Prof Andy Baker (left) demonstrates his drip water data loggers to attendees at the recent 13th Cave and Karst Presenters' Conference at Wellington Caves.

GROUND WATER HYDROLOGY AT WELLINGTON CAVES

– Andy Baker, Catherine Jex, Nerilee Edwards, Ian Acworth, Martin Andersen and Peter Graham*

Wellington Caves, NSW, are of course world famous for their well-preserved bones of Australian fauna that includes now extinct megafauna. However, we have recently started investigating ground water hydrology at the caves. Some of this work was discussed at the 2010 *Cave and Karst Presenters' Conference* held at Wellington, including demonstration of automatic drip counters that are recording data throughout the caves. Here, we provide some more information about the science and the questions that we are trying to tackle.

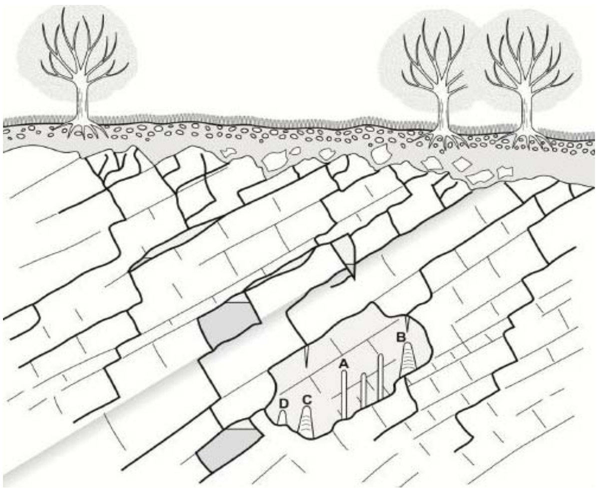

***Figure 1**. Cartoon showing possible water flow routes to cave stalagmites. From Bradley et al (2010).*

Figure 1 shows, in cartoon style, some possible flow routes that water can take through the limestone bedrock, from the base of the soil to stalagmites in a cave. It presumes that there are two important types of flow pathway.

The first is fracture flow, through fissures that naturally occur in the limestone, and which is a relatively fast flow route. The second is matrix flow, which is water which moves more slowly through pores within the limestone itself.

Stalagmites A, B, C and D in the cartoon are all fed by different proportions of these two flow pathways. So, for example, stalagmites A and D are fed mostly by matrix flow, with water coming from (the limestone bedrock. Stalagmite D is further from the surface than stalagmite A, so you might expect that the water takes a longer time to reach this stalagmite. Stalagmites B and C, in contrast, are fed mostly from a fracture. The flow route to stalagmite C is different, in that water has also passed through a smaller cave, which can act as a natural water store.

Whilst our cartoon is a huge simplification, it does start to show some of the complexities of water flow through cave bearing limestones. For example, drip water reaching a cave has probably come from both fracture and matrix flow types, and quite likely from more than one store. This leads to a complexity of drip water response to rain events, which is probably observed in your cave. If you are a cave guide, is there a drip in your cave that occurs all year and at a relatively constant rate? Is this like stalagmite C in the cartoon, with a water store above it? Or is it like stalagmite A, with a large volume of stored water in the matrix itself? How do we tell the two apart? Do all the drip waters respond at the same time to intense rainfall events, or do they start dripping faster at different times? Do some drip waters slow down after heavy rainfall, instead of speeding up? Can you see the effects of evaporation from the soil, and transpiration from trees? Do you see a rapid response to rainfall in winter, when surface evaporation is lower, and a lack of response in summer?

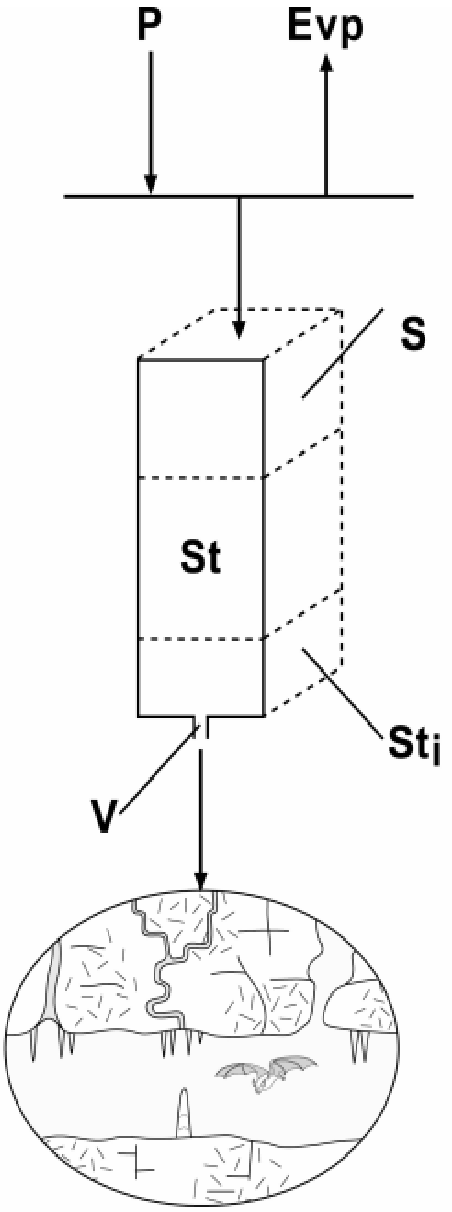

Figure 2. *A simple conceptual diagram of ground water storage relevant to limestone caves (Baker and Bradley, 2010).*

Figure 2 shows a simple conceptual diagram of some of these processes. Precipitation (rainfall, snowfall, etc.) is shown as P, some of which is lost by evaporation or evapotranspiration (shown as Evp). The remaining water passes through a store (S) which could be of any volume, from a narrow fissure with very low volume, to a large cave chamber. The outlet of the store is also of variable volume V, so this outlet could be large, so that water passes through quickly with little storage, or it could be very small, so that water builds up in the store. This store might have water in it from the start (Sti) and at any particular time the amount of water in the store is St. The amount of water passing through the store, into a cave as drip water, is therefore dependent on all of these different processes. If the store runs dry, for example because the volume S is small, or the outlet volume V is big, then the drip will stop. If the outlet volume V is small, water will build up in the store and the drip will be relatively constant.

Figure 3. *Some of the Stalagmate © drip loggers at Cathedral Cave, Wellington.*

For people who like to play with spreadsheets, this conceptual diagram can be converted into a working model showing the many varied responses to surface rainfall and climate change. For those that don't, the basic concepts can also be visualised as water flowing through a bath. The size of the bath is S, the size of the plughole is V, and the tap is the input water P.

You might want to have your bath already with water in it (Sti). If the taps are turned on so high that the bath overflows (e.g. a high value of P, like the recent high rainfall experienced in large parts of Australia this year), then new drips will be seen, at new locations, and with a delayed response to the initial rainfall.

In order to answer some of these questions, our research team from the Connected Waters Initiative Research Centre (CWI) at the University of New South Wales have, for the first time, installed over fifty state-of-the-art loggers at Wellington, which automatically measure the water flow rates from stalagmite forming drip waters.

One is shown in Figure 3 – drips hit the upper surface of the casing, and the vibrations are recorded by a data-logger housed inside. Data is manually downloaded every month and the loggers have batteries which last for five years. By recording the response of fifty different drips at the same time, we can start to characterise the ground water response to surface climate events. In other words, we are using the caves as a unique natural laboratory, which allows scientists to walk into this part of the aquifer called the 'unsaturated zone' (e.g. the part which is not full of water) and analyse the complexity of groundwater flow.

This is of particular importance if we want to better understand the pathways that surface pollutants might take in limestone or the suitability of limestone aquifers for water supply. Additionally, stalagmites and stalactites which are actively forming crucially depend on groundwater supply for their continued growth.

The climate and environmental records found within them are also influenced by changes in groundwater flow over time. The latter factors are poorly understood. The drip logger data will enable us to quantify the variability of flow and relate it to aquifer properties such as sedimentary structure and fracturing. In addition, other experiments are comparing drip rates in the caves to local and regional groundwater levels measured in both flooded cave passages and boreholes. To give a taster of the first results, Figure 4 shows the response of just four drip locations to a rain event that occurred on the 14th July 2010, with about 30 mm of rain that day. One drip logger can be seen to be completely inactive before the event, but one day after the rainfall, drip rates increased rapidly, before stopping again after five days.

This drip therefore behaves according to the 'overflowing bath' theory, where the bath takes one day before it overflows; this drip is the overflow, which lasts for five days until the water level drops back below the top of the bath. The second drip has a continuous slow drip rate, but also an immediate response to the rainfall. So this is similar to stalagmite C in Figure 1, with some storage to keep a background drip rate, but also a rapid response to the rainfall by a fracture flow route.

The third drip also responds to the rain event: drip rates are much slower and the drip rate continues to slowly increase for many days after the rainfall. The final example, the drip rate is very slow and does not respond at all to the rain event. In this case, drip rates vary by a fraction of a drip per hour, and this occurs every 5-7 days.

This drip rate variation is too small to be noticed by visitors to the cave – the drip loggers are needed to see it. It is actually recording the effect of changing air pressure with the passage of low and high pressure systems across the Central West NSW, and therefore this drip is fed by water which is coming solely from the matrix of the limestone (such as stalagmite D in Figure 1).

We hope these initial results and a description of the processes of ground water flow is of use to cave guides and managers, as the observations that we make at Wellington will be applicable to other limestone caves systems. For further updates and additional information, we'd be delighted to answer any questions at our contact details below. The research forms part of a new long-term groundwater monitoring project at the caves by the University of New South Wales. The town of Wellington has been a base for a UNSW Research Station for many decades. The university is taking advantage of research funding from the National Centre for Groundwater Research and Training (NCGRT) and the Federal Government Groundwater Environmental Infrastructure Fund (EIF) to establish long-term groundwater and surface climate monitoring facilities in the region, alongside a new teaching and education facility at the UNSW Research Station. The long term groundwater and surface climate monitoring will also include a new rainfall radar for the region, soil and surface hydrology instrumentation and new boreholes in contrasting rock types including the Devonian Garra formation in which the Wellington Caves are situated.

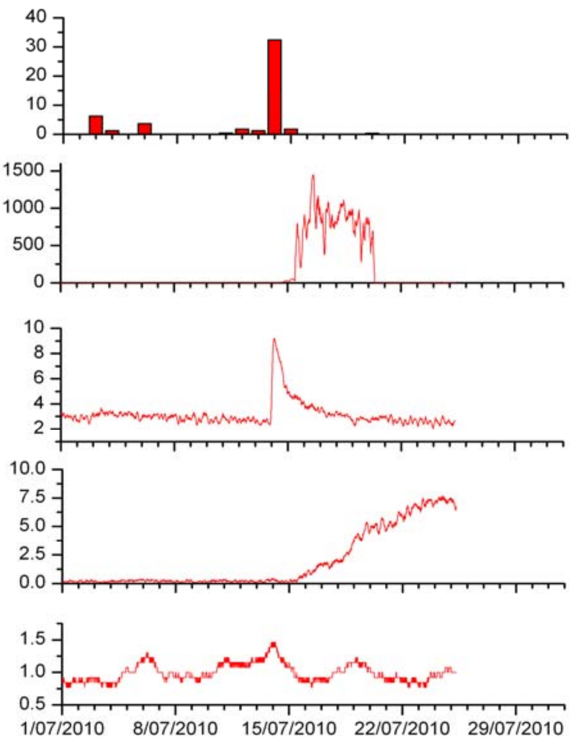

Figure 3. *Cave drip water response to a rain event in July 2010.*

* Connected Waters Initiative Research Centre, University of New South Wales. For more details on any aspect of this project please contact Prof Andy Baker <a.baker@unsw.edu.au> or Dr Cath Jex <c.jex@wrl.unsw.edu.au>. Further details of the wider project can be found at the Connected Waters Initiative website at:
<http://www.connectedwaters.unsw.edu.au/technical/research/projects/projects_caves_and_palaeohydrology.html>

ACKNOWLEDGEMENTS

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