Capacity building in Hydrogeophysics at University of Malawi

Final report

To

Geoscientists Without Borders

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Abstract

Capacity Building in Hydrogeophysics (CBHP) is a two-year (2017-18) project implemented by the Universities of Illinois and Malawi designed to enhance the groundwater capacity in southern Malawi with funding support from Geophysicists Without Borders (GWB). The project seeks to improve knowledge of groundwater resources for sustainable management and improved access by the local communities. The University of Illinois brings expertise in geophysical methods for groundwater exploration to strengthen the existing Water Resources Program at the University of Malawi using this project as an opportunity to evaluate the effectiveness of the program and to revise the curriculum and train local capacity.

Using water-deprived communities as local case studies in four rural areas east of Zomba City, the project employs electrical resistivity tomography (ERT) techniques to map areas with potential for potable groundwater resources. These targets are evaluated through a multi-disciplinary analysis of local geological knowledge and participatory rural appraisal (PRA) to determine best sites that are also acceptable to the local communities. With a 100 percent success rate, the use of scientific and PRA techniques highlights the importance of an integrated approach in water resources evaluation for complex situations such as these. In addition, we anticipate that the participatory nature of this method will result in a high degree of local ownership and maintenance of the new resources.
1.0 Background

1.1 Goals

This project, a partnership between the University of Illinois and the University of Malawi, has several interlocking goals all designed to enhance the groundwater capacity in southern Malawi. The project seeks to improve knowledge on groundwater resources for sustainable management and improved access by the local communities with funding support from Geophysicists Without Borders (GWB). The University of Illinois brings expertise in geophysical methods for groundwater exploration to strengthen the existing Water Resources Program at the University of Malawi using this project as an opportunity to evaluate the effectiveness of the program and to revise the curriculum and train local capacity. To this end, the project has funded the MSc program for three graduate students of the Water Resources Program, introducing them to modern geophysical methods and teaching them best practices for conducting participant-centered water point projects. In order to demonstrate these practices, the project uses geophysical methods to provide the technical information needed to meet the water needs of specific water-challenged villages in the area.

1.2 Location

The southern Malawi city of Zomba is the home to Chancellor College of the University of Malawi, which provides liberal arts and science higher education for the University of Malawi system. Twenty-five km east of the city is the shallow-water Lake Chilwa. The internally draining brackish-water lake is a Ramsar Convention wetland site of global significance and is a major fishery for Malawi. Villagers living near the lake report that some groundwater points have water that is too salty to drink. Despite the lake’s local and global significance, availability of potable water remains a key challenge to the communities within the lake’s riparian habitat. For example, a previous canvass of the region has documented localized instances of high TDS (> 1500 ppm), boreholes with seasonal yield, and the presence of heavy metals in some living organisms. Although many boreholes in the area produce fresh water, they are inadequate in quantity for the high population in the area.

1.3 Geological Setting

The geology of Malawi is dominated by high-grade metamorphic rocks of the Precambrian-age crystalline basement overlaid and intruded by younger formations of various ages. Various phases of rifting episodes have affected the region since the Triassic-Jurassic Periods (associated with the splitting of Gondwana) to the Cenozoic rifting associated with the development of the East African Rift System (EARS). Minor igneous intrusions of the former rifting are represented in the area by northeast striking
The country lies near the southern-end of the great East African Rift System (EARS) and Lake Malawi, the world’s eighth biggest and Africa’s third biggest lake is a prominent physiographic feature in the country. Our study site is south of the lake and east of the rift. A suite of alkaline intrusives (ascribed to the Chilwa Alkaline Province) and associated dikes including the Zomba Mountain and several other large and a few smaller hills of Jurassic and Cretaceous age are a manifestation of the igneous activity associated with the development of the EARS in the area. Much of the large plain east of Zomba Mountain was once occupied by Lake Chilwa. As the lake recedes to the northeast it has left an expanse of alluvial clays and sands. All four of the villages in our study area are within the Chilwa basin with varying thickness of alluvial sediments overlying metamorphic bedrock.

2.0 Capacity building at University of Malawi

2.1 Curriculum Reforms at University of Malawi

As a way of ensuring long-term sustainability, one of the goals of this project is to build capacity of the local institutions. One way to do this is to strengthen the teaching at the local partner university through curriculum reforms of the existing Water Resources Program at Chancellor College by incorporating aspects of ground water geology and geophysics which are largely missing from the current curriculum. The water resources program has incorporated stakeholders’ views into the curriculum through a stakeholder’s workshop held at Splendor Hotel in Zomba on the 11th August, 2017 with funding from the project. The workshop considered the gaps in the existing Master’s program and how hydrogeology and geophysics could be incorporated in the Water Resources Modelling and Governance (WRMG) program.

The workshop was opened by the Principal of Chancellor College, Professor Richard Tambulasi who was also the guest of Honor. Other dignitaries included the District Commissioner for Zomba, The Dean of the Faculty of Science at Chancellor College, a Hydrogeologist from the Ministry of Water
Development and a representative from World Vision (Malawi), a non-governmental organization (NGO) which among other things, works in the water sector, faculty, and staff from Chancellor College. A total of 21 participants attended the workshop. The one-day workshop included stakeholder presentations to highlight the nature of existing initiatives and areas of need within Malawi’s water sector and how a water sciences program could address those needs. In general, the workshop participants observed that the WRMG program lacks enough content in Hydrogeology and that some of the existing modules need to be restructured and organized.

As a result of this workshop, the WWRMG Program has been restructured around multiple specialties including geophysical exploration, geochemistry, hydrology, groundwater modeling, and water governance. Modifications to existing curricular modules are being implemented.

2.2 Human capacity at staff/student level

In order to implement a geophysical exploration specialty, T. Larson taught an inaugural module on geophysical exploration with an emphasis on electrical methods. To complement this module, the program has purchased an ABEM Terrameter 1000 with a 64-channel electrode switch and cable set along with a license for RES2DINV processing software. Following the week-long classroom section of the module, the class spent a week collecting field data. During this time, each of the students learned to operate all functions of the instrument. After the initial field course, the class reconvened for a day devoted to processing the data with the new software.

Student recruitment into the project was based on their interests in groundwater research and were nominated after an interviewing process. Those who met the set criteria for recruitment were offered scholarships for their tuition fees and fieldwork support to enable them to carry out relevant research that could benefit the project. Apart from the initial training provided in a classroom situation, the individual student projects carried out as part of their master’s theses imparted practical hands-on and transferable problem solving skills to real-life problems.

2.3 Field studies

2.3.1 General introduction

Field studies included in this project fulfill multiple project objectives. Field work provides hands-on training in state-of-the-art geophysical technology and continue with analysis and application of hydrogeologic principles as applied to specific problems. Instead of a strictly theoretical or heuristic study, this project applies hydrogeologic principles to real-world problems and links technical solutions to social-political realities within the study area. The field work has been chosen to provide humanitarian benefit to villages within the study area in the form of new, operable boreholes that will be sustained by the villagers after the conclusion of the project. Specifically, the project has worked with four villages in eastern Zomba District, all within 25 km of Chancellor College campus. The four villages represent three distinct geologic settings within the Lake Chilwa Basin. The three geologic settings are: the area surrounding Mpyupyu Hill (Kimu), the area surrounding Chanda Hill (Jimu and Kuchilimba), and the fishing villages at Kachulu harbor (Likapa). Mpyupyu Hill is a relatively small syenitic pluton of the Chilwa Alkaline Province that intrudes metamorphosed granulites of the basement complex. In contrast, Chanda Hill is composed of resistant quartz-rich metasediments within a background of more easily weathered gneisses, all part of the crystalline basement. The geology of the Kachulu harbor area, along the modern shoreline of Lake Chilwa, is strikingly different from the other two regions with alluvial sediments exceeding 50 m in thickness. The primary challenge in the hillside settings is to find a site with sufficient thickness of saturated weathered or alluvial sediments to sustain a borehole that is also suitably located within the village. Boreholes along the lake shore must meet several challenges. The lake is seasonally brackish to saline, resulting in groundwater with high salt content near the shore. Sandy deposits that can be utilized as aquifers are frequently thin and
interbedded with low-permeable clays. Boreholes must be placed in locations that are not likely to be inundated during seasonal flooding.

Geophysical field studies, specifically electrical resistivity tomography (ERT) surveys have been accomplished using an ABEM Terrameter 1000 resistivity meter with a 64-electrode switch box in a LUND configuration for multi-electrode data acquisition. Wenner electrode configurations are used in all ERT profiles with a nominal electrode separation of 5 m. Problems with the instrument are discussed in other sections of this report. In general, depth of investigation varies from 40 to 60 m. Apparent resistivity pseudosections have been inverted to topographically-corrected modeled resistivity profiles using the program RES2DINV. We report resistivities and depths from these inversions. Except for the profiles at Likapa, which have unusually low resistivity values, all images of the resistivity inversions are presented with the same color scale ranging from 10 ohm-m to 4,600 ohm-m.

Boreholes have been constructed using air-rotary equipment at Jimu, Kuchilimba, and Kimu, and mud-rotary methods at Likapa. All boreholes have been cased with standard 113 mm PVC well casings and fitted with Afridev hand pumps, masonry and concrete aprons, and wash stands. Water committees have been organized to supervise the operation of the boreholes. These committees will be responsible for setting and administering rules and fees for using the boreholes. They will work with a trained mechanic from the region to conduct regular maintenance on the boreholes.

Figure 3. Location of field sites in relation to Chancellor College. Small red circles are locations of geophysical profiles.
2.3.2 Kimu

Kimu Village is nestled at the base of Mpyupyu Hill, a prominent igneous hill that rises several hundred meters above the eroded rocks of the surrounding crystalline basement. Kimu is experiencing significant population growth. The one borehole in the village provides reliable, high-quality water, but a new supply is desperately needed to meet the increasing demand. Initial ERT profiling suggested likely borehole targets northwest of the existing borehole. During PRA conversations, villagers expressed concern that these sites are in a neighboring village. Furthermore, the main pressure on their existing borehole comes from new users to the east, and new boreholes to the northwest would not alleviate this pressure. In response to these objections, we acquired additional ERT profiles. These easterly ERT profiles indicate that favorable aquifer conditions similar to those at the existing borehole extend to the east. Our first suggested easterly location was not politically acceptable, but another site within our technically favorable area was acceptable to the villagers.

The borehole constructed at this location encountered 2 m of hard laterite over 13 m of soil, clay and increasingly weathered granulite. Partly weathered granulite encountered at 15 m depth matches the same depth that the ERT profile measured a sharp transition from low resistivity values of 40 to 100 ohm-m to very high resistivity values of 1000 ohm-m. A fracture zone from 21 to 31 m depth occurs just above the depth of the saturated zone at 33 m. Total depth of the borehole is 42 m. This new borehole produces abundant water.

The experience at Kimu is a good example of the integrated and iterative nature of our methodology that values the input of the village-level user-community. In response to valid objections to our initial site locations, we extended the region for technical investigation. Because the local community has been fully engaged in the final site selection, we are confident that they will use and maintain this new resource.

2.3.3 Likapa

Likapa is a fishing village on the shores of the shallow-water Lake Chilwa. With its internal drainage, the lake water is brackish to saline, depending on the season. Likapa and other fishing villages along the shores of the lake have difficulty finding reliable, fresh, groundwater sources. The sandy soil around the village proved a challenge for ERT profiling. Initially, we acquired two profiles: one along a road following the crest of a sand dune running parallel to the shore, but about 0.5 km inland; and a second profile, perpendicular to the first profile, extending to the lake shore. Partly because of the dry sandy conditions and partly because of equipment problems, the data is very poor quality. We twice repeated parts of the shore-perpendicular profile during wetter times of the year. Very low resistivity values (about 8 ohm-m) occur in the soils near the lake and gradually increase inland. Alternately high- and low- resistivity areas not near the shore could be caused by alternating sand and clay or by saline water or both conditions. What appears to be a thick, freshwater sand deposit (about 450 ohm-m) is present at a depth of 20 m beneath the sand dune. The sand dune also acts as a barrier to freshwater draining to the lake. This has caused the formation of a wetland, or dambo, on the inland side of the dune. During the PRA discussions, the villagers characterized the existing boreholes closest to the dambo as having the highest quality water. Given this information we reached a consensus target location for a new borehole on the back side of the sand dune near a cross road. An unexpected problem occurred when the driller refused to attempt a borehole because the surficial sand might not support his vehicles or sustain drilling. Knowing that the ERT indicated that a layer of clay was only a few meters below the surface and that a fresh-water sand aquifer would likely be encountered within the upper 20 m, we parted with this driller and negotiated with a different operator. The new driller persisted through the difficult surface materials using mud-rotary methods and eventually completed a very productive borehole.
Figure 4. Resistivity profiles at Kimu. Above: NW-SE profile (Kimu 2) acquired October 2017 has three distinct layers: high-resistivity surface layer of dry, lateritic soil above very low-resistivity weathered material and moderate-resistivity basement complex rocks. Below: west-east profile (Kimu 4) acquired August 2018 is similar to northwest line, but with much higher resistivity in basement. Position of new borehole is shown. Transition from weathered to fresh rock was within 1 m of depth indicated by resistivity model.

The borehole at Likapa encountered 9 m of clayey sand at the surface above 8 m of alluvial clay. These correspond to a localized zone of high-resistivity material over low-resistivity material in the ERT traversing the dune. Below the clay, the borehole encountered sand that varied in texture with
increasing depth from coarse to medium to fine at the base of the borehole at a depth of 39 m. Water was encountered at a depth of 19 m. The saturated sand corresponds to a zone of moderately high resistivity (450 ohm-m) at this same depth in the ERT profile. The new borehole provides an abundant amount of high-quality water.

At Likapa, poor data quality led to high uncertainty in the technical solution. As a result, our integrated approach relied on information concerning the local hydrogeology provided by the villagers themselves. Highly motivated to complete the borehole, they worked hard to repair access roads for drilling equipment. Ideally, the drilling contractor should be considered a stakeholder and should be brought into the conversation concerning the location of the borehole. Treating the driller as a service provider led to misunderstandings and delays.

Figure 5. North-south resistivity profile along road on top of sand dune in Likapa Village acquired October 2017. The dry conditions resulted in very noisy data. Low-resistivity zones could be caused by clay or by high-salinity ground water. High-resistivity zones are likely caused by sandy sediments.
Figure 6. Repeated west-east resistivity profiles along fisheries road from Likapa to Lake Chilwa coast. Upper profile acquired in October 2017 was the longest profile, but equipment malfunctions and dry conditions resulted in very poor data, especially in the western part of the profile. Extremely low resistivity values on the eastern end are caused by highly saline groundwater beneath the coastal areas. Middle: The western part of the profile was re-acquired in April 2008 during a wetter time of the year. Bottom: The western part was re-acquired and extended to the west, across a dambo in August 2018. The new borehole, shown in bottom image, encountered sand with low-salinity groundwater within 1 m of transition in resistivity model. All three profiles shown at approximately same distance and depth scales but different resistivity scales.

2.3.4 Jimu

Jimu village lies at the south end of Chanda Hill, formed by a localized deposit of quartzite within a gneissic metamorphic terrain. The quartzite is much more resistant to erosion than the surrounding gneiss, resulting in Chanda Hill. Previous geologic mapping suggests the presence of igneous dikes within the country rocks. The village is at the south end of the hill and is divided into 2 sub-villages—Jimu1 to the north of the village center and Jimu2 to the south. A single borehole a few hundred meters to the northwest of the village center supplies water to both sub-villages.

Two ERT profiles have been acquired at Jimu. A north-south profile parallels the west edge of the hill north of the village center, then crosses to the east side of a small southern extension of the hill south of the village center. An east-west profile crosses the southern end of the main hill east of the village center, then continues downslope away from the hill to a small stream west of the village center. Very high resistivity values along the length of the north-south profile indicate the shallow presence of the quartzite. At some locations, the high resistivity values are recorded at the ground surface. These locations correspond to outcrops of quartzite. Similar conditions are present on the eastern part of the east-west profile. The resistivity section west of the village center is different than the other sections in the Jimu area. A continuous, shallow zone of low resistivity (25 to 40 ohm-m) is 10 to 40 m thick along the entire section. Beneath this low resistivity zone a zone of moderate to high resistivity varying from
300 to 1000 ohm-m, is much less than the 2000 to 5000 ohm-m in the rest of the area. We interpret the shallow low resistivity material to be weathered gneiss or alluvium. We interpret the high resistivity material below to be unweathered gneiss. On closer inspection of the profile and comparison to previous geologic maps, we interpret a narrow zone of slightly elevated resistivity near the center of the western profile as a weathered igneous dike.

Based on this analysis we recommended construction of a new borehole immediately uphill (to the east) of the dike, using the dike as a downstream barrier to water flow. The recommended location is on either side of the road leading into the village. This road also serves as the boundary between Jimu 1 and Jimu 2. Since the existing borehole is in Jimu 1, the villagers decided to locate the new borehole on the south side of the road, in Jimu 2. This decision was technically neutral, but was politically advantageous.

The new borehole at Jimu encountered 9 m of highly weathered quartzofeldspathic and biotite hornblende gneiss above 12 m of fractured gneiss and dolerite and 7 m of mostly weathered dolerite. Water was encountered at 28 m depth at the top of fresh, unweathered gneiss and dolerite to a total depth of 42 m. We expect that the weathered and fractured section will provide storage for fresh water to the borehole.

![Figure 7](image-url)

Figure 7. North-south (above) and west-east (below) profiles at Jimu on the south end of Chanda Hill. The lines were acquired in October 2017 as four segments radiating from the trading center at the center of the village. For continuity, the lines are shown linked together, but the interpolated profiles beneath the centers do not contain valid data. Both profiles are shown at the same distance, elevation and resistivity scales.
Figure 8. The same resistivity profiles shown in Figure 7 are displayed as two 3D panels. Inset is regional geologic map showing Chanda Hill quartzite (yellow) within the brown alluvial sediments of the Lake Chilwa basin. Green lines are igneous dikes. Position of the resistivity lines (red) are overlain on the inset map. The western line appears to intersect the southern end of an igneous dike.

Figure 9. Above, the same west-east resistivity profile shown in Figure 7 with location of probable igneous dike outlined. Below, the western part of the profile was reacquired in August 2018 and also shows an anomaly at location of igneous dike. The location of the new borehole is shown on this western ERT profile. The two profiles are shown at same distance, elevation and resistivity scales.
2.3.5 Kuchilimba

Kuchilimba Village is located on the north end of Chanda Hill. During initial conversations, villagers indicated that their borehole did not sustain continuous pumping while a nearby borehole gave a plentiful, continuous flow when pumped. In order to investigate the conditions at Kuchilimba, we acquired two ERT profiles: one perpendicular to the slope of the hill passing next to the existing borehole and continuing downslope. The second profile aligns parallel to the hill, but in the alluvial sediments at the base of the hill. This profile intersects the down-slope profile and terminates near the neighboring, good borehole. The low-resistivity (20 to 40 ohm-m) weathered zone similar to that encountered at Kimu and west of Jimu is also present in the slope-parallel profile and the lower parts of the down-slope profile, but is absent from the higher parts of the down-slope profile, at the existing borehole and above it. We interpret this result to mean that the existing Kuchilimba borehole is too close to the hill, whereas the neighboring borehole had been completed in weathered gneiss at considerable distance from the base of the hill. Our technical recommendation is that Kuchilimba re-establish their water source further downhill. Upon further conversation with the villagers our technically preferred location was criticized as too far from the village center, likely to be vandalized and difficult for transporting water back up to the village. However, the technical information from the ERT profiles provides a rationale for not reconstructing the existing borehole or deepening it. Instead, we have located a site at the edge of the village but still within the ERT-derived acceptable zone.

Figure 10. Resistivity profiles at Kuchilimba village on the north end of Chanda Hill acquired in October 2017. Above: west-east profile in alluvial sediments at base of hill are similar to resistivity values on the west end of the Jimu profiles. Below: north-south profile through center of village and passing existing borehole. The low-resistivity weathered zone begins north (downhill) of the existing borehole, suggesting that there is little saturated thickness within the borehole, probably contributing to poor quantity of water from this borehole. The location of the new borehole is also shown. The transition from weathered to fresh bedrock was encountered within a meter of position shown on resistivity profile.
The borehole constructed at this site encountered 9 m of soil and weathered gneiss above 6 m of fractured gneiss. This corresponds to the low-resistivity zone in the ERT profile and is similar to the materials encountered at Jimu, but without the dolerite. Below the fractured gneiss is 9 m of partly weathered gneiss, then a weathered biotite-hornblende gneiss saprock to the base of the borehole at 51 m. Water was encountered at 28 m near the top of the saprock. This borehole provides a continuous supply of high quality water.

3.0 Human element

3.1 Team leaders

Timothy Larson, Senior Geophysicist, Illinois State Geological Survey, University of Illinois
Dr. Larson served as Principal Investigator for this project and primary liaison with GWB. As an expert in geophysical methods, he taught a one-week seminar on applied geophysics, led the geophysical field work and interpreted the resulting profiles. He worked closely with Dr. Dulanya and Dr. Mwathunga to develop technically feasible locations for the boreholes in each village.

Zuze Dulanya, Professor of Geology, Chancellor College, University of Malawi
A senior lecturer at Chancellor College of the University of Malawi, Dr. Dulanya served as Principal Investigator at the local University and expert on the local geology. Dr. Dulanya supervised field work for the project.

Evance Mwathunga, Professor of Geography, Chancellor College, University of Malawi
Dr. Mwathunga is a lecturer at Chancellor College and expert on water management and water politics. Dr. Mwathunga provided liaison with local and regional administrative and political officials and worked directly with village stakeholders to determine exact location of each borehole. He also assists each village in developing governing structures for the new boreholes.

3.2 Other university faculty

Maurice Monjerezi, Associate Professor in Chemistry, Chancellor College, University of Malawi
The revised Water Resources Programme piggy-backed on an existing program without which there would have been project delays and unforeseen costs that would have derailed project implementation. As the coordinator for the WRMG Programme, Maurice provided valuable insights and support to the curriculum reforms.

3.3 University officials

Campus Principal Richard Tambulasi
Principal Tambulasi supported this project from the outset. Since its inception, there has been a lot of document exchanges by the partner institutions. The Principal was key in ensuring that the necessary paper work was done to the satisfaction of the implementers. He delivered the keynote address at the WRMG stakeholder workshop where he emphasized the importance of building cross-disciplinary collaborations if we are to resolve the severe challenges faced by rural people today. Later, he visited one of the drill sites and attended several of the ceremonies at the opening of the boreholes. Because the college has no official extension capacity, the Principal used this project to demonstrate how the academic community can give tangible assistance to their community.

3.4 Students

Steven Chanyenga
Steven teaches Geography at Malosa Secondary School. His primary focus of study is in water governance. His thesis examines how villagers’ perceptions of the quality of their water influences their
Steven participated in the applied geophysics seminar and in all the field work. He also conducted several preliminary field surveys to help us understand the challenges in each of the villages and to narrow our emphasis to the final four.

Joseph Saidi
Joseph teaches Chemistry at Balaka Secondary School. His primary focus has been the regional water quality. Lake Chilwa varies seasonally from brackish to saline. Groundwater recharging from the lake has high levels of salt and the water in many boreholes has very low quality. Joseph participated in the applied geophysics seminar and in all the field work. He also measured water quality parameters in boreholes and other water points throughout the region. This work helped us to understand the challenges in each of the villages.

Tryness Banda
Tryness has an academic background in water and sanitation. At the start of this project, she was working with a major NGO on water projects in the Central Region of Malawi. Currently, she is considering starting her own consultancy. Tryness participated in the applied geophysics seminar and in all the field work. She is using our geophysical data to investigate the saline water intrusion into soils in the Kachulu area.

3.5 Professionals
Ted Sonani
Ted Sonani is a groundwater consultant in the Zomba area. He is leading a regional project to develop a robust network of pump mechanics and pump parts so that villagers have a means of maintaining their boreholes. Ted supervised the drilling operations for us, contracting with the drillers and ensuring that the concrete aprons were constructed and pumps installed. He is also working with Dr. Mwathunga to establish water committees for each of the boreholes. Ted was familiar with VES electrical methods, but the 2-D ERT methods were new to him. Skeptical at first, he was impressed with the precision that we could achieve in predicting the thickness of the weathered zone at each site. In the end, he went out of his way to make sure we had a quality drilling company to complete the difficult borehole in the sandy soil at Likapa.

3.6 Local government: District Commissioner, chiefs
Zomba District Commissioner Emmanuel Bambe
Early in the project, long before we began geophysical field operations, we met with Commissioner Bambe to explain our project. He was happy to support a project that intended to benefit what he knew to be water-poor villages in the district. He gave us a letter of introduction, and later, when we were having difficulties securing a drilling contractor, he introduced us to Ted Sonani.

Village chiefs Jimu, Kimu, Likapa, Kuchilimba
Throughout the project we worked closely with all the village chiefs, keeping them informed as to the progress of the project and notifying them whenever we were to visit their villages. They each enthusiastically supported our work and assigned villagers to work with us while we were collecting data. Chief Kimu was particularly active in the project, having lunch provided for us during our field days. These relationships were important when it came time to finalize the borehole locations. All of the locations not only met our technical criteria, but were personally approved by each respective chief.
3.7 Villagers: water committees
Some of the villagers who worked with us did so at the request of the chief and because we offered to pay them for the day’s work. Others were clearly much more engaged in the project and had a stake in the outcome of the projects. At Kuchilimba and Jimu, both in the Chanda area, the local pump mechanic was involved in many of our conversations and field days. The chairwomen of the existing boreholes at Kimu and Kuchilimba were strong advocates for their villages. They were present at all our meetings and participated in our field work. When we were suggesting that our technical information was leading us to a borehole location northwest of Kimu, it was the strong objections of the chairwoman that called us back to Kimu where we eventually located a good borehole. Similarly, it was the persistence of the Kuchilimba chairwoman who continued to negotiate with us to locate a borehole in Kuchilimba at a site that was technically feasible, yet reasonable for the villagers. Because we listened to them, and modified our plans to meet their objections, we believe that they will be motivated to cherish and maintain these new resources.

4.0 Lessons Learned
4.1 Administrative challenges
4.1.1 System of pre-proposal/final proposal
The time allowed by GWB between the notice of acceptance of the preproposal and the thirty day deadline for submittal of the final proposal was very short, particularly for such a complicated proposal involving two very diverse universities. This was aggravated by the standard university practice that administrators and accountants do not review pre-proposals. As a result, implications of some aspects of the agreement, such as the subcontract payment schedule, were not fully appreciated until the contracts were being negotiated. This led to considerable delays in starting the project. Similarly, throughout the project, any change to budget or scope required considerable paperwork at the university with attendant delay in execution.

4.1.2 The two universities had different management styles and expectations
Malawi is typically a cash-based society, with little reserve for credit operations, therefore there is a strong need to be paid up-front. On the other hand, the University of Illinois’ standard accounting practice assumes payment for sub-awards occurs at the end of the project. But, since University of Illinois was receiving funds up-front, we were able to negotiate a process to pass these funds through to Malawi. It would have been useful to have been able to resolve these issues and set up both the primary and sub-accounts before the start of the project. Even though the award was announced six-months before the start of the project, the subaward was not finalized until several months after the start of the project.

4.2 Curriculum development
An important goal of the project was to enhance the existing Water Resources Program at the University of Malawi. This goal was under-budgeted and under-scoped in the original proposal. After discussions in April 2017, it became clear that a stakeholder workshop would be necessary to provide input to justify revisions. Fortunately, we were able to revise the year one budget to fund this important meeting. As a result, we were able to justify adding geophysics to the curriculum because geophysical surveys are commonly required by NGO’s and government agencies before new boreholes are sited or permitted.

4.3 Equipment
Because the equipment was to be owned by University of Malawi, the original budget assigned this cost to the subaward. But it became apparent that this would be very difficult to execute, so the
cost was reassigned to the primary awardee. In the end, this was a good decision, but it resulted in
several month’s delay in executing the subaward because of the required approvals needed to make this
change to the budget. Finally, we arranged for a third-party purchase by Illinois for Malawi.

When it arrived, the equipment was faulty. This was a major problem because only T. Larson
had sufficient expertise with the equipment to recognize and troubleshoot the problem and his time in
Malawi was very limited. Initially there were two problems. An interconnect cable was not included in
the shipment even though it was listed on the invoice. This was resolved fairly quickly, but it also
entailed about a week’s delay in the first field survey as we waited for the cable to be shipped from
Sweden.

When the interconnect cable finally arrived and we were able to test the instrument, we
realized there were additional problems with the system. Sixteen of the 64 electrodes failed to connect
to the system. At first we thought that this was a field problem caused by inadequate electrode contact.
But the same electrodes failed all the time regardless of the physical connections on the ground.
Unfortunately, the failed electrodes included the 5 outer electrodes on each end of the spread so that
our Wenner-array configuration was very limited in its depth of penetration. After extensive tests in the
field we determined that there was nothing wrong with the electrodes or the cables. We implemented a
partial work-around by turning off the bad connectors and repeating the initial data sequence at each
incremental location along the line instead of applying a standard roll-along sequence. This gave us
adequate data coverage at shallow and medium depths, but didn’t penetrate to deeper depths. After
the field season we sent the instrument back to the manufacturer. Their testing found a minor fault with
the instrument, which they fixed, tested and returned.

We then re-configured our field time to allow for more geophysical data acquisition on our
second field trip which should have been devoted to conversations with the stakeholders about exact
locations of the drill sites. We did have sufficient data to conduct some of these conversations. We
agreed on a tentative site at Jimu. At Kimu, the villagers requested that we do further studies east of the
existing borehole. At Kuchilimba, the preliminary data revealed that their existing borehole was too
close to the hill. This led to a lengthy negotiation with the villagers to agree on the location of a new
borehole that was further down the hill and thus likely to encounter good aquifer materials while still
being close enough to the main part of the village for convenience and security. The original data at
Likapa was very poor. We were glad to have the opportunity to acquire more data in the sandy soils
along the coast.

However, when we began to acquire more data at Kimu and Likapa we found the same errors
reoccurring. This time we were able to trace the problem to incorrect cable connectors originally
supplied with the system. The manufacturer agreed with this assessment and sent new connectors.
These did not arrive until after the second field season was concluded. The final field trip did not have
any time scheduled for geophysical data acquisition, only drilling. But without the final, definitive data
acquisition, we could not make firm drilling recommendations at three of our sites. Fortunately, the
manufacturer was willing to provide credit on the purchase of the equipment to allow us to extend the
field trip two additional weeks. Finally, the equipment worked correctly without the field work-around.
We collected new data at Jimu, Kimu, and Likapa. These new data sets allowed us to confidently choose
borehole locations at these villages.

4.4 Students and tuition
An early challenge in the project was to recruit and fund graduate students. Because of the
delay in starting the funding caused by administrative issues at Illinois, we decided to recruit students
already in the Water Resources Program. This assured that we would have qualified applicants. We
interviewed five students in April 2017, offering stipends to four of them. After discussions, one student
dropped out and we continued with three students. This allowed us to extend a greater stipend to each
student and to repurpose the original budget to other important tasks. However, further delays in transferring funds from Illinois to Malawi resulted in losing a full year of tuition funding. Using other funds we were able to cover this temporary shortfall until the money arrived from Illinois. Better planning would have reduced this problem.

4.5 Drilling Contractor

There are no drilling machines in Zomba district. The closest drilling contractors are in Blantyre (2 hour drive) or Lilongwe (4 hour drive). Our drilling contractor had a mechanical failure the week before drilling was to commence and was not available. Normally this would not be a problem in Malawi, but we wanted to complete as much of the drilling as possible while T. Larson was available. We had to search for a new contractor. To do this, we first needed a groundwater consultant to broker the contract with the drillers. Upon the recommendation of the District Commissioner, we contacted Ted Sonani, who had experience in our field area. He worked with us to find a new driller from Blantyre and negotiate a contract with him. This was difficult because in order for the drillers to accept a new job on short notice, they demanded a very large percentage of the payment up-front. However, the university wanted a small up-front payment or a large assurance bond. Eventually, we were able to execute a contract for 2 of the 4 boreholes and completed these 2 during the available field time. The technical information provided by our geophysical surveys and the good working relationships we had developed with the villagers combined to make both of these boreholes very successful and gave us confidence that we would be able to achieve similar success at the remaining 2 boreholes. Eventually, the team was able to come to terms with another contractor who worked hard to construct successful boreholes at the remaining sites. In the end, we were pleased with the results of the drilling and Ted Sonani will continue to work with the villagers to develop maintenance procedures.

5.0 Conclusions: impact on local community

This project had impacts at two levels: at Chancellor College and in the rural villages. For Chancellor College, this project has provided the opportunity to review and revise their existing Water Resources Program. The stakeholder workshop catalyzed changes to align the program more toward the needs of the program’s stakeholders. The Water Resources Program is, in theory, interdisciplinary. This project has been devised to facilitate practical interdisciplinary collaboration. Student projects have emphasized chemistry and water management as well as incorporating geophysics. Instead of using only the technical results of the geophysical surveys to dictate the locations of the boreholes, we have engaged the local villagers as partners in the siting process by employing established water management tools such as Participatory Rural Assessments. Because Chancellor College has no formal outreach program, this project was an important means of demonstrating commitment to the local constituency, both with the District Commissioner and with the individual villages.

As a result of the careful technical and social work that was done on this project, we have been successful in completing boreholes at all four villages. The new boreholes will alleviate crowding at Kimu and Jimu and will provide a reliable water supply at Kuchilimba. The plentiful, fresh water at Likapa will be a benefit to a community with otherwise relatively poor water quality. Through this project these villages have established ties with local borehole maintenance and management networks to assist them in maintaining their new boreholes.
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
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<tbody>
<tr>
<td>March 28, 2016</td>
<td>Receive notice of preliminary acceptance</td>
</tr>
<tr>
<td>June 16, 2016</td>
<td>Receive notice of final acceptance</td>
</tr>
<tr>
<td>January 30, 2017</td>
<td>Execute award</td>
</tr>
<tr>
<td>February 8, 2017</td>
<td>Execute sub-award</td>
</tr>
<tr>
<td>March 2017</td>
<td>Revise award so that equipment is purchased by Illinois, but owned by Malawi</td>
</tr>
<tr>
<td>September 2017</td>
<td>Execute revised sub-award</td>
</tr>
<tr>
<td>February 2018</td>
<td>Revise Year 2 budget to formalize carryover from Year 1 and adjust amounts</td>
</tr>
<tr>
<td>April 2018</td>
<td>Execute revised sub-award</td>
</tr>
<tr>
<td>June 2018</td>
<td>Revise Year 2 budget to include credit for equipment malfunction</td>
</tr>
<tr>
<td>July 2018</td>
<td>Execute revised sub-award</td>
</tr>
<tr>
<td>November 2018</td>
<td>Revise Year 2 budget to sweep remaining Illinois funds to Malawi to pay for drilling</td>
</tr>
<tr>
<td>January 2019</td>
<td>Final fund transfer</td>
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</table>