NEWSLINE

Unidata

Environmental Monitoring & Industrial Measurement No. 18, 2021

Groundwater Projects – Improvements and Lessons Learned

This year Unidata has been involved with several large groundwater projects, some of which are detailed in this Newsline. Over these projects, we have developed more experience, learned lessons, and made several technology improvements for groundwater projects, including the introduction of recently available new digital sensors, all of which have contributed to the success of these projects.

While the core technology remains the same, the equipment housings and configurations differ based on different customer needs.

Different Form factors in the field

Unidata has completed recent projects with different form factors, as described below. Each form factor type has advantages and disadvantages.

- *Medium Size Data Loggers/Telemetry units* with solar panel and battery in a small enclosure with a high gain cell phone or satellite antenna. These systems bolt onto the side of a bore casing and allow for easy access for service. As there is a small solar panel, there are no concerns about battery life. An unrestricted borehole case makes the depth sensor installation and the process of checking depth to water straightforward. The high gain cell phone antenna extends the range of coverage of cell towers enabling the deployment of the cell-phone-based system in remote areas. Consequently, the requirement to use the more expensive satellite-based systems is reduced. The disadvantage of this system configuration is that they are large and more exposed to vandalism.

- *Small Size Data Loggers/ Telemetry Units* with battery power only, housed in smaller enclosures mounted on the outside of the borehole case with the small patch cell phone or satellite antennas mounted on top. This configuration allows easy access to the bore case for depth sensor installation, checking depth to water and general service. While the equipment is not as apparent as larger systems, they still have the disadvantage of being noticeable and exposed to vandalism.

- *Very Small Size Data Loggers / Telemetry units* with battery power only, housed in a very small enclosure, mounted inside the bore case, connected to a small patch cell phone or patch satellite antenna mounted on top of the bore case. Access to the bore case for water depth sensor installation, checking depth to water and service is more difficult with these systems because the Data Logger/ Telemetry unit must be taken out for these activities. The advantage of these systems is their unobtrusiveness, apart from the small patch antenna, which substantially reduces the possibility of being damaged or stolen.

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Telemetry Improvements

Unidata has always considered microsatellite technology a good option for groundwater telemetry. However, despite many announcements, only a few have a practical and robust solution. In Australia, Myriota is operational and it has a data payload of around 20 bytes. That may not be sufficient to carry the required payload if there is more than one reading per day. Unidata is working with Swarm Space, based in California and part-funded/part-owned by the US Government. We have Swarm Space trials running for several months, and their service proved to be robust. The Swarm Space data payload is around 200 bytes, making it a similar data payload to the Iridium SBD service. The satellite airtime will be perhaps 10% of the cost of Iridium. Swarm Space seems a good option for the future. The Unidata Neon units will be designed to support both, Iridium and Swarm options. Unidata will also support the emerging Iridium Certus as Iridium releases the low data rate systems to market in the next year or so.

Sensor Improvements

We see the market with categories of sensors as follows. We have seen the newer, lower-cost Modbus sensors gain momentum in the market this year and are becoming a reliable and cost-effective option.

- *Traditional high-quality sensors such as Insitu, high accuracy, interfaced with a digital interface such as Modbus or SDI 12.* We see many customers remaining with these sensors, often because they already have many units. These work well and are of excellent quality. They come with a calibration certificate, usually from the supplier, it is most likely correct, but it is not an independent calibration. The price point is often high.
- *Industrial grade analog sensors, typically 4-20 mA.* These have reasonable accuracy, analog 4-20 mA and are interfaced to a logger's analog data channel. The two analog conversions both contribute to the instrument inaccuracy. Matching the sensor to the analog channel of the data logger significantly improves the accuracy overall, but using matched pairs is less convenient. An external calibration laboratory needs to be employed to do the calibration. That adds to the cost but using an external calibration laboratory assures purchasers have an independent calibration. The price point is medium.
- *Newer, lower cost digital interface sensors (e.g. Modbus).* These sensors are emerging onto the market now. We have identified reputable sensor manufacturers, and we are working with one of them to produce a dedicated Unidata specified digital sensor. We have these sensors under test at Unidata, and they work very well. The sensors have digital interfaces (Modbus), options for different stainless-steel housings (304 and 316) and further options for accuracy, either 0.1% or 0.25%. Using a more accurate sensor than needed allows for some drift before that sensor is out of specification. Using a digital interface also eliminates one of the contributors to inaccuracy because it is a direct digital interface. A calibration certificate is included. The price point for such sensors is medium.

Depth Sensor Settling Time.

We have noted that some customers/tender requests define a settling time from when the sensor is installed until the time the reading from the sensor is stable. For example, before installation, a sensor could have been in a hot environment that elevated the sensor's temperature. However, when the sensor is installed into the water in a groundwater bore with a lower temperature, the sensor may need time to stabilise. Also, if the sensor's cable and chain have been wound up for a long time, it may take a while to straighten and extend to its normal length, affecting the readings. We have noted typical sensor settling time specifications to be 30 minutes.

Use of QR codes for configuration

Unidata has implemented a more straightforward arrangement for system set-up in the field. As we have all noticed in COVID times, most people are using QR codes. We are also using them on our Neon units, so a person in the field can more easily access the Neon server node by scanning the QR code, and they can also access the documentation from our website.

Groundwater Monitoring for South 32 in NT and

Unidata secured large projects for groundwater monitoring in the Northern Territory and Western Australia this year for the large miner, South 32. This company was a large spin-off company from BHP some years ago. One of the tallest buildings in Perth, the former (Alan) Bond Tower, now bears the South 32 name and logo at the top of the tower. The BHP tower and the Rio Tinto tower are close by the South 32 tower.

Hydroterra was the lead partner for the project, Gemco were the project managers, and the customer and Hydroterra chose the sensors. Unidata supplied the Neon Telemetry systems and the associated power systems and enclosures. Both projects used cell phone telemetry, utilising their own mine based private LTE / cell phone system at these locations. The customer chose to have their own dedicated Neon Server for each project rather than using our Neon hosting service for security purposes. Seeking own servers is often a requirement to ensure the high level of data security these large corporations require.

Technical challenges included the slightly different setup requirements for a Private LTE / cell tower system and the remoteness of some of the sites, as well as very heavy rains in the Northern Territory soon after the installation. The over the air management facilities provided by the Neon system allowed us to adjust and make configuration changes over the air without the need to travel to the site.

Use of Bluetooth

Unidata has completed the integration of the latest technology, low power/ low energy Bluetooth interface on all models of Neon Remote Loggers. We are now working on the Phone App that will assist the configuration of Data Loggers / Telemetry units in the field. There is an often-misunderstood question about the use of low power and high-power Bluetooth. The older Bluetooth interface consumes higher power and is appropriate for systems with a robust power supply for the field unit (solar panel and larger battery) and the laptop computer that connects with such systems. Low power Bluetooth is appropriate for smaller systems powered by a battery that communicate with mobile phones rather than laptops. Low power Bluetooth connections do not support an always-on Bluetooth connection for a serial interface connected to a laptop computer.

A USB connection to a laptop computer is more appropriate for more complex operations when the unit is connected to a laptop computer.

Over the Air Configuration

Full IP Telemetry Services. Data Logger/ Telemetry units that are connected via a cell phone connection (an IP connection) have a full suite of over the air configuration features are available, including remote programming, remote diagnostics and firmware downloading.

This over the air configuration is also available on satellite IP connections, such as Inmarsat and Globalstar and the soon to be released Certus service from Iridium. The problem with such satellite IP connection systems is that they are higher cost and not economical for low data volume application such as groundwater monitoring.

Message-Based Telemetry Services. These Message-based services are the most appropriate satellite transmission service for remote groundwater monitoring applications. Message-based telemetry (like a text message) such as Iridium short burst data and Orbcom global beam service and the emerging microsatellite services are economical but are limited in capacity. The small antenna does not need to be aimed at the satellite, making installation easier. These message-based services cannot practically include all the over the air configuration facilities available for the cell phone and other IP based services. Unidata design objective is to offer the functional equivalent of the IP connection based over the air management facilities in time. This year we can support a subset of those over the air management facilities, including logger commands, remote reset, and data replay, if some data is lost in the server. We plan to release additional features on an incremental basis over the next year or so, provided they can be reasonably supported by a message-based communications system.

Automating Installation Processes

Providing some form of automation support has assisted in several projects. Providing workflow definition and good documentation for measuring and recording Depth to Water and sensor settling times helps field staff promptly and reliably install these systems on-site. For areas where there is cell phone coverage, installation is easier because there is internet connectivity to check system operation. For systems where satellite communications are needed, having a satellite phone call back to the office and check operation assists significantly and provides a higher level of health and safety in remote regions.

Automating Reporting and Data Ingestion Processes

Telemetry systems, such as the Neon system, are never the end analysis system for groundwater applications. Systems such as Envirosys, Hydstra and Aquarius are typical end systems for data analysis and modelling requirements. The ability to automatically ingest data from the telemetry system is an important consideration. The Unidata Neon system allows for automatic FTP reports and Secure FTP reports into end systems. The Neon platform also allows for a more efficient / more immediate ingestion of data via an API, using REST Web Services into more recent systems such as Aquarius. Web services ingestion of data is faster, more efficient and is now the more widely used interface method between such systems.

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Engineering meetings using Teams, training using Teams and most of the work in the setup and commissioning of Neon Field Units was completed remotely because of COVID. Even if there was no COVID, it was the most efficient approach to the project anyway. The cell phone connection to the Neon Field units is a full two-way communications function. These robust full IP communication connections allow for a high degree of over the air (OTA) management of equipment in the field.

Groundwater - Vented (Gauge) / Non-Vented (Absolute) Depth Sensors

Measuring water depth using a pressure sensor means measuring the weight of the water plus the weight of the atmosphere. The atmospheric pressure is ~ 100kPa, and 10 metres water pressure is ~ 100kPa.

There are two ways of measuring this pressure, Using an absolute pressure transducer referenced to a vacuum to measure the combined weight of the atmosphere and water (say 0 to 200kPa) and Using a gauge pressure transducer referenced to the atmosphere to only measure the weight of water (say 0 to 100kPa).

Summary

- With an absolute transducer, the measurement begins halfway (or more) up the transducer's span (at 0m depth = 100kPa, at 5m = 150kPa). This means that a 5m transducer must have a span of 15m (10m atmos + 5m water), and the error is, therefore, three times as much when compared to a 50kPa gauge transducer.
- With a gauge transducer, there is a need for a vented cable and desiccant and sealing, which is a significant cost and source of problems.
- Using a coupling tube (like in a bubbler system) connected to a gauge transducer located above the water may be an option, but accuracy will reduce due to increased ambient temperature variations (could be compensated).

Hydrostatic water depth and temp probe

Pressure Sensors Mechanism

All pressure transducers use a silicon strain gauge (in a bridge configuration) as the measurement element. This strain gauge is bonded to a diaphragm made of ceramic or stainless steel or, in some cases, directly etched onto a silicon wafer diaphragm. The (water) pressure pushes against the diaphragm, and the strain gauge measures the amount of deflection (strain) in the diaphragm caused by the pressure being applied.

Mechanical errors occur in

- The linearity of the pressure vs. diaphragm deflection.
- The linearity of the diaphragm deflection vs. the strain gauge output (resistance).
- The temperature stability of both.
- The mechanical stability & ageing of both.

Electronic errors occur in:

- The measurement of the strain gauge bridge (low mV signal).
- The temperature stability of the electronics.

Starflow (and other water depth sensors) improve these errors by adjusting for zero offset when out of the water and at a full-scale reading, thereby choosing the best "straight line fit" through the composite error band. In water, the errors are also less due to limited temperature change.

Digital instruments perform error correction over a wide temperature range using a multi-term polynomial rather than a "straight line" fit. This technique can significantly improve the temperature errors in the mechanics and the electronics. The mechanical linearity errors can also be mapped (by multi-point calibration) and form part of the polynomial correction. Mechanical stability errors are more difficult to model and correct as they are due to the number & span of deflections and long-term ageing.

Conclusions

- It may be difficult to achieve accuracy using absolute sensors, even when remotely corrected for atmospheric pressure.
- All sensors are mechanical and non-linear with secondary temperature and aging effects.
- Digitally pressure sensors are an improvement over the analogue MPX transducers.
- The sensor must be mechanically protected from dirt and other deposits that will damage/distort the diaphragm. The sensor needs to be interfaced to stilled water to reduce the velocity vs. pressure effect. The water interface section of the sensing "chamber" needs to be serviceable.

(this is a shorter extract from a Unidata Technical paper on this subject- download the full paper from our website)

Depth Sensors - Ultrasonic and Pressure Measurement Stability

We have recently completed some long-term monitoring on Starflow QSD tests sites around the world, and we have observed some interesting results in a real-world installation in a natural stream, where Starflow QSD performs best. The instrument has both ultrasonic and pressure methods of measuring water depth, with one of those methods more suitable for some applications.

The instrument uses hydrostatic pressure to measure water depth with an absolute sensor which is referenced to a barometric sensor vented to the atmosphere. This simplifies the instrument's construction and makes installation easier by eliminating the need for a vented cable. To compensate for atmospheric pressure variations affecting the reading, a small external barometric reference sensor is used.

The graph below (Graph 1) shows a few days of recordings in shallow, slow-flowing water. There is a fixed offset between the ultrasonic UDepth and the pressure PDepth of ~10 mm H_2O because, on installation, the PDepth was not zeroed to the local conditions. The reference barometer changes by ~ 115 mm during this period and experiences diurnal temperature variations (not shown) of ~ 30ºC.

Examining the UDepth (red) and PDepth (brown) measurements shows a slight divergence. Assuming that the UDepth is correct (a valid assumption in slow-flowing water with a flat-water surface), any PDepth differences are due to the two-pressure sensors temperature stability.

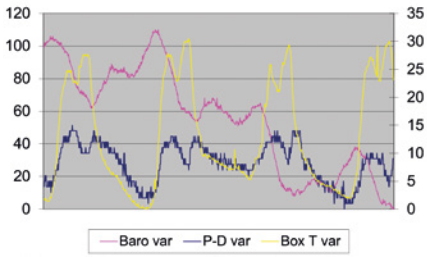
The water temperature (not shown) varies less than 0.5ºC, so temperature effects in the hydrostatic sensor in the instrument can be ignored. Therefore, these PDepth variations are due to temperature effects in the small external barometric reference sensor.

The small external barometric reference sensor is housed inside a black box exposed to full sunlight with "in box" temperatures reaching 50ºC, dropping to 20ºC at night.

Barometric Reference Sensor Temperature Stability

The graph below (Graph 2) shows only the variations in the above measurements. The LH scale is Barometric (purple) variation in mm, and the RH scale is Box Temp. (yellow) in ºC and the relative difference between PDepth and Udepth (blue) in mm.

From the data, we see a clear positive temperature effect between the Box T and the P-D. This effect induces a PDepth error of ~ 0.5 mm/ºC of Barometric temperature variation. This effect is not visually obvious in the Barometric measurements as there is no reference barometric pressure to compare.



Graph 2

From these tests, we concluded that the barometric reference temperature effect on PDepth is within the QSD specification (~0.3% FSS). We also concluded that reducing the temperature variation of the barometric reference will improve the PDepth accuracy, so it is best to not install the barometric reference sensor in full sunlight.

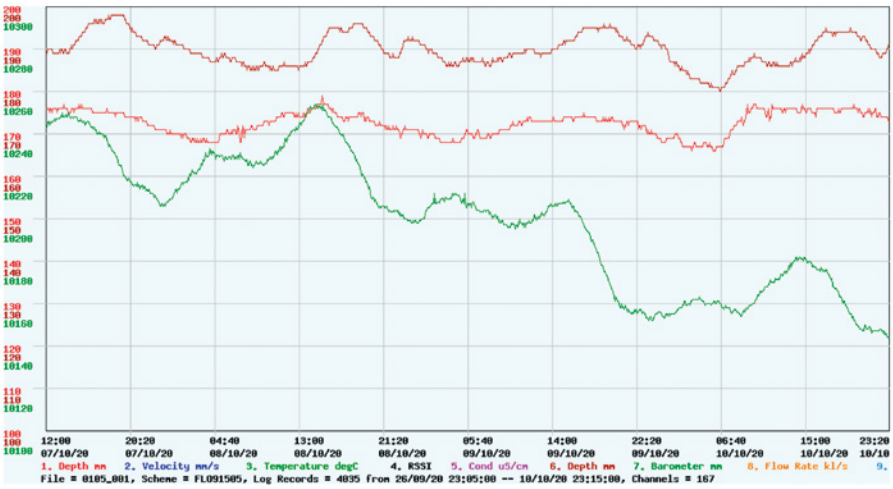
Barometric Reference Enclosure Venting

The graph below (Graph 3) shows the barometric reference enclosed in a poorly vented enclosure. A rapid increase in Box Temp (blue) causes a rapid increase in Barometer (purple) and vice versa. Box pressure increases due to the Box temperature (Charles's Law) and only slowly equalises because of inadequate venting.

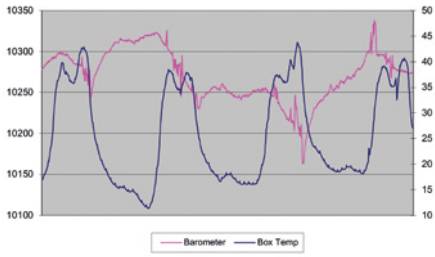
Clouds and shadows cause these rapid changes and the Box venting doesn't balance out the related inside air pressure change quickly enough. The box temperature is measured inside the communicator housing so there is some delay and smoothing that occurs.

In this installation, a 1mm hole in the bottom of the Box was sufficient venting to eliminate this error.

Note: *that the size of vent will depend on the enclosure's air volume, the rate of change of box temperature and how quickly the pressure balance is required to be achieved.*



Graph 1



Graph 3

Unidata Assists Inmarsat with IOT Kiosks

This year we worked with our good partner, Inmarsat, to build some new and innovative LoRa based IOT concentrator systems, called IoT Kiosks.

These systems are intended for high-end customers who need a robust IoT Concentrator or Kiosk to provide a connection between sensors in the field, using LoRa technology, and the central Inmarsat Actility System in Europe, using BGAN technology.

These kiosks are robust, and they have new and innovative super capacitor power supply storage units instead of the traditional battery technology. These new supercapacitors can deliver high currents, and they can survive an order of magnitude more charge/discharge cycles when compared with traditional battery technology.

Unidata worked with Inmarsat Engineers, who were in South Africa, to build, test and then deploy these systems. As we were in Covid times, we did most of our work online, so the distance between our factory and the Inmarsat Engineering facility was not a significant issue during the project.

Kiosk front

Kiosk back

Kiosks being shipped

QR Codes in Unidata Manufacturing

As we have all noticed in Covid times, more people are using QR codes. At Unidata, we are using them in our manufacturing process to identify a product and access support materials.

If you are in the field, accessing the product QR code will directly connect you to the Product Manual on the Unidata Website.

We are also using Neon QR codes on our pre-configured Neon units for systems.

This assists a person in the field access the Neon server node for this logger more easily.

Please see a few examples of QR codes to the right.

Argyle Diamond Mine Visit 2020

In late 2020, Unidata staff visited the Rio Tinto Argyle Diamond Mine in the East Kimberley region of Western Australia, near Kununurra, to assist with configuration and data unload of Unidata Loggers, both the older Starlogger and the newer Neon Remote Loggers.

Our staff travelled to the site in what is called the wet season, and the local environment, while very hot and humid, is rich in vegetation and quite beautiful at that time of year. Rio Tinto took great care to ensure the health and safety of our staff while working around the now-closed mine site.

The mine was established in 1983, and it was, for a time, the largest diamond mine in the world by production volume. The mine was initially an open pit, and then the operations were moved underground. The mine was closed in November 2020, and the site will be monitored for many years after the closure to ensure the environment is protected into the future.

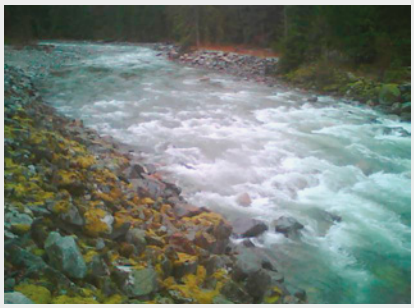
Radar Flow Measurement in Thailand

This year Unidata was involved with a large project for flow measurement in Thailand for the Royal irrigation Department. The project involved several down looking Sommer radar flow measuring instruments connected to Unidata Neon Remote Logger / Telemetry units.

The down-looking radar measurement method is very convenient as it can be mounted on a bridge and is not affected/damaged by flood events. They provide reliable measurement during flood events and are a non-contact method of measurement. They are less expensive to set up because they can be attached to an existing bridge.

These instruments are an alternative to a more traditional Ultrasonic / Transit time measuring device, which may be affected by turbulence and bubbles in the river. However, they are more expensive to set up because they involve some civil works/ construction on the riverbank.

Photo Snapshot of Fast Flowing Coquihalla River



This photo is taken with the Neon low-resolution camera module at a river monitoring station along the fast-flowing Coquihalla river in British Columbia, in Canada.

The camera's resolution is minimal, and the data files transferred over the satellite link are tiny files, less than 50KB. Remarkably the low-resolution image tells the customer a lot of information about the river and the flow every hour.

Unidata has recently been involved in some new high-resolution image and video capture of rivers projects this year. They remain research projects. Still, there is a trend to analyse video content to monitor many aspects of river flow. We are working with our shareholder NIWA on some of these projects. We expect video analysis and deriving flow information from video streams to grow in the years to come.

Microsatellites Update

Unidata has continued to work with microsatellite companies, and we believe that these systems will become significantly important in the telemetry market in the next few years.

Last year we started working with Swarm Space (LEO) Microsatellite based in California, USA, and those tests are going well. Swarm has a payload of 200 bytes. It has a back channel, which aligns it more closely with the higher cost and very robust Iridium short-burst data service. The Swarm Microsatellite service is not an always-on service, delivering messages in under one minute like Iridium, but for applications such as groundwater monitoring where daily or hourly messages are needed, it is a good fit and substantially lower cost when compared to iridium SBD.

We continue to work with other microsatellite companies such as Hiber (144-byte payload).

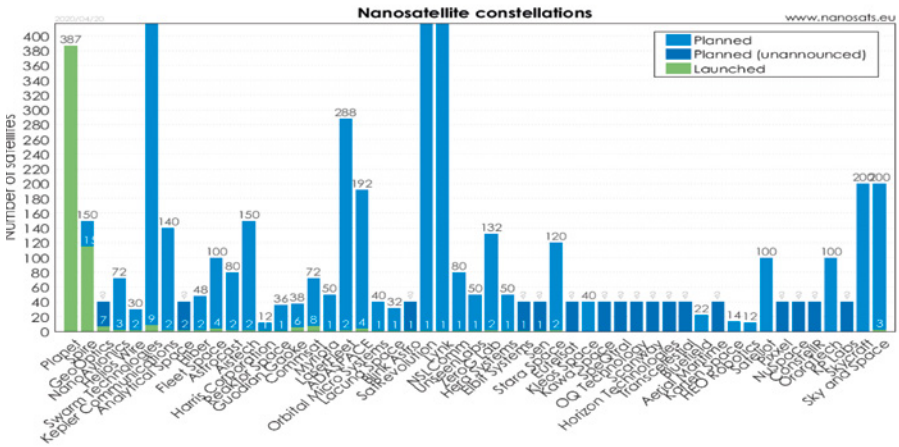
We also note that others, such as Myriota (20 Byte payload), are growing their satellite deployment. Systems with very small payloads seem suitable for some applications, especially soil moisture, but higher payloads are needed for other applications.

For groundwater monitoring, the typical payloads of 500 bytes per day are needed, so the smaller payload systems struggle to keep up with the data load.

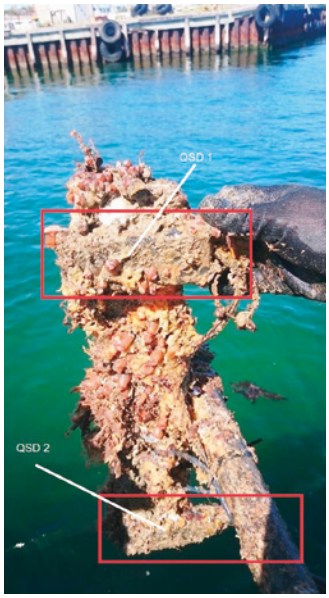
The other consideration is that microsatellite systems and Iridium SBD are message-based systems, sending and receiving text message like messages with long latencies.

Other systems, such as Inmarsat, Globalstar and Iridium Certus offer a full IP communications channel which allows for much better over the air (OTA) capabilities, which minimise visits to the site. The cost of site visits needs to be compared with the higher capability satellite services airtime cost to determine which approach is lower cost overall.

Below is a summary of the microsatellite industry participants; some will do well, and many will fail.



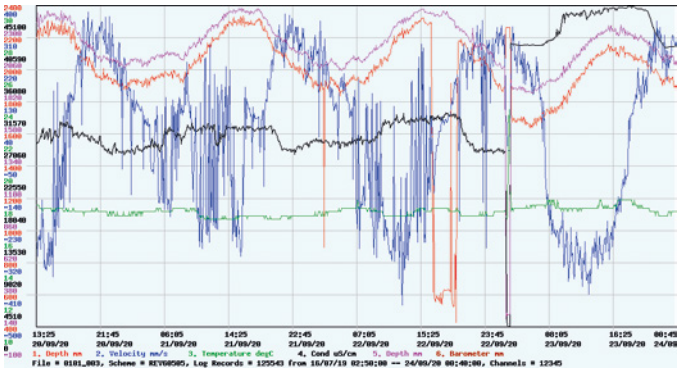
Starflow QSD Instruments in Tidal Harbour – Abundant Marine Life



Unidata has two test Starflow QSD instruments in a tidal harbour setting as long-term test instruments. The tidal area is salt water, and it appears to be very healthy water because the marine life which grows on the Starflow QSD instruments is prolific. This was after around four months in the water.

Interestingly, despite the bio foul, the Starflow QSD instrument continued to perform well, and that surprised us. Looking at the graph, you can see that the U Depth and P Depth were working before and after with little or no errors. The Velocity was also still working, though the reverse flow had become noisy. However, it returned to noise-free after the instruments were cleaned and the bio foul was removed. The graph shows the time the Starflow QSD instruments were cleaned and the effect of the cleaning.

The Starflow QSD conductivity sensor was still measuring EC variations in the heavy bio-fouled state, but its calibration was around 10% incorrect. After cleaning, it jumped back to the correct readings for this time last year. It is not difficult to understand that the calibration would be affected by biofouling as the conductivity electrodes are in electrical contact with the water, and any additional interface material will cause measurement errors. We could "assume" that the biofouling formed an electrical insulation layer, thereby reducing the measured conductivity.



It is remarkable that this Starflow QSD instrument can perform reasonably despite a large amount of bio foul. It is also great to be reminded that the water is healthy and there is an abundance of sea life.

UNIDATA **STAFF PROFILE**

Matt Saunders

Matt Saunders is our General Manager, and he has worked at Unidata since 2006. Matt is our most senior staff member, in the company and in years.

Matt is married to Margaret and has three children and, recently, five grandchildren. He has a share in a keel yacht, which he races on the swan river most Saturdays with his fellow syndicate members. Winning races is the objective and is very important. Unfortunately, everyone else on the river has the same objective.

Matt is an Electronics and Communications Engineer. He graduated from North Sydney institute of Technology many years ago and is a senior member of the IEEE Communications Society. Matt started his career at the Carnarvon Satellite Tracking Station, which was under contract to NASA, then worked for Hewlett Packard, Telstra, Fugro, Curtin University and more. He also had his own software development company which developed software for optical fibre undersea cable networks for some years. The photo of Matt is one of his recent trips to the moon.

Matt works in Sales & Marketing, Administration and Engineering. He has an interest in satellite technology, and the growing microsatellite industry.

Like the other sensible people at Unidata, Matt supports the best AFL team, the West Coast Eagles. He has been a West Coast Eagles member for 25 years, a true commitment to the best team.

3D Printing comes to Unidata

Over the last year, Unidata has used 3D printing to build mechanical prototypes for new products. Using a 3D printer allow for easier, less cost and faster preparation of prototypes direct from engineering drawings.

This 3D print model took around 20 hours to print, but it runs unattended, so it can be set to work overnight. The cost to print 3D models is relatively low, and they are exact size representations of traditional metal or polycarbonate prototype.

This 3D print model is of the soon to be released new Neon Remote Logger, in the same form factor as the older 2016 NRT model, which is shown beside the 3D print model.

This new model of Neon Remote Logger called the 3004AN would suit customers who wish to maintain the same equipment housing when upgrading from the older NRT to the new NRL.

Busy Unidata Mechatronics Factory

Unidata has had a very busy time over the last quarter, in the lead up to the end of the financial year.

While Unidata is a manufacturer of products and software, we also build full systems for customers, that is often called the mechatronics business. These complete systems can include enclosures, batteries, solar panels, wiring and system and field setup documentation.

Many customers seek such systems integration so they can be confident an entire system has been manufactured and tested in the factory before shipment to the site.

The photo includes the equipment and the final shipment on pallets; job done!

Repairing 20-year-Old Unidata Starflow Instruments

Unidata continues to receive Starflow products to repair, and here is another example. This product was manufactured about 20 years ago. It was returned to the Unidata Factory for service recently. We will service it and return it to the customer.

Unidata has shipped several thousand of this model of Starflow. It has been a reliable instrument for many customers over many years. Starflow instruments housed in drainage pipes or other pipes generally maintain the same temperature, and that stable environment is very good for electronic instruments.

This model of Starflow has been in production for many years, and we have now shipped several thousand units.

We now have newer models of Starflow, and we hope they also have a very long production life.

Lowering Unidata's Impact on the Environment

Unidata has an environmental management system as well as a quality management system which is audited annually. We need to continue to reduce our impact on the environment year on year. This year we replaced all our fluorescent lights with LED lights, this reduced our power usage by about 50%.

This initiative was suggested by Kevin Chung, and through his idea we are saving money and reducing our impact on the environment.

The lights used were a direct mechanical replacement, it was a simple matter to have the electrical contractor unplug the old ones and plug in the new ones. The new lights are also 25% of the weight of the old lights. We could also choose the colour temperature of the new LED lights, we chose the middle temperature, slightly warmer looking light which is easier on the eyes.

The photo shows the small form factor of the new lights and our electrical contractor doing the replacement. The old lights were then taken by the electrical contractor to recycle.

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