WATERQ2: UNDERSTANDING WATER QUALITY & QUANTITY IN THE LIMPOPO BASIN

2019 Stakeholder Meeting Report

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WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin

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Cover photo: Elephants standing in Shingwedzi River, Kruger National Park, photo credit: David M. Kahler.
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Project Information

Project Title: Water Q2: Understanding Water Quality and Quantity in the Limpopo Basin
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PROJECT OVERVIEW

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 report the convening and results of stakeholder meetings conducted in August 2019. All of the collaborators were involved in these meetings: Duquesne University (Duquesne), University of Venda (Univen), and Rensselaer Polytechnic Institute (RPI). The meetings included the University of Venda administration, Kruger National Park scientists, representatives from government agencies from Botswana and South Africa, and Endangered Wildlife Trust conservation workers.
INTRODUCTION

“If you want to go fast, go alone
if you want to go far, go together”
-proverb

Central to the work of the WaterQ2 project is gaining information from a range of stakeholders who work in the Limpopo River Basin and building collaborative relationships with these stakeholders. This report summarizes five meetings held with stakeholders in August 2019. These stakeholders ranged from national agency directors to scientists and conservationists working on the ground. Another stakeholder meeting has been scheduled for January 2020 in Maputo, Mozambique. This meeting will focus on the needs of the Limpopo Watercourse Commission (LIMCOM) and officials from Mozambique, although all of our current contacts will be invited; a representative from LIMCOM has confirmed availability. This meeting will be reported in an addendum to this report.

The project also conducted a training workshop with students from the University of Venda on surface water measurement. This short course focused on practical river measurement techniques and data quality assurance. The WaterQ2 project plans to offer additional training to a broader audience in January 2020. This training will be reported in an addendum to this report.

UNIVERSITY OF VENDA MEETING: 14 AUGUST

The collaborators met with Professor John Odiyo, Dean of the School of Environmental Sciences at the University of Venda (Univen). The collaborators discussed the current initiatives under the USAID-funded WaterQ2 project and specifically the training programs that have been planned. Many of these training programs will be offered at Univen. The Dean was very excited for Univen to be part of the USAID grant and he looked forward to the upcoming training sessions. The WaterQ2 project also supports two graduate students and their research, and attendance for the Univen collaborators to attend and share their research at international scientific meetings.

The collaboration between the collaborators and the University of Venda has made this work in the local communities possible. The Dean of Environmental Science gave us his full support and offered to set up future talks and learning opportunities at the university, and invited the collaborators to present public lectures at the Univen to help increase awareness of the project and its goals.

Duquesne and Univen are drafting a memorandum of understanding (MOU) to formalize the relationship between the universities. This MOU will facilitate future research collaboration, and student and faculty exchanges.

KRUGER NATIONAL PARK MEETING: 16 AUGUST

The collaborators were invited to meet with staff from the Conservation Services and Scientific Services of Kruger National Park. These groups work in concert to fulfill the park’s role as stewards of the vast natural resources within this protected area. As part of the Greater Limpopo Conservation Area and
responsible for monitoring rivers of two transboundary watersheds (the Limpopo and the Komati river basins), Kruger staff play an important role in transboundary natural resources management.

**KRUGER AS STAKEHOLDERS**

Kruger staff monitor river gages in the park to provide data quality control to the South African Department of Water and Sanitation, who operate automated stations throughout South Africa. They are also monitor the rivers for environmental flows and flow required to maintain mandated transboundary flows. The staff communicates water flow needs to upstream dams on the regulated rivers to release water as needed. In the Komati River Basin, this communication is facilitated by the active Komati Watercourse Commission between eSwatini, Mozambique, and South Africa. In the Limpopo River Basin, the communications are informal; upstream dams cooperate with requested flow adjustments.

Environmental flows, as minimum flow rate and dynamic range of flow, is integral to the health of the rivers, which represent the water for the extensive biodiversity of the park and habitat for its fish, aquatic birds, and emblematic macrofauna (e.g., crocodiles and hippopotamuses).

The park is also responsible for water quality in the park to support the biodiversity for which the park is best known. Specifically, several external researchers monitor water quality parameters in the Olifants River due to extensive development in the catchment, especially mining. Kruger seeks to increase collaborations to supplement their water research.

**KRUGER AS COLLABORATORS**

We met with scientists at Kruger National Park to find out more about their current projects and their data needs. In discussions with the scientists at Kruger National Park, the collaborators identified several potential projects to enhance the research collaborations with Univen.

**UNDERSTANDING TEMPERATURE AND TURBIDITY EFFECTS ON FISHES OF KRUGER NATIONAL PARK**

The rivers of Kruger National Park contain nearly 50 fish species, yet little is known about how these fishes respond to environmental perturbations or climate change. For example, the thermal tolerances of fishes are unknown. Temperatures have been increasing with unknown consequences. Additionally, Kruger maintains minimal environmental flows in Park rivers by having upstream dams release water during the dry season when flows fall below a legally defined minimum. However, dam releases are usually pulsed water from the hypolimnion of the water column, and the temperature of released water...
is substantially colder than the what is in the rivers beforehand. The ecological consequences of these pulsed dam releases and the rapid changes in water temperature are unknown; while they may preserve the minimum environmental flows, the cold temperature may have other adverse ecological impacts. Finally, agricultural growth throughout the Limpopo River Basin is correlated with an increase in river turbidity levels. Anecdotal evidence collected by Kruger National Park scientists indicate that the deep river pools, which are essential for the largest fishes, have been filling in. Yet it is unknown what this loss of habitat has on the biodiversity of the rivers.

THE IMPACT OF AGRICULTURE AND SAND MINING ON RIVER ECOLOGY

Local agricultural production is a keystone for food security and jobs provisioning in South Africa. However, South Africa’s Department of Environmental Affairs estimated that 1.5 million hectares is degraded. Erosion, mineral and sand mining, and lack of land management have contributed to land degradation, which has diminished agricultural productivity and increased river turbidity levels. CSIR has proposed engaging with stakeholders and land managers to establish strategies to rehabilitate land. The Olifants River catchment (see Figure 1) is one area that has been identified as an area of substantial land degradation. However, best practices guidelines for agriculture have not been established. Additionally, there is a growing sand mining industry in the Basin, which is unregulated, occurs on riverbanks, and whose ecological and water resources impacts are unknown.

THE HYDROLOGY OF THE MAKULEKE WETLAND

The Makuleke Wetlands is located along the northern border of the Park and adjacent to the confluence of the Levuvhu and Limpopo Rivers. The Makuleke wetland is 7,757 hectare, Ramsar-recognized wetland within South Africa (http://www.saramsar.com/2015/06/makuleke-wetlands.html, https://rsis.ramsar.org/ris/1687). The wetland consists of 31 pans; however, the groundwater-surface water interactions have not been investigated. The wetlands are important to support the unique biodiversity of northern Kruger and provide regulation ecosystem services of river flow and water quality in the Levuvhu and Limpopo Rivers.

PLANS WITH KRUGER NATIONAL PARK

The collaborators will apply to conduct research activities within Kruger National Park. This will allow the collaborators to conduct the identified projects in the Park and access the Park research infrastructure. These projects currently include:

- Hydrologic investigation of the Makuleke Wetland with ERT and
- Water quality and its relationship to upstream land use in the Olifants River.

Figure 2: Kruger Scientist Eddie Riddell explains some data and research needs in front of one of the transboundary rivers in the Park.
PRETORIA STAKEHOLDER MEETING: 19-20 AUGUST

The WaterQ2 project is pleased to welcome our partner in research, the Council for Scientific and Industrial Research (CSIR) in Pretoria. CSIR graciously hosted the Pretoria Stakeholder Meeting. CSIR was also instrumental in the identification of key stakeholders in the South African government, other riparian state governments, and other scientific organizations near Pretoria. A two-day meeting was held at CSIR, Pretoria campus. The goals of the meeting were to learn from the stakeholders about their needs around:

- Module 1: Water Resources Monitoring and Modeling,
- Module 2: Stakeholder meetings, technical training, and scientific conferences,
- Module 3: Reporting and sharing information, and
- Module 4: Limpopo Resilience Lab and technical resources in the basin.

In the WaterQ2 project application, the collaborators planned to hold large stakeholder meetings at Univen and invite representatives from all of the riparian states (Botswana, Mozambique, South Africa, and Zimbabwe), relevant transboundary organizations (e.g. LIMCOM), and sub-national stakeholders. While gauging interest in the meeting, the collaborators were advised that representatives would likely not be permitted to travel for a week (the proposed duration and pragmatic for the longer journey) for a meeting with a new organization. The collaborators decided to change the stakeholder meeting format in favor of smaller meetings close to the centers of government. To start, the collaborators selected Pretoria to target representatives from stakeholders from the South African government. Representatives were invited (invitation Appendix A) from LIMCOM and the other riparian states and a representative from Botswana was able to attend. Future meetings are targeted for Maputo, Mozambique in January 2020 and Gaborone, Botswana in August 2021.

AGENDA

Attendance was requested for our two-day meeting in August (attendees, Appendix B; RSVP survey, Appendix C). The agenda is summarized in Table 1.

<table>
<thead>
<tr>
<th>DAY</th>
<th>TIME</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 August</td>
<td>08:30</td>
<td>Registration (please allow extra time for security)</td>
</tr>
<tr>
<td></td>
<td>09:00-10:00</td>
<td>Welcome, introduction, review of goals</td>
</tr>
<tr>
<td></td>
<td>10:00-11:30</td>
<td>Plenary: SWOT Analysis</td>
</tr>
<tr>
<td></td>
<td>11:30-11:45</td>
<td>Break</td>
</tr>
<tr>
<td></td>
<td>11:45-13:00</td>
<td>Breakout: water monitoring and modeling discussion (module 1)</td>
</tr>
<tr>
<td></td>
<td>13:00-14:00</td>
<td>Lunch</td>
</tr>
<tr>
<td></td>
<td>14:00-14:45</td>
<td>Breakout: training needs discussion (module 2)</td>
</tr>
<tr>
<td></td>
<td>14:45-15:30</td>
<td>Breakout: synthesis report and data sharing discussion (module 3)</td>
</tr>
</tbody>
</table>
### TABLE 1: PRETORIA STAKEHOLDER MEETING AGENDA

<table>
<thead>
<tr>
<th>DAY</th>
<th>TIME</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:30</td>
<td>16:00</td>
<td>Plenary: revisit the day’s accomplishments, SWOT Analysis</td>
</tr>
<tr>
<td>20 August</td>
<td>09:00-09:30</td>
<td>Review Monday’s discussion, geographic priorities</td>
</tr>
<tr>
<td>09:30</td>
<td>11:00-11:15</td>
<td>Breakout: Limpopo Resilience Lab services and fostering collaborations (module 4)</td>
</tr>
<tr>
<td>11:15</td>
<td>12:00-13:00</td>
<td>Plenary: Presentations from participants</td>
</tr>
<tr>
<td>12:00</td>
<td>13:00-14:00</td>
<td>Networking lunch</td>
</tr>
</tbody>
</table>

### SWOT ANALYSIS

#### OVERVIEW OF SWOT

A SWOT Analysis is an organizational planning technique used to identify strengths, weaknesses, opportunities, and threats related to the project at hand. In our use of the SWOT analysis, we identified the Limpopo River Basin as the “project” at hand, asking stakeholders to identify strengths, areas of improvement (as a proactive term for weaknesses), opportunities, and threats to the basin’s water management.

The SWOT Analysis typically arranges the four areas into a table (Table 2) with the project’s internal aspects on the left and the external aspects on the right. The enabling and supporting aspects, internal or external, go on the top row and existing challenges or confounding aspects go on the bottom row. The stakeholders were convened in a plenary session to identify the strengths, areas for improvement, opportunities, and threats to water resources management in the Limpopo River Basin.

#### KEY SWOT ANALYSIS CONCLUSIONS

The results of the SWOT analysis (Table 2) will be analyzed as qualitative data to identify trends and themes from the stakeholders. From the collaborators observations, several themes are evident.

**Policies-in-Place**

The Department of Water and Sanitation of South Africa has recently established a data management policy and begun to develop the systems for said data management. This data management policy builds off of the existing policies to collect data such as the depth of boreholes. These strengths dovetail with the opportunities for data support organizations such as the South African Development Community (SADC), the Limpopo Watercourse Commission (LIMCOM), and the International Groundwater Resources Assessment Centre (IGRAC). Additionally, there are areas for improvement in coordination of data collection, storage, and sharing. The stakeholders also identified opportunities to coordinate with other entities; these entities include other transboundary organizations, organizations under the SADC, industry groups, and local municipalities. While policies are in place for data collection, storage, and sharing, there are still challenges to synchronize these data objectives.
### TABLE 2: SWOT ANALYSIS

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>OPPORTUNITIES</th>
<th>AREAS FOR IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Organizational relationships intra- and inter-basin.</td>
<td>• EFTEON (call for landscapes - 6, 20 years, provides infrastructure)</td>
<td>• Drought extent, prediction</td>
</tr>
<tr>
<td>• Availability of policies, current, national-level, transboundary, collaboration</td>
<td>• Digital Earth Africa (Australian)</td>
<td>• When will rainfall start – for farmers for mitigation</td>
</tr>
<tr>
<td>• Local expertise</td>
<td>• External donors (EFTEON, NRF, ODAs, UNESCO, SIDA, GIZ)</td>
<td>• Real-time information on a number of parameters. Early-warning systems (drought, flood)</td>
</tr>
<tr>
<td>• Donor-funded projects and data</td>
<td>• Other support, data management (IGRAC, ORASCOM)</td>
<td>• Indicators suggest that water quality and quantity are declining, need prioritization of monitoring networks, alternative products (e.g., satellites).</td>
</tr>
<tr>
<td>• Resilient Waters identified hotspots already</td>
<td>• New organizations: SADC GMI (groundwater)</td>
<td>• Knowledge management, lots of work done, hard to find what was done, hard to access data.</td>
</tr>
<tr>
<td>• Strong stakeholder participation</td>
<td>• Other organizations: Waternet (capacity building), mining organizations (Chamber of Mines, NBI), agriculture (farmers’ union), local municipalities.</td>
<td>• Enhanced capacity building, joint cooperation, focused courses</td>
</tr>
<tr>
<td>• Existence of and functionality of the RBO (LIMCOM, SADC, JPTC).</td>
<td>• WSLSG – water and sanitation sector leader group (“360 group”, high-level)</td>
<td>• Best practices for data management, QA/QC, infrastructure, monitoring, and management</td>
</tr>
<tr>
<td>• Groundwater aquifer research</td>
<td>• Demographic changes</td>
<td>• Consistency/sustainability from basin organizations for M&amp;E for water data</td>
</tr>
<tr>
<td>• Networks of quality and quantity monitoring.</td>
<td>• Data access and availability from external organizations: cost, availability</td>
<td>• Sharing of data, one center for your data/common repository</td>
</tr>
<tr>
<td>• Seasonality: two regimes</td>
<td>• Open-access as a key principle</td>
<td>• Collection and management of water data – harmonization (QA/QC, metadata)</td>
</tr>
<tr>
<td>• FET Water, IHP short courses</td>
<td>• Lack of information infrastructure: external data sources, formatting, data infrastructure (NIWIS as an opportunity to address this)</td>
<td>• Effective, integrated planning for wasted water, facility planning,</td>
</tr>
<tr>
<td></td>
<td>• Highest-level prioritizations sometimes don’t consider long-term</td>
<td>• Planning for results, long-term</td>
</tr>
<tr>
<td></td>
<td>• Lack of polluter pays principles</td>
<td>• Systems thinking to consider externalities</td>
</tr>
<tr>
<td></td>
<td>• Limited institutional knowledge management</td>
<td>• Surface water, lots of data, need to take data from just numbers to actionable, derived products (e.g., floods in Limpopo)</td>
</tr>
<tr>
<td></td>
<td>• ODAs – can change prioritizations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Gender and water</td>
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</tbody>
</table>

The goal of the collaborators is to present the SWOT analysis results at an upcoming water conference.
Gender and Water

There are many gender issues around water and even more when water is considered to include sanitation and hygiene. The plenary discussions did not go into specific issues as the purpose of the SWOT analysis exercise was to identify high-level issues around water resources management. Nevertheless, one issue was identified: increasing gender diversity in water-related careers and projects.

BREAKOUT SESSIONS

In the breakout sessions, stakeholders were randomly divided into three groups to respond to a series of questions. The questions aligned with the focus areas of the WaterQ2 project and were designed to identify key factors not brought up in the plenary session.

MODULE I: WATER MONITORING AND MODELLING

What data are targeted and collected most frequently? How often? Are there automatic dataloggers? Respondents indicated that water quantity and quality, and biodiversity were recorded. Water quality and biodiversity data were stored in national datasets; however, some additional data are not easily accessible; furthermore, it may be difficult to know what data exist.

Surface water quantity measurements are taken every 15 minutes and automatically logged at weirs and relayed via telemetry to databases. Data quality control is sporadic. There exist around 4000 measurements of groundwater; many are static measurements and not all are government owned or operated.

What data, which are lacking, are the top priority to collect? Are datasets comprehensive enough (that is, they are already there, but not complete, etc.)?

While water quantity data are obtained automatically, water quality data are recorded infrequently and are insufficient to support decision-making. There are, “large data gaps and lack of records.”

There is a network of weather stations; however, they are too spread out to resolve the actual precipitation or other parameters, especially for land-use planning.

The national land cover database does not include sufficient sediment data. Specifically, in the Limpopo River Basin, there is a need for greater monitoring of groundwater and boreholes.

What scientific methods/studies are intriguing or useful (what are able to support decisions)?

Respondents identified several studies that would be helpful in decision-making:

1. How does climate change affect recharge?
2. What is the overall effect of climate on surface and groundwater resources?
3. How do pollutants affect the total water demand?
4. What are the consequences of land use change and loss of biodiversity on economic productivity such as agriculture?

Are data actively used to promote/develop policy?

Water discharge standards will be implemented shortly in response to water quality data. The respondents indicated that more data would be helpful in the policy arena.
MODULE 2: TRAINING AND CONFERENCES

What training (professional) has been accessible or offered in the past?
Respondents indicated that there have been a few consultant-based training courses offered in the past; however, training opportunities were not helpful to the organizations as they were only offered during the contract period. There was significant interest in ongoing training that could be offered by an institution such as Univen.

The groups identified several groups that routinely offered training programs in the region. These were provided by UNESCO, specifically on groundwater, and FET Water. These programs were especially appealing as they had been accredited to offered professional development hours to maintain professional certification.

For the purposes of our project, there was a consensus on the need for routinely offered, professionally accredited training programs. For topics, there was broad interest in GIS and remote sensing, hydrologic modeling, and management topics such as integrated water resources management (IWRM) and environmental flows. The main concern for training was not the topics to be offered; it was the consistency of availability.

MODULE 3: SYNTHESIS REPORT AND DATA SHARING

Is there active data sharing or availability?
There were two primary barriers to data availability that were identified by the respondents. First, data are housed in disparate locations in a range of formats. Data are housed in different agencies across the governments of the riparian states. These data are sometimes housed in databases; however, there were several references made to data stored in spreadsheets on individual's computers. While data stored in spreadsheets are readily usable by individuals, this format restricts more advanced manipulations of data. Data on individual computers may not be properly backed up or stored in redundant locations. Data that is stored in databases are not uniformly formatted and many databases are not maintained; furthermore, data quality control is not uniformly applied.

Second, data are costly; this is both a valuation statement and a barrier. Individual agencies are not incentivized to share their data because data is costly to generate and maintain quality control. Unfortunately, support of data acquisition by other agencies does not appear to be within the budgets of other management agencies. This has created a reinforcing loop, as it is identified in systems thinking, in the Limpopo Basin (Figure 3). There are other interactions to this reinforcing loop; an injection of funds to support data acquisition or sharing could slow or reverse this loop. External efforts to support data quality, such as this project, can help to bolster data integrity. Other, less-expensive data acquisition methods, such as those supported through this project, could ease the burden of data collection.

An additional stress on data sharing is that there are no current protocols on data sharing. Official channels for data sharing or data quality control do not exist in the Limpopo River Basin. Here, and elsewhere in the breakout sessions, participants identified the need to engage the public in water science, including data collection (see conclusions, “Citizen Science”).
**Priority Areas Identified**

There was unanimous concern over the effects of land use on water quality; specifically, grazing and sand mining. While other industries have known water quality impacts, grazing and sand mining do not have regulation or significant oversight.

**Other stakeholders**

The participants generated a number of additional stakeholders whom should be involved in future work. The WaterQ2 collaborators appreciate the input and will seek to curate the relevant stakeholders.

- Southern African Development Community (SADC)
- Limpopo Watercourse Commission (LIMCOM) (invited, but could not attend)
- National Water Information Systems (NWIS)
- Groundwater Management Institute (GWMI)
- Global Water Partnership (GWP)
- Joint Permanent Technical Committee (JPTC)
- Climate Resilient Infrastructure Development Facility (CRIDF)
- WATERNET
CONCLUSIONS OF THE STAKEHOLDER MEETING

At the conclusion of the meeting, highlights of the meeting, some of which occurred in breakout groups, were shared and discussed with the plenary group. Up to this point, the collaborators tried to limit involvement in the discussions; they asked for information, organized discussion, and moderated discussion. In this session, the collaborators offered some responses to the discussions.

The collaborators greatly appreciate the input from the participants (Figure 4).

CITIZEN SCIENCE

In the breakout sessions, the participants indicated the need for increased citizen participation in water science (that is, engagement in their watershed, data collection). WaterQ2 scientist David Kahler introduced a project that was developed by the United States Geological Survey (see references). The program, which has gone by the names Social Water and Crowd Hydrology (Figure 5), uses the general public to report the water level in rivers via text message. The current US-based system uses Google Voice and a python script to collect data on the river stage. This river stage, 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.
Figure 5: Schematic of “Crowd Hydrology” as in Lowry et al. (2019). This graphic appears on the signs near the river staff gages near each station.

This concept was of great appeal to the participants with one stopping the meeting and asking to return to the conversation; his exact words were, “we need this right now!” A citizen science project such as this could serve several purposes (Appendix D):

- Residents could become more involved with their watershed
- Local users (e.g., farmers) may become more connected and be more conscientious water users
- Data quality control measurements could be collected
- New data sources could be developed with less cost than an autonomous data logger
- Schools can use the staff gage and data generated in lessons

Figure 6: Staff gage in Kruger National Park for data quality control. Park staff routinely record the water level and transmit that information to data managers. This staff is on the Lower Sabie River in the Komati River Basin, where transboundary data sharing is facilitated.

Figure 7: Staff gage on the Mutale River at the Mutale Weir.
In some locations, the staff gages already exist (Figures 6 and 7); however, additional stations would be ideal to grow this program. Based on the collaborators’ experience, there is some concern over how readable the existing staffs are; a scale similar to Figure 5 may be more familiar to the general public.

**Citizen Science References**


**ECONOMICS OF WATER**

According to many of the stakeholders, economics of water could be a major factor in changing water resource management within South Africa. This is one of the great questions in the field of water resources management: how do you price water such that the value of potable water is appreciated while the ideals, such as the human right to water (see, among others, the United Nations Covenant on Economic, Social, and Cultural Rights of 1966, in force 1976, and United Nations General Comment No. 15 of 2002), are recognized? Unfortunately, this topic is outside of the collaborators’ field; however, due to the importance of this issue, the collaborators will seek to include water economics in our work to the extent possible.

**RESILIENT WATERS: 22 AUGUST**

The United States Agency for International Development, Southern Africa Regional Mission has a large program on water security run by Chemonics, Inc. called Resilient Waters. This program is staffed in Johannesburg. In addition to staff from Resilient Waters attending the WaterQ2 stakeholder meeting, the collaborators were invited to meet with the Resilient Waters staff. The discussion included a discussion of the shared goals of these two programs and potential collaborations. Professor Willem presented his work on the Vhembe Biosphere Reserve.

Resilient Waters has issued an annual program statement with a grant program. Univen is interested in applying to this program to support continued activities within the Limpopo Resilience Lab.

**ENDANGERED WILDLIFE TRUST: 23 AUGUST**

Endangered Wildlife Trust (EWT) has a field station at Medike Nature Reserve and collaborative conservation agreements with Leshiba Wilderness Reserve, Sigurwana Lodge, and Lejuma Research Center. EWT received funds from World Wildlife Fund South Africa and the Coca-Cola Foundation to
remove invasive trees from the various farms and lodges near Medike Nature Research in the Sand River catchment in the Soutpansberg Mountains. The trees to be removed are the Black Wattle, or Acacia, Acacia mearnsii and Eucalyptus Eucalyptus camaldulensis. These trees are not adapted to water-stressed environments and have been shown to detrimental to groundwater resources (Le Maitre et al., 2002). The trees in this western Soutpansberg region are sparsely populated in contrast to the occurrence of timber farms with Eucalyptus trees and the spread of this invasive species in the eastern Soutpansberg. EWT’s goal is complete eradication of these invasive species in the western Soutpansberg. The research component of this conservation measure is to monitor the water budget in these high-elevation catchments to determine if the removal of these trees increases the water resources that flow to the Sand River. The Sand River is dry through the Soutpansberg Mountains; these high-elevation catchments may be the most important water source for the agricultural region north of the mountain range.

Figure 8: WaterQ2 and EWT staff after a tour of the tree removal projects.

Figure 9: The project manager at Endangered Wildlife Trust, Oldrich van Schalkwyk shows the flow downstream of a wetland in the middle of the area being cleared of acacia and eucalyptus trees.
TRAINING WORKSHOP: 26-27 AUGUST

RIVER DISCHARGE MEASUREMENT AND MONITORING

TRAINING OBJECTIVES: participants should be able to:

- Apply empirical formula to the calculation of discharge
- Apply the mathematical relationships of hydraulic geometry to river gages
- Measure the discharge of a river with a current meter

Participants were provided the training outline with additional resources (Appendix E) and participate in hands-on training on river discharge measurement (Figure 10 and 11). Additionally, students will gain experience with an automatic level used in surveying (Figure 12) and other hydrology and water quality instruments as available.

Figure 10: WaterQ2 graduate students, Garrett Sharp explains instrument placement to measure river current.
Participants took turns using the current meter. An automatic level and electrochemical multiparameter meter (pH, dissolved oxygen, conductivity, and temperature) were also used.

WaterQ2 scientist Joshua Edokpayi instructing participants on the automatic level and how to read a staff through the instrument.

Participants at the training. Full roster is available in Appendix F.
This Meeting Report has been received and approved by USAID. This satisfies the requirements set forth in the Milestone Plan, item #5: Report of Stakeholder Meeting.

Signature: ________________________________

Name: ________________________________
Agreement Officer’s Representative

Date: ________________________________
APPENDIX A: STAKEHOLDER MEETING INVITATION LETTER

The following page contains the invitation letter sent out to agencies.
Dear Professional Colleague:

We are an international group of scientists that work on natural resource management. We have recently been awarded a grant by the United States Agency for International Development to understand water resources and biodiversity in the Limpopo River Basin and develop the training capacity to support evidence-based management. Based on your position and background, we think that you have important insight into water quality and quantity, and biodiversity, and can help identify training needs.

We are writing to invite you to participate in a two-day meeting in which we plan to discuss water and biodiversity data needs, data availability and sharing, training needs, and best management practices in the Limpopo River Basin with key stakeholder groups. We would like to have your input to prioritize research activities in the Basin and design education and training programs for you and/or your staff. An output of the meeting will be custom-tailored training modules for you and/or your staff, beginning January 2020.

The meeting will be held from 19-20 August 2019 in Pretoria on CSIR’s campus in the Kingfisher Room. If you can join us for this meeting, please respond to the survey included in the email, which can also be found online: https://forms.gle/eyCyCqA4P8fKnwtr6. Lunch and tea/coffee breaks will be provided. The tentative agenda is:

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 August</td>
<td>08:30</td>
<td>Registration (please allow extra time for security)</td>
</tr>
<tr>
<td></td>
<td>09:00-09:30</td>
<td>Welcome, review of goals, discussion of geographical priorities</td>
</tr>
<tr>
<td></td>
<td>09:30-11:00</td>
<td>Presentations from participants</td>
</tr>
<tr>
<td></td>
<td>11:00-13:00</td>
<td>Small group brainstorming on data needs</td>
</tr>
<tr>
<td></td>
<td>13:00-14:00</td>
<td>Small group brainstorming on geographic priorities</td>
</tr>
<tr>
<td></td>
<td>14:00-16:00</td>
<td>Small group brainstorming on information sharing</td>
</tr>
<tr>
<td>20 August</td>
<td>09:00-11:00</td>
<td>Participant presentations</td>
</tr>
<tr>
<td></td>
<td>11:00-13:00</td>
<td>Large group discussion on data needs and geographic priorities</td>
</tr>
<tr>
<td></td>
<td>13:00-14:00</td>
<td>Networking lunch</td>
</tr>
</tbody>
</table>

We look forward to your valuable input!

Sincerely,

David M. Kahler, Ph.D.    Joshua N. Edokpayi, Ph.D.    Kevin C. Rose, Ph.D.
Duquesne University        University of Venda          Rensselaer Polytechnic Institute
APPENDIX B: ATTENDEE LIST

Tables B1-B3 contain personal information and have been removed in this version of the report. Please contact the project staff if you would like to connect to these groups.

WATERQ2 SCIENTISTS

PIs and students were present at all meetings.

<table>
<thead>
<tr>
<th>NAME</th>
<th>AFFILIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joshua Edokpayi</td>
<td>University of Venda</td>
</tr>
<tr>
<td>David Kahler</td>
<td>Duquesne University</td>
</tr>
<tr>
<td>Kevin Rose</td>
<td>Rensselaer Polytechnic Institute</td>
</tr>
<tr>
<td>Max Glines</td>
<td>Rensselaer Polytechnic Institute</td>
</tr>
<tr>
<td>Mackenzie Martin</td>
<td>Duquesne University</td>
</tr>
<tr>
<td>Ntwanano Mutileni</td>
<td>University of Venda</td>
</tr>
<tr>
<td>Hilton Thivhonali Shimbabu</td>
<td>University of Venda</td>
</tr>
<tr>
<td>Garrett Sharp</td>
<td>Duquesne University</td>
</tr>
</tbody>
</table>
APPENDIX C: RESPONSE SURVEY RESULTS

The invitation included an RSVP survey where respondents were asked, among registration details, “What training options would you like to see offered for yourself or your staff? The respondents were asked to select no more than four of the options that are shown on the subject axis of the response graph (Figure C1).

Figure C1: Responses to the RSVP survey on, “what training options would you like to see offered for yourself or your staff?”
**APPENDIX D: CITIZEN SCIENCE**

The stakeholders present indicated a strong interest in the citizen science project. Based on previous studies, this type of program needs community engagement. This may be best accomplished with the tribal authority and local schools. To monitor the progress towards the goals, measurements should be taken (Table D1).

<table>
<thead>
<tr>
<th>GOAL</th>
<th>MEASUREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residents could become more involved with their watershed</td>
<td>Interviews with traditional leaders, local municipalities</td>
</tr>
<tr>
<td>Local users (e.g., farmers) may become more connected and be more conscientious water users</td>
<td>Interviews and surveys of local farmers and other water users</td>
</tr>
<tr>
<td>Data quality control measurements could be collected</td>
<td>Surveys of the Department of Water and Sanitation staff responsible for data quality</td>
</tr>
<tr>
<td>New data sources could be developed with less cost than an autonomous data logger</td>
<td>Comparison of data accuracy and timeliness compared to a datalogger</td>
</tr>
<tr>
<td>Schools can use the staff gage and data generated in lessons</td>
<td>Interviews and surveys with local school teachers</td>
</tr>
</tbody>
</table>

Ideally, the project would take this on fully in response to the positive feedback during the meeting. Under the current budget, this would be difficult to roll out on a large scale.


**APPENDIX E: TRAINING MATERIALS**

**Training: River Discharge Measurement and Monitoring**

**Typical mathematical treatments**

Surface water is critically important for most water use. The vast majority of agricultural and domestic water services draw from surface water resources. Measuring these resources is typically a governmental responsibility.

![Figure E1: A cutaway of a segment of river at an angle of $\phi$. The forces are identified for the imaginary box in the center of the channel.](image)

In hydrology, the most common way to estimate the flow in a river is with Manning’s formula. Manning’s formula is empirical; however, it has roots in the energy equation. Let’s consider a uniform segment of a channel (Figure E1). The sum of the forces in the direction coincident with the flow reduces to:

$$F_u - F_d - \tau P L + \gamma L A \sin \phi = 0$$

where $F_u$ and $F_d$ are the hydrostatic forces at the upstream and downstream ends of the channel segment, respectively, $\tau$ is the shear stress on the bottom of the channel, $L$ is the length of the segment, $P$ is the perimeter, $A$ is the cross-sectional area, $\gamma = \rho g$ is the specific weight of water, and $\phi$ is the bed slope angle. Since this segment is considered uniform (an important assumption), the hydrostatic forces are equal. Since most bed slopes are very small, we take the sine of the slope to be equal to the slope, $S_0$.

$$\tau = \frac{\gamma A L S_0}{P L}$$

The hydraulic radius is defined as the area divided by the wetted perimeter $R_H = A / P_w$. The stress should be equal to the dynamic pressure, $\rho V^2/2$. This is an equality that is common in hydraulics.

$$k_1 \rho \frac{V^2}{2} = \gamma R_H S_0$$
where \( k_2 \) is a proportionality constant, \( \rho \) is the fluid density, and \( V \) is the velocity. Recall, the specific weight is the density times the acceleration due to gravity, \( \gamma = \rho g \). In an alternative derivation, the Darcy-Weisbach equation is modified:

\[
V = \sqrt{\frac{8g}{f} R_H S_0}
\]

where \( f \) is found by the Moody diagram. Chezy defined a parameter, \( C \), and stated:

\[
V = C \sqrt{R_H S_0}
\]

Manning set a fixed \( C \), subsuming the \( f \) and wrote:

\[
V = \frac{R_H^{2/3} S_0^{1/2}}{n}
\]

where \( n \) is the Manning roughness coefficient, or Manning’s \( n \) (Table E1) and these coefficients are valid for SI units. This substitution is only valid for fully turbulent flows.

<table>
<thead>
<tr>
<th>CHANNEL LINING</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>0.012</td>
</tr>
<tr>
<td>Gravel with concrete sides</td>
<td>0.020</td>
</tr>
<tr>
<td>Gravel with riprap sides</td>
<td>0.033</td>
</tr>
<tr>
<td>Natural channel, straight, little vegetation</td>
<td>0.030</td>
</tr>
<tr>
<td>Natural channel, winding, with weeds</td>
<td>0.050</td>
</tr>
<tr>
<td>Natural channel, winding, with brush and timber</td>
<td>0.100</td>
</tr>
<tr>
<td>Flood plains in pasture</td>
<td>0.035</td>
</tr>
<tr>
<td>Flood plains in dense brush</td>
<td>0.070</td>
</tr>
</tbody>
</table>

The condition for turbulence in Manning’s equation (values in meters):

\[
1.1 \times 10^{-13} \leq n^6 \sqrt{R S_f}
\]

**River Discharge Measurement**

There are several ways to measure discharge, also called flow, streamflow, or flow rate. Sometimes, this quantity is also called stage or gauge/gage (conventional spelling/preferred United States Geological Survey spelling – both are correct); however, gage and stage actually refer to the height of a river.
Ask the participants to provide ways to measure discharge, perhaps without additional instrumentation. What are some of those ways? Such a list might include:

- Placing a tracer (leaf, twig) on the surface and timing the travel along a measured distance
- Measurement of water velocity with a current meter and numerical integration
- Acoustic Doppler Current Profiler (ADCP)
- Weir, either permanent or temporary

Without any equipment, you can estimate discharge by getting a feel for the speed of the water. Place a leaf or small stick in the river (as long as it is safe to do so and you will not interfere with anyone else’s use of the water). Remember, if the tracer is in the center, you will not be measuring the average velocity, but the maximum velocity; up to twice the average velocity.

With a current meter, the operator sets up a measuring tape across the river called a tag line. This must be as level as possible because if it is sagging significantly, the position measurement will be further along than the actual position. A rope strung tightly can help to keep the measuring tape straight, as the tape should not be tensioned too much (Figure E2). Measuring tapes should be made out of fiberglass as cloth ones stretch and fatigue and metal ones change length with temperature. Once measured, the discharge can be estimated through numerical integration of the measurements across the cross-section (Figure E3).

The United States Geological Survey method uses rectangles with the average velocity measured in the center of the rectangle, typically called the mid-section method. The ISO method constructs trapezoids to represent the cross-sectional area of the river, typically called mean-depth. The velocity assigned to each trapezoid is the average of the velocity measured at each side of the trapezoid. The numerical integration differences are analogous to the rectangular rule or the trapezoid rule from Riemann sums in calculus.
Additionally, there are multiple different current meters. Some of the most common instruments include the Price AA current meter (Figure E4, left), the acoustic Doppler velocimeter (ADV) (Figure E4, right), and electromagnetic induction (not shown).

Figure E4: Common current meters: the Price AA current meter (left) up close (A), in use on a wading rod (B), and suspended attached to a weight (C); and an acoustic Doppler velocimeter (right). Figure from the United States Geological Survey.

The acoustic Doppler current profiler is used for larger rivers where it is difficult to get in the water. They are typically small boats that have the sensors mounted on the hull (Figure E5). An ADCP performs a similar measurement to that of a current meter; however, because it does it in more places, the on-board software usually integrates the velocity across the cross-sectional area automatically.

Figure E5: Measurement strategy with an acoustic Doppler current profiler (ADCP). Figure from the United States Geological Survey.

Weir methods include the sharp-crested, contracted rectangular notch weir (dam) that allows direct discharge measurement from depth based on empirical hydraulic relationships (1).
\[ Q = \frac{2}{3} C_d B H^{3/2} \sqrt{2g} \]  

(1a)

\[ C_d = 0.602 + 0.083 \frac{H}{P} \]  

(1b)

where \( C_d \) is the discharge coefficient, an empirical constant that accounts for the friction loss of the notch, \( B \) and \( H \) are the width and height of the notch, respectively, \( g \) is the gravitational constant, and \( P \) is the height of the weir on the upstream side above the soil surface. Equation (1) is populated for SI units.

For a V-notched weir, a similar equation is for \( Z \) measured from the point of the V to the water surface. \( \theta \) is the angle of the notch and \( C_w \) is the weir coefficient ~0.43.

\[ Q = C_w Z \sqrt{g} \tan\left(\frac{\theta}{2}\right) \]

There are a couple of types of gages but the most common is the USGS bubbler. A bubbler is a three-way tube that measures the pressure at the bottom of the river. By hydrostatic pressure, the depth of the river is then determined: \( p = \rho g h \). But that just gets you height; you still need to correlate that to discharge. The general relationship between height and discharge was developed by the Leopold and Maddock in 1953. They showed that the relationship looked something like this:

\[ d = c Q^f \]

which means, the formula must be calibrated. There are a number of ways to generate the calibration, called a rating curve, but the most common are wading rod and current meter, which can be an impeller design, EM, or ADV, or a boat with an ADCP.

To use a wading rod, you set up a tag line perpendicular to the mean flow and measure the velocity profile, usually at two or three points vertically, at regular intervals across the river – the exception to that is when the bathymetry changes abruptly.

**References and Resources**


Colorado State University. What is a measuring weir?  
[https://www.openchannelflow.com/blog/what-is-a-flow-measuring-weir](https://www.openchannelflow.com/blog/what-is-a-flow-measuring-weir)
This training ended with a fieldtrip to a nearby river. All participants were able to use a current meter and also gained experience taking other measurements including pH, conductivity, dissolved oxygen, and temperature with a multiparameter meter, turbidity with a turbidimeter, and surveying the river cross-section with an automatic level.
APPENDIX F: TRAINING PARTICIPANT LIST

Participants are tabulated in Table F1 and entered into TraiNet.

Participant information has been removed in this version of the report.

The participants have been entered into Tranet.
APPENDIX G: FINANCIAL SUMMARY

The direct and proximal costs for the Pretoria Stakeholder Meeting (Table G1).

Financial information has been removed in this version of the report.
WaterQ2: Understanding Water Quality and Quantity in the Limpopo Basin