# FINAL TECHNICAL REPORT

# GROUND WATER MONITORING SYSTEM

CYBERNAPTICS LTD

*This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*

## Project factsheet information

| | |
|---|---|
| **Project title** | *Development of a proof of concept (POC) for an affordable method of monitoring ground water level resources in remote areas in Africa*. |
| **Grant recipient** | Cybernaptics Ltd<br>Taylorsmith House, Old Quay D Road, Port Louis<br>Phone +230 206 3950, fax +230 206 3951<br>www.cybernaptics.mu |
| **Dates covered by this report** | 01 – 07 – 2013 / 30 – 05 – 2014 |
| **Report submission date** | 03 – 06 – 2014 |
| **Country where project was implemented** | Mauritius |
| **Project leader name** | Dr. Viv Padayatchy, viv.padayatchy@cybernaptics.mu |
| **Team members (list)** | Dr. Emilio Saldivar, Emilio.saldivar@taylorsmith.mu; Sona Gokhool, sona.gokhool@cybernaptics.mu; Brian Malecaut, brian.malecaut@cybernaptics.mu |
| **Partner organizations** | Water Research Ltd |
| **Total budget approved** | 10,000 USD |
| **Project summary** | Development of a proof of concept for a low cost ground water monitoring system. The project relies on |

integrating readily available components and open source software. The project also makes use of the GPRS/GSM cellular network for transmission of data between the Data Collection Unit and the monitoring server.

## Table of Contents

# Project Summary

Ground water is a critical resource for any country. It provides fresh water supplies for domestic, agricultural and industrial uses. However, the danger of over utilisation (known as over abstraction) can lead to depletion of reserves faster than its replenishment rate and loss of the borehole or, even worst, environmental problems such as subsidence of terrain.

Monitoring of ground water in developing countries remains a challenge because of various factors such as limited monitoring resources (staff), geographical spread of bore holes over large areas, accessibility etc. The aim of this project is to develop a prototype for a low cost solution for a fully automated and autonomous monitoring system. By being low cost, fully automated and autonomous in terms of energy supply, we shall ensure that the system can be can deployed on a large scale at an affordable cost.

In terms of architecture, the system consist of a ruggedized stainless steel water level sensor which feeds its output into a micro controller via some signal conditioning device. The micro controller converts the analogue signal into a digital reading and saves it onto a data logger. The data logger then, intermittently (every 2 mins), transmits the data via the cellular network onto a monitoring server. Finally, a web interface allows the user to query the data and graphically display the water level fluctuations for any given period.

Since the device is designed to be installed in remote areas, it needs to be mounted inside a weatherproof enclosure. It also need to be automous in terms of power and, hence, the final prototype provides for a solar powered unit with a 12V battery.

# Background and Justification

Ground water is a vital natural resource which requires careful monitoring and management for sustainable development. This applies equally to both developed and developing countries alike. Recent studies in the SADC region (IGRAC, 2013) have shown that at least 70% of the population in the member countries relies on ground water. However, while developed countries have implemented extensive monitoring systems to manage their underground water resources effectively, this still remain a challenge in the case of many developing countries (Hansen, 2011). Furthermore, ground water is a renewable resource whereby the aquifer (underground water reservoir) gets replenished from rain water percolating through the soil and rocks. For sustainable development, the rate of extraction should not exceed the rate of replenishment which would, otherwise, lead to over abstraction of underground water. Over abstraction can lead to various kind of environmental problems such as drying up of surrounding rivers and springs and subsidence (K. M. Hiscock, 2002).

The purpose of this project is to develop a low cost underground water monitoring system that can be readily deployed anywhere with relative ease. This would make it a viable candidate for mass deployment in developing countries. One of the key aspect of the project is that the measurements of ground water level is relayed to a web server by a telemetry system running over the GPRS network. The cellular network is the most pervasive telecommunication network in Africa and, by using the lowest bandwidth GPRS over GSM or 3G, we ensure universal connectivity across a wide range of signal quality. By using readily available components and open source software, we have aimed to reduce costs even further. The scope of the project is limited to the development of a proof of concept and, therefore, a large component of the cost went towards the research and development linked to the project.

*This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*

# Project objectives

The overall objective of the project is to develop a proof of concept for the following:

1. Data Collection Unit (DCU)

The data collection unit will consist of the ground water level sensor, analogue/digital signal conversion, data storage and processing device and data transmission device using the cellular network. The DCU will also include the solar panels, charger and batteries for power the devices.

2. The Data Collection Server (DCS)

The data collection server will consist of a rugged industrial rack mounted linux or FreeBSD server that will collect all the data from the DCU into a central database. It will compile the data into reports and present them to monitoring staff via an internet based web server.

## Users and uses

The key users of such a system are;

1. Government

The department in charge of water resource management will find this solution extremely useful to monitor their reserves, usage and replenishment of underground water. Its low cost and design for remote and isolated locations make it a good candidate for mass deployment.

2. Farming community

The farming industry is a major user of underground water for irrigation and animal husbandry. They will find our monitoring solution very useful to monitor their reserves from their own borehole.

3. Industry

Several industries like beverage, food processing, manufacturing etc. relies on bore holes. Therefore, they too will find a monitoring tool very useful.

4. Private Individuals

In some countries where the national water distribution network is not well developed or reliable, individuals resort to their own private boreholes. Our system should be useful to them too.

**Final Technical Report**

# Indicators

| Baseline | Indicators | Progress | Assessment | Course of action |
|---|---|---|---|---|
| - Absence of ground water level monitoring | 1. Installation of measuring probe<br>2. Data Logging<br>3. Telemetry<br>4. Website development to display data<br>5. Migration to solar power | At the time of writing, Indicators 1 to 4 have been fully achieved. Indicator 5 is still outstanding | So far, all systems are working and stable.<br>We want to collect a bit more data before we complete indicator 5 | We need to prepare the measurement station to migrate to 12V battery and Solar Panel charger. |

# Project implementation:

*Problem statement: To develop a proof of concept for a low cost ground water monitoring station with telemetry (data transmission) capabilities using the cellular network.*

To implement this project, we collaborated with another company, *Water Research Ltd*, which specializes in bore hole drilling and maintenance. The project started out with the selection of an appropriate site in Mauritian. Eventually, we settled for a site known as *Trianon*, located in the north-western region of Mauritius (see below)

Bore hole location, Trianon

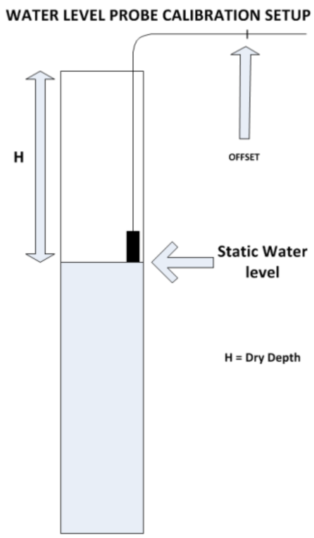

The bore hole selected was 34 meters deep and fitted with a submersible pump (see below):

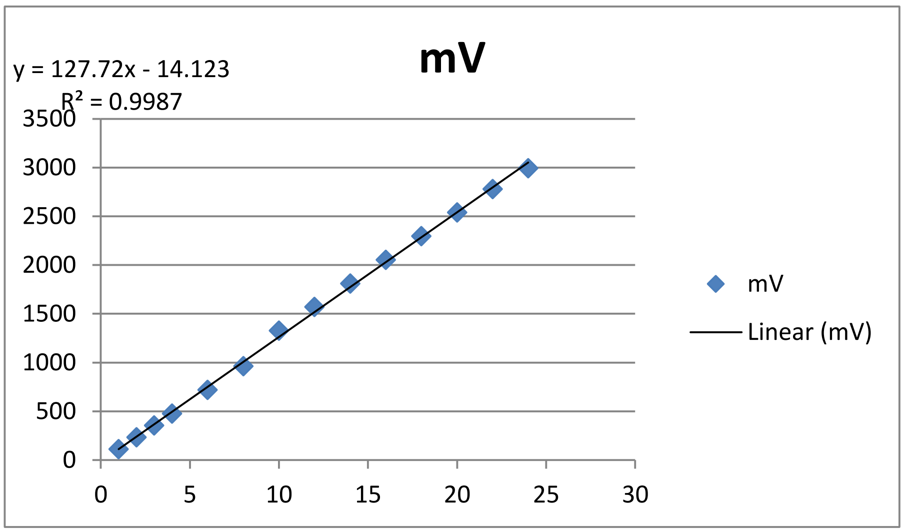
This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013

Water Level Probe Characteristics

The probe used for this project is a 3-wire LMP 307 sensor from BDSensors (Germany). This probe was chosen for its ruggedness and corrosion-resistant construction and its output signal linearity over the measurement range.

Calibration of Sensor Probe:




This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013

The probe was calibrated by lowering it at known depths in the well and measuring the output signal. From the readouts, the following linear relationship was established between output signal (mV) and water depth (mH2O).

Lowering of probe in the board hole

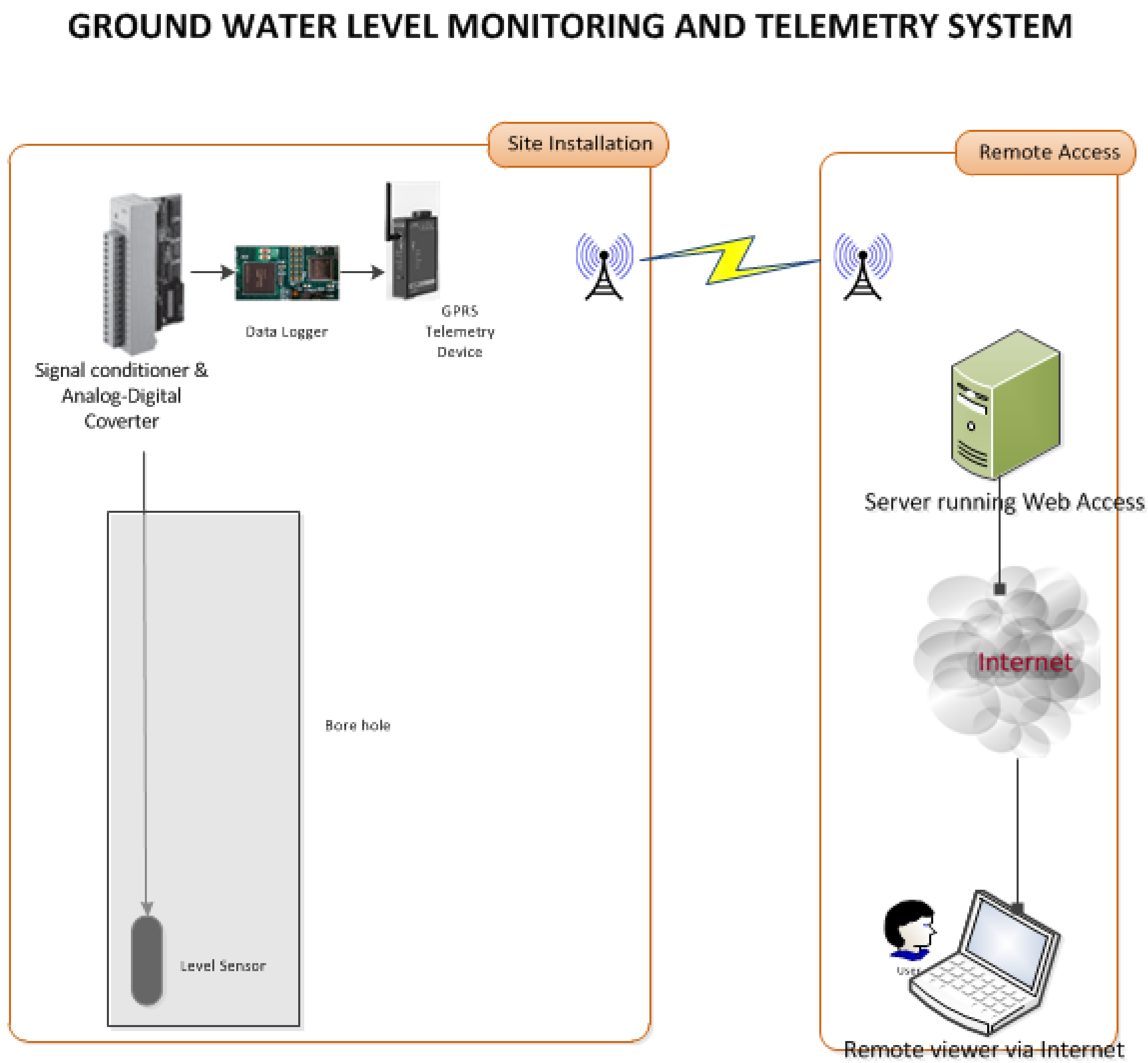
Probe Calibration


Device electronics mounted inside enclosure

Weather proof enclosure housing all sensitive electronics.

*This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*

# Project Schematic




This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013

| Input | Project activities | Outputs | Outcomes | Timeline | Status | Assessment |
|---|---|---|---|---|---|---|
| Collaboration of Water Research Ltd | Selection of bore hole, site preparation and general advice on the project. | Bore hole selection and site preparation | Allow for implementation to proceed on site | July 2013 | Completed | This activity was a critical milestone and it was completed successfully thanks to the participation of Water Research |
| Acquisition of Measuring probe and related electronics | Installation and Calibration of probe | Water level probe calibration | First stage of proof of concept achieved. Allowed us to move to the Telemetry part | August 2013 | Completed | Probe calibration was effected on site jointly by staff of Water Research and Cybernaptics. Readings were taken by lowering the probe at various measured depth and output signal (in mV) was recorded. |
| Acquisition of Telemetry Equipment<br><br>Software developer | Installation and testing of telemetry device<br><br>Data streaming control software | Telemetry Activation<br><br>Data Streaming | This result allowed us to demonstrate the capability of this system to be remotely deployed.<br><br>Without the telemetry functionality, data collected will have to be manually downloaded from the data logger. This is both expensive and time consuming. It is also not suited for real time monitoring. | September 2013<br><br>October 2013 | Completed | Installation and testing of telemetry system was carried out by Cybernaptics |

This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013

| | | | | | | |
|---|---|---|---|---|---|---|
| Final site installation works. Acquisition of a UPS for the power supply | Securing the electronics components in an IP65 enclosure and tidying all cables and power supply.<br>Stabilising the power supply with a UPS | Equipment is secured | Protection of the recording device was achieved in a metal weather proof enclosure which also offers protection against tampering. | October 2013 | Completed | Final site installation was completed by Cybernaptics |
| Software Developer | Development of a web site to collect and display the ground water level data | Web site creation | Creation of the website allowed the user community to interact with the system and become aware of its capabilities | October 2013 | Completed. Web site available at http://gwms.cybernaptics.mu | Web site development was achieved by Cybernaptics |
| Staff resources for monitoring | Data Collection | Historical Data | Historical data will serve as the final demonstration that the proof of concept works | Nov 2013 – Jan 2014 | Done | Data collection and monitoring is being jointly performed by Cybernaptics and Water Research |

*This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*

| | | | | | | |
|---|---|---|---|---|---|---|
| Acquisition of Solar cells, charger and battery | Installation of solar powered energy source and modification of device electronics to function on same | Solar Powered Unit | The outcome of this milestone will demonstrate that the system can run off the power grid. This is especially important for remote areas not equipped with electricity | August 2014 | Pending | We ran into difficulties with the solar equipment that we chose. First of all it took us a while to find the right equipment with the appropriate features in terms of voltage and current output and at the right price for a project of this type.<br><br>We carried out a few trials with equipment that performed poorly. We have ordered another set with a different supplier that we will be receiving in June 2014.. |

*This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*

## Project outputs, communication and dissemination activities

| Project outputs | Status | Assessment | Dissemination efforts |
|---|---|---|---|
| Bore hole selection and site preparation | Completed in July 2013 | We decided to choose an existing bore hole in order to minimise costs. The criteria for selection were:<br>1. Easy accessibility<br>2. 40 m depth or less (to keep cost of cabling down)<br>3. Availability of power supply (required in the initial phase of the project)<br>4. Not dried up | This site is intended to be used as a demo site to bring in potential users of the system. |
| Water level probe calibration | Completed in August 2013 | Calibration was successful as the probe demonstrated almost perfect linearity between water level and signal output within the measurement range. | Calibration data will be kept for demonstration purposes to potential users |
| Telemetry Activation | Completed in September 2013 | Transmission successful as confirmed by receipt of data bytes on our server | |
| Data Streaming Control software | Completed October 2013 | Development of the client and server communication software over UDP protocol using python programming language. The Streaming software makes use of UDP communication protocol to minimise transmission overheads and maximise payload. This is important to reduce communication costs on the GPRS/GSM data network. | The data streaming software will be published as open source. |
| Securing Equipment | Completed October 2013 | In order to protect the equipment from weather, tampering and vandalism, we enclosed it in an outdoor weatherproof metal enclosure fitted with a fan for heat dissipation. Therefore, we had to adapt the equipment to become mountable in such type of enclosure. | The measures taken to secure the equipment enhances its suitability as a rugged device fit for installation in remote areas. |
| Web site creation | Completed October 2013 | The web site is an essential component of the project in order to provide a platform for the user to visualise and interact with the monitoring system. | The website is expected to become the key communication tool for the project. Eventually, we will enhance it to include other information about the project. |

*This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*

| | | | |
|---|---|---|---|
| Historical Data | Nov 2013 – Jan 2014 | Collection of historical data is part of the project and is a key milestone to demonstrate that the proof of concept is working. We have set ourselved a target of collecting 3 months of historical data. | The historical data feeds into the website and demonstrate the capabilities of the system. |
| Switching to Solar Power | Pending | This is the final stage in the project whereby the device will be modified to work from a 12V supply which is connected to a solar panel charger<br><br>Unfortunately, we have been delayed on this since the equipment we received performed poorly and we have had to order to a new set of panels and electronics.. | Switching to solar power is our final goal in making the system completely independent. This is in line with our intention to design the system for installation in remote areas with poor accessibility. |

## Project Outcomes

The project outcomes can be described in terms of the following criteria:

Economic

This project has demonstrated that it is possible to use low cost hardware and open source software to develop a complete turnkey system for monitoring ground water. This should make this project easily scalable for mass deployment in Africa or elsewhere.

Social

This project was about building a low cost prototype as described earlier in the report. Therefore we have not measured the social impact of the implementation of such a ground monitoring solution on a community. This would have to be done in a separate project based on careful selection of the target population.

Environmental

This is no doubt one of the major outcome of this project. We have successfully demonstrated that ground water, an essential life supporting resource, can be managed using common available parts and software and at minimal costs. Judicious management of a country’s water resources can have tremendous positive impact on its environment.

## Project Management

The project administration was relatively straightforward in terms of keeping track of materials and labour costs on this project. However procurement was challenging for the following reasons:

a. Lead time:
   Most of the parts are ordered from Europe, US and Asia (Hong Kong and China) which are all far from Mauritius leading to long lead time.

b. Experimental nature of the project
   Being a new and experimental project, most of the parts and equipment were being purchased for the first time. Therefore, we had no history of suppliers reliability or even the reliability of their parts. Sometimes, due to wrong decision on design we had to back track and reorder different parts hence delaying the project.

As far as human resources are concerned, our collaboration with Water Research allowed us to draw on their pool of labout for the site installation works and calibration. We used our programming resources for web development, the telemetry software and embedded software for the data logger.

The FIRE program has enabled us to develop our skills in Team Building and Research and Development. From an initial project concept (ground water monitoring), we learned to choose the right partner and assemble the skill set for implementation. Because we required multi-skills for this project, we also learned a lot on project coordination and planning.

Another skill that has benefited the FIRE team at Cybernaptics has been the will to persevere. There has been times where it was felt that we were going nowhere with the project. Equipment would not work, software would not run and results were missing. However, despite the setbacks, there was a common will among our staff and those of our partners to complete the project and show the world that we could do it.

Finally, the greatest impact of the FIRE program on Cybernaptics, by far, has been the acquisition of new skills in the area of embedded system programming and instrumentation. This was an area we wanted to explore for a number of years but we only the chance to do it thanks to the FIRE program.

## Sustainability

Although the initial cost of the project itself is relatively high, one has to remember that most of that cost got sunk into the research and development effort that went into designing the solution. Scaling up the proof of concept from a prototype status to a fully commercial solution should result in bringing down the cost significantly.

The sustainability of the project is ensured by the fact that the project fulfils a very basic and critical function which is ground water resource monitoring. We have increased its sustainability even further by taking the following considerations into account:

Cost:
The project has been implemented using readily available and low cost components and using open source software throughout the project.

Ruggedness:
The whole installation is mounted in an IP65 weatherproof enclosure to prevent water and insect ingress, tampering and vandalism.

Use of cellular network:
The cellular network is the most pervasive telecommunication network in Africa (Mbiti, 2010). Therefore, rather than adding radio transmission capabilities for telemetry, we have preferred to use the GPRS/GSM network instead. Therefore, this has allowed us to keep costs down while ensuring an almost universal deployment foot print in most countries. However, it is true that if there is no cellular network coverage, the telemetry functionality will not work.

Off grid functionality:
Although the current prototype is still dependent on the electricity mains, the final design will allow the system to power itself from a 12V DC battery supply which will be continuously recharged via solar panels.

*This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*

## Impact

The impact of the ground water monitoring project is best described in terms of impact areas:

a. Development Impact

Water is an essential resource for any government. Therefore, good management practices of that resource is critical for development. Monitoring of ground water is therefore bound to become more and more integrated in the overall water resource management policy of developing countries. We are therefore confident that our solution will be able to attract the attention of governments, development agencies and other organisations directly or indirectly linked to water resource management.

b. Social Impact

Bore holes are, very often, the only source of water for domestic and agricultural usage in rural areas. Therefore, we expect our solution to be of practical importance to those communities in helping them to better manage their water resources. Hence the social impact of our project will help to create a need for it and, hence, ensures its sustainability.

c. Economic impact

Various sectors of the economy such as agriculture, manufacturing, hospitality and food industry are all dependent on a regular supply of potable water. In many cases, this water comes from underground. These stakeholders may have a direct interest to install and use their own monitoring system and our solution may provide them with an affordable alternative.

T*his work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*

## Overall Assessment

So far, the project has met all but one objective. The last objective which is pending is the migration of the entire system to a solar powered battery system. The proof of concept has successfully demonstrated the key functionalities we set out to demonstrate at the project onset. These are continuous water level measurements, digitising those readings onto a data logger, forwarding the data at programmable interval to a data streaming system transmitting over the GPRS/GSM network and, finally, storing and display the live readings on a web server. The whole project was realised by integrating low cost components and open source software. The final objective, i.e. migrating to solar power, was left for last since we wanted to collect some test data and evaluate the overall system performance first. Unfortunately we have accumulated delays in choosing the right equipment for powering the device. The initial solar panel and charging device did not work well and we have had to order a new set of panels and electronics from a new supplier. We expect that we shall receive the equipment in June and complete the installation in August.

The project itself has revealed that is can be adapted and extended for other situations and needs beyond just ground water level monitoring. For example, the water level probe can easily be adapted to measure any liquid level in an enclosed container. We have had interesting discussions with Petroleum companies in Mauritius who have declared an interest in using our solution for monitoring fuel sales in petrol stations for the purpose of adjusting their supply chain for replenishment. Similarly, we have had interest from the Mauritius Meteorological Services to use our solution to monitor rain gauges in over 125 sites within the country.

This project has the potential to make a significant contribution to the problem of ground water monitoring in Africa and other emerging economies by proving real time and accurate data to water resource management agencies. To this end, we intend to take this project to the next level in Africa by approaching the SADC chapter of the International Ground Water Resource Assessment Centre (IGRAC), http://www.un-igrac.org. We hope to attract the attention of SADC resource people who are concerned with ground water monitoring and management.

The success of the project was largely determined by the fact that the system integration of the various components of the monitoring system was achieved by software. This allowed Cybernaptics to leverage its software engineering capabilities to integrate all the project components successfully. Also, this allows us to easily adapt and enhance the system according to specific requirements that may arise in the future.

This project was, in essence, a research and development assignment. It started out with a concept that was meant to solve a real world problem (ground water monitoring). From that concept and initial objective, the team had to research the most cost effective and, yet, the most appropriate design to solve the problem. The design work cut across various disciplines such as electronic and software engineering and underground water drilling and management. The skills acquired on this project will certainly be of value for similar projects that may be undertaken by the company in the future.

Finally, there are some areas which will need to be improved.

Firstly, it is necessary to reduce the system's power consumption if we want to migrate to a battery system. The most energy demanding activity is data transmission. At the moment, data transmission is being effected every 120 secs. Increasing to, say, one transmission every 5 mins will help save power..

Secondly, it will be nice to modify the system to read other sensor data such as electrical conductivity (for water quality) and acidity (pH). This will increase the usefulness of the monitoring system into a mini “lab-in-a-box”.

Thirdly, if this project is going to be scaled up, it will be best to have the electronics component surface mounted on a circuit board rather than soldering them manually. Although that might increase the costs slightly, it will improve the overall robustness of the system.

The website will need a lot of improvement. We need to add more background information on the monitoring system such as its characteristics and features. We will need to make the system multi user with access rights to protect privacy and confidentiality of information for the parties’ data.

Finally, the data transmission software could be enhanced for better error correction during transmission. At a later stage, we could even enable encryption of data for sensitive information.

## Recommendations

Thanks to the FIRE program, we have had the opportunity to explore the real of embedded computing and apply it to a real life problem which is ground water monitoring. Although, overall, we feel that the program is well managed and we have been quite happy with the secretariat, we would like to make the following recommendations.

Organisation:

We had to submit our MoU three times. The first time, it seems that the format given to us was not the right one so we resubmitted. Then there was a staff change in the organisation and we had to resubmit again. As a result, there were significant delays in the disbursement of funds to start the project.

Sustainability:

We think that sustainability of projects is a key criterion and will determine the future success of the FIRE program. Therefore, some help or guidance in this area from the program organisers will be most welcome.

Marketing:

In order to promote the project, the participants will need to engage in promotion and marketing both within and outside their borders. It will be a great help if the program organiser can provide a platform to showcase our projects and obtain media coverage.

## Bibliography


Hansen, L. J. (2011). Regulating groundwater use in developing countries: a feasible instrument for public intervention. *Institute of Food and Resource Economics*, 3.

IGRAC, I. G. (2013). *Groundwater Monitoring in the SADC Region.* Stockholm: Stockholm World Water Week 2013.

K. M. Hiscock, M. O. (2002). Sustainable groundwater development. *Geological Society, London, Special Publications*, v. 193;p1-14.

Mbiti, J. C. (2010). Mobile Phones and Economic Development in Africa. *Journal of Economic Perspectives*, 24(3): 207-32.


*This work has been developed with the support provided by the FIRE PROGRAMME – 2012-2013*