# Caver Counting – Why and How

***Stuart France** presents reasons for monitoring caver activity and explains how to construct and deploy caver counter equipment.*

Counting the traffic through caves might sound a strange use of electronics in caving yet it can provide benefits to the caving community: maintaining or improving access and planning appropriate cave conservation. In addition, for those who need a means of counting cavers themselves, some guidance is presented here on the main approaches to building the necessary equipment.

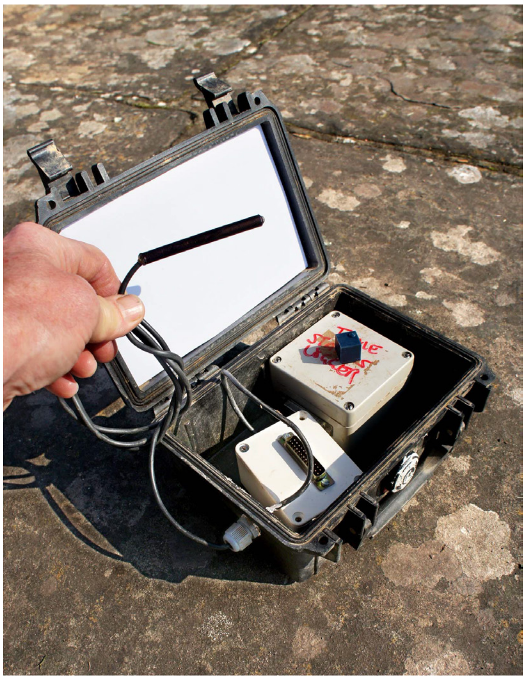
## Why Count Cavers?

The usual motive for monitoring caver visits is to inform conservation and management of caves where rising trends or high levels of activity, or simply significant persons arriving in organised groups on a regular basis, might be of concern. Other reasons may include monitoring sensitive areas or to reassure a landowner that annual visitor numbers remain reasonable and that their pattern is well spread out. Sometimes one is hoping to discover a near-zero count, when visitors are mainly absent, such as at active bat roosts or on a sensitive route.

It is beyond the scope of this article to consider what a cave management group should do or stop doing if visitor research points to rising or falling or unreasonable caver numbers. Such questions invite a political value-judgement concerning who should be able to access, explore and extend caves and in what ways. The sample results given here are for information only, but it is only a short step further for readers to paint these on to a political canvas for themselves.

Automated monitoring is not always welcomed. Many people seem quite willing to document their personal lives in social media, or to sign their names and describe their intended caving activities in a cave logbook or a club newsletter, but then illogically these very same people may be hostile to a gadget gathering anonymous visitor statistics. People placing such equipment can rest assured that if it is visible, then sooner or later it will disappear or be damaged, at least in the UK. This is not what happens here in the outdoors where mass surveillance by CCTV and ANPR, and all manner of indiscriminate data interceptions by government are tolerated, even encouraged, for the cause of public safety. But where there is little or no chance of crime detection, such as in caves or in the hills, opportunists may more easily persuade themselves to indulge in damaging counters, and this needs to be borne in mind when designing and deploying any visitor counter equipment.

Citizens of other countries can have a more respectful attitude to other people's property. For instance I have seen a Japanese people counter on a national park trail which looks like a giant metal tripod planted at the edge of the path. It would not last long in my part of the world. In some countries the data from counters is put openly on websites along with photos of the equipment and map references to find them. This seems unthinkable or extremely naïve to me.



***Logger with 3mm photodiode set in a cigarette-size black plastic tube filled with polyurethane***

## A Brave New World

Image analysis software, using mains power and IP-addressable ceiling mounted cameras, can be seen in shopping malls and larger department stores or above supermarket checkout queues, tracking 'blobs' moving across 'rectangles of interest' selected within a larger image. This really does count people (the blobs) and also finds their direction of movement. The next generation of cheap tiny 40MP cameras will not need optical zoom as they will be able to extract tiny zones of interest while retaining high resolution. This will solve many technical issues concerning Orwellian people-tracking projects such as FIND (Facial Identities National Database) in the UK into which any future national ID card scheme and automated passport controls fit all too elegantly. Data storage and bandwidth is now so plentiful and cheap that I expect during my lifetime that some UK government will begin to log the movements of every individual by street cameras.

Mobile phones and contactless payment cards can be pinged to discover a unique identity. Many people cannot now be stopped from carrying their pocket-size ID broadcasting and people-tracking devices everywhere. They even take their wallet and GSM phone caving. Far be it from me to encourage anyone to deploy 'pingers' to read payment cards and Bluetooth-enabled phones as they pass through a confined space such as a cave entrance, or a shop door, to obtain a log of who visited and when, and to discover how often each person returns. The companies in the 'Big Data business' must be hoping that the ignorant masses will keep their next-generation phones switched on all the time, enabling tiny fixed beacons running for months on button batteries, and the associated snooper apps, to harvest personal data. The allure of all this wireless technology for intrusive government is all too obvious. Governments everywhere are addicted to mass surveillance already, and they are going to find the internet-of-things hard drug irresistible.

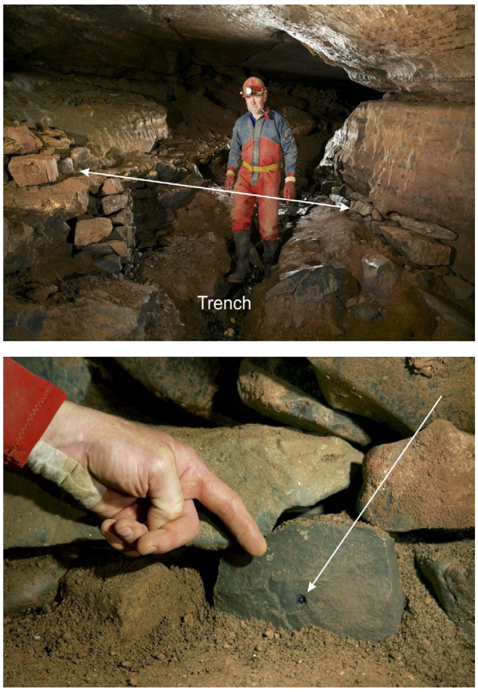
To do Big Brother in a caving context, without mains power and networks, it is cheap and practical to place covert wildlife cameras (see examples at **trail-camera.co.uk**) to photograph cavers with timestamps, perhaps see who they were and what they were carrying, though not perhaps so easy to deploy these block-of-cheese size boxes in a covert way underground. Wildlife cameras can be shrunk a lot and made harder to spot. For instance, the tiny Arduino camera module coupled to image differencing software has been used to collect evidence of big game poaching in Africa.

## Review of Methods

The real need for caving is to gather broad statistics rather than identity information, and this avoids any legal or privacy issues with taking photographs and pinging people's wallets. Any kind of low tech sensor that can detect a person moving along is good enough for caving purposes, and in many ways caves are easier to instrument than the outdoors in this respect – there is no bothersome livestock or bad weather.

### Light Sensors

The most obvious sensor is one for light, since caves are totally dark well beyond any entrances. Any light present means cavers, but cavers shine their lamps around them, so one individual can make a series of flashes over a sensor, and conversely a whole group could pass a sensor while keeping it constantly illuminated. So it is virtually impossible to count individuals in this way, but light makes a good job of counting groups of cavers. Since groups are relatively uncommon at specific points in typical caves at most times, one can feed the light pulses into a re-triggerable timer of, say, 20s. The timer, which should be implemented in software, will output a single clean pulse that lasts 20s longer than the last flash detected from some caving light, and this pulse drives the counter.




***Break-beam sensor positioned where cavers are forced to walk in a trench***

### Instances vs. Individuals

The above description makes an important point: simplistic sensors based on caving lights, or the weight of the caver on a sandy floor containing a pressure sensor, or the noise of cavers moving in silent passages, or breaking an infrared beam, or body heat emissions in a cold environment, and so forth, all work because the visitors momentarily change something in their environment. If the changing process is far from standardized then it is hard to turn these sensor events into accurate counts. In other words, these counters count instances of visitor behaviour rather than people. It is vital to grasp this point. This is true even of camera-based systems where if one individual re-enters a place several times that creates the same number of counts as several individuals who enter once each. The perfect monitoring of distinct individuals, taking account of re-entries and other unpredictable motion patterns, would require their identity to be established, which moves us from 'Low Tech' into the 'Brave New World' already described.

### Positioning Sensors

In the outdoors, and this applies to caves too, it is usually best to find a good place to count people first, where their behaviour is predictable, ideally where one instance of a predicted behaviour equals one person, and then find an appropriate sensor technology to use at that place. It is less effective to decide in advance on light sensors, say, and then look for locations to deploy them that may be non-ideal in terms of behaviour. Having said that, it is fairly easy to find places for tiny covert light sensors in the typical caves that the author regularly visits in Wales. An easy path going round a corner is a good choice since cavers travelling in either direction will illuminate the sensor, and they are not likely to stop or stumble. Recorded figures can be halved to yield the number of groups, assuming the route is not a through-trip or on a circle. If it is near an entrance then the time of day will say a lot about whether a group likely entered or left the cave there.

Deploying two sensors and loggers, with an accurate calendar-clock, some distance apart will reveal the direction of travel, and placing a lot of sensors into a large cave system will allow the frequency of visits to particular zones to be studied, and also their duration can be discovered if the number of groups per day is one or very small. It is therefore useful to record timestamps rather than counts-per-hour or counts-per-day in the logger. Later, PC software can used to 'bucket' these raw timestamps into counts-per-hour or per-15-minutes or per-day, etc.

Through-beam sensors need two modules either side of a passage, where one is a transmitter that outputs short intense infrared pulses and the other is a receiver which detects them. When the pulse train is interrupted, then a caver has stepped into the beam. An ideal place to put these is either side of a trench where there are many rocks already on ledges at waist height. It is not easy to design low power tiny break-beam systems that run for months on retail alkaline batteries and are not affected by nearby caving lights, nor is it easy to align them in a cave since without a horizon one's perception of the vertical is weakened. Break-beams, however, can make excellent sensors for counting individuals, rather than groups, since they will reliably detect one person at a time in single file moving along a carefully chosen narrow path where they are unlikely to halt or hesitate.

### Body Heat Sensors

Body heat sensors, as found in burglar alarms and wildlife cameras, tend to be unsuitable in that format for visitor counting because they have a wide capture angle, as a result of using large area Fresnel lenses, and they have a long latency once triggered. It is possible to build your own using the example circuits in manufacturer datasheets, e.g. Murata IRA-E712ST3, as a starting point. A Fresnel lens in front is not needed in counters, but engineering a narrow capture angle is essential to collimate the incident


***Light sensor positioned on a corner to detect light from cavers travelling in either direction***

| | Hours |
|---|---|
| 2011Q2 | 15 |
| 2011Q3 | 5 |
| 2011Q4 | 9 |
| 2012Q1 | 5 |
| 2012Q2 | 9 |
| 2012Q3 | 6 |
| 2012Q4 | 6 |
| 2013Q1 | 11 |
| Total | 66 |

| | Hours |
|---|---|
| Mon | 5 |
| Tue | 11 |
| Wed | 7 |
| Thu | 10 |
| Fri | 5 |
| Sat | 6 |
| Sun | 22 |
| Total | 66 |

| | Mon | Tue | Wed | Thu | Fri | Sat | Sun | Total |
|---|---|---|---|---|---|---|---|---|
| 10-11h | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 11-12h | 1 | 1 | 2 | 1 | 0 | 3 | 1 | 9 |
| 12-13h | 0 | 2 | 0 | 1 | 0 | 0 | 1 | 4 |
| 13-14h | 0 | 1 | 0 | 2 | 0 | 1 | 5 | 9 |
| 14-15h | 0 | 0 | 0 | 3 | 0 | 1 | 3 | 7 |
| 15-16h | 1 | 0 | 1 | 1 | 2 | 0 | 3 | 8 |
| 16-17h | 0 | 1 | 0 | 0 | 2 | 0 | 4 | 7 |
| 17-18h | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 2 |
| 18-19h | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 19-20h | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 4 |
| 20-21h | 2 | 4 | 1 | 0 | 1 | 0 | 1 | 9 |
| 21-22h | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 4 |
| 22-23h | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Total | 5 | 11 | 7 | 10 | 5 | 6 | 22 | 66 |

***Example 1 – Llygad Llwchwr 2***
***Activity per hourly period***

caver radiation. A 50-70mm long tube above the sensor element will separate out individuals who are not bunched up into separate pulses. Most PIR sensors have twin elements, both under one oblong silicon window, and a radiation level imbalance alters the output level. The datasheet will show the geometry. Covering one element with something impermeable to low infrared, such as sticky tinfoil, while leaving the other element exposed, creates a 1-pixel sensor which is enough for counting purposes.

The sensor will now detect a change in the difference between the temperature of the tinfoil and the background heat level looking out into distant empty space until a caver occupies it. The front of the tube must be a window made of high density polyethylene (HDPE) plastic sheet which transmits low infrared, and the whole thing must be totally damp-proof. PIR sensor pieces left exposed to a cave environment will not work for very long. It is best to place body heat sensors where cavers get hot, such as after an energetic dry crawl or a boulder-hopping section, and to avoid wet cold places.

When counting individuals on the move with break-beams or body-heat sensors, a one-second one-shot software timer will remove any jitter from the sensor output, such as when an individual wobbles or swings their arms or has a tackle-bag dangling and swinging about too. Never use 555 timers for de-bouncing sensor outputs as they have a bad habit of adding glitches of their own.

### Other Methods

Other methods, untested by the author in a caving context, include piezo pressure detectors buried in a sediment floor and ultrasonic ranging sensors. Piezo wire and piezo disc sensors are susceptible to damp so careful construction would be necessary. Ultrasonic sensors work well as reversing aids on cars and are clearly dirt and waterproof in that context. Ranging sensors sold for liquid depth measurement in tanks with a range of up to 10m might work too, but waterproof versions are not tiny and might be hard to hide even if put a few metres away to overlook a well-used and possibly taped path through a cave and painted to match the surroundings. Piezo detectors are devices in the microwatt range whereas ultrasonics are far more power-hungry, and battery life must always be carefully considered when a run time of many months is required.

### The Logger

A DIY logger could be based around a mid-range PIC device and $I^2C$ serial EEPROM. The author's data loggers have exchangeable flash memory modules (cubes) containing 24LC512 chips encapsulated in coloured polyurethane blocks leaving a DIL8 socket exposed. The date-time is entered on to loggers with a small robust plug-in control box comprising an LCD screen and a couple of push buttons. This accessory avoids taking a PC along to control loggers.

A 64kbyte flash memory will store ten thousand year – month – day – hour – minute – second timestamp events without any data compression, and that is a lot of caver counts. There are real-time calendar-clock $I^2C$ devices, but it is straightforward to implement a RTCC on a PIC with a 32kHz crystal clocking the processor or one of its internal timers and thus causing an interrupt to occur every second.

Three alkaline AA batteries will run a PIC-based logger and a light or PIR sensor for over a year without any voltage regulator.

## Some Practical Examples

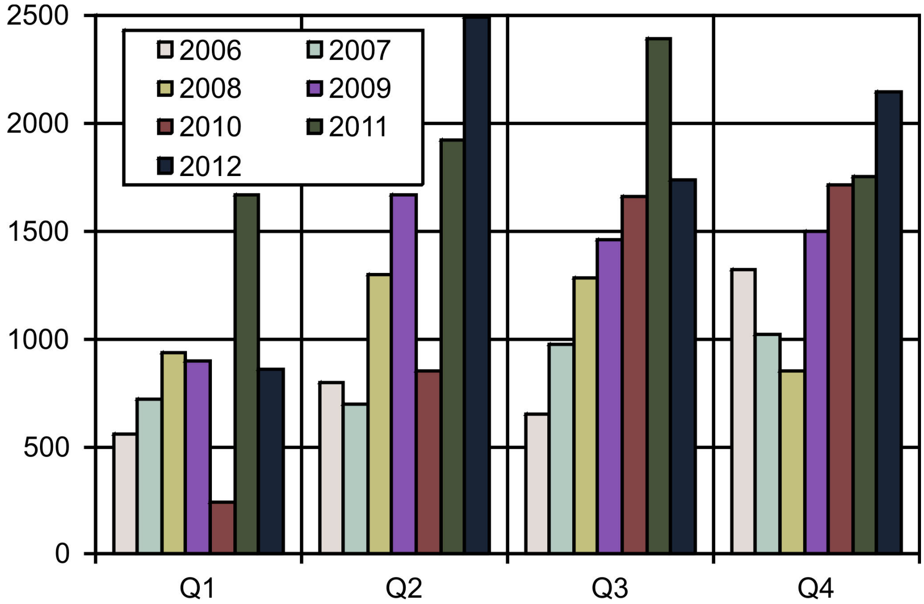
Here we look at a few case studies to see the sort of information that can be obtained and the benefits provided.

### Example 1 – Llygad Llwchwr 2

An experiment is described where a new section of cave – short and very beautiful and potentially vulnerable, being close to the road and the much larger Llygad Llwchwr 1 cave which is frequented by outdoors groups. The new extensions were opened in 2011 without a gate or any access control. Impressive photographs of this colourful pristine cave are available at **ogof.org.uk**. The counter experiment ran from March 2011 to May 2013 with a light sensor placed in the final chamber and set with a 20-second re-triggerable software timer in the data logger. The logger was programmed to record time-stamps. From this it was possible to deduce the number of groups and their visiting times.

It was not possible to count individuals because many lingered to take photographs in that final chamber, so in retrospect 20s was not long enough to separate out the groups here. Perhaps a 5-minute re-triggerable timer would have been better.

Extremely sensitive light sensors can be made with reverse-biased photodiodes where the leakage current tracks light level. Care has to be taken to avoid stray leakage developing due to damp ingress since this error signal will also be amplified. The first photo shows a 3mm photodiode set in a cigarette-size black plastic tube filled with polyurethane. This device is good enough for a year or two underground but after that the dampness gets in. Drying the sensor out in front of a log fire for a few days reverses that situation, but it is best avoided in the first place by building the diode into a glass or plastic test-tube that provides for a sealed




*Example 2 - Ogof Clogwyn*
*Quarterly breakdown for 2006 to 2012*

| | Q1 | Q2 | Q3 | Q4 | Total |
|---|---|---|---|---|---|
| 2006 | 555 | 794 | 649 | 1323 | 3321 |
| 2007 | 719 | 696 | 973 | 1018 | 3406 |
| 2008 | 934 | 1302 | 1285 | 852 | 4373 |
| 2009 | 901 | 1672 | 1457 | 1500 | 5530 |
| 2010 | 240 | 850 | 1664 | 1718 | 4472 |
| 2011 | 1667 | 1920 | 2393 | 1752 | 7732 |
| 2012 | 856 | 2497 | 1741 | 2148 | 7242 |

*Example 2 – Ogof Clogwyn*
*Quarterly breakdown for 2006 to 2012*

window at the bottom end. The cigarette shape is useful when embedding this sensor in a mud or sand bank and angling it at the cavers, with the data logger a metre or two further away at the end of an umbilical cable. PVC sheathed cables have proved to be damp-proof indefinitely.

Light sensors can also be made by amplifying the photovoltaic effect of diodes, but the author has not tried this for caver counters, though it worked very well for flashgun slave units. There are many practical circuit examples of both types in manufacturer datasheets and Internet circuit sites.

Turning now to the results in the table on the previous page, it was first decided to convert the timestamps to a simple hourly count of one if any activity was detected in that hour since it was unlikely, with the remoteness of this cave, that more than one group would be in the cave simultaneously.

Whilst the first quarter following the cave's discovery was the busiest, these modest numbers representing groups are hardly a cause for concern about over-use. The total groups per fiscal year is fairly constant, in the mid-30s, and the most popular time to visit, unsurprisingly, is Sunday afternoon which points to experienced cavers looking for an easy trip, rather than professionally-led groups of novices, as do the evening visits. The equipment is also proven totally reliable since there were no spurious overnight or early morning counts at all in two years run time.

| | Mon | Tue | Wed | Thu | Fri | Sat | Sun | Total |
|---|---|---|---|---|---|---|---|---|
| 0-1h | 0 | 1 | 5 | 1 | 2 | 2 | 1 | 12 |
| 1-2h | 0 | 2 | 10 | 1 | 7 | 0 | 0 | 20 |
| 2-3h | 2 | 0 | 2 | 0 | 0 | 5 | 5 | 14 |
| 3-4h | 4 | 0 | 1 | 3 | 1 | 1 | 0 | 10 |
| 4-5h | 3 | 1 | 3 | 0 | 1 | 0 | 1 | 9 |
| 5-6h | 1 | 1 | 1 | 3 | 4 | 1 | 1 | 12 |
| 6-7h | 1 | 1 | 2 | 0 | 3 | 3 | 1 | 11 |
| 7-8h | 6 | 5 | 7 | 0 | 0 | 5 | 2 | 25 |
| 8-9h | 7 | 0 | 16 | 0 | 3 | 4 | 5 | 35 |
| 9-10h | 54 | 72 | 30 | 25 | 14 | 4 | 38 | 237 |
| 10-11h | 24 | 183 | 119 | 68 | 95 | 50 | 26 | 565 |
| 11-12h | 45 | 261 | 113 | 272 | 224 | 47 | 109 | 1071 |
| 12-13h | 97 | 204 | 226 | 223 | 125 | 75 | 51 | 1001 |
| 13-14h | 81 | 334 | 174 | 202 | 211 | 65 | 92 | 1159 |
| 14-15h | 115 | 204 | 280 | 263 | 139 | 55 | 17 | 1073 |
| 15-16h | 104 | 132 | 218 | 175 | 50 | 68 | 48 | 795 |
| 16-17h | 14 | 63 | 140 | 104 | 19 | 65 | 32 | 437 |
| 17-18h | 6 | 1 | 71 | 4 | 1 | 65 | 32 | 180 |
| 18-19h | 25 | 23 | 21 | 18 | 34 | 26 | 6 | 153 |
| 19-20h | 42 | 15 | 8 | 1 | 0 | 21 | 0 | 87 |
| 20-21h | 53 | 42 | 19 | 1 | 47 | 2 | 3 | 167 |
| 21-22h | 104 | 4 | 4 | 7 | 2 | 0 | 0 | 121 |
| 22-23h | 0 | 27 | 2 | 1 | 4 | 1 | 0 | 35 |
| 23-24h | 1 | 0 | 0 | 5 | 3 | 0 | 4 | 13 |

*Example 2 – Ogof Clogwyn*
*24/7 profile for 2012 only*

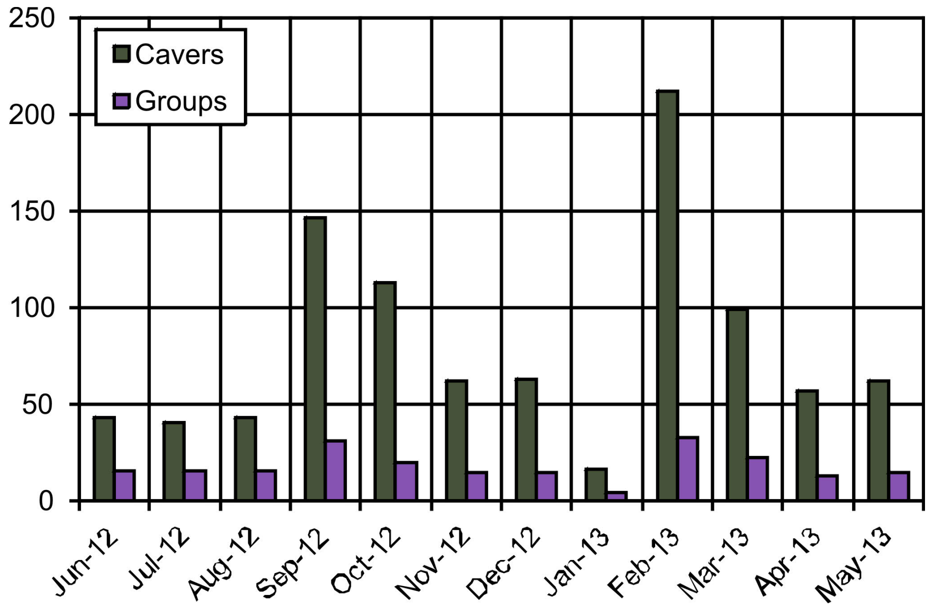
## Example 2 – Ogof Clogwyn

Another experiment has been run by Natural Resources Wales since March 2005. The two tables and graph on this page show their results to the end of 2012. The sensor is a piezo pressure sensor with an area of 600 × 500mm buried in a narrow section of path leading to the cave. This cave is much frequented by professionally led groups of novices, mainly young people on outdoor education activity weeks. Once novices get into the cave they are impossible to count as individuals: some rush about or hesitate, move back and forth, form clusters or wander off, and so on, but on the access footpath outside they behave much more like the archetypal organised school crocodile.

The long-term data is interesting in that it shows rising numbers for seven years, except 2010-Q1 which is probably lowered by a severe cold winter, and the non-summer of 2012-Q3 when there was severe wet weather. The years 2011-2012 have had roughly double the activity of the first two years in this set. The landowner, which is the government, has invested in recent years in the exposed path with steps and belays to make the site more attractive to led groups and to ease the pressure on another cave. The visitor counters appear to evidence success in this operation since the group numbers being recorded at the other cave fell to their lowest in 2011-2012.

| | Cavers | Groups | Ratio |
|---|---|---|---|
| 10-11h | 149 | 36 | 4.1 |
| 11-12h | 425 | 95 | 4.5 |
| 12-13h | 386 | 92 | 4.2 |
| 13-14h | 305 | 83 | 3.7 |
| 14-15h | 399 | 89 | 4.5 |
| 15-16h | 241 | 60 | 4.0 |
| 16-17h | 212 | 58 | 3.7 |
| 17-18h | 82 | 26 | 3.2 |
| 18-19h | 90 | 19 | 4.7 |
| 19-20h | 81 | 20 | 4.1 |

| | Cavers | Groups | Ratio |
|---|---|---|---|
| Mon | 117 | 33 | 3.5 |
| Tue | 130 | 33 | 3.9 |
| Wed | 135 | 28 | 4.8 |
| Thu | 114 | 26 | 4.4 |
| Fri | 99 | 32 | 3.1 |
| Sat | 1048 | 242 | 4.3 |
| Sun | 865 | 208 | 4.2 |
| Total | 2508 | 602 | 4.2 |




***Example 3 – Ogof Ffynnon Ddu 1***
***Cavers vs. Groups for June 2012 to May 2013***

A quarter-by-year chart, as shown above, is a useful view to reveal long-term trends, but the disruptive effects of bad weather or other external influences such as site closures or new infrastructure need to be borne in mind when interpreting it. A 24/7 view, or a more simple weekday or hour-of-day table can also be revealing tools.

### Example 3 – Ogof Ffynnon Ddu 1

The final example is a site where the new landowner wished to get a feel for overall numbers of cavers, group sizes, and if professionally-led groups (midweek-middle-of-the-day visitors) were using the cave. Two counters were installed. One was an infrared break-beam in the ideal trench position already described to count cavers walking single file separately, and the other was a light detector with a 20-second delay to count passing groups at a corner nearby. The table at the top of this page shows a strong correlation between the two devices. The group size is consistently around 4 people, which rules out the professionally-led group scenario. The day-of-week analysis also shows highest usage is at weekends, indicating sport cavers, and little happens outside a 10am-8pm window. The midweek numbers are fairly level across Mondays to Fridays which is further evidence against professionally-led groups who tend to do caving activities on Tuesdays to Thursdays because residential study centres have groups arriving and leaving on Mondays and Fridays.

The large monthly variations in the above chart were not expected. January 2013 was low because of deep snow making minor roads dangerous. Cavers might prefer to take holidays abroad in the summer months. Nevertheless, September-October 2012 looks odd and worth another look. A day-of-week analysis on these particular months still showed 87% of cavers coming at the weekends, and 75% of the midweek cavers came after 6pm, so there was absolutely no sign of professionally-led large size groups. Repeating this analysis on the February-March spike showed that 85% of cavers came at weekends, and 50% of the midweek remainder came after 6pm. This is pretty solid confirmation of the autumn result, and the landowner was reassured that the caver activity pattern here is a sustainable one.

## Acknowledgments

I would like to thank Brendan Marris for taking the cave photographs for this article. Thanks also to my caving friends who have carried my boxes through caves and even retrieved data for me on some occasions, while tolerating this data-collecting hobby of mine intruding into their normal caving activities.

I hope that cavers in the wider world will be reassured that simple statistics gathering can be useful to support responsible access continuing on some agreed basis and this type of research is not an assault on anyone's privacy.

## *Further Reading*

If you'd like to delve further into this fascinating subject, here are some other articles that have been published in *CREGJ* that you might find interesting.

### Background Reading

France, Stuart (1996) *Counting Cavers*, CREGJ **25**, pp. 23-24.

### Practical Designs

Drummond, Ian (2000) *Simple Caver Counter offers Improved Performance*, CREGJ **39**, p. 11

Gibson, David (1994) *A Caver Counter*, CREGJ **15**, pp. 24-26.

France, Stuart (1996) *A 'Stealth' Caver Counter*, CREGJ 26, pp. 24-26. See also corrections, CREGJ **27**, p. 30.

### Miscellaneous

The following article describes an intruder alarm that was installed in a cave in Kentucky to protect an endangered bat species.

Newman, John W (2004) *An Earth-Current-Based Cave Intruder Alarm*, CREGJ **55**, pp. 4-6.

CREG