Cave Flood Pulse Data Logging in OFD1

***Stuart France** describes a work-in-progress project to monitor flood pulses in the Ogof Ffynnon Ddu streamway that has been running since the summer of 2015. A data logger inside the OFD1 cave is currently being used, but a live feed to the Internet is to be developed, then the system is to be replicated in other caves.*

Architecture

Previous work from 1999 by the author (France, 1999) used inexpensive Honeywell air gauge sensors, with a flexible plastic bladder submersed in the stream water, at several locations, including the Ogof Ffynnon Ddu (OFD) resurgence, the Byfre stream sink for OFD, and the main sink locations and resurgence for Dan-yr-Ogof (DYO), and later still in underground water courses of Agen Allwedd.

These sensors, such as Honeywell part number 26PCBFA6G, are inexpensive at around £20+VAT each now, but they cannot be fixed easily under water. Instead, they were connected by an air tube to a submerged bladder for the purpose of measuring the water depth. The sensor has two ports, of which one is vented to atmospheric pressure, so the pressure at the other port, connected to the submerged air bladder, measures the pressure difference. This difference will be due to the water depth only, since the variable atmospheric pressure affects both sensor ports and thus always cancels out. Fixing the air bladder in a flood-proof fixed position under flowing water requires some sort of tough perforated plastic container on a metal bracket bolted to the bedrock.

By contrast, the 2015 system uses professional grade submersible sensors, General Electric's UNIK5000 range, which can be ordered in many variants. These have a bonded-on waterproof electrical cable containing a capillary tube as an air vent to the submerged strain gauge part of the device. This enables the sensor body, made of stainless steel tube, with the analog electronics inside it, to be fixed underwater whilst the control and data logging equipment is connected to the other end of its control cable on dry land. We used GE part number PTX5042-TA-A1-CA-H0-PW with 12m of feeder cable (which cost about £200+VAT) for the experiments in OFD1. It was set up by GE so that 0-4m of water depth corresponded to a 4-20mA current flowing through the 2-wire device.

Current signalling sensors are common in industry since the resistance of the feeder cable, which could be very long in a factory, is of no consequence. In air, the device allows 4mA to flow and under 4m of water its current rises to 20mA. Dropping that current through a small resistor yields a voltage which can be digitized and recorded by a data logger, just from a 2-wire sensor. Current sensors will suit caves where a command wire is laid from the river to the cave entrance, or elsewhere on the surface, and this is what is being worked towards in OFD1, when the tactics changes from data logging to telemetry.

Mains electricity is usually unavailable in caves, so systems should be designed to run off batteries. But these will not last for long if the load is milliamps or more continuously. Ideally, the data logger needs to do more than just record data: it needs some sophistication, to act like a SCADA device (System Control and Data Acquisition), so it can turn on the sensor only when it wants a reading, and turn on the flash memory or telemetry system only when it wants to save it. Thus the sensor and communications blocks will be powered off nearly all of the time. Most commercial data loggers will not do this, but if you program your own logging devices, using PIC processors in our case, then such is not a problem.

A further complication is that the data logger, certainly ours, is a 5V device internally. We digitise water depth readings in the range of 0-4095mV, so 1 AD unit = 1mV, using a very accurate 4.096V reference chip. Of course the sensor current always has an offset of 4mA, so the offset voltage for that has to be subtracted arithmetically when converting voltages into water depth.

The voltage reference leaves almost 1V headroom inside the logger to run it. This reference is powered on demand too, to save energy. The 0-4095 range conveniently produces a 12-bit number which suits AD conversion by modern PIC processors or with AD converters like Microchip's MCP3201, which we use.

A further complication is that a UNIK current sensor requires a 7-28V DC supply, so the logger must control a secondary power supply which is at a higher voltage than its

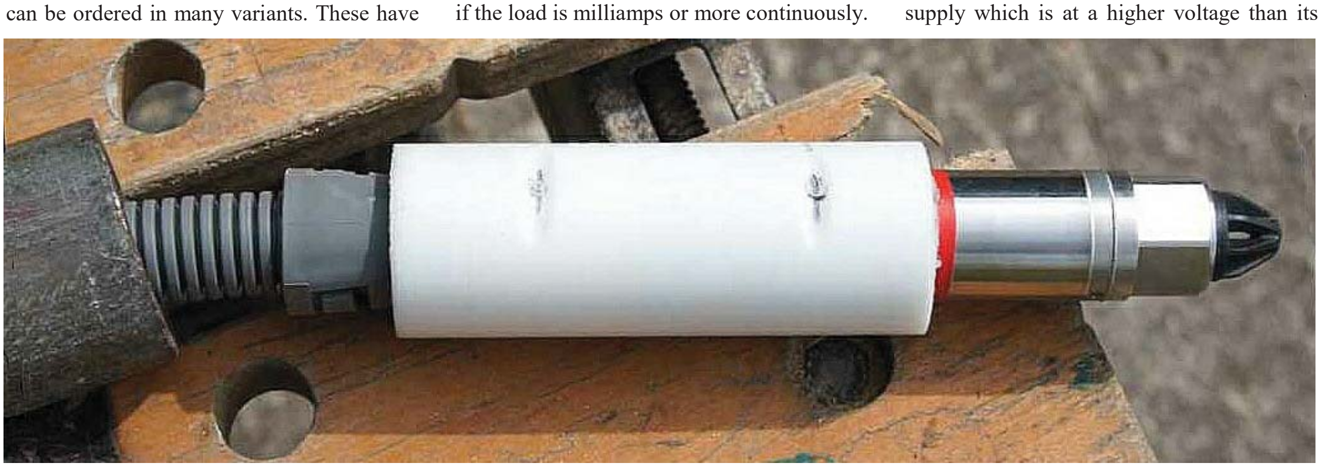

Figure 1 – Sensor in acetal tube prior to mounting in 3m scaffold pipe

Flexible conduit is seen on the left leading into the scaffold pipe, locating notches are visible on acetal and the sensor tip is on the right.

Figure 2 – 3m pipe and UNIK sensor in OFD1 streamway

own. The control for this feature is also within our powered-on-demand circuit block. We used 12 AA batteries as the power supply for the UNIK sensor and voltage reference and control block, which will last for years when taking 30 minute readings. The logger, clocked at 32kHz, is powered from a 9V PP3 battery which will last for 6 months when run at 5V internally via an always-on micro-power regulator chip.

Figure 3 – Data logger, data-and-power-on-demand controller and AA batteries in enclosure on cave wall 6m above streamway

Fixing a Unik 5000 Sensor to the Cave Wall

We guessed that the OFD streamway (in the middle part of OFD1) would never exceed 3m depth because of the shape and slope of nearby passages. We might be wrong about that as we have recorded more than 2m depths several times already during the winter of 2015-16, which was exceptionally wet.

A 3m length of galvanised scaffolding pipe was drilled and tapped at one end to accept two grub screws made from short M8 stainless steel bolts. Some tube made of acetal (a hard engineering plastic) was sourced. Its outside diameter was just less than the inside diameter of the scaffolding pipe, and the acetal tube's inside diameter was reamed out to 25mm to a depth of 50mm to match the UNIK sensor's outside diameter. The other end of the acetal tube was reamed out to engage with a 20mm plastic conduit which protects the bonded-on sensor cable. This acetal tube was also filed with a couple of grooves across its outside surface to engage with the two grub screws through the scaffolding pipe. The UNIK sensor was pushed tight into the acetal tube, and the latter then positioned in the scaffolding pipe with an insertion tool made from wide plastic hose, so that the sensor nose cone ended up about 25mm inside the scaffolding pipe. This protects it from any loose rock being carried along by the cave river in flood.

The water flows up and down the scaffolding tube, mirroring the cave stream depths, and the tube acts as a stilling well. We adapted two scaffolding clips to bolt the pipe to a near vertical cave wall in the streamway at a point where there was also a small pothole in the riverbed to anchor the bottom of the pipe against downstream displacement by the force of the cave river in flood.

The 12m sensor cable allowed the logger to be housed in an IP65 plastic case bolted to the wall of a cave passage situated well above river level. This outer case must be vented to atmospheric pressure, as do all plastic boxes in our system containing electronics, since the capillary tube inside the UNIK feeder cable must conduit ambient air pressure into the submersed sensor so it cancels out and the sensor is then indicating only the pressure due to the water depth.

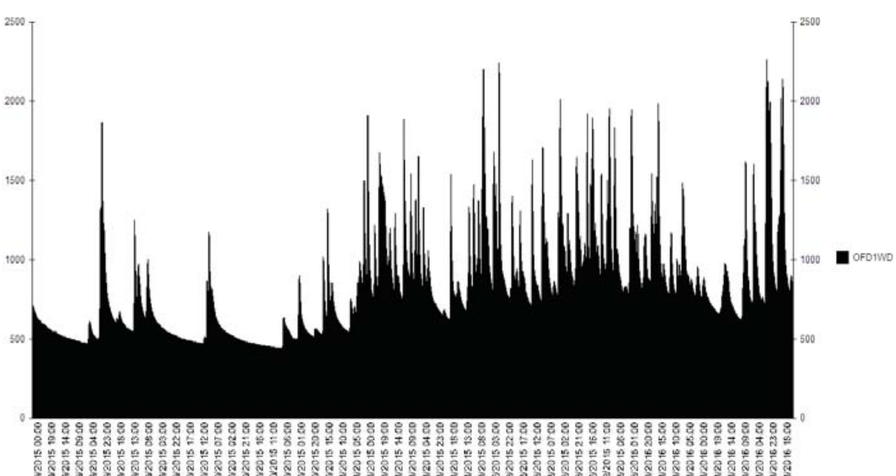

Figure 4 – OFD1 streamway depth as hourly averages over 5 months, units mm

Results

There have been apocryphal tales of tsunami-like walls of water developing in just moments in the OFD1 cave streamway, but we have yet to record one despite the some appalling weather this winter. However, the rate of flooding can be impressive. The logger was normally set to take readings every 30 minutes but one run was done with 10 minute readings.

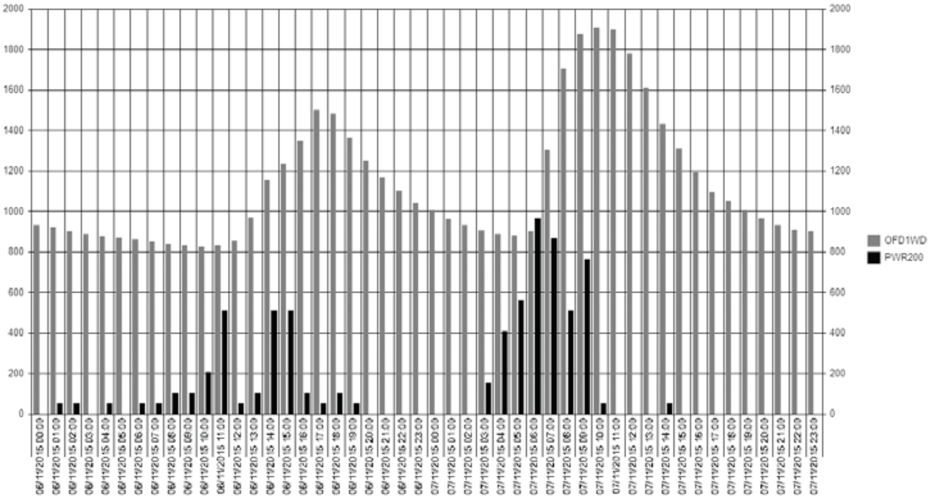

Figure 5 – Single hour rainfall ×200, versus streamway depth, over 2 days, units mm

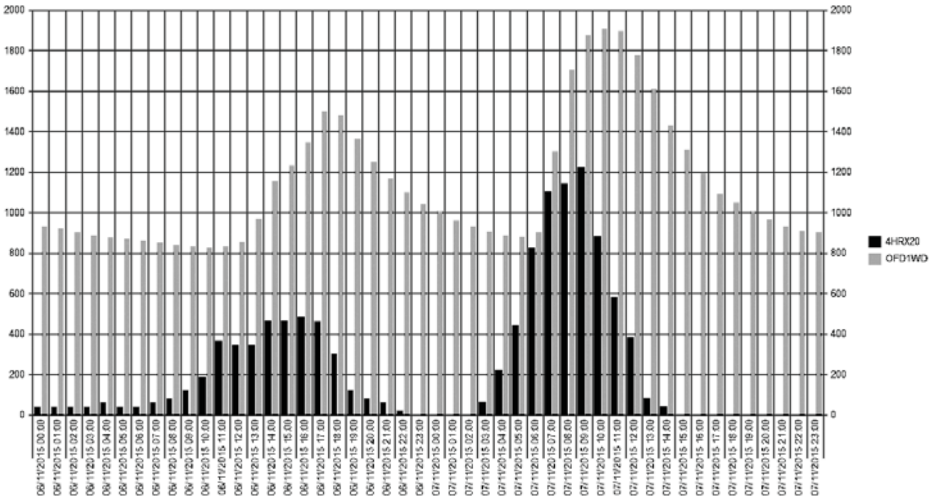

Figure 6 – 4-hourly integrated rainfall totals ×20, versus streamway depth, over 2 days, units mm

The fastest increases in river depth between readings have been in the order of 60mm in 10 minutes, 400mm in 1 hour and 800mm in 8 hours. When we have a system controlled from the surface and a radio link with the Internet, we will probably take depth readings much more frequently.

Interpretation

Limestone and the soil above act like a reservoir with a pipe system attached. Peat bogs can be more like a sponge which absorb rainfall completely - up to a certain point - and can then begin to release a lot of water at some speed, known as a 'bog bursting'.

The first rainfall after a long period of dry weather, though a significant amount, may have only a small effect on underground water levels. Subsequent rainfall of the same or smaller amount may have a more dramatic effect underground. In prolonged wet periods, rain can raise the cave river level very quickly indeed.

We have 30 minute rainfall data for the locality but need to convert this to a derivative, such as the rolling total rainfall during the past 4 or 8 hours, to take account of the travel time of water through the ground when comparing with streamway depth. This simple model can be thought of as integration (e.g. 4 hourly) and a gearing process (e.g. 20 times) to give a better correlation of weather with water depth. In due course a better mathematical model will be developed, involving rainfall history over several weeks plus rolling rainfall. The available cave river and weather data is available for download.

Figure 7 – Xbee transceiver at 1km range using dog bowl as reflector

Telemetry Developments

Caving club members from SWCC laid a 250m multi-core cable from the cave entrance to the UNIK sensor in December 2015. This will enable the device to be controlled from the surface, either to log the river data there or transmit it. We need a little more cable across the land surface to get clear of tree cover by the cave entrance and to obtain a line of sight on to a National Park building exactly 1km away where we can access an internet router.

Promising experiments have taken place using £20 Xbee Pro radio modules linked to a whip antenna. A test box transmitting 'hello world' style messages generated by a PIC powered by a PP3 battery has connected to a similar receiver box, powered over USB and displaying the messages in Hyper-Terminal on a laptop PC.

It soon became clear that 'line of sight' means both antennae are outdoors, not behind double-glazed windows, which attenuate the signal dramatically, as do solid walls of buildings. In air, we achieved 500m range almost immediately and increased this to 800m by walking up a nearby hill until we ran out of land to extend our line of sight. This experiment was repeated from above OFD1 to the National Park office at Craig y Nos, which are 1km apart. Initially, this did not work, but after borrowing a dog's stainless steel water bowl and putting it behind the receiver whip to act as a parabolic reflector, we received the 'hello world' messages from the simple whip transmitter across this valley with no problems, and also connected to the router in the office. So all the system blocks are now proven and only various engineering works remain to join it all up.

References

France, Stuart (1999), *Flood Pulse Logging with PICs*, CREGJ **37**, pp26-27.

Data is available at
www.linetop.co.uk/creg/ofd1science.xls.

CONSERVATION NOTE

The cave discussed in this article is scheduled for conservation as an SSSI and official permission was obtained to carry out this project.

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