understand if historic and current sparse monitoring is accurate. Since rural users withdraw water in informal schemes, measurements of water use currently do not exist.

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**. All sensors and data will be shared. Increased monitoring and data sharing will provide the platform for individual biodiversity and water resources projects to conduct impact evaluations, as requested in the USAID Biodiversity and Development Handbook. The project will include key practitioners from government, academia, industry, and agriculture to be **environmental champions**. These persons will be invaluable resources to the project, local collaborators, and other stakeholders as they support a sustainable technical resource for the Basin's decision-makers.

To improve Basin data quality and sharing and produce tools that can be used in the Limpopo Basin and elsewhere, the collaborators will develop open-source methods and make measurements to characterize water resources through verifiable satellites and *in situ* sources, including autonomous sensors. For surface water quantity, the collaborators will develop methods to monitor river flow based on width and river channel geometry from satellites based on the work presented recently at the American Geophysical Union Fall Meeting (Martin et al., 2018). For groundwater, the collaborators will implement methods based on Gravity Recovery and Climate Experiment (GRACE) satellite data (Richey et al., 2015) for Basin-scale monitoring and use open-source models such as U.S. Army Corps of Engineers, Hydrologic Engineering Center, Hydrologic Modeling System (HEC-HMS) and River Analysis System (HEC-RAS) and the U.S. Geological Survey groundwater model, MODFLOW for sub-basin monitoring. Groundwater quantity and flow will be estimated based on electrical resistivity tomography (ERT) (Hubbard et al., 1999 and Vanderborght et al., 2005). We will characterize water quality using measurements of turbidity, clarity, algae, and organic matter loads. These characteristics are the most common causes of water quality impairment, biodiversity losses, and human disease risks. These characteristics can be remotely sensed based on region-specific validated algorithms.

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 (Dyson et al., 2008 and Richter, 2009). Environmental flow analysis is a method to address minimum quantities and natural fluctuations in flow that is critical to health river populations and to maintain the ecosystem services of riparian zones. The implementation guidance for the previous USAID Water and Development Strategy specifically identified IWRM and Agricultural Water Resources Assessments in water project planning. Water resources monitoring, especially in biodiversity hotspots, will support the mission's IR 1.4, *Improved management of transboundary natural resources* with additional benefits to IR 1.1, *Improved agricultural productivity*. Based

on needs of the water professionals, technical training on subjects such as Geographical Information Systems (GIS) and hydrologic models (e.g., HEC-HMS, HEC-RAS, and MODFLOW) may be included.

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 network of environmental sensors installed is described. Furthermore, the project presents the strategy to use these data, combine these with other data and ensure their quality, and use these data for water resources tools.

## PURPOSE

The purpose of the WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin project is to improve the management of water resources in the complex, transboundary Limpopo River Basin. This will be accomplished by the collaborators through the following activities:

- Collect and share hydrologic data,
- Train students, resource managers, and decision-makers,
- Facilitate networking and communication among institutions based on shared data, and
- Establish dedicated technical resources in the Limpopo Resilience Lab.

The primary activities described here are data collection and dissemination. The data collected will help scientists calibrate remote-sensing methods, provide third-party verification for government sensors, and provide more data for areas that do not currently have any hydrological or meteorological monitoring.

In order to communicate with stakeholders, assist in data dissemination, and serve as a central referral location for reports and findings, the collaborators have set up a project website (Site map Appendix A). This website integrates materials from across several platforms such as: reports on USAID's Development Experience Clearinghouse, data on USAID's Development Data Library, and related work curated on Duquesne University's institutional repository, the Duquesne Scholarly Collection.

[duq.edu/limpopo](http://duq.edu/limpopo)



## MONITORING LOCATIONS

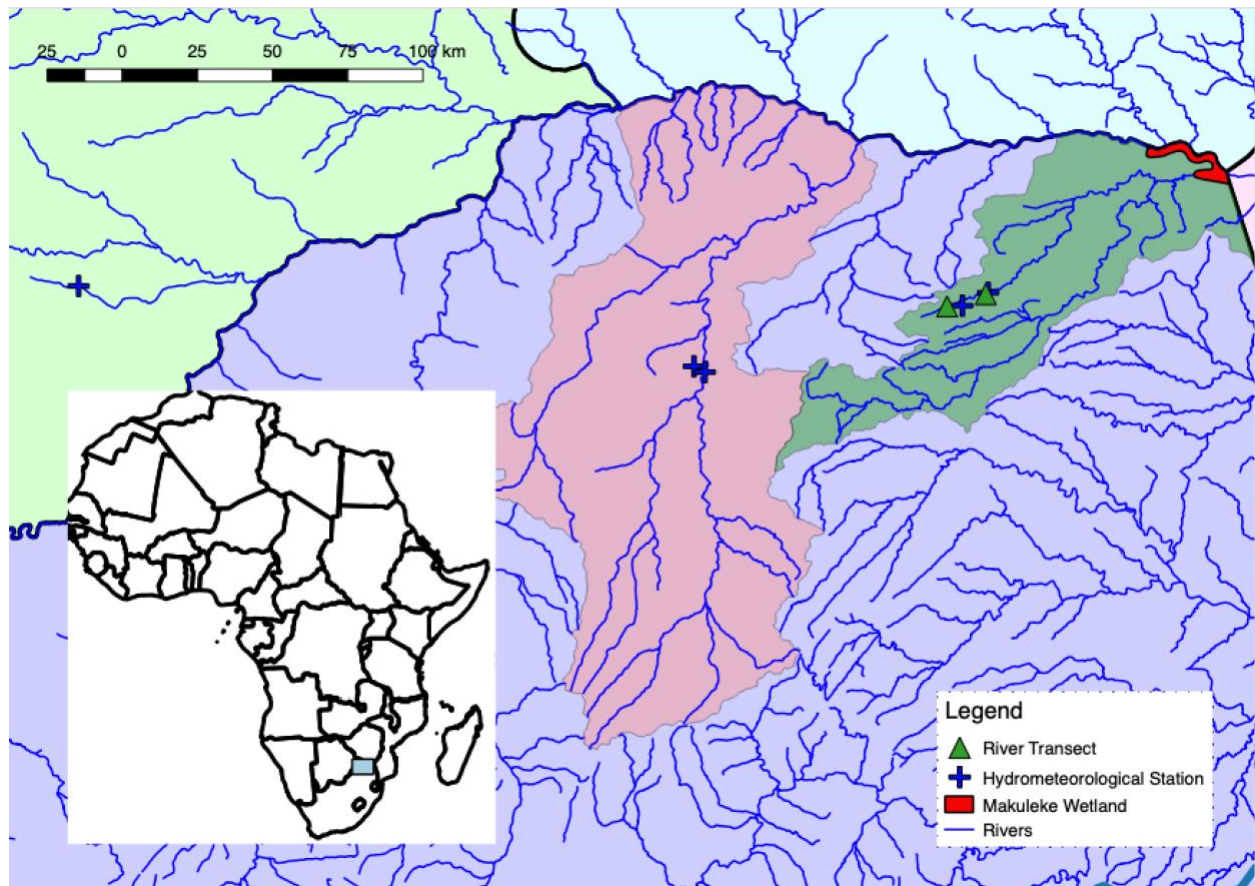


Figure 1: The Limpopo River Basin and Sand River catchment (pink) and Levuvhu/Mutale River catchment (dark green). The Basin spans Botswana (light green), Mozambique (light pink), South Africa (lavender), and Zimbabwe (light blue). Locations of installed and proposed stations, transect locations, and proposed groundwater investigation locations. The Leshiba Wetlands are located near the station in the Sand River.

The WaterQ2 project proposed to collect data through the development of these stations to collect meteorological and surface hydrology (blue crosses, Figure 1). Project scientists are also developing methods to measure river discharge with remote sensing; river transects along the Mutale River (green triangles, Figure 1) were used in this development. To examine the groundwater resources, sites within the high-elevation Soutpansburg Mountains, specifically in the Sand River catchment near the hydrometeorological stations, the Mutale catchment near existing stations, and near the Makuleke wetland in Kruger National Park (red, Figure 1).

## STATIONS

Stations have been or will be set up in the catchments of interest as described in the Mobilization Plan. These catchments include:

- Mutale River (near Tshilamba, the weir, and upstream)
- Sand River (near Medike Nature Reserve and tributaries)
- Tswapong Hills
- Olifants River (near Kruger National Park border)

Various stations (Figure 2, Table 1, Table 2) were installed to collect data to assist with quality control, remote sensing calibration, and provide greater resolution on hydrometeorological variables.

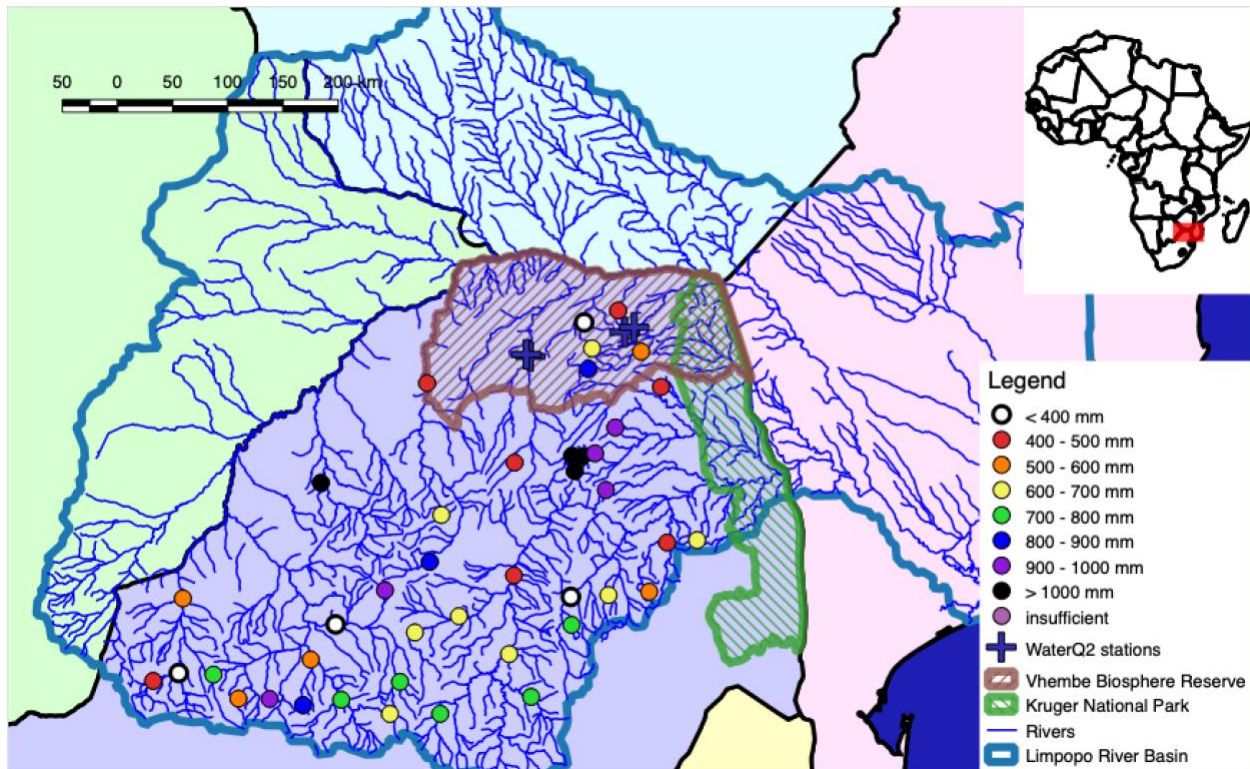


Figure 2: Locations of the four WaterQ2-installed stations. The Tswapong Hills station has not yet been installed; however, this location is described in the USAID-funded *Risk, Vulnerability, and Resilience in the Limpopo River Basin* report. The existing precipitation gages operated by the Department of Water and Sanitation of South Africa are also shown (circles). Those stations that report at least five years of data within the past ten years have the annual rainfall color coded. Data sources: GIS from the Department of Water and Sanitation, South Africa, Kruger National Park, UNESCO; Precipitation data from the Department of Water and Sanitation, South Africa.

**TABLE 1: HYDROMETEOROLOGICAL STATIONS**

| SITE                                     | PARAMETERS   | INSTALLATION                                      |
|--|--|---|
| Mutale Weir                              | Precipitation<br>Solar radiation<br>Air temperature<br>Relative humidity<br>Wind speed and direction<br>River stage<br>Water temperature and conductivity<br>Water turbidity | March 2019<br>(some parameters added August 2019) |
| Mbahela Primary School<br>(Mutale River) | Precipitation<br>Air temperature<br>Relative humidity  | December 2017<br>(repaired August 2019)           |

|  |  |                        |
|--|--|------------------------|
| Medike Nature Reserve<br>(Sand River)                | Precipitation<br>Solar radiation<br>Air temperature<br>Relative humidity<br>Wind speed and direction   | August 2019            |
| Leshiba Wetland<br>(Unnamed Sand River<br>tributary) | Precipitation<br>Air temperature<br>Relative humidity<br>Wetland stage   | August 2019            |
| Kruger National Park<br>(Olifants River)             | Precipitation<br>Air temperature<br>Relative humidity<br>River stage<br>Water temperature and conductivity<br>Water turbidity<br>Water chlorophyll | January 2020 (planned) |
| Tswapong Hills                                       | Precipitation<br>Solar radiation<br>Air temperature<br>Relative humidity<br>Wind speed and direction<br>River stage                                | July 2020 (planned)    |

**TABLE 2: DATA LOCATIONS**

| SITE                   | DATUM   |
|------------------------|---|
| Mutale Weir            | Height of meteorological sensors: 3 m above weir platform; water depth is height above the rectangular notched crest in the weir. |
| Mbahela Primary School | Height of tipping bucket: 2.3 m, height of temperature sensor 1.5 m.  |
| Medike Nature Reserve  | Height of sensors: 2.3 m.   |

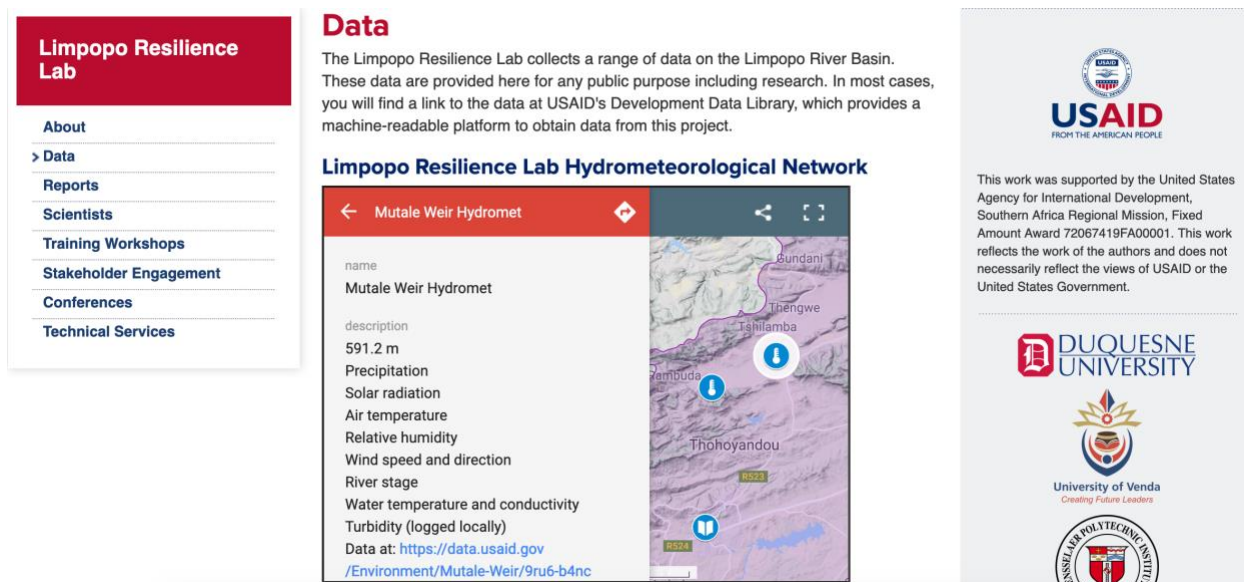


Figure 3: Screen image of the project and Limpopo Resilience Lab website, hosted at [www.duq.edu/limpopo](http://www.duq.edu/limpopo). The Data page contains a dynamic map (hosted by Google MyMaps) that contains the locations of the stations, the parameters measured, and a link to the data on USAID's Development Data Library.

A dynamic map (preview: Figure 3) with links to the data is available on the project website, [duq.edu/limpopo](http://duq.edu/limpopo) under "Data" (<https://www.duq.edu/academics/schools/natural-and-environmental-sciences/academic-programs/environmental-science-and-management/limpopo-resilience-lab/data>). Current website analytics are obtained with Google Analytics (Appendix B).

Data are available through the Development Data Library, ([data.usaid.gov](http://data.usaid.gov)); however, users may find the map interface on the WaterQ2 project website to be more convenient to locate the data. The following stations have data available:

- Mutale Weir: <https://data.usaid.gov/Environment/Mutale-Weir/9ru6-b4nc>
- Medike Nature Reserve: <https://data.usaid.gov/Environment/Medike-Nature-Preserve/chfb-yzu5>





Figure 4: photographs of the current stations: Mutale Weir (upper left), Mbahela School (upper right), Leshiba Wetland (lower left), and Medike Nature Reserve (lower right).

## HYDROMETEOROLOGICAL STATION DATA

The stations are installed within catchments of interest. Instruments record a range of measurements (Table 3); although, not all variables are recorded at all of the stations. The data are available at USAID's Development Data Library, [data.usaid.gov](https://data.usaid.gov).

**TABLE 3: STATION DATA VARIABLES**

| CODE | DESCRIPTION          | UNIT                |
|------|----------------------|---------------------|
| PRCP | Precipitation        | mm                  |
| SRAD | Solar radiation      | W/m <sup>2</sup>    |
| TEMP | Air temperature      | °C                  |
| RHMD | Relative humidity    | %                   |
| APRS | Atmospheric pressure | kPa                 |
| WSPD | Wind speed           | m/s                 |
| WDIR | Wind direction       | Directional degrees |
| RIVS | River stage          | m                   |
| WTMP | Water temperature    | °C                  |
| COND | Water conductivity   | μS/cm               |
| TRBD | Turbidity            | NTU                 |

All data were outputs from the instruments except for relative humidity. The instrument reported temperature and vapor pressure, from which relative humidity can be calculated (1). The saturation vapor pressure,  $e_s$ , can be computed by the Goff-Gratch equation, provided in nested form (2) (Lowe, 1977; Brutsaert, 2005)

$$r = \frac{e_a}{e_s} \quad (1)$$

$$e_s = a_0 + T \left( a_1 + T \left( a_2 + T \left( a_3 + T \left( a_4 + T \left( a_5 + T a_6 \right) \right) \right) \right) \right) \quad (2)$$

where  $r$  is the relative humidity,  $e$  is the vapor pressure and the subscripts  $a$  and  $s$  refer to the air and saturation, respectively, and  $T$  is the temperature in Kelvin. The parameters  $a_n$ ,  $n = 1$  to  $6$ , are calibrated parameters of the Goff-Gratch equation:

|       |              |       |                               |       |                               |       |                               |
|-------|--------------|-------|-------------------------------|-------|-------------------------------|-------|-------------------------------|
| $a_0$ | 6984.505294  | $a_2$ | 2.133357675                   | $a_4$ | $4.393587233 \times 10^{-5}$  | $a_6$ | $6.136820929 \times 10^{-11}$ |
| $a_1$ | -188.9039310 | $a_3$ | $-1.288580973 \times 10^{-2}$ | $a_5$ | $-8.023923082 \times 10^{-8}$ |       |                               |

## DATA FLAGS

Data flags (Table 4) are used to describe quality control or missing data.

| TABLE 4: DATA FLAGS |   |
|---------------------|---|
| FLAG                | DESCRIPTION   |
| No flag             | Data normal   |
| -9999               | Data missing/not recorded                           |
| -8888               | Data for this measurement has not yet been uploaded |
| -7777               | Data unreliable                                     |

## ORGANIZATION

The data are available according to the variables listed in Table 1. Data are collected and reported by YEAR, MONT, DAYN, HOUR, and MINU for the year, month, day, hour, and minute, respectively, that the data were recorded. The data appear as numerical values for each unit listed in Table 3. Where data must be flagged, the value was replaced with one of the non-physical values in Table 4. Time is in South African Standard Time (SAST), which is Universal Coordinated Time (UTC) +2.

## METEOROLOGICAL SENSORS

### LOCAL DATALOGGER

Precipitation was measured with a tipping bucket rain gage (HOBO RG3-M, Onset Computing, Bourne, MA, USA) connected to a data logger (Mbahela: HOBO Pendant UA-003-64, Leshiba: HOBO USB Micro H2I, Onset Computing). Atmospheric pressure was measured with an absolute pressure sensor (HOBO S-BPA-CM10, Onset Computing) inside a water-resistant housing and connected to a data logger. Data were recorded every 15-minutes. Data are downloaded from the local dataloggers and uploaded to the Development Data Library every six-months

### CLOUD-BASED DATALOGGER

Precipitation was measured with an electronic drip-counter rain gage (ATMOS4I, Meter Group, Pullman, WA, USA). Along with precipitation, the ATMOS4I has other instruments integrated into the device to measure:

- solar radiation by silicon-cell pyranometer,
- air temperature by thermistor,
- vapor pressure (to compute relative humidity),
- wind speed and direction by ultrasonic anemometer, and
- barometric pressure.

Data were recorded via a cloud-based ZL6 (Meter Group) cellular-enabled data logger and transmitted every hour. Specifications of the ATMOS4I are available:  
<https://www.metergroup.com/environment/products/atmos-4i-weather-station/>.

## **HYDROLOGICAL SENSORS**

### **LOCAL DATALOGGER**

Water level was measured by an absolute pressure sensor with an integrated data logger (HOBO U20L, Onset Computing). Hydrostatic pressure was computed as the difference between the water pressure measured as a fixed location in the river and the atmospheric pressure measured by the adjacent meteorological sensor.

Turbidity is measured by an optical turbidity sensor (Turner Designs, Sunnyvale, CA, USA) equipped with an automatic wiper; data are recorded locally with a datalogger (Cyclops datalogger, Precision Measurement Engineering, Vista, CA, USA).

### **CLOUD-BASED DATALOGGER**

Water level was measured by a differential pressure sensor with a vented port that follows the data cable above the surface of the water (CTD-10, Meter Group). Integrated into this device is a thermistor temperature sensor and electrical conductivity sensor (four-point Wenner Array). The hydrostatic pressure, temperature, and conductivity are recorded with the same ZL6 data logger (Meter Group).



## CITIZEN SCIENCE

In the WaterQ2 Stakeholder Engagement meeting in August 2019 in Pretoria, participants expressed the need for citizen participation in water resources management. This participation would be part of a larger effort by national governments to educate the general public on water scarcity. Citizen science was proposed to address two challenges: first, the participation of the general public in water resources surveillance, and second, data acquisition and quality control for water resources data.

As an example, the United States Geological Survey (USGS) and the State University of New York at Buffalo (SUNY) have developed software that uses Google Voice and a server-side python script to collect river height data sent via text message (Fienen and Lowry, 2012). The experiment showed that the river level reported by the citizen science program was consistent with traditional data loggers (Lowry and Fienen, 2013). Researchers also determined several limitations of the program; such river-monitoring programs needed feedback to the community to encourage continued participation (Lowry et al., 2019). Data collection also benefited from particular members of the community becoming involved and engaged in data collection; these citizen scientists were consistent data collectors (Lowry and Fienen, 2013).

WaterQ2 would like to develop a similar system in the Limpopo River Basin to collect citizen-science-reported river height data. These data can be used to measure river discharge (flow) as long as collected where a rating curve (Leopold and Maddock, 1953) exists or can be established, can be used to either provide a data quality check or populate the data itself.

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## APPROVAL

This Hydrometeorological Station Report has been received and approved by USAID. This satisfies the requirements set forth in the Milestone Plan, item #4: Comprehensive data and website report.

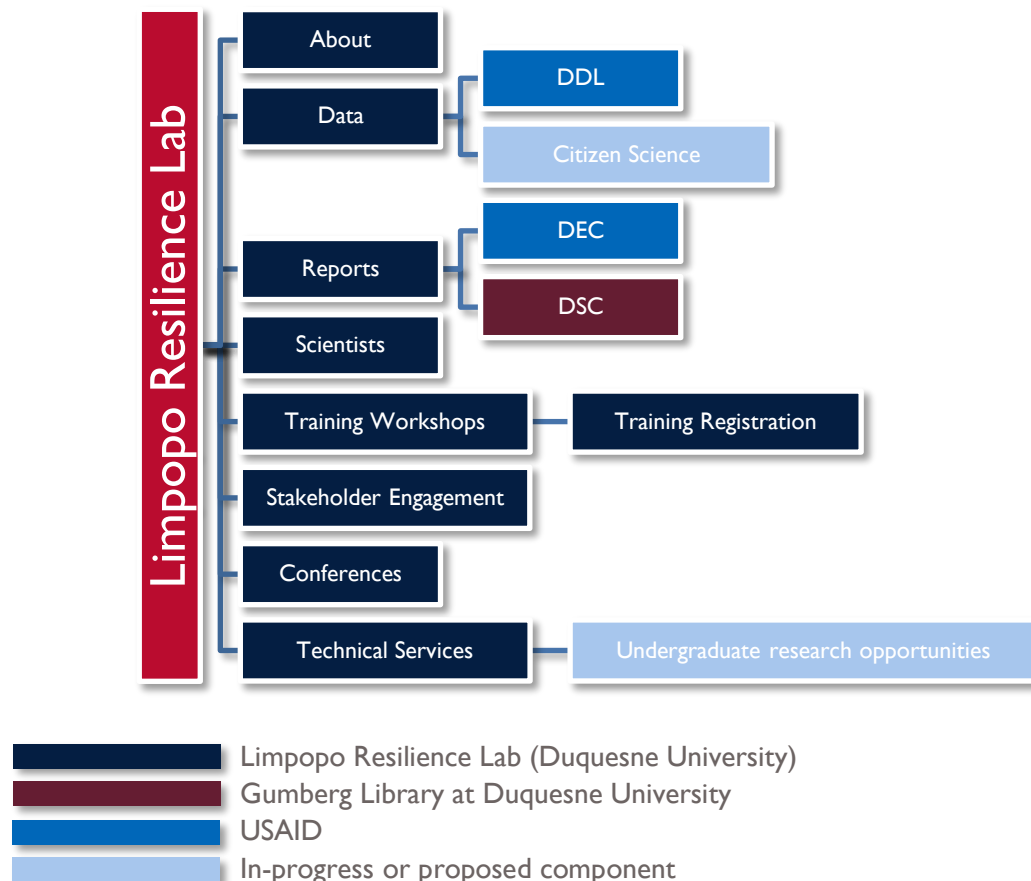
Signature: \_\_\_\_\_

Name: \_\_\_\_\_  
Agreement Officer's Representative

Date: \_\_\_\_\_

## APPENDIX A: PROJECT WEBSITE MAP

The project website is easily accessible by the link, [duq.edu/limpopo](http://duq.edu/limpopo), which points to the full universal resource locator at <https://www.duq.edu/academics/schools/natural-and-environmental-sciences/academics/departments-and-programs/environmental-science-and-management/limpopo-resilience-lab>. It is the intention of the collaborators to forge a long-standing relationship; this website has been named for the Limpopo Resilience Lab, which is the project's sustainable entity, which will remain functional after the end of the current grant.



- Data are housed at USAID's Development Data Library, [data.usaid.gov](http://data.usaid.gov). The collaborators are considering other databases better designed for scientific data.
- Reports will be housed at USAID's Development Experience Clearinghouse, [dec.usaid.gov](http://dec.usaid.gov).
- Some materials that are not generated by the project will be stored on Duquesne University's institutional repository, the Duquesne Scholarship Collection (DSC), [dsc.duq.edu/limpopo](http://dsc.duq.edu/limpopo).
- In preliminary discussions with the South Africa Department of Water and Sanitation (DWS), DWS has indicated willingness to ultimately host the database on their server. Currently, the testing software is hosted on a development server at RPI.

## APPENDIX B: WEBSITE TRAFFIC REPORT

The project website has experienced some traffic since going live; however, we expect the website traffic to increase as more materials are made available. Site visits have come from around the world (Figure B1) with a concentration from the United States of America and South Africa (Table B1).

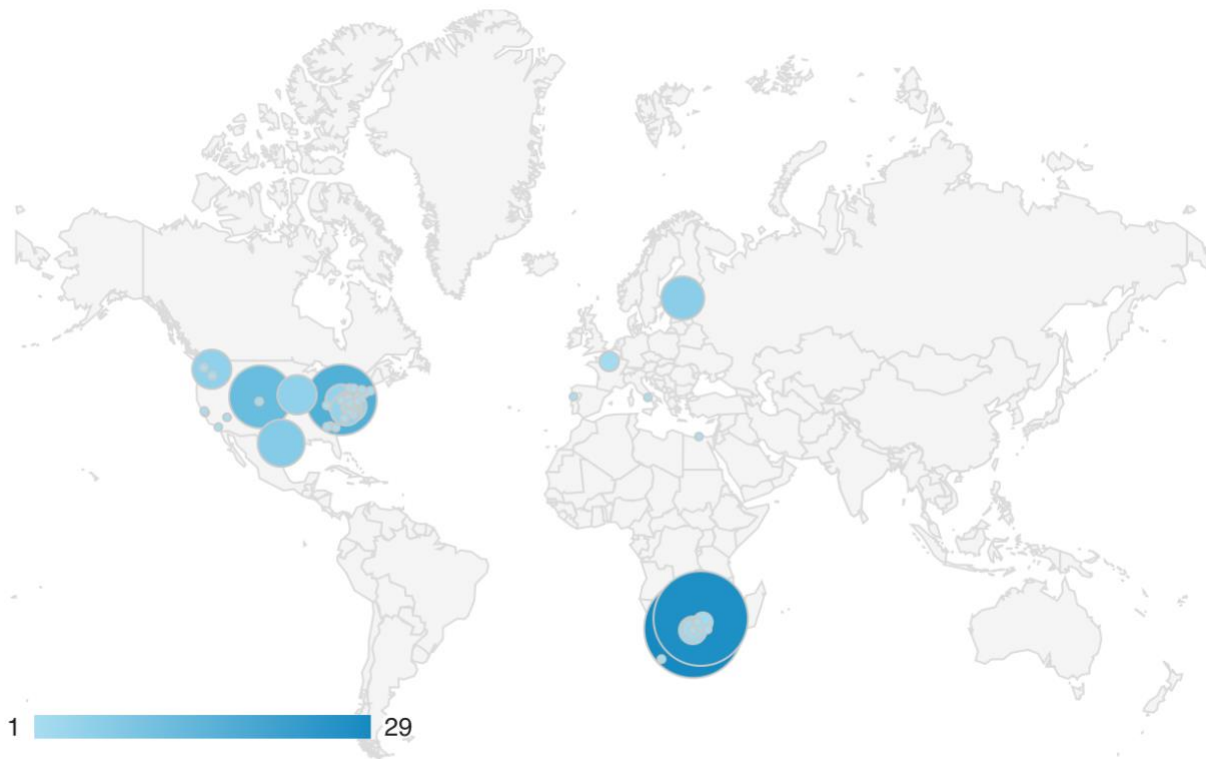


Figure B1: Map of audience for 01 June to 10 December 2019. Plotted are unique users for the period according to access of any page within the Limpopo Resilience Lab website (as indicated in Appendix A, excludes the DSC). Graphic from Google Analytics.

| TABLE B1: GEOGRAPHICAL WEBSITE TRAFFIC REPORT FROM 01 JUNE TO 10 DECEMBER 2019 |              |          |                   |                                    |
|--|--------------|----------|-------------------|------------------------------------|
| COUNTRY  | UNIQUE USERS | SESSIONS | PAGES PER SESSION | AVERAGE SESSION DURATION (H:MM:SS) |
| United States of America   | 116          | 161      | 1.94              | 0:02:24                            |
| South Africa   | 65           | 86       | 2.57              | 0:03:45                            |
| Italy  | 2            | 2        | 6                 | 0:01:54                            |
| Egypt  | 1            | 1        | 3                 | 0:18:03                            |
| Lebanon  | 1            | 2        | 1.5               | 0:04:18                            |
| Mozambique   | 1            | 1        | 5                 | 0:17:17                            |
| Finland  | 6            | 6        | 1                 | 0:00:00                            |

|                |   |   |   |         |
|----------------|---|---|---|---------|
| France         | 2 | 2 | 1 | 0:00:00 |
| United Kingdom | 1 | 1 | 1 | 0:00:00 |
| Portugal       | 1 | 4 | 1 | 0:00:00 |

Unique user access of the website (Figure B2) shows light use of the website except for the period of application for the upcoming GIS and Image Processing training offered at Univen in January. Data show the most frequently accessed page, other than the landing page, is the training workshops page.

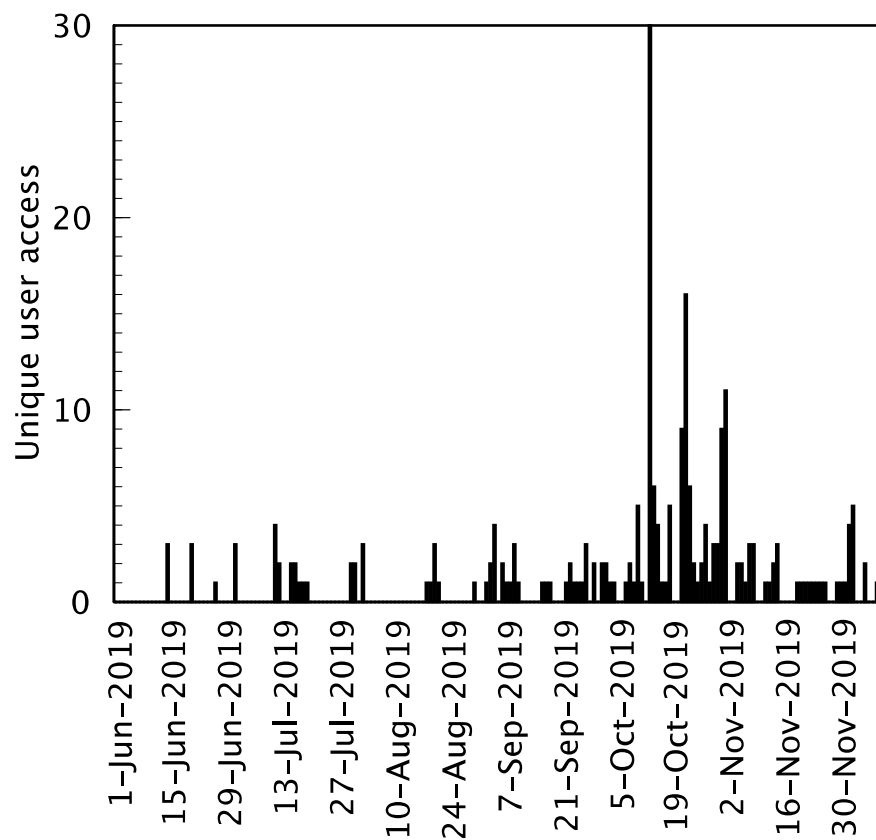


Figure B2: Daily unique users of all pages within the Limpopo Resilience Lab.

Website analytics will continue to be reported to USAID in quarterly reports.

WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin