WATER FLOW MONITOR
A
COLABORATIVE DESIGN

Authors:

Andrew W.S. Ainger
Mike de Haaff

Date: 8th March 2017

With contributions from:

- Peter Jennings
- Brian Skinner
- Maurice Smith MBE

COMPANY DOCUMENTATION CONTROL

This file is authorised for use on BTecNet, Intranet.
Authorisation for this document is BMS Change Process.

This page left blank.

CONTENTS

1 EXECUTIVE SUMMARY

This document details the design and development of a water flow monitor for use on hand-pumped Wells.

The water flow monitor has to: last for over a year with no maintenance: be low cost; be easy to fit and retro-fit to hand-pumped Wells: be capable of sending its totalized water data information to a remote central point; be designed such that it can be assembled and repaired by locally trained staff and later, be considered for commercialization.

General research in this area shows high levels of activity but, to-date, little practical output. This paper is updated on an ongoing basis and as such represents the current thinking of the authors.

In summary, the electronic unit of the Well Water Monitoring Service will: Monitor the *time* the Well's pump is active; store the measured cumulative value locally; convert the stored digital number into speech; transmit this value to HQ every 24hrs; enable the Well to 'phone HQ on demand and leave an answer phone message of the Well-Time data; send to HQ the location coordinates of the Well's electronic unit upon demand; be designed such that it can be assembled in-country and finally, the Well's electronics unit will be able to announce, in English and Swahili, its identification name and ID number over the mobile telephone network.

Significant changes have been made to this document since this its initial draft version several months ago. There have been two main drivers for these changes: *Cost* and the *Power-Budget*. For example, the initial twin frequency approach to monitor pump-action and water-flow has been replaced by monitoring just one frequency band. This will enable the unit to monitor the *time* the Well's pump is being used. From the *time*, together with a detailed calibration process, it will be straightforward to derive the amount of water pumped. This approach saves both cost and electrical power.

To save more power, other parts of the electronics unit are put-to-sleep when they are not needed. The power-budget is still a concern but it is much improved by this approach.

The new approach of: single frequency combined with power conservation has changed the block diagram and the operating procedures from the initial concept significantly. These changes are most obvious in Section 2 where the operational activities of the User are outlined.

2 A-DAY-IN-THE-LIFE-OF THE: WATER FLOW CONTROLLER

In systems design it has been found beneficial to start with a use-case scenario. For example, we will outline a typical day in the life of the *Well Water Flow Controller*, the guy in operational charge at Head Office. (The Head Office Team consists of a part-time *Finance Director*, the full-time *Water Flow Controller* and a part-time *General Assistant*.) This use-case scenario helps refine the system specification and has highlighted gaps in our thinking thus improving the systems design. But first, a general outline of the operation of the Wells electronic unit and operating procedure.

When the Well starts pumping the sound it makes is detected. The time the Well is in operation is stored cumulatively into a calculator unit. Once a day the Wells electronic unit wakes its phone circuitry and the Wells time-count is played into the phone module together with the Well's name and ID number. It is this time-count that the operator listens to and records into a spreadsheet. Through the Well's calibration process the time-count is then converted into water flow volume and it is this that is displayed in the spreadsheet charts.

Thomas was very pleased with himself, two months ago he had been appointed the Water Flow Controller of the Well Monitoring Service in Dodoma. Thomas, in his mid-30s, was easy to get on with, quick to learn and eager to please. He had used a computer and mouse to access the internet and has already sent reports in both Word and Excel. Thomas has a reasonable command of English although his mother tongue is Swahili.

From the reports Thomas has sent in Excel it is clear that he has a good understanding of the navigational principals required to use Excel. However, if he needed more information on certain aspects of Excel he knew he could contact a colleague from the Well Monitoring Service in Tanzania or in the UK.

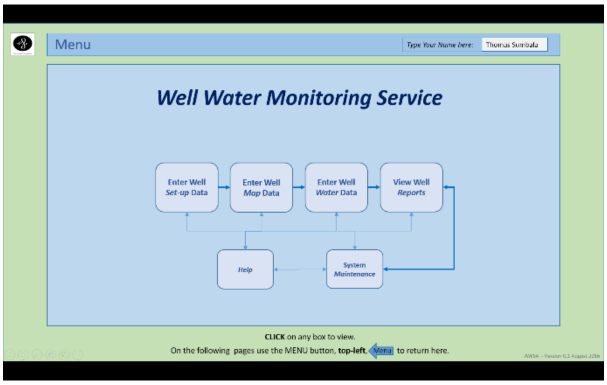
Thomas realizes how important the hand-pumped drinking water is to people in the area. He also realizes it is important to understand: how much water was being used; when the water supply stops & which Wells are broken and need repairing.

The job is a full-time position and as part of his role he is expected to devote an equivalent of at least one day a week at the office collecting data from the Wells. He understands the time taken to record the Well data may change over the next few months as more Wells are constructed and brought into service.

2.1 Weekly Tasks:

Today started as all the other days of the previous two months when Thomas was in the office. He arrived, powered up his computer and started the Well Monitoring Service' system, an easy to use spreadsheet application. He then opened his e-mails and was pleased to find that another Well had been built so he added it to his task-sheet.

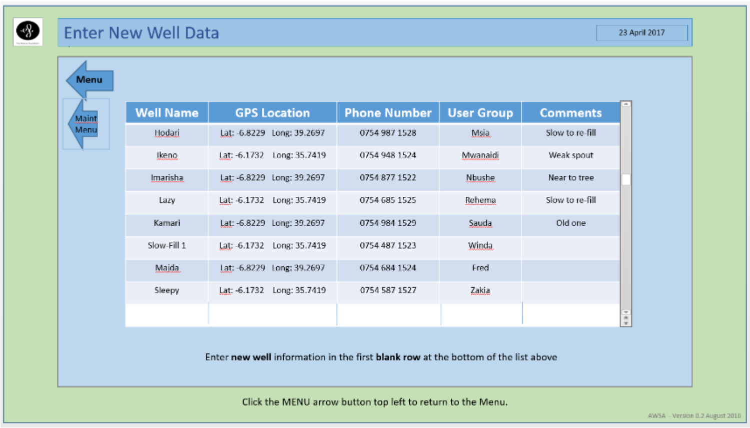
He knew the location of the new Well as he used to live close-by, so he could easily place it on the embedded map in the spreadsheet. After noting and recording the mobile telephone number of the Well's cell phone module he saved the spreadsheet. He then closed the office door because he would now need to concentrate and not be distracted. Thomas then started the Well Recording and Monitoring Sequence, a procedure he was proud of as he had provided input into its content.



Thomas clicked on the spreadsheet's 'Enter Well Data' button. This action brought up a list of: Well names; their telephone numbers and; the Well-Open-Time-Slots. (WOTS). Thomas looked at his watch and noted the time. He then looked at the time each Well was open for calling and which Well-Open-Time-Slot were current.

Thomas called the first Open-Well on the list and, after just three rings a female 'Stephen Hawking' type voice announced the time, in units of 15 second intervals, which the Well had been in use. The 'phone then repeated this totalised number together with the Well's name and Well identification number. Thomas recognized the Well identification message as it was his voice! He had commissioned and tested the electronics of this well himself. He had decided to call this Well 'Eshe'.

Thomas entered Eshe's data, the 'spoken' number from the Well, into the spreadsheet noting that the numerical gap between today's number and the previous number was roughly the same. This indicated that the Well was performing normally. He then put today's date and time next to the Well which he had just listened to and saved the spreadsheet.



Well Name	GPS Location	Phone Number	User Group	Comments
Hodari	Lat: -6.8229 Long: 39.2697	0754 987 1528	Msia	Slow to re-fill
Ikeno	Lat: -6.1732 Long: 35.7419	0754 948 1524	Mwanaidi	Weak spout
Imarisha	Lat: -6.8229 Long: 39.2697	0754 877 1522	Nbushe	Near to tree
Lazy	Lat: -6.1732 Long: 35.7419	0754 685 1525	Rehema	Slow to re-fill
Kamari	Lat: -6.8229 Long: 39.2697	0754 984 1529	Sauda	Old one
Slow-Fill 1	Lat: -6.1732 Long: 35.7419	0754 487 1523	Winda	
Majda	Lat: -6.8229 Long: 39.2697	0754 684 1524	Fred	
Sleepy	Lat: -6.1732 Long: 35.7419	0754 587 1527	Zakia	

After clicking on the next Well with an Open-Time-Slot and dialing the Well's number he noted that the voice gave the Well's time-count exactly the same as last time he called that Well. This suggested that this Well was broken or that nobody was using it for some reason. He made a note on the spreadsheet, entered today's time and date and saved it. Thomas knew that the discrepancy he found would have to be flagged up in his spreadsheet's 'action-list' which he would address later on.

On another Well, the voice announced a slightly increased time-value when compared to any of the previous three readings. Thomas noted this but recalled that the output from this Well had been very high for the past few weeks. This could indicate the Well was still refilling. Thomas noted it on the spreadsheet and saved it. Thomas wanted to check the Well's output tomorrow, however, he knew he would be out of the office during the Well' Open-Time-Slot (WOTS). As a result, as soon as that Well closed for that day, he sent a special text code to the Well so that when the Well opened up again the next day the Well would automatically send the data to Thomas's answer phone. He noted his actions into the spreadsheet.

On the next Well the voice sounded muffled. He found it difficult to hear the numbers being 'spoken'. This was the third time in succession this had happened. As a result he made a recording on his 'phone of the Well and send it to the Well's local Area Group Leader so that she could address the situation and clean the microphone.

He did not record the muffled data in the spreadsheet because he was not certain of the numbers. He hoped he would get a clearer signal the next time. He noted his actions in the spreadsheet.

The next Well should have been number 8 – 'Matilda', but there was no answer from that Well, not even noise. The Well could be broken, or the electronic unit could have failed or the system be corrupted. He then sent the Well's 'phone module a special text message which requested the digital whereabouts (DW) of the Well's electronic unit. He expected an e-mail reply to his phone the next day. The e-mail would provide a link to a map which would show the location of the Well's electronics unit.

A couple of hours later he had finished and had collected most of the Wells' time-usage figures. There were further Well-Open-Time-Slots later that afternoon so he returned after lunch to capture these and record the data in the spreadsheet.

After he had finished logging all the Well data Thomas reviewed the reports and produced a weekly summary for circulation. The report contained displays of each Well's estimated water flow and highlighted various concerns and discrepancies. Thomas's next job was to decide what recommendations he should make to resolve the discrepancies.

Thomas reviewed his action list. He noted a Well with reduced water output. He knew that area and remembered there was a festival in the next village. This could account for the reduced usage. He decided not to take any action in this particular case but chose to make a note for next week.

At another Well there was no information at all. He looked at the surrounding Wells and noticed their usage was slightly higher than normal. This could indicate the Well was broken. He decided to call the local contact of the Well User Group in that area who confirmed that the Well was broken. Thomas highlighted this fact in his report. Thomas did ask why the Well User Group Leader had not reported it, but he said he had "not got round to it yet". Thomas noted this in his report too.

Then, just as a backup, (and because his PC will certainly fail one day as no hard drive lasts forever, and as there was no RAID-1 storage operational in the Office yet) he made a copy of the spreadsheet to his memory stick. He then closed down the computer and went home.

The next evening he popped into the office to listen to the few messages. Unfortunately there had been a power cut that night so no messages from the Wells had been recorded. Thomas then went to his PC, reviewed his report and re-sent the various text message codes to the Wells so the Wells would send their data the next day.

The next morning the messages were there as expected. Thomas recorded his findings, collated his report and sent it to Head Office.

Next week happened to be the end of the month. Thomas knew that in addition to the weekly tasks there were monthly responsibilities too. There were six principal activities that he had agreed with Head Office needed to be completed. The systems and data were still settling down, so these tasks were currently completed monthly. However, after a few months he expected to be able to gain agreement from Head Office to reduce the frequency of at least some of the activities. However, before we discuss the monthly tasks let us summarize the instruction-set mentioned in the above actions:

2.2 Command Instruction Summary

In summary the Well's electronic unit will:

a) **Record**, for 23.5 hrs. a day, the amount of **time** the Well is operating and is making noise.

b) **Store** the cumulative time-count locally.

c) Be available to **receive** and answer telephone calls for 20 mins a day. During this time the caller/User will be able to **listen** to the Well's ID name and ID number together with the cumulative time-count of the Well. (during the first 10 mins of the powered-up state the Well will be waking itself up; preparing the network connection and performing other administrative tasks)

d) The time the electronics unit will be **woken-up** will be at approximately the same time each day. However due to the temperature changes the time will drift up to several minutes a week. This drift will be logged and predictions made as to when to 'phone the electronics unit's phone module. (In extreme circumstances, when the drift has been significant, an automated text procedure has been established to alert HQ when the phone module has been woken-up)

e) **Calibration**: The longer the calibration process the better the accuracy of the predicted Well's water flow rate. Default calibration values have already been established and entered into the Well Monitoring Service's Spreadsheet. It is these default values that can and should be over-ridden during each Wells calibration process. The Wells calibration process should be conducted once every two years.

The instruction-set that the Electronics Unit has been designed to respond to are as below:

1. ***Dial the Well during its Well-Open Time-Slot.***
   This enables the caller to listen to the Well's totalized Well Time Count and to the Well's identification name and number.

2. ***Send the Well a text of '1111'.***
   This instructs the Well's mobile 'phone module to call the mobile telephone that sent the text code to leave a message of the Well's Name, Well Number and the cumulative Well time-count. This is a chargeable SIM card activity and should be used sparingly.

3. ***Send the Well a text of 'DW'.***
   This instructs the Well to send a text to the mobile telephone that sent the text code (DW) the approximate geographic location of the Well's electronic module, this includes the latitude and longitude data. This is a chargeable SIM card activity and should be used sparingly. (This text will also elicit the percentage left of the battery. Anything under 10% should represent a concern.)

4. ***Note**: The Well's Open-Time-Slot (WOTS) is about twenty minutes. The Well-Open-Time-Slot is kept short due to power budget constraints. If left open for too long the Well's battery will go flat and all data will be lost. The text messages can be sent to confirm when the Well's WOTS time is first opened as the Well will respond as soon as it receives the text. The WOTS operates a 24hr cycle. The WOTS time is normally at the same time every day. The time is set during the electronics unit's testing phase prior to installation Well-side.*

2.3 Monthly Tasks:

There are six monthly task, these are:-

1. ***Check the Well's location**.*

   *Or more accurately check the location (the **D**igital **W**hereabouts - DW) of the Well's electronics unit. Thomas sends the 'DW' text to every Well during its WOTS. This is to ensure the electronic unit is where it was expected to be. After sending the DW text he then receives a text message which includes a web page address. eg:*

   (http://gpsui.net/smap.php?lac=2024&cellid=32549&c=234&n=30&v=6890)

   He then sees a map of the location of the Well's electronics unit. (See opposite)

   Powered By gpsui.net
   LatLng: 51.817242,-0.355181

   From this page he can see the approximate location (not GPS accuracy but within 250 meters or so) of the Well's electronics unit. The latitude and longitude are also provided. Is the box of electronics where it is supposed to be? If not why not?.

2. ***Check the Well's Microphone**.*

   Thomas then reviews his spreadsheet comments to identify if any Well is sounding muffled. From his review he will be able to determine if the microphone in the Well's Unit is still clear from any sound-absorbing mildew.

   The temperature and humidity of the location of the electronics all promote mildew growth. Although the unit is sealed, occasionally a small leak can let in bacteria. Although this is not a serious problem, sometimes the mildew can grow over and inside the microphone. This will hinder the acoustic clarity of the speech module making it difficult to hear accurately the numbers 'spoken'.

   Cleaning the inside of the unit should be done every two to three years. All this information (with dates) should then be recorded in the spreadsheet.

3. ***Check the Well's Count Trend**.*
   This involves formally reviewing a Well's charts over the past three months and comparing them with the other Wells in the area. This should indicate the state of the Well in comparison with others, but also will show up any deterioration of the Well's output. Any concern over the Well's output could indicate concern as to the Pump's health.

Sometimes, by just listening to the Well whilst it is being operated, it is possible to determine basic sounds and an experienced operator will be able to triage and make an initial diagnosis of the Pump's health. Thomas is not at this level yet but he is learning all the time and hopes to gain this level of expertise whilst undertaking the day-to-day Well activities and after viewing the training videos on Well Diagnostics. (Listening to the sounds of the Well this way can only occur during WOTS and when the Well is being used.)

4. ***Check the Well's SIM Contract Status.***

   This involves reviewing the SIM card contract details. Thomas has to ensure that any contractual time-outs and/or expiry dates are not due in the coming month.

   Also, on some SIM contracts, a chargeable-call has to be made every three months. In most cases this is not a problem because the Wells responds to text messages and telephone HQ to report its Count etc.. However, if the Well has not been asked to automatically report its Count for more than three months the 'phone module has to be sent the special code (1111). It is this code that initiates the automatic, and chargeable, 'phone-home' dialup facility. It can be this chargeable activity that keeps the SIM card activated.

   In addition, some SIM contracts state there must be a top-up every 6 months even if it's only £1 and even if there is still credit on the SIM card. The UK prototype is just such a case.

5. ***SIM Card Credit Review.***

   Thomas has to ensure that each SIM card has sufficient credit to be able to phone-home. He performs this task on this PC. He logs in to the network carrier's web site, enters the Well telephone phone number, the e-mail address for that Well and his password and can then see how much credit is left on each SIM card. If the credit is low then details must be reported to Head Office, the card topped-up and the situation rectified. If this is not done the Well's 'phone will be unable to phone-home and will not respond to any commands.

6. ***Maintenance Review.***
   This involves reviewing the actions and recommendations made over the past four weeks or more. If a Well has been recorded as failing or is non-operational, has the Wells local team been alerted, have they all the spares and knowledge to correct the fault, and has it been done? All this type of information will be in the spreadsheet. (But only if Thomas is fastidious enough to enquire and record it.)

2.4 Quarterly Tasks:

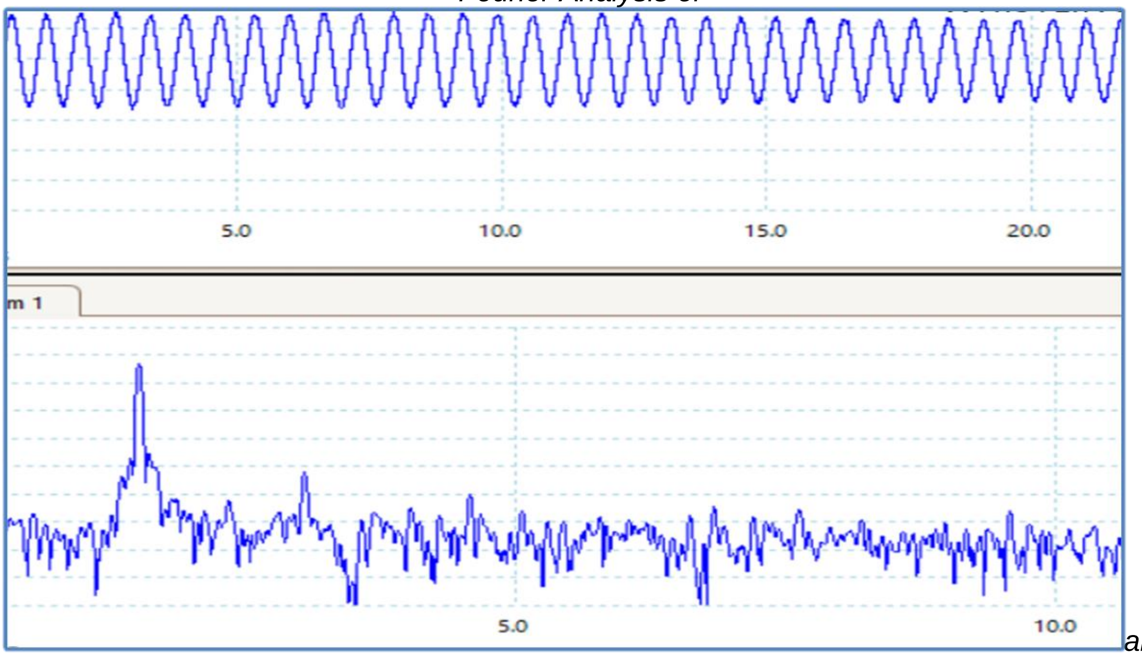
Every three months a special task could be undertaken that focusses on the detailed mechanical health of the Well's pump.

This task is similar to a skilled mechanic listening to a car as it goes past. If there is a rapid tap-tap-tap noise (in the old days before hydraulic tappets) then the tappets needed adjusting. If there was a low knocking noise in line with engine speed then one of the big-ends is saying 'farewell', and if a clunking sound is related to road-speed and not engine speed then a universal joint may need looking at etc.. This type of skill and knowledge will, over time, become apparent to Thomas with the Wells. Some training too will be required but this could be in the form of a series of videos and discussions with the local University.

Although this form of analysis sounds complex, the local University could assist here. (Muhimbili University of Health and Allied Sciences, Chair: Mrs. Mariam Mwafisi or Dr. Ali Hassan Mwinyi). The local university will benefit and gain significant public relations (PR) from research in this area and should be willing to help in the analysis, provided of course that Thomas can record the Wells acoustic signature over time. (Thomas can do the analysis himself, but only if he has the skill and basic equipment, e.g. a 'Picoscope', which is just over £100. https://youtu.be/ZZjbrsuHISE)

The Well's health can be analyzed through a spectrum or Fourier analysis. For example the two charts below are actual recordings of the ***same*** *sound. (The author whistling.) The top chart shows the signal in the traditional Time Domain, (a one kilohertz whistling sound) whilst the lower chart shows the same sound after Fourier analysis, in the Frequency Domain. Looking carefully at the spectral display, you can see the main tone, but also see the second and third harmonics.*

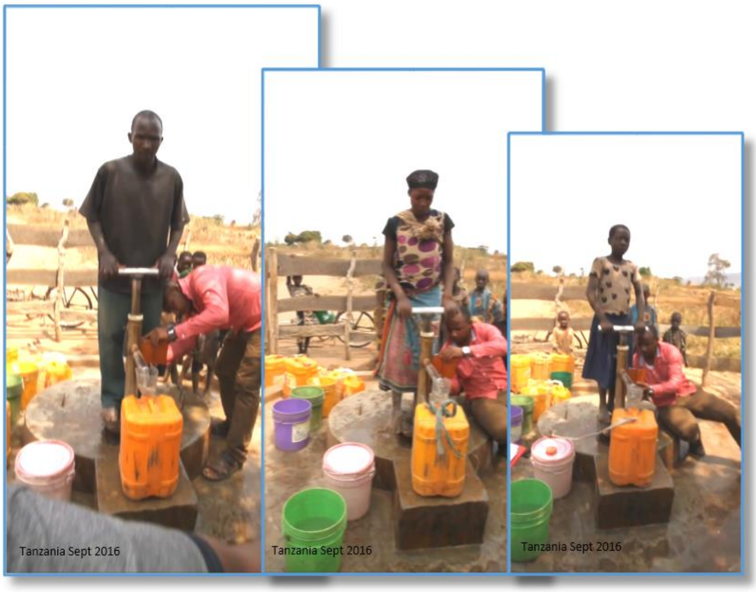
Fourier Analysis of

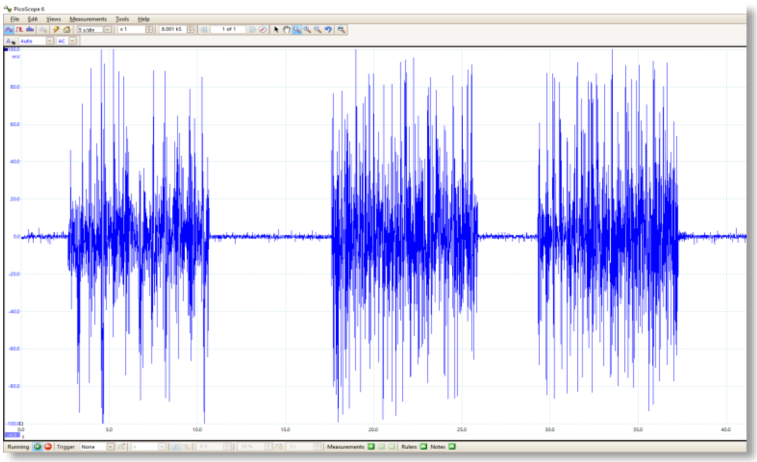


an Acoustic Signal.

After recording the Well's operational acoustic signature over a period of a year or so it may be possible to predict when the lower foot-valve will wear out, and when the plunger valve is weak etc.. This approach will reduce operational costs and greatly assist in migrating the maintenance regime from ambulance-type (that is already in place) to a pro-active (and cheaper) 'preventative maintenance' strategy.

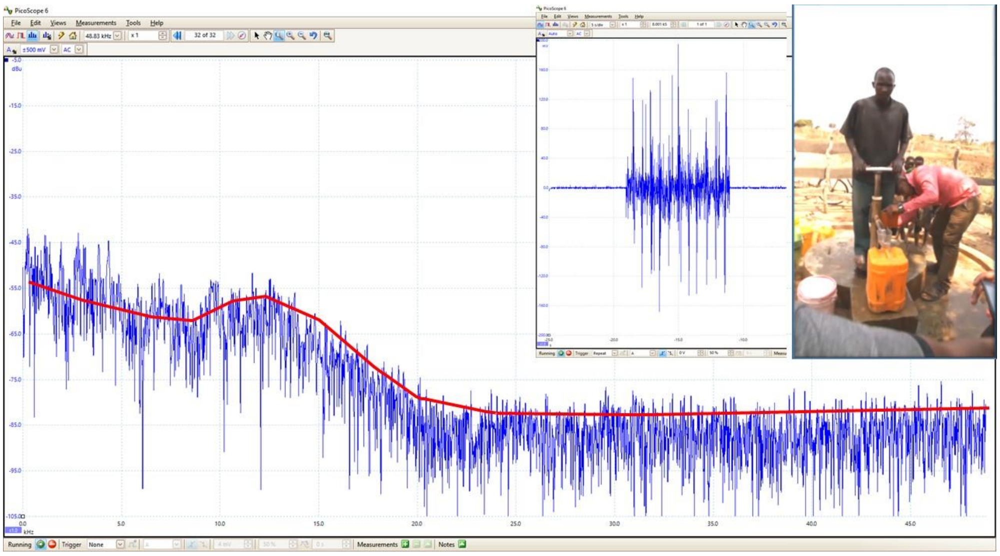
Further video material was taken during late 2016. Here we had three different people pumping the same volume of water. The picture below show the people involved and, a portion of the time-domain display.

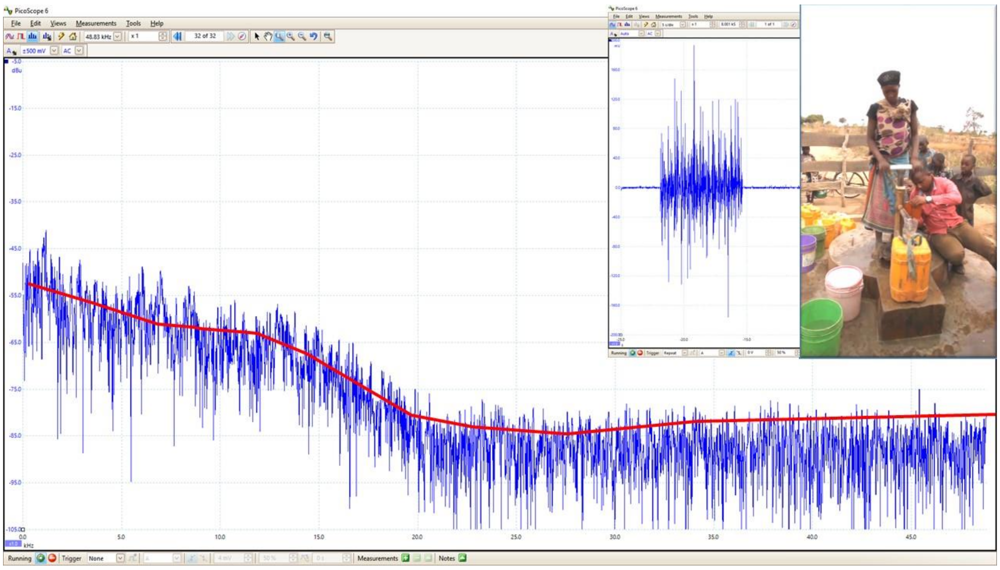


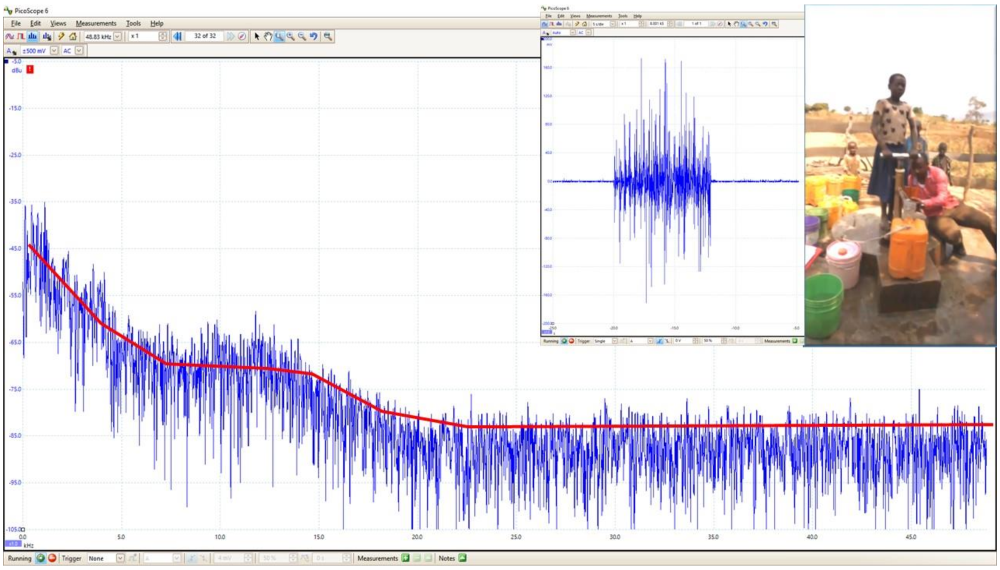


As can be seen, the frequency of operation in each case increases, however, the time to pump 20 liters of water is within 8% (the young girl pumps the given volume of water the fastest) See later sections for further details.

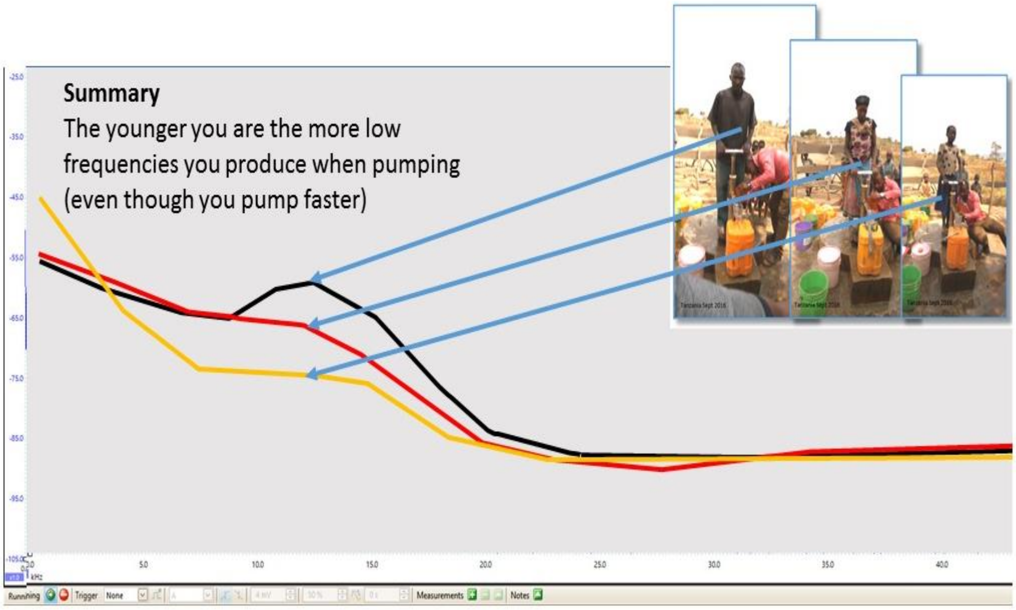
In addition, a Fourier analysis was performed on each waveforms. The differences were surprisingly small but a counter intuitive result emerged:







Comparing each summarized and averaged spectral analysis gives us the surprising counter-intuitive result below:



2.5 Occasional Tasks:

In addition to the regular tasks mentioned above, there are some occasional tasks that also need to be completed. For example, when a new Well is about to be brought online Thomas will have to make sure a new Well Monitoring Service Electronics Unit is available and can be fitted to the Well. In order to do this Thomas will:-

1. *Review the Well Monitoring Service electronics parts-list and either order the parts from eBay, or request Head office to order and pay for them. The eBay Web addresses are provided and a special eBay account could be set up.*

   Thomas may be able to order the components, but paying for them will have to be done by the Financial Controller at Head Office. This could be as simple as checking the parts-list ordered and confirming payment using a special PayPal account.

2. *In addition, Thomas will have to request a housing unit be made by the Carpenters in accordance with the latest design.*

3. *And finally, Thomas will have to prepare the workspace necessary for both himself and his assistant to assemble the electronics unit. Wiring up the unit takes manual dexterity, concentration, and the ability to follow complex instructions. This is rather like making a bead necklace where a complex pattern can be made with multicolored beads using string or nylon cord. The only difference in wiring up the electronics unit will be that the cord will be replaced by colored wires. The instructions for this intricate wiring up process will be pictorial together with an instruction video.*

   The assembly and test of the electronic unit will be similar to the IKEA range of furniture. Making the IKEA type of furniture can be straightforward provided the *pictorial instructions are followed. It is anticipated that making the Well Water Monitoring Services' electronics unit will follow a similar process. The skill of Thomas's assistant in making necklaces' etc. can then be used in making the electronic unit.*

4. *A much more complex task is the hacking of the calculator module. This requires skilled soldering and careful dismantling and assembly. It is expected that Thomas (or his assistant) will be able to do this task following the IKEA type of instruction booklet. They will also be given training in the: use of the soldering iron; the safety aspects; and a maintenance of the soldering iron.*

5. *When: the electronics housing has been delivered; the electronic unit wired up by Thomas's assistant; and when the calculator has been modified and all sub-units have been assembled, then testing can commence. The testing process will once again follow an IKEA like process. These instructions will appear in an appendix of a later version of this document. A training video should also be provided.*

A critical setting which is to be set up during the testing stage is the first triggering Monostable. (ie: when the phone module is triggered.) Ideally we do not want all the units to have a WOTS time at the same time, so there will have to be some local input and thought as to how to set the WOTS times. However, WOTS times can coincide and overlap as it does not take long to dial, listen and record the time-count from each Well.

When Thomas has a holiday, nothing gets done. No recordings are listened to and no records are made. Upon his return he erases all messages and starts again. The Well counters are cumulative, this means that the Wells will, the next time they are woken up or receive the 1111 text, 'say' their total count-to-date.

Thomas can the record the new data and the Well charts will automatically smooth out the missing data for that week or two. (To avoid unnecessary costs of the Wells 'phoning and leaving messages Thomas should send the cancellation text code to all Wells (0000) so that no messages are sent during his holiday.)

3 WATER MONITOR SPECIFICATION

Below is a list of objectives the system has to achieve to meet the above scenario. The water flow monitoring system must be able to:

1) Record the number of time periods (multiples of seconds) the hand pumped Well is being used.
2) Data collection from the Wells will be made from a central remote point.
3) The equipment at the Wells will be robust and tamperproof.
4) Have a high mean-time-between-failures (MTBF). For example, the Well should not need to be attended to for at least a year.
5) Repeated readings must be consistent ± 15%.
6) Will operate under a break/fix maintenance regime. (Ambulance-mode, but an aim is to migrate to a preventative-maintenance strategy later).
7) Location of the Wells should be made manually and recorded upon installation.
8) Location of the Well's electronics unit shall be checked via the tower location network website. (GPRS).
9) Installation of the monitoring equipment will be made by trained local personnel.
10) The measurements will be performed on an on-demand basis. (The data will be *pulled* from the Wells, data will only be *pushed* by the Wells upon request.)
11) The aim is to assemble, from parts, & test the equipment in-country.
12) The equipment will be solar powered charging an internal battery.
13) The battery should last for 12 hrs.
14) The equipment must be low-cost.
15) The equipment will be 'fail-safe' and will not interfere with the pumps operation.
16) The Well's monitoring equipment should have zero (or very few) moving parts and should not impede the water flow and be biologically safe.

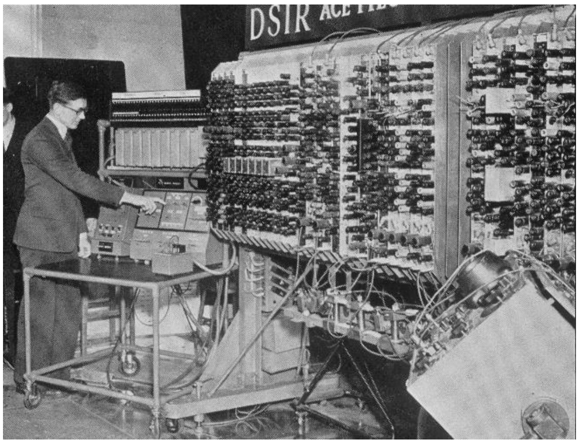
Below are a list of **assumptions** under which the system will be expected to operate:

1) The pump water flow time measurement equipment will operate on known Well types.
2) The Wells will be within a cellular telephone network range.
3) Initially, the number of fifteen-second intervals the Well is in use will be recorded.
4) The electronic equipment shall operate between 0°C and 50°C.
5) The electronic equipment at the Well must be retrofitable to existing Wells.
6) The pumps at the Wells will be 'Nira AF-85 Direct Action Hand pumps'.

3.1 Specification Development:

In addition to the above, it is expected that the development of the electronics unit will follow the below process:

1) Two prototypes will be built in the UK.
2) One prototype will be retained as a Reference Model.
3) The second prototype will be tested at Loughborough University on their direct-action Tara Well.
4) This porotype will then be transported to Guernsey and re-tested locally.
5) This porotype will then be transported to Tanzania and tested on a convenient Well.
6) After a successful pilot run in the UK, Guernsey and Tanzania a small manufacturing run of a half a dozen will be considered.
7) Of the next six units two will be manufactured in the UK and a batch of four will be manufactured in Tanzania.
8) A basic spreadsheet system will be created to enable the Well-data to be recorded, displayed and record actions taken.
9) Due to cost issues, the electronics unit may *not* look like other electronic units, and will consist of many separate modules all wired together.
10) The modules will be wired up by local staff. This Heath-Robinson approach will: keep costs down; enable items to be assembled locally; will not require more specialist Printed Circuit Boards (PCBs) than necessary and be repairable locally.



The wiring up of these units may look unusual, but it could save time, money, be educational and self-sustaining. (But not as bad, or as big, as the Bletchley Park computer picture above during World War two.)

4 WATER MONITORING SYSTEMS DESIGN:

This section discusses the overall design. It briefly mentions issues and concerns in the current prototype.

The main design parameters are:

1. Mean time between failures (MTBF)
2. Cost
3. Manufacturability (assemble, manufacture and test in-country)
4. Accuracy

To ensure the mean time between failures (MTBF) is as good as possible it has been decided that ***no*** moving parts are to be used. This is a difficult decision to make as there are some elegant part-solutions already in existence. However, as the Press and others have stressed the unreliable nature of some of the Wells, it would be a PR and cash-flow disaster to add further failure-modes to the Wells.

As a result the sensor of choice is simply a *microphone*. By listening to the noise of the Well it should be possible to determine whether the handle is being used (pumped) and if the water is flowing. The human ear however is a very sensitive instrument. Whether a selection of low-cost electronics is able to draw the same conclusions has yet to be proven.

In essence the basic design was founded on separating various acoustic frequencies and attributing the frequencies to different parts of the Well. For example, the low frequencies could be associated with the pumping action of the Well's handle. The system could count the strokes, or simply count the number of seconds the pump is being used.

The mid-frequencies could be attributed to the water flowing in the output spout. By using a dual frequency detection method and some basic mathematics (simultaneous equations) and the calibration procedure (see Appendix) it is possible determine the amount of water the Well has pumped during the period. (Day/week/month etc.).

The current prototype unit has been built by using one frequency band and counting the number of fifteen-second time intervals the Well is in use. At a later date the frequency analysis unit could be changed and other frequency bands monitored. This change from *time-measurement* to number of *pump-actions* and *water-flow time* in the spout can be performed easily as all the main electronic parts are identical. The only change is the Fourier analysis module and simple filters together with a duplicate copy of the current electronics.

In order to keep costs to a minimum it has been decided to source items from China. China produce good electronic modules at very low cost. (The Chinese government appear to sponsor postal charges for their manufacturers). Unfortunately e-bay's Terms & Conditions *do not* permit electronic modules to be delivered to Africa directly. This means that the electronics will have to delivered to Guernsey or elsewhere in the UK and be sent on from there. This could increase the cost of the modules due to possible import/export charges post Brexit.

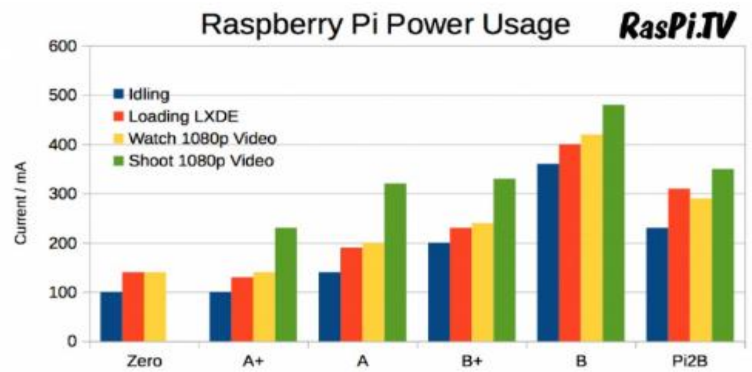
Also, as man-power is expensive, it was decided to use pre-built modules where ever possible. Not only does this reduce assemble time but also help reduce costs. The Chinese manufacturers manufacture and sell some modules cheaper than we can obtain the components in the UK..

As far as accuracy is concerned, the longer the *calibration* time the more accurate the results. This system will not be the most accurate water monitor, but its MTBF and cost should be better than many other systems.

4.1 Overall Design:

There was a choice between an analogue or digital design. For example, do we use individual electronic modules to split the sound into its frequency bands or do we use a computer? At this stage it was decided to adopt the analogue approach. This will ensure a *bug-free* solution. It will also ensure that a prototype can be built relatively rapidly, and mean that we can turn off certain parts of the electronics when they are not needed, this will improve the power-budget which is very limited.

This analogue design approach will also ensure the requirements specification is fully understood. It will enable a micro-PC solution to be better considered at a later stage. (The Raspberry Pi Zero is an option, but it will require many supporting input/output boards and still consumes over 100mA even in standby mode – see diagram on the right)



Raspberry Pi Power Usage Chart

The next big decision was how to get the data back to Head Office (HQ). Sending a text was considered however, this was too complex without the use of a microprocessor and further digital functionality. As a result it was decided to send the data back to HQ acoustically. We would use the ‘phone module as a ‘phone and simply transmit speech.

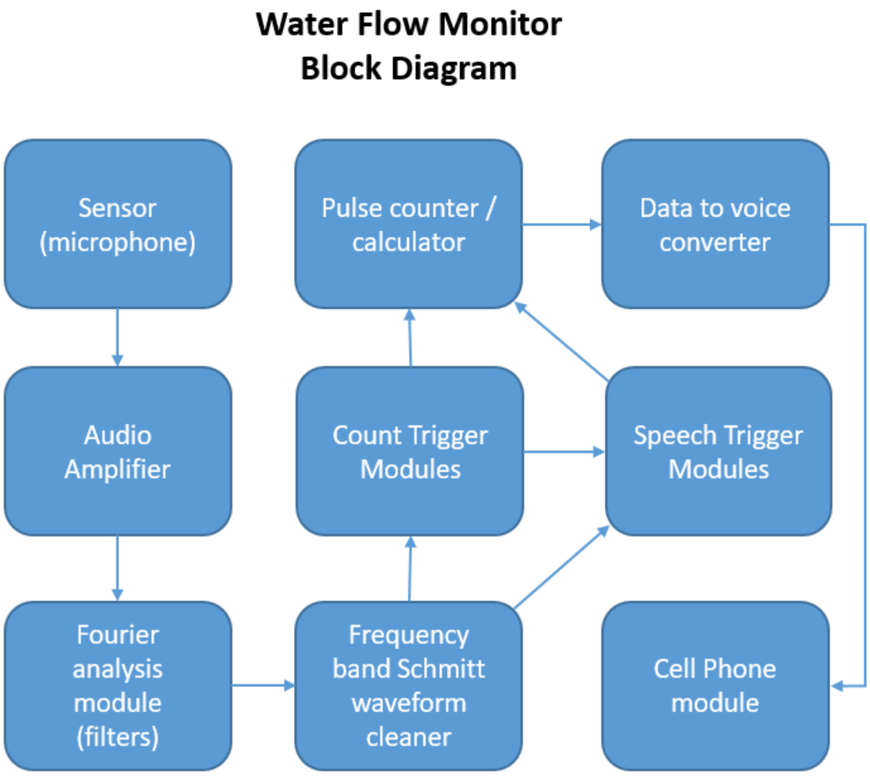
The next question was how do we get a digital count into an acoustic signal without a microprocessor? A calculator for the blind was then discussed. There are some really low cost units available which, if modified, could ‘say’ the totalized count into the phone module’s microphone. This was tried and tested in the first prototype and worked well.

The Water Monitor System currently consists of twelve modules:

1) Sensor.
2) Sensor amplifier.
3) Mobile Cell module.
4) Fourier analysis circuits.
5) Schmitt waveform cleaning modules.
6) Count Trigger module.
7) Pulse Counter/calculator.
8) Data to voice converter.

9) Speech Trigger module.
10) Solar battery charger.
11) Calibration process.
12) Housing.

These units are connected as in the simplified system Block Diagram below:



4.2 Normal Operation of the Unit:

Normal operation of the unit is as follows:

1) The microphone picks up the complex acoustic waveform from the pump.
2) The waveform is amplified, fed into the Fourier analysis frequency circuit (initially a first order RC filter) where it is separated into basic high/low frequency bands.
3) Mid-band frequencies will be cleaned and fed into a counter unit. This unit will count the number of fifteen-second intervals the Well is used.
4) The counter unit will have an attached data-to-voice converter.
5) When the cell phone module is activated by the 24hr PLC Monostable module, the trigger circuits will activate the count-vocalizer and the cumulative count recalled from memory. This will be fed acoustically into the microphone circuit of the 'phone module.
6) In addition, when the cell 'phone module is activated by a *text* from the Controller/Manager, the cell 'phone will automatically call back the number that sent the text and (provided the answer phone is on) leave a message of the Well-Time-

Count together with the Well's name & identification number (ID) in English & Swahili.

7) The person listening to the phone, or the answer-phone, will hear the spoken numbers and record them on the Well Monitoring Service's spreadsheet.
8) The spreadsheet will be able to record the data, the dates and comments.
9) The spreadsheet will also perform calculations; linearize calibration; present results, check for anomalies and indicate areas where action is recommended.
10) To save power, the Well's 'phone module and other modules will be put-to-sleep when not required.
11) Under sleep conditions the Well's electronics will store and remember the Wells count activity as these modules will be kept on.
12) It should be noted that the Well's time-count will increase by one every 24 hours regardless of Well usage. This acts as an automatic check that the electronics unit is operational even if the Well is not used.

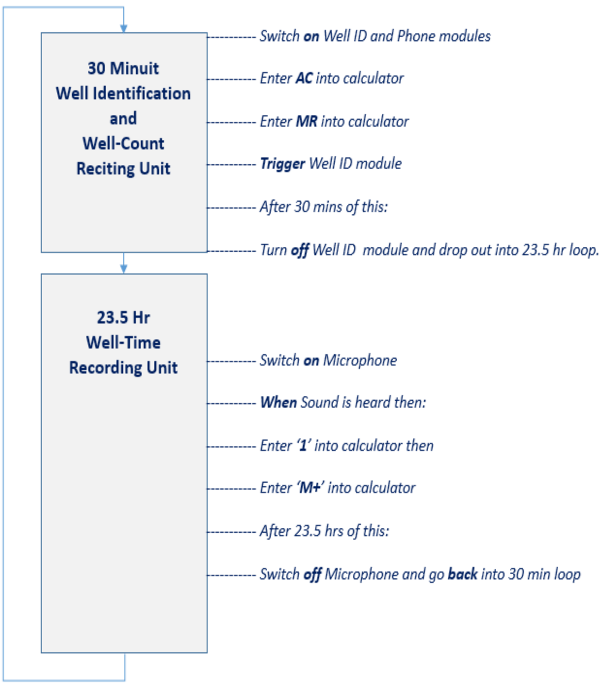
The abnormal operation of the unit will be as follows:

1. When the Well's time counter reaches 99,999,999 it will need to be reset manually. All modules will need to be switched off and on again. This action will reset all counters and all local information will be lost.
2. The Spreadsheet will have predicted this and the next reading should be noted as the new-start.
3. The counters will reach their maximum count in just over forty seven years.
4. Should the solar charged battery go flat the cumulative time-count will be zeroed. If this occurs and the solar cell then recovers and restarts the electronics, then the zero or close to zero count will indicate to the User what has happened. Two things should then happen:
   (a) The User should inform the local agent to check the electronics unit and
   (b) Request the solar cells be cleaned,
5. The PLC monostables will drift in their time slots. When this happens the User can send a text of 1111 to the 'phone module. This will result in the phone calling the User back at the *start* of its Well Open-Time Slot (WOTS) enabling the User to synchronize and record the new times in his spreadsheet.

4.3 Block Diagram

The *Overview* and the *Block Diagrams* are shown below:

WELL MONITORING LOGICICAL BLOCK DIAGRAM



Currently the Well Monitoring Unit uses Relay Logic. This is power hungry. A microcontroller (Arduino) would be better.

Logic Outline:

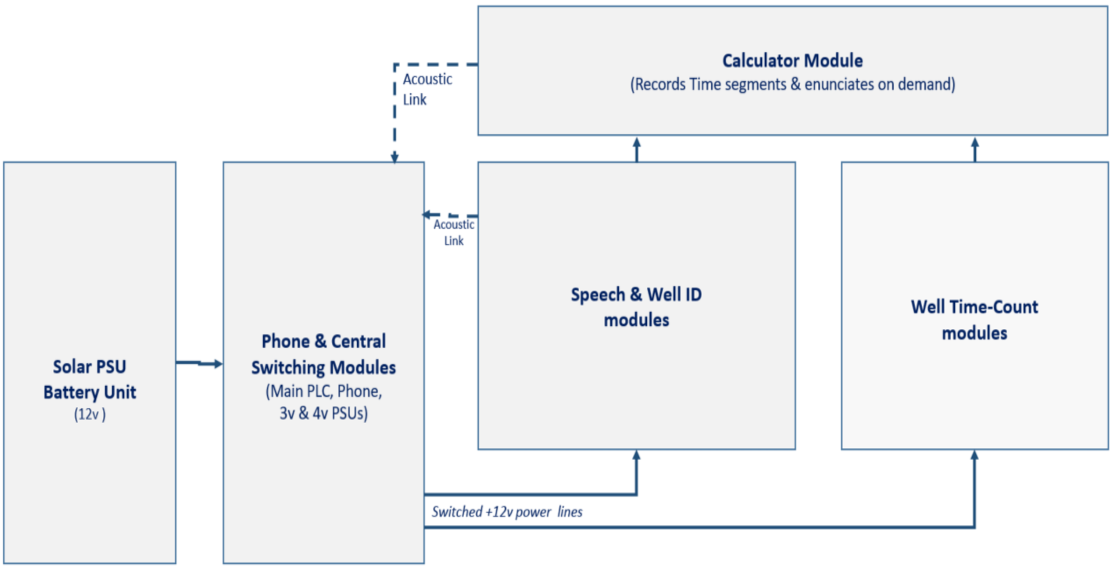
The system wakes up for 30 mins a day and starts acoustically reciting its pre-recorded Well identification number and name. Such that when the Phone module is called the information can be listened to and manually recorded into Head Office's spreadsheet. After 30mins it saves power and switches itself off.

For 23.5 hrs of the day the unit switches on its Well microphone such that any noise the Well makes increments the calculators memory by ONE for each 15 seconds of Well use. After 23.5 hrs this unit is put to sleep and it then enters the 30 min loop again.

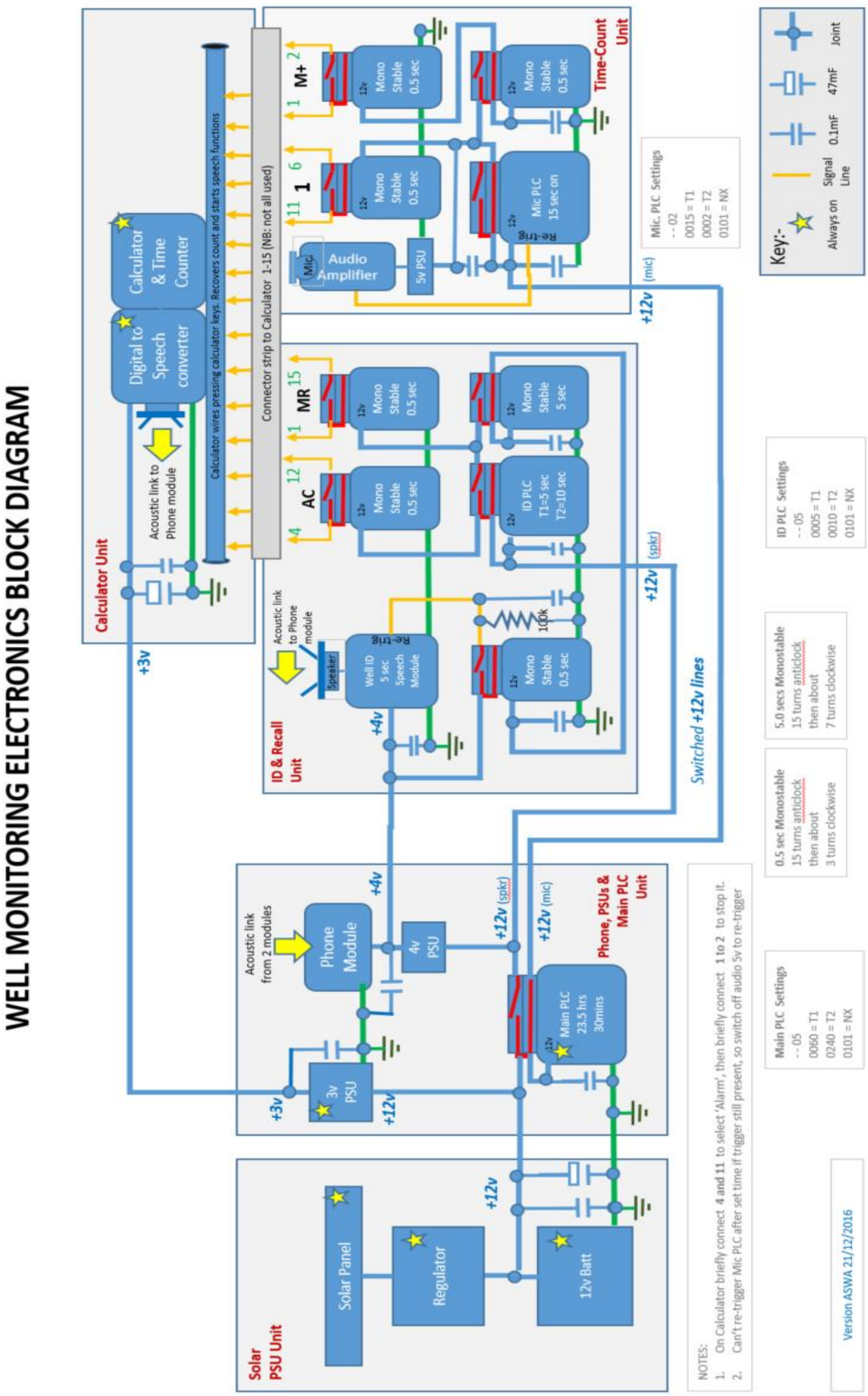
I can see how his could be done with three Arduinos. However, the next challenge is to make nested loops and do it in just two, or even one Arduino?

Ideally though it would be best if the microphone was on all the time and captured all Well activity rather then switching to annunciator mode for 30 mins every day to report back to head office. It would be even better if an RTC could be used, but I can't see how to do this. (yet!)

WELL MONITORING ELECTRONICS BLOCK DIAGRAM

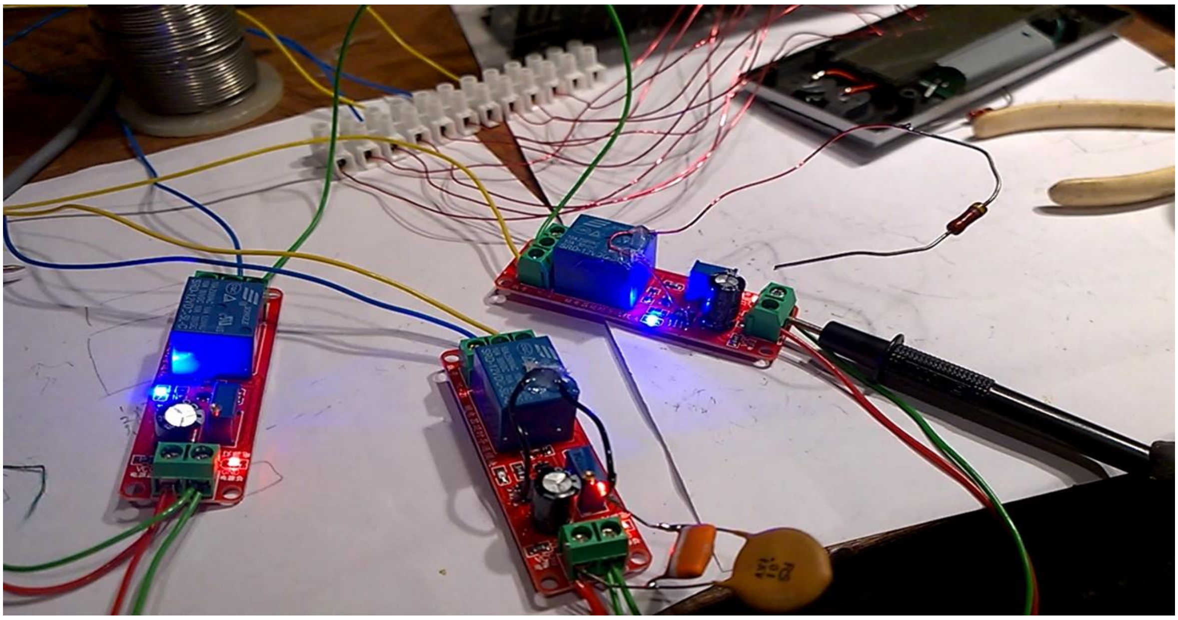


This diagram also represents the
Physical layout of the current Prototype and
Matches the detailed block diagram detailed below.

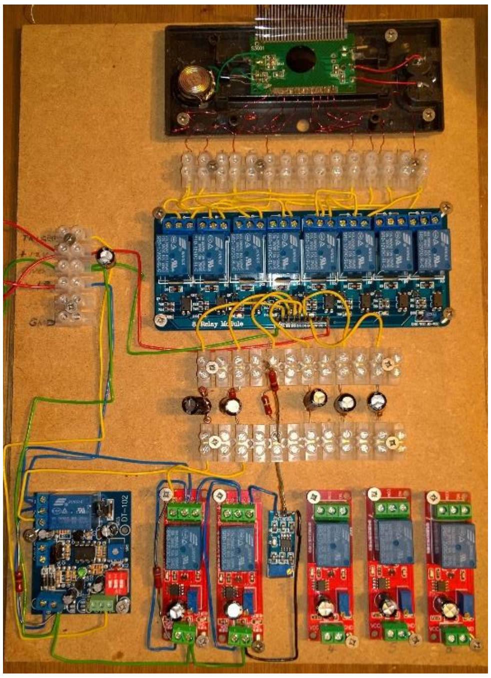

WELL MONITORING ELECTRONICS BLOCK DIAGRAM
Calculator Unit
Calculator & Time Counter
Digital to Speech converter
Acoustic link to Phone module
Calculator wires pressing calculator keys. Recovers count and starts speech functions
Connector strip to Calculator 1-15 (NB: not all used)
+3v
M+
1
2
11
6
4
12
AC
MR
15
Mono Stable 0.5 sec
Mono Stable 5 sec
12v
Mic
Audio Amplifier
5v PSU
Mic PLC 15 sec on
Re-trig
Time-Count Unit
Mic. PLC Settings
- - 02
0015 = T1
0002 = T2
0101 = NX
+12v (mic)
Key:-
Always on
Signal Line
0.1mF
47mF
Joint
ID PLC T1=5 sec T2=10 sec
100k
Acoustic link to Phone module
Speaker
Well ID 5 sec Speech Module
+4v
ID & Recall Unit
+12v (spkr)
Switched +12v lines
ID PLC Settings
- - 05
0005 = T1
0010 = T2
0101 = NX
5.0 secs Monostable
15 turns anticlock
then about
7 turns clockwise
0.5 sec Monostable
15 turns anticlock
then about
3 turns clockwise
Acoustic link from 2 modules
Phone Module
4v PSU
3v PSU
+12v
Main PLC 23.5 hrs 30mins
Phone, PSUs & Main PLC Unit
Main PLC Settings
- - 05
0060 = T1
0240 = T2
0101 = NX
Solar PSU Unit
Solar Panel
Regulator
12v Batt
NOTES:
1. On Calculator briefly connect 4 and 11 to select 'Alarm', then briefly connect 1 to 2 to stop it.
2. Can't re-trigger Mic PLC after set time if trigger still present, so switch off audio 5v to re-trigger
Version ASWA 21/12/2016

Each of the key modules have been tested individually. The below outlines progress through the prototyping process:

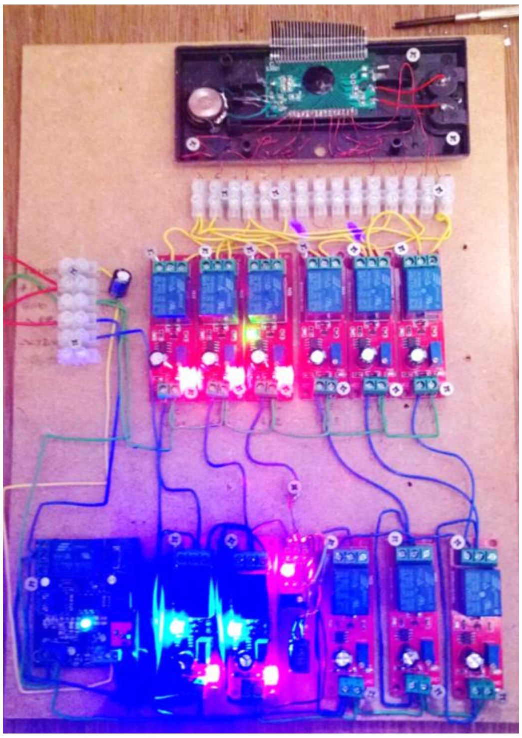
Prototype One - Speech Unit.
The first test was to test the hacked calculator. Below is shown a working and sucessful view of three of the delayed-start mono-stables ‘pressing’ the highly-hacked calculator’s / pulse counter’s buttons.



Prototype Two - Trigger Circuit.
The complete trigger unit using the eight channel relay board and the complex (& troublesome) multiple power supply units: (PSUs) (NB: PSUs not shown)

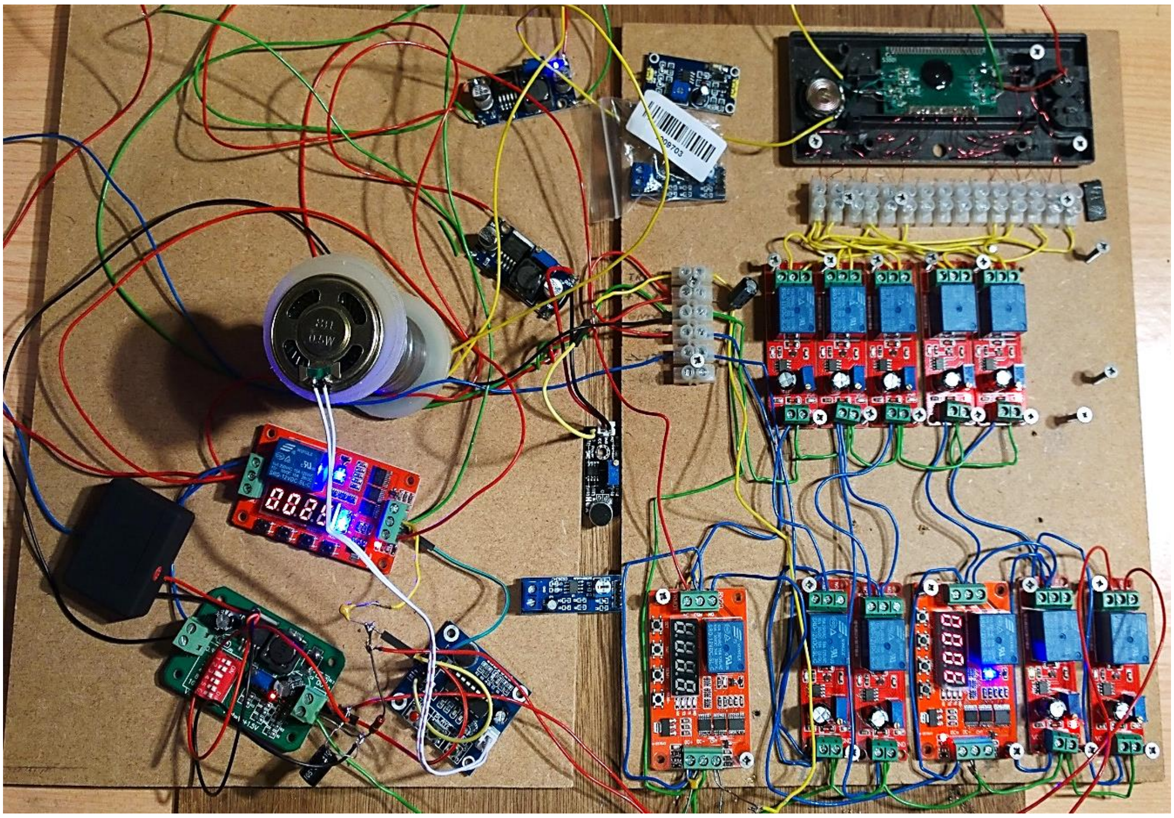


Prototype Three - Trigger Circuit.
A fully working version of the trigger Count-Unit using the new mono-stable boards and the simplified power supply arrangement: (NB: PSUs not shown)



The Light Emitting Diodes (LEDs) are *not* required, but they come with the modules. However, the LEDs are invaluable when setting up the unit as they clearly show which monostable have timed-out and which have switched. Unfortunately there is a power budget penalty for having the LEDs (about 10mA each) but they are not on for long and flash most of the time.

Prototype Four - Trigger Circuit.
A working version of the Trigger and Well identification unit based on a rapid test cycle. This unit has been left on for over 350,000 cycles and all seems well. Care must be taken though with setting the gain of the microphone amplifier. Too much gain means it detects the switch-on relay’s vibrations and starts to count itself! However, as we now need to change the Monostable unit for a PLC digital one (more time accuracy) this PLC unit has proved to be less sensitive to triggering so can be regarded as both an advantage and disadvantage. Tests continue.



The Picture above shows the latest Relay/PLC Prototype (Dec 2016). All functions work. During 2016 this unit successfully completed over 350,000 test cycles. Many lessons were leant during its construction and the subsequent testing phase. As mentioned at the start of the project it is now possible to consider a digital version. This new version should be smaller, cheaper, consume less power and be more accurate. Only time and the next Prototype will tell!

4.4 Power Budget of Prototype:

The power-budget for the current prototype is shown below. Normal operation of the modules are assumed and the time they are used per day are also assumed. If either of these figures change significantly then this will have an impact on the final size: operation; physical location and financial viability of the unit.

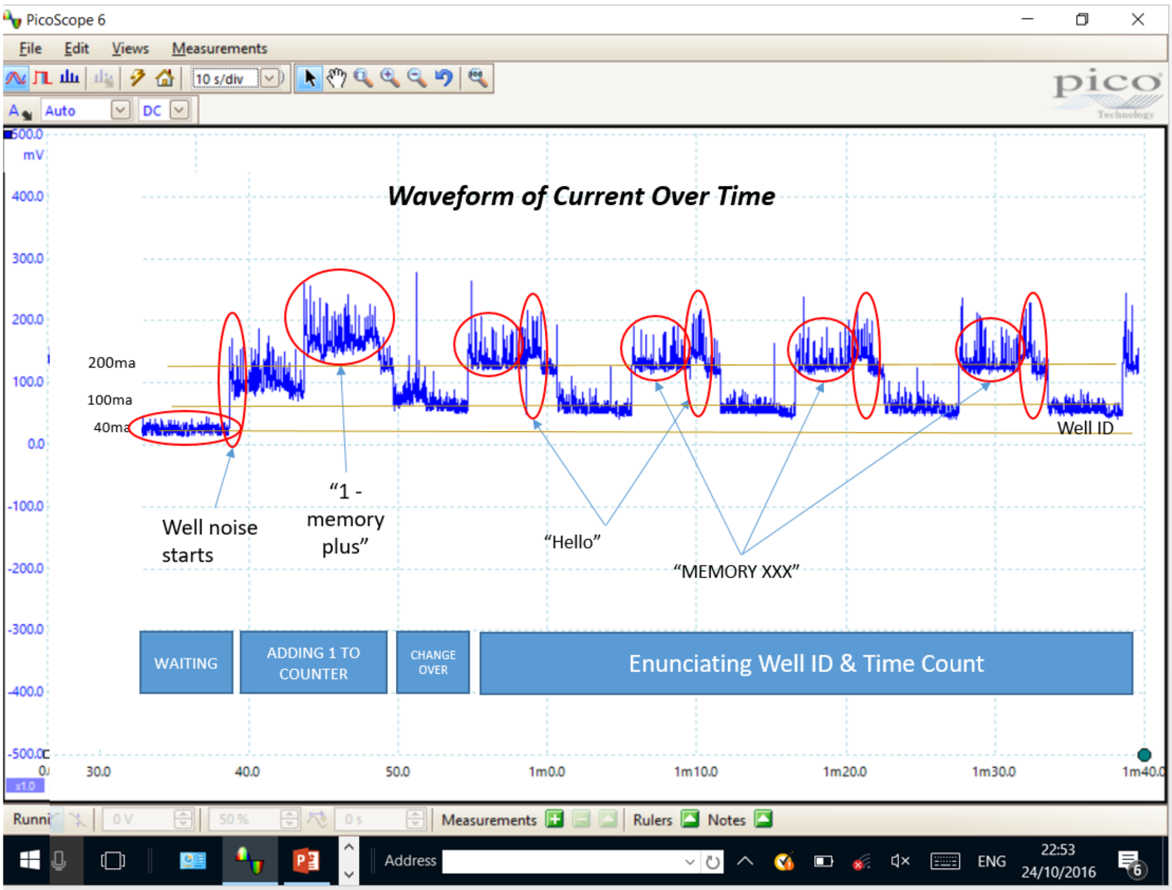
WATER FLOW MONITOR

Circuit: version 1.0 - 29 Oct 2016

MODULE	Average Current (mA)	Voltage	Hrs Utilisation /Day	Power Used /day (Wh)
Count Module standby	42	12	16.5	8.32
Count Module active	220	12	5	13.20
Speech Module standby	0	12	23.5	0.00
Speech Module active	200	12	0.5	1.20
Total (Watts Hours)				**22.72**
Average power requirment (Watts/hour)			**0.95**	
Battery voltage		**12**		
Average current (mA) will be	**=**	**78.88**		
Capacity of Battery used (Ah) is:	(reserve factor)	**2.5**	**Day & Night Ah**	**4.73**

The graph below shows when and how-much current is used in the prototype #4. Both the low current 'waiting phase' (waiting for sound from the Well), is shown together with the higher current 'enunciation phase' (when the unit speaks and repeats the Well ID together with the total time-count). From this chart a visual integration was performed which established that the calculated Power-Budget is in the correct ball-park.

(Note: The waveform below was obtained across the meter measuring total ad varying current to the Unit. The Picoscope was set at 5sec/division, and the current meter was an old but trusted AVO 8 set at 1amp DC.)



Design Notes:
There are some unusual design choices in the circuit. Below is an attempt to outline the reason behind some of these choices.

1. **Why use analogue and not digital solution.**
   The use of a Raspberry Pi 3 (or Zero) was considered, however their maximum power budget (of 2.5 Amps) was considered too high. Also, we felt happier in the analogue domain to first check out all the issues. Also, the relays are used to turn off most of the circuit when not needed. We can't turn off parts of the micro PC. However, a Pi zero with Hats could be the next version.

2. **Why use a multi-Voltage System**
   There was no choice! The mono-stables feed each other with twelve volts in the power chain. However the phone module requires five volts and the calculator three volts. These voltages are best obtained by individual power supply regulators as show in the block diagram. These appear excellent PSUs and also are available at very low cost.

3. **Why use a calculator for the blind.**
   This was the lowest cost method of counting pulses and converting it to speech. The main issue is in 'pressing' the keys. The relay solution seems to work well at providing this function. A PC could have been used but this would cost more, both in terms of financial outlay and in the power budget requirements too.

4. **Why not put it all on one PCB**

Cost. It was felt the modules from China are such low cost, building it all on a PCB is likely cost more. *However*, a PCB version of the trigger unit is being investigated (By a retired Aerospace & Defense Senior Hardware Designer) and the results will feed this document as soon as we have the details.

5. **Why use the PLC Monostable**
   Timing accuracy & ease of use. The PLC Monostable is a remarkable bit of kit. It does all we need for only a few pounds. It takes 5.7mA in standby and about 50mA when active. However, the main advantage is accuracy. Thomas will be able to predict when the ‘phone module is receptive to his calls and texts. If we were to use a normal analogue Monostable this level of accuracy would not be possible. This uncertainty would make operation of HQ very difficult. It will be difficult enough even with the digital Monostable as temperature will drift the timings. The amount of drift is in the region of 28secs/hr. Allowances can be made for the drift in the spreadsheet and will be reflected in the WOTS time.

   Note: *Calling the Wells is much cheaper than the Wells calling Head Office.*

4.5 Modular Design Issues:

Each of the modules mentioned above are discussed below:

The microphone & Amplifier.
Research showed that China produce a microphone and amplifier module at a lower cost than it is possible to secure (in the UK) the individual components.

It is this (adjustable) module that listens to the pump and passes the signal to the Fourier analysis module. It works well, however the adjustment is key as acoustic feedback from the relays can create positive feedback which keep re-triggering the Count units.

The Mobile Cell Module.
To produce a mobile cell module from scratch would cost a significant amount. The level of ASIC required is a multi-million pound investment. However, it turns out that China produce an almost ideal module for our use.

There is no keyboard or screen on this ‘phone module. It is just the electronics that perform the radio frequency (RF) & other digital work necessary to answer a call automatically. As an added bonus this module, if given the correct codes, will let the User know its approximate location. (Via a map from China – so remember, the locations and all the date transmitted from the phone modules go through China.)

The SIM card purchased in the UK needs topping up, but (for the ee network) it’s only £1 every 6 months. The local SIM card will be different and its contractual issues must be included into the latest version of the User Manual.

(Unfortunately, this first ‘phone module did not function when it was delivered. However, the suppliers did eventually replace it. Their service and support process worked well, as did the replacement unit.)

The Fourier Analysis Module.

The simplest of all frequency analysis methods was implemented – a capacitor (C) and resistor (R) making a first order filter. The CR network will, it was hoped, split the output from the microphone’s amplifier and feed the signals into the next stages - the Schmitt waveform cleaning module.

In the current design the signal from the amplifier is fed directly to the PLC Monostable to trigger the Count sequencer. The high volume and high frequencies seem to be very effective at triggering the unit. As this has been proved in all the prototypes it is this circuit that is reflected in the block diagram. This has meant that most of the electrolytic capacitors can be replaced with the more reliable low value ceramic decoupling capacitors.

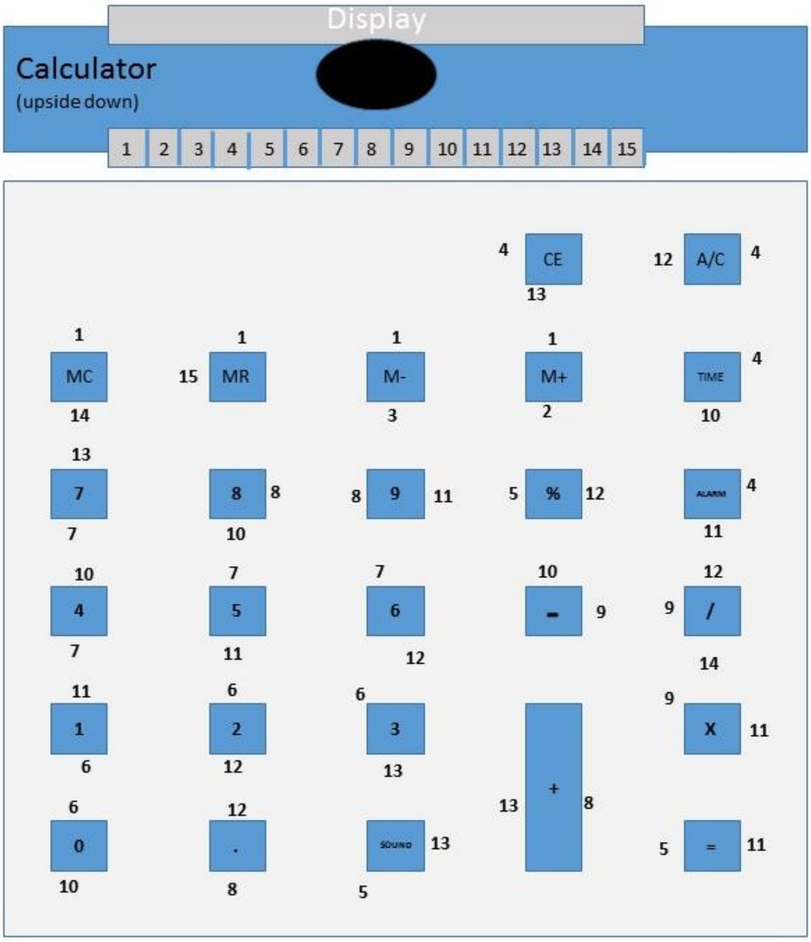
The Schmitt Module.

The new microphone and audio amplifier provides a digital output. This appears fast enough to trigger the Count Monostable Unit as required. So, the Schmitt unit initially considered as a separate unit is now incorporated into the new microphone amplifier. This simplifies the design and keeps the cost down. (In the author's opinion China produce some really excellent and well thought-out Modules)

The Pulse Counter & Data-to-Voice Converter Module.

This counter and speech module posed the greatest challenge. How to count pulses and then convert them to speech for transmission over the 'phone module. After researching a variety of methods, (all of which used a computer) a calculator for the blind was: purchased; severely hacked; tested and found to work! The main drawback of this approach is the complexity of the triggering circuitry necessary to invoke speech from the calculator without actually pressing any of its buttons by hand.

After removing the: flexible keyboard, the display together and their foil connections, we were left with the PCB, speaker and battery. There are 15 connections onto the keyboard. These 15 connections were traced to the keys as outlined below. These connections are carefully soldered to and brought out to a chocolate-block. It is highly recommended that a 15 way chocolate-block is used even if we don't use all 15. If this is not done it is very confusing trying to connect all the wires up to the correct relay later on.



The numbers inside the blue boxes above show the calculator's functions. The numbers outside the blue boxes show the pin number on the calculator PCB. (Remember to read the calculator pin numbers the right way up!) This forms the basis for the design of the Count Trigger Unit.

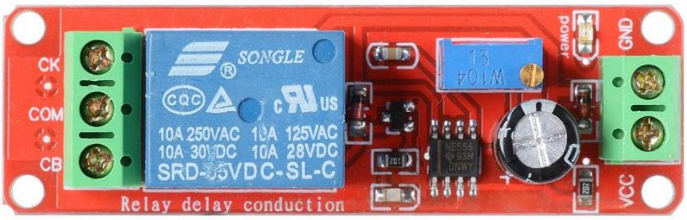
The Trigger Unit Module.

This composite trigger unit module is essential, it sorts the data, stores it in the calculator and retrieves it when needed. It is a basic compute engine and is PC-like. The data is stored in the calculator's memory and the trigger unit sorts out the logical functions necessary for it to function. This section forms the Unit's most complex set of modules.

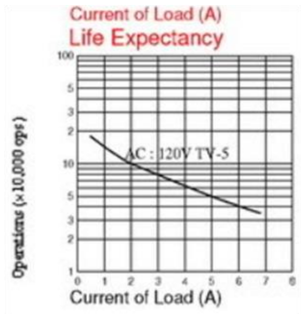
As a result of the required functional complexity, over a dozen sub-modules are used for each frequency band (only one frequency band is used on this prototype, but more bands could be added later). Each of these sub-modules are small (size of your thumb) but their operation is key.

The delayed start Monostable units pictured below are used extensively. It is lucky therefor that, once again, they come from China and are low cost. Fifteen of these units have already been delivered and all work perfectly. As a result more will be ordered from this supplier and will be wired up with the other modules as per the block diagram in the previous sections.

However, *great care* must be taken when purchasing these units. There are two **very** similar units. In the one we use the relay comes on *immediately* power is connected and goes off after a given time. The other unit works the other way round. In this almost identical unit the relay is <u>not</u> activated as soon as power is applied, the relay only comes on after a period of time. Although functionally and logically identical, the latter unit consumes far more power than the former. Do ***not* purchase** the delayed relay-on unit, purchase the delayed relay-off unit! (The only external clue here there is no Chinese lettering on the correct PCBs – but do not rely on this, check)

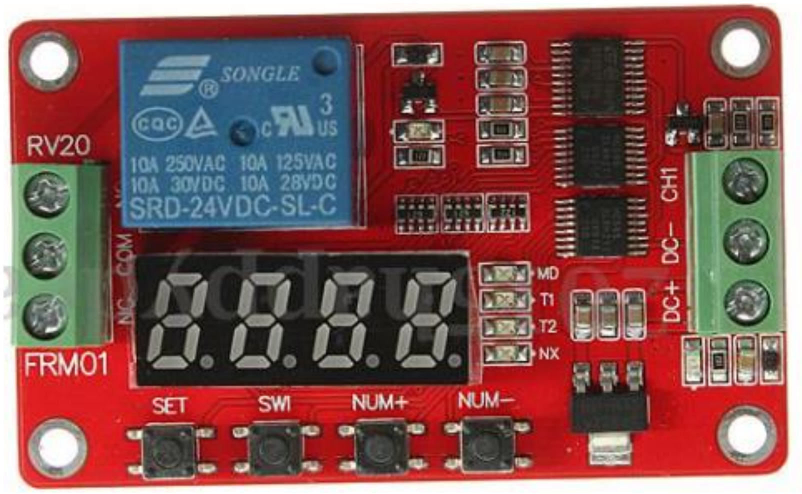


Shock Endurance Error Operation	 100G Min. 10G Min.
Life Expectancy Mechanically Electrically	 10^7 operations. Min. (no load) 10^5 operations. Min. (at rated coil voltage)
Weight	abt. 10grs.



The relay's operational specification, at the current used in the trigger circuit, is rated at ten million operations. The author has conducted endurance tests in excess of 100,000 contacts and the trigger circuit and relays never faulted once. However, the relay life time is short when compared to a two year maintenance schedule. As a result the Well time counter will *not* now count seconds of water flow, but will count in increments of multiple seconds. (15secs) this will extend the life of the relays. A longer time cannot be used as some of the Users only take 30 seconds to fill the water container. (Shannon's Law)

In addition to the above, a re-triggerable PLC Monostable is used to drive the rest of the triggering modules. These PLC Monostable will power up all the other modules required and then switch them off again when the time is up. This will save considerable amounts of power.



Re-triggerable PLC Monostable

The triggering unit for the speech set of modules is activated by the above. Various other methods of ‘phone module activation detection were investigated and other modules purchased. (See Appendix). For example, the reliance on the increased current taken by the phone module when transmitting was ill founded. The change was so small it was not detectable reliably.

Another method was investigated, an RF sniffer. (As used in James Bond movies.) This unit was again low-cost and appears to detect the phone module well. However, the power budget implied that we should use an alternative method to trigger the transmission of data.

A photo diode module was used to act as a day-break detector. This would trigger the phone module and speech circuitry. This way removed the need for the James Bond RF sniffer too. However, the very slow sun rise failed to trigger the opto switch. A Schmitt trigger could have improved the situation here.

The PLC Monostable has proved excellent. Its instruction manual however could be improved.

The Solar Battery & Charger Module.

This module is simply a battery with attached solar panel. A low-cost test version will be used first (pictured below). However, a much larger and more expensive unit will be required in the field. (To be detailed later after testing of the full prototype.)

The unit used in the trial is made for a Smart Phone. The overall power budget of the flow monitor is high because the phone and other modules are so power hungry.

The above solar charger battery pack outputs five volts, however most of the circuitry requires twelve volts, as a result a voltage booster (from 5v to 12v) will be required as below:

The Power Supply Modules.

Three PSU modules are required from the main power supply: We require a 12v regulated supply for the monostable modules, we will also need a 5v supply for the most power hungry unit on the circuit, the ‘phone module, and a 3v supply for the hacked calculator module.

The above 12v unit has now been tested and works well. It operates from 3 volts to over 7v and keeps the output at 12v. There is a little noise, so this should not trigger the trigger circuits accidentally. The precaution of decoupling capacitors will be taken, but generally this unit performs very well.

The 3 and 5 volt board is shown below (just different switch positions used). This module works well. However, it should be noted that the silk-screen on the PCB is wrong way round.

To obtain the voltage required (say 5v) you must appear to switch off the 0.5v, the 1v and the 2v switches as this, when added to the base voltage of 1.5v adds up to the required 5violts.

Current calculations show that a 12 volt solar cell unit with 7AH battery and charging circuit may have to be used as shown below:

This large solar cell cannot be attached to the Well as first envisaged. It will have to sit on a pole close to the Well. A link on the Well (radio? see below) may then have to be engineered to transfer the acoustic information from the pump to the electronics unit on the pole. This link could be achieved by using a cable. It would be easier, cheaper but would be liable to more damage.

The Electronics Housing Unit

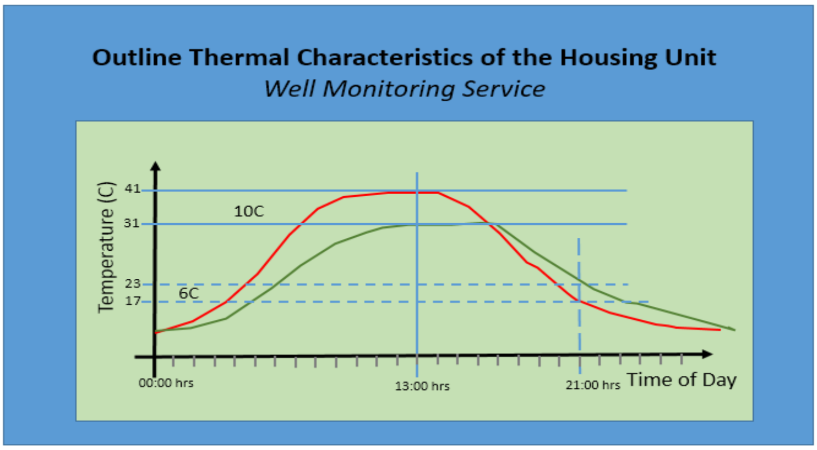
The housing for all this electronics will not be insignificant. Its initial size was thought to be just larger than a shoe-box size. It now looks like to be twice this size.

The electronic unit must not be subject to temperatures exceeding 50C otherwise they will eventually fail. After taking temperature readings off a car's metal-work in the UK after a hot day (30C) temperatures in excess of 70C were recorded on the roofs of black cars left in the sun.

Current best thinking is that a form of artificial shade be provided. A form of heat-pipe could be used but this would be expensive. This is still all Work-In-Progress (WIP) but the camera unit below is a likely design. It has a 'hat' with a brim which is isolated from the main camera with an air-gap.

It has been decided that the box shall have to be constructed in a similar fashion but from PVC or wood. The specific dimensions still need to be determined as does the umbrella structure to create the shade. In this case there should be an air gap between the umbrella and the box as this will ensure minimum thermal conduction between it (the umbrella) and the box.

A concept-model of the housing unit has been made and is shown below. The temperature characteristics of the box were measures and are shown below. Note the shade producing umbrella with thermal air gap. (The box contains two A4 size circuit boards)



Initial studies indicate that the above housing unit (when subjected to the hottest day in the UK for 25 years) reduces the peak temperature by 10 degrees C, and delays the thermal curve by two and a half hours.

This shows that the initial design of the housing unit for the electronics appears beneficial at reducing the top temperature the electronics is subjected to and this design could be used.

Although the concept of the housing is fine, it's too big! An alternative has been purchased as a trial for the prototype. An umbrella and solar cell (may be the same?) will have to be retrofitted. Also, the circuit boards will have to be reduced in size in order to fit.

4.6 Parts List & Costs:

This current design employs the modules mentioned above. The modules are listed below with current costs and estimates (Q4 2016)

The cost of the manpower to assemble, test and install are unknowns. Current estimates of components total about £150/unit.

A list of websites is below and the invoices for the New Prototype follow:

Website details

Single Frequency Version

Part Name	Supplier
12v to 5V converter with ter	http://www.ebay.co.uk/itm/221551519038?_trksid=p2057872.m2749.l264
5v to 12v power converter	http://www.ebay.co.uk/itm/141760266639?_trksid=p2057872.m2749.l264
Box - wood	Local
Box clamps (plastic tie)	
Cables (yellow/green/black/	http://www.ebay.co.uk/itm/111296954068?_trksid=p2057872.m2749.l264
Calculator for the blind	http://www.ebay.co.uk/itm/360603965403?_trksid=p2057872.m2749.l264
Capacitor components	http://www.ebay.co.uk/itm/111866006955?_trksid=p2057872.m2749.l264
Capacitor components	http://www.ebay.co.uk/itm/250869479096?_trksid=p2057872.m2749.l264
Chocolate Blocks	http://www.ebay.co.uk/itm/201618835940?_trksid=p2057872.m
Manufacture & Test	Local
Microphone & gain Amplifier	http://www.ebay.co.uk/itm/181997464191?_trksid=p2057872.m2749.l264
Monostable pack delayed	http://www.ebay.co.uk/itm/191845043339?_trksid=p2057872.m2749.l264
PCB base	Local
Phone Module	http://www.ebay.co.uk/itm/222094710735?_trksid=p2057872.m2749.l264
Pole	http://www.ebay.co.uk/itm/1-x-10ft-Aluminium-Scaffolding-Tube-Scaffold-H
Solar Cells battery & charger	http://www.ebay.co.uk/itm/Solar-Kit-pro-10W-12V-Solar-Panel-Charge-Regu
Well head Transmitter Rx	http://www.ebay.co.uk/itm/291345625513?_trksid=p2057872.m
Well head Tx Rx housing	
Well head Tx Rx solar psu	http://www.ebay.co.uk/itm/231993849194?_trksid=p2057872.m
Well head housing	
PLC Module Cycle Timer	http://www.ebay.co.uk/itm/like/Multifunction-Self-loc

Note: These costs do not include the equipment recommended to build and test the electronics unit. The full test kit will be an additional one-off cost of £250 ca. however a test kit-lite could be made available for just a few pounds. The housing costs are also unknown.

Parts List Orders for New Prototype

See below:-

Spend on New Prototype Water Monitor Services Electronics System

					number used	total cost
						158.485
01-Nov-16	shenzhen estone trading company	Details Payment To shenzhen estone trading company 1YC928250B624594T	-£7.58	2x **PLC** Cycle Timer Module Delay Time Switch [12V]	1.5	-11.37
30-Oct-16	cao ying	Details Payment To cao ying 09E368735Y3350806	-£2.58	1PCS Voice ISD1820 Recording **Recorder** Module With Mic Sound Audio+Loudspeaker	1	-2.58
20-Oct-16	D&M COMPONENTS	Details Payment To D&M COMPONENTS 8YV52346S42642646	-£1.35	Ceramic Disc **Capacitors** 50V - Range 120pF to 1uF, Pack of: 10, 25	1	-1.35
20-Oct-16	GEREE TECHNOLOGY CO., LIMITED	Details Payment To GEREE TECHNOLOGY CO., LIMITED 8GX32012PT595293V	-£3.16	DC DC Converter **Step Down** 24V 12V 5V Adjustable Power Module 5V-36V to 1.5V-33V	1.5	-4.74
14-Oct-16	VERA ENTERPRISES CO. LIMITED	Details Payment To VERA ENTERPRISES CO. LIMITED 4NF383849V899330X	-£9.75	**Phone module** Bug Listening Device Audio Tracker Surveillance	1	-9.75
06-Oct-16	Air Cargo Trader Limited	Details Payment To Air Cargo Trader Limited 7A600819A2296063P	-£1.88	**Microphone** MIC Controller for Sound Detecting	1	-1.88
16-Sep-16	In-Excess UK Ltd	Details Payment To In-Excess UK Ltd 38R629778B188891R	-£6.90	Large Garden Weatherproof Enclosure Dry **Box**	1	-6.9
13-Sep-16	PUNTOENERGIA ITALIA SRL	Details Payment To PUNTOENERGIA ITALIA SRL 7C258888E1923271S	-£53.57	Solar Kit pro 10W 12V Solar Panel Charge Regulator 5A-PWM 1xBattery 7Ah	1	-53.57
11-Sep-16	深圳市艾姆诗数码科技有限公司	Details Payment To 深圳市艾姆诗数码科技有限公司 3XD62877K9170921P	-£1.98	New LM386 Audio Amplifier Module 200 Times 5-12V 10K Adjustable	1	-1.98
07-Sep-16	Welsky Technologies Limited	Details Payment To Welsky Technologies Limited 2GA41244DM654970M	-£20.38	5X 12V Delay Timer NE555 Monostable Switch Relay Module Adjustable Arduino	2	-20.38
07-Sep-16	D&M COMPONENTS	Details Payment To D&M COMPONENTS 53717349KF436761T	-£1.19	Ceramic Disc Capacitors 50V - Range 120pF	1	-1.19
28-Aug-16	胥 家良	Details Payment To 胥家良 0WE15873XS1335249	-£1.95	jumpers cables	1	-1.95
28-Aug-16	liu gui ying	Details Payment To liu gui ying 9XD647405V8654301	-£8.97	multi **wires**	1	-8.97
28-Aug-16	Siu Yi Leung	Details Payment To Siu Yi Leung 83A92071FF4688744	-£5.26	green **wire**	1	-5.26
19-Aug-16	Maltby Auto Electrical Services Ltd.	Details Payment To Maltby Auto Electrical Services Ltd. 0T3922967Y688974E	-£5.95	Chocolate blocks	1.5	-8.925
18-Aug-16	Easygift Trading Ltd	Details Payment To Easygift Trading Ltd 5NM20218N91773353	-£5.98	blind **calculators**	0.5	-2.99
17-Aug-16	Falcon Workshop Supplies	Details Payment To Falcon Workshop Supplies 40L55529WD904154G	-£9.79	ss wood **screws**	1	-9.79
06-Aug-16	TOMTOP TECHNOLOGY LIMITED	Details Payment To TOMTOP TECHNOLOGY LIMITED 0NA1939594500593U	-£4.91	magnifying **loop** glass	1	-4.91

NB: Search EBay on the Text Description to locate components.

5 COMPONENT SELECTION AND DESIGN CONSIDERATIONS

In this section each of the major items or components are considered individually. A brief statement of the suitability for each component is made ready for further action.

5.1 Flow Sensor:

After considering numerous options (see table opposite) the current view is to measure the water flow rate acoustically and just use a *microphone*.

Other methods considered viable were, ultrasonic, and the magnetic Hall Effect. Another sensor considered was the electromagnetic EMF sensor. Although this has no moving parts its component count and power requirements are high.

Type of Flowmeters

1. Correlation Method
2. Corriolis
3. Elbow Tap "Elbow Meter"
4. Electro-Magnetic
5. Flow Nozzles
6. Flow Tube
7. Nutating Disk
8. Orifices
9. Oval Gear
10. Pitot Tube
11. Positive Mass
12. Reciprocating Piston
13. Rotary Vane
14. Swirl
15. Target
16. Thermal Dispersion
17. Turbine
18. Ultrasonic Doppler
19. Ultrasonic Transit Time
20. Variable Area
21. Venturi Tube
22. Vortex
23. Weir & Flume

By using a microphone (or geophone) the reliability of the sensor will be excellent, however the estimated accuracy of the meter will not be high. The proposed method of getting information from the microphone is through frequency analysis. The accuracy will be improved through rigorous calibration procedures.

This frequency analysis method should enable us to determine when the pump handle is being used but no water flows, this would indicate a dry Well or Well that is currently refilling or is broken.

5.2 Data Collection:

Satellite data modes were considered, however the price placed this option out of reach. Not only are the satellite phones expensive but the monthly charges can also be significant, see table on the right.

Voice & Data Plans

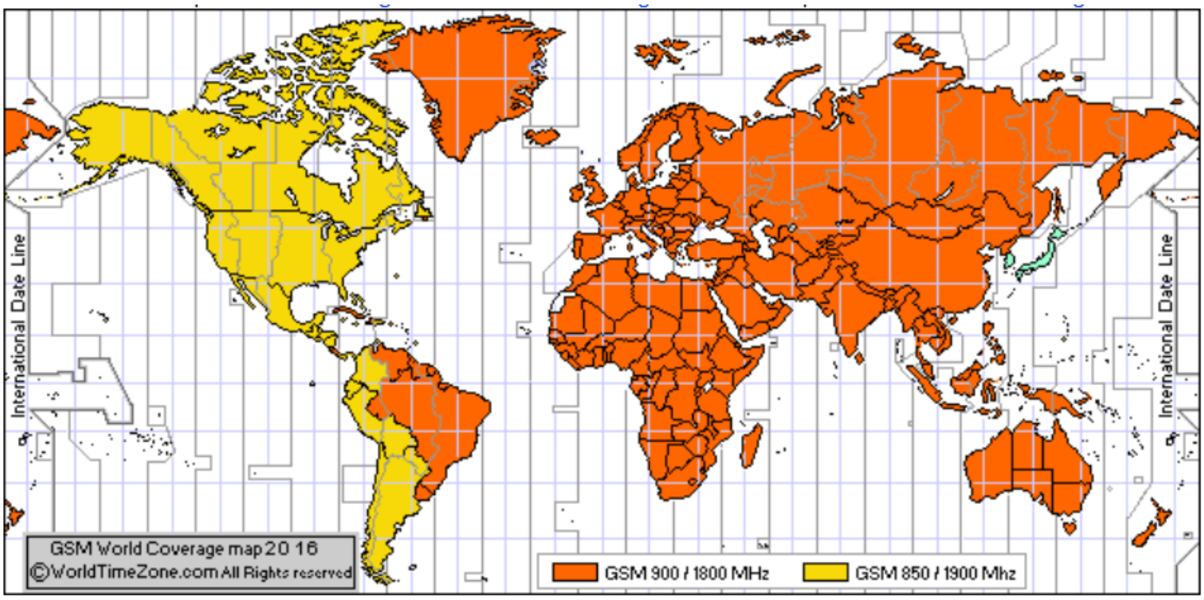
Standard Plans

Service	Standard
Activation Fee	$55.00
Monthly Fee	$18.50
Minimum Term	1 Month
Inclusive MB	0
Background IP - Overage per MB	$3.75
Voice to Fixed - per Min	$0.75
Voice to Cellular - per Min	$1.13
SMS	$0.46

Water Flow Data will therefore be collected using the cellular mobile phone network. The cell network has reportedly good coverage in the areas concerned. The mobile phone module used will:

- Receive the Controller's call
- Auto-answer and
- Recite pump usage and the flow totalizer.

The GSM (Group Special Mobile) phone bands most used throughout the world are as below:



The frequency allocations in Tanzania are currently:

Tanzania	900	1800			3G 2100 Airtel Tanzania; 3G 2100 Tigo; 3G 2100 Vodacom;	4G LTE Smile Tanzania - Vodacom 800Mhz; 4G LTE Tigo NEW!; 4G LTE Smart Telecom; 4G LTE TTCL NEW! ; 4G LTE Zantel in Zanzibar NEW! ;

5.3 Data Recording:

The Water Monitor Controller will call each Well in turn and listen to the automated flow readings. The data can be collected on-demand, either monthly or daily. The only limit will be on the battery life and the SIM card parameters.

The Water Flow Controller will call or text each pump in turn and manually record the recited totalized well-time data onto a special spreadsheet. A Point-and-Click approach will be used in the development of this highly graphical application. System self-checking will be important here as it will be very easy to manually transpose figures and corrupt the data.

It will be necessary for the person who records the data to concentrate on the task in hand and not be distracted.

The Data Recording Application will be a simple-to-use spreadsheet where few, if any, formulas will be visible. It is expected that further details will appear in the Story-Board screen shot section following and as time progresses.

5.4 Data Reporting:

The Water Flow Controller will perform basic analysis of the totalized Well-time data. S/he will create reports and email them off to the Team. Care must be taken here to ensure the person performing this role is well motivated, otherwise basic data errors will creep in making the reports worthless.

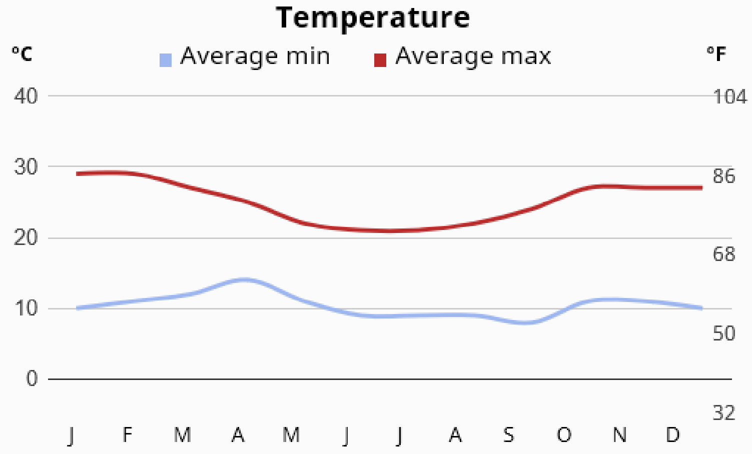
Job satisfaction is important too. Financial incentives have proved valuable, however the author has found that, in Africa, the financial side not as important as in Europe and additional incentives must be employed

5.5 Data Environment:

In addition to the above, the temperature of the region must be considered. The housing of the unit must provide a form of umbrella or false roof. This should ensure the electronics are in the shade. Temperatures must be kept below fifty centigrade, otherwise military components will have to be used as these can go up to eighty five degrees centigrade. However, under these conditions the cost of the proposed unit could become excessive. From the below chart the highest temperatures are reached in February and, in the shade, reach 30C. However, exposed metal structures will greatly exceed this figure.

Tanzania - Weather & Climate

Climate chart Arusha - 1400m/4594ft



6 MEASURES OF SUCCESS

There is only one critical success factor for this project. It is that Thomas's documented scenario is operational: a water monitoring system is working (on at least one prototype); collecting data remotely and recording it on a spreadsheet.

6.1 Water Resource Common Concern

There appears to be some truth in the conservative dictum that everybody's property is nobody's property. Will a few people close to the Well, pump the Well dry for self-gain? Do we need to restrict water flow artificially to stop this potential water-robbing situation?

'Wealth' that is free for all (eg: Water; IT Networks/Servers/Group-Drives etc.) is valued by no-one because he who is foolhardy enough to wait for its proper time of use will only find that it has been taken by another....

For example, suppose we think of the players in a game as being herders using a common grazing meadow. For this meadow, there is an upper limit to the number of animals that can graze on the meadow for a season and be well-fed at the end of the season. We call that number L. For a two-person game, the "cooperate" strategy can be thought of as grazing L/2 animals for each herder. The "defect" strategy is for each herder to graze as many animals as s/he thinks s/he can sell at a profit (given his private costs), assuming that this number is greater than L/2.

If both herders limit their grazing to L/2, they will obtain 10 units of profit, whereas if they both choose the defect strategy they will obtain zero profit. If one of them limits his number of animals to L/2, while the other grazes as many as he wants, the "defector" obtains 11 units of profit, and the "sucker" obtains -1. If each chooses independently without the capacity to engage in a binding contract, each chooses his dominant strategy, which is to defect. When they both defect, they obtain zero profit. (*This is called the Hardin-herder syndrome*.)

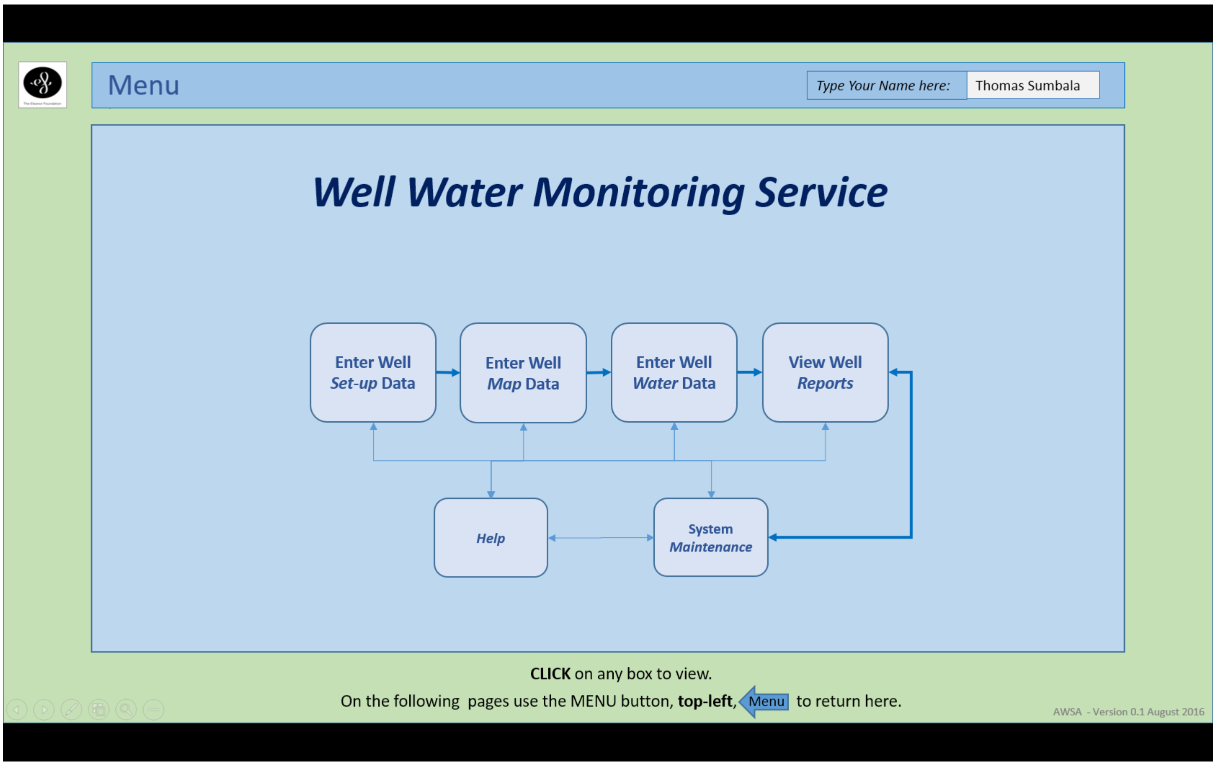
We have common resources, whether they be People, Water or other assets. If they are 'free' to use then we could find ourselves in the same predicament of every player 'defaulting'. This, once again, demonstrates the importance of not only prioritization but also of consultation and the gaining of a *common* view, a strategic purpose that we all understand and share.

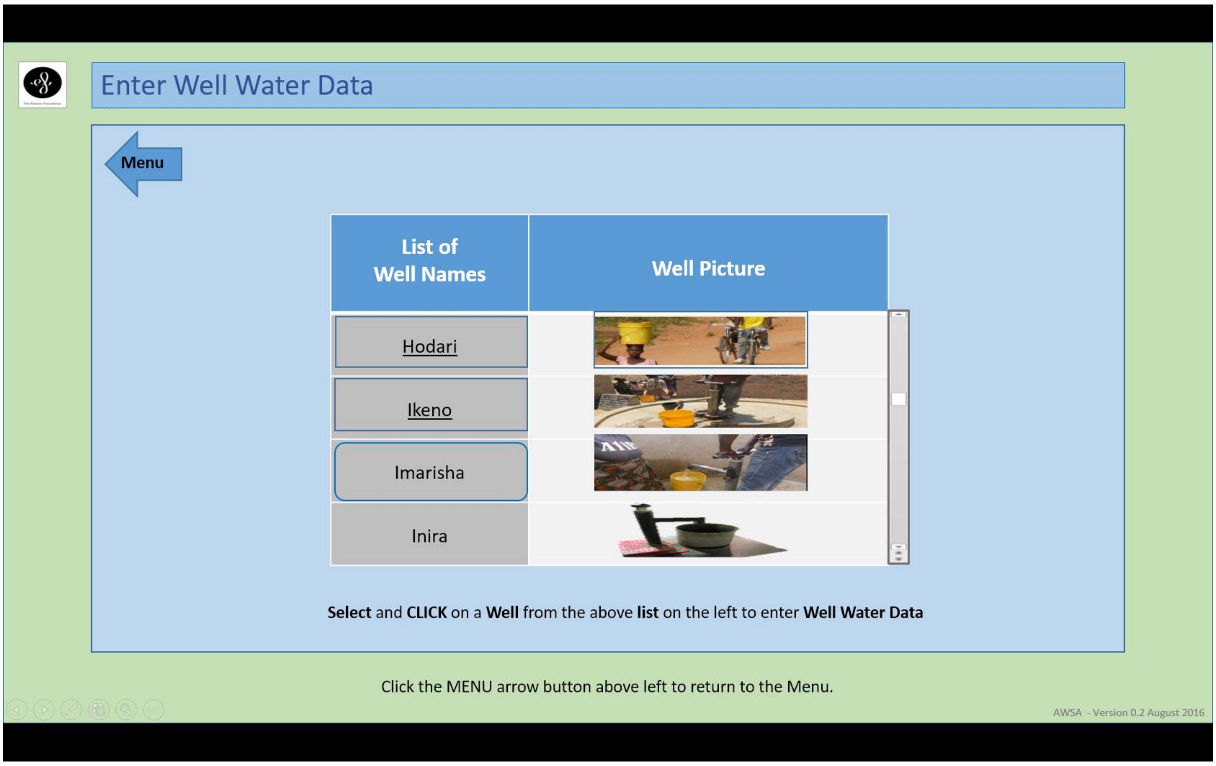
Will this situation occur in Africa? Will a few people close to the Well pump the well dry for self-gain? Do we need to restrict water flow artificially to stop this potential water-robbing situation?

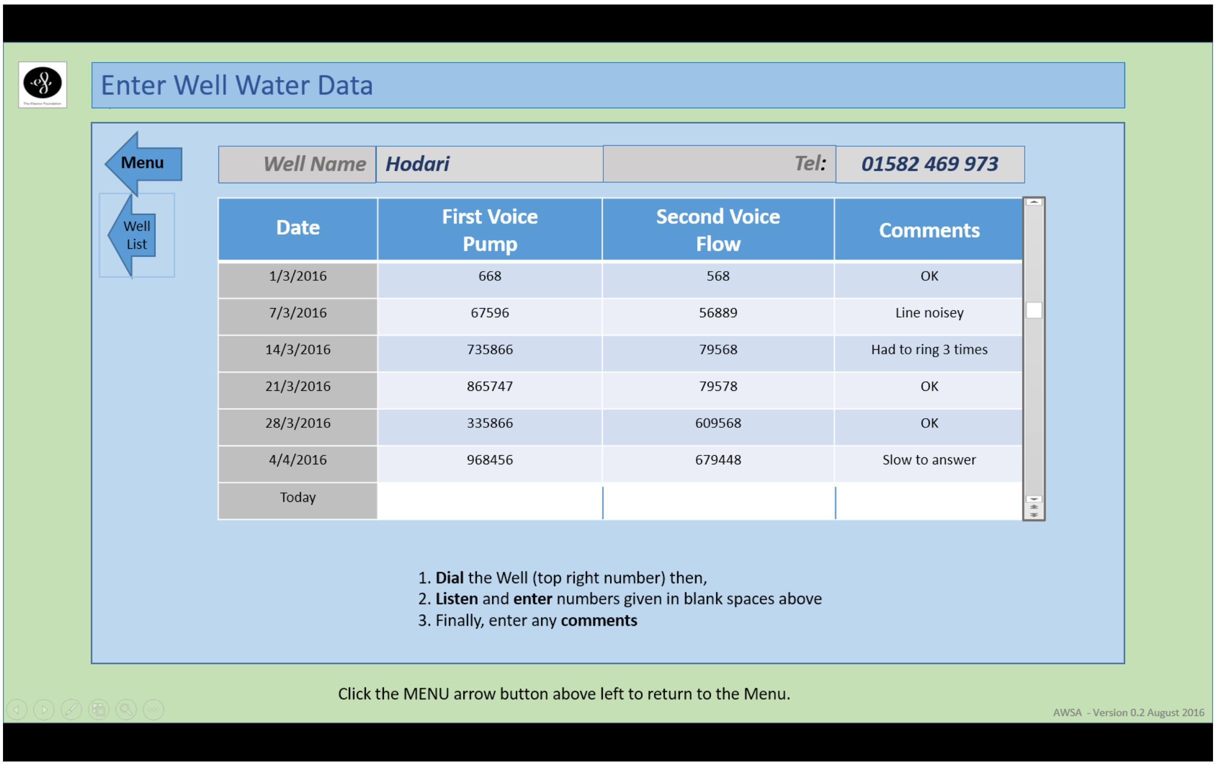
(Note: a few years ago the Hardin-herder syndrome won its' author the Nobel Prize in finance.)

7 STORY-BOARD OF SOFTWARE APPLICATION

The below are potential sample screen-shots of the Well Monitoring System. It should be noted that these 'screen-shots' are for the dual measurement system and not the single time measurement process. This section will be update shortly.

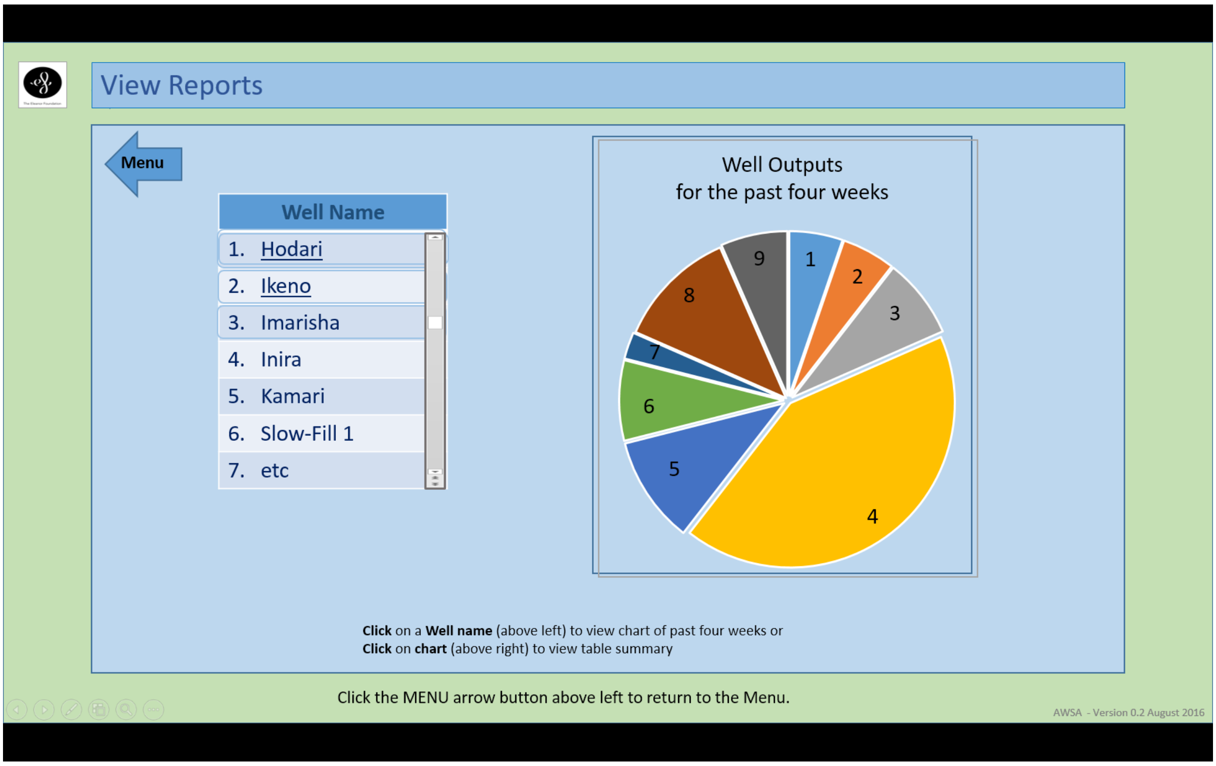


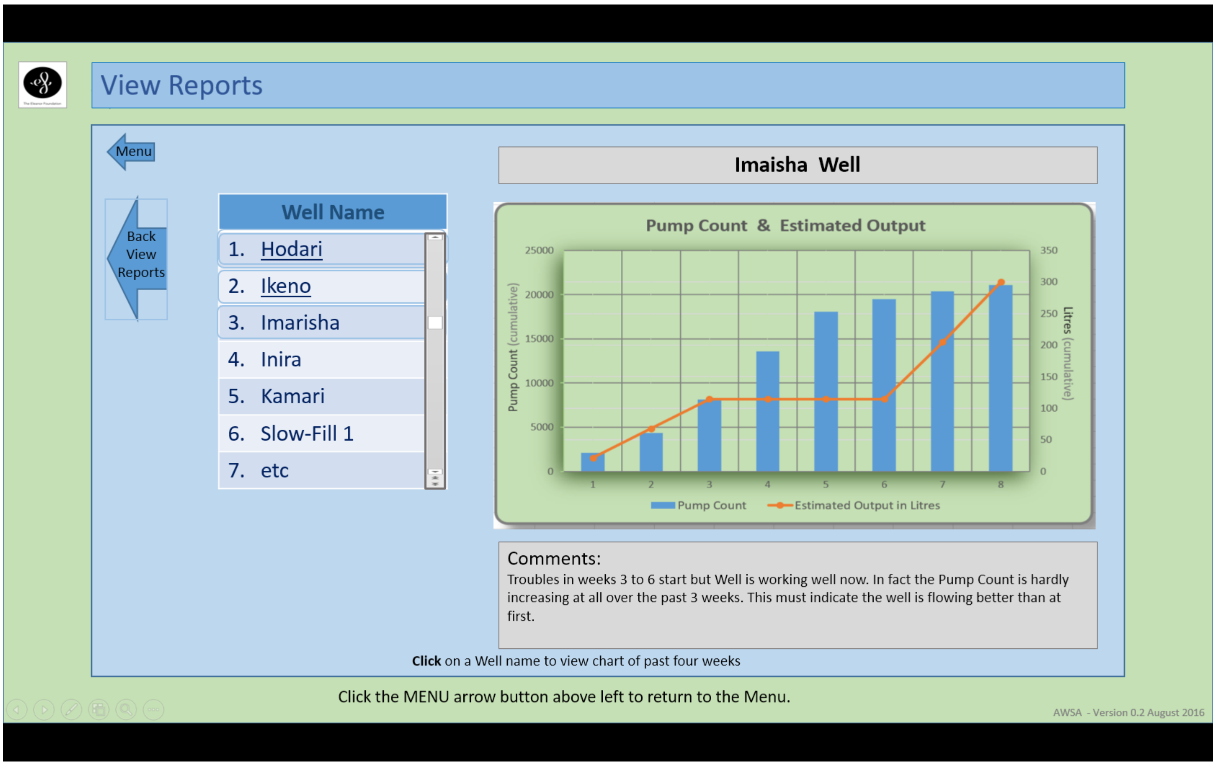



Enter Well Water Data
Menu
Well List
Well Name
Hodari
Tel:
01582 469 973

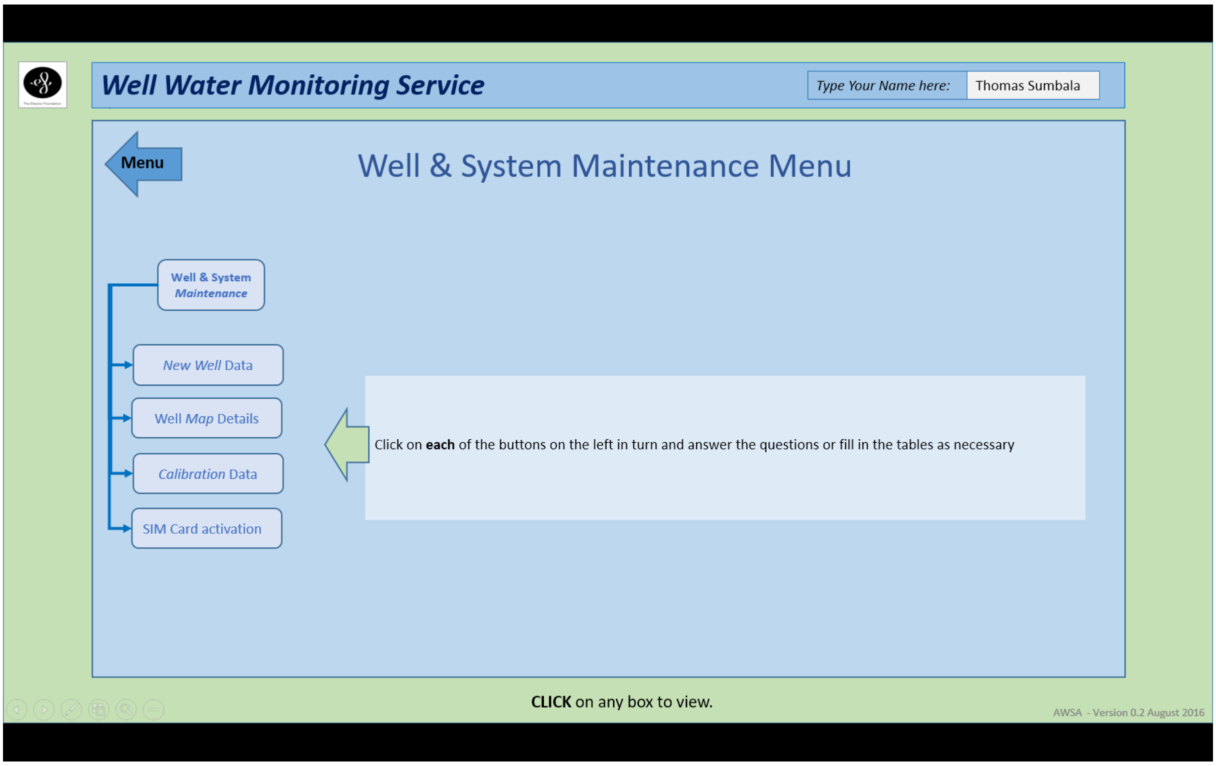
Date	First Voice Pump	Second Voice Flow	Comments
1/3/2016	668	568	OK
7/3/2016	67596	56889	Line noisey
14/3/2016	735866	79568	Had to ring 3 times
21/3/2016	865747	79578	OK
28/3/2016	335866	609568	OK
4/4/2016	968456	679448	Slow to answer
Today			

1. Dial the Well (top right number) then,
2. Listen and enter numbers given in blank spaces above
3. Finally, enter any comments
Click the MENU arrow button above left to return to the Menu.
AWSA - Version 0.2 August 2016

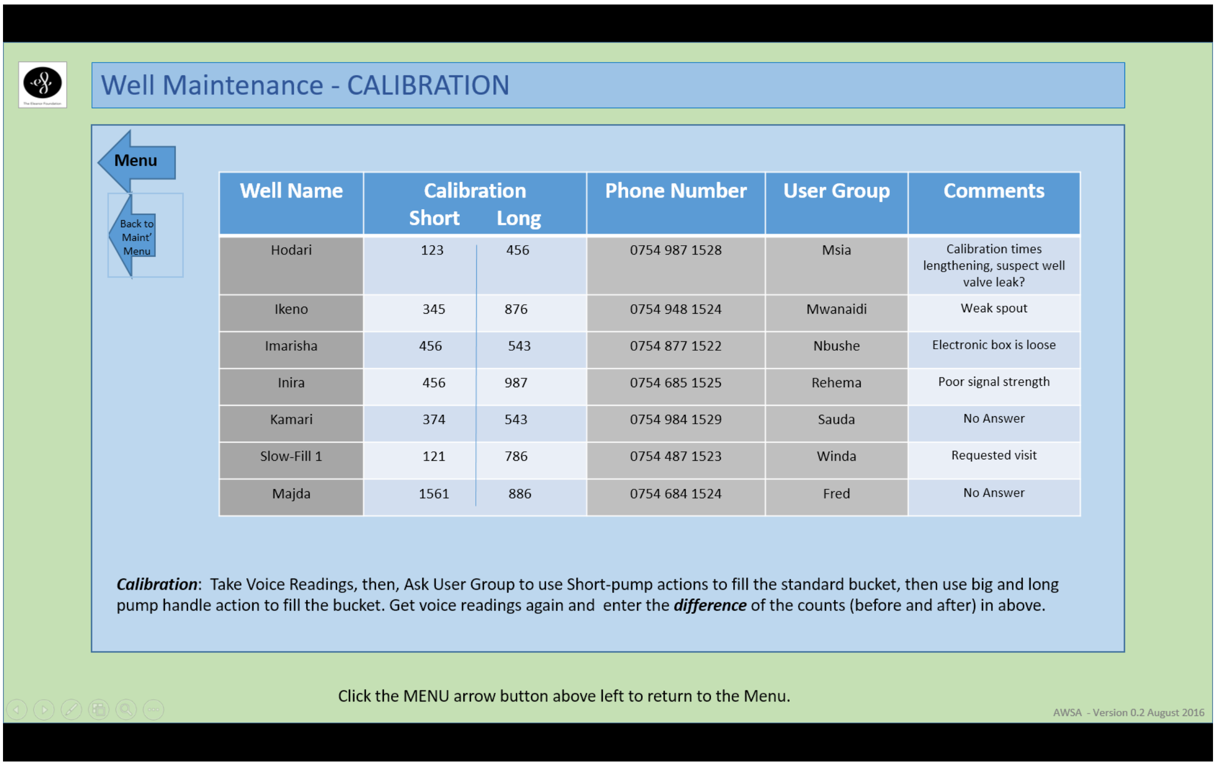

View Reports
Menu
Well Name
1. Hodari
2. Ikeno
3. Imarisha
4. Inira
5. Kamari
6. Slow-Fill 1
7. etc
Well Outputs
for the past four weeks
1
2
3
4
5
6
7
8
9
Click on a Well name (above left) to view chart of past four weeks or
Click on chart (above right) to view table summary
Click the MENU arrow button above left to return to the Menu.
AWSA - Version 0.2 August 2016



Note: These charts demonstrate the twin frequency analysis displays. The current thoughts and current prototype utilises just one frequency band and so only the line graph will be shown, the bar charts will not be present.


Well Water Monitoring Service
Type Your Name here:
Thomas Sumbala
Menu
Well & System Maintenance Menu
Well & System Maintenance
New Well Data
Well Map Details
Calibration Data
SIM Card activation
Click on each of the buttons on the left in turn and answer the questions or fill in the tables as necessary
CLICK on any box to view.
AWSA - Version 0.2 August 2016


Enter New Well Data
23 April 2017
Menu
Maint Menu
Well Name | GPS Location | Phone Number | User Group | Comments
Hodari | Lat: -6.8229 Long: 39.2697 | 0754 987 1528 | Msia | Slow to re-fill
Ikeno | Lat: -6.1732 Long: 35.7419 | 0754 948 1524 | Mwanaidi | Weak spout
Imarisha | Lat: -6.8229 Long: 39.2697 | 0754 877 1522 | Nbushe | Near to tree
Lazy | Lat: -6.1732 Long: 35.7419 | 0754 685 1525 | Rehema | Slow to re-fill
Kamari | Lat: -6.8229 Long: 39.2697 | 0754 984 1529 | Sauda | Old one
Slow-Fill 1 | Lat: -6.1732 Long: 35.7419 | 0754 487 1523 | Winda
Majda | Lat: -6.8229 Long: 39.2697 | 0754 684 1524 | Fred
Sleepy | Lat: -6.1732 Long: 35.7419 | 0754 587 1527 | Zakia
Enter new well information in the first blank row at the bottom of the list above
Click the MENU arrow button top left to return to the Menu.
AWSA - Version 0.2 August 2016



Well Name	Calibration Short	Calibration Long	Phone Number	User Group	Comments
Hodari	123	456	0754 987 1528	Msia	Calibration times lengthening, suspect well valve leak?
Ikeno	345	876	0754 948 1524	Mwanaidi	Weak spout
Imarisha	456	543	0754 877 1522	Nbushe	Electronic box is loose
Inira	456	987	0754 685 1525	Rehema	Poor signal strength
Kamari	374	543	0754 984 1529	Sauda	No Answer
Slow-Fill 1	121	786	0754 487 1523	Winda	Requested visit
Majda	1561	886	0754 684 1524	Fred	No Answer

8 WELL TESTING & CALIBRATION PROCEDURES

In this section thoughts and information gleaned from a variety of sources, including Loughborough University's web pages, have been recorded. The below options should be considered for inclusion into the calibration and proving procedures.

As soon as the Well has been released for use, which is after disinfecting and limited volume use and checks, then operational tests can commence.

These tests are performed in three stages:-

1. Well Pre-Operation Acceptance Leakage Test
2. Well Pre-Operation Acceptance Discharge Test
3. Calibration Procedure

8.1 Leakage Test Proceedure:

a) Operate the pump handle until water is flowing from the spout.

b) Stop operating the pump handle for approximately 30 minutes.

c) Then operate the handle and count exactly how many strokes required until the water is starting to flow again.

If more than 5 full handle strokes are required to make the water flow again, there must be a leakage in the rising main or the foot-valve. Leakage mostly occurs because of worn bobbin or O-ring of the foot-valve, disconnected rising main joints or perforated or cracked riser pipes. Report this problem immediately to the pump mechanic and ask for rectification.

8.2 Discharge Test Proceedure

a) Operate the pump handle until a continuous water flow has been achieved (pump ratio approximately 40 full strokes per minute).

b) Place a bucket in the continuous water flow for exactly one minute.

c) Take the bucket off the water flow and check the amount of water drawn. The water collected should be generally not less than 15 litres. If the discharge is less then 10 litres for 40 full strokes, there might be a problem with the bobbins or the cup seal.

8.3 Calibration Process:

There are two Calibration Processes. The first method is for this prototype. It measures the number of seconds the pump is used when delivered a recorder output. The second and more complex Calibration Process is for future use and is for measuring the Pump Strokes AND the Water Flow time. The first Calibration Process is outlined in this section, the more complex and future calibration process is outlined in the appendix.

The Time-Pumped Calibration Process:

Basically, all we have to go on here is the average number of liters pumped over a long period of time. We then have to divide the number of liters delivered during the calibration process by the time over which the measurements were made and the Well was active.

This will yield the average number of milliliters of water pumped per second of active Well time. This figure can then be used in the spreadsheet and, over time, the measurements should be, on average, correct. The calibration process is therefore:

Visit the well:

1. Measure the Well usage for ideally 24 hours, but more realistically, for at least one hour of pump use.
2. First, note the Time-Count of the Well at the Start.
3. Then, note the *output* of the Well each time a person uses it (liters pumped)
4. Measure the time the pump is used (use the Water Monitoring electronics to do this)
5. Add up the total number of liters of water pumped, and
6. Add up the total time taken at the pump
7. Log the figures in the Spreadsheet
8. Calculate the milliliters of water/second pumped during the Well's operation.

This procedure will present us with the number of milliliters per second of pump use. The recorded time figures will then be multiplied by this figure to provide a derived water flow rate and water used volume.

This calibration procedure should be repeated every month for three months and then the measurement can be relaxed to yearly or as appropriate.

The Pump-Strokes and Water Flow-Time Calibration Process:

If a dual frequency method of measurement is adopted in the future then the calibration process below will provide more information than purely the time-pumped. (This section is included in the **Appendix** for information. It is to ensure that the procedure is not lost as the simultaneous equations took far too long to sort out!)

Calculator Alarm Canceling Process

When the calculator is first switched-on on-site, the alarm will be set. To turn the Alarm off briefly connect pins 4 and 11. This action will select the Alarm option (it should make a cuckoo sound). Then briefly connect pins 1 and 4 together (this should make a high squeak sound. The alarm icon on the display should now have disappeared. Each time the calculator loses power the above process should be performed otherwise the alarm will sound at about midnight!.

Calculations Accuracy

Initial analysis of the detailed video recording made during September 2016 indicate that the average error is in the region of 8%. This assumes the water pumping load is evenly distributed between male and female genders. However, it is expected that the women and girls will do most of the fetching and carrying of the water. An estimate of the ratio of each operator will be made and fed into the calculations during the calibration process. The table below details *current* results:

Statistics of Well Operation Filling 20L container (September 2016 Mike's team Videos)

Operator	Time to Fill 20L	No. Pump Actions	Pumps/ Min	Centilitres /Pump	Centilitres / Second	Base FFT (Hz)	FFT Thumb nail	Operation Comments
Man	1min 46 sec	170	96	12	18.9	TBD	TBD	90% arm work. Rapid short pumps towards the end (135/min) otherwise 85 pumps/min. Did not want to overfill
Woman	1min 37sec	190	118	11	20.6	TBD	TBD	Almost all arm work, then back (bending down) Appeared concerned how she looked, well dressed.
Girl	1min 29sec	218	145	9	22.5	TBD	TBD	Bounces on feet first, very little use of arms until the end, but legs and feet do most of the work.
Total	281	578	123	10	21.4	TBD	TBD	
Average					20.7			
Measurement Comments	Surprising the young girl was fastest	High deviation, but as expected	Varience as expected	Varience as expected	Surprisingly constant. Estimates are 3.4% high?			

This gives us the average water flow of 20.7 centiliters per second. If we now estimate the people using the Well are 15% men, 55% women & 30 girls/children, then we can improve the estimated average flow by weighting and a recalculation. This yields about 12.5 liters a minute. It is this figure that will be set as the *default* in the spreadsheet and this will be used prior to any calibration figures being entered locally. (Wild deviations from this figure will be automatically flagged up in the spreadsheet and a r*equest-to-check* be made.)

During tests at Loughborough University the volume of water pumped was found to be proportional to the energy of the person pumping. It is therefore recommended that the Well calibration process is performed over several hours. This will ensure that the users of the Well will attain their 'regular' pumping action and normal water volumes will be recorded.

Cyclic Test Results

Over 386,000 test cycles were performed. Initial tests were conducted on the relay logic side every second. This took the initial count up to a quarter of a million cycles. All systems performed well. The next stages involved the full system but used accelerated time scales. For example the logic was speeded up so that 24hrs was compressed into five minutes. This cyclic testing was conducted over the majority of November and all of December 2016. Temperatures ranged from plus twenty to minus six degrees Celsius. At about minus two the Well ID module tended to lose its memory. However, this did not interfere with the rest of the unit as it continued to work well.

The only two units (relay Monostables) caused general system failure. It is suspicious that the two units appeared to fail at the same time. Also, as the units were physically close to each other it is suspected that something could have been dropped on them causing the failure. Replacement were installed and the tests continued. They system continues to perform well.

9 CONCLUSIONS

A Water Monitoring System has been designed, prototyped and successfully tested for over 386,000 cycles. The design has changed significantly since the project started on the 19th June 2016 some six months ago now. The changes have been due to an improved understanding of the detailed requirements and the limited power available. Unfortunately, although the current design works well, it is *not* recommended to proceed to the next stage, that of producing multiple units.

Although the prototype detailed in the block diagram works very well and although the individual modules are low-cost, the sheer number of modules plus the solar cells necessary to power it all works out higher than expected. (£150 + pole & wiring for solar panel). During the past six months it has become apparent an improved design would be to reduce the amount of hardware, thus reducing both cost and power consumption, and to re-engineer many of these functions in software.

Small, low cost microcontrollers are now available that appear to fit-the-bill. The current design concept has been proven to work, as a result the overall design it is not expected to change, so section two of this document will remain. (As will many other sections). What will change is the number of hardware modules, the overall cost, the simpler set-up process and, hopefully, reduced power required for the unit.

The small micro controller units (Arduinos) are able to perform many of the hardware functions of the current relay-logic prototype in software. It is this digital approach with its reduced module count, lower overall cost and easier manufacturability & set-up that is now being investigated.

10 TERMS OF REFERENCE

Mike De Haaff initiated this *African Water Meter Challenge* (19 June 2016). Several e-mail exchanges later data was collected and placed in this document. This document will be in a continual state of flux until the specification and design issues have been resolved. This document is for discussion purposes only.

11 AMENDMENT SUMMARY

Author	Summary	Revision	Date
Andrew WS Ainger & Mike De Haaff	First (incomplete) draft - Not released	Draft 0.1	2016-07-20
Andrew WS Ainger	Second (incomplete) draft – Team only	Draft 0.2	2016-08-18
Andrew WS Ainger	Change focus to Well-Time monitoring - draft – Team only	Draft 0.3	2016-08-19
Andrew WS Ainger	Change Block Diagram & some typographical errors - draft – Team only	Draft 0.4	2016-08-20
Andrew WS Ainger	Quarterly Tasks & Housing added – Team only	Draft 0.5	2016-08-20
Andrew WS Ainger	Major Block Diagram changed	Draft 0.6	2016-08-28
Andrew WS Ainger	Block Diagram changed (reflect PCBs and auto turn off of phone at night – power budget)	Draft 0.7	2016-08-29
Andrew WS Ainger	Significant changes to most sections: To keep costs down we are not now NOT adopting a dual frequency mode. Also, due to the limited power budget and the fact that solar cells increase the total costs, we are now not keeping the phone module active all the time waiting from the call from HQ. This new approach changes the block diagram and the operating procedures significantly.	Draft 0.8	2016-09-06
Andrew WS Ainger	General update.	Draft 0.9	2016-10-01
Andrew WS Ainger	Significant changes due to power-budget. Set-up and Mono timings and Layout improved too.	Draft 1.0	2016-12-19
Andrew WS Ainger	Changes logical Block Diagram, test results included, Digital option discussed.	Draft 1.0	2017-03-08

12 RELATED DOCUMENTS

Directly related documents are listed in this section, in addition, referenced documents and standards are listed.

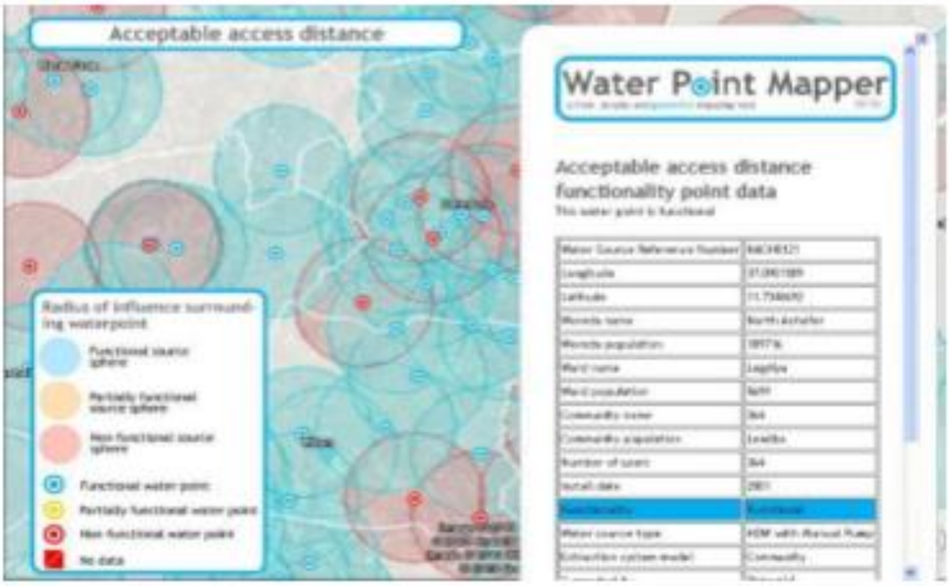
Ref. #	Document Name

1. E-Bay and mainly Chinese web sites (see Parts List)
2. Loughborough University (discussions on Direct Action wells)
3. Maplin Electronics shop in the UK. (Small parts only.)
4. Google for everything else.

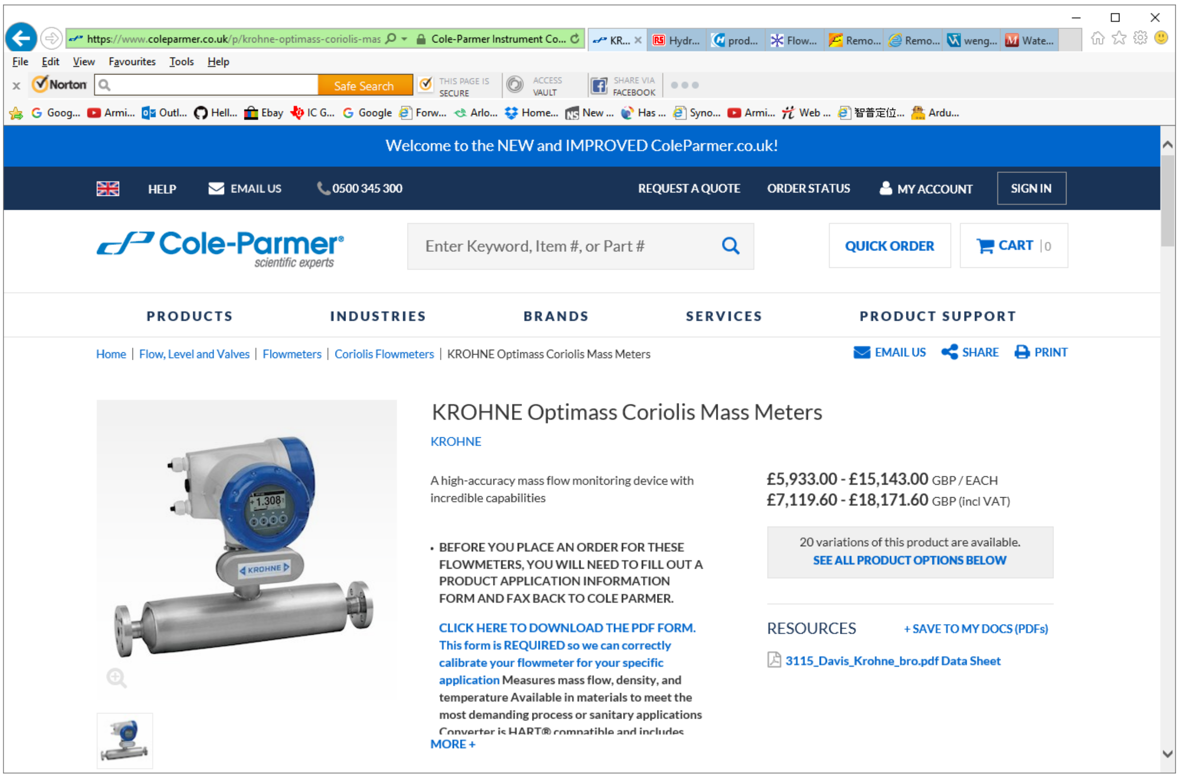
13 APPENDIX: COMERCIAL OPTIONS

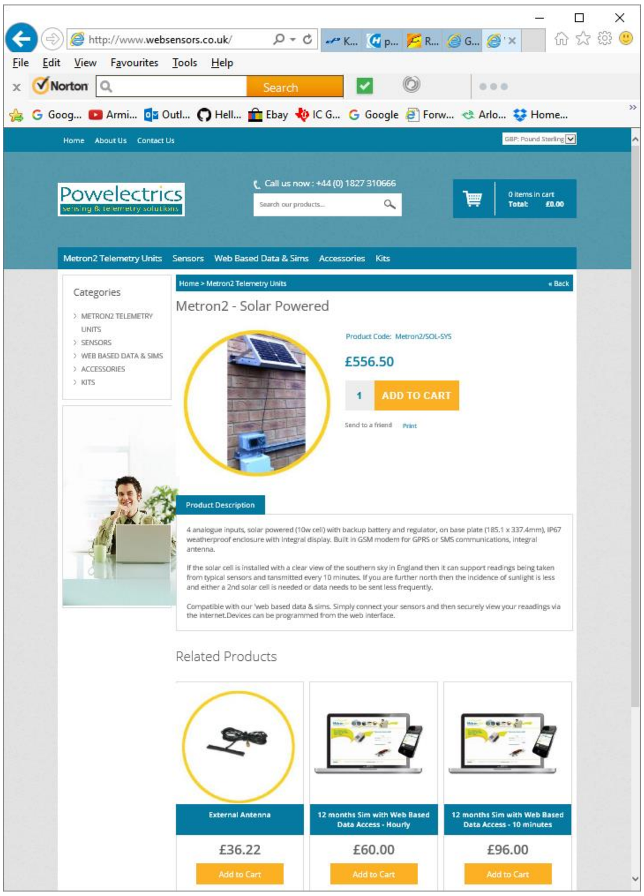
13.1 Closest Commercial Alternative

The closest commercial flow meter alternative is shown below. Unfortunately it will not call-home and so still requires other modules for it to work as expected. For example it will require a small local PC to drive it and a Phone module for communications together with the solar pack module. This commercial unit alone costs in the region of three hundred and fifty pounds (£350 plus taxes). The additional modules will have to be added on top. Due to this expense this hand-held ultrasonic unit was not adopted.



The map is liked, especially the effective radius of each Well.





There is no sensor, software or aerial in the above.

13.2 Other Modules Purchased & Investigated

There have been other modules purchased but all have been rejected for various reasons. Just for the record pictures & comments of these other modules are below.

One moving part Flow Meter

Nice unit but very small flows would not be detected.

Could easily jam up.

A temperature sensor and display to record water flow by its cooling action.

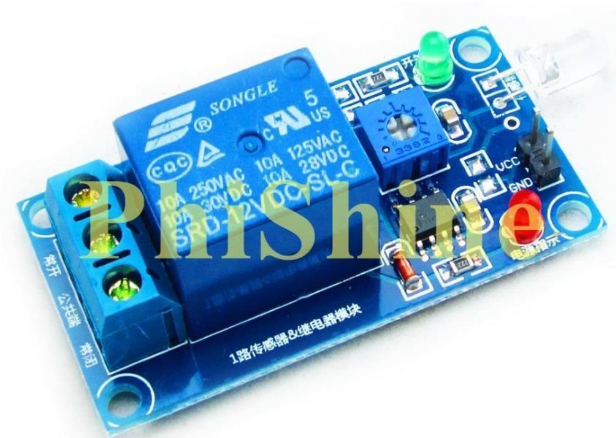
Too difficult to remotely record and read the display

The triggering unit for the speech module is to be activated by a text message to the unit. Various methods of phone module activation detection were investigated and other modules purchased. (See Appendix).

For example, the reliance on the increased current taken by the phone module when transmitting was ill founded. The change was so small it was not detectable reliably.

Another method was investigated, an RF sniffer. (As used in James Bond movies!) This unit was again low-cost and appears to detect the phone module well. However, the power budget implied that we should use an alternative method to trigger the transmission of data. The photo diode module was selected to act as a day-break detector. This would trigger the phone module and speech circuitry. This way remover the need for the James Bond RF sniffer too.

The photo diode module and relay is below:



This opto-switch unit was tested, it works from 12 volts and has an adjustable sensitivity. It seem to work well. When pointed to an LED which is running on un-smoother rectified AC, it even tries to operate the relay at 50Hz. It is this type of module that could detect the daylight first thing in the morning and initiate the triggering module sequence.

Photo diode relay output unit in conjunction with the below.

An alternative for the delayed-start Monostable triggers.

A possibility but difficult to single-trigger the below.

Flowing lights for sequence generation.

Too many different circuits and difficult to make one-shot flow trigger.

Monostable kit

Expensive, time consuming and no capacitor on PSU or on pin 5.

Would fail in the field.

Another Monostable kit

Expensive, time consuming and no capacitor on PSU or on pin 5.

Would fail in the field.

Nice flow sensor

A moving part, and would not detect very low flow rates.

Would jam up in the field in time.

Current sensor.

To detect when the phone module was activated.

Not sensative enough.

Current sensor.

To detect when phone module was activated. Not sensative enough.

An equavalent form of microphone (geo-phone), vibration detector with amplifier.

Keep in reserve but form factor difficult to work with.

The microphone module first used. It had limited gain and a discrete amplifier had to be made to supliment its output.

Switch matrix to program count-to-speech unit.

Needed separate isolated switches not a matrix.

The below monostable from the UK is in kit form so has to be self assembled and it five times more expensive than the chinese version which is built, tested and has free delivery.

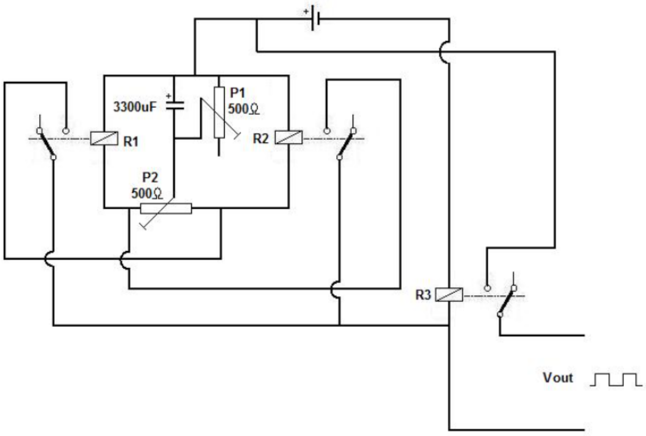
A small pulse generator or oscillator module was required for each frequency band used. However, now the 15sec count has been decided upon and not the single second count, this did work but is not now needed.

Re-triggerable Monostable

The monostable above was considered prior to the PLC monostables. The above have a separate transistorized output switch as well as a relay output. The relay track could be cut and replaced with a 47mF capacitor. This short pulse could then trigger the calculator directly saving significant power. However they were (unfortunately) tricky to set-up and were inaccurate so were rejected & replaced by the PLC monostable.

Box.

Too small, purchased too soon also it’s too flimsy, would fail in the field.



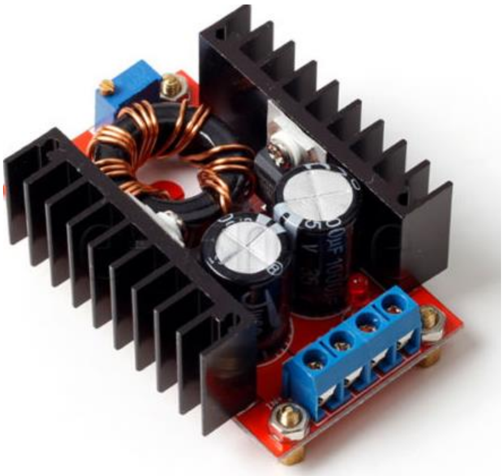
Oscilating relays were also considered, but only briefly. If used they would take considerable power and be acoustically noisy, but, they would keep the component variety count down.

The triggering unit for speech will have now be activated by a PLC pulse to the unit. Various methods of phone module activation detection were investigated and other modules purchased. However, the reliance on the increased current taken by the phone module was ill founded. The change was so small it was not detectable reliably.

Another method was investigated, an RF sniffer above. (As used in James Bond movies!) This unit was again low-cost and appears to detect the phone module easily. However a simple photo diode module was then selected as it was a more robust solution.

The PLC monostable was used in the end as it saves on power, component count and complexity of set-up/

Finally, on the PSU front, the main supply was to be the 12v to 24v module, shown below:



At the time of writing this is now not required as we have improved the design and migrated to a single 12v rail.

This, as all the modules in the above section have been rejected and so are now surplus to requirements.

14 APPENDIX: PUMP TYPES, RATES AND FAILURE RATES

14.1 Documents Reviewing Pump Types

There are many different types of pumps available. This section collated and presents a major report on the pumped volumes and the failure rates.

- **Direct lift:** Water is physically lifted in a container. E.g. rope and bucket, bailer, *Persian wheel*.
- **Displacement:** Water is incompressible. Hence, it can be pushed or displaced (reciprocating technique). E.g. piston pumps, rope pumps, progressive cavity pumps, diaphragm pumps.
- **Creating a velocity head:** Water can be propelled to a high speed. The momentum produced can be used either to create a pressure or a flow (Rotary technique). E.g. helical rotor, propeller pumps, centrifugal pumps, rebound inertia pumps, jet pumps.

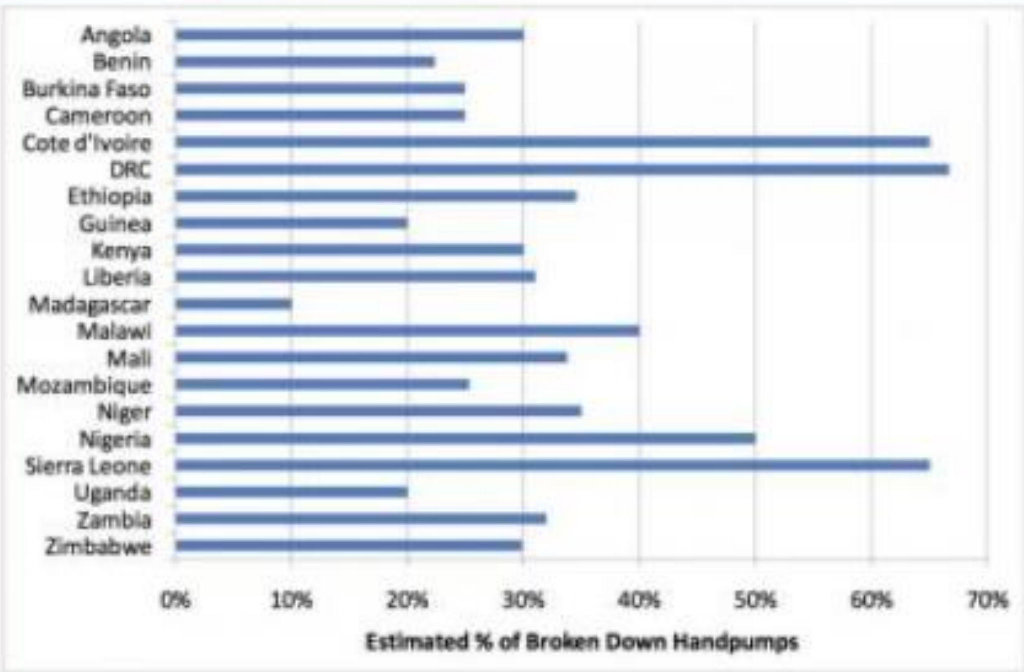
Human-powered pump systems are often categorised in shallow-well (up to 7 metres) and deep-well pumps (above 7 metres).

Type	Manufacture	Investment Costs	Village Level Operation and Maintenance (VLOM)	Low-cost option available	Max. Lift Height [m]	Typical Lift Height [m]	Typical Flow Rate [l/min]
SHALLOW WELL PUMPS							
Suction/Piston/Plunger pump (cylinder is above water table)	Industrial	Low to medium	Yes	Yes (e.g. No. 6 pump)	7	7	24-36
Rower pump/ low-lift pump	Traditional	Low to medium	Yes	Yes	7	4	50
Treadle pump (foot pump)	Basic/ Traditional	Low to medium	Yes	Yes (e.g. pedal pump)	7	4	100
Chain / washer / 'pater noster' (rotary) pump	Basic / Traditional	Low to medium	Yes	Yes	6	6	80
DEEP WELL PUMPS							
Direct action / direct drive/ reciprocating lift / high-lift pump (cylinder is below water table)	Traditional/ (Industrial)	Medium to high	Yes	Yes (e.g. EMAS, Tara)	12	12	15-26
Rope (rotary) pump	Basic / Traditional	Low to medium	Yes	Yes	35	10	40
Deep-well diaphragm pump	Industrial	Medium to high	No	No	70	45	20
Helical rotor / progressive cavity pump	Industrial	Medium to high	No	No	100	45	16
Deep-well hand / lift / piston pump	Industrial	Low to high	Depends on design	Yes	100	45	11-17

Human-powered pump systems for community water supply. Adapted from OLLEY (2008)

Costs

Capital costs for human-powered pumps are mainly associated with the purchase of the pump, installation, construction of the *apron* and drainage system, and fencing (HOLDEN & SWANEPOEL 2004). The costs for the pump strongly vary according to the chosen pump type and materials. For most pump types, low-cost options exist making use of locally available material and labor. See BAUMANN (2011): Low-cost *Hand Pumps* for a detailed description of specific low-cost pump models



Estimated percentage of broken human-powered pumps in African countries. Source: RWSN (2011)

14.2 Reliability Reports 2015

“Rural water supply sustainability has remained an enduring policy challenge in sub-Saharan Africa for decades. Drawing on the largest data set assembled on rural water points in sub-Saharan Africa to date, this paper employs logistic regression analyses to identify operational, technical, institutional, financial, and environmental predictors of functionality for over 25 000 community-managed handpumps in Liberia, Sierra Leone, and Uganda.

Risk factors significantly associated with nonfunctionality across all three countries were

(a) system age,

(b) distance from district/county capital, and

(c) absence of user fee collection.

In at least one of the three countries, other variables found to have significant multivariable adjusted associations with functionality status included well type, handpump type, funding organization, implementing organization, spare parts proximity, availability of a handpump mechanic, regular servicing, regular water committee meetings, women in key water committee positions, rainfall season, and perceived water quality.

While the findings reinforce views that a multifaceted range of conditions is critical for the sustainability of community-managed handpumps, they also demonstrate that these factors remain absent from a high proportion of cases. Governments and development partners must ***significantly strengthen postconstruction support for operation and maintenance systems***, and greater efforts are needed to test and evaluate alternative models for managing handpump water supplies.

In rural sub-Saharan Africa, where handpumps are common, 10–67% are nonfunctional at any one time, and many never get repaired. Increased reliability requires improved monitoring and responsiveness of maintenance providers. In 2014, 181 cellular enabled water pump use sensors were installed in three provinces of Rwanda. In three arms, the nominal maintenance model was compared against a “best practice” circuit rider model, and an “ambulance” service model. In only the ambulance model was the sensor data available to the implementer, and used to dispatch technicians.

The study ran for seven months in 2014–2015. In the study period, the nominal maintenance group had a median time to successful repair of approximately 152 days, with a mean per-pump functionality of about 68%. In the circuit rider group, the median time to successful repair was nearly 57 days, with a per-pump functionality mean of nearly 73%. In the ambulance service group, the successful repair interval was nearly 21 days with a functionality mean of nearly 91%.

An indicative cost analysis suggests that the cost per functional pump per year is approximately similar between the three models. However, the benefits of ***reliable water service may justify greater focus on servicing models over installation models.”***

15 APPENDIX: PUMP-STROKES AND WATER FLOW-TIME CALIBRATION PROCESS:

If a dual frequency method of measurement is adopted in the future then the calibration process below will provide more information than purely the time-pumped. (This section is included for information. It is to ensure that the procedure is not lost as the simultaneous equations took far too long to sort out!)

From the Well Videos there appears to be two principal methods of pumping water and filling the buckets:

a) Fast short strokes

b) Long slower strokes

This variability could create measurement errors, however by using linear interpolation between these extremes and using simultaneous equation calculations a better measurement accuracy can expected. For example:

On the videos, the bucket being filled (by taking measurements off the PC screen) looks about 20 liters. The strong pump action person filled the bucket in 40 strokes and took 40 seconds. The other person using much shorter but rapid strokes filled the bucket in 200 strokes and took 120 seconds. These figures can be used (until better information is available) as the base calibration data. See summary table below:

Calibration and Readings Data:

	Count of Pump Actions	Time in Seconds to Fill	Count of Time Timer Pulses	Liters Filled
Slow Strong fill	40	40	400	20
Fast Casual fill	200	120	1200	20
A Weeks Readings	800	Derived	6400	TBD

The issue here is to determine the weekly water usage above TBD (in liters) from the above *example* measurement readings and the calibration data.

The calibration of the Wells is expected to be done, initially, every month. However as soon as the system settles down the frequency could be relaxed.

But first, how do we calculate the water used over the last period as represented in the table above?

As we don't know who fills what bucket and how often, let us assume there are X strong men filling the buckets **and** there are Y young girls filling the buckets. So the sum of each person filling each of their buckets will equal the Pump Reading results:
So:

(Slow).X + (Fast). Y = The weeks Pump Reading results

So in the case above: (vertically)

$$40.X + 200.Y = 800 \ldots\ldots (1)$$

Similarly, the time (pulses – see the design section for explanation) taken to fill the bucket is:

$$400.X + 1200.Y = 6400 \ldots\ldots (2)$$

From (1)

$$200.Y = 800 - 40.X$$
$$Y = (800 - 40.X)/200 \ldots\ldots (3)$$

Now substitute (3) in to (2)

$$400.X + 1200\,(800 – 40.X)/200 = 6400$$
$$400.X + 6\,(800 – 40.X) = 6400$$
$$400.X + 4800 – 240.X) = 6400$$
$$160.X = 1600$$

Therefore: $X = 10$

This indicates there were 10 strong men filling the buckets that week.

Now substituting this result back in to (1)

$$40.X + 200.Y = 800$$
$$400 + 200.Y = 800$$
$$Y = 400/200$$
$$Y = 2$$

This indicates there were 2 young girls filling the buckets that week as well.

So, the total volume of water pumped that week is:

10 men and 2 women filling the 20 liter buckets:

volume of water pumped = Buckets x bucket capacity

volume of water pumped = (10+2) 20

Volume of water pumped = 240 liters . . . . QED.

What matters here are not the figures, but the mathematical principal. Will this simple simultaneous equation hold for real data? We will know only when detailed calibration figures and actual readings are taken and when the Fourier Flow Meter is under test.

A short Calibration Process could be included in the spreadsheet software. (see Spreadsheet Story-Board section in the appendix) basically it will ask the Well Users: eg. A strong man and a young girl etc. to fill a bucket and let the Fourier Flow Meter system record the results. These figures will be checked and used in the equations for that particular Well. It should be noted that calibration will be Well specific.

These equations will be embedded in the Fourier Water Flow Meter's spreadsheet application. They will ***not*** be visible to the User (*Thomas*) unless requested.

Implementation the above worked example on the spreadsheet is below.

Calculation to determine the Well's Output (in litres)

The well's output will be determined in two steps. First to assess the number of each type of people who have used the well, then to multiply this by the bucket size.

Calibration		Pump Counts	Multiplier	Use case users	Flow count	Multiplier	
			1		secs	10	
Short Stroke X		200	200		120	1200	
	35	a	7000	35		42000	b
Long Stroke Y		40	40		40	400	
	15	c	600	15		6000	d
The weeks meter readings		e	7600			48000	f
			+1.0% -33%			+1.0% 4.60%	
			-1.0% +33%			-1.0% -4.60%	

(NB: Long pump strokes are 10x more efficient than short ones - & more accurate reading can be made)

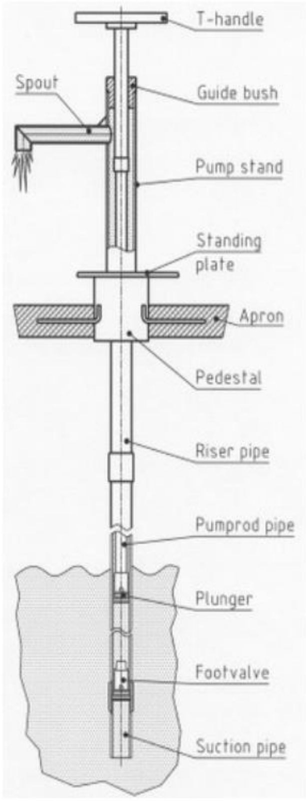
Lest us say that **X** people used the **Short** Stroke to fill the bucket, and **Y** number of people used the **Long** Stroke to fill the bucket

So, multiple uses of **Long** and **Short** pump stroke people have created the Weekly Results figures. We need to establish how many people have used the pump so we can estimate the total amount of water used.
(Assume a bucket is 20 litres and it gets filled each time)

						Equation #
The Weekly Results are made up as below . .						
	x.a	+	y.c	=	e	1
	x.b	+	y.d	=	f	2
	from 1					
Long stroke number of people using well . .			y	=	(e-(x.a))/c	3
now substitute equation 3 in equation 2						
	x.b	+	d.(e-(x.a))/c	=	f	
	x.b	+	(d.e-d.x.a)/c	=	f	
multiply both sides by C						
	x.b.c	+	(d.e-d.x.a)	=	f.c	
	x.b.c	-	d.x.a	=	f.c-d.e	
			x(b.c-d.a)	=	f.c-d.e	
Short stroke number of people using well . .			x	=	(f.c-d.e)/b.c-d.a)	4
So, using equations 3 & 4 and using the data in the table above:						
X people			x	=	35	QED
and						
Y people			y	=	15	QED
So Total litres multiply by size of bucket:		35	x20	=	700	
		15	x20	=	300	
			Total litres	=	1000	

16 ACTION LIST

This section lists the current actions by members of the team. Completed items have now been removed for clarity.



Mike:

1. What is the legal situation regarding Hallotell SIM contracts in Tanzania? Do they need a chargeable call every so often or do they need topping-up even if they are in credit etc.? (WIP)
2. Module procurement - (later)
3. Local Batch assembly workshop – (later)
4. Staffing (later)
5. Office space (later)
6. Mobile signal checks at Head Office (later)
7. Which is the preferred method of securing parts for a new electronic unit when new Wells are planned? (Suggest a non-African based e-bay account; a parts-list and a sign-off process with a second person paying the e-bay account.)

Andrew

1. Circulate revised document for comments-(WIP)
2. Assembly & Test prototypes (WIP)
3. Define Calibration procedure. (draft)
4. Update Software Story-Board (WIP)
5. Develop a Training videos on: Electronics Unit Assembly; Well Diagnostics; Electronic Unit Testing.
6. Web site purchase and creation (for training and document details.(WIP)
7. E-Mail address creation for future SIM cards. (In UK each SIM card requires a different e-mail address!)
8. Consider Digital alternative (WIP)

Maurice

1. Comment on the draft document (WIP)
2. Review the Trigger circuit approach and
3. Consider PCB approach (WIP)
4. Consider software for microcontroller
5. Consider MS Access version of the Story-Board (WIP)

Peter

1. Comment on the revised draft document (done)
2. Prototype testing & discussion at Loughborough University. (TBC)

----------- End ----------