A Decade of Data Logging in Fort Stanton Cave and Snowy River

By Pete Lindsley

March 30, 2021

Snowy River between Turtle Junction and the Plunge Pool (Lindsley #0156)
(Comment overheard at Turtle Junction: "This may be the worst-ever site for measuring the flow of Snowy River!)

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Preface: This documentation of the World Class Fort Stanton Cave Karst System with its two stream systems is unique in the extent of water and temperature data logging. This hydrogeology report includes the work of many Fort Stanton Cave Study Project (FSCSP) cavers and support of that work by BLM, USFS, NCKRI, NMT, the Fort Stanton Cave Hydrology Working Group, and others, some of which are shown in the above photo, taken during the 10-15-2017 FSCSP Expedition. (Lindsley #5852) The author spent about a year during the Covid-19 pandemic, processing data from the cave with the goal of presenting each data set in a manner that a quick look could compare the characteristic of each site with the others, and also at a single site over several flow events in some cases. It is expected that interested readers will likely see some correlations that have not been previously discussed and will be able to offer comments and suggestions for future data logger sites in the cave that might reveal additional facts currently unknown. The charts presented were all generated using Mac Microsoft Excel 2016 after importing the raw data downloaded from the data loggers. Most of the loggers were In-Situ Rugged Troll 100 non-vented units, but when available other loggers in the cave are also shown for comparison, and in several cases, they provide unique information. The In-Situ loggers have an almost unique 3-digit number that makes identification of a particular data set easier. Data considered duplicate or incomplete was not included in this report. The References section at the end of the report includes additional comments and data. Hopefully other scientists can make efficient use of this report plus future data from this world class underground laboratory. This report will be updated at the end of the 2021 season.

Organization: The order of the logger sites presented in this report starts at the upstream section of Snowy River where an insurgence joins the main Snowy River passage. (Exploration beyond the 12 Mile point from the single entrance has stopped short of the BLM boundary, but we hope to continue exploration under private lands when conditions improve.) The logger sites progress downstream heading North towards the known resurgence at Government Spring. Following the description of the Crystal Spring site, another group of data loggers in the Main Corridor is described up to the Sewer Pipe Landing (SPL) site. The exact connection between the water at SPL and Snowy River between Turtle Junction and Crystal Spring is only suspected. We do know, however, that the Rio Bonito, during certain undefined flow conditions, "leaks" water into the Main Corridor near the entrance and likely ultimately exits the cave at Government Spring.

This was suspected prior to the discovery of Snowy River after Cave Specialist Buzz Hummel performed a dye test in 1983. Following the logger sites in the Main Corridor, three surface sites are also discussed.

For those interested in a particular logger site, refer to the previous Table of Contents for easiest access. During the processing of the data, occasionally there were more extensive discussions of related topics, and some of these discussions are included as an appendix at the end of the report. There is also information providing details on how the data was converted into mostly similar charts. With around a dozen different people programming data loggers for the cave, using three different brands of professional data loggers, with multiple ways to define units and program the individual units, it was not a trivial exercise to compile these charts into a uniform format. If a reader identifies a particular logger that did not appear in this report, it may be because inadequate location information was available, or in some cases the handheld in-cave computer and cable connection caused bad readings. But the possibility of additional information or charts becoming available will be welcome, as will data acquired after 2020. Rather than adding footnotes to a rather long document, I have chosen to instead add a list of References of various sources and papers at the end. There are several appendixes following the list of References that focus on various topics.

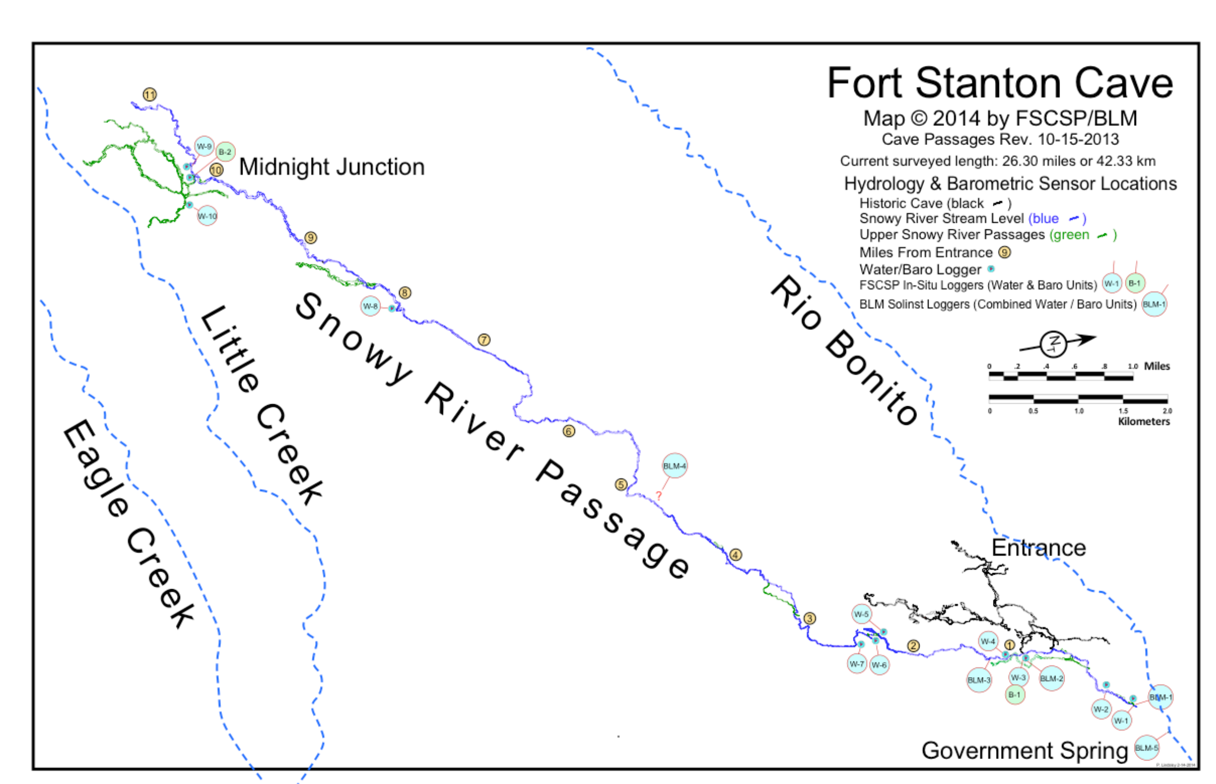
Goals of this Report: This report is intended as a reference document with comments and provides a uniform presentation of much of the data from the data loggers in Fort Stanton Cave. Previously the temperature correlation with the water flow had gone almost unnoticed, and an early goal of this work was to point out several correlations and introduce additional ideas for both the casual cavers and also the professional hydrologists that may be able to implement more powerful software that will improve our knowledge of the Fort Stanton Karst System. By using the generous amount of data available at the excellent USGS 08387600 Eagle Creek measurement site, and perhaps others with temperature data, our information for better predicting both the initial flows and drying parameters of Snowy River can be improved. Perhaps a future hydrology student will be able to perform a more detailed analysis using professional applications such as MODFLOW.

Overview of Data Logger Design & Plans:

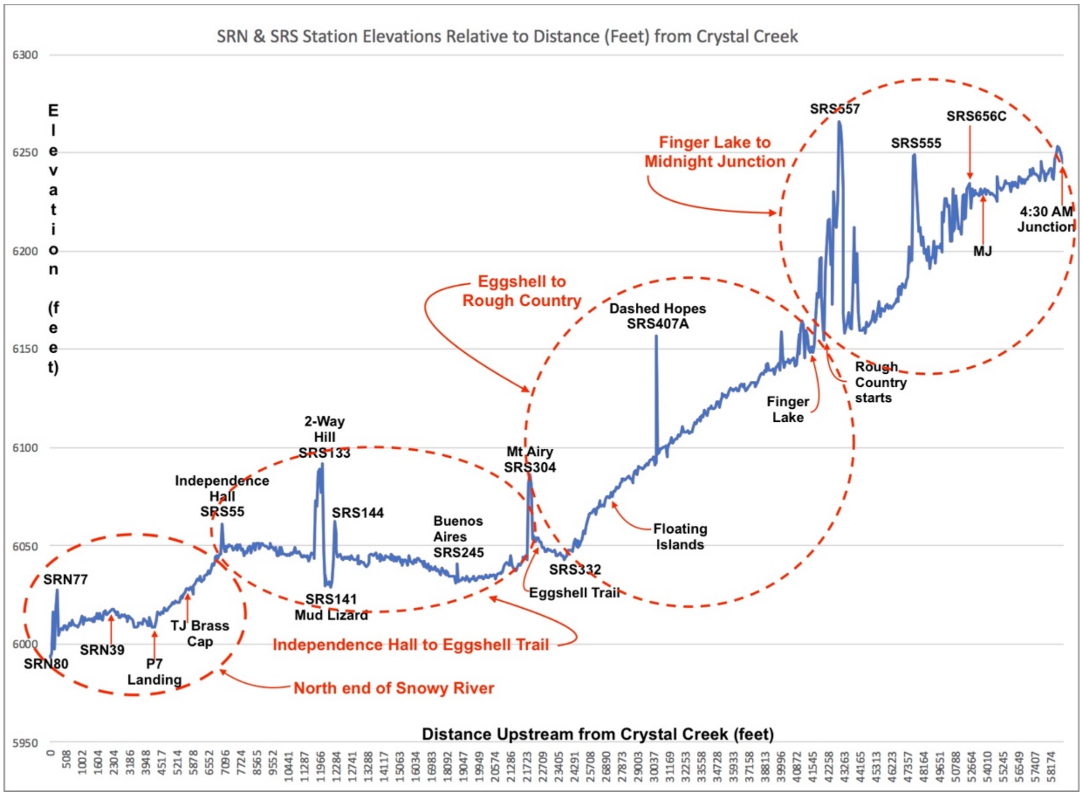
The work represented in this paper started out as a temperature study. Previous requests for information on the temperature over the winter of the Entrance Sink and Wash Tub Room created charts showing the temperature from the In-Situ loggers in the front part of the cave. At that time the primary analysis of the growing array of In-Situ loggers in the Snowy River section of the cave, which was reported by Steve Peerman in numerous expedition reports, placed emphasis on the correlation of the surface rainfall and snow-melt measured at the USGS Eagle Creek station (USGS 08387600) with the arrival time of the Snowy River flow at Turtle Junction where we have had various data loggers since 2010.

The cave maps show the approximate locations in the cave of the data loggers. Each of the sites will be covered in order starting with Snowy River from the South end going downstream to the North end. Next the sites in the Main Corridor of Fort Stanton Cave will be covered from the entrance, going downstream towards Snowy River. Finally, the surface sites will be shown.

Some of the baro data will also be shown with comments about the raw data. Where most appropriate, the available post processed water logger data will show their compensated graphs with the rest of the site information.



The map above shows the relationship of the cave to three surface streams to the known parts of the cave in 2014, shortly after the first array of ten In-Situ water data loggers was deployed. Original logger sites are marked by the green circles. It now appears that the majority of water feeding Snowy River is provided by Eagle Creek. The Rio Bonito appears to only occasionally provide water that causes significant flooding in the Main Corridor, and up to 7 feet deep at the Sewer Pipe Landing site. So far, Little Creek does not appear to provide any significant water to the cave.

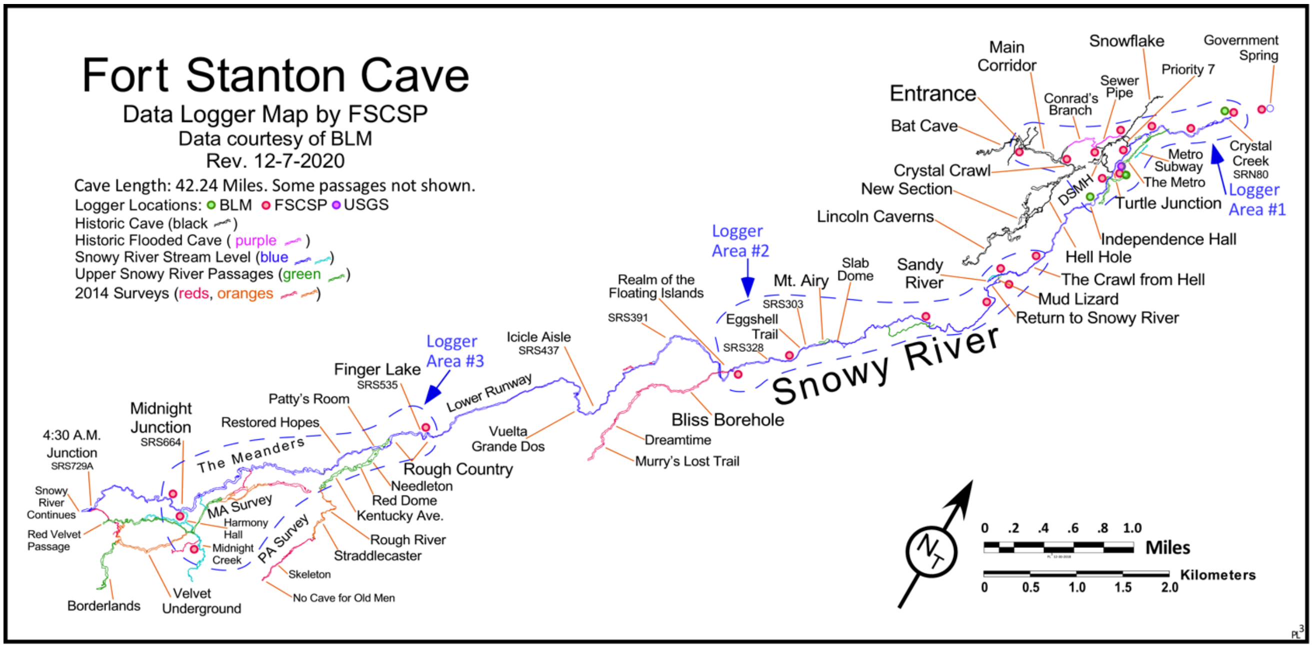


A profile of the Snowy River passage is shown on the right. This profile was generated simply from the COMPASS survey program and plotting the apparent floor level of the survey from the far south extent of the passage at 4:30 AM Junction all the way north to the Rough Country breakdown. Note that it appears the average slope of the passage beyond Eggshell Trail is fairly uniform and the peaks above the Snowy River calcite formation are various domes and high points above Snowy river. We believe that in the Rough Country breakdown area, the lower level Snowy River formation is consistent with the average slope. The area at Mt. Airy and Eggshell Trail is an obvious change to this average slope and in some places the apparent negative slope is likely due to the inaccuracy of the Suunto surveying gear in attempting to measure an almost level passage. (Past this point most survey was done with more modern Disto-X2 equipment and recent closures via upper level passages will likely improve this particular profile view. A future goal is to improve the survey in the third zone marked as “Independence Hall to Eggshell Trail”.)

The area called 2-Way Hill and Mud Lizard was recognized as a potential safety issue for trips going past what appeared to be a Mud Lizard sump. That’s exactly why three logger sites in this area were chosen for early deployment of water logger, and it is interesting to see the results as described in the water logger detail pages later in this report. Fortunately, in 2020 the Black Rock Bypass was found as a more level route bypassing the sump area, and partially explains some of the water level characteristics shown in the charts.

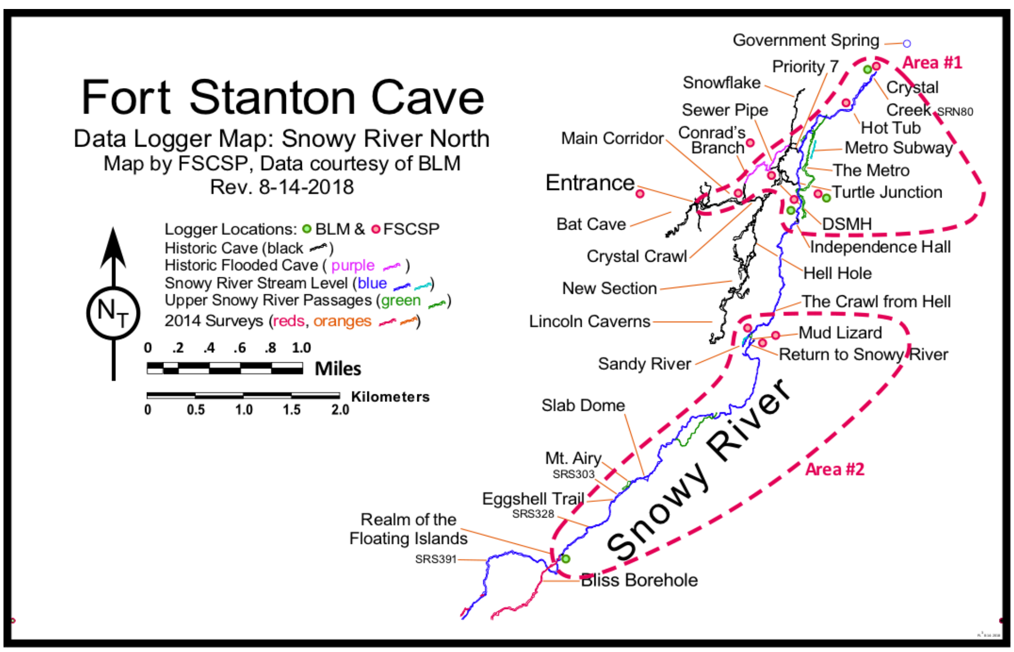
There are several additional loggers in the fourth zone called “North end of Snowy River” as this area is of fairly easy access for several science projects. Of course, the only access point for the whole Snowy River complex is currently at Turtle Junction, with easy access through the 44-foot hand-dug Access Shaft. Access to the only Snowy River water data loggers during a Snowy River flow are located in the Turtle Junction area. Continuing north to the far-left end of the profile map there are no more large breakdown areas that block the Snowy River flow, and parts of Snowy River North have both steep sections and also flat sections where pools remain for several months immediately after a flow stops. The final area, which is called Lincoln's Bathtub, has a large breakdown pile that forces the flow through a small passage that drops into the final room. Crystal Lake at the far end is only slightly above the Government Spring pool level.

The next map shows the water level data logger locations in Fort Stanton Cave as of 12-7-2020.

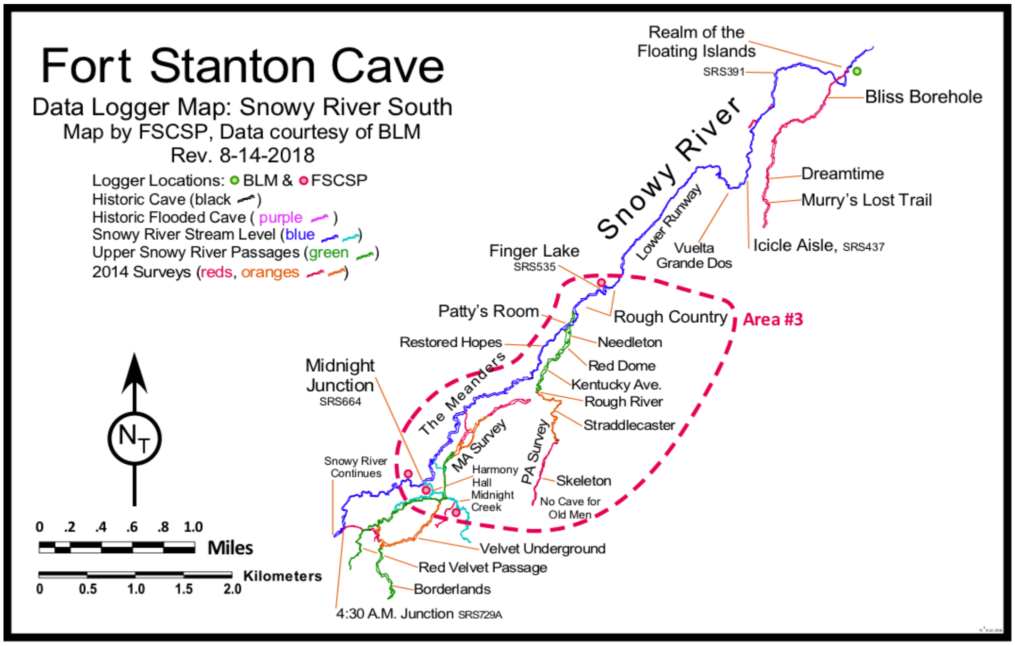


This map shows three logger areas within blue dashed lines.

The smaller maps on the right and below are 2018 version maps that show the majority of loggers and shows three "service areas" of loggers, with Area #1 being the closest area to the entrance. This area covers the Main Corridor plus Snowy River from Independence Hall North to Crystal Spring. Area #2 covers the Snowy River Passage from the Crawl-From-Hell upstream to the climb up to Bliss



Borehole where additional data loggers Snowy River were placed in 2019 and 2020. Area number 3 starts at Finger Lake and Rough Country and covers the Snowy River South passage all the way to Midnight Junction and two near areas.



Exploration and surveys in 2019 and 2020 had to deal with a slowly drying Snowy River. Most of these trips also included maintenance of the “magic carpets” and maintenance of data loggers, but they opened up a whole new wealth of data on many historic upper level passages that are part of the hydrogeological formation of the current lowest level Snowy River Passage.

Data Logger Results

This section of the report will show the actual results from the various logger sites in Fort Stanton Cave. It will start with the loggers in far South Snowy River near Midnight Junction, and proceed downstream to the North, ending at Crystal Creek and Crystal Lake, which feeds Government Spring. Next, the sites in the Main Corridor will be shown from the entrance and heading NE towards Turtle Junction at Snowy River. Finally, two surface sites in addition to the Government Spring site will be shown, one on Eagle Creek and the other on Rio Bonito.

Additional information and continuing updated discussion on the logger sites discussed in this report are also shown on the Fort Stanton Cave Study Project (FSCSP) web site at:
[http://fscsp.org/science/hydrogeology/logger%20sites.html]

Snowy River Logger Array

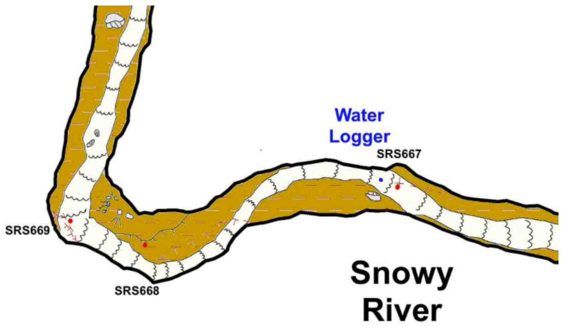
The original FSCSP deployment of In-Situ loggers in Snowy River South was done in May 2013 by members of the Strong & Light teams which were making 30 & 36-hour long trips from the entrance. The original logger programming was based on what we had seen during Snowy River flows in 2007, 2008 and 2010, which usually lasted around 9 months. In 2014 approval was finally given to allow multi-day camping at Midnight Junction. The first camp trip was June 15, 2014, followed by the 2nd camp trip on July 6, 2014. Then on August 16, 2014, a science trip was headed back towards Midnight Junction, but encountered a Snowy River flow part way there at SRS391. Since at that time we had no data from the water loggers, and it was believed that the Mud Lizard passage could sump, the team beat a hasty retreat in front of the slowly moving water and exited the cave safely.

Since that time, almost 7 years ago, no one has been able to return to the Midnight Junction camp to retrieve the three remaining loggers deployed in the area in 2013.

MJ27.5, Midnight Creek:

Midnight Creek is the main side passage with water that we suspect drains into Snowy River at or downstream from Midnight Junction. This location offers possible indications of a Little Creek insurgence, and depending on the initial results from the 2013 installation, additional loggers may be deployed in this remote area. The Midnight Creek site is halfway between stations MJ27 and MJ28, where in 2013 there was a small section of water that we assumed could be an indication of an insurgence from Little Creek. We have not yet recovered this In-Situ water data logger, and will need Midnight Junction baro for best smoothing.
The W9 logger was installed 5-3-2013 (photo P1030672) will offer stage & temperature vs time from 2013, but only covered 2013-2014. It has not yet been replaced due to high stream flows preventing access.

SRS667, Snowy River Far South:

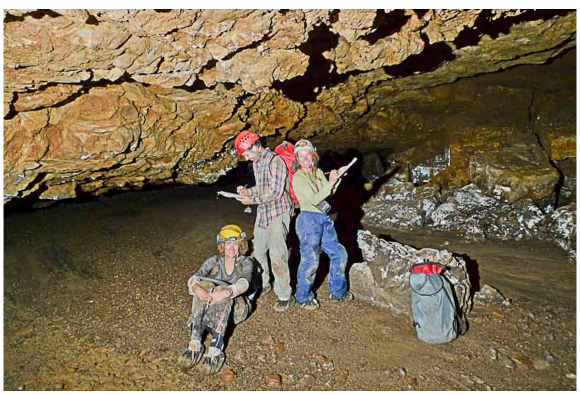


This Snowy River site was chosen following what appeared to be the primary Snowy River passage just beyond Midnight Junction, where the Midnight Creek passage appears to be an in-feeder to the primary Snowy River Passage. We have not yet recovered this In-Situ water data logger, and will use the Midnight Junction baro for best smoothing.

This location is the main continuation of Snowy River, only 4 stations past Midnight Junction, and is likely the primary flow which was later confirmed by early 2014 trips. (When additional access and loggers are available, the 4:30 AM Junction location will compliment this logger with future flow measurements.)

The W10 logger installed 5-3-2013, stage and temperature vs time covering 2013-2014 may be available in the future.

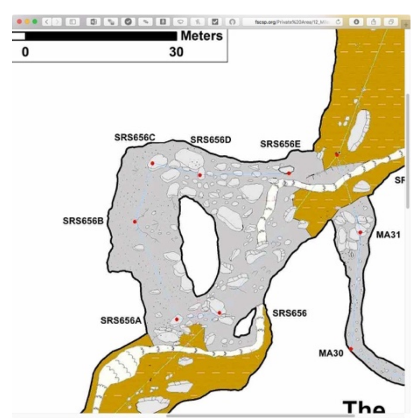
SRS663, Midnight Junction:



This junction room marked a series of side passages, both upper level and near the Snowy River base level. This room was designated as a campsite in 2014, but was only used two times before the major 4-year Snowy river flow started. This site is near the Midnight Creek and Snowy River Far South sites, and in only occupied by an In-Situ Baro logger, which has not yet been recovered due to high water and delicate floors.

This is the primary campsite, 10 miles from entrance, for deep Snowy River South trips. There is only a baro logger at this location which will be used for calibration of the two water loggers in this remote area. The B2 Baro logger was installed 5-3-2013. Baro pressure and temperature vs time covering 2013-2014 should be available in the future, and will be used to compensate the water level data loggers in the southernmost sections of the cave.

SRS656, Future Logger Location



Just 7 stations downstream from Midnight Junction, the SRS656 area is a proposed future location for a water logger that could provide real-time water level data in far-upstream Snowy River. Both a small diameter utility core hole and a battery powered low-data-rate low frequency digital radio have been discussed that might provide this information.

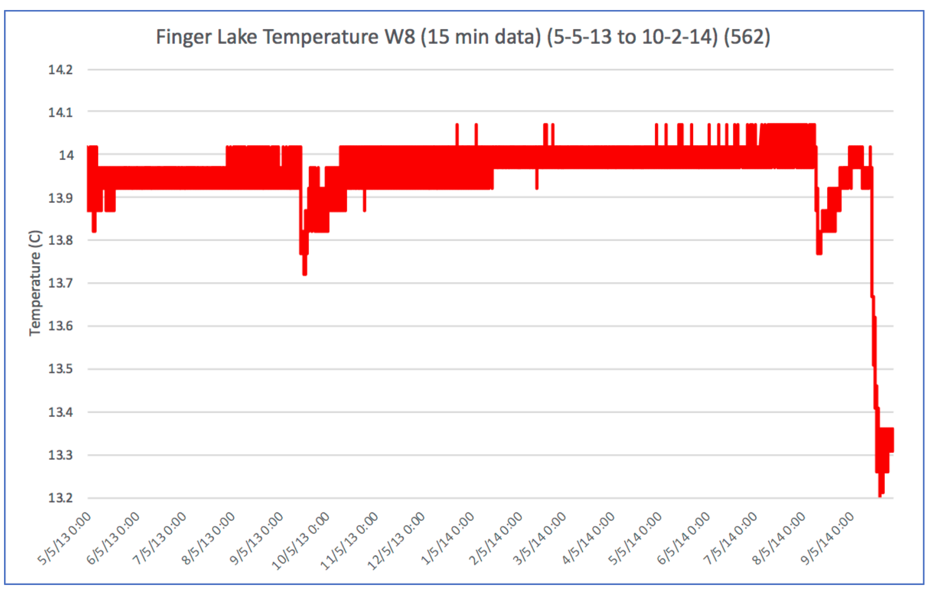
SRS535, Finger Lake:

As one of the first In-Situ data logger files to be shown in this report, the following detail will also apply to many of the following files. Comments will be made that at first may seem trivial, but will become more obvious as additional logger graphs are presented. The great majority of these graphs will show the temperature in red and the pressure (representing the water depth) in blue. Depending on the site location, the pressure noise caused by the changing surface barometric pressure will often conceal the precise arrival time of a flow event as well as small changes in the actual water depth. These plots are labeled “Uncompensated”. Also note the 3-digit code applied to the end of the In-Situ logger file name. These three numbers are random, perhaps not unique, but are generated each time the logger is downloaded to create a .CSV file, which is then processed by a Microsoft Excel (or equivalent) application. With the long “default” names applied by the In-Situ download software, it is convenient to be able to search the long file names using these 3 digits, and they have been added to most of the graphs so that their origins can be determined. (photo P1080015) This is the primary water source for the Midnight Junction campsite, 10 miles from entrance, for deep Snowy River South trips. Water samples have been collected and the non-porous bottom of this pool seems to contain water for a long time.

W8 logger installed 5-3-2013, stage & temperature vs time 2013-2014. W8 logger removed 9-8-18. W21 logger installed 10-3-20.

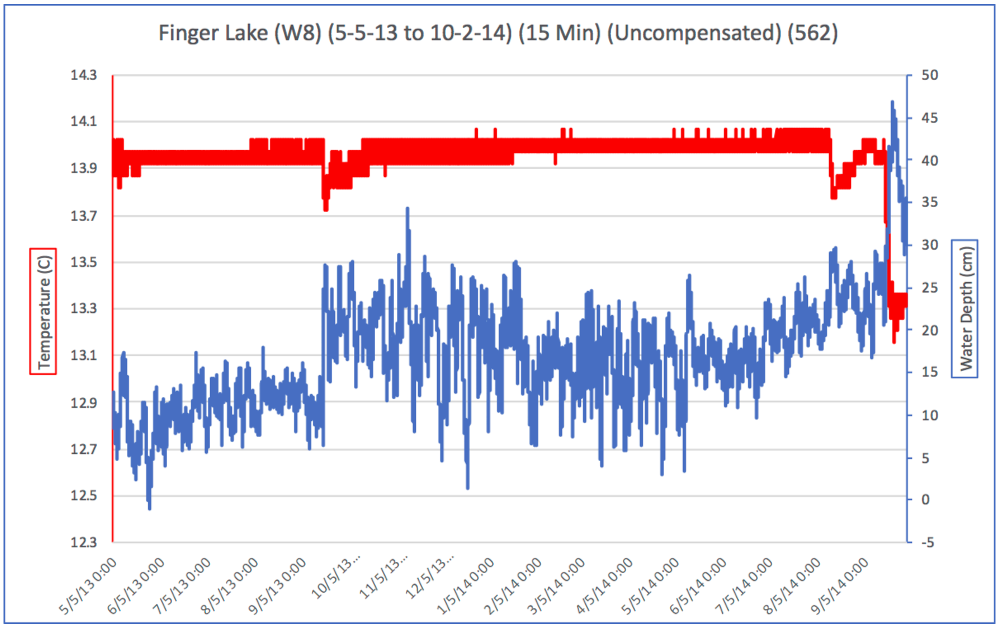
(562) (5-5-13 to 10-2-14)

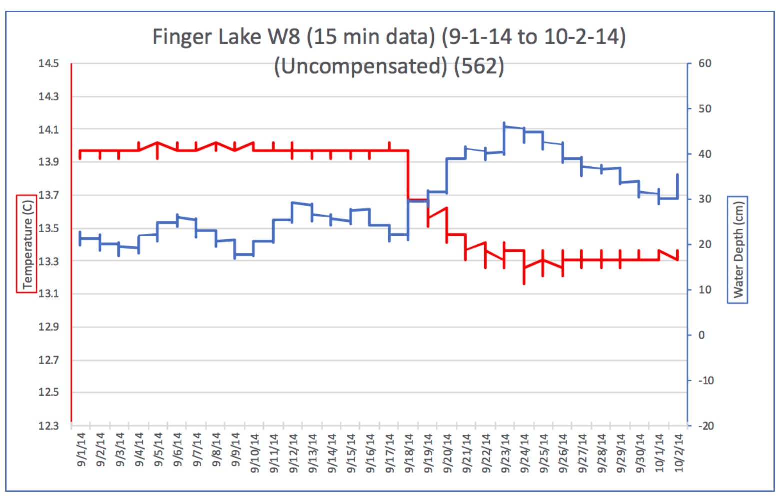
An example temperature file [File: Finger Lake 1_2018-09-23_11-45-23-562] is first shown by itself to point out that multiple temperature changes indicate several flows prior to October 2014 occurred at Finger Lake. The logger was installed in Finger Lake on May 5, 2013, and we might expect that 5-17 days later the temperature would remain stable. However other teams in the Midnight Junction area may have caused the appearance of the Finger Lake temperature to drop by 0.1-degree C so that the possibility of surface waters causing this dip in temperature is slim. Then on 9-18-13 an obvious small flow starts, then the temperature is back to normal ~ 10-8-13.



Almost a year later on 8-14-14 another obvious flow starts, then peaks at 9-6-14. Finally, on 9-18-14 @ 18:45, a much larger flow starts, the temperature drops 0.7 Degree C, then logger memory fills on 10-2-14. (Note: since the original In-Situ loggers were deployed in 2013, with a 15-minute sample time, the RAM memory has been doubled and the sample rate set for 30-minute intervals, which are expected to provide over seven years of data for the loggers deployed "deep in Snowy River South" where we have experienced long flows resulting in very limited access.)

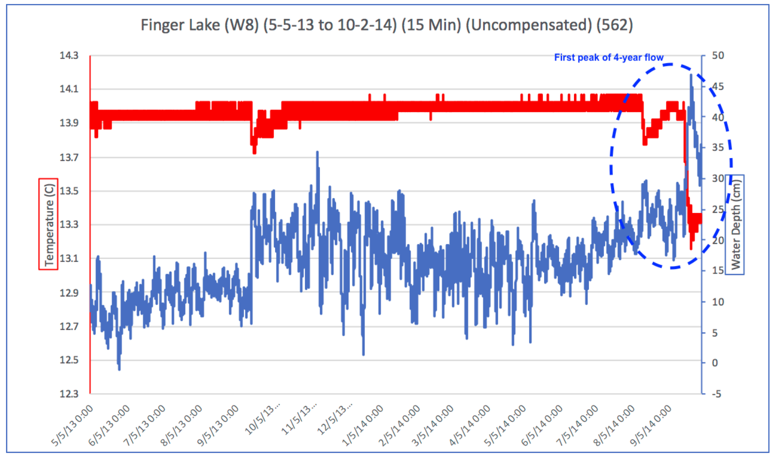
The next chart shows both the Finger Lake water depth (in blue) and the same temperature (in red) with scales optimized for each particular site. The same temperature data was shown in the previous chart, but hidden here somewhat by the noisy water depth data. The initial May 2013 data possibly shows a slight water rise, but until the water level pressure reading is compensated with the Midnight Junction Baro unit it will be difficult to verify the exact values. By doing a "visual averaging" of the noisy blue line one can guess the water level in Finger Lake may have increased by about 10 cm, then steadily declined until in mid-August 2014, an apparent start of a flow which peaked on 9-24-14 at about 46 cm (about 1.5 feet) from the bottom of the Finger Lake pool. Note that at the same time the water depth peaked, the temperature dropped to an abnormally low value. Although this was likely before the snowpack on Sierra Blanca started forming for the winter of 2014-2015, there must have been a large volume of cold water that started flowing in far South Snowy River.



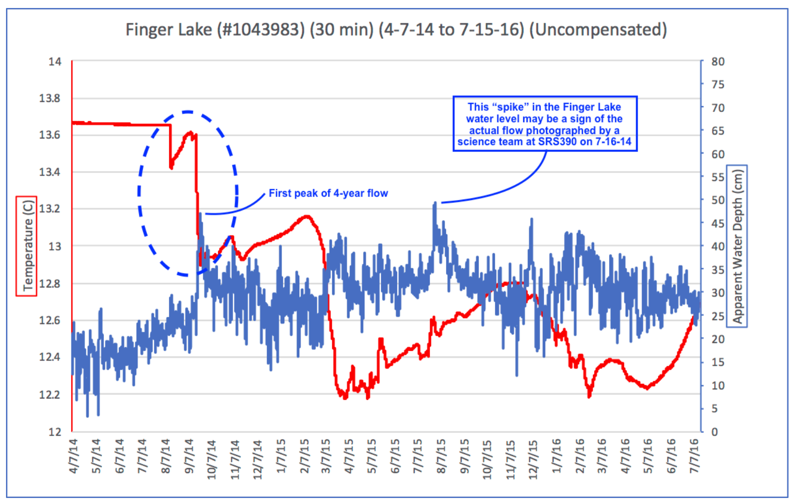


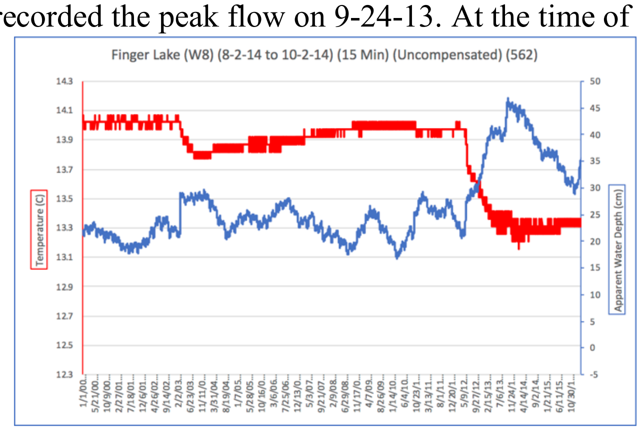
This expanded graph from September 1 to October 2, 2014, shows the significant rise in the water depth at Finger Lake. We will see this same characteristic in the other loggers downstream in Snowy River. (Note: the easiest way to understand the dates is to look for the start and stop dates in the title of each chart.) If other researchers wish to get a more exact date and time resolution for a chart, the file is most easily identified by the 3-digit number at the end of the chart caption, which in the case above is (562). In most instances this random number is unique and is assigned when the In-Situ .wsl file is downloaded from the data logger itself. However, duplicates are sometimes formed if there are multiple downloads.

During initial formatting of the charts for this report, the decision was made to format all the charts in a similar format. This allows a quick visual observation of multiple charts over time at each site, and also allows easier comparison between sites. The temperature data is in red, with the associated temperature axis also marked in red. The water depth data is in blue, and the conductivity data is in green. Some of the expanded charts, like the one at the bottom of the previous page, do not show the exact data on the X-axis, but instead just shows the default data logger data format, which is different for all three Finger Lake data loggers covered in this report. In these cases, the chart title shows the dates covered.

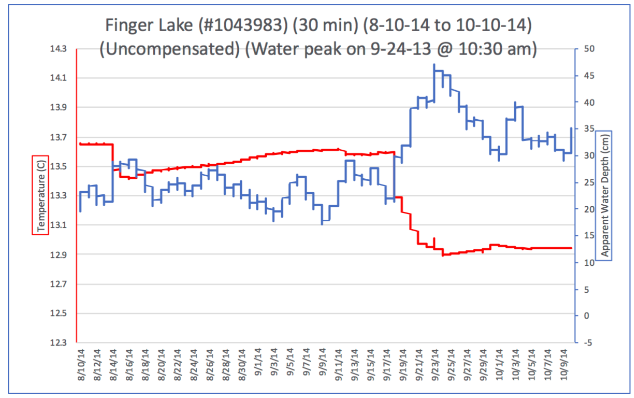


Faulty documentation caused an issue with an unknown pair of BLM Solinst data loggers being placed next to the In-Situ logger (W8) in Finger Lake, well beyond the Floating Islands site which also had a pair of Solinst loggers prior to any In-Situ loggers. The only documentation on the installation and removal of these deep Snowy River Solinst loggers was word of mouth. Fortunately, the Finger Lake W8 In-Situ logger ran until 10-2-14, just past the major pulse of water that resulted in a 4-year flow. Apparently the Solinst logger was placed in Finger Lake on 4-7-14, and it ran until 7-15-16. Both loggers recorded the peak flow on 9-24-13. At the time of this writing, neither the In-Situ B2 baro logger at Midnight Junction nor the unknown Solinst baro logger were available for proper water compensation. Once the B2 logger and the other Solinst baro logger data become available, the charts can be improved. The water depths in this report were adjusted so that the peak water depth in Finger Lake was about 45 cm for both units. The upper 2 charts show a dotted ellipse around the final period that shows the initial 4-year flow, which we now know propagated down the next 10 miles of Snowy River all the way to Government Spring. That final 2-month period ending on 10-2-14 is shown in the smaller graph above.





The Solinst logger chart on the middle right of the previous page starts before the In-Situ logger at the top of that page filled its memory. The dashed lines show the common data area. Apparently, the team that brought in the Solinst logger pair were following instructions and placed the water logger next to the In-Situ unit in Finger Lake around May 3, 2014. The dotted ellipse near the start of the logging period shows a similar set of data for both the temperature and the water depth. The only trip in deep Snowy at that time was a survey trip to the PA passage with John Lyles, Adam Weaver, Brian Kendrick and Derek Bristol. There was a brief mention in the expedition summary report of needing to replace (or remove) a rusting stainless-steel staff gauge in Finger Lake, and it is likely that this is when the Solinst logger pair was handed to the team as they left on the trip, perhaps along with the replacement staff gauge from BLM hydrologist Michael McGee. The chart at the middle of the previous page is also of significant interest as it shows at least three "large" flows of cold water (snowmelt?) that follow the initial pulse of water that started dropping the water temperature. The small chart on this page shows a 2-month span on the Solinst logger.



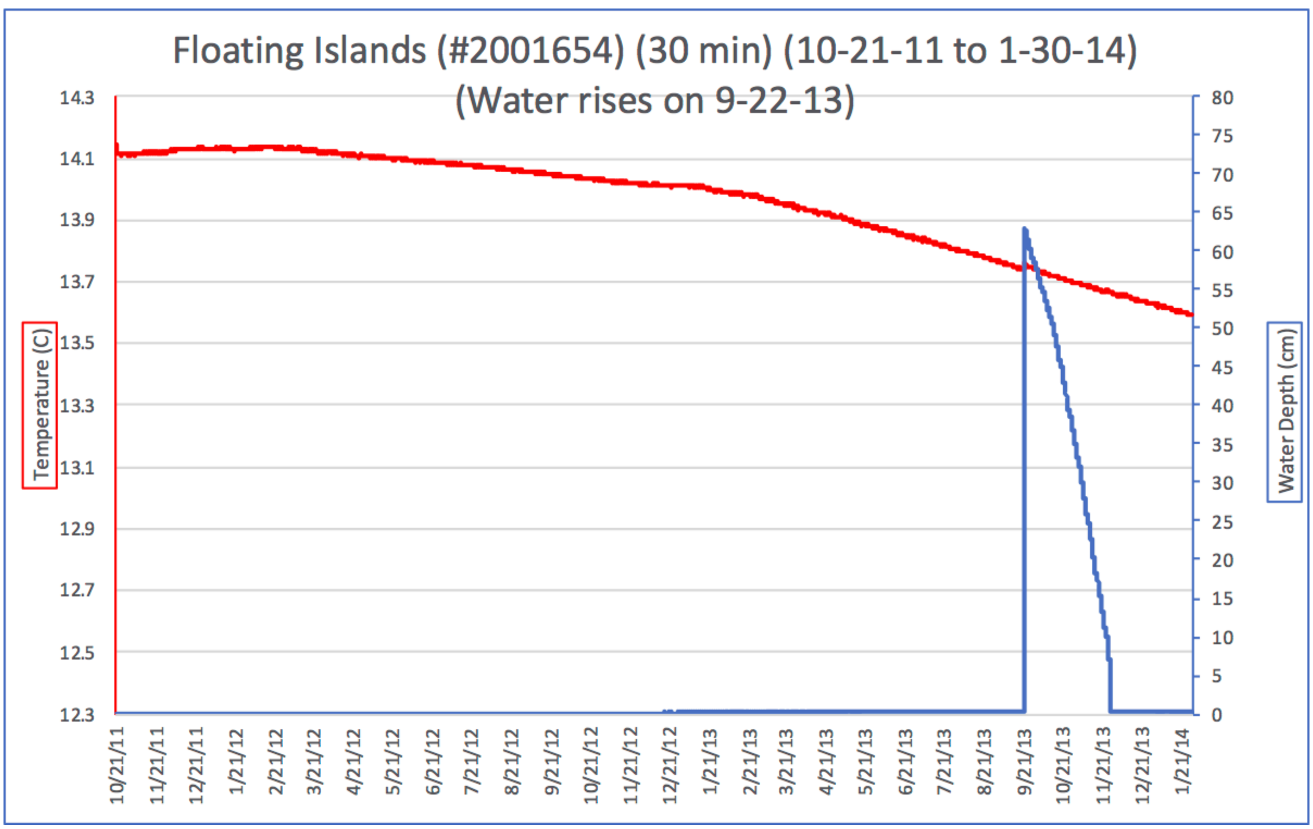
There were no pictures or any other text found in the team records about this apparent date of the Solinst logger installation. We did have a photo of the team exiting the cave on May 3, 2014, as they approached a LIDAR team working in the Main Corridor. Near the center of the photo you can see two tall white PVC staff gauges (next to the LIDAR instrument) that have been used in the past to measure the depth of water below the floor in the Main Corridor. (Lindsley #0943)

SRS374, Floating Islands:

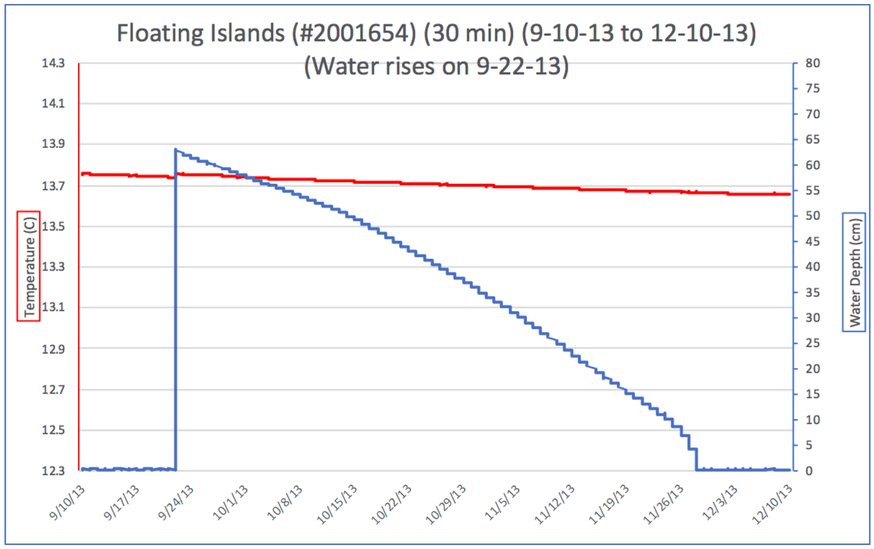
The first logger placed at the Floating Island site by Jim Goodbar (BLM Management Trip) was a Solinst logger. (Note: The Floating Island logger files were improperly named “Egg Shell Trail”, but this was corrected in the chart titles in this report.)

Baro, stage & temperature vs time from 2011. Solinst logger installed 10-20-11 (Photo: J. Goodbar IMG_0942). A pair of In-Situ loggers replaced the BLM loggers in this location in 2018.

This location was originally chosen in 2011 by a BLM team and a pair of Solinst loggers were deployed. It was assumed to be a good pool location downstream from possible side passages that might connect to an in-feeder under Elk Valley, just past the airport. The chart below is significant because we believe the sharp rise without a significant temperature change illustrates a sub-surface water flow, due to pressure forcing water below the Snowy River calcite surface upward at the Floating Island site.



2020 analysis of the recovered BLM Solinst data logger appears to show a sub-surface flow in the 2011-2014 data. We believe this to be the case because of the sudden change in water depth when the temperature increase is an almost imperceptible amount. Talon Newton explained this effect as the second of four different scenarios in an email on October 20, 2020.



After briefly looking through the graphs and your abstract, I think the temperature and water level data are consistent with our current conceptual model. We can define the following states or scenarios:

1) Snowy River is dry - Air temperature is fairly constant but likely shows small seasonal fluctuations with a lag-time with respect to surface temperature seasonal fluctuations. (Does our current data show this?) A shallow water table exists in sediments below the Snowy River streambed.

2) Initial occurrence of water in Snowy River - Water input from Eagle Creek results in a large increase in head in the shallow aquifer at the recharge zone (headwaters of Snowy River). A pressure response to this increase in head results in the increase in head in the shallow aquifer at down-gradient locations. This pressure response is very quick. Therefore, the first occurrence of water is water coming from the aquifer below (water that is moving upward), which appears to be slightly warmer than the air temperature in the cave. This process is important to understand. At this stage the water in the Snowy River stream is coming from below, now from upstream stream discharge. When analyzing the timing of this initial occurrence of water at different locations, you are looking at the timing of this pressure response, not the rate at which water is flowing in the streambed.

3) Snowy River is filled and starts flowing - At this point, water is flowing through the channel and at any location, more water is coming from upstream stream discharge than from below. Also, at this point, there is likely a spring at the far upstream end of the passage that discharges directly into Snowy River. Therefore, water at downstream sections has been in contact with the cave atmosphere for a longer period of time, and the water temperature will equilibrate with the cave air temperature over time. However, at this stage, if there is another flood event that significantly increases the input of water from Eagle Creek, resulting in increased discharge in Snowy River, the water temperature in Snowy River will change, reflecting the temperature of the new water (in some cases, cold snowmelt).

4) Snowy River stops flowing but still contains water (steep recession curve) - There is not enough of a gradient for water to flow in Snowy River. Therefore, water is percolating downward, recharging the underlying shallow aquifer. The temperature of this stagnant water quickly equilibrates with the cave air temperature.

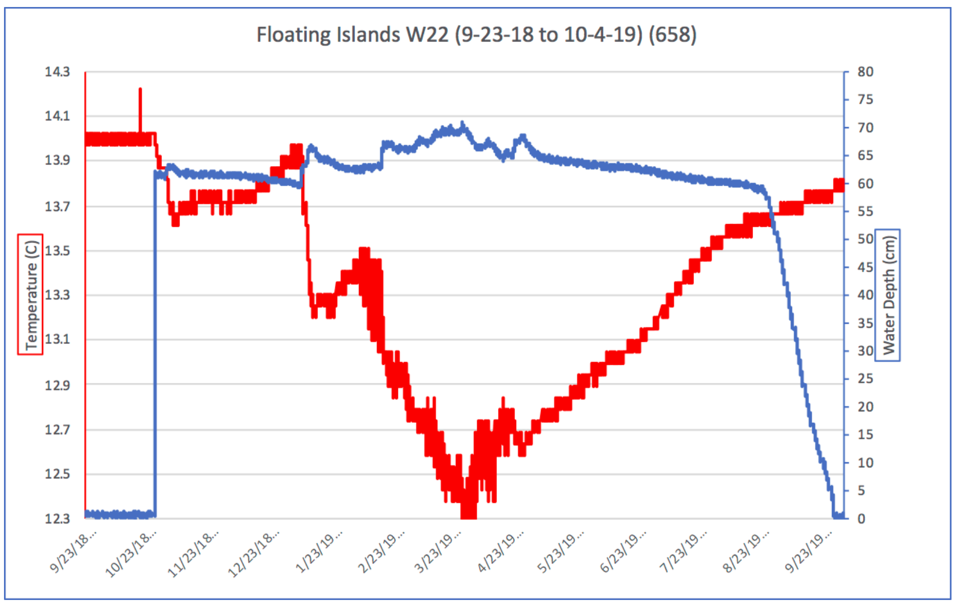
- Talon Newton (10-20-20)

In 2018 the Hydrology Team decided that it would be more efficient to replace the dual Solinst loggers with both an In-Situ water logger and also a baro logger. The new In-Situ baro at SRS374 will be more accessible during some flow events when the Midnight Junction baro is not, and will be able to compensate the area water loggers even when our teams can't reach the Midnight Junction baro unit due to high water.

The history at this site is: Solinst water logger (only) removed 9-8-18; W22 & B5 loggers installed 9-8-18; W32 & B4 loggers installed 10-4-19.

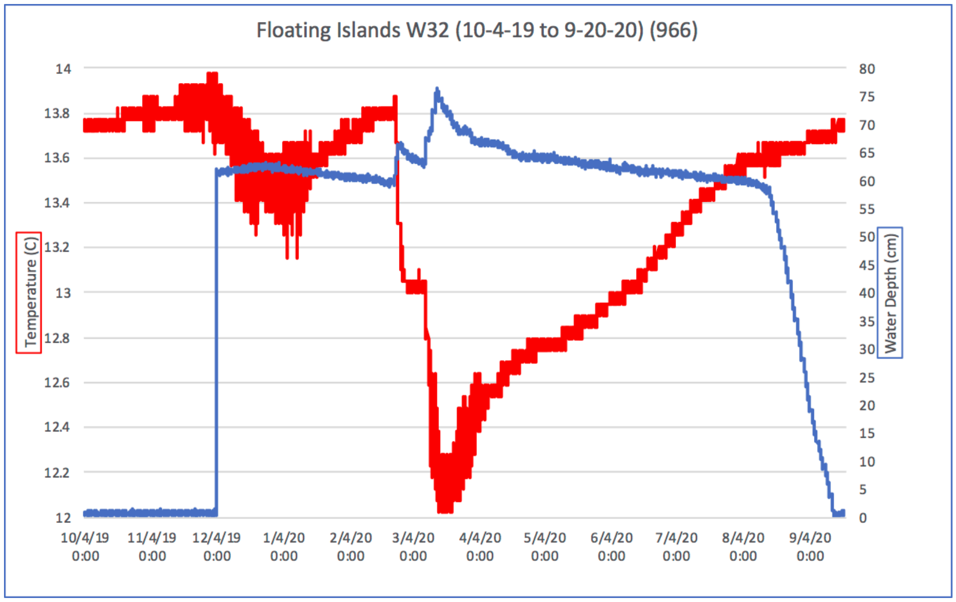
(658) (9-23-18 to 10-4-19)

Two Snowy River flows between September 2018 and September 2020 are shown on the next two charts. Once the water depth is compensated with the baro logger it becomes apparent that these two flows are very similar in many respects. Some of the slight water peaks can be traced downstream and now timing information is available to enhance future in-cave predictions. The October 2018 plot shows a sudden rise of 60 cm with a temperature decrease of 0.4 degrees C. (There is an interesting short temperature peak of about 0.2 degrees just before the temperature drop associated with the water flow.) The water depth decreased slightly as the temperature of the incoming flow increased almost back up to the value in September. The next pulse of water dropped about 0.6 degrees C, then warmed up 0.2 degrees, before a much colder volume of water (1.2 degrees cooler) arrived at the Floating Islands site. In April 2019 the water began to warm back up as the flow continued. Finally, in August 2019 the water temperature was almost back up to the same value in 2018 at the start of the flow. The tailing edge of the water depth chart exhibits what seems to be a typical drainage characteristic of other similar downstream pools in Snowy River (Plunge Pool and the Swimming Pool).



(966) (10-4-19 to 9-20-20)

The chart for October 2019 to September 2020 is quite similar to the previous year. It shows a rather abrupt water depth increase to around 60 cm, only this time the incoming water flow appeared to arrive slightly warmer than the previous fall. Likewise, the temperature of the incoming February water, which is likely snow-melt, is seen to drop by 1.8 degrees C. It will be interesting to see how this characteristic in the Snowy River flow tracks the surface water temperature of the logger we have installed at the Eagle 1 site.



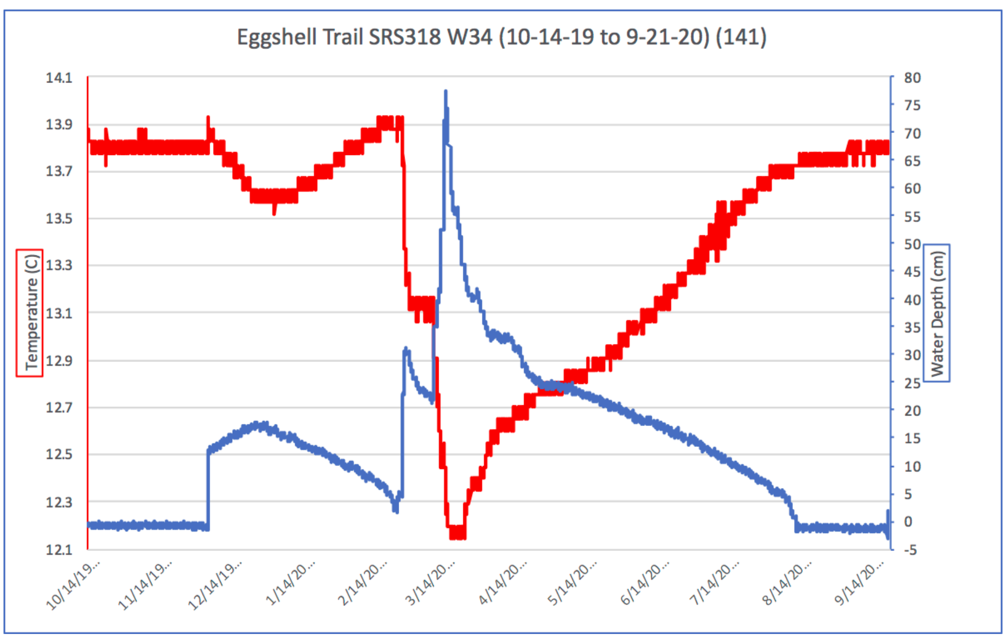
SRS318, Eggshell Trail:

This location is just upstream of Mt. Airy. (Stage & temperature vs time from 2019.) W34 was placed on 10-14-19. (From Station SRS318 the logger is located 36.4 ft., @ 19.1 Deg Az, and -3.3 Deg Inclination). Note the uniform passage depth and width to better match the Manning equation assumptions. (Photo: G. Jorgenson #3624)

Moving 56 stations downstream from the Floating Islands site we find ourselves at SRS318 which is currently named “Eggshell Trail”. (Note: the “real” Eggshell Trail area named on the map was where the 2014 BLM S&L team started a survey when the Floating Island logger was installed.) Eggshell Trail was named by the April 2009 discovery S&L team due to the very thin calcite surface over underlying sand and clay. Since that time, as our hydrologists became more interested in establishing several discharge inference sites in straight sections of Snowy River, this site and the next site 91 stations downstream at SRS227 were established with the goal of checking for possible insurgences in the Mt. Airy breakdown zone. This photo of the SRS318 site was taken by the October 2019 S&L team placing the logger. A photogrammetry cross-section has been obtained, and a future "mini-Palmer Pole" measurement of the slope at this site will be made on a future trip. This will support using Manning equation flow measurements for possible change in flow volume characteristics.

(141) (10-14-19 to 9-21-20)

Compare the temperature plot to the similar chart for Floating Islands (SRS374). We see a similar 1.8 degrees C temperature drop, as expected, but now the average water depth is closer to 20 cm and again we notice the correlation between the water depth and the changes in water temperature. In mid-February the Snowy River flow almost stops, just before the major cold water enters the Snowy River channel. Following charts will show a similar split into “two flows” by the time the flow reaches Turtle Junction.

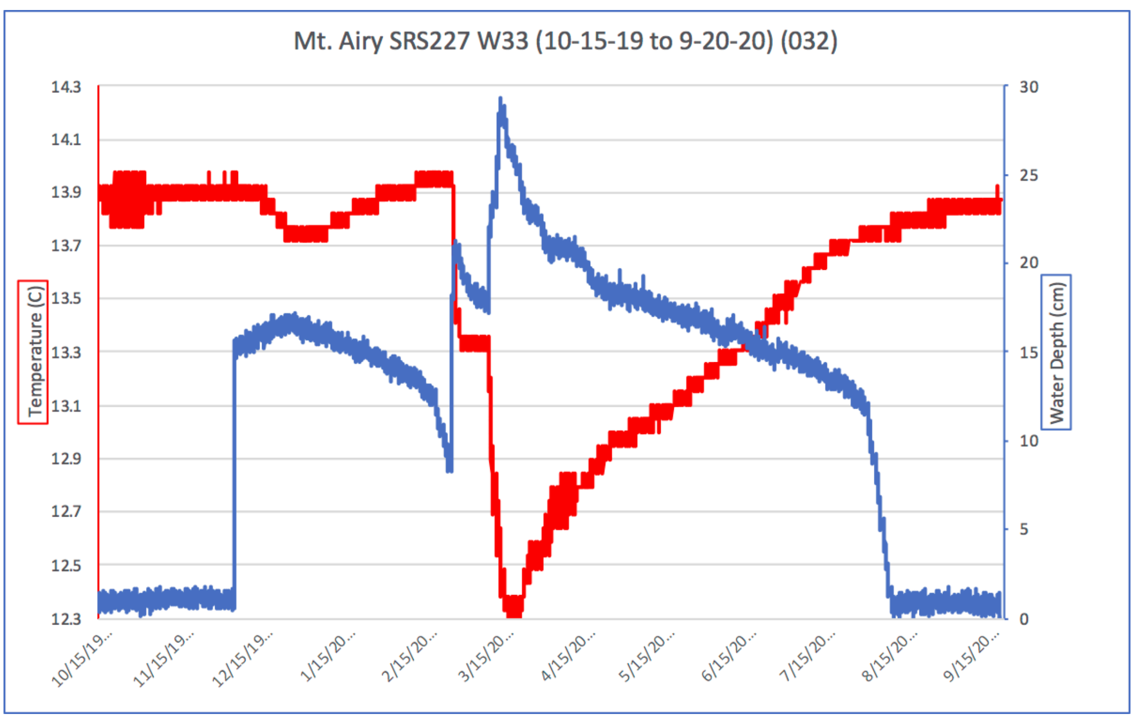


SRS227, Mt. Airy:

This discharge inference site was chosen to look for possible insurgence in the Mt Airy breakdown zone. W33 was placed here on 10-14-19. (From Station SRS227 the logger is located 23.9 ft., @ 279.6 Deg Az, and -12.1 Deg Inclination) (Photo: G. Jorgenson #3611)

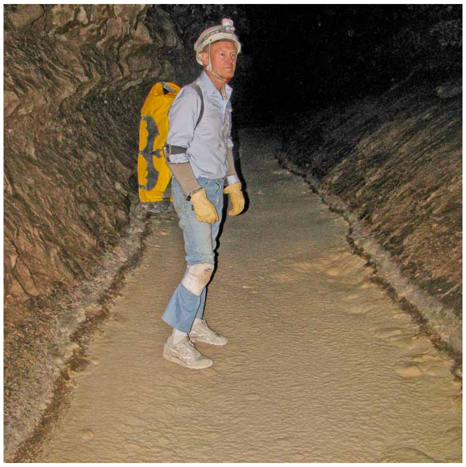
This site, along with SRS318, was added in October 2019 at a good location for future Manning equation discharge flow measurements. A photogrammetry cross-section has been obtained, and a future "mini-Palmer Pole" measurement of the slope will be made on a future trip. Both sites should show similar characteristics of the Snowy River flow, and the charts in this report are very similar for both sites.

(032) (10-15-19 to 9-20-20)



The obvious difference between this SRS227 site and the previous SRS318 site is the depth of the water. The apparent snow-melt influenced flow caused a sharp peak in the water depth around the middle of March 2020. The upstream SRS318 site peaked around 75 cm, while this Mt. Airy site only peaked around 28 cm.

SRS181, Underground Railroad:

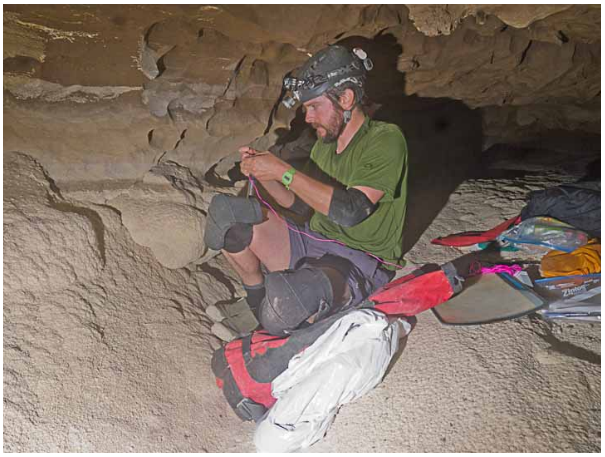


This section of Snowy River was first reached in May, 2008. The "waterline bathtub rings" on both side of the passage provided the idea of an "Underground Railroad". Ten years later Ron Lipinski, shown here in the 2008 picture, suggested that this location would be a better spot than Bobbitt's Blvd. for discharge measurements in his 2018 paper "*Recommended Locations for Water Level Data Loggers to Infer the Time-Dependent Snowy River Discharge North of Floating Islands".* Although we do not presently have a data logger at this location, the Hydrology Team plans to place a logger at this site 10 stations upstream from the 2013 placement of the Bobbitt's Blvd. site. (Photo: R. Harris #3929)

In 2012, as the Hydrology Team was choosing the original choice of the 10 best locations to place loggers in Snowy River, it was strongly suggested that the Two-Way Hill breakdown area was thought to be a possible sump that could trap upstream Snowy River explorers if a "100-year" flood occurred again as happened in July 2008 when the Gulf Hurricane Dolly came ashore and the extra rainfall in Ruidoso caused significant flooding of surface streams. (Lindsley "*Rainfall in the Fort Stanton – Snowy River Cave Area", 2014.*) The Two-Way Hill breakdown area required three loggers to best understand this blockage mechanism for Snowy River. These three loggers were placed at SRS171, SRS141 and SRS125.

Currently the team is considering moving the SRS171 logger to the SRS181 Underground Railroad location where the site is better suited for more accurate discharge measurements.

SRS171, Bobbitt's Blvd:

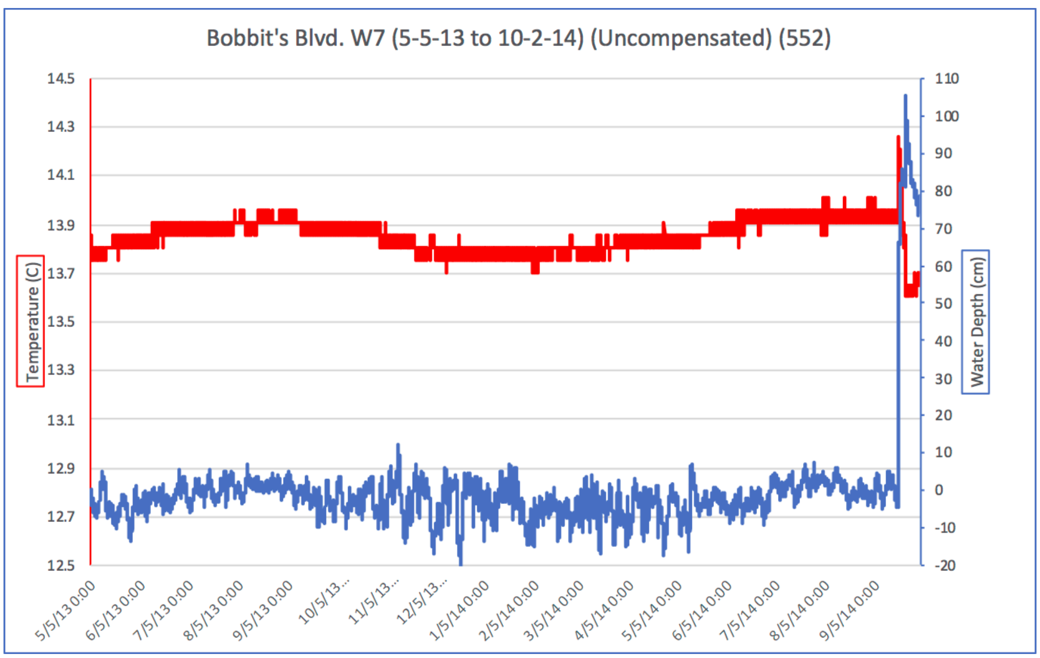


This site was positioned closely to Mud Lizard to provide timing and water depth data for a Snowy River flow suspected of filling the low areas in the passage upstream from Return to Snowy River breakdown room. The newly discovered Black Rock Bypass re-joins Snowy River just upstream from this site. Based on recent analysis, it has been suggested that this site be moved 10 stations upstream to SRS181 (Underground Railroad) where the passage is more uniform. (Photo: S. Thomas #0664)

W7 logger installed 5-3-13 (photo xx & IMG_3929), stage & temperature vs time from 2013-2014; W21 logger installed 9-8-18; W31 logger installed 10-4-19.

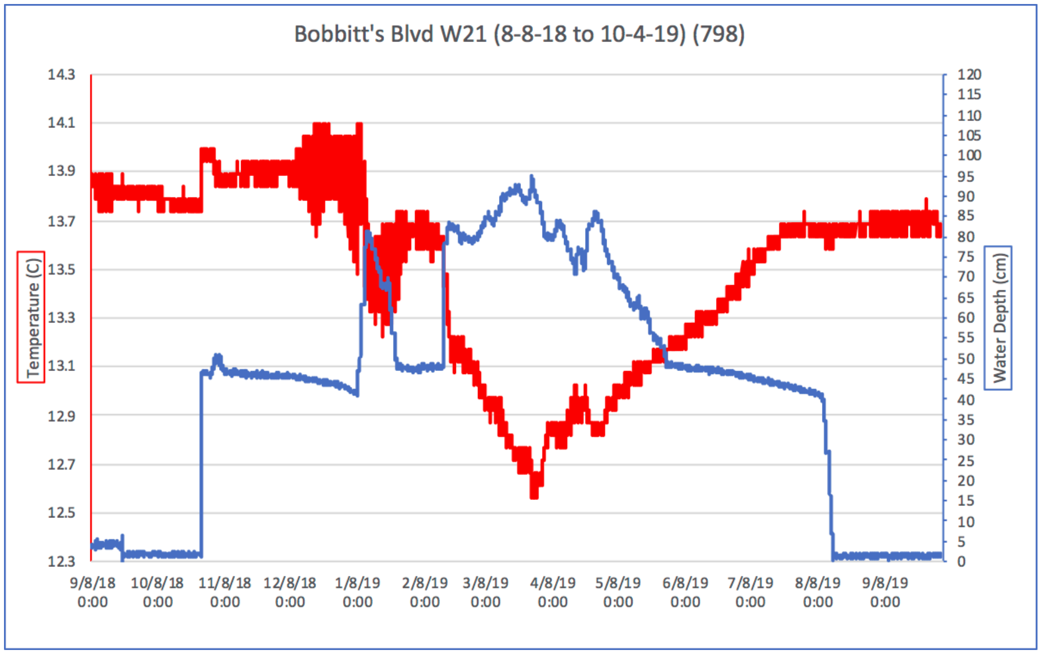
(552) (5-5-13 to 10-2-14)

The water depth with the major flow starting in the fall of 2014 peaked at about 110 cm (3.6 feet). The unexpected 4-year Snowy River flow created a gap in our measurements when the memory filled before the teams were able to return upstream and exchange the loggers. (Fortunately, during this time an internal In-Situ ROM memory update allowed double the number of data records, and changing the sample time from 15 minutes to 30 minutes now allows just over 7 years of continuous data before the memory is filled for data loggers replacing these deep Snowy locations.)



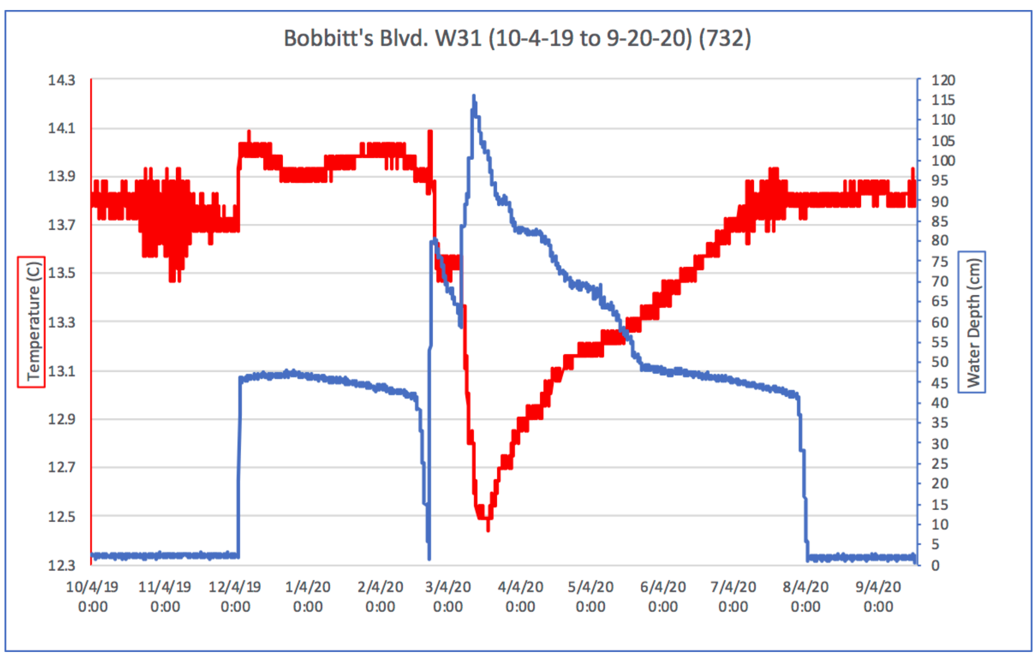
(978) (8-8-18 to 10-4-19)

During the shorter winter 2018-19 flow the water depth was slightly less at about 90 cm (3 feet).



(732) (10-4-19 to 9-20-20)

For 2020, the distinctive dip near the end of February is quite sharp, and now the temperature trace during the initial three months of flow has also changed somewhat. This logger is just upstream from the Mud Lizard sump, and this downstream blockage appears to be increasing the depth at Bobbitt's Blvd. to 114 cm (45 inches). Fortunately for team safety during a Snowy River flow, this is also the location of the south end of the newly discovered Black Rock Bypass, reached via an upper ledge just before the Bobbitt's Blvd. data logger.



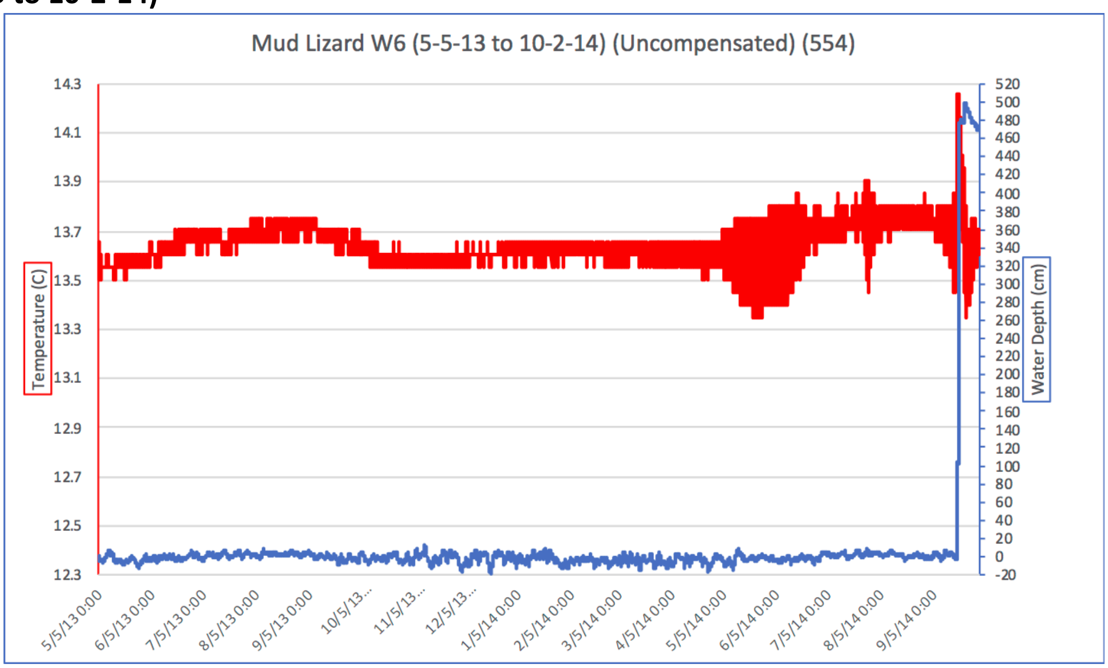
SRS141, Mud Lizard:

The original logger placed at this location in 2013 was retrieved years later, and showed a 10-12-foot-deep sump for a long period of time. (Recently the Black Rock Bypass was found to significantly minimize the danger of entrapment to deep Snowy River South teams during future flows.) The purpose of this logger was to measure the flow timing and water depth at the now known sump. (Photo: R. Harris #6166)

(Photo:) W6 logger installed 5-3-13, stage and temperature 2013-2014; W20 logger installed 9-8-18; W30 logger installed 10-4-19.

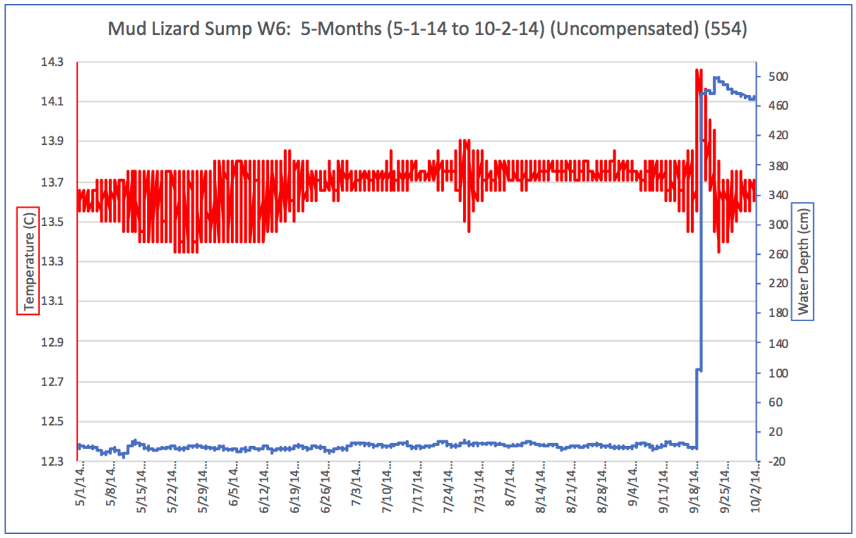
The photo shows Wayne Walker installing a “floater” which was simply a small floating plastic cube tied with thread to a stainless washer buried in the mud. These devices were placed in several areas, usually above the white Snowy River Formation Top (SRFT), and were intended to verify the flow direction of the water if it rose above the SRFT elevation. If there was a flow in this area, we assumed that the floating piece of foam would unwind the and float to the end of the foot-long thread. (Photo: R. Harris #0612)

(554) (5-5-13 to 10-2-14)



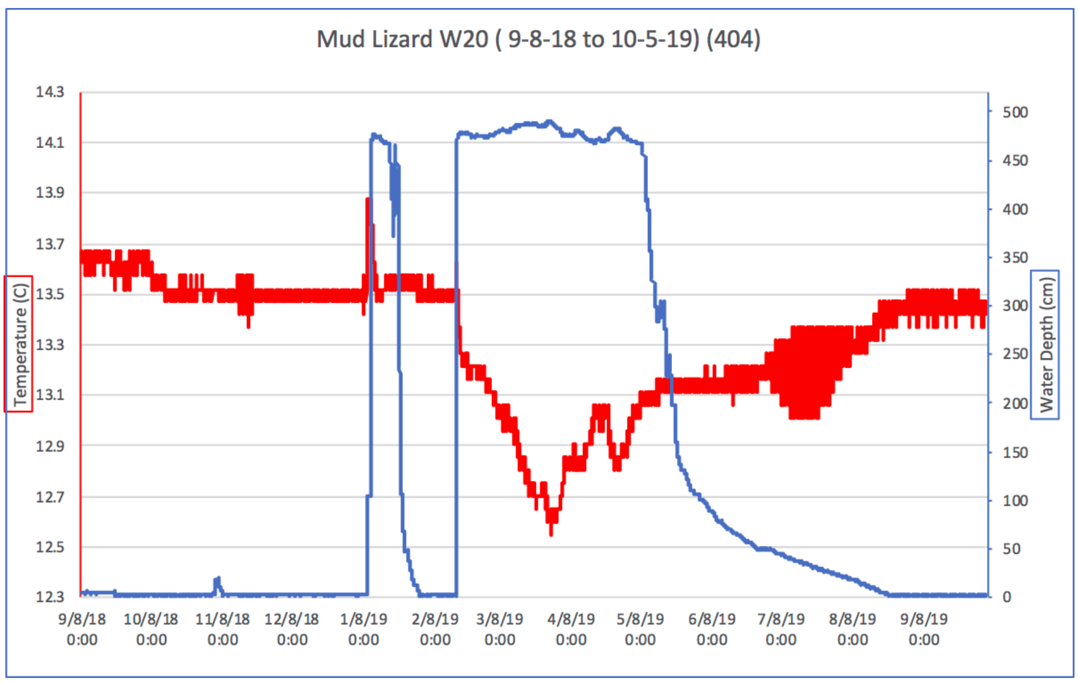
The chart on the right is typical of most of the Snowy River loggers installed in May 2013, just before what was to become a 4-year flow. As suspected, the lower level Mud Lizard crawl, which had a ceiling caked with mud from some previous flows, was most certainly a sump with the water level reaching perhaps 10 feet up into the clay fills above the Mud Lizard ceiling. The expanded 5-month chart is shown next.

The water depth with the major flow of 2014 reached about 500 cm (16.4 feet). The temperature chart may suggest some smaller flows, prior to the main peak in October 2014. Could these temperature variations be the result of upstream hydrologic pressure on an underlying aquifer that could have seeped up through the porous calcite floor but did not actually flow down the stream channel until the sudden peak in the September time period? The expanded 5-month chart on the right shows this interesting temperature variation.



(404) (9-8-18 to 10-5-19)

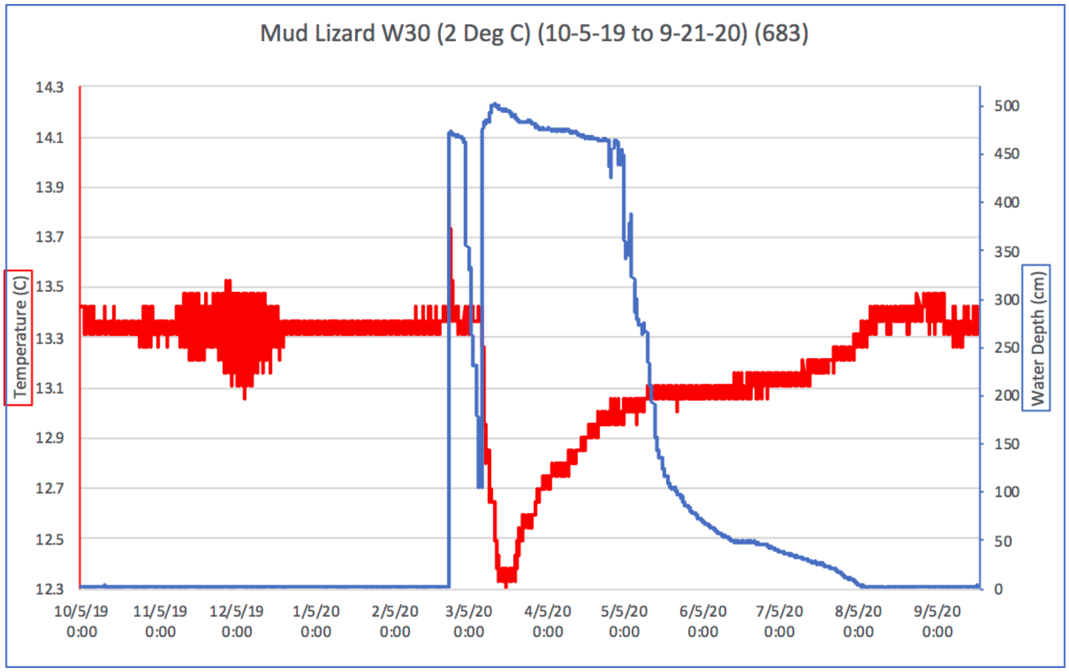
It would be another 4 years before we were able to replace the Mud Lizard logger with a newly programmed unit. During the winter 2018-19 flow the water depth was slightly less at about 480 cm (15.7 feet). The water depth in the Mud Lizard sump increased rapidly in January, dropped to zero for a short time in February, then again rose suddenly to 470 cm. In fact during November there was a tiny change in the water level associated with some temperature variation. Note that the overall flow experienced a short pulse of warmer water for about a month, then quickly stopped for over a month. The second pulse of water was colder and lasted for several months, followed by a much longer "draw down" which also lasted several months. This is a complex area hydrologically, with a large breakdown (Two-Way Hill) blocking the open route for formation of the Snowy River calcite surface.



The author believes this constriction (or "filter") causes a flow limiting situation that impacts the downstream flows of Snowy River.

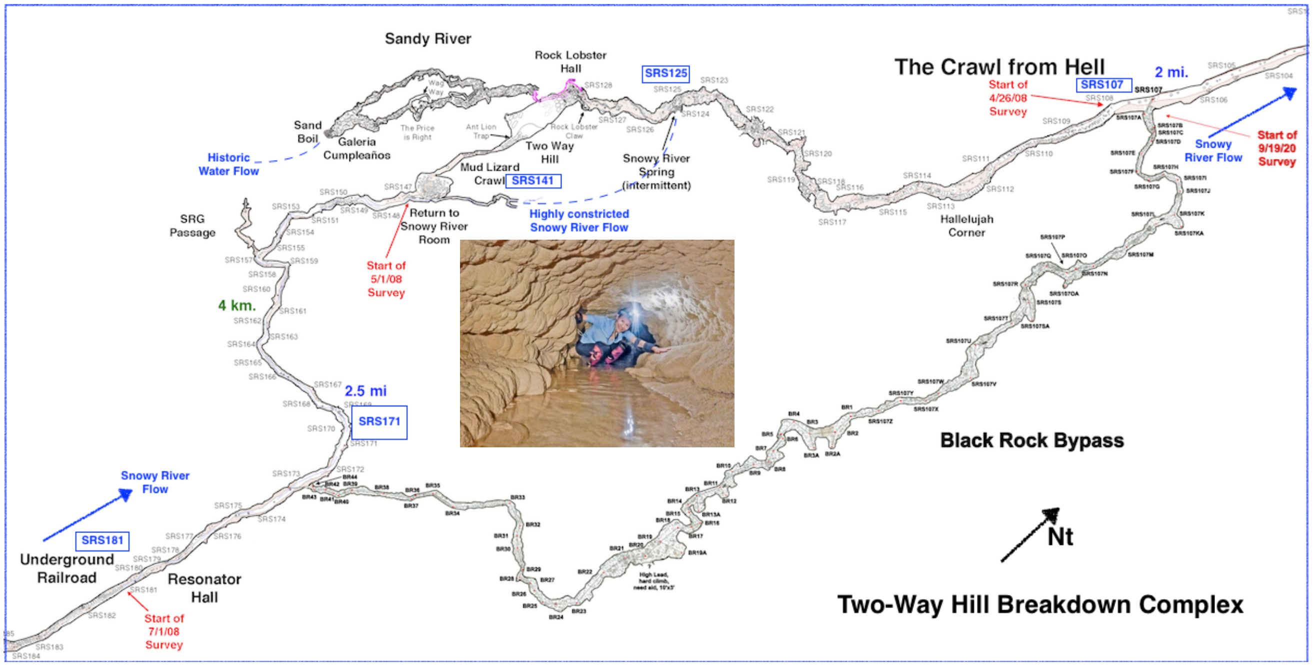
(683) (10-15-19 to 9-21-20)

Apparently the upstream 2019-2020 flow between December and March did not supply any water to the Mud Lizard site even though the water level at that time was about 46 cm (18 inches) deep at Bobbitt's Blvd. Note that the temperature curve at that time remained flat, also confirming little to no water appeared at Mud Lizard. However, the second spike in the water flow did fill up Mud Lizard for a few days and then appeared to drain down. Note that the temperature first increased about 0.3 degrees C before dropping back down to the previous level. The third spike of water from upstream also quickly filled the Mud Lizard sump in the first part of March and the temperature plot essentially followed the upstream characteristics. Note that during the drain-down in May, there were several sharp variations in the water level as the sump drained. A close examination of the raw data shows the peak depth above the Mud Lizard logger was about 495 cm (16.2 feet) on March 20, 2020.



It was only in the fall of 2020 that we learned new information about the Two-Way Hill area when an S&L team discovered the Black Rock Bypass. During one of the S&L trips to the area in 2019 the team found that the previous 4-year flow had washed at least one, "magic carpet" downstream.

A "magic carpet" is an 18-inch-wide, 6 mil thick poly strip, positioned to allow a team to cross over a mud bank to bypass a low crawl along the calcite covered Snowy River floor, without changing out of clean footwear. The 2019 and 2020 S&L teams performed a maintenance task that pinned the poly strips to the clay floor underneath. It was suggested that a magic carpet could have washed into the tiny calcite covered crawl passage that exits from the lower Return to Snowy River Room area. It is believed that water from a Snowy River flow connects to the downstream Snowy River Spring. In October 2019 another team was unable to locate any washed-in poly strips as far as was passible. The area map shown on the next page includes Kevin Manley's photo (#4834) showing Cynthia LaCoe-Maniaci in the calcite-covered "constricted flow route" during the trip to check the passage for washed-in poly.



The map above illustrates the hydrologic complexity of the Two-Way Hill area. This is probably the second most extreme examples of a large breakdown area that impacts the normal flow of Snowy River downstream from this area. (As we learn more about the hydrology of the Rough Country area we may find that the Rough Country breakdown is also a significant blockage to the “easy flow” of Snowy River. There are currently four logger sites shown on the map above with their station numbers located in blue-edged rectangular boxes near each site. (The proposed SRS181 logger site is on the far left, 10 stations upstream.) The newly discovered Black Rock Bypass passage is to the East of the current water flow. The Two-Way Hill sump area is in the Mud Lizard Crawl, which has a lower elevation than the average elevation of the flowing Snowy River. The data loggers in this report shows the flooding characteristics of this sump area.

There is also a ancient water flow evidenced by the “Sand Boil”, a sand and small gravel slope formed by the hydraulic action of flowing water, and includes some small charcoal bits (discovered by Donald Davis) that the BLM has dated. Did this Sand Boil water come from the historic Snowy River passage, or could it have come from the recently discovered upper level Capitan Caverns Passage? There is no visible evidence that the Sand Boil water caused any “Snowy River calcite” formation, so it is believed by some to pre-date the deposition of calcite along what is now known as Snowy River. (Photos: P. Lindsley #8455 & #8390)

SRS125, Snowy River Spring:

The original explorers heading south in the Snowy River Passage were relieved when the Crawl From Hell opened up again into larger passage. But then they were immediately blocked by the Two-Way Hill breakdown, and the source of water seemed to come from a small hole which they named Snowy River Spring. (Photo: R. Harris #6160) A changing area was made using the polyethylene “magic carpets” where they could change out of clean equipment and prepare to find their way through an extremely muddy area which even covered some of the trail of white calcite they had followed for miles. We now know that the sump area has a lower elevation than the adjacent calcite-covered floor, but the breakdown constriction causes a sump that completely blocks the passage during heavy and long Snowy River flows. With the Mud Lizard logger measuring water depths up to 15 feet, we believe that this water tends to leach the mud out of the large breakdown pile that caused this restriction in the first place. The original water data logger placed at this site during the 4-year flow became covered with calcite and had to be forcefully removed by the team maintaining the loggers. (Photo: J. Lyles #2660) Fortunately, the Black Rock Bypass, discovered in 2020, provides a safety exit in the case where an S&L team might become stranded upstream during a sudden, large flow.

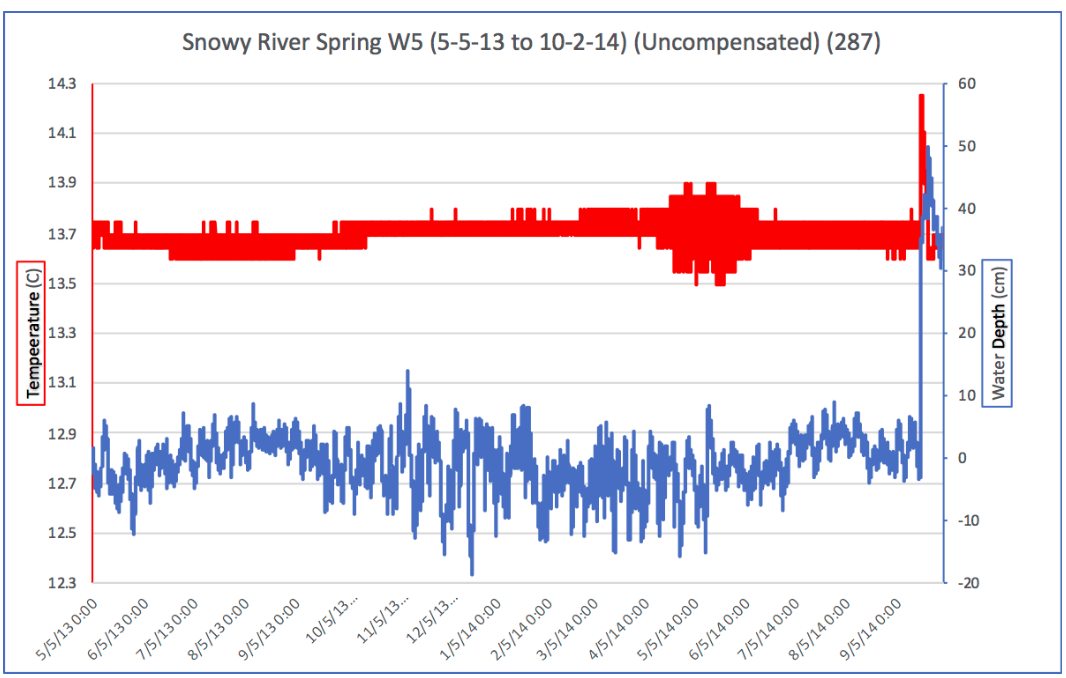
(287) (5-5-13 to 10-2-14)

W5 logger installed 5-3-13

W19 logger installed 9-8-18

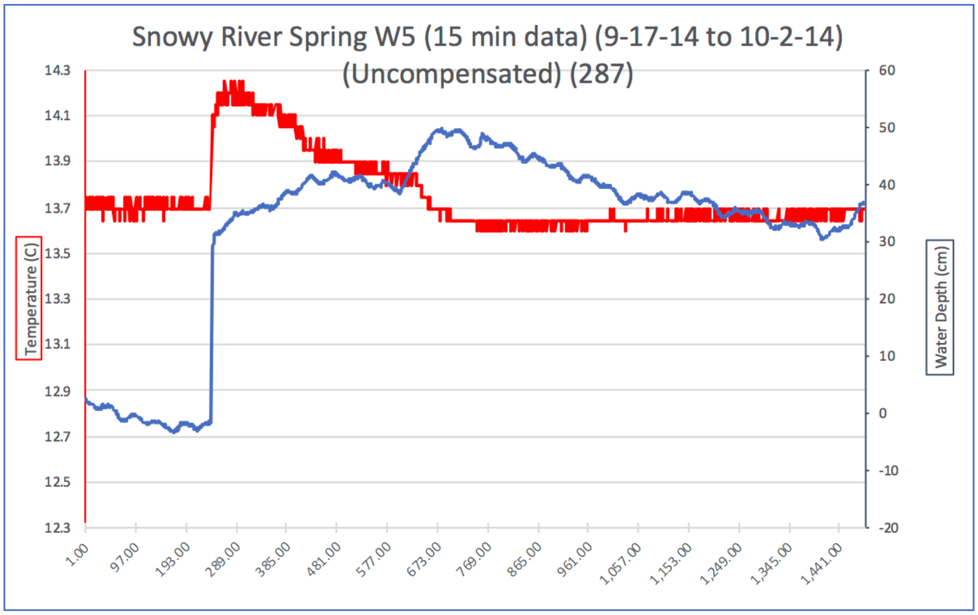
W29 logger installed 10-4-19

The water depth with the major flow of 2014 reached about 50 cm (1.6 feet). The temperature chart also suggests some much smaller prior flows.



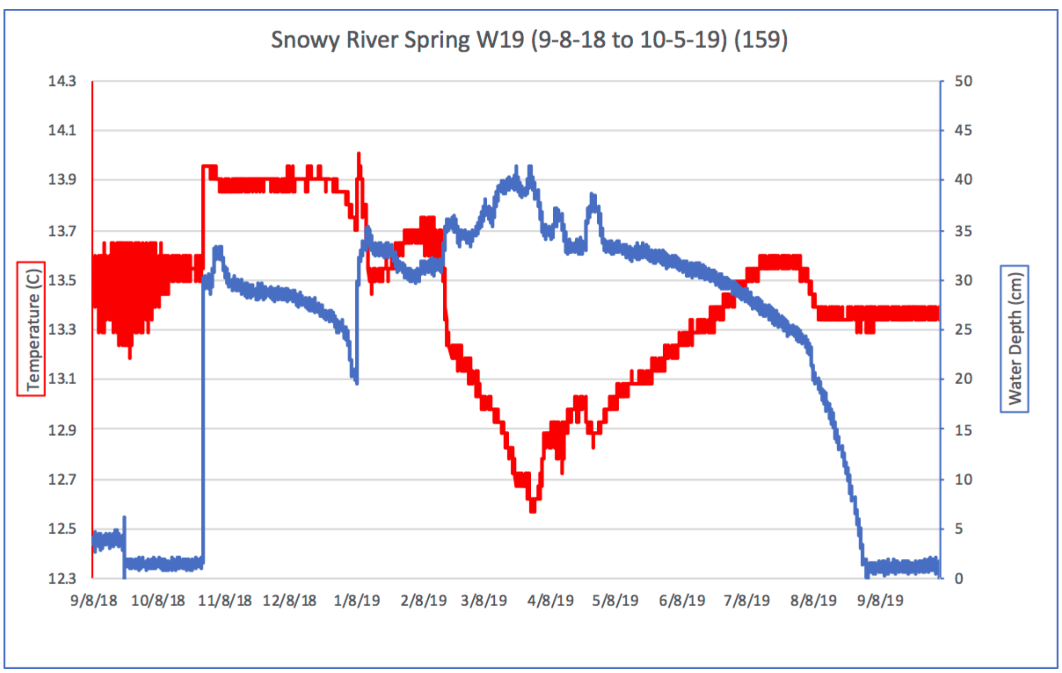
(287) (9-17-14 to 10-2-14)

This second chart of the 2014 flow is expanded to a two-week period and shows a similar correlation of the temperature change noted previously when the surface waters reached the Snowy River Spring site. (The x-axis tick marks are 24 hours apart, and this format was used to show better resolution.)

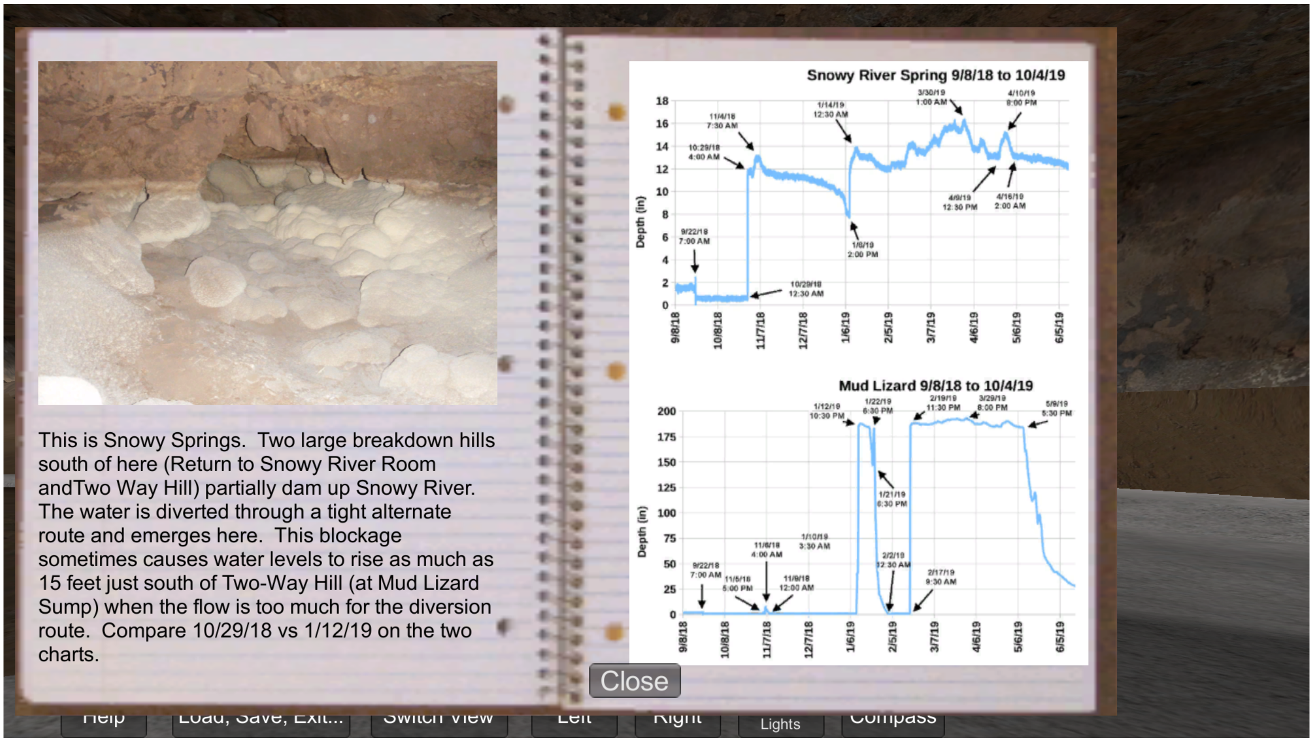


(159) (9-8-18 to 10-5-19)

Replacing the 2013 data loggers with new units extracted new timing information for the 2018-2019 Snowy River flow period at Snowy river Spring. With several years of flows lasting into summer, travel planning for extended Snowy River survey trips by the S & L teams became very challenging. Tests done at the Turtle Junction site determined that the soft calcite would take at least a couple of months to become strong enough for careful teams to traverse the soft floor without visible damage. At this point it also became obvious that in addition to the calculation of the start of a flow at Turtle Junction, it was even more important for trip planning to be able to determine the outflow timing of the pools along sections of Snowy River. As the readers look at the collection of charts in this report, it is hoped that ideas will be developed that can enhance the calculation of Snowy River drying following a flow of various time periods.



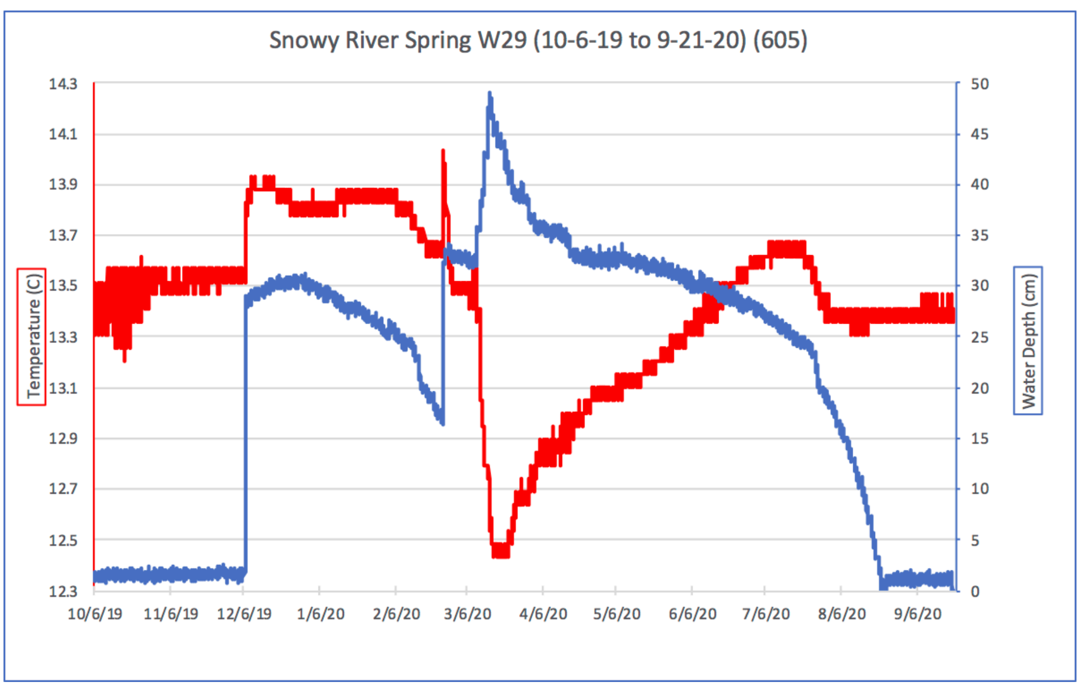
Steve Peerman has started this timing analysis process in several expedition reports by expanding his Turtle Junction timing study. The 2018-2019 Snowy River flow offered the new opportunity of a greater number of data loggers being retrieved from upstream Snowy River that seemed to show various water depth peaks that could be correlated too changes in the flow rate. Some of this



analysis has now been incorporated into the Caver Quest simulation software as seen in the note above. This shows Steve's detail analysis of the timing of the SR Spring flows compared to the Mud Lizard flow peaks.

(605) (10-6-19 to 9-21-20)

The logger at Snowy River Spring explains what happened to the water flow before Mud Lizard filled on the 2nd and 3rd "spike". The initial December to February flow apparently "leaked around" the Two-Way Hill blockage and started flowing out of Snowy River Spring

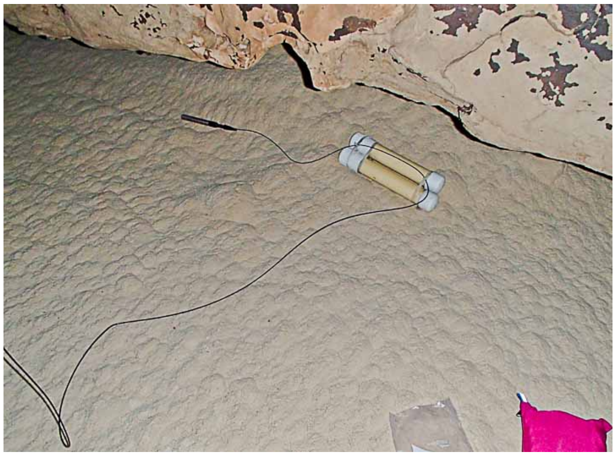


before the water appeared in Mud Lizard. Some of the same temperature characteristics can be seen in the Snowy River Spring water. The 2nd spike was warmer and the 3rd spike just days later was colder. Obviously the third water flow pulse was due to snowmelt or at least cold winter conditions on the surface, and it was this volume of water that allowed Snowy river to keep flowing until early August, at which time Snowy River apparently started to "drain".

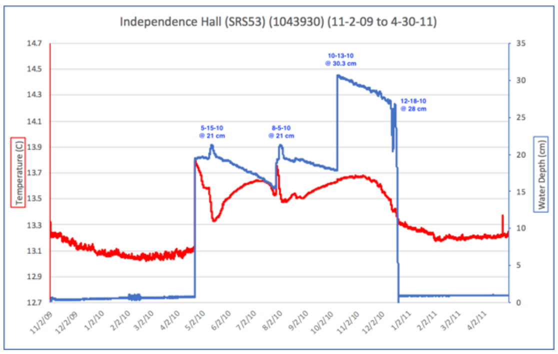
SRS107, Black Rock Bypass:

A new station was set in 2020 near this location first recognized for the strong airflow as the then virgin Snowy River Passage lowered through the crawl that was named the "Crawl From Hell". (Photo: J. Lyles #3877) When a 2020 S&L team checked a side passage lead they discovered a bypass route to Snowy River that re-connected 64 stations upstream through a low lead near Bobbitt's Blvd. By-passing the SRS125 Snowy River Spring site, where it had been planned to install a Baro data logger to improve the calibration of the Mud Lizard Sump, the team instead installed the planned Baro near SRS107 along with an "extra" water logger as a temporary site until it could be decided which route would become the "trade-route" for future teams. If Snowy River access is available in 2021, these two sites may be consolidated to enhance efficient data logger maintenance. However, in the recent October 2020 Expedition Report Garrett and his "B" Team discussed several hydrology related features of both Snowy River and the Black Rock Bypass which indicated the possibility of flows in this cut-around passage, possibly when the flow backs up at the Mud Lizard Sump.

SRS53, Independence Hall:

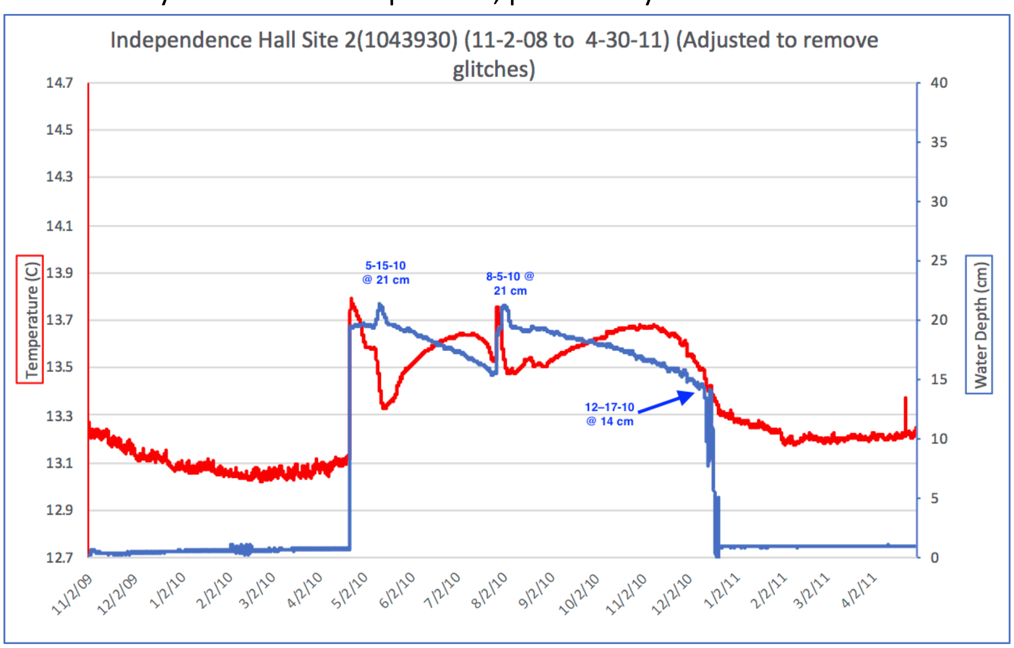


This site is a typical SR passage downstream from a small breakdown blockage area at Independence Hall. (Photo: W. Walker #0099) Unlike Two-Way Hill, the breakdown in this area just covers the floor, and is not a significant blockage to a Snowy River flow. This site was the second BLM site just upstream from Turtle Junction. BLM Solinst loggers have been installed in this location since 11-2-09. The 2nd photo (Lindsley #9997) shows Knutt Peterson downloading the Solinst Logger pair with a handheld unit.



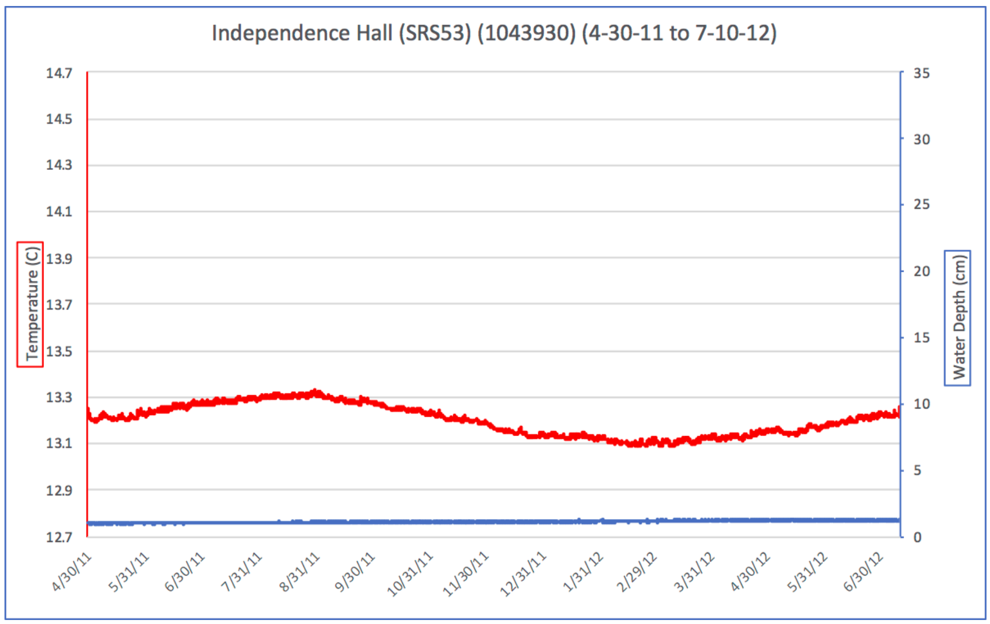
Although this technique has worked acceptably for sites near Turtle Junction, the In-Situ loggers have been more appropriate for the sites far away from Turtle Junction. Unfortunately, due to a defective cable, several of the Solinst loggers had several glitches in the data, and wasted a lot of processing time, such as the example on the left. After processing most of the other loggers, when I came back to the small chart just above, I realized there was a hidden glitch instead of a unique 3rd spike of SR.

The BLM Solinst loggers have still yielded some unique data, particularly at times before the first In-Situ deployment in 2013. As seen on the revised chart on the right, the Solinst charts display a 7-digit serial number instead of the (xxx) 3-digit number assigned by the In-Situ download software. As in this case, when the Solinst baro data is available, the Solinst software offers a compensated logger file that does a good job in smoothing the water depth information. But



sometimes you may still have to do it by hand. The reader will recognize some characteristics relating the temperature of the water flow at the time of the increases of water depth. When properly corrected to "fix" obvious glitches, the 3rd spike for this site went away after it was realized that the temperature did NOT change during the "3rd spike". This BLM Solinst logger (1043930) was documented both at Turtle Junction and also "Site 2", which we believe was at SRS53. This data was not charted until recently in 2020, with parts of the water depth data adjusted at the glitch seen during October 2010 in the Solinst data set. Note the apparent temperature spike near the end of the plot that may indicate another small water flow not seen on the other plots for this flow event which were terminated prior to this last temperature spike. (For this reason, it is now assumed the location was probably at SRS53. The above chart can also be compared to the FSCSP Schlumberger data shown in a chart in the Turtle Junction section, which was verified by a staff gauge measurement during the early flow period.

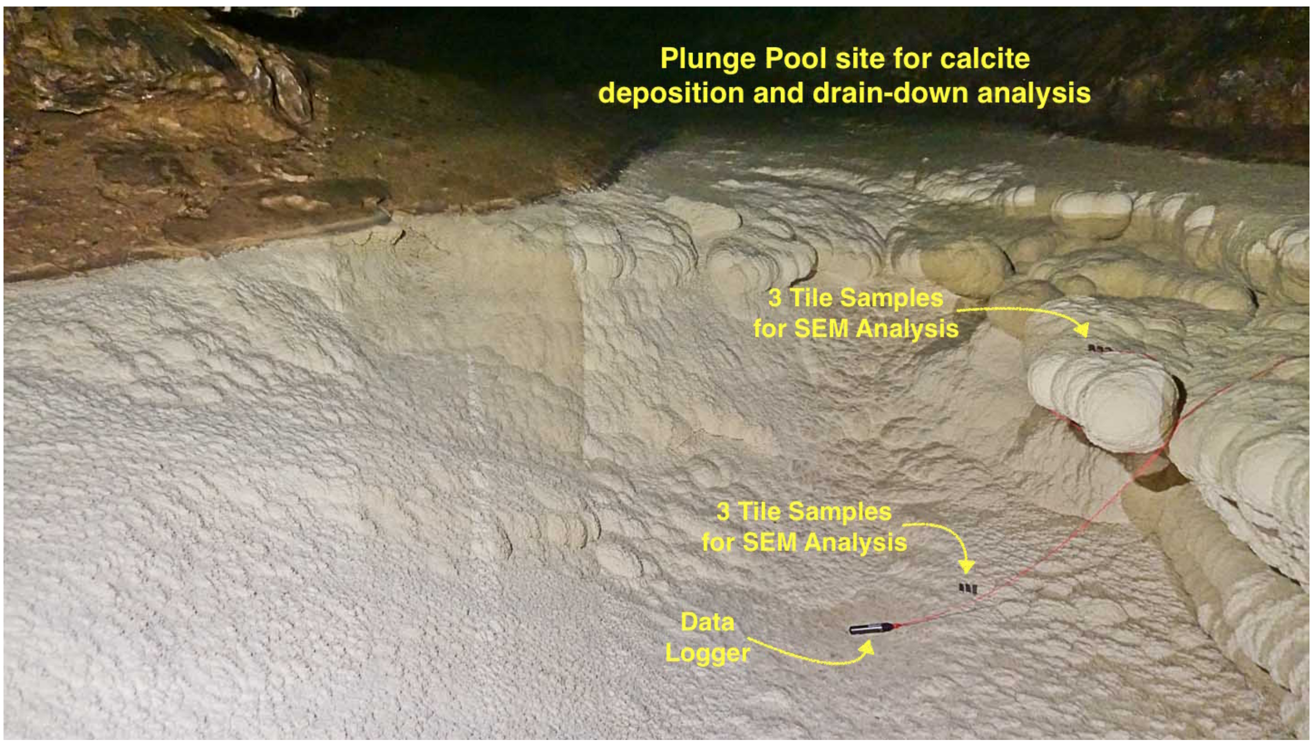
The chart on the right shows a plot that immediately follows the plot above. Together they cover the November 2, 2009 to July 10, 2012 time period. When additional data sets become available we hope to add more charts at the SRS53 site location.



SRS31, Plunge Pool:

Looking upstream, this 3-foot deep pool just upstream from Turtle Junction (TJ) cam provide limited access during a Snowy River flow. Timing information between this pool and the primary logger site just downstream is part of a drain-down study. The second photo (Photos: Lindsley #0018 & #0988), about 30 feet upstream from the Plunge Pool on 10-24-2015, is looking downstream towards Turtle Junction during a “normal flow”.

The Plunge Pool is one of two relatively large pools about 3-4 feet deep on the North end of Snowy River, with the other being the Swimming Pool located at SRN53, about half way to the final Crystal Spring and associated Crystal Lake which feeds the sump that connects to Government Spring. Both the fill rate and the depletion rate of the Plunge Pool relative to nearby Turtle Junction offer additional analysis opportunities not available elsewhere. The volume of the pool can be determined with LIDAR measurements, and precision Palmer Pole measurements can yield the slope between these two data logger sites. Dr. Mike Spilde has several tile samples at both locations and has already obtained calcite deposition rates at Turtle Junction. When we noticed that the nylon cord attached to the deeper Plunge Pool data logger had a variable calcite coating at different water depths, additional tiles were positioned at the Plunge Pool. The photo below shows the relative locations of the tiles and the data logger.



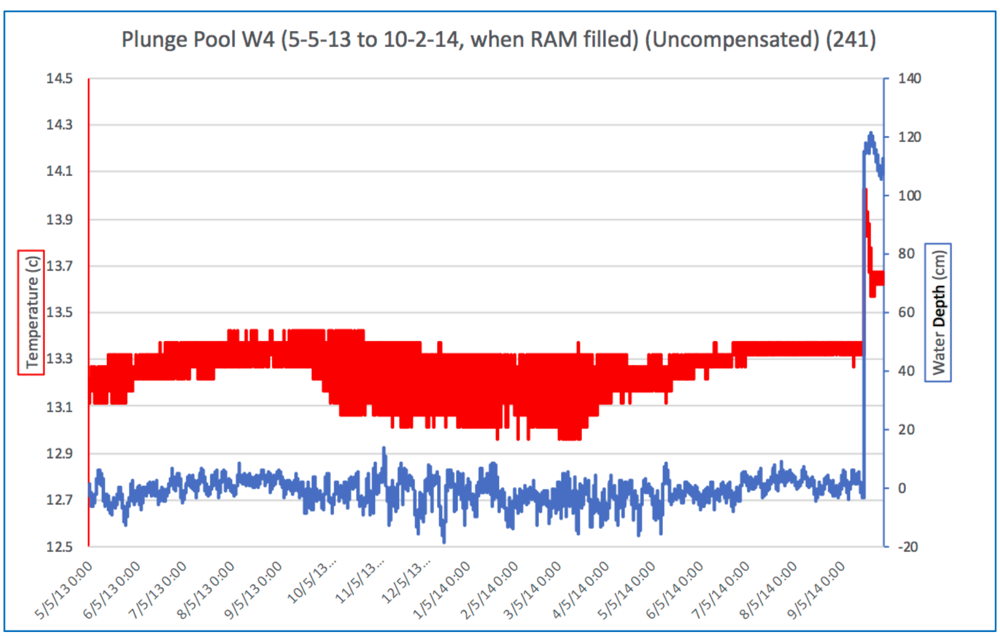
Stage and temperature vs time data is available from 2013. Some of the loggers installed at this site include: W4 logger installed 4-30-13; W11 installed 10-24-15; W13 installed 9-10-16; W15 logger installed 5-6-18; W7 installed 10-12-19. In addition, a pair of In-Situ water loggers with event-programming were installed in 2019 and tested the performance of the loggers set to record at closer time intervals when there was a sudden change in pressure. On two occasions following a Snowy River flow a difference in the drain-down rate between the Plunge Pool and a much shallower pool at Turtle Junction was noted. One time the Plunge Pool was dry but the TJ pool had water; then at another time the opposite was true. This suggests that the saturation below the calcite floor is different for a 4-year flow versus a 1-year flow. By deploying a pair of event-level programmed loggers at these two locations we may be able to gather additional information in the future. (Photo: Lindsley #4561)

The nylon cord attached to the 3-foot deep logger was retrieved for SEM analysis of calcite growth versus depth. (The folding engineer's ruler shown in the photo was used to mark the nylon cord prior to packing and removal from the cave.) The shape of the drain-down curve of the Plunge Pool seems to be similar to other logger sites, but we plan additional data collection to generate a larger database of similar Snowy River characteristics. (Photo: Lindsley #2139)

The smaller photo (W, Walker #0119) to the right, shows "ripples" in the calcite at the outflow of the Plunge Pool. This characteristic is likely formed on top of "sand ripples" which were formed prior the layer of white calcite we now call Snowy River. The reason a logger was installed in the bottom of the pool was to better understand both the filling and drain-down data as compared to the straight stretch at Turtle Junction, just eight stations downstream. As one of the larger pools in Snowy river, it takes a while to fill the pool until the overflow point is reached, just beyond the floor ripples. Then, once the flow stops upstream the pool levels off, the pool slowly drains. The calcite floor is several centimeters thick in this area (Land, 2010) and the data will support future analysis of likely water flow under the apparent calcite floor of Snowy River. Drain-down at various sites is covered more extensively in Appendix 8.

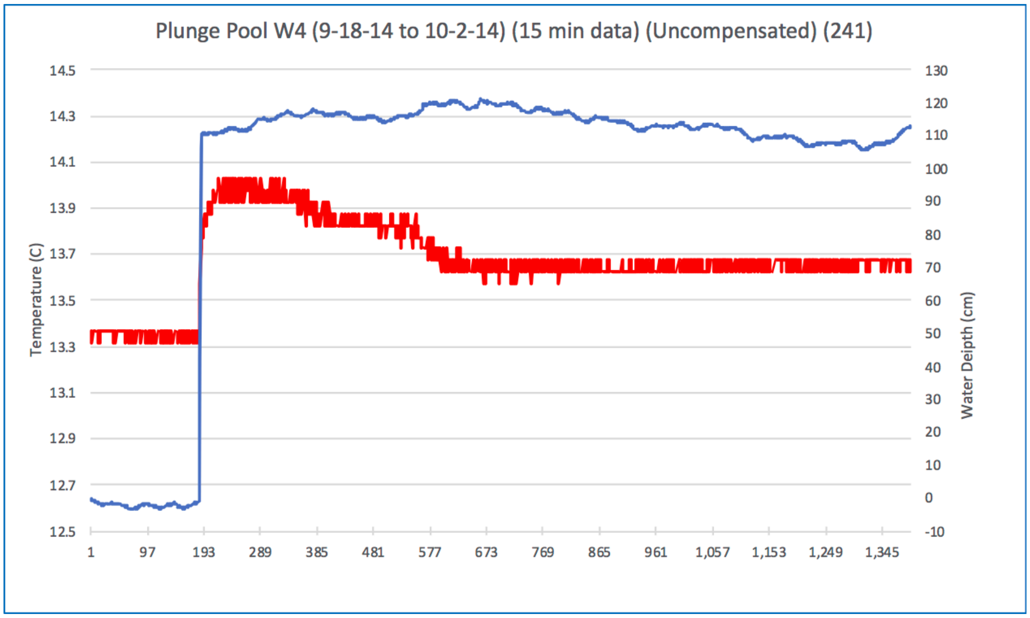
(241) (5-5-13 to 10-2-14)

This 17-month plot was the first record of the Plunge Pool, deployed in 2013 just upstream from Turtle Junction. Typical of most of the other 2013 deployed loggers, the chart shows the start of the 4-year flow of Snowy River.



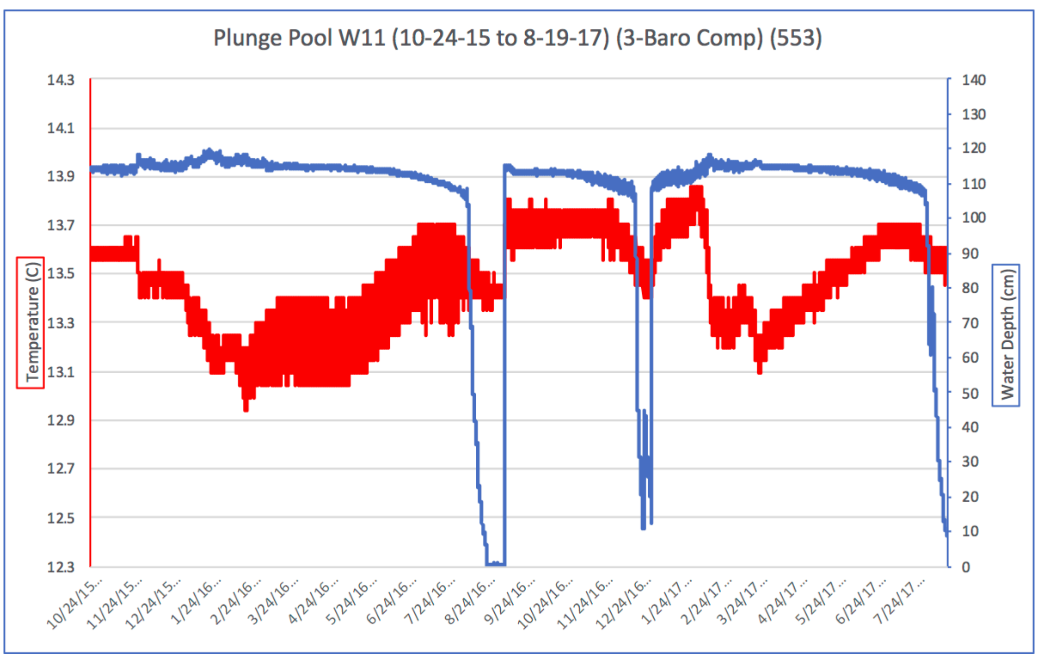
(241) (9-18-14 to 10-2-14)

This 2-week plot shows the sharp rise of the water level, which very quickly filled the Plunge Pool. (The X-axis shows marks for every 24 hours.)



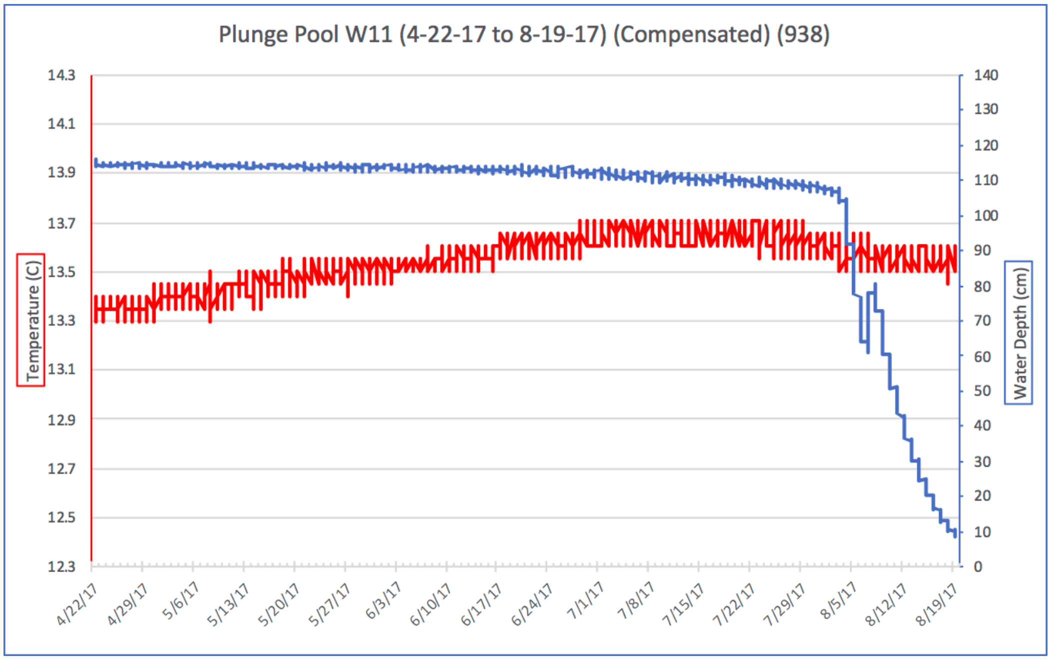
(553) (10-24-15 to 8-19-17)

This 22-month plot starts with a filled and flowing Plunge Pool. The logger was installed on the same day as the previous photo above was taken. Snowy River flow stopped two times before the final "drying" in August 2017.



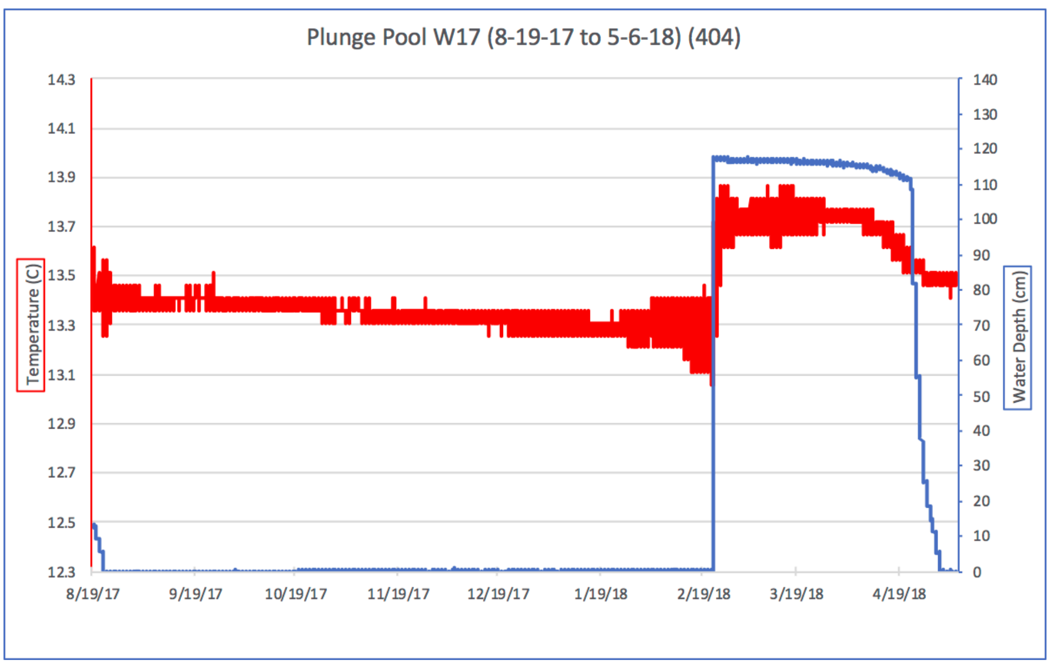
(938) (4-22-17 to 8-19-17)

This chart expands the last 4 months of the previous chart, and shows the drain-down of the Plunge Pool.



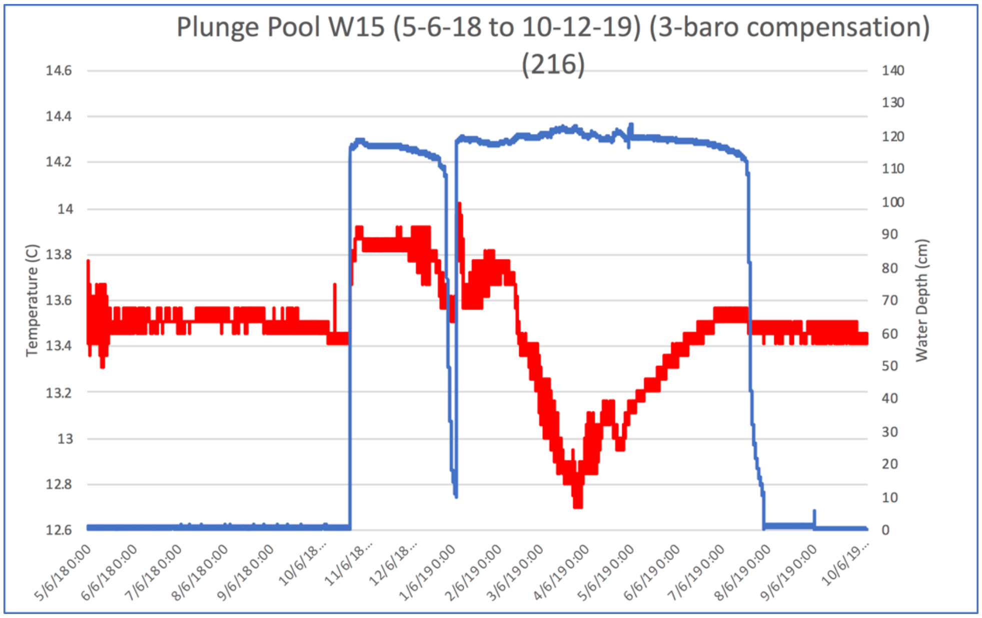
(404) (8-19-17 to 5-6-18)

This 10-month plot shows the tail end of the drain down of the previous chart, then it shows Snowy River flowing for a 3-month period in the spring of 2018.



of

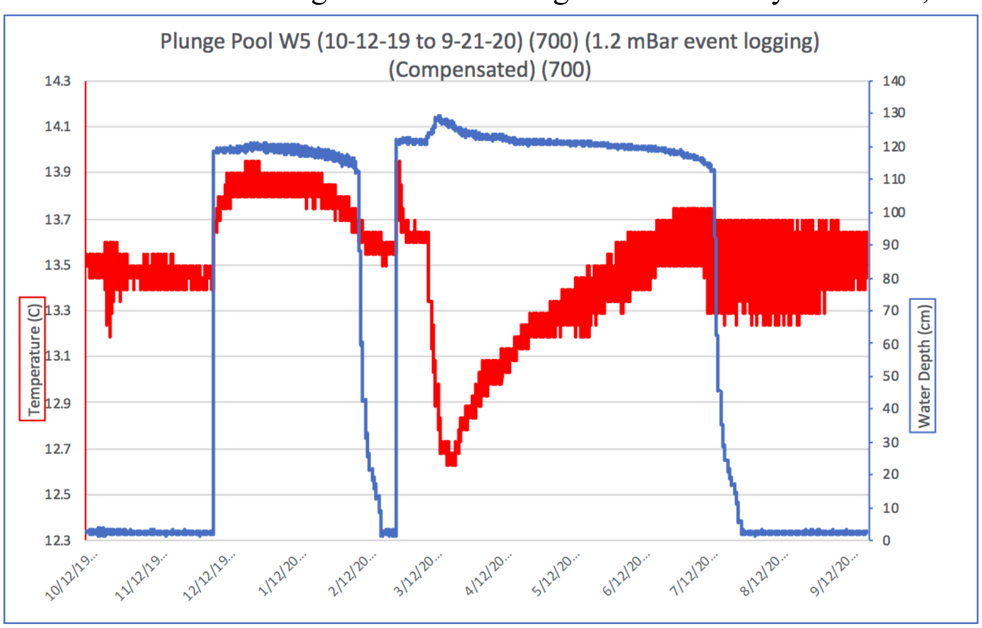
(216) (5-6-18 to 10-12-19)



This 17-Month plot was compensated with three different baro loggers that were located at Turtle Junction. When the baro units are pulled out of the cave prematurely to support a single logger at Turtle Junction, it can make proper compensation of all the other loggers in the Turtle Junction area much more time consuming and sometimes will introduce a slight "jump" or step in the plot, as seen in two places on this chart.

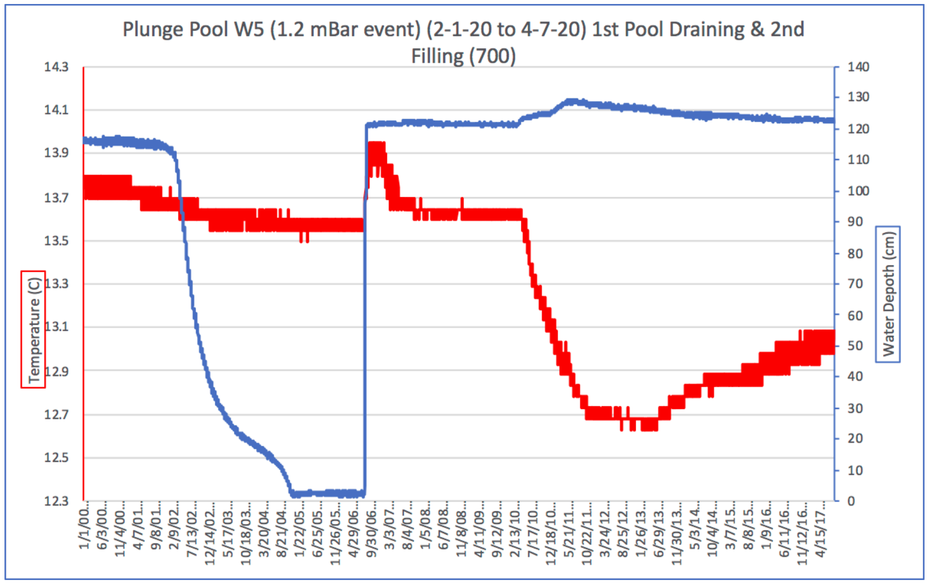
(700) (10-12-19 to 9-21-20)

In this 11-month plot the water level characteristics at the Plunge Pool seem to show similar characteristics to what was seen at the Floating Islands site during the same Snowy river flow,



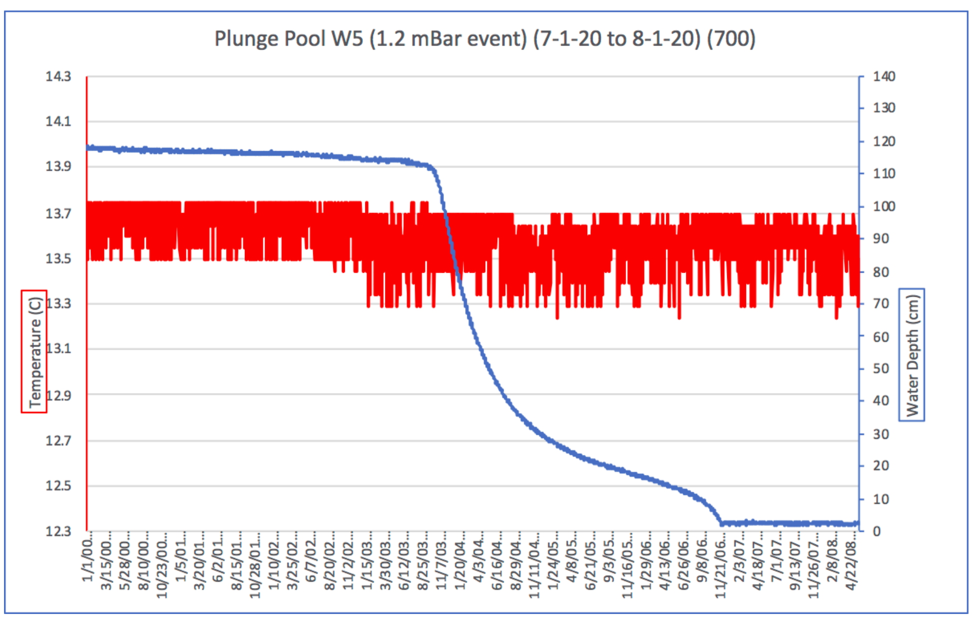
probably because both are large pools that tend to maintain the filled water level. The other charts during this flow show sharper peaks when the flow first starts, but falls off more quickly due to the slope of Snowy River at their locations. Since the Plunge Pool is just eight stations upstream from Turtle Junction, this site is useful for computation of drainage characteristics

(700) (2-1-20 to 4-7-20)



This 2-month plot shows the first drain-down and restart of the flow of the last chart on the previous page. (The notation "1.2 mBar Event" is an example of an "event level" test started in October 2019. The In-Situ loggers can be programmed to change their sample rate based on a "special event", which in this case was triggered by a 1.2 mBar pressure change (caused by a change in the water pressure). In this example data was recorded every 2 minutes instead of every 30 minutes, as long as the change in pressure was 1.2 mBar or greater.) Since we happened to have a pair of older loggers available that we did not want to deploy deeper in the cave, because their batteries may run down during a flow lasting longer than 5-6 years, these two loggers were deployed at both the Plunge Pool and Turtle Junction to see if we could generate fill-up and drain-down data with higher time precision.

(700) (7-1-20 to 8-1-20)



This 1-month chart shows similar enhanced precision of the final drain-down of the Plunge Pool.

By using this enhanced sample rate when the water level was dropping at the end of a flow, it may be possible to develop a new algorithm that can correlate this drain-down characteristic between these two sites which are less than 400 feet apart and known to have a calcite floor thickness of around 5-6 cm.

SRS23, Turtle Junction:

Turtle Junction is the main access point to Snowy River, and also provides a location available for Pygmy discharge measurements during flows. This is also the primary Baro reference location for compensation of the daily barometric pressure fluctuations for the logger stage measurements from Crystal Creek to Mt Airy, and beyond. Several times there have been multiple data loggers monitoring this Snowy River location all at the same time, so some of the duplicates are not shown in this report. (Photo on 7-2-2016: Lindsley #1803)

The initial discovery of Turtle Junction was from the Priority 7 discovery point of a dry Snowy River passage. As the first upstream side passage in Snowy River South, 23 survey stations south of the Priority 7 clay bank called the "Boat Landing", Turtle Junction was to become the destination goal of a proposed Access Shaft which was located on the side of the breakdown covered floor of the Don Sawyer Memorial Hall (DSMH) some 60 feet above. Two years later after the newly dug shaft in DSMH connected to the Mud Turtle passage, the dig team was surprised to find Snowy River was actively flowing. That was the start by the FSCSP of a long-range plan to monitor this water flow by selective placement of an array of water level data loggers that would also incorporate several BLM Solinst data loggers. (Discussions of some of this planning is discussed in Appendix 5.)

Roger Harris installs a "floater" water measuring device on the eastern bank of Snowy River at Turtle Junction. The float is tied with thread to a stainless Washer buried in the clay bank a few inches above the SRFT elevation. To date, we have not seen indications of Snowy River flows reaching more than an inch or two above the SRFT elevation. (Photo: Lindsley #8219)

At first, placing data loggers at Turtle Junction would only provide information on the arrival time and drain-down time, plus a water depth. This allowed the start of timing analysis with surface water events shortly after the first data was extracted from Turtle Junction. The addition of the BLM logger at Crystal Creek at the far north end of the cave would provide correlation with the timing and levels in Government Spring. Later, the BLM would add a conductivity data logger at Turtle

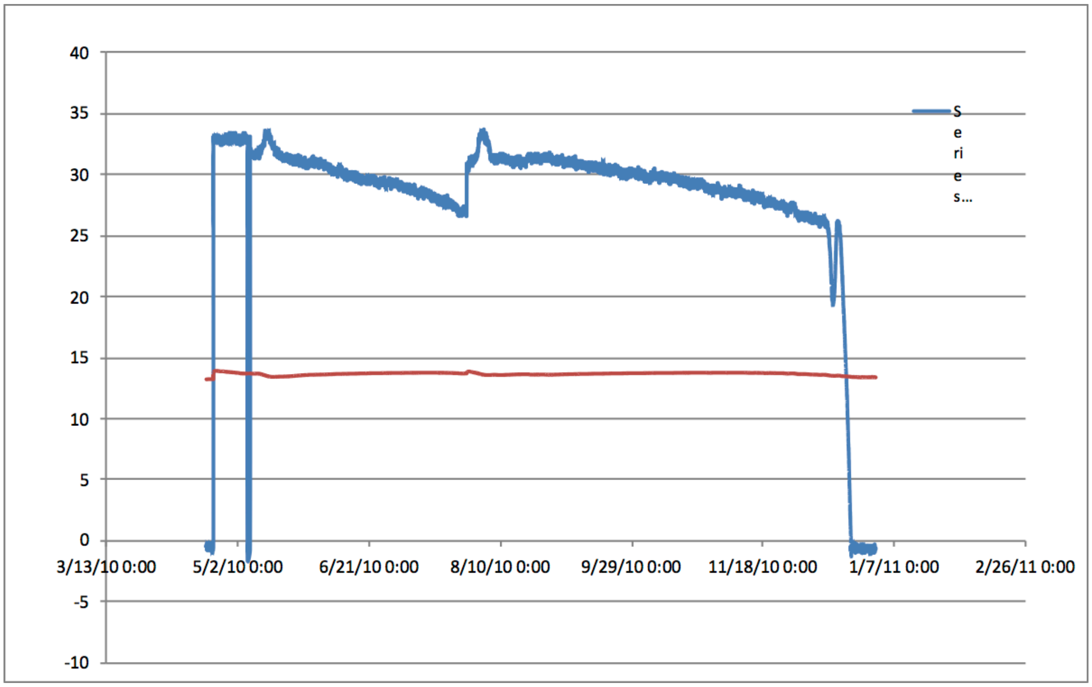
Junction, and the FSCSP began to fill in a logger array that went over 11 miles upstream from the single cave entrance. Core holes were drilled in several Snowy River locations close to Turtle Junction.

After a failed attempt to measure the Snowy River flow rate during one of the flows, our recourse at determining the flow rate was using a simple “floating stick” method. (The water at Turtle Junction was so clear and free of sediments, the borrowed ADV flow instrumentation was unable to provide a flow rate.) Finally, an “old style” Pygmy meter was acquired and an actual flow measurement was successful at two locations near Turtle Junction, providing the first measured flow data of ~ 1 cubic foot per second (1 cfs) which also correlated with a similar measurement the next day at Government Spring. Currently our latest assumption is that Snowy River provides the majority of water to Government Spring. We also now know that determining any additional flows from the Main Corridor, and possibly other unknown sources, will require more precise measurements and better analysis. The primary goal of this report is to provide a growing mountain of data from all the Fort Stanton Karst loggers that can be used in the future for more detailed analysis. (Photos: Lindsley #6514, #2047 & #2167)

The bottom photo shows one of the photogrammetry techniques to calculate the cross section at the various data logger sites we will be using in the future to correlate some of the charts in this report with an estimated flow rate, which is expected to change with different water levels measured by the loggers.

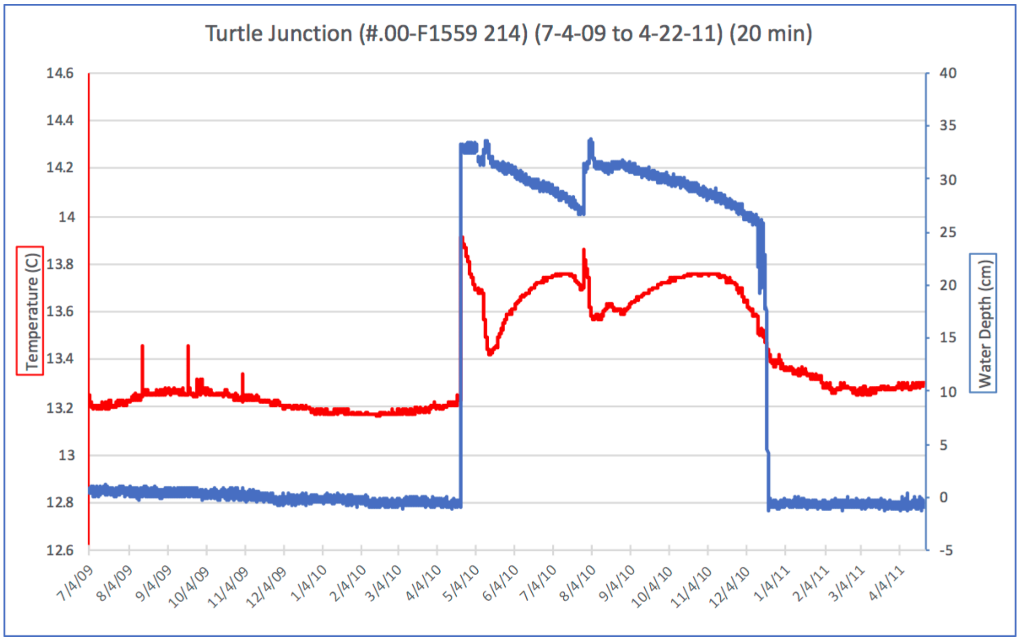
(Schlumberger) (7-4-09 to 4-22-11)

The Schlumberger logger chart below was the first "precision" full cycle data from the Turtle Junction (TJ) site after it was accessed through the newly dug access shaft in Don Sawyer Memorial Hall. It shows the characteristic "sudden water level increase" (in about an hour) when Snowy River starts flowing at Turtle Junction. (The second blue "spike" was during the 2010 Summer Expedition where the logger was brought out of the cave, downloaded, and immediately taken back to TJ. This also shows a second flow increase in August which peaked the water level at about the same depth, then tapering off slowly until December. At that point we now recognize an often-seen flow stoppage dropping the water depth by around 6 cm, a return to the previous level, then followed by a continuing sharp drop to a no-flow condition in early January. The data rate is 20 minutes between samples, which resulted in over 32,000 data points in the final data set which caused the Excel analysis to take significantly longer for computations of charts displayed on the computer screen.



(Schlumberger #00-F1559 214) (7-4-09 to 4-22-11)

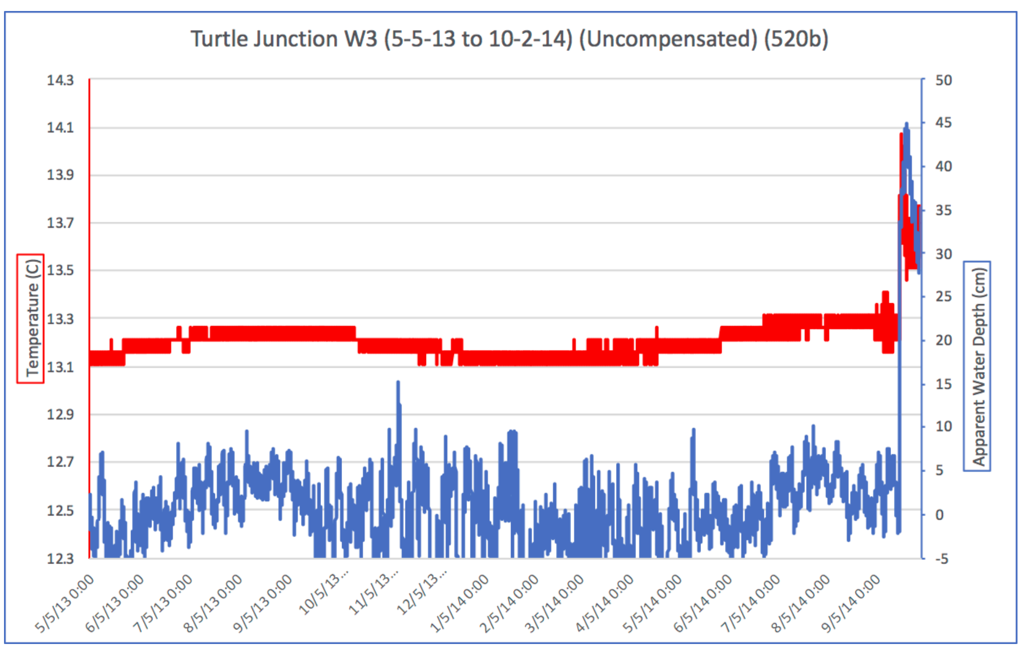
This chart is the same Schlumberger data set shown above, but processed in 2020, with this dual axis graph logger maintenance glitch cleaned up. This basically includes the same data charted previously over a longer period of time and now the temperature plot (red) of the water is shown with an expanded scale on the left, and the water depth (blue) is shown in cm on the right.



By expanding the temperature plot overlaid on the water depth plot we can now easily see that small spikes in what was likely a very low water flow for a short time may have occurred. (This becomes more obvious when looking at this characteristic on the other charts in this report.) It now appears that small, short water flows could have occurred on 8-15-09, 9-19-09, 9-26-09 and 11-2-09. It is obvious that a more significant temperature change occurred both on 4-22-10, 5-12-10 and 7-30-10 when these temperature changes occurred simultaneously with water depth changes.

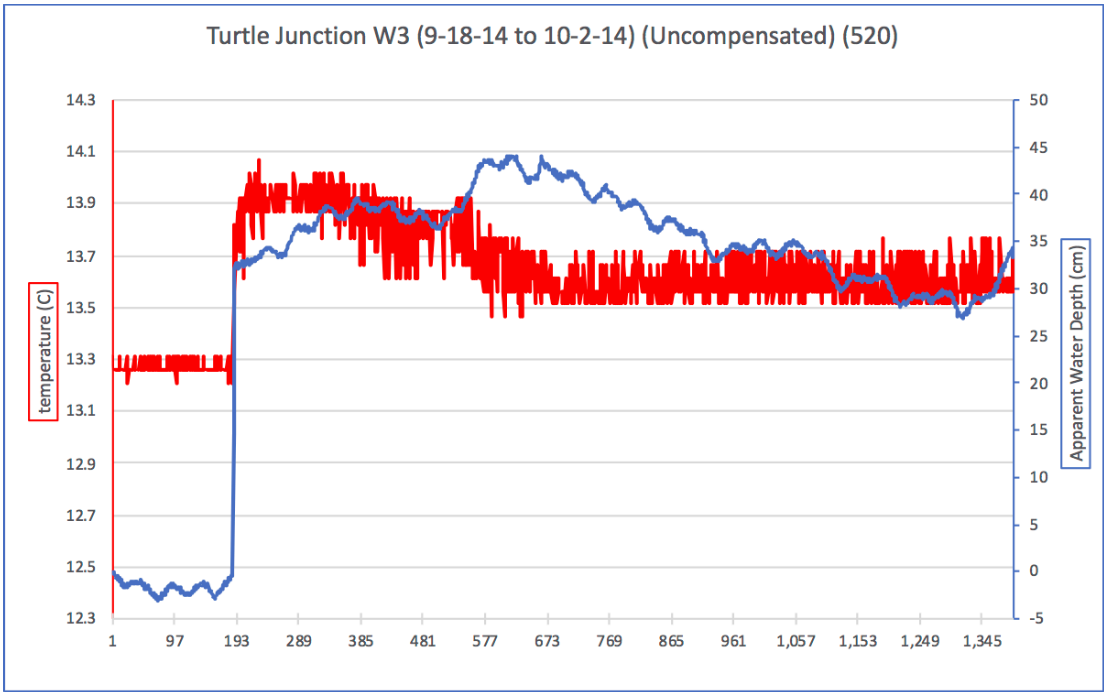
(520b) (5-5-13 to 10-2-14)

The In-Situ Loggers were first deployed at Turtle Junction in 2013 as part of the original array of 10 water loggers in Snowy River. This chart is similar to the others in the array, all of which show the start of the 4-year Snowy river flow.

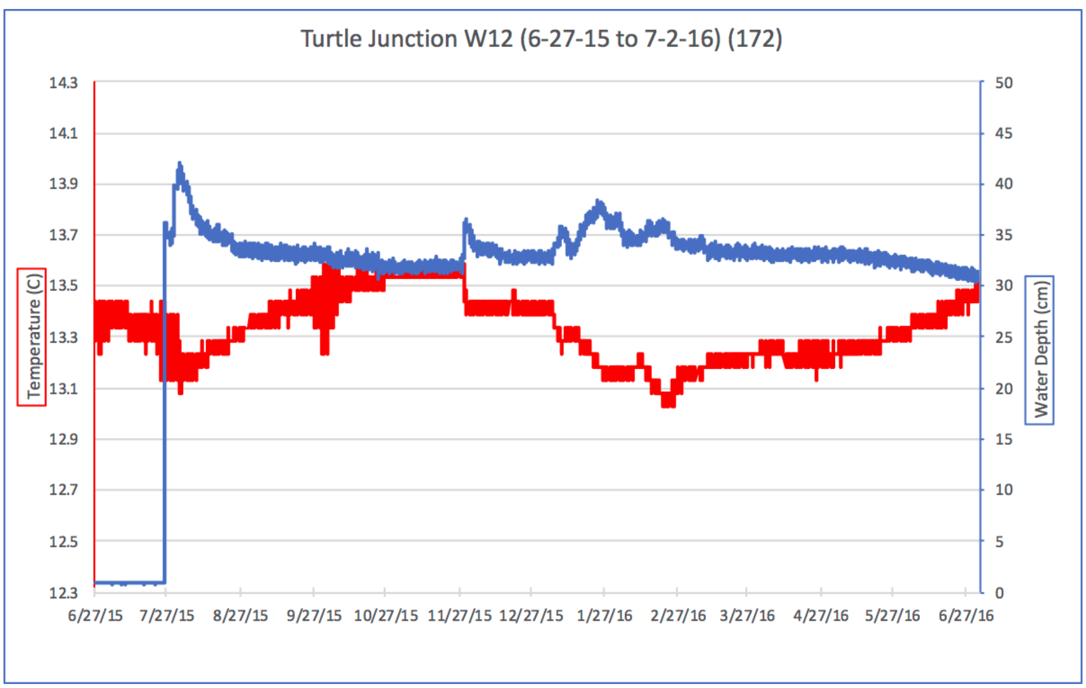


(520b) (9-18-14 to 10-2-14)

This chart shows initial flow in 2014, expanded to cover the last 1-month period the logger recorded prior to filling the logger memory. (The X-axis shows marks for every 24 hours.)

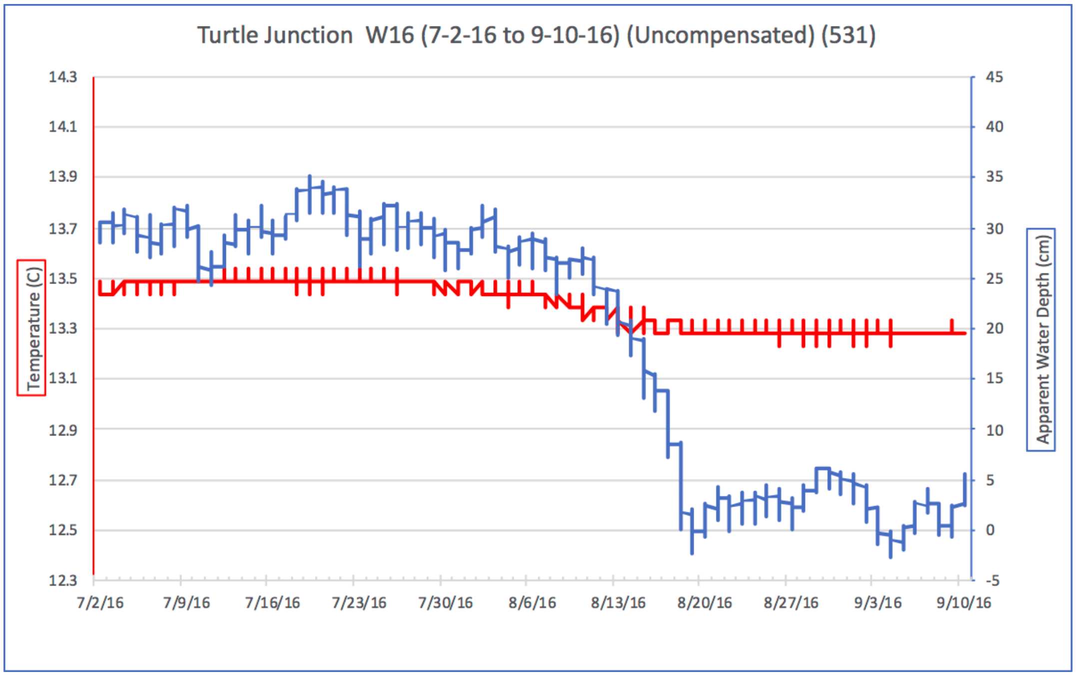


(172) (6-27-15 to 7-2-16)



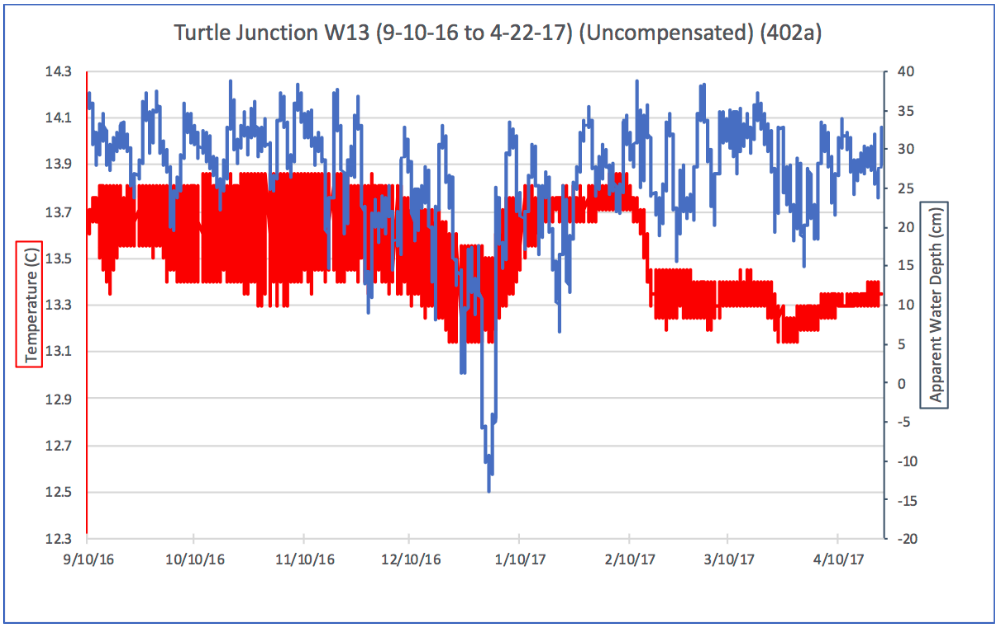
(531) (7-2-16 to 9-10-16)

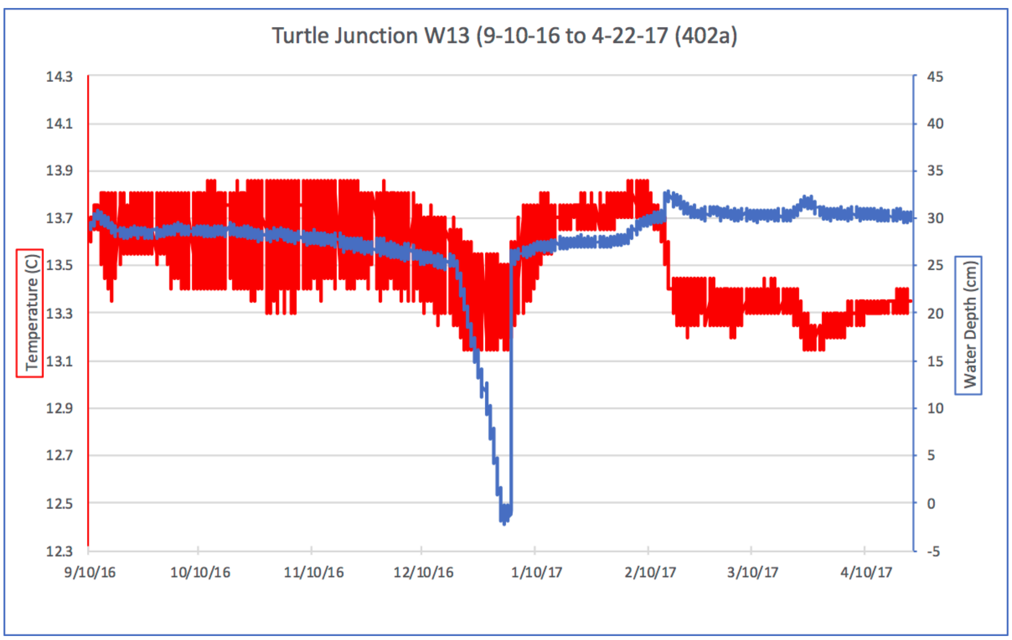
This chart shows the drain-down of the flow that was shown in the previous (172) chart.



(402a) (9-10-16 to 4-22-17)

Comparison of raw water logger data and the same data corrected with baro data: Over the winter of 2016-2017 we knew that Snowy River continued to flow. The raw water level data shown on the first chart supported this but at the same time gave a suggestion of a reduced flow around the end of the year. The second file below was not properly processed until almost four years after the unit was retrieved because of complications of duplicate file names and a challenge of baro loggers with a variety of sample times. In the past at Turtle Junction, the sample times had ranged from 15, 20, and 30-minute sample rates, and even included a baro setting of 60 minutes for the first setting used at the initial deployment in 2013. Apparently at midnight on 1-3-17, as the water at Turtle Junction was almost gone, a warmer shot of water almost immediately re-filled the pool level to 26 cm. Then on February 14 a cooler shot of water entered the channel and raised the water level at Turtle Junction another inch. A question that is still unanswered is why is there an expanded range of temperature variation in November and December, yet in January and February this range is reduced?

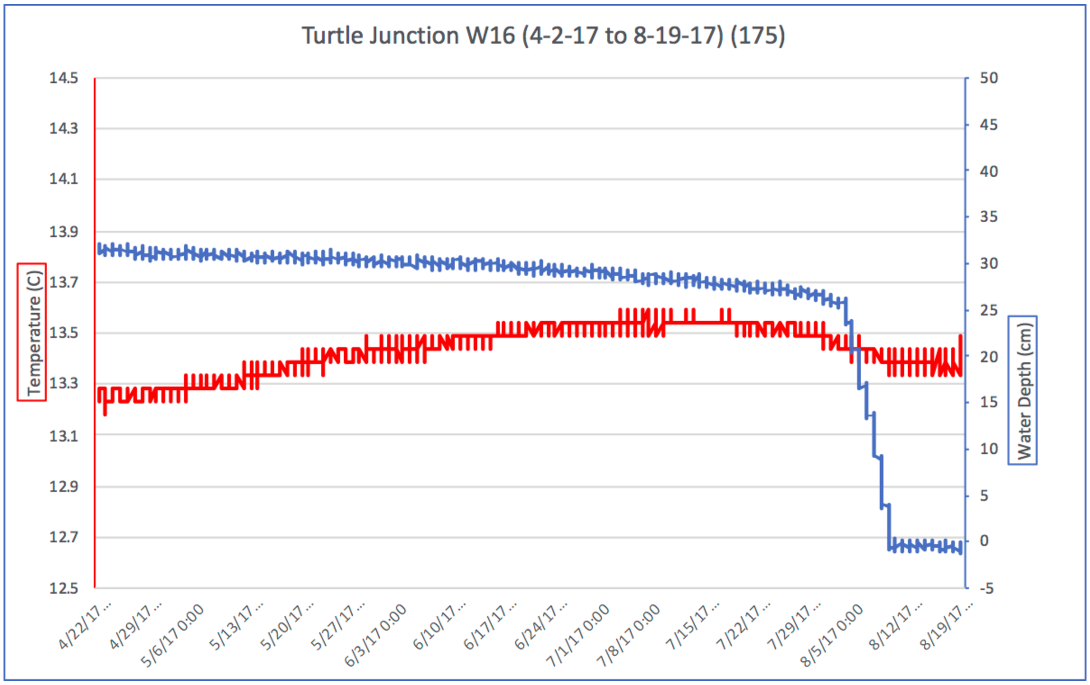




Lesson Learned: The sample rate of the barometer and water loggers should be at the same time interval, and the decision was made in 2019 to use a 30-minute sample rate which also would provide a run time of just over 7 years for the In-Situ Rugged Troll 100 data loggers.

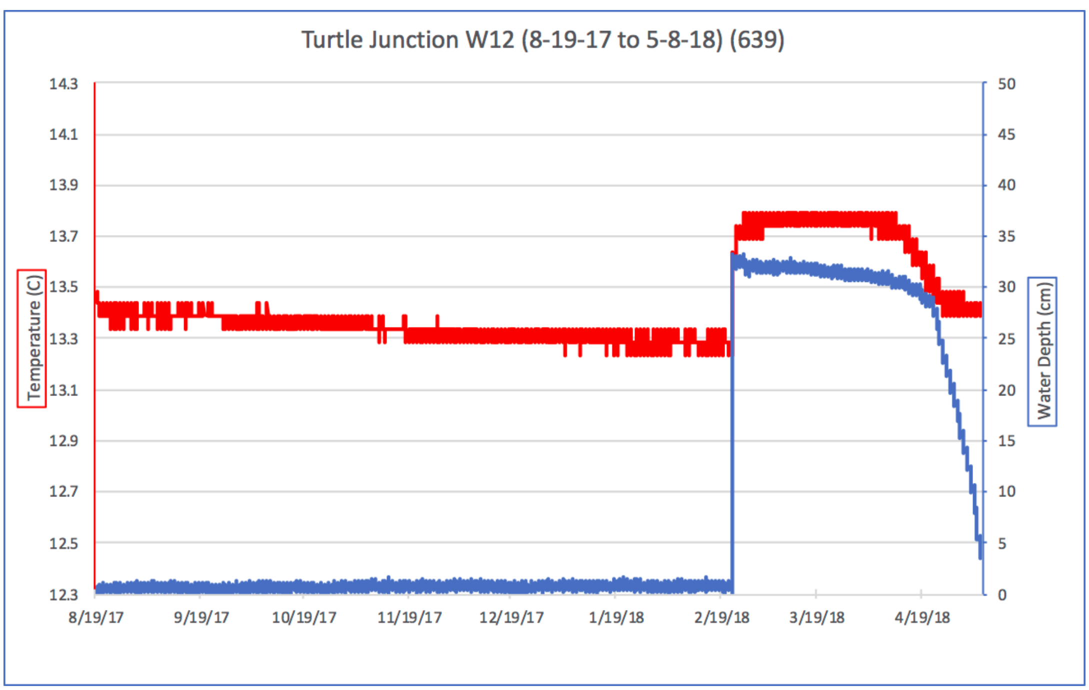
(175) (4-2-17 to 8-19-17)

This 4-month chart shows another drain-down event.

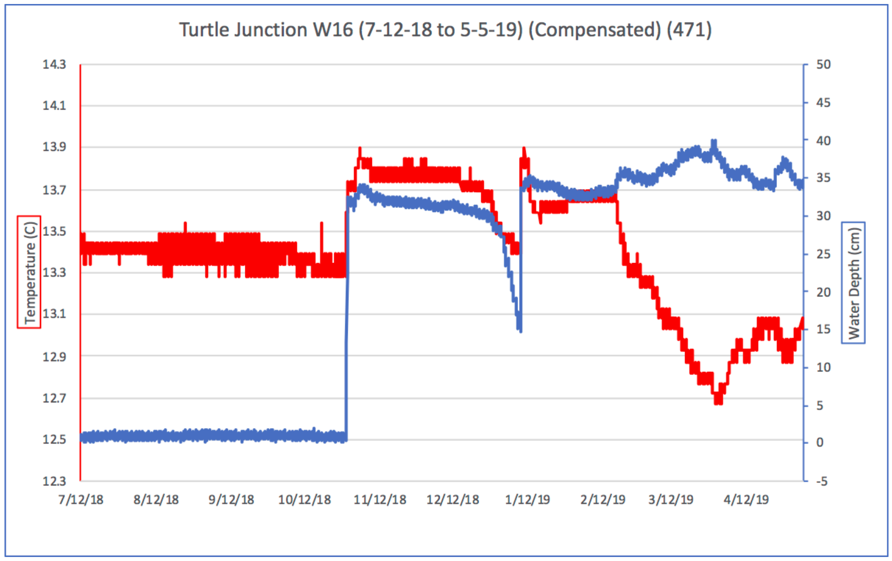


(639) (8-19-17 to 5-8-18)

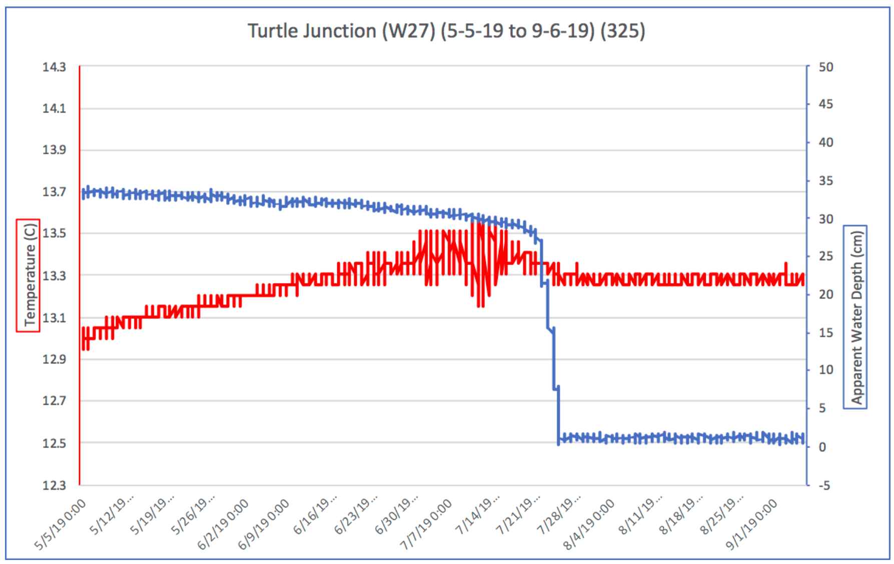
This is the next flow following the previo9us chart.



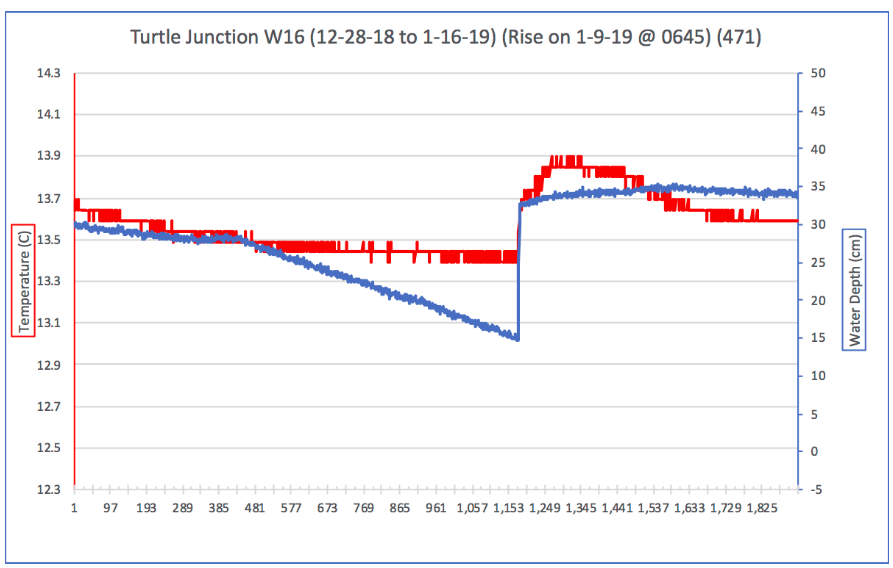
(471) (7-12-18 to 5-5-19)



(325) (5-5-19 to 9-6-19)

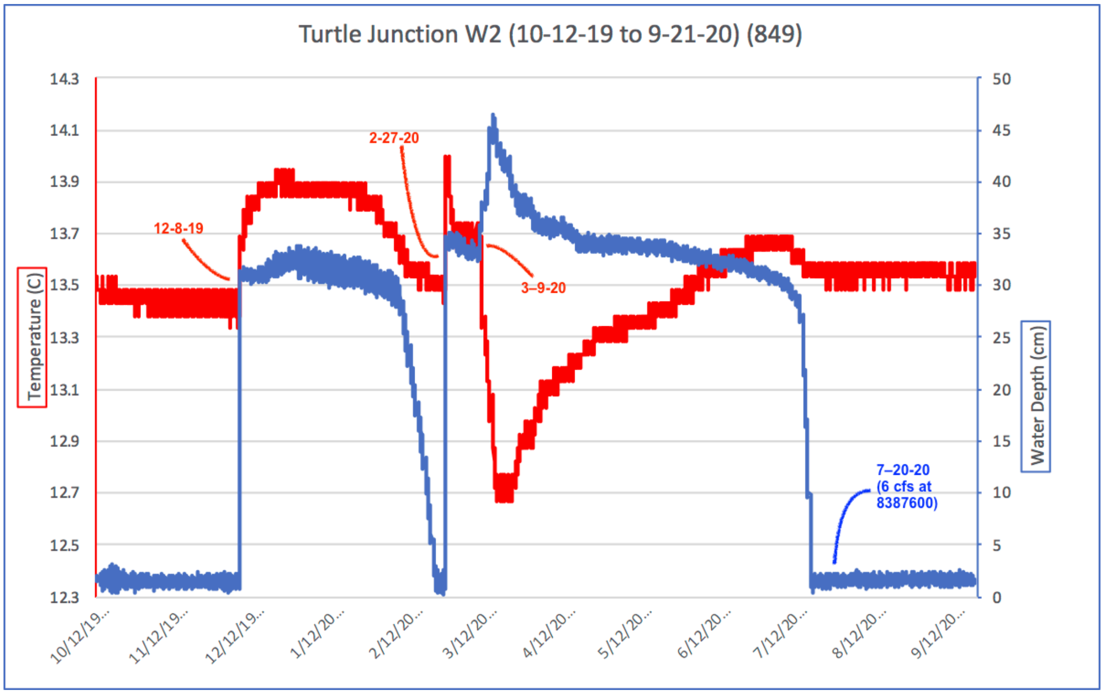


(325) (12-28-18 to 1-16-19)



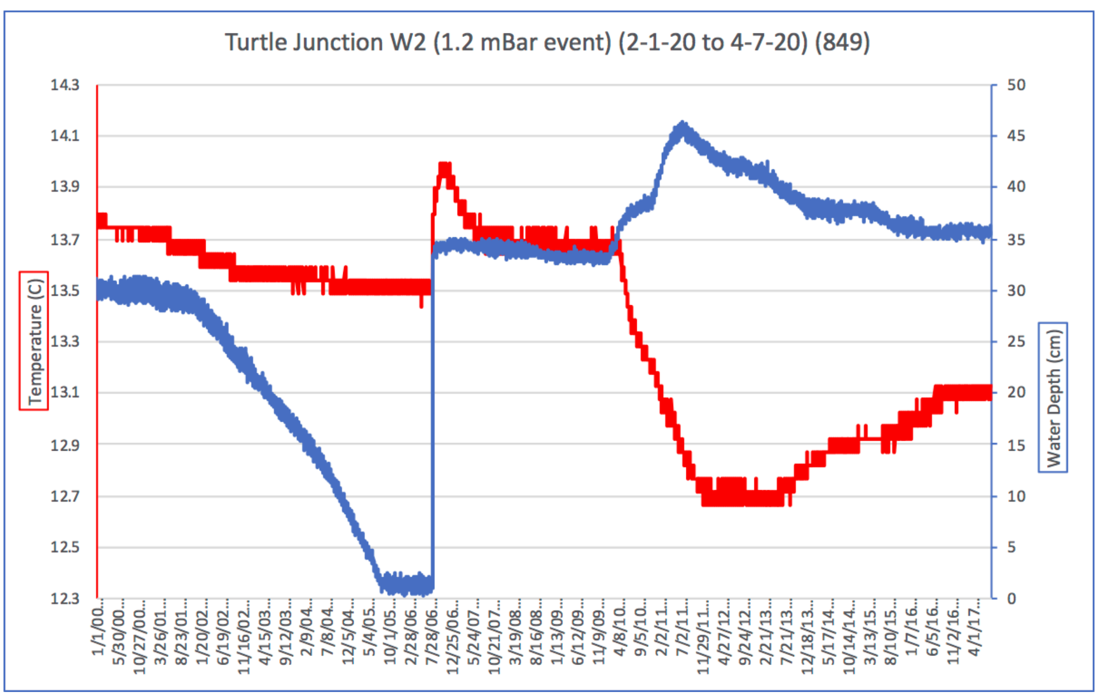
(849) (10-12-19 to 9-21-20)

This chart for the Turtle Junction logger shows much of the same temperature characteristics of the previous “upstream” charts. Two “warm” pulses of water on December 7 and February 26, were followed by a larger and much colder pulse of water on March 11, 2020. Close examination of the timing difference between Floating Islands and Turtle Junction loggers show a 2-3-day delay as the water passes through the constriction at Two-Way Hill. Likely due to the Snowy River Passage restriction at Two-Way Hill, plus the exact volume of water entering the system, the loggers at the Plunge Pool and Turtle Junction sites appear to show two flows of Snowy River.



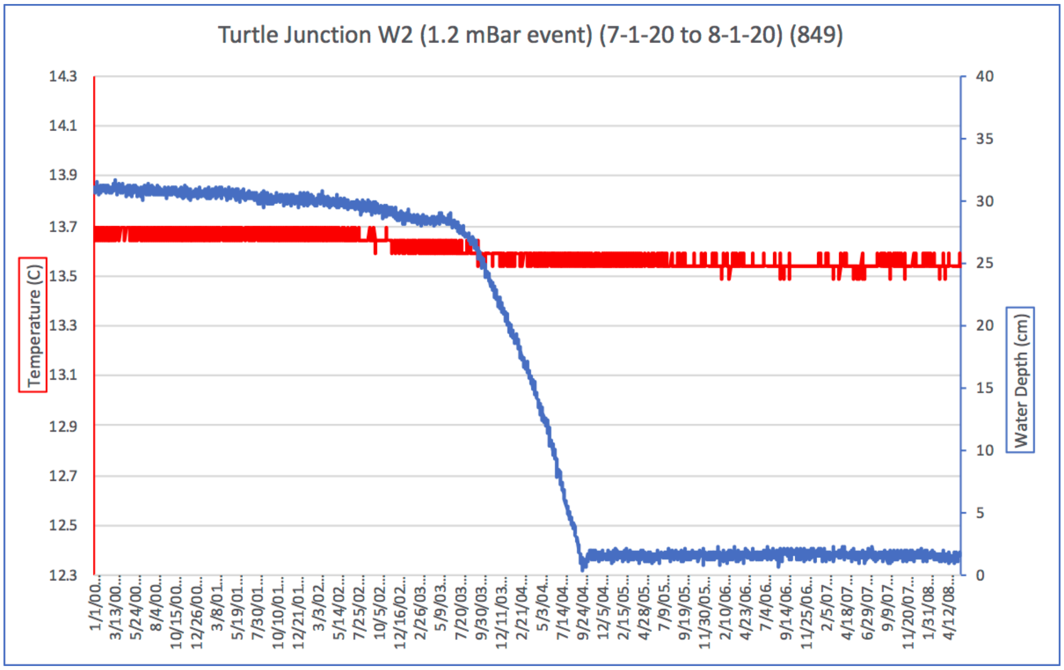
(849) (2-1-20 to 4-7-20)

This expanded chart shows the drain-down from the first pulse of water, and also the sudden rise on 2-27-20. It can be compared with previous upstream sites around the same time period. (More accurate timing analysis can be obtained from the raw data.)



(849) (7-1-20 to 8-1-20)

Compare this chart with the associated Plunge Pool chart using the 1.2 mBar event logging feature on a previous page to see a distinctively different curve shape. The Turtle Junction channel shows a typical drain-down once the flow stops, and the Plunge Pool chart shows a typical "pool draining" characteristic where the water level continues to drain through the "floor" of the pool instead of just running down the Snowy river channel.



SRS23, Turtle Junction Conductivity Loggers:

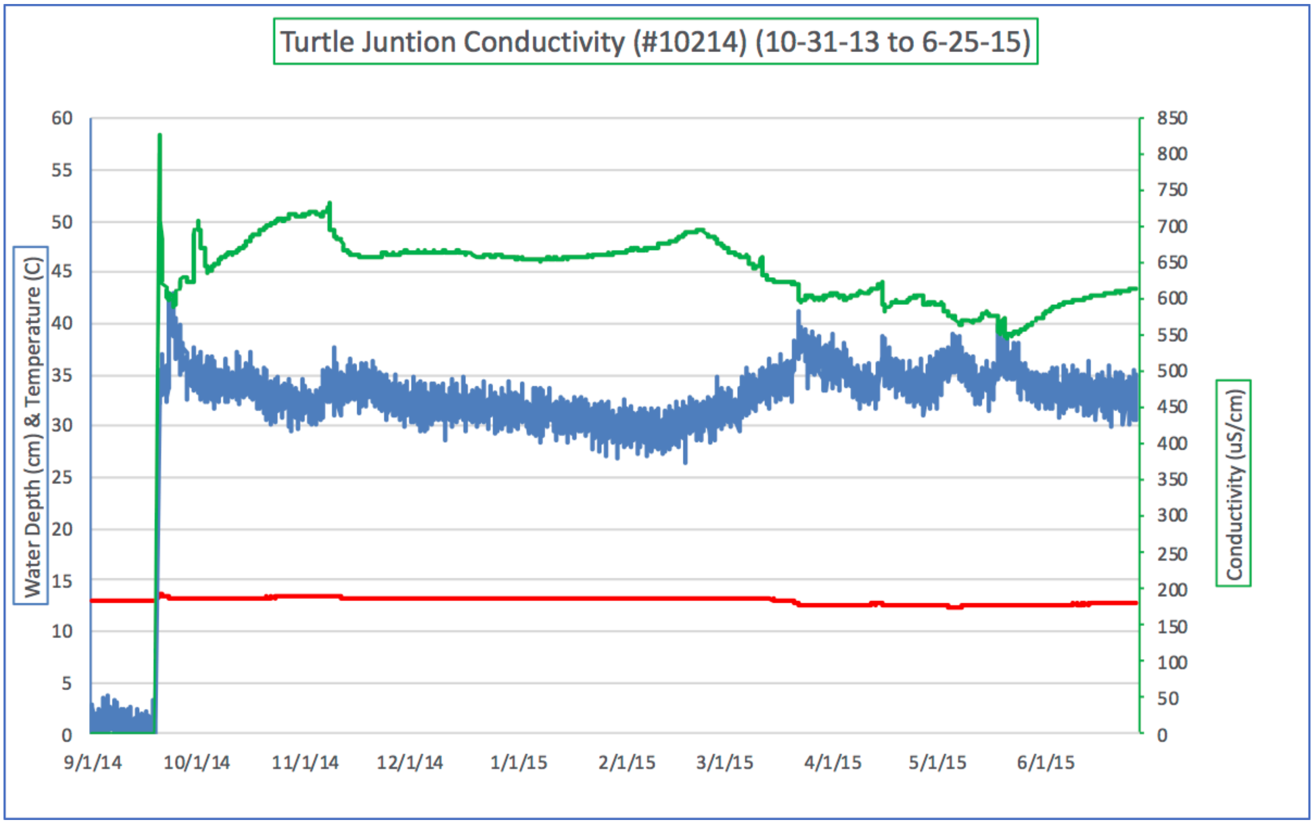
Michael McGee (BLM) installed a Solinst conductivity logger at Turtle Junction around the same time that the In-Situ loggers were originally deployed. The logger was downloaded about once a year by various teams, and they used a wired serial cable connection with a handheld Solinst computer. A year after the 4-year Snowy River flow started we began to notice that both the loggers and the attached nylon cords had a significant calcite deposit forming on the outer surface. The above photo is the Plunge Pool logger (553) after experiencing a Snowy River flow for 22 months. The photo of the Solinst conductivity logger on the left shows a similar deposit from the Turtle Junction site. Next to the Solinst logger there was a stainless staff gauge with the markings almost covered by the calcite deposits. The lower photo on the right shows additional crystal growth on the back, “slick” side of the staff gauge. Obviously if there is enough calcite deposit on these loggers and staff gauges, at some point it would be necessary to remove this deposit. Typically, on the In-Situ loggers, where the calcite deposit is not easily removed by rubbing with a coarse rag, we have soaked the units in a vinegar mixture for an hour or so to remove the calcite both on the thin pressure sensor and the titanium outer case.

(Photos: Lindsley #2276, #2198, #2177)

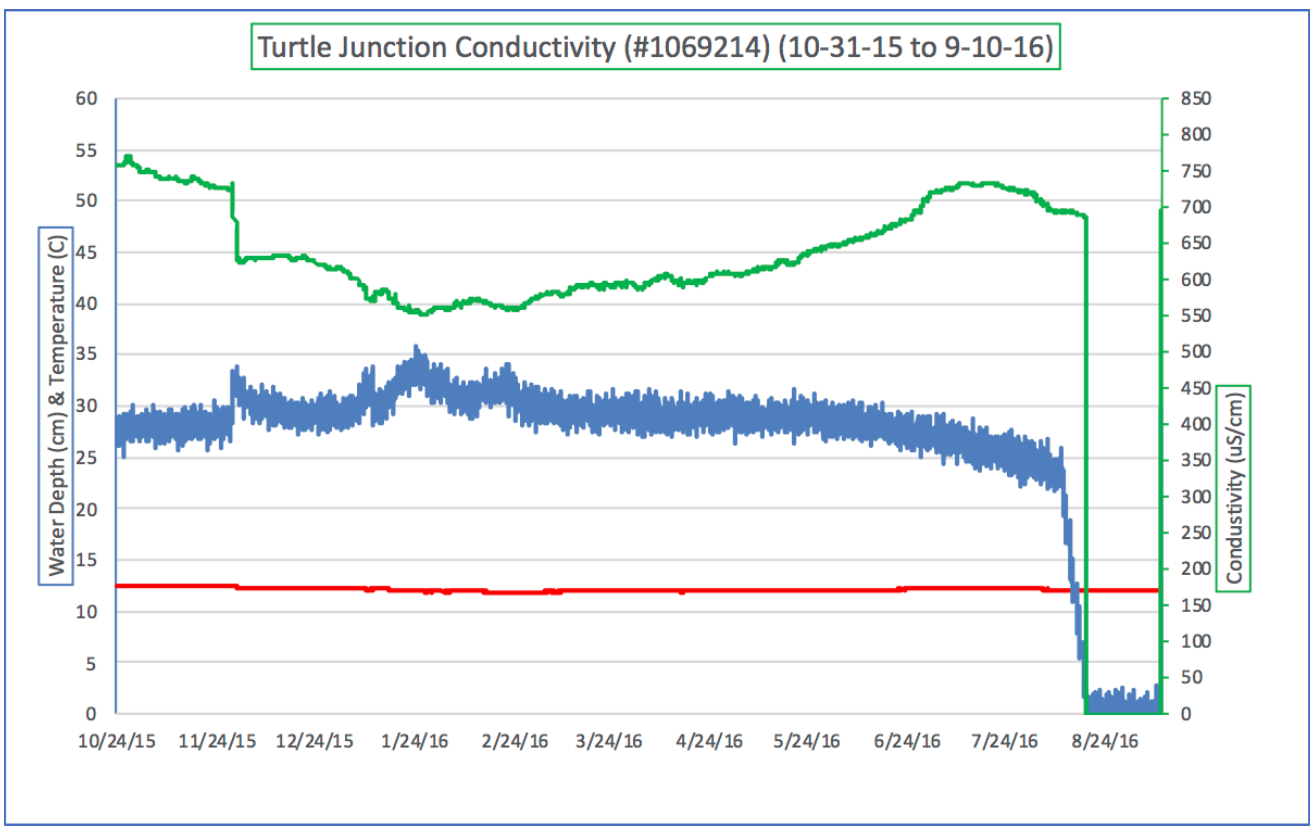
After two years, the Solinst logger was brought out of the cave and cleaned before deployment back at Turtle Junction for another two years. The results are shown on the next two charts. Unfortunately, on the 5th deployment, the internal battery on the Solinst unit was dead after retrieval and had to be sent back to the factory (in Canada). Only a small part of the data was recovered, and without a proper time reference that data is not shown here.

Nevertheless, we are very fortunate to have conductivity data for almost all of the 4-year Snowy River flow. The conductivity values are shown by the green trace with units of (uS/cm), with the water depth (cm) and temperature (C) shown on the same scale on the left side Y-axis.

(#10214) (10-31-13 to 6-25-15)



(#10214) (10-31-15 to 9-10-16)



SRS19, Snowy River, North of Turtle Junction:

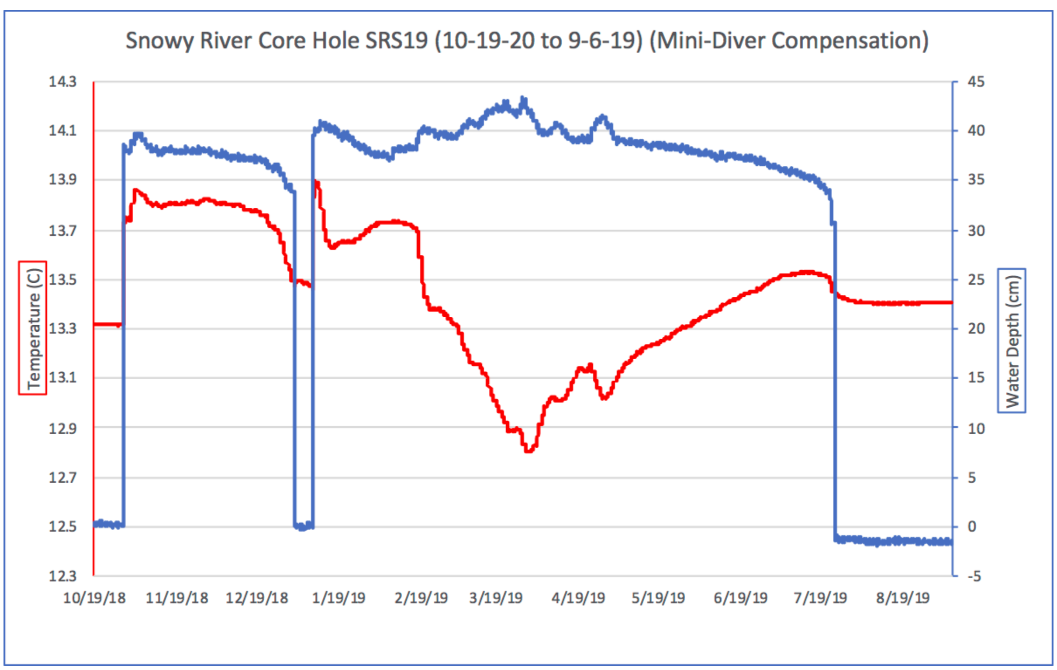
Just downstream from Turtle Junction, this typical Snowy River stretch has uniform widths with few rocks causing rapids, making it a better site for future flow measurements. A core hole was drilled so that a Schlumberger Mini-Diver could be used to monitor water levels under the calcite floor. (Data is Snowy River sub-surface stage & temperature vs time from 2018)

This site has the potential capability of measuring the drain-down characteristics of a "typical Snowy River surface" which is not immediately on top of a limestone base. (See Appendix 8.) (Photos: Lindsley #5691 & #5698)

The logger is a Schlumberger Mini-Diver (plus a Baro just downstream from the Mini-Diver) and was installed by Dr. Johanna Blake (USGS) in the core hole several inches below the top of the Snowy River Calcite surface.

The logger was installed under the calcite surface on 10-15-18 and we expected some interesting results when retrieved after the October 31 2018 Snowy River flow passed Turtle Junction.

(Mini-Diver) 10-19-20 to 9-6-19)



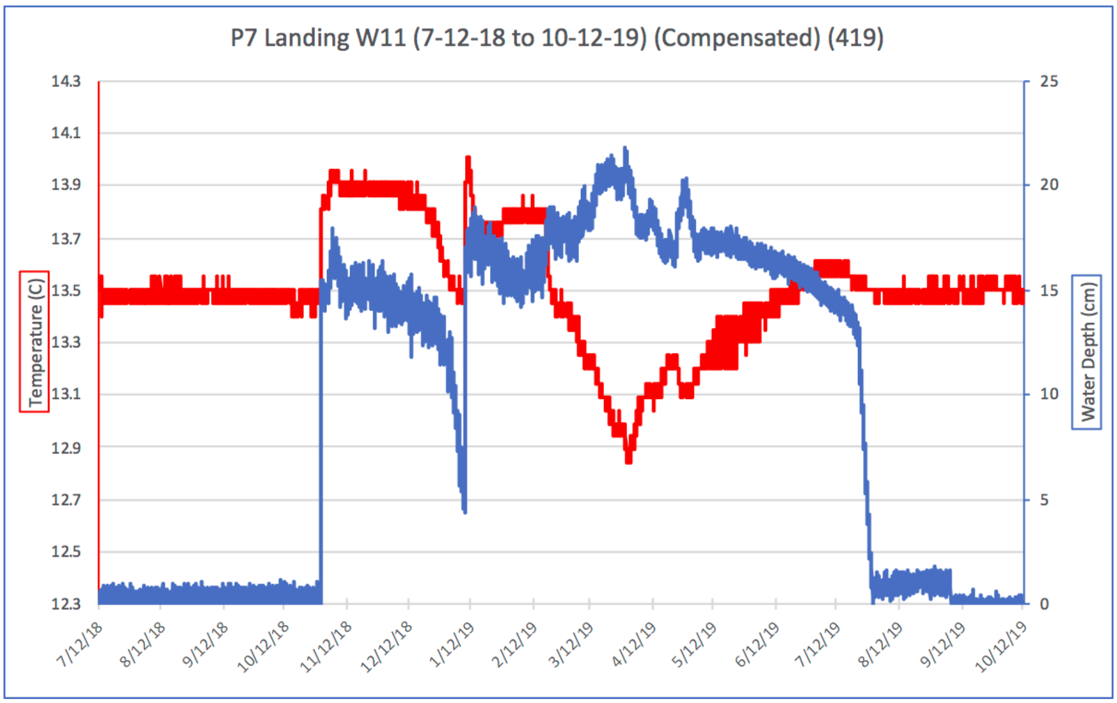
The chart on the right is for the USGS / BLM Schlumberger Mini Diver logger which is compensated with the companion Schlumberger Baro logger. The results are to be expected when compared with other loggers, with the exception of the sharp drop-off when the flow stops. Appendix 8 expands on this discussion and has additional charts.

SRS10, P7-Landing: (Stage & temperature vs time from 2018)

The SRS10 site has a uniform straight cross section optimized for discharge inference between Turtle Junction and the Priority 7 Landing. It provides value to compare with Turtle Junction measurement to see if discharge is gained or lost to sub-crust flow. It can also be used for comparison with SRN08, 18 stations downstream, for discharge gain from Main Corridor flow. The cross section and slope has been measured at this location. (Photo: Lindsley #5114)

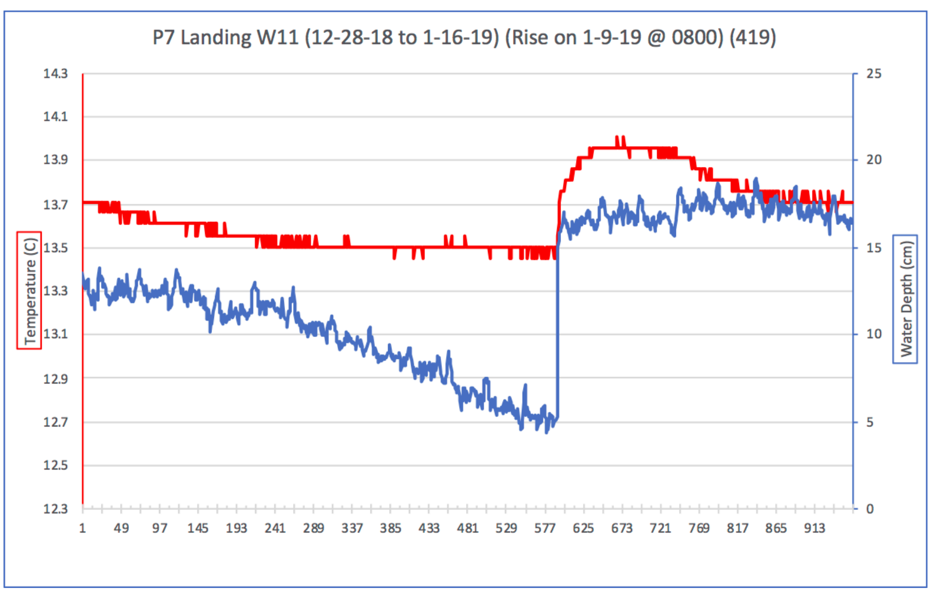
(419) (7-12-18 to 10-12-19)

13-Months



(419) (12-28-18 to 1-8-19)

This shows the drain-down and the second pulse of water from the previous chart above.



SRN08, Window Passage: (Stage & temperature vs time from 2018)

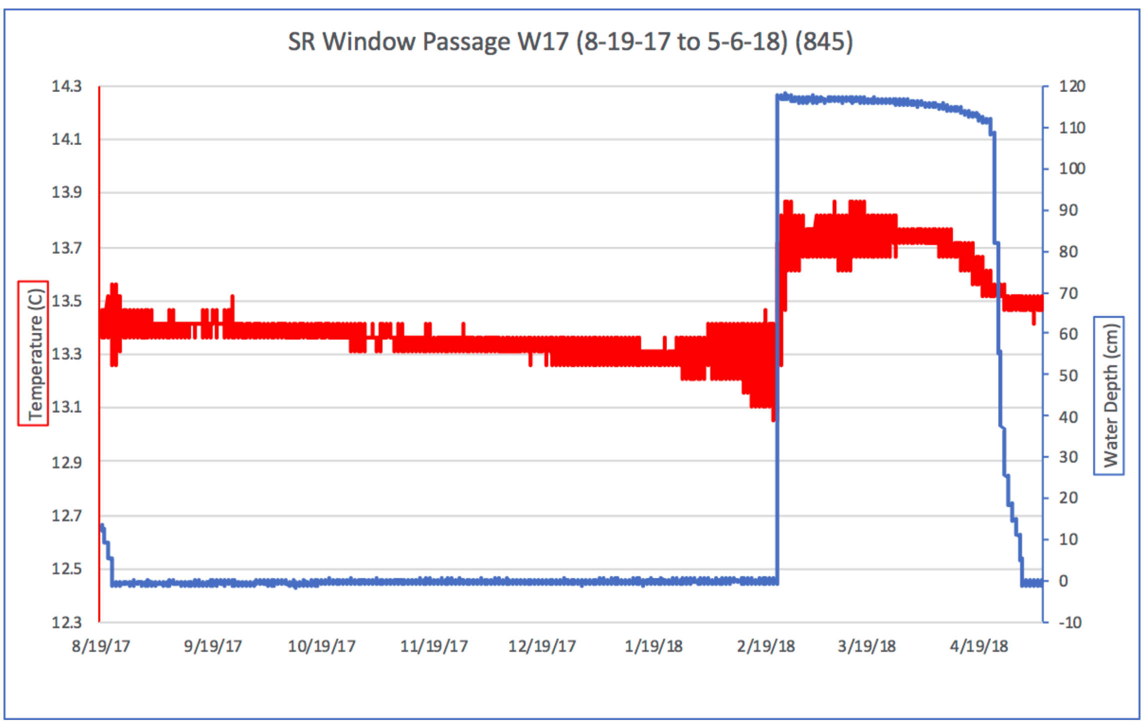
This uniform straight cross section is best for discharge inference downstream from SRS10 and past the estimated location where water from Main Corridor and Sewer Pipe Passage might flow through breakdown into Snowy River.

This location is near the path up to the upper Metro level. It is the downstream measurement point of the SRS10-SRN08 stretch which incorporates a wide stream "uniform" width with measured slope and cross section which will allow Manning Equation flow estimates.

(Photo: Lindsley #5164)

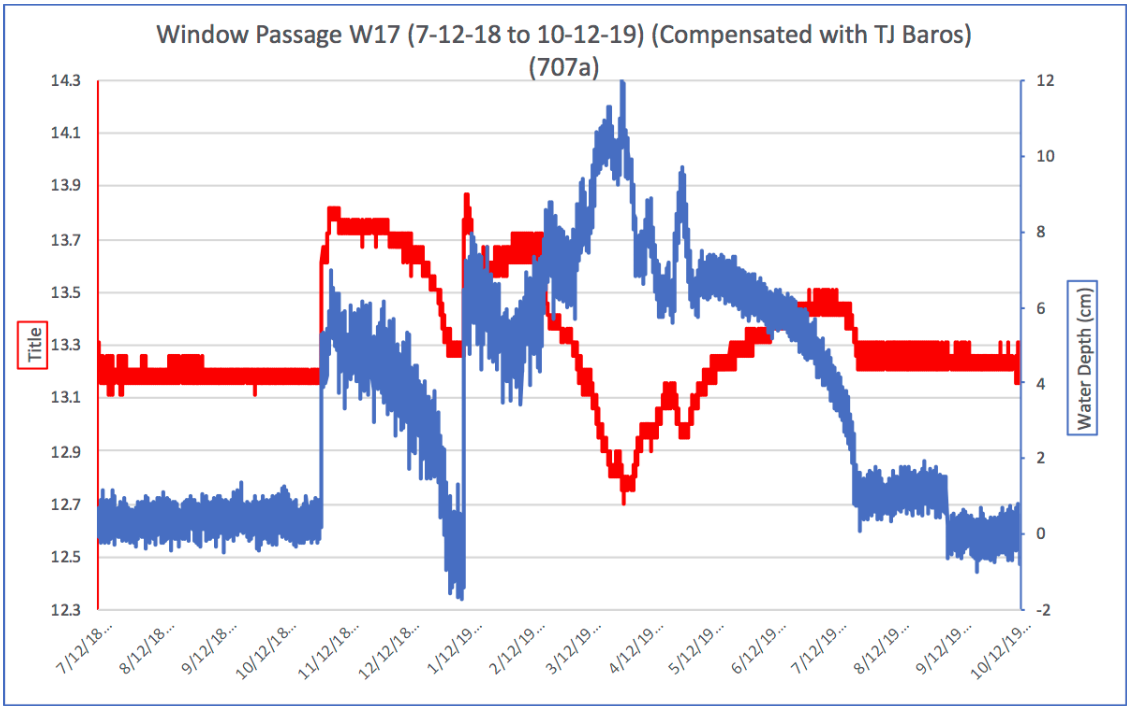
(845) (8-19-17 to 5-6-18)

This SRN08 Snowy River flow for the 2017-2018 Winter season is reasonable when compared to previous upstream sites.



(707a) (7-12-18 to 10-12-19)

However, the chart below seems to have much more noise than expected when compared with other sites during the same time period. This begs the question:

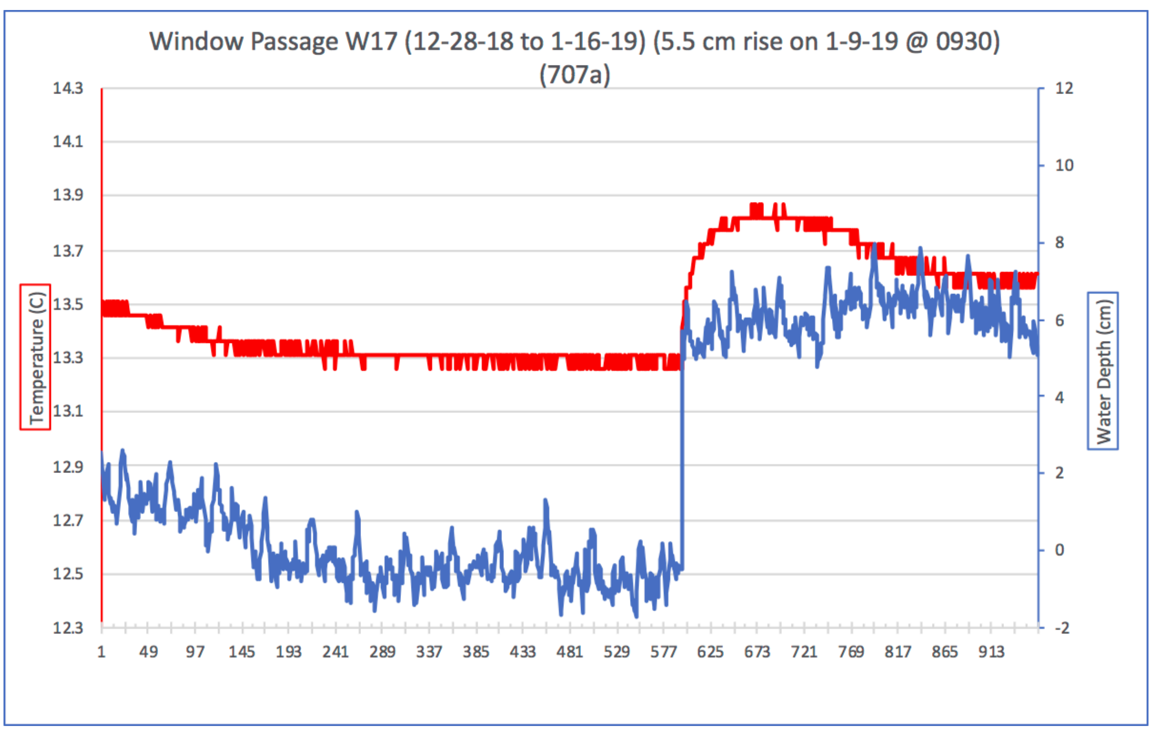


Why is this 2018-19 flow so much less than the 2017-18 flow?

The compensation may be less accurate when doing the compensation against more than a single Baro logger with the same data interval. This site is shallower than some of the upstream sites, and suggests that a dedicated baro logger should be used with this site when used for flow analysis.

(707a) (12-28-18 to 1-16-19)

This 13-day chart expands the first drain-down shown on the chart just above. (The X-axis shows marks for every 24 hours.)



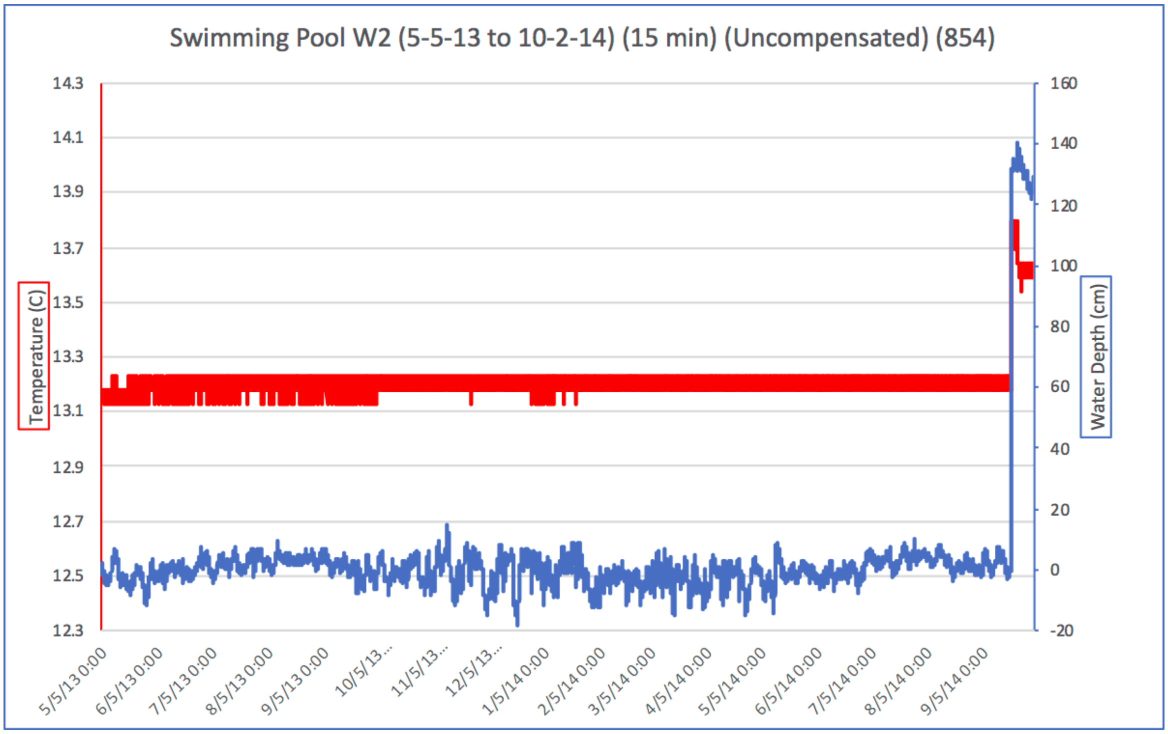
SRN53, Swimming Pool: (Stage & temperature vs time from 2013)

Originally this location was called the "Hot Tub", but on closer inspection of the original survey notes the Hot Tub location was actually upstream from this large pool, so this location became known as the Swimming Pool. The top photo (Lindsley #0046) shows the location of the newly placed logger in 2013, a location not quite at the "pool bottom" as seen in the photo below.

The stitched photo below (R. Lipinski: #2945 + 3019) was shot on 10-12-19 when a series of photogrammetry cross section photos was recorded at several sites. The obvious bathtub ring of white calcite shows the quite large extent of this pool. Future analysis may involve the rate of filling and water level decline of this site for determination of the calcite floor porosity. This view is looking upstream towards SRN53 on the rock at the top center. The SRN53 logger is next to the remaining pool of water by the lower boulder. Note the "ripple marks" under the SR calcite in the foreground of this photo. The red text points out the SRN53 station, the logger location, and the photogrammetry scales at the edge of the remaining pool water on 10-12-19.

(854) (5-5-13 to 10-2-14)

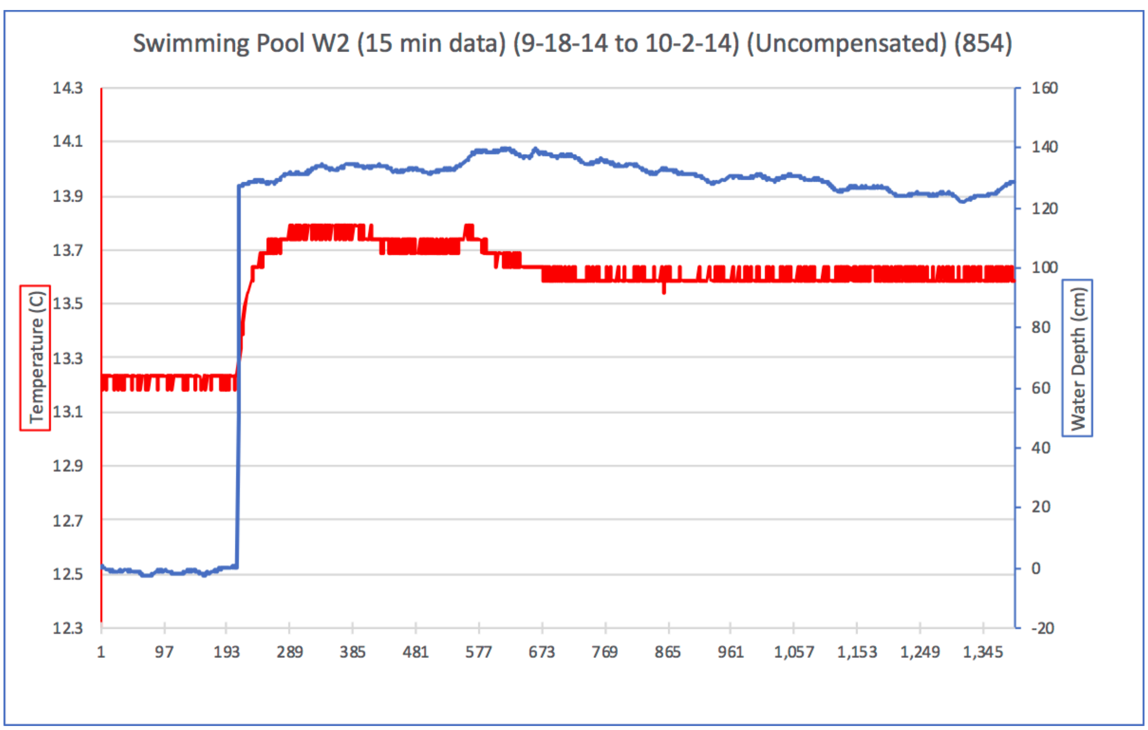
This chart is for the initial 2013-2014 installation of the In-Situ loggers at the SRN053 site.



(854) (9-18-14 to 10-2-14)

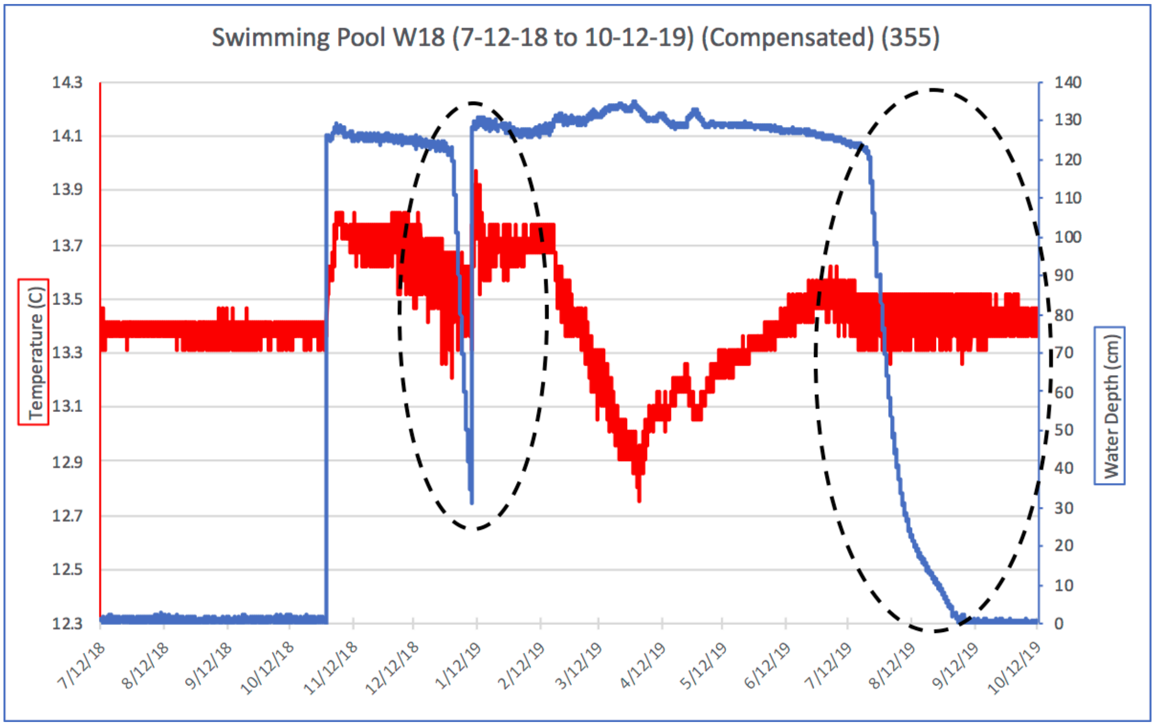
This Is an expansion of the start of the 4-year Snowy River flow shown above.

(The X-axis shows marks for every 24 hours.)



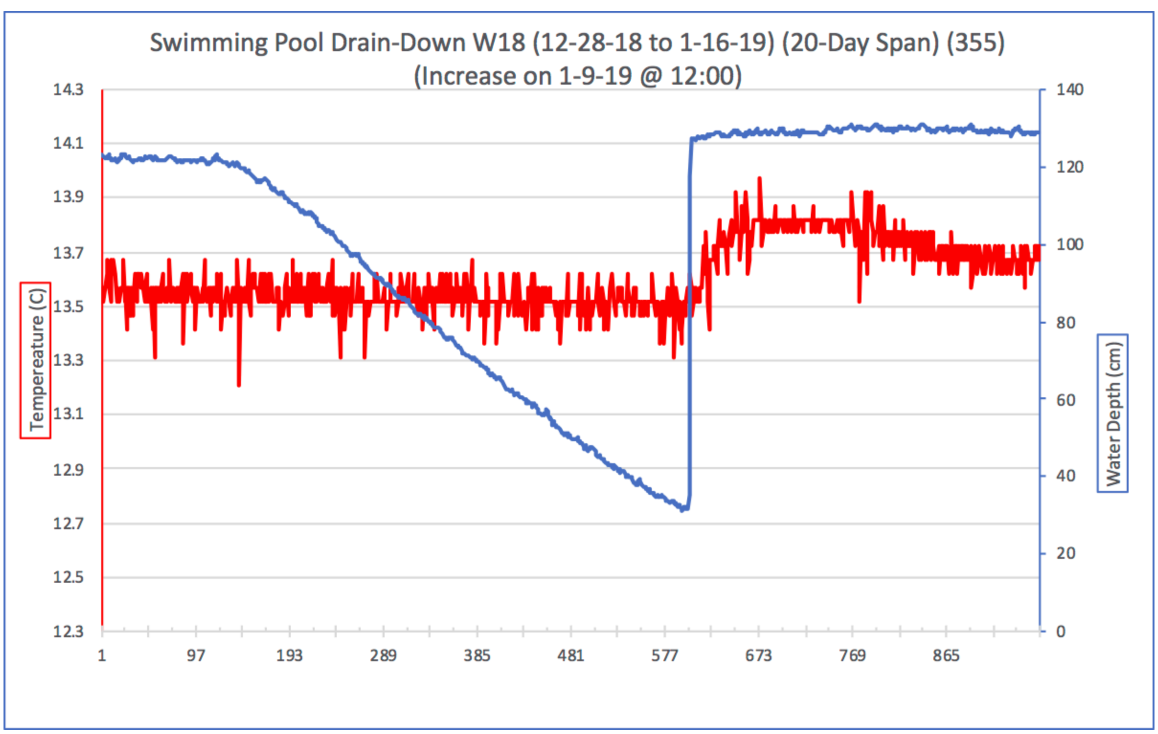
(355) (7-12-18 to 10-12-19)

The dotted lines show two areas in the 2018-2019 data where we show an expanded Plot. The initial flow stoppage is shown below, and the final pool drain-down is shown on the next page.

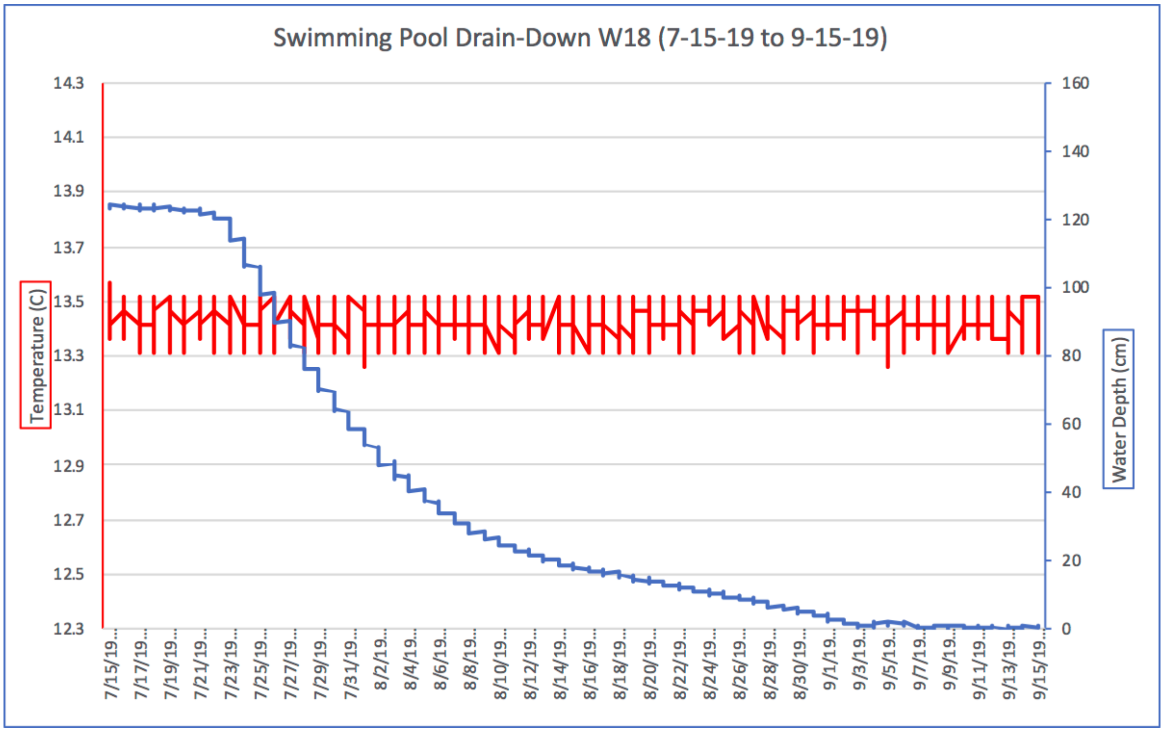


(355) (12-28-18 to 1-9-19)

Note that this first drain-down of this pool is essen-tially linear down to a depth of about 30 cm before the next pulse of water starts flowing. (The X-axis shows marks for every 24 hours.)



(355) (12-28-18 to 1-9-19)



The final drain-down over 13 days of the pool at SRN053 did not show the same linear curve shape after the depth dropped to about 40 cm. This certainly complicates future analysis of drain-down characteristics for a pool of this type. (The interested reader is directed to Appendix 8 where there is additional discussion on the drain-down analysis.)

SRN79.5, Crystal Creek Falls:

This site is about 15 feet "upstream" from the original location of the "Crystal Spring" or "Crystal Lake" or "Crystal Creek" logger location. The purpose of the new site, placed in 2019, is to measure the incoming flow from both Snowy River and the much smaller flow coming from under the

Lincoln Bathtub Breakdown pile. From this location to the SRN80 survey site there is normally a 2.0-3.5-foot drop into the pool that connects to Government Spring. The SRN79.5 site is intended to provide flow information into Crystal Lake that can be correlated with other sites upstream all the way to Turtle Junction, and perhaps even further South. The photo shows Ron Lipinski taking the photogrammetry photos towards Crystal Lake, about 1 m upstream from the In-Situ logger. A new elevation station marker is shown under the LIDAR tripod with Crystal Lake in the background. (Photos: Lindsley #7722 & #4211)

SRN80, Crystal Spring: (Stage & temperature vs time from 2009)

The first logger placed at this site was a BLM vented Solinst logger placed after a water sample was taken by Michael McGee on 4-26-2008. The photo shows Michael with an improvised "water scoop" that allowed a water sample to be acquired without entering the pool, which appears to be about 2 feet deep at that time.

The Solinst data logger pair was apparently installed on 11-2-2009. Since the potential depth of the water in Crystal Lake, fed by this "spring", was unknown at that time, the vented Solinst logger was installed in the pool just below this pour-off, and the baro logger was installed on a ledge about 20 feet above this spot. (Photo: J. Lyles #3741)

Then four years later, on 4-30-13, the non-vented In-Situ logger was placed at the same site, but about 6-8 cm above the Solinst unit, just out of the water. The photo shows the Solinst logger monitoring the level of "Crystal Spring" which seems to be slowly flowing at any time an almost dry Government Spring is flowing on the surface. When conditions are "dry", Crystal Spring flows feeds "Crystal Creek" for a short (3-4 m) distance before reaching the water level of "Crystal Lake". We think that the far end of Crystal Lake appears to be just slightly higher in elevation than Government Spring at time of low flow, and is terminated by a sump where the cave passage goes under water.

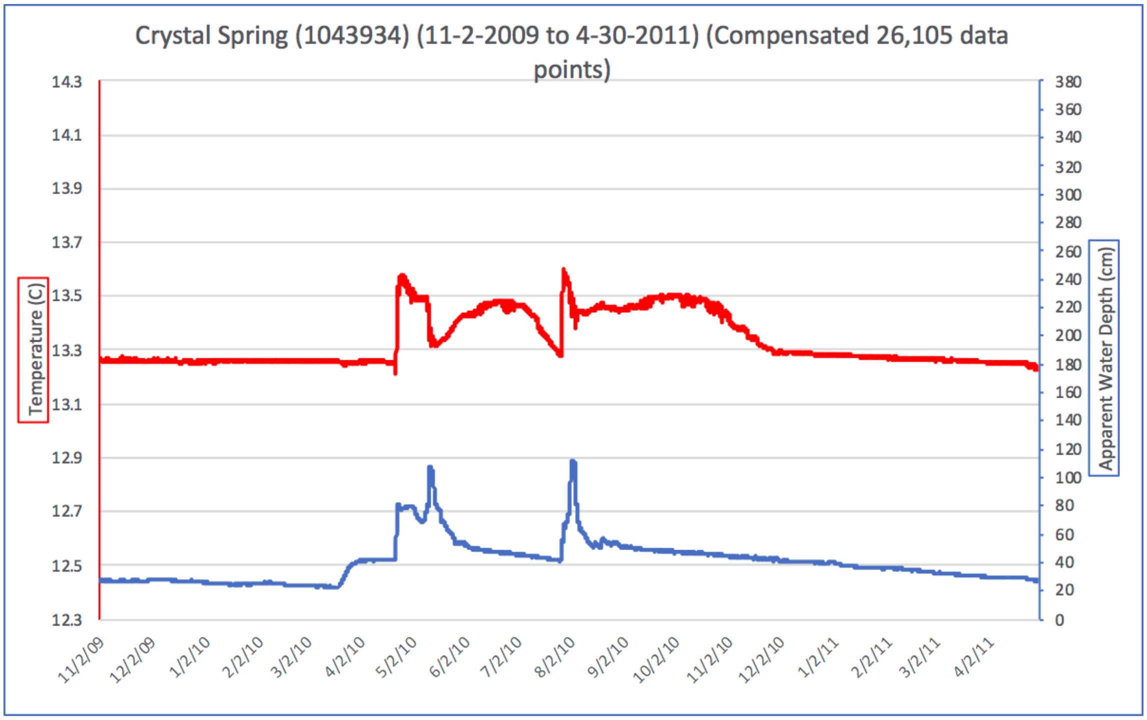
The above photo shows the Crystal Spring Pool at the low water level in 2013, and a careful look at the upper right part of the pool shows the Solinst logger installed in 2009. Wayne Walker is also shown taking a different type of water sample which requires multiple "pumps" of water through a special DNA filter which is later analyzed by Dr. Diana Northup at the University of New Mexico. (Photos: Lindsley #0171 & #0079)

The room photo (R. Lipinski #0934) on the left shows the extent of this area under the Lincoln Bathtub dome. Taken from the top of the breakdown pile, the caver (Carrin) in the red shirt is near the 3-foot drop off into Crystal Creek and slightly upstream from the new logger location. The caver (Pete) in the blue shirt on the far ledge is at the upper location of the Solinst logger pair where the baro unit was located far above any possible high-water level in this large chamber. The 3rd caver (Steffanie) is climbing up the muddy slope towards the upstream direction of Snowy River.

The photo looking towards the junction of Crystal Creek and Crystal Lake (same elevation in this Lindsley photo #7279) shows Carrin moving the nylon cord attached to the replacement In-Situ logger to a new tie-off location only 1 m from the location of station SRN80NEW. (Apparently the original SRN80 was washed into the lake during a previous flow event, and currently the new elevation station (EL1) (shown in the above section at SRN79.5 under the tripod) will be used by future precision elevation surveys, and is approximately the same elevation as the cave radio location. (The original tie-off point placed the In-Situ logger directly under the 1-meter waterfall next to the Solinst logger, and months of flowing water severed the nylon cord connecting to the logger.)

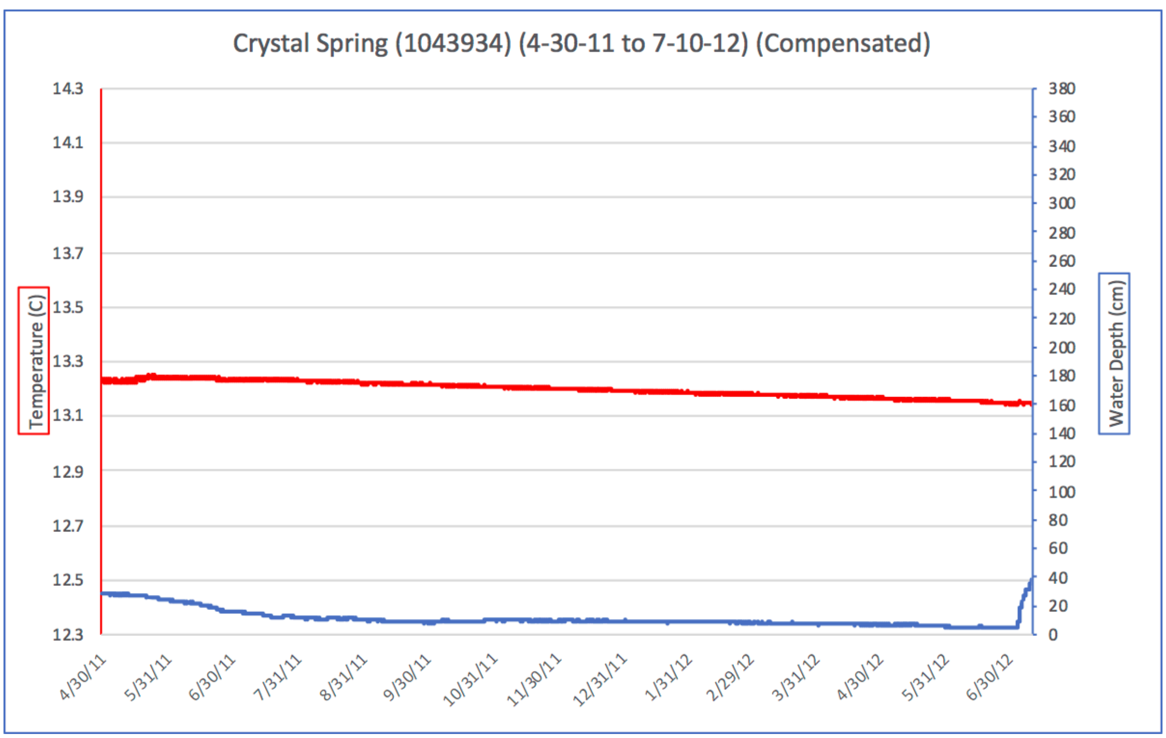
The photo on the left shows the same location where the cave radio location was done in 2009. (Photo: R. Lipinski #3866).

Solinst Logger (1043934) (11-2-09 to 4-30-11)



This is the first Crystal Spring chart shown in this report. Since it did not start on the assumed 4-26-08 trip install date, perhaps the memory filled after the 26,105 data points in the chart. It shows two flows that peaked at 102 and 110 cm on 5-14-10 and 8-4-10.

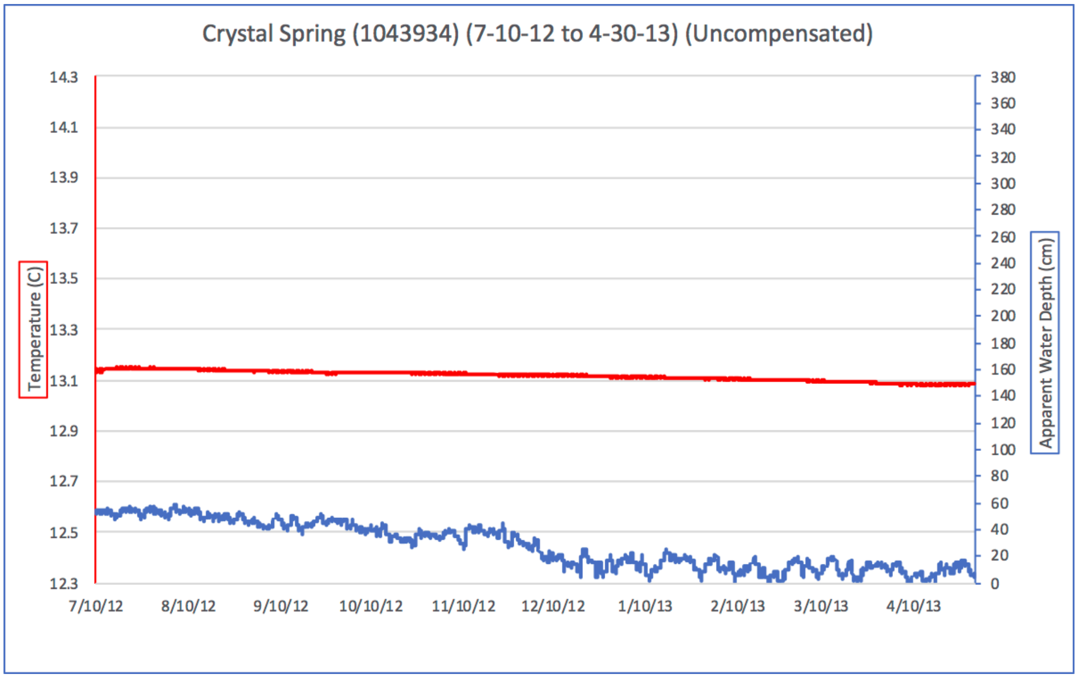
Crystal Spring (1043934) (4-30-11 to 7-10-12)



The next chart shows the water level at this site slowly decreasing to a point in June 2012 where the flow begins to pick up slightly, but with no apparent temperature change at that time.

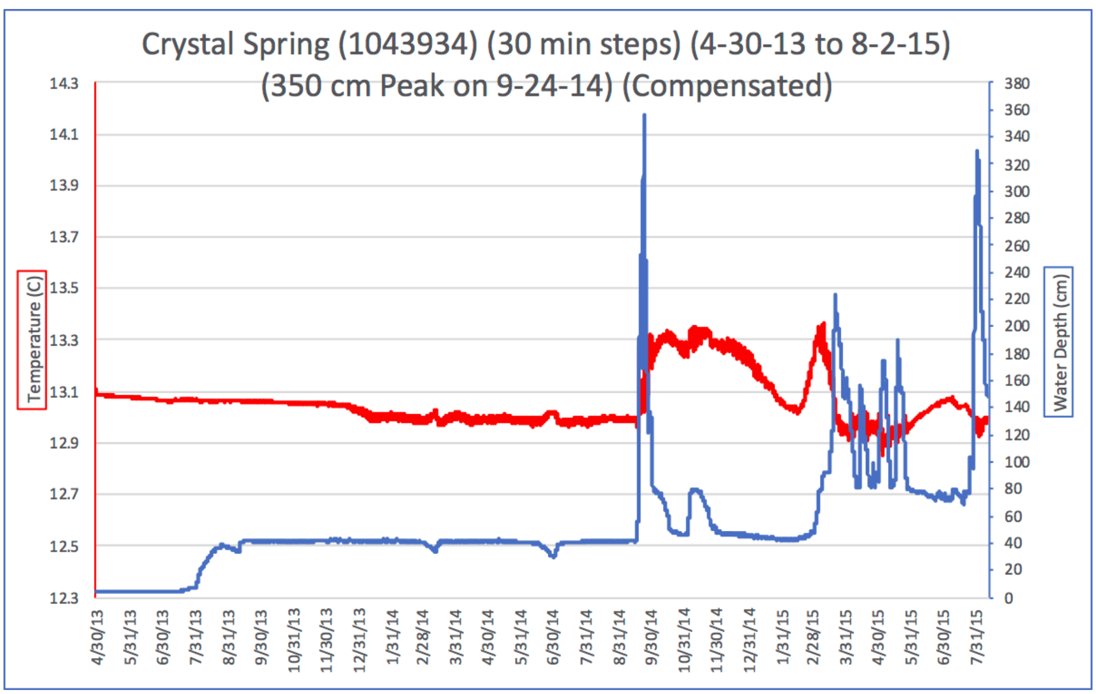
Crystal Spring (1043934) (7-10-12 to 4-30-13)

The water depth at Crystal Spring continues to decrease.

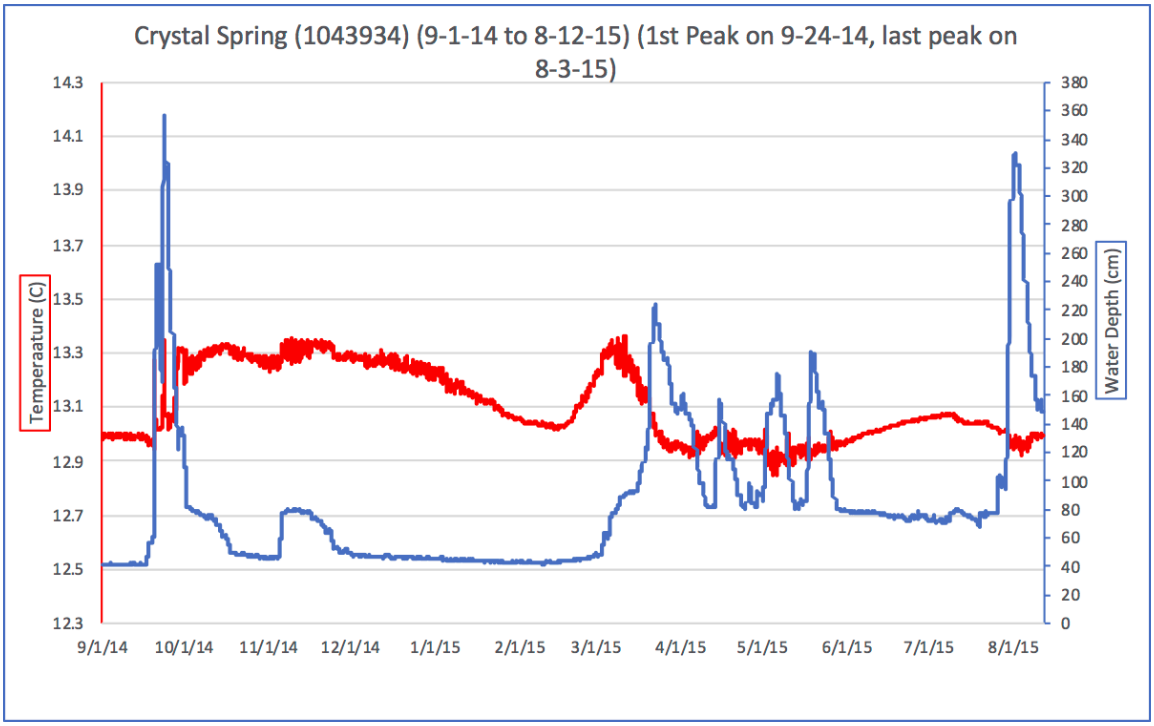


Crystal Spring (1043934) (4-30-13 to 8-12-15)

The next maintenance period started about the same time as the first In-Situ logger was installed next to the Solinst logger. This time the Solinst logger recorded data in 30-minute sample rates until 8-2-2-15, long after the 15-minute sample time of the In-Situ logger filled the RAM memory. (We currently have updated the In-Situ ROM memory which allows over 7 years of data at 30- minute sample rates.) The chart above shows exactly 39,999. Data points.

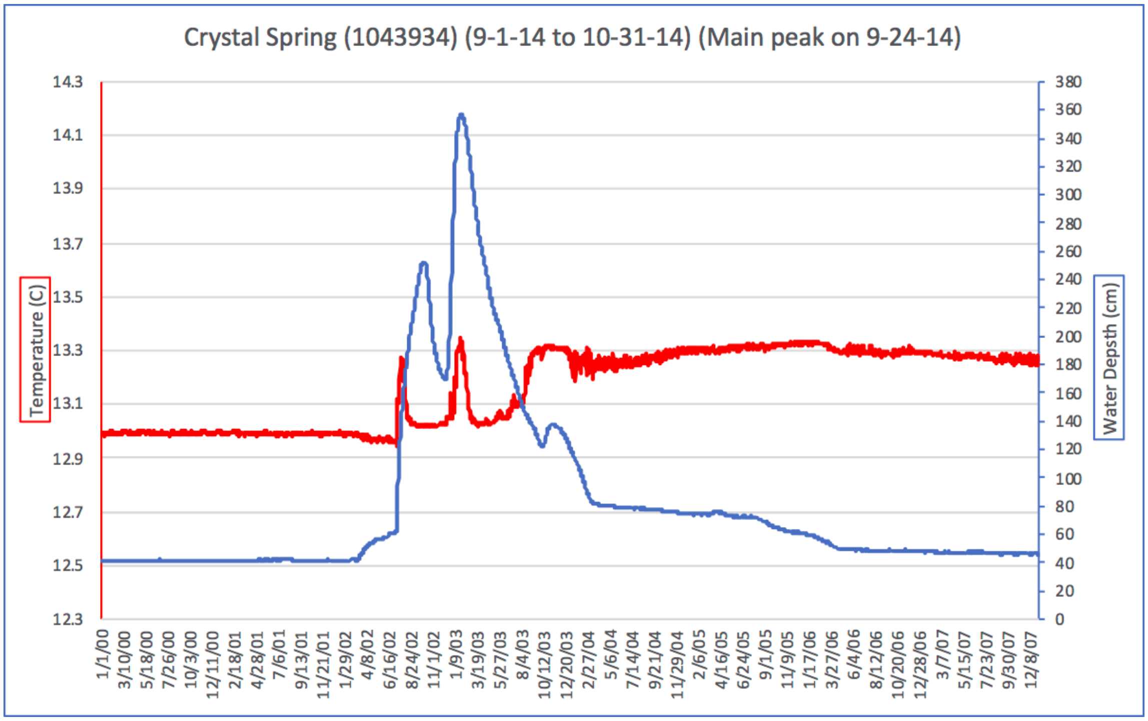


Crystal Spring (1043934) (9-1-14 to 8-12-15)



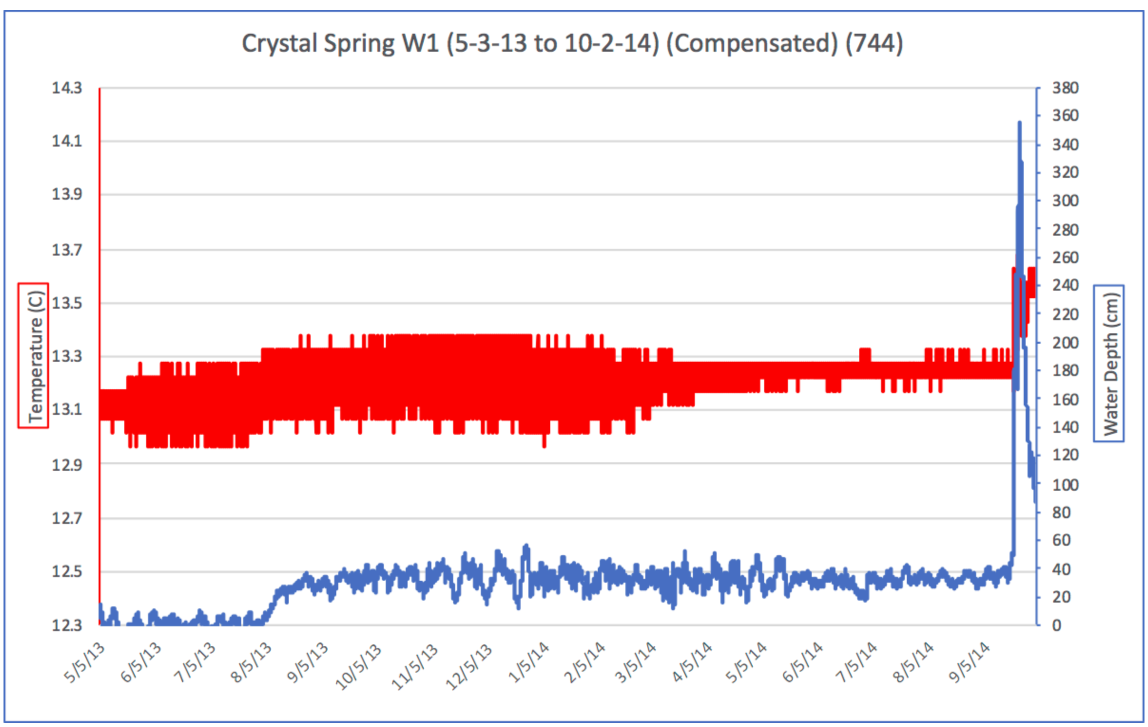
This chart starts just a month before the start of the 4-year Snowy Flow. Although this was a lot of water intro-duced into the aquifer, it tapered off by the end of the year, but was followed by another strong flow starting in the following March.

Crystal Spring (1043934) (9-1-14 to 9-24-14)

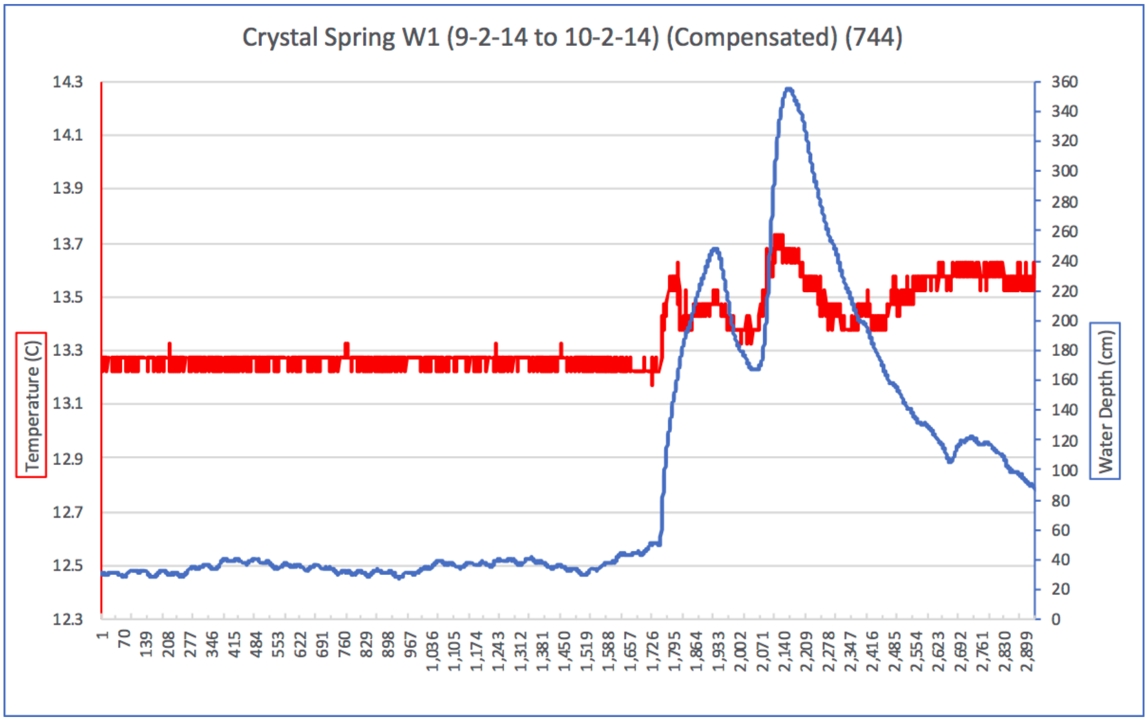


(744) (5-3-13 to 10-2-14)

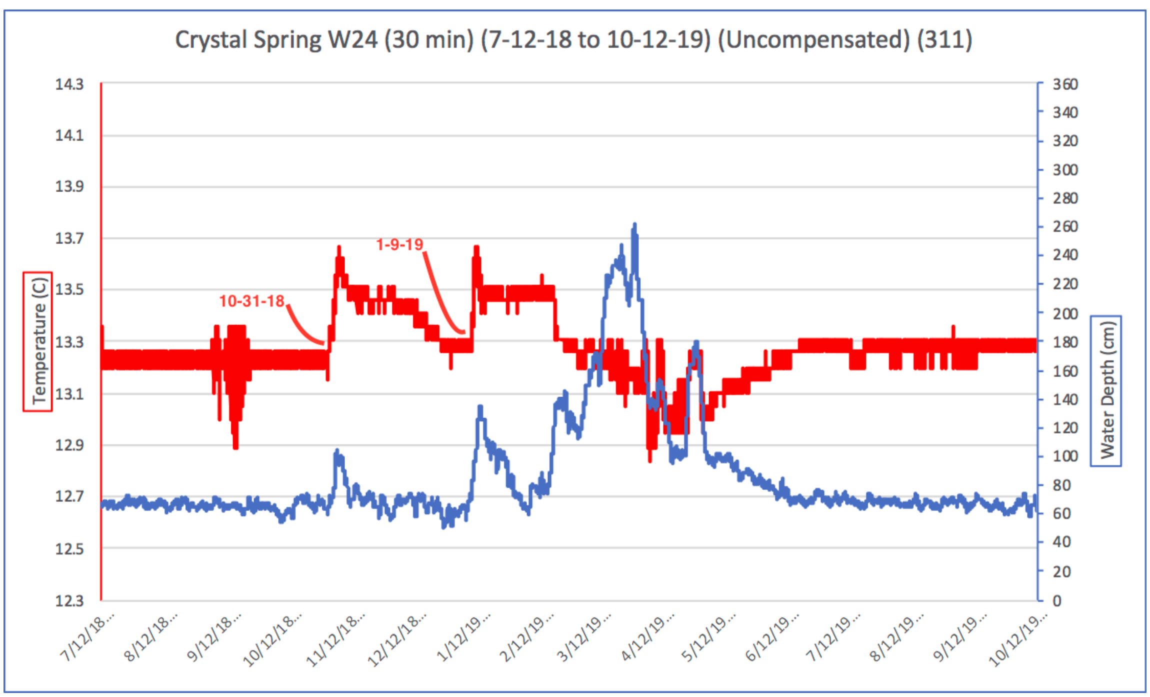
:



(744) (9-2-14 to 10-2-14)

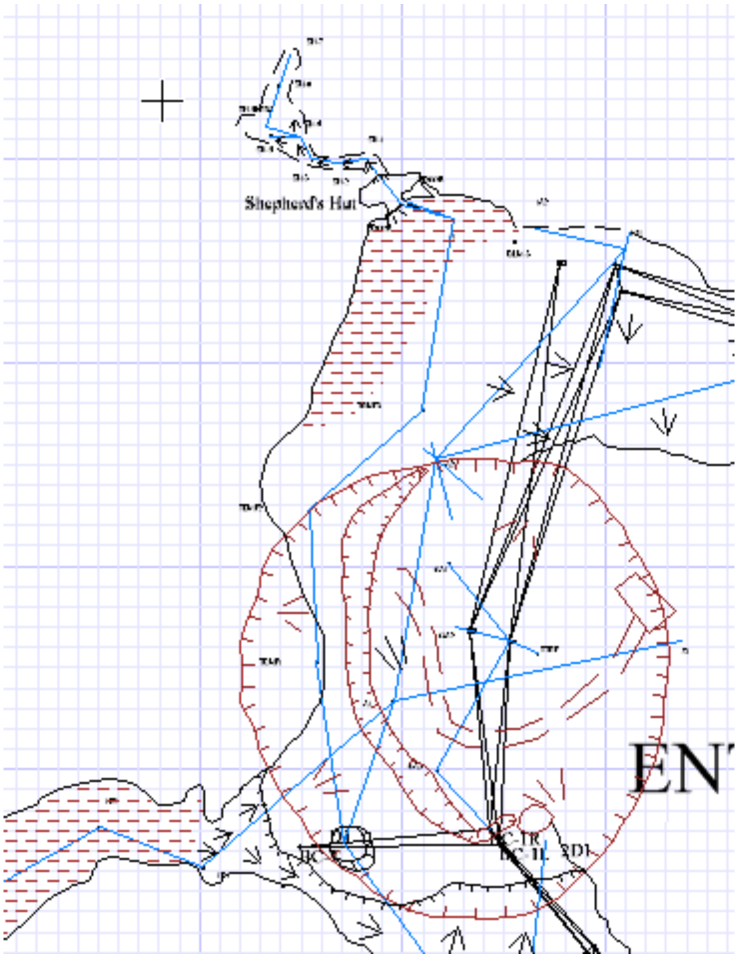


(311) (7-12-18 to 10-12-19)



Main Corridor Logger Array

Entrance Sink:



The Entrance sink is primarily of interest in this data logger report because occasionally we have had baro data loggers at the first overhang over the trail going down into the sink. There is a key brass cap on the surface where the lines converge at the top of the image.

←- The locked gate along the road is located just to the left of this text.

Below that key brass cap is the start of the Main corridor that leads to the Main Cave Gate. Just beyond that is the Wash Tub Room.

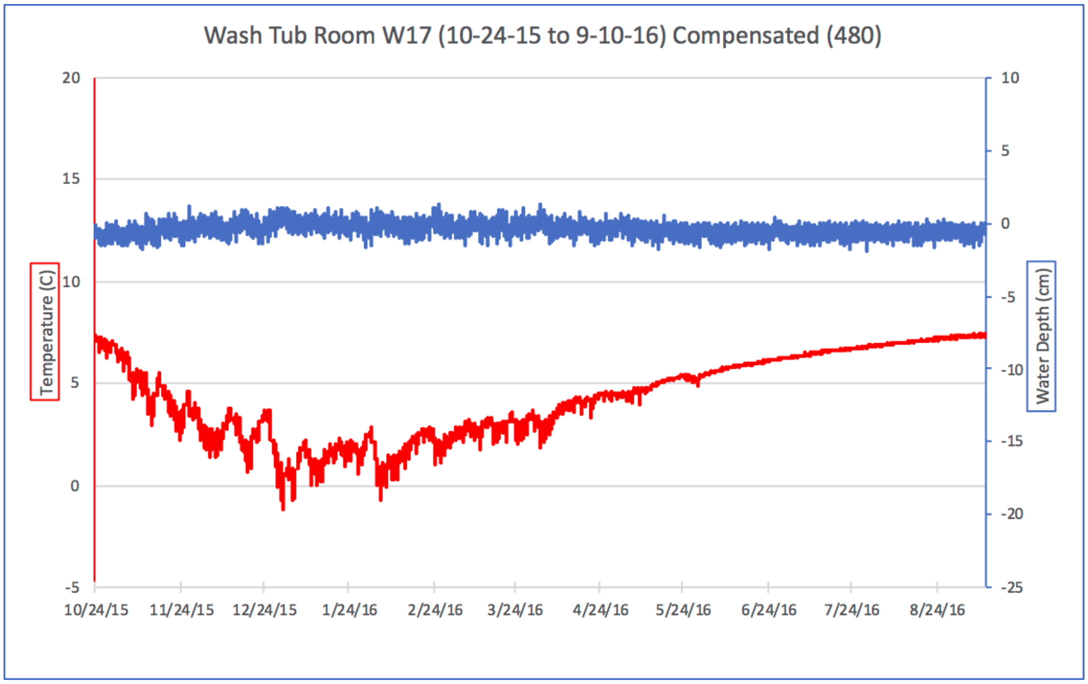
A6, Wash Tub Room:

The Wash Tub Room site is just past the main entrance gate to the cave. This site is used for detection of a possible entrance area storm-water event, most likely detected by a temperature change. A second likely source of water is outflow from the HOTP passage, which crosses the entrance trail across the bottom of this chamber, so named because in the 1960s an old metal tub was left behind by previous visitors prior to the main gate being installed by Southwestern Region cavers. The Baro installed at this site is also used for calibration of other Main Corridor and Snowflake water loggers as well as local surface loggers. (Photo: Lindsley #1056)

The photo (Lindsley #3409) on the right was taken in on April 20, 2015, and shows an apparent waterline from a flow about 3/4- feet deep. Looking across the normally “dry creek” flow coming out of HOTP, and possibly also from the Entrance Sink, the trail heads out towards the entrance. The A6 water logger site is about 20 feet to the left, and is shown in the top photo. Unfortunately, we did not place a logger at this site until after the event that appeared to leave damp evidence of a flow at this location. However, the winter of 2018-2019 did record another possible event which is documented below.

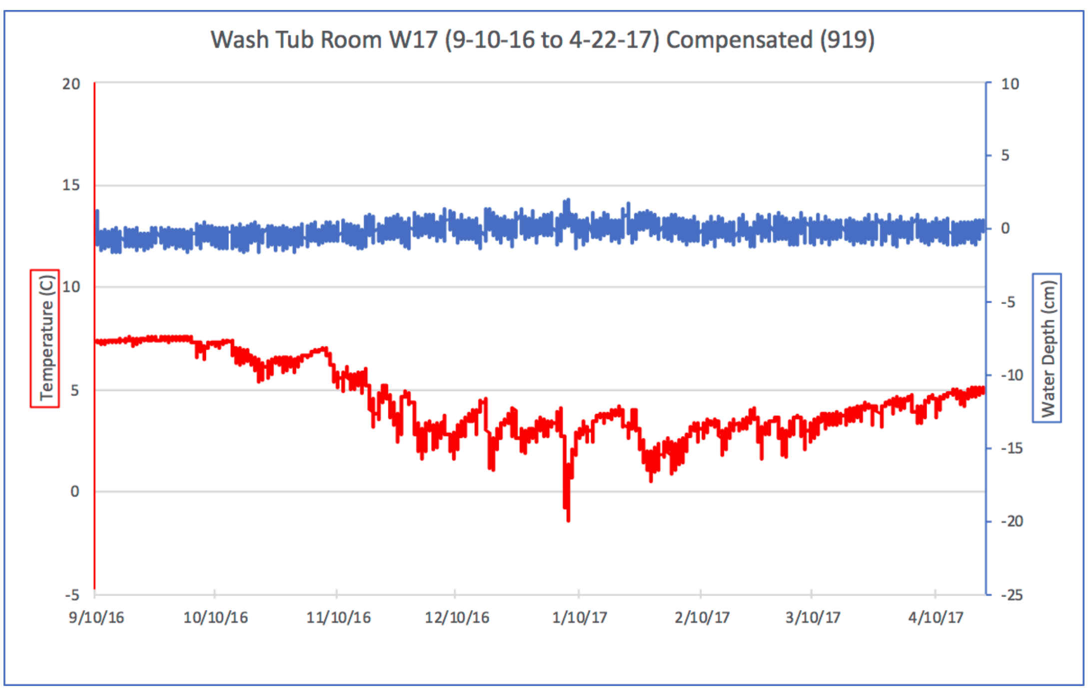
(480) (10-24-15 to 9-10-16)

This chart is typical of most of the charts in this location. There is usually no water indicated, and the temperature follows the surface weather which usually is coldest in January.



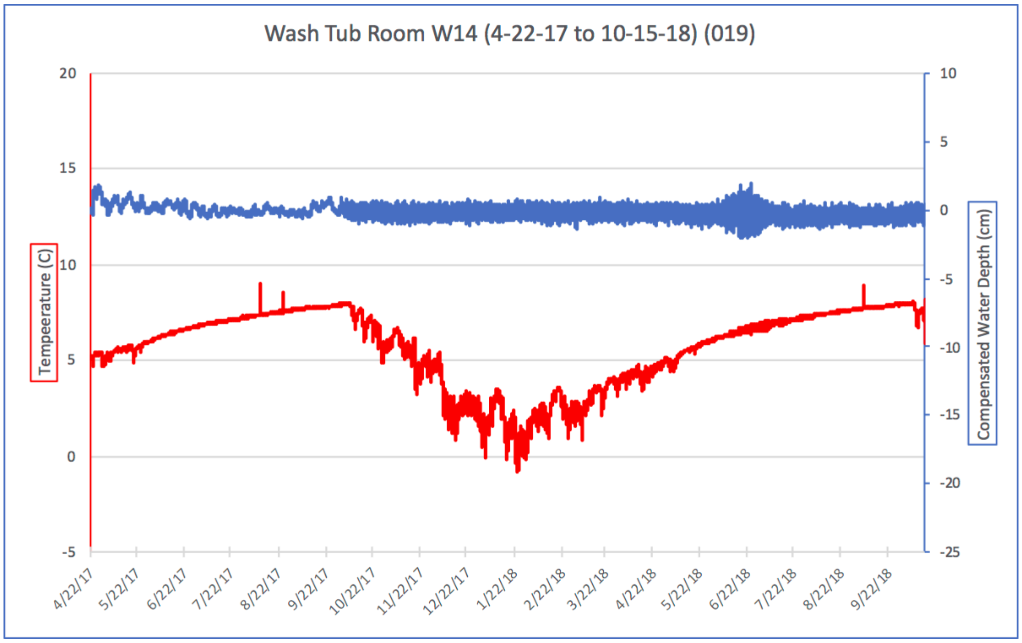
(919) (9-10-16 to 4-22-17)

If the temperature falls below freezing, it is usually for only a very few days.



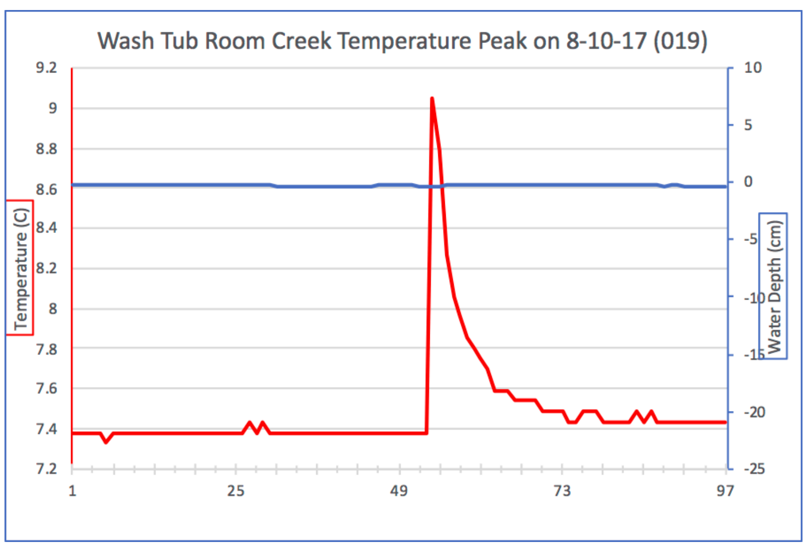
(019) (4-22-17 TO 10-15-18)

This chart shows about 18 months of data at the Wash Tub Room. Since we only had a baro logger in the proper location for the last 12 months, this chart used a nominal 820-mBar elevation pressure compensation from April to Oct. 2017, then used the In-Situ BaroMerge program after that. It is interesting to note that no water flows were detected by the water pressure data from the data logger in the dry creek bed, however a flow probably only 2 cm deep was detected by the temperature data in the creek bed detector. (The companion baro logger was just a few feet away, positioned about a foot above the dry creek bed.) Note the three obvious red spikes in the temperature plot. Between the months of October and May the temperature in the Wash Tub Room dropped sharply and for a short time in January 2018 the temperature was slightly below freezing. This “cold-trap” effect in the entrance area is one of the reasons the cave is closed for bat hibernation November through April, and the bats are often enjoying the cold air that enters the cave during the winter, every time a cold front blows through Lincoln County.

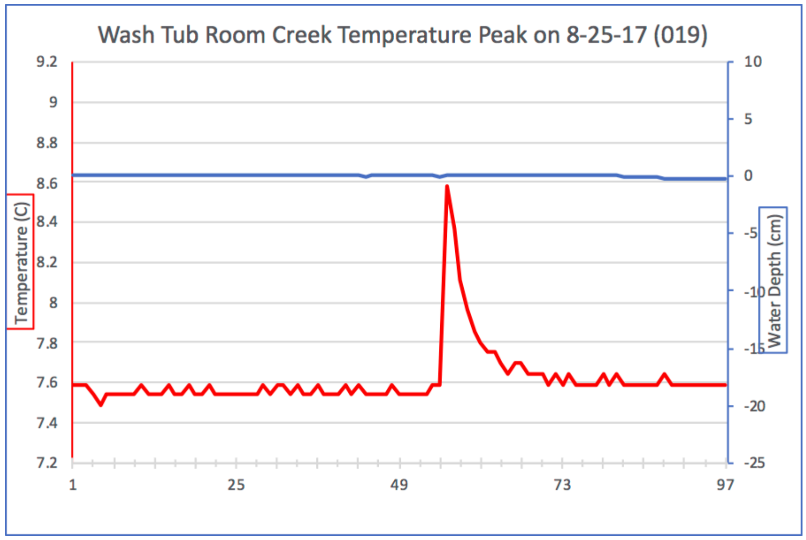


The small temperature spikes that indicate small, short water flows apparently are not seen during the winter months, likely because the weather above is often freezing and any moisture ends up as snow that slowly melts and does not cause an actual water flow.

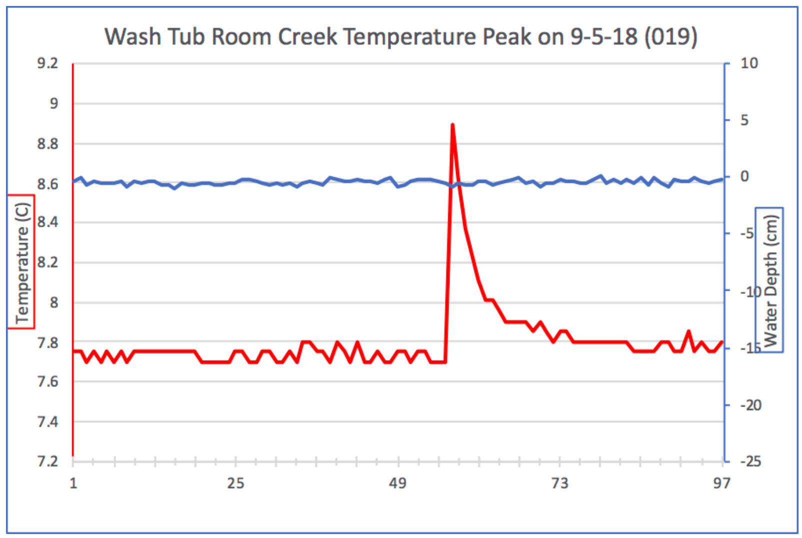
This is probably somewhat like the Snowy River flow caused by melting snow several miles away on Sierra Blanca. It is not unusual for the surface equipment measuring the Eagle Creek flow at the USGS station to freeze up during some winter months, and elsewhere in this report in the Snowy River charts we see a similar spike in the water depth. It is similar because of the sharp rise and then a slower parabolic reduction in the shape of the curve.



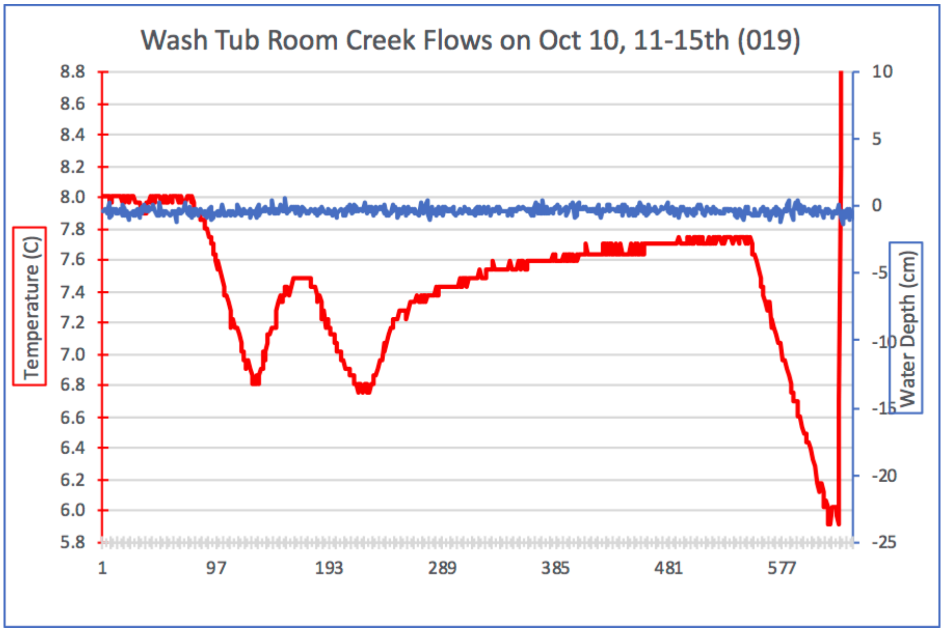
Typically the short New Mexico summer rains appear in the months of August through October, and we notice that same pattern in these three temperature spike charts.



Normally when the water data loggers are replaced with newly programmed units the in-cave units are brought out of the cave and downloaded. This causes a disrupted data line at the end of the data logging sequence because there is an obvious temperature (and pressure) change as the units are placed in a cave pack and brought back to the surface. In the summer months there is an obvious temperature increase once the units are on the surface and before the data logger is stopped when the data is downloaded from the unit.



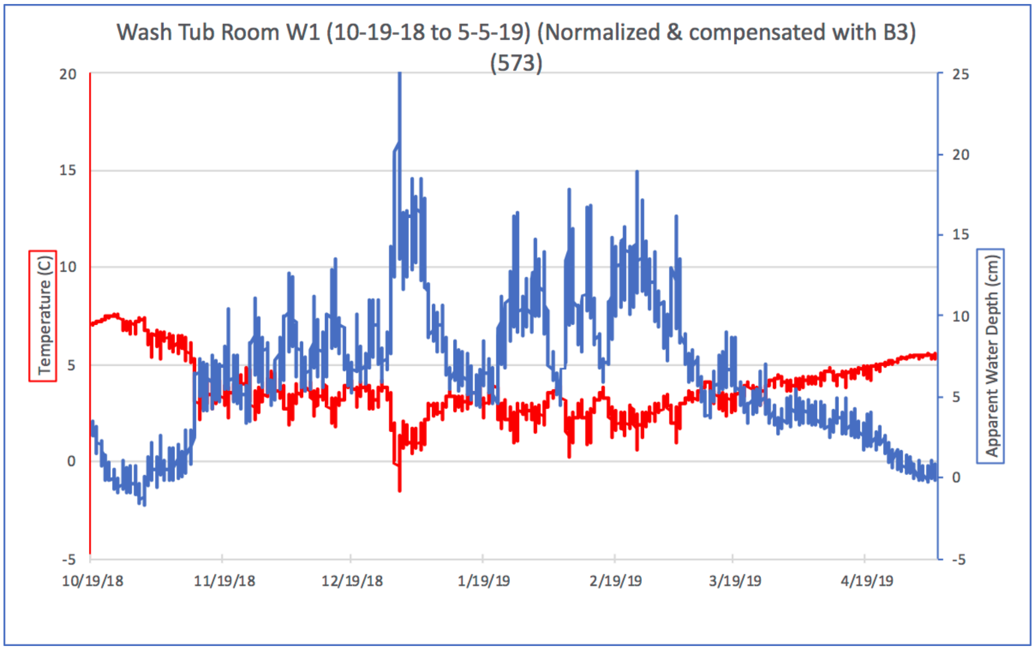
Going back four charts to the first chart of this (019) series you might have noticed an apparent possible “cold flow” at end of the logger record. At first this was assumed to be the point when the data logger was replaced with a new unit, and for some reason the logger recorded a drop in the temperatures. When checking the logger activity with the FSCSP expedition trip logs, we verified the approximate date of the logger maintenance. Checking the associated trip times along with the digital photo records, we were surprised to verify that the apparent dip in temperature was likely due to a small water flow almost a week before the logger maintenance trip. Only this time there appeared to be two small flows followed 6 days later by a sudden, linear temperature decrease of 1.8 degrees C. The bottom of that dip at 6.0 Deg. C correlates with the date of the photo of the logger site taken during the Dr. Lewis Land Science trip to Snowy River on 10-15-18. This was the same trip where we installed Johanna Blake's Schlumberger Mini Diver core-hole logger in Snowy River, two hours later at 14:00.



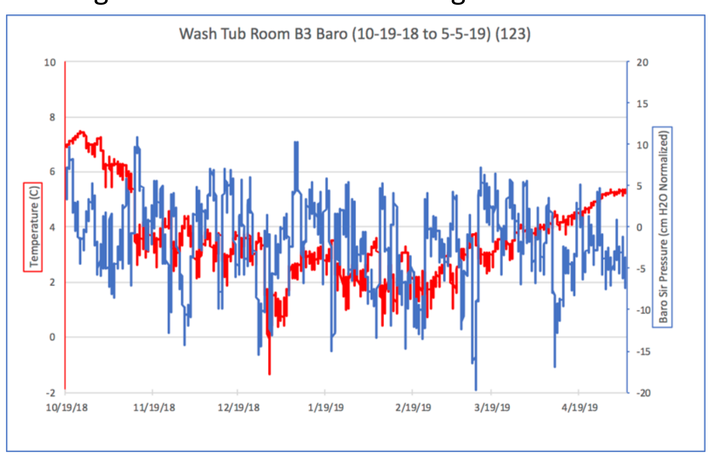
The water flow was so slight, probably less than 2 cm, that at first glance there was no flow of water. However the 6.7-day temperature chart shows that water flowed on Oct 9 & 10th, and stopped flowing on Oct 14th at 18:15. The next day on Oct. 15 the temp reached a low @11:45 when we exchanged the logger and placed the W14 data logger in a pack where the temperature sharply increased from 6.0 degrees C. So why did this temperature not spike up like the three previous charts? One explanation is that the water did not come in from the entrance just 100 meters away, but instead it flowed out of the Hell Of a Thousand Pinches (HOTP) passage and therefore had time to adjust closer to the actual cave temperature. (This was also verified by observation that the HOTP passage had a damp stream channel that led all the way to this logger site location.)

(573) (10-19-18 TO 5-5-19)

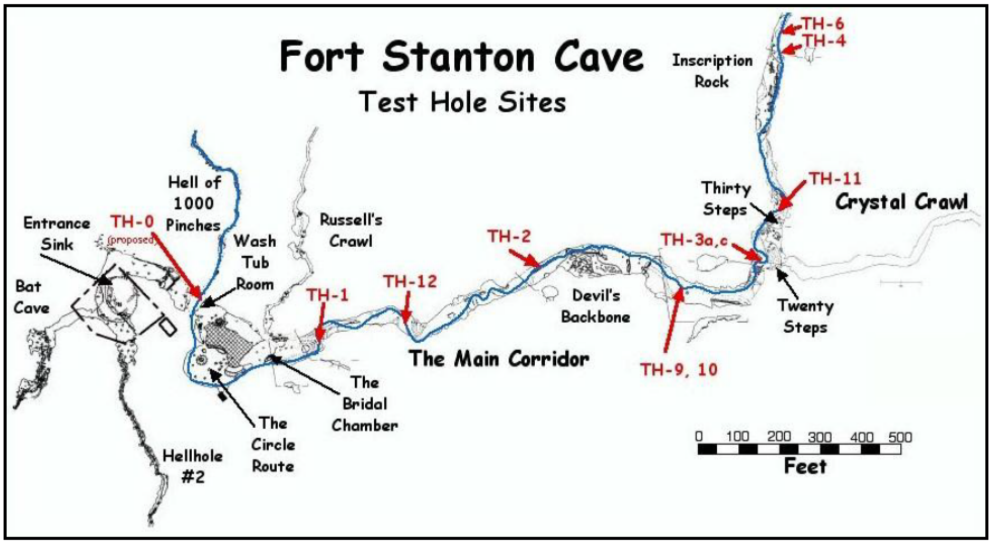
The chart on the right is perhaps the most controversial chart in this report. This is a very unusual chart in that it shows a more significant water flow just inside the entrance in the "dry creek" coming out of the Hell Of a Thousand Pinches (HOTP). The fact that we have apparently identified a very surprising flow out of the HOTP passage just during the winter months when we did not have access to the cave raises questions, but also the ragged water depth response is unlike the other charts in this report. Although this plot was compensated by the near-by baro logger, it indicated a water depth of about 8 cm at the Main Corridor trail during the time two weeks later when the logger was retrieved. Because we "know" there was no water flowing at retrieval time, the overall plot was normalized by lowering the whole plot by 8 cm.



If we go both by the temperature and water plots, it appears that the first flow had a temperature drop of 2.7 Deg. C on 11-12-18, and another 4.2 Deg. C to a level below freezing on 12-29-18 when the water momentarily peaked at 29 cm. These air temperatures are not unusual during the winter this close to the cave entrance, and this cold weather rolling down into the entrance may explain some of the jagged response of the water data logger. The chart for the raw Baro data shows a similar temperature plot (red) along with the air pressure variation (blue) (normalized for the cave elevation). We are looking forward to retrieval of the replacement loggers at this site so that we can see if over the winter of 2019-2020 as well as 2020-2021 we see any additional flows coming out of the HOTP passage passing through the Wash Tub Room.



20-Steps Pipe (TH3a):

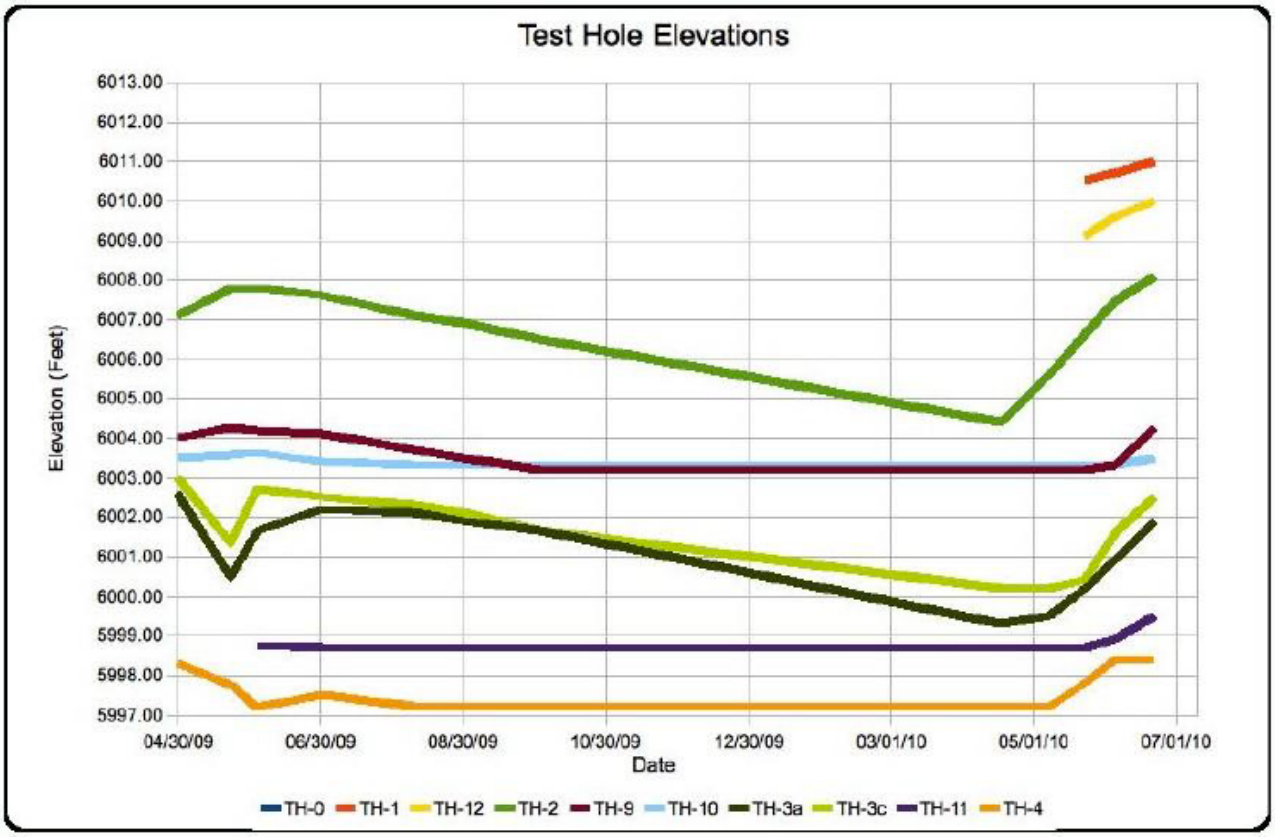


20-Steps is a major landmark in the Main Corridor as the top of the climb is the entrance to Crystal Crawl that goes to the main part of the "Historic Cave" areas. The map (Steve Peerman 6-26-2010) to the right shows a project that drilled core holes in the floor of the Main Corridor and then inserted PVC pipes into the core holes.

These sites were used to track the water depth both above and below the floor level for several years. Finally, when In-Situ water loggers were available, the TH3a was selected as the best location for sub-surface water depths since this pipe penetrated the clay floor the deepest, about 30 feet. (The 2nd pipe just a few feet away hit a boulder just a few feet under the normally dry floor.) When there is standing water in the Main Corridor, there is also standing or running water starting at the Inscription Rock location which goes all the way to Sewer Pipe Landing which is another logger site. The photo on the right (W. Walker #0845) shows the insertion of the PVC pipe into the TH3a core hole on 4-29-2009.

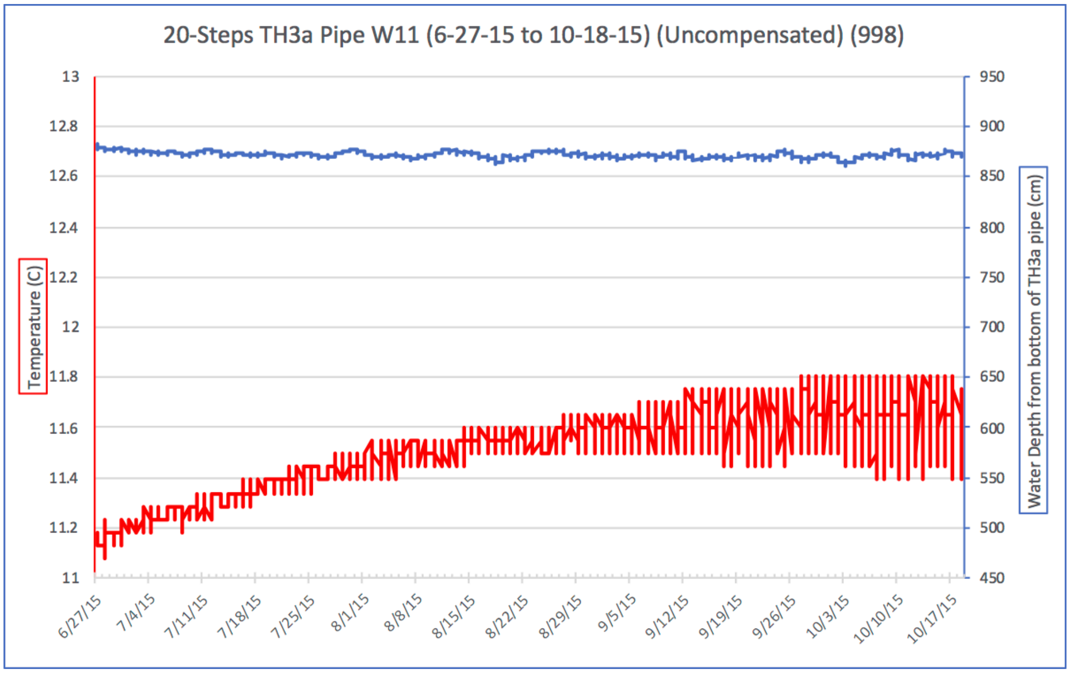
The photo on the left shows both pipes at the 20-Steps location, and in this case, there is standing water on the Main Corridor floor. Wayne positions a logger down the 20-Steps TH3a pipe on 7-2-16. (Photo: Lindsley #1334).

The chart below (Steve Peerman 6-26-2010) shows a series of measurements resulting from the Test Hole Project in the Main Corridor. All these measurements were taken by hand by dropping a measuring device down each hole and recording the apparent elevation of the water surface relative to the reference point at the top of each pipe. Since these measurements were made only a few times a year, the curves assumed a smooth transition between data points. Overall, this data suggested that the water level beneath the floor of the Main Corridor was slowly changing, and that perhaps the insertion of a water logger into TH3a, the deepest floor pipe would yield higher resolution data. The elevations shown in the chart below were referenced to a single point at the TH0 location, and should be treated as relative water levels over a period of time covering 2009 - 2010. The following water logger data is the actual depth of the water from the bottom of the hole.



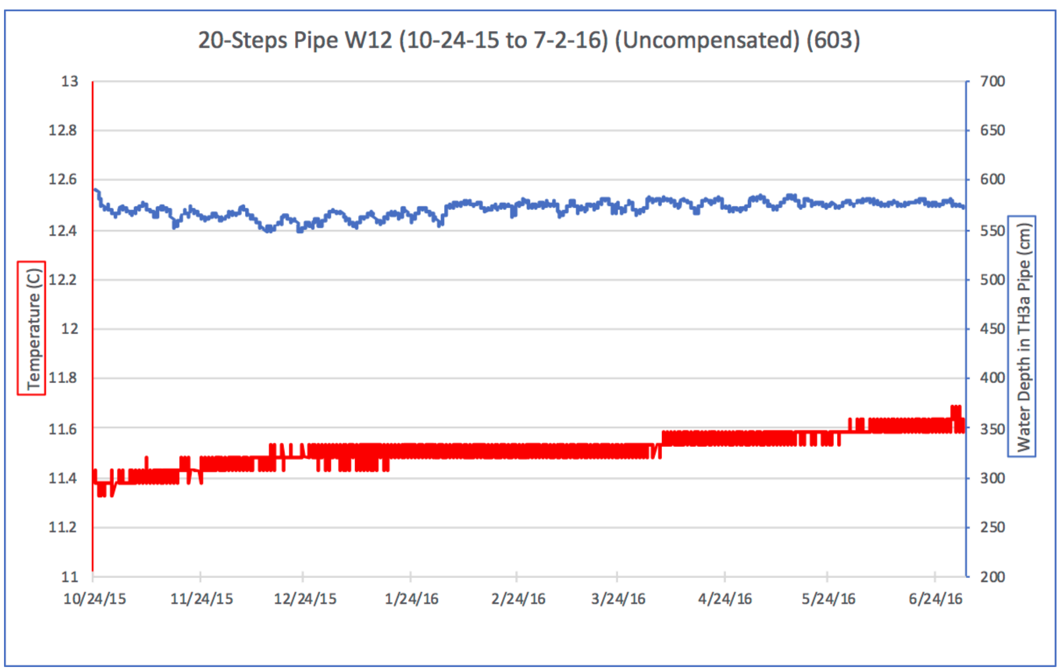
The first In-Situ water logger was placed in the TH3a hole, the deepest hole, and showed a water depth of 28 ½ feet of water.

(998) (6-27-15 to 10-18-15)



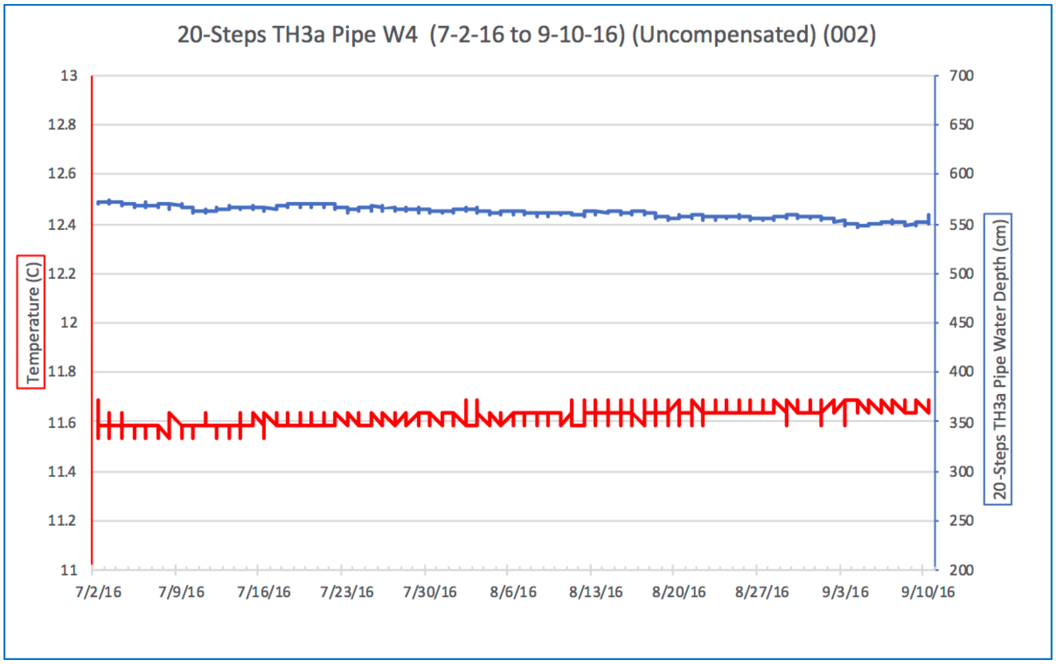
The first logger chart in the TH3a hole shows a slowly decreasing water level. It also shows a warming of about 0.5 degrees C over about 4 months. The nylon cord that was tied to the logger had a knot placed at the top of the cord positioned at the edge of the PVC pipe. The intent was to be able to repeat the logger location in the future.

(603) (10-24-15 to 7-2-16)

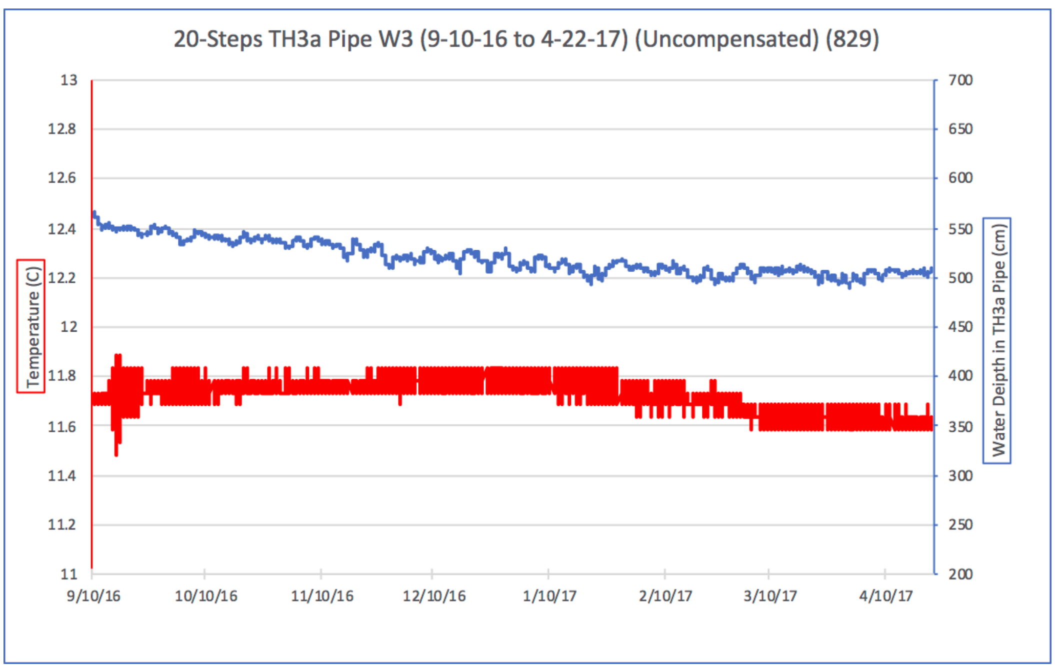


When the first W11 logger was replaced by the W12 logger we noticed that the bottom of the logger was slightly "stuck" to the bottom, and when the logger was extracted from the pipe there was a conical shape of semi solid clay attached to the bottom. We believe this could be infiltration of muddy water from the unknown sub-surface flow. Since we do not yet have any local Rio Bonito water depth data, it is difficult to understand the data from the TH3a pipe at this time.

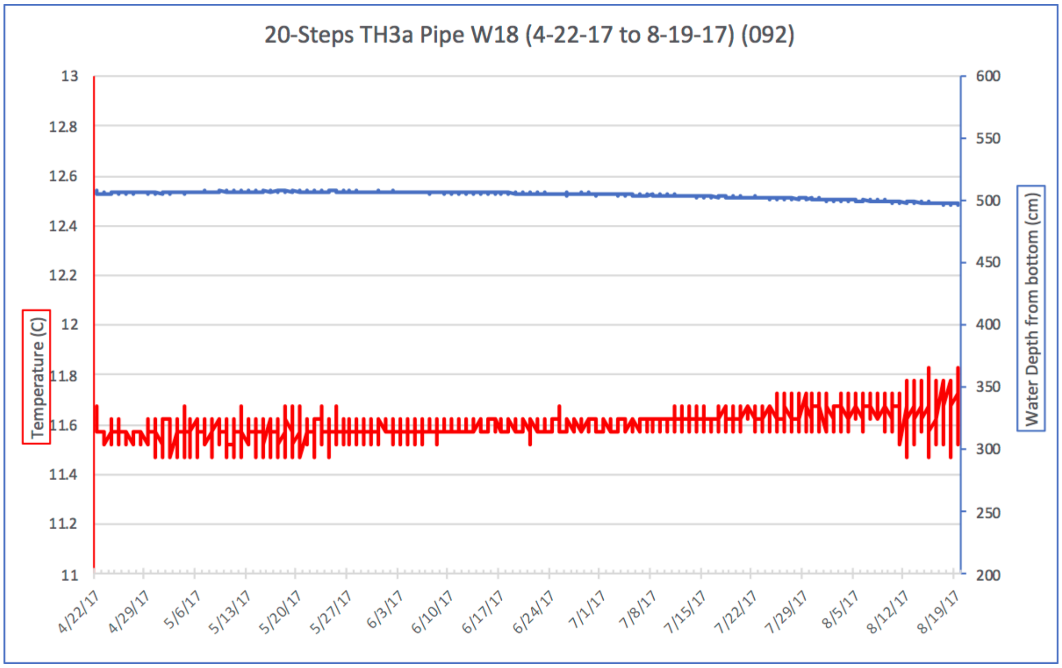
(002) (7-2-16 to 9-10-16)



(829) (9-10-16 to 4-22-170

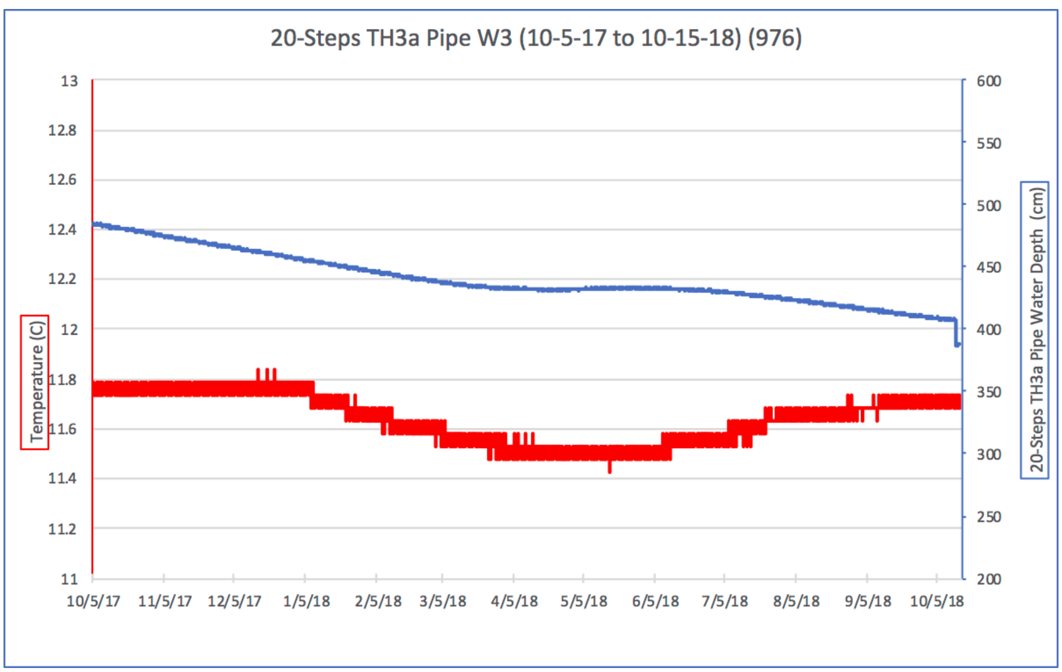


(092) (4-22-17 TO 8-19-17)



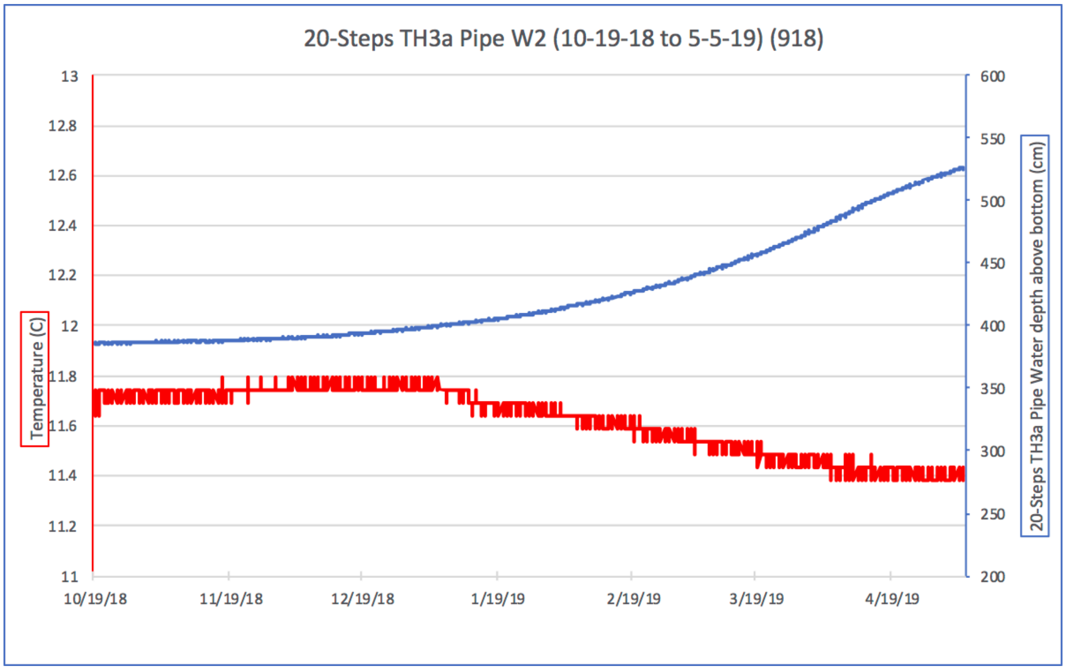
(976) (10-5-17 to 10-15-18)

In this chart we finally begin to see a more rapid change in the water level as the Main Corridor dries out.



(918) (10-19-18 to 5-5-19)

Rainfall starting in December 2018 may be starting to infiltrate the aquifer that supplies the water below the floor of the Main Corridor.



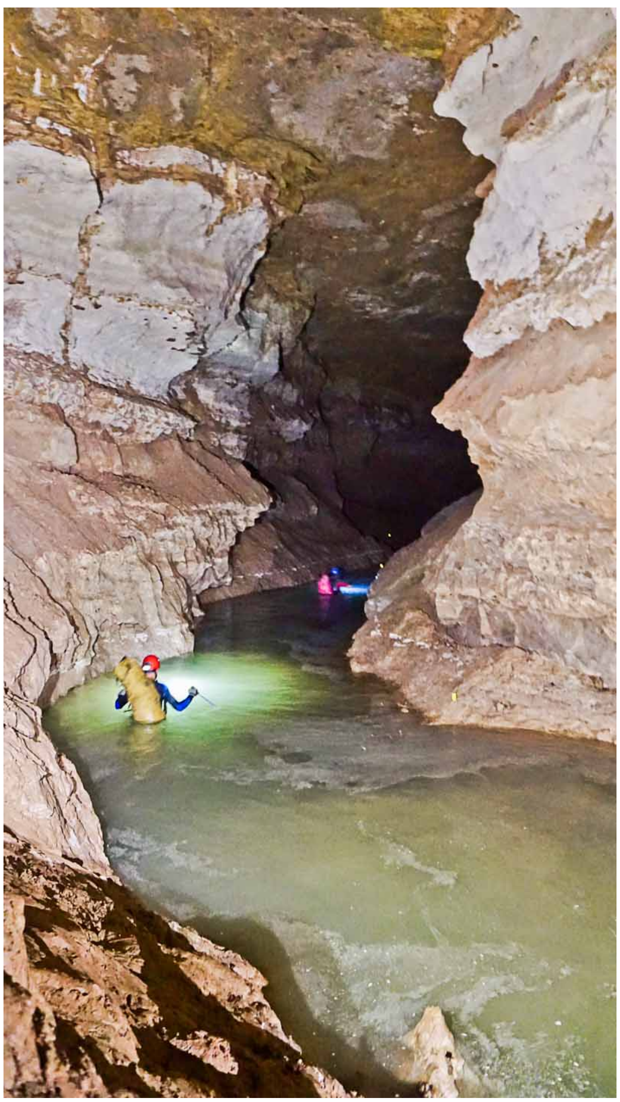
Sewer Pipe Landing: SW-1 (Logger elevation is below DD-1 brass cap reference)

This site provides constant monitoring of the "deep water" which is backed up from the Fool's Crawl Sump. We are relating this water depth to other observed water depths just below Inscription Rock, where most visitors wear wet suits during high water trips. The deepest monitored water level at Sewer Pipe Landing (SPL) is about 7 feet deep. When the logger was first installed at this site, a small raft and inner tube flotation were used to safely enter the cave. At other times when the Main Corridor and Conrad's Branch is flooding, wet suits and sometimes an inner tube is used for safety. (Photos: J. Hunter #5655 on left, Lindsley #1032 above right)

The climb out of the deep water to the "landing" is facilitated by a ladder, the top of which is usually above the waterline. During long durations of flooding, it is common to see calcite "rafts" that seem to collect at the Landing, probably due to a very slight water flow through the downstream Sewer Pipe, which leads to Snowflake Passage through "Fool's Crawl". Exactly where the water drains is not yet known, although a dye test by Buzz Hummel, BLM Cave Specialist, indicated that the dye deposited in the Rio Bonito appeared in the Main Corridor, and finally exited the cave via Government Spring.

We now know that the elevation at Sewer Pipe Landing is only slightly above the elevation at Turtle Junction, and therefore when Snowy River is flowing we suspect that the drainage of Conrad's Branch is significantly retarded. Currently there is an array of loggers at approximately the same elevation, at SPL, Snowflake Passage, Turtle Junction and several more just downstream from Turtle Junction. Our goal is to use data from this array to better understand the hydrological relationships between these two major water sources in Fort Stanton Cave. There are numerous levels of calcite "bathtub rings" at the SPL location, as seen in the photo (Lindsley #4473) on the right. Today there is a fairly obvious calcite line between the floor of Conrad's Branch below Inscription Rock, where many early explorers probably stopped due to high water, that continues all the way to SPL. These upper lines above this major calcite line were likely caused by even more significant Main Corridor flooding than we have seen since the discovery of Snowy River.

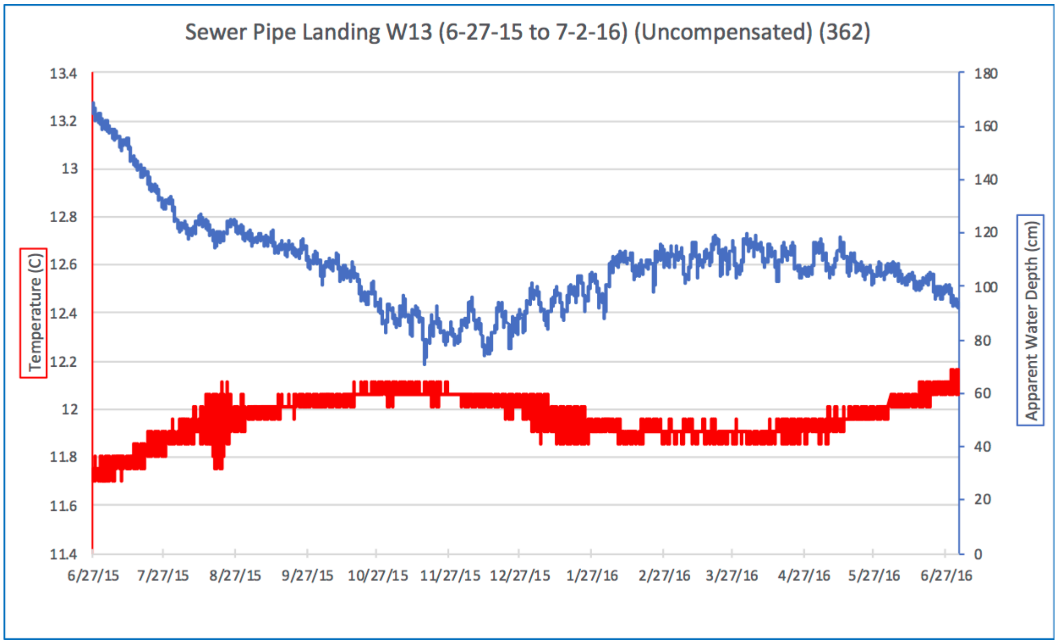
Starting in 2018 we began to realize the importance of a better elevation survey between the DD-1 precision survey brass cap located about 20 feet above the SPL logger site and the Turtle Junction logger site on Snowy River. The photo on the right (Lindsley #4442) shows the team connecting DD-1 to the elevation at the exact logger elevation using a modified "Palmer Pole" water tube technique. Shown L-R is Talon Newton, Henry Schneiker and Wayne Walker, who made multiple elevation surveys between DD-1 and the TJ Brass Cap during 2018 and 2019, each time improving the process and resulting minimization of the elevation closure error. The above photo was taken from the top of the aluminum ladder, as was the Conrad's Branch photo (Lindsley #6574) on the left taken on May 5, 2019, just a year after the passage was dry. The expanse of the Main Corridor is very impressive, even when you are wading in cold water. Look closely and you will see the "surface scum", which is actually calcite rafts floating on the surface. This photo is looking towards the cave entrance, which is at the far end of the Main Corridor and Conrad's Branch.



Stan Allison was ready to hit the water on 6-27-15 during one of the deepest floods we have monitored. Beth Cortright (#0744) shot this photo as she and James Hunter prepared to launch their high-tech raft, near the resting place of the wooden boat that explorers used in the 1860s.

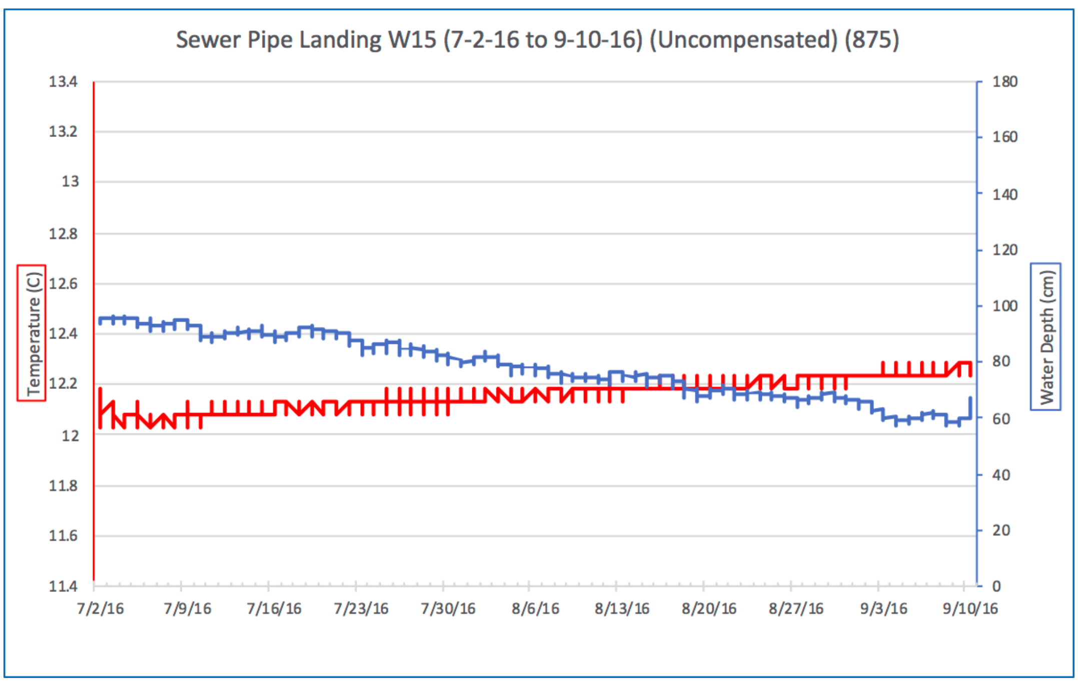
(362) (6-27-15 to 7-2-16)

This logger was installed at Sewer Pipe Landing by James Hunter, Beth Cortright and Stan Allison using the flotation equipment shown on the previous page. The water level was steadily, declining. But we suspect that in the past the water levels were higher during extremely wet periods.

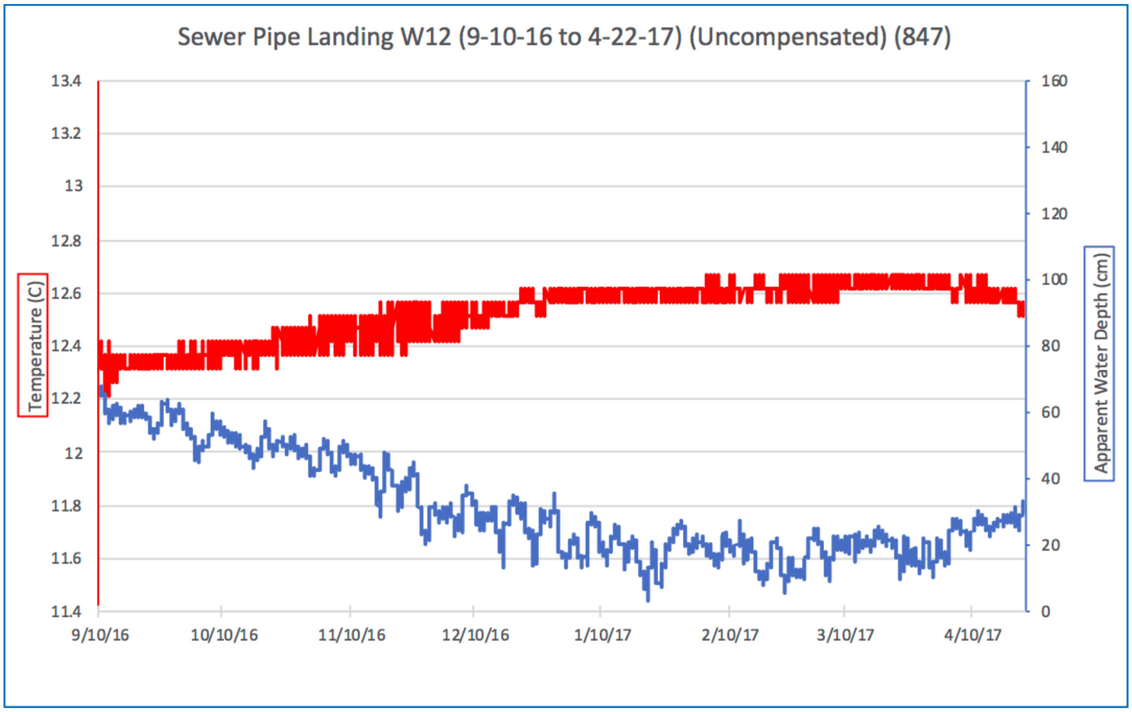


(875) (7-2-16 to 9-10-16)

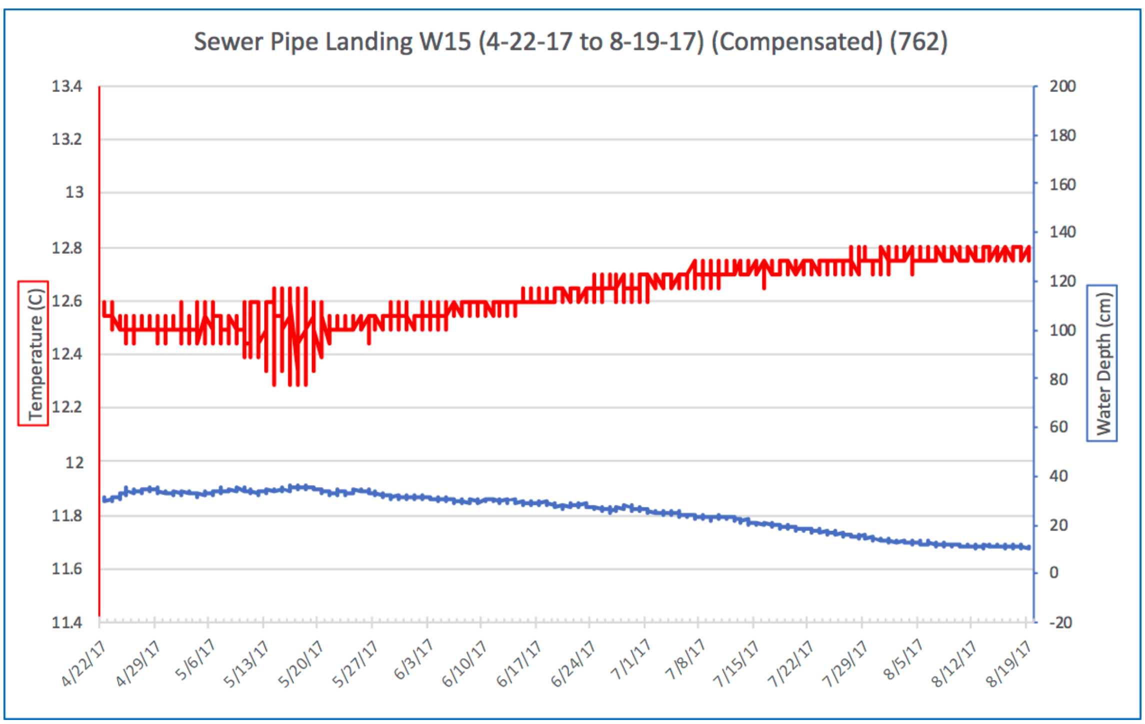
This chart covers just two months before being replaced with another logger to cover the winter season when the cave is closed for the bats.



(847) (9-10-16 to 4-22-17)

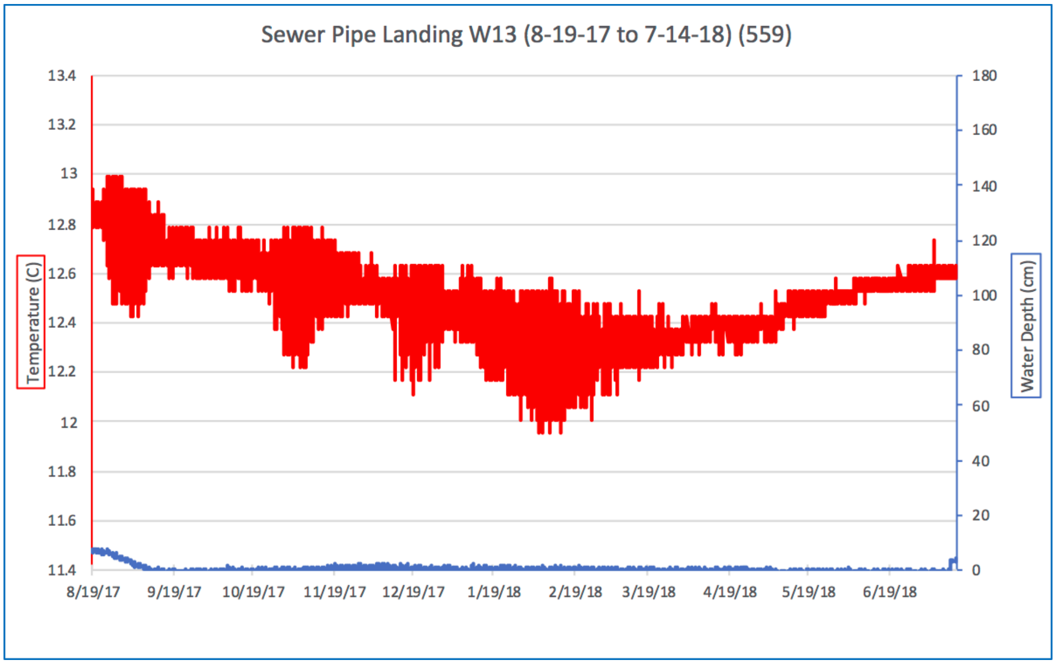


(762) (4-22-17 to 8-19-17)



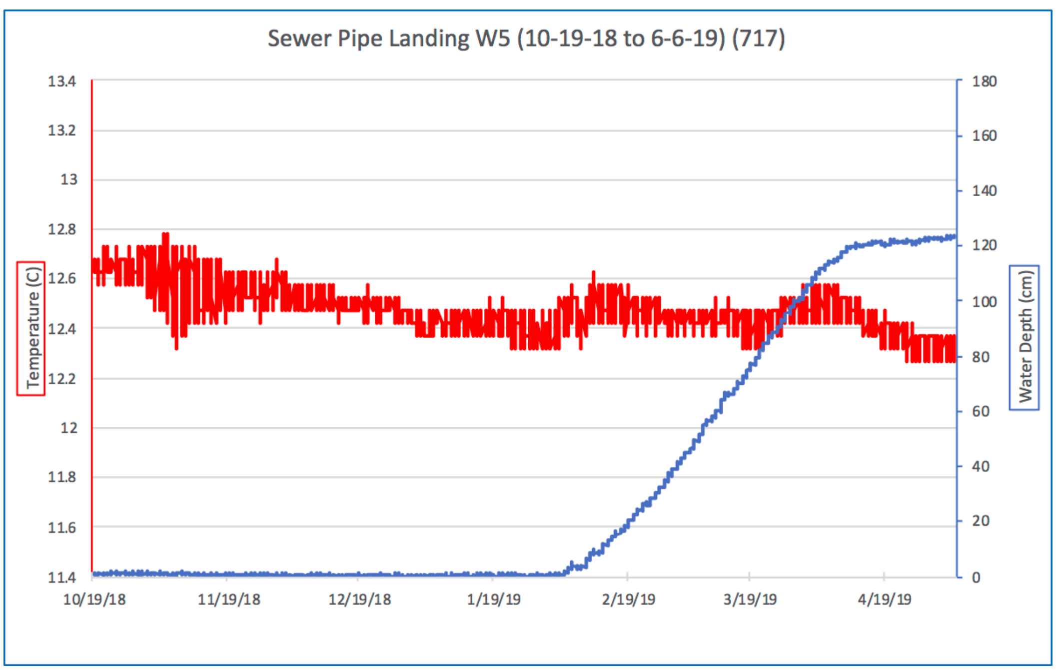
(559) (8-19-17 to 7-14-18)

Finally the water level at Sewer Pipe Landing dropped to ankle depth during the summer of 2017.



(717) (10-19-18 to 6-6-19)

This chart is the first data we have that shows the rate of water depth inicrease. After January rains in 2019 the depth increased 120 cm in just a couple of months.



Z9, Snowflake Passage:

Snowflake Passage is normally entered from the Sewer Pipe Landing (SPL) area through Fool's Crawl ONLY when this far side of Conrad's Branch is not flooded with water. (A high-level cut around, developed during the Priority 7 Dig, was used in July 2016 which found flooded passages which were obviously at the same elevation of the flooded passage at SPL.) This high-level passage also connects to the Priority 7 passage, the original discovery route of Snowy River. The pictures below show a flooded Snowflake Passage on July 2, 2016, near the site of the future logger, the approximate location shown in the square photo. (Photos: Lindsley #1839 & #1826)

Justification for this site is to learn more about the likely hydrological joining of this site, which is assumed to be fed by the Rio Bonito via Conrad's Branch, with the Snowy River Passage, which is essentially fed by Eagle Creek. Apparently, this possible Snowflake to Snowy River connection is a very tight, slow-flowing constriction that so far has no obvious joining point with the adjacent Snowy River Passage

Recent precision elevation survey work between SPL and Turtle Junction has proven that their relative elevations are about the same. We hope to answer the question of a possible hydrological connection between SPL, Snowflake, and Turtle Junction using flow timing including water depths and temperature. The photo above on the right (Lindsley #5770) is a "sinkhole" on the west bank of Snowy River near SRN29. The team is comparing the clay bank upstream with the small sink just in front of them, while discussing the possibility of such a unique feature being related to drainage of Conrad’s Branch through Sewer Pipe Landing.

Surface Logger Locations

USGS Eagle Creek Gauging Station: This USGS monitoring station has provided a significant amount of valuable data for an upper portion of Eagle Creek. Steve Peerman has used the almost real-time flow data from this site to correlate the timing of the arrival time of Snowy River at Turtle Junction in the cave for the known Snowy River flow since 2016. Appendix 3 provides additional information on data from this USGS station.

Eagle 1:

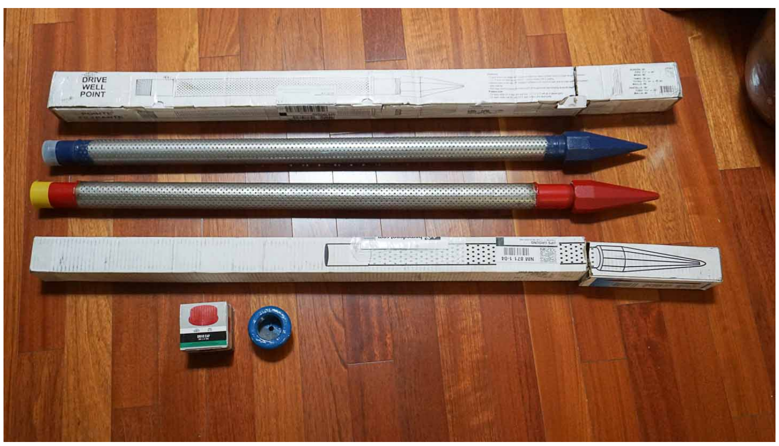
Following a public outreach presentation on Fort Stanton Cave and Snowy River, presented by the FSCSP in Ruidoso, the owner of this section of Eagle Creek came forward and commented on his observation of the initial Eagle Creek flows after a dry spell. Visiting the site in person, the FSCSP located several "cracks" in the creek bed upstream of this location where we considered the possibility of insurgences during times of constant Eagle Creek flow.

A couple of years later, after our research turned up a significant hydrogeology report published in 2010 [*Hydrogeology, Water Resources, and Water Budget of the Upper Rio Hondo Basin, Lincoln County, New Mexico, 2010*], we decided to investigate this interesting area in greater detail. Scott Christenson, retired USGS hydrogeologist, was able to support additional stream flow measurements using a calibrated ADV instrument on loan from the USGS. After contacting numerous private property owners along Eagle Creek, Scott and Steve spent several days during an Eagle Creek flow measuring the stream flow in the next creek section two miles downstream from the Eagle 1 site, confirming that approximately 2 cfs of the flow at this location was "lost" into the ground in the same area mentioned in the 2010 Hydrogeology report.

The Eagle 1 site is about a mile upstream from what we call "Eagle's Mouth", an obvious area of stream piracy. The data logger position is in this rocky area about 20 meters upstream from what appears to be a fault zone where fresh flows in Eagle Creek appear to stop for more than a day before filling what we believe is a shallow aquifer, which seems to allow the flow to continue on downstream after it is filled. Pictured in the photo (Lindsley #9954) (L-R) are Dr. Johanna Blake, Wayne Walker and Knutt Peterson. A possible fault area is just above Wayne's head, and Knutt is standing on the right-hand bank of the stream.

Shortly after a Hydrogeology Field Trip sponsored by the FSCSP in 2017, we decided to install a water level data logger in Eagle Creek. The photo on the right was taken during a field trip on October 16, 2017, where we visited Government Spring and several private properties. The photo (Lindsley #2685) shows some of the participants of the Fort Stanton Hydrology Working Group at the possible insurgence site we named "Eagle's Mouth". Discussions at that time included future dye tests and the need for more Eagle Creek data. The following spring, after negotiations with the private property owner, we acquired permission to install our water logger near the upstream location of the suspected insurgence zone.

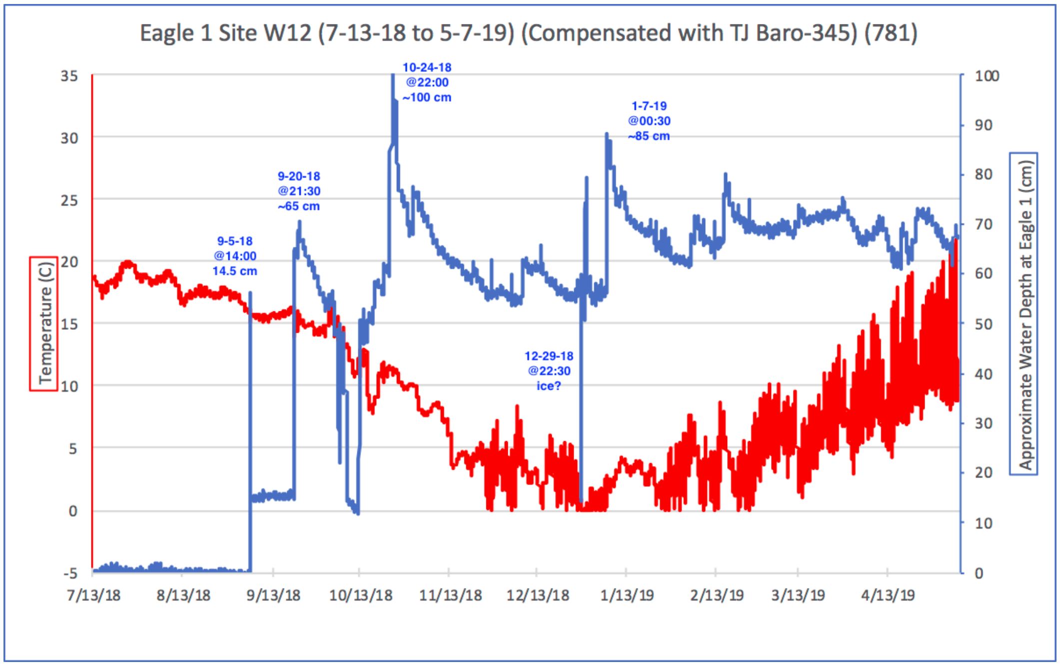
To properly install a data logger in an active stream bed often requires a significant structure to provide security protection of the equipment and at the same time protecting the logger from possible flood events that are known to carry large logs (2 feet in diameter, and 20+ feet long) down a stream. In the past, on the Rio Bonito, even simple metal staff gauges secured to metal fence T- posts with guy wires have been washed downstream over ½ mile from the Rio Bonito site adjacent to the Field House. Following discussions with several hydrologists, we decided to use an easily available device called a well point, shown in the photo on the left. The 3-foot steel pipe is perforated with many small holes which allow the water pressure to transfer to the water logger inside the bottom of the pipe. The bottom of the pipe has a cast iron "well point" attached which might be useful for sandy soils, but is of little use in heavy rocky soils in the Fort Stanton karst area. The blue pipe cap in the photo is a special hardened "drive cap" that can be used in some situations where you need to protect the upper pipe threads from damage. (Photos: Lindsley #4344 & #2419)



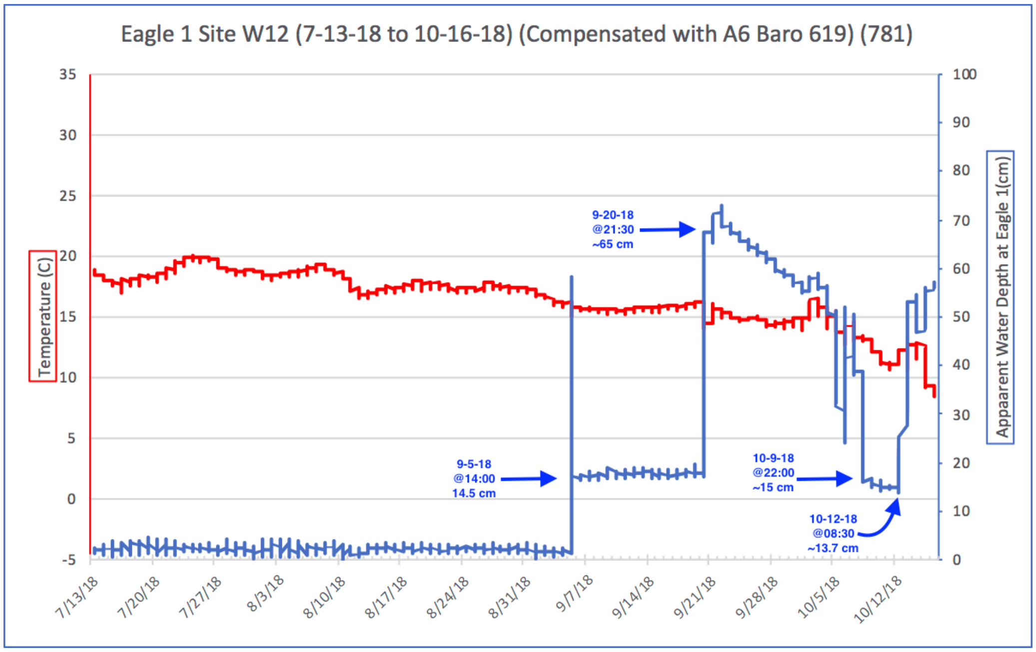
However, since the stream bed of Eagle Creek was so rocky, with many boulder-sized rocks, the installation process involved finding a site where we reached a 15-inch deep hole below the stream bed could be implemented next to some larger boulders that could be used to secure the top of the well point with a steel strap bolted to the boulder. The photo shows John Moses and Wayne Walker assisting the installation of the Eagle 1 data logger station. A standard pipe cap closes off the top of the well point after the data logger is inserted. Dual loops on the logger are used to retrieve the unit with a simple bent-wire coat hanger.

(781) (July 2018 to May 2019)

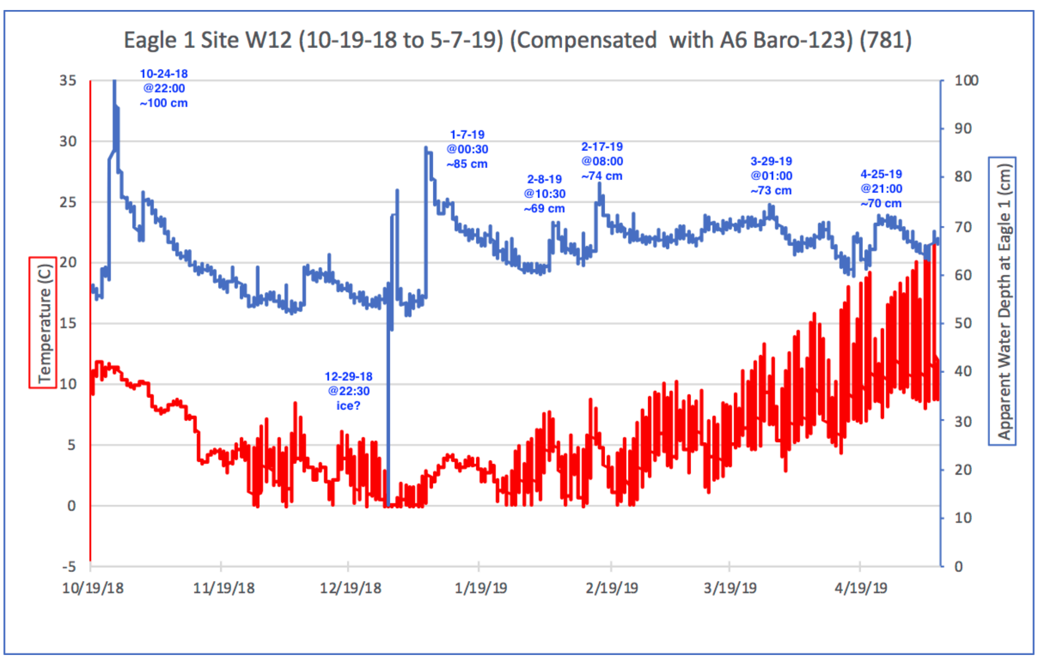
Understanding stream data logging can be quite challenging, more so than in a cave where you have a single channel with obvious upstream and downstream flow directions at the site. Besides the expected variation of barometric pressure that needs to be corrected if you want more precise data, you are faced with a much wider range of temperatures which includes both air and water temperatures for an intermittent flow. If the water logger is near enough to the surface to experience freezing conditions during deployment, water freezing in the tiny pressure sensing compartment of the data logger can cause loss of data, or in extreme cases it could permanently damage the data logger. The Eagle 1 site has all these issues. Due to a lack of available baro loggers, it was decided to deploy three surface loggers and simply rely on the baro units in the cave to provide the water level compensation. At first we processed the data using the single baro unit a mile deep in the cave at Turtle Junction to yield the full chart shown above. By using two other baro loggers near the cave entrance (which is still 11 ½ -miles away as the bat flies) we were able to get slightly better data smoothing and is shown on the two following charts. The photo (Lindsley #2158) shows the water flow on 5-9-19 when the logger was retrieved. The logger reference point was about 15 inches below the dry creek bed.



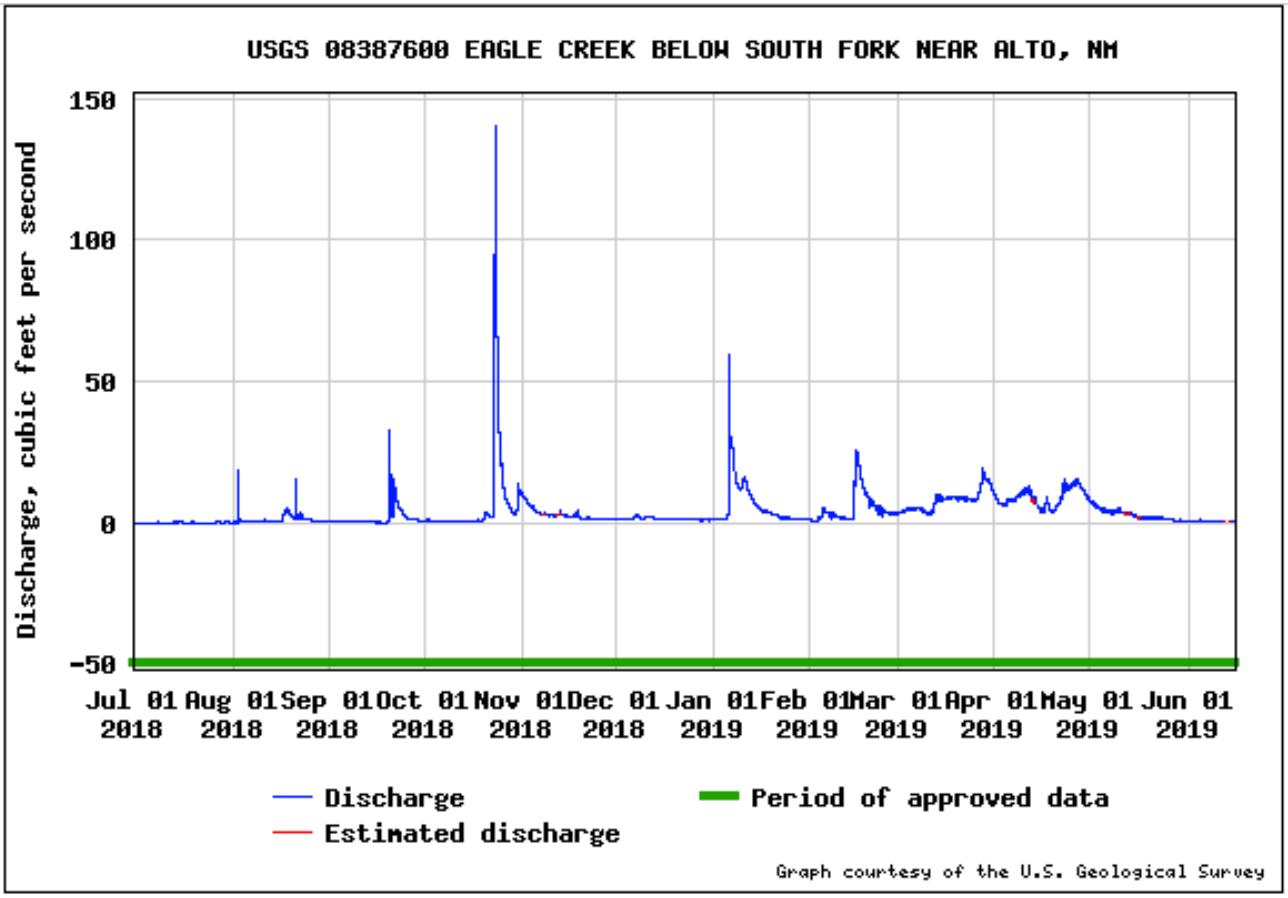
Looking at the 10-month long chart above we can see some interesting possibilities of correlating the data logger chart with local rainfall and temperature data. The USGS station is about 4 ½ miles away at a higher elevation, but unfortunately it does not have temperature data available. The Ruidoso airport is about 9 miles away and there are several other private weather stations that have sporadic weather data available that could be correlated in the future. The chart above has notations for several water level “spikes” in the data, and the note for 12-29-18 near the center of the chart shows a point of “bad data” caused by the freezing temperatures at the data logger location.



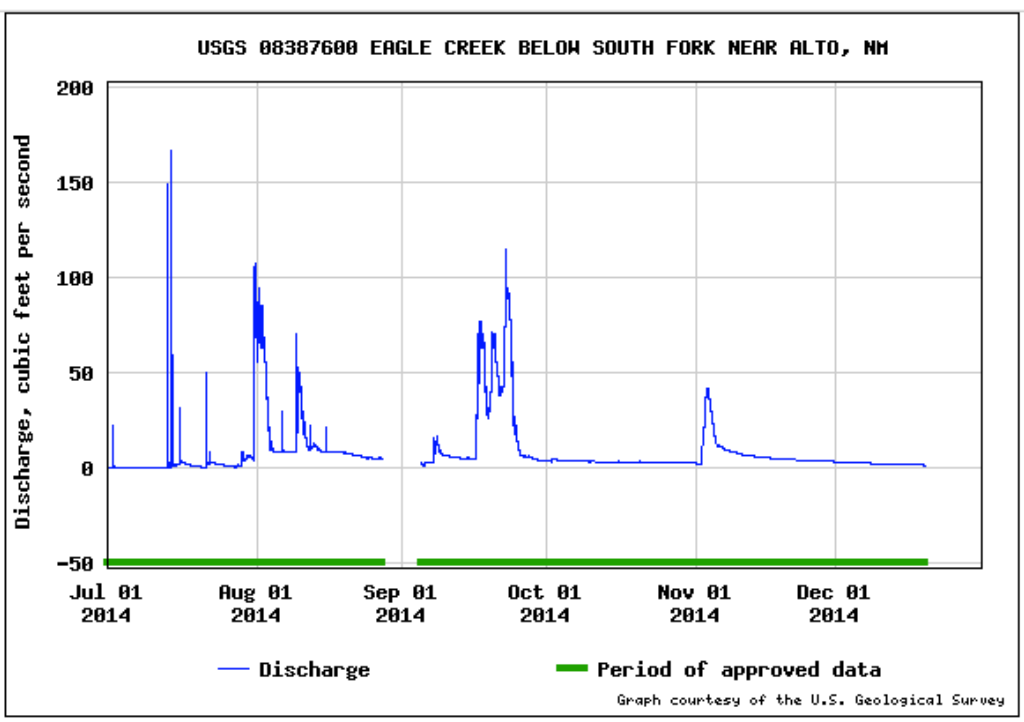
The 2nd chart for the Eagle 1 site was compensated with a baro logger just inside the entrance of Fort Stanton at station A6. This chart, which covers the 3-month span between 7-13-18 and 10-16-18, shows an interesting phenomenon we believe could be associated with a shallow aquifer in the Eagle Creek area. The creek bed was dry when the data logger was installed and the chart was normalized for this condition by using an elevation difference factor that forced the apparent water depth to zero. Then on September 5, 2018, we see a sudden surge or spike of water that shot up to 50 cm depth and quickly dropped back down to 14.5 cm. Perhaps a cavity under the creek bed was taking this sudden flow and kept the water depth in the creed fairly constant at 14.5 cm. Two weeks later on 9-20-18 another surge of water suddenly raised the water depth to ~ 65 cm, and slowly decreased for the next 3 weeks until 10-9-18 when the level dropped back down to 15 cm. Three days later on 10-12-18 another even larger flow bumped up the water level to a 100 cm high point on 10-24-18, which is shown on the next chart.



The 3rd chart for Eagle 1 covering the period between 10-19-18 and 5-7-19 used a third baro logger, also at the entrance to the cave. We don't see that uniform ~15 cm level at the start of the flow at the Eagle 1 logger site again on this chart. It will be interesting in 2021 when we recover the data for two winter seasons to see if this ~15 cm steady level is repeated. The chart above lists several other water level spikes for correlation.



The October 24, 2018 spike on the FSCSP Eagle 1 Data Logger occurred about 10 ½ hours after the spike shown above on the USGS data. Future detailed study of various USGS measured flow rates can be correlated with our Eagle 1 logger which might yield additional understanding of the suggested aquifer-filling action and timing of various flow rates which certainly will impact the Snowy River flow analysis in the cave.



The USGS chart on the right shows the data for the heavy 2014 rainfall that started the 4+ year Snowy River flow. Who will be able to correlate this data with the charts included in this report? ;-)

Rio Bonito:

This site, adjacent to the Field House, has been used with a standard commercial staff gauge in the past. The distorted panorama photo above and below (Lindsley #1061). Unfortunately located along a long straight section of the Rio Bonito, every time we installed a new gauge, it was washed away by the flooding Rio Bonito within months. Attached to a T-post driven into the creek bed, and often secured with another upstream T-post to fend off tree parts floating down the stream, the gauge was swept downstream and sometimes completely lost.

The next photo (Lindsley #90081), taken on July 9, 2012, shows the Rio Bonito at flood stage after large rains that followed the extensive Little Bear Fire on Sierra Blanca. Although this flood event did not significantly impact the Snowy River Hydrology, it likely "primed the pump" and started filling lower level aquifers in the Eagle Creek area. This flood brought many large sections of trees downstream, and the burned ash from the fire left blackened mud along its path including the Government Spring resurgence. Two days later on July 11, 2012, the bottom left photo (Lindsley #9116) illustrates a problem at Alto Lake. The lake was almost filled with sludge from the mountainside and would affect flow rates down the Rio Bonito for at least the next 8 years.

After more attempts to install a proper staff gauge following the flood, we finally decided to install a well point bolted to a tree on the east side of the Rio Bonito. In fact, the chosen tree is shown in the top two photos on the previous page. We knew that this particular tree would probably protect a properly installed well point with a data logger inside. We hoped it would not be an attraction to unknown folks visiting the Field House, although it is in plain site from the west side of the often-dry stream where there is an occasionally used campfire ring. The next two photos (K. Peerman #0094 & #0016) taken in July 2019 and October 2020, show Steve Peerman at work on this installation. The shiny new well point was spray-painted when we installed the logger. But then in October 2020 we were unable to access the logger for download because "someone" (kids, we think) had dropped so many small rocks and clumps of clay down the pipe that we were unable to retrieve the loop on the logger below. So, at the end of October Steve and Kathy Peerman returned with some ¾ inch clear plastic hose attached to a shop vacuum and were able to suck out several inches of debris. But not enough to reach the logger.

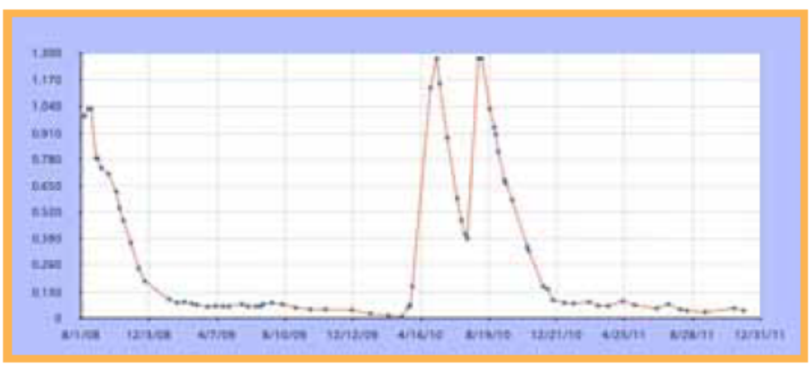
So, data from this logger will have to wait until spring 2021, and might require a shovel (and some socket wrenches) to dig down to the bottom of the well point so that it can be removed and cleaned before re-installation. The top picture shows a yellow circle around a lag bolt installed in the tree exactly 48 inches above the logger sensor. The bottom photo appears to show several inches of added material at the base of the well point around the tree. The reason for adding this story to this data logger report is to illustrate another "lesson learned". The closed cave is much better protection for logger security, but surface locations require protection from both natural forces as well as human vandals.

This location on the Rio Bonito is particularly important for a better understanding of how and when the Rio Bonito reaches a level which allows insurgence into the Main Corridor of Fort Stanton Cave. Just upstream from this logger site is an ideal stretch of the Rio Bonito that is now being used to establish Rio Bonito flows which will be used to generate a discharge graph that will correlate with the discharge data measured by the data logger. By measuring the channel geometry and the calculated flow measured by a flow meter taking measurements across the flowing water channel, we will be able to approximate the actual flow of the Rio Bonito which can be correlated with loggers in the Main Corridor in the future.

Government Spring:

The panorama photo above (Lindsley #6293-6297), taken in March 2013, in the riparian area of Rio Bonito, upstream from Government Spring, is looking East towards Government Spring, to the right of the big tree in the center. Additional information is available on the FSCSP.ORG web site: [http://fscsp.org/science/springs/gov_spring.html].

As shown on the web pages, the FSCSP first started monitoring the outflow of the spring between August 2008 and July 2012 with the installation of a ½ inch plywood sheet being used as the weir control device along with a homemade data logger. The photo shows the spring pool in July 2010, filled with watercress with the junction of the Rio Bonito shown at the top of the photo. (Photo: Lindsley #6004) (Chart: Steve Peerman)



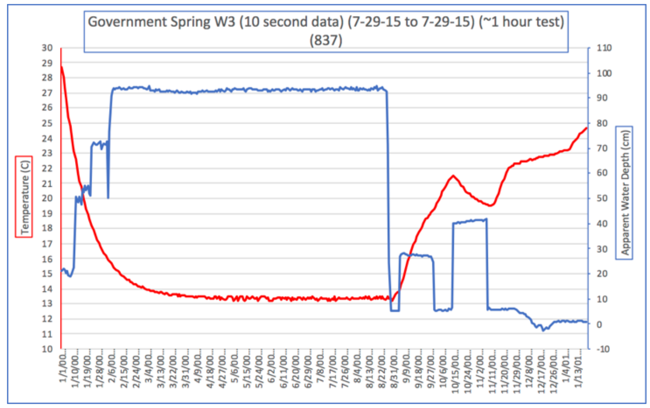
The chart above illustrates 4 years of weir operation. In July 2012 the FSCSP weir was washed out during the big Rio Bonito flood following the Little Bear Fire. Unfortunately, there was so much ash in the flow that the spring was covered with a black hard-pack layer of mud that prevented flow during the winter. Later the BLM carefully dug out the old spring pool and installed an improved rocky rip-rap area in the bend of the Rio Bonito just upstream from the spring and added additional material to the small “peninsula” that kept the normal flow of the Rio Bonito from entering the spring pool. Silt covered the much older shallow concrete “V-notch just downstream from the nearby USGS station, and so far, no records from the initial USGS monitoring installation have been recovered.

Restoration of Government Spring was undertaken by the BLM and included heavy equipment and tons of rock. Finally, in August 2017 the BLM acquired a professional flume (on the left) to use instead of a weir with the expectation that future floods would not destroy the measurement site. The next year, in May 2018, the new flume was installed in the spring pool. (Lindsley: #2211 & #2391) Shown in the photo below L-R is Steve Peerman, Michael McGee and Wayne Walker. We soon began to realize that a successful flume installation was not as easy we thought due to a number of reasons. Unknown at the time, Government Spring had several narrow slits in the limestone three feet below the normal pool level. This caused some of the small crushed fines used to build up the peninsula to slowly erode away from the bottom, to the left of the white HDPE plastic sheet that was used to repair the washed-out spring. Another contributing factor was a downstream beaver dam, about 2 feet tall, that backed up the Rio Bonito and formed a long "lake" that reached upstream to the spring pool. ThIs caused an abnormal wet area at the flume installation that prevented proper packing of the material around the flume. After lowering of the beaver dam, the water in the Rio Bonito receded a bit, and an "almost water-tight" condition occurred when the Rio Bonito flow was significantly reduced.

The next attempt to install a data logger in Government Spring was by Michael McGee, the BLM Roswell Field Office Hydrologist, and he installed a professional data logger (a Solinst logger, the same as he used in Snowy River). Alas, with this site fairly close to US Highway 380, simply carefully camouflaging the cables and locating the shiny logger in the willow roots in the spring pool was not sufficient to protect the expensive data logger from theft by vandals. Someone with a sharp eye with a sharp hunting knife in their pocket was likely responsible for the theft of government data logger property.

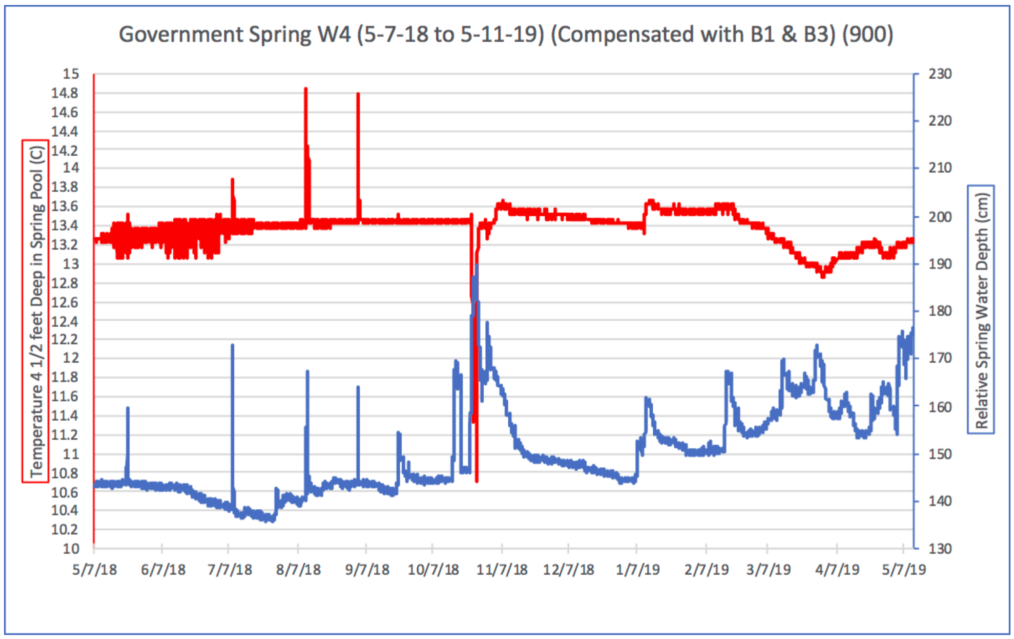
Working on the flume installation is difficult, at best, because when the site is dry enough for heavy equipment to be able to access the site, operators of large enough equipment to properly change the ground area had more important duties at other sites. When the Rio Bonito is running, slight rainfalls upstream can quickly flood the area. So most of the adjustment of the new weir installation has been performed by hand in the summer months before the early fall rains. Once the approximate level of the pool was adjusted by the position of the flume, the floor of the pool was cleared and the largest crack in the limestone where the water was flowing was checked for depth. We were able to add an 18-inch extension to the top of the well point for an approximate 4 ½ foot depth for the data logger. Michael provided a long steel angle section that was driven into the mud bank between willow roots such that the top of the well point could be securely attached to the steel angle. Normally the top of the installation would be at or slightly below the water level of the 3-foot deep spring pool. For the data shown below we were able to retrieve the non-vented In-Situ Rugged Troll 100 data logger using a long wire with a hook that caught the pair of loops that attached to the data logger cap. Unfortunately, an attempt to maintain the logger in October 2020 failed because the pipe cap was too firmly attached to the well point by rust. (Either a special tool or likely entry into the water with larger wrenches will be required for maintenance in the spring of 2021.) (Photos: S. Peerman #0051 & K. Peterson #4129)

We still need to meet the challenge of proper flume elevation adjustment, a more permanent flume level adjustment and leak minimization in the future, before we will have a more precise and calibrated flow data from the logger. We are also considering the use of new technology that would allow almost real-time spring data to be accessible in the cloud via the internet. [https://in-situ.com/us/vulink]

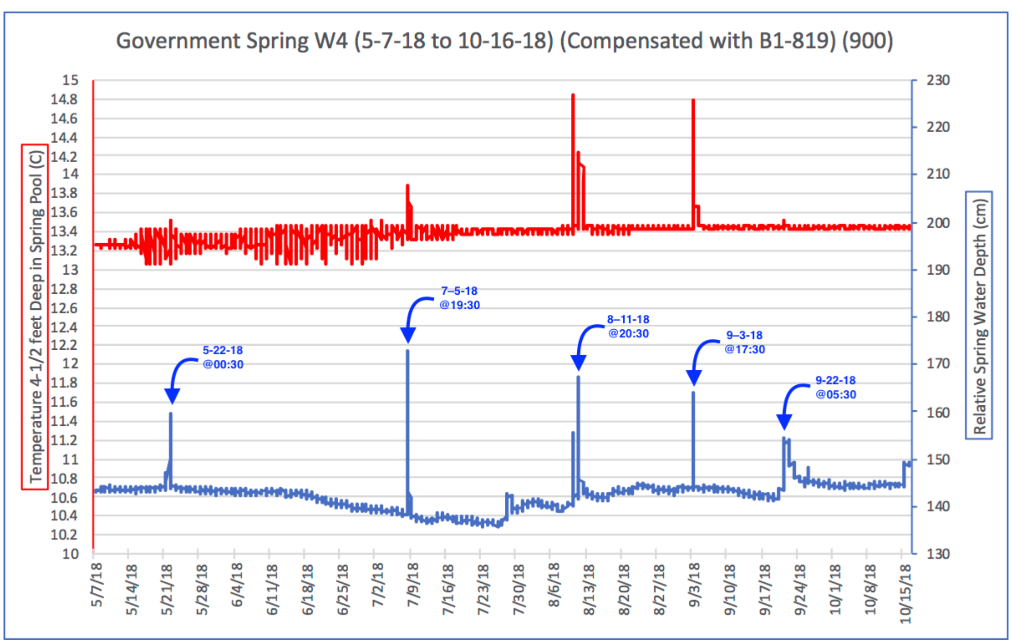


During the flume and well point installation, we made a quick data logger sample run. Shown on the right we see from the red trace that the precise temperature response time of the titanium packaged logger is approximately 20-30 minutes. The blue trace illustrates various depth measurements as the unit was lowered into the well point assembly.

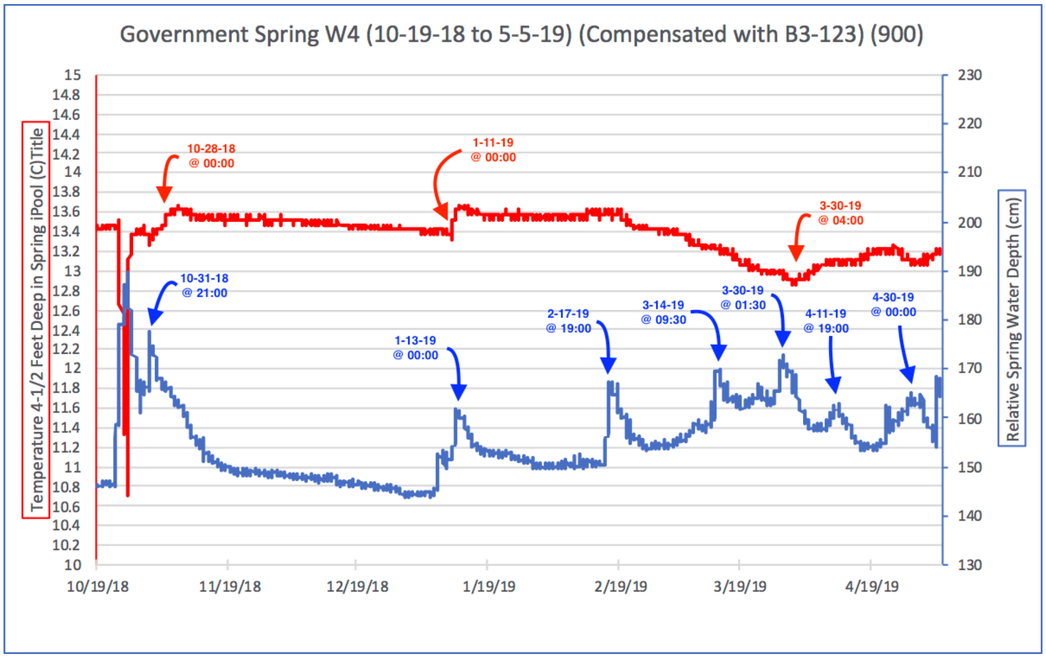
(900) (5-7-18 to 5-11-19)



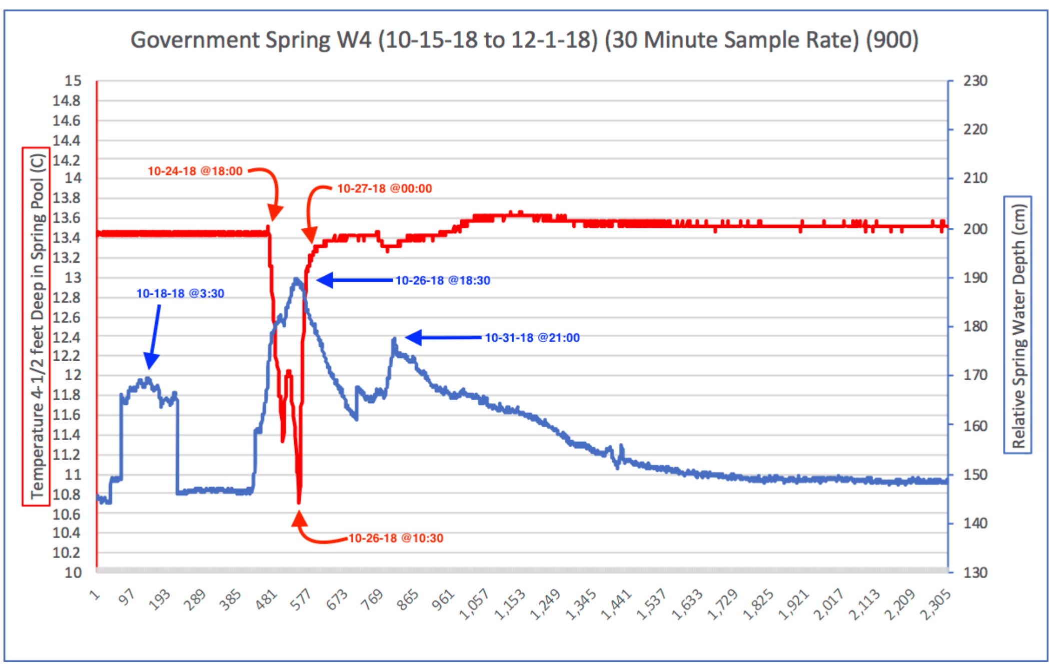
Without a suitable baro correction, the raw data is almost useless. For this logger we used baro units in Fort Stanton Cave to compensate the changes in barometer pressure. Because the data logger is approximately 4 ½ feet below the pool surface, we expected water level readings of about 137 cm. The top chart shows a full year of data by combining compensated data from two baro loggers in the cave. Just as we saw in the cave, changes in water depth are often correlated with temperature changes of the water coming out of Crystal Lake which may or may not be fed by a Snowy River flow. The bottom chart on this page is the



first 6 months of data and dates for several water level “spikes” are shown which can be correlated with surface data, or Snowy River data elsewhere in this report. Although due to lack of flume installation calibration, we can only gather change of water level during times when the Rio Bonito had significant flows. The related temperature spikes are no doubt due to water backflow into Government Spring during times of elevated flow of the Rio Bonito.



The most interesting chart, which shows the 2nd half of the year-long data, happened on October 24, 2018. This date also corresponds to a Snowy River flow about the same time, but due to the temperature data on these two charts we now know that the Rio Bonito also had a sudden drop of about 2.6 Degrees C. The Rio Bonito insurgence of Government Spring lasted several days and the level of the Rio Bonito increased about 53 cm during this time. Shortly after this cold water appeared in the Rio Bonito, the next two water level spikes were warmer by 0.2 degrees C. The first 2.6-degree cooler water was likely caused by cold weather up on the mountain, but possibly the two warmer increases were caused by warmer Snowy River flow reaching the spring exit. {Homework for the reader: can you find any surface temperature data that will correlate with this data, or is there a correlation with Snowy River logger data in this report?}



Lessons Learned and Conclusions:

1. When processing Fort Stanton / Snowy River data loggers for exact timing, either the temperature change or the conductivity change provides a more accurate determination of the water arrival times. This is due to the water level data that is noisy, and should be corrected by a baro logger when possible. However, for the temperature, there may also be a slight time lag due to the mass of the titanium data logger housing, and sometimes the baro unit used for correction may be some distance from the site being corrected, and there could be an additional timing delay such as the Mud Turtle ("Hobbit") door.
2. It is more efficient and very helpful if a baro logger is deployed at the same time the water loggers are deployed. If there is a need to pull out a baro logger before the associated water logger array, we should consider adding a separate baro/water logger set for that purpose.
3. Processing all the data in this report took about a year because there were various units used on the logger set-up, there was poor documentation in some cases, equipment malfunction caused occasional issues, and there were also many duplicate copies of the data sets that used different file names from the original down-loaded data files. The programming and downloading of the logger units as well as the post-processing was performed on several different PC (Win 10) computers, and the raw data files were not generally shared. This caused multiple duplicates which had to be plotted before analysis revealed the duplicates. The next level of post processing was mostly done on Mac computers, and a few PCs, usually converting a (.CSV) file to a spreadsheet file using perhaps as many as a dozen different programs. Even the Microsoft Excel versions (5 on a Mac, 3 on a PC) and multiple versions on the spreadsheet copy-cats (at least 4 on Libre Office, and an unknown amount on "Open Office") were not exactly compatible. The final charts presented here in this report were done using Mac Excel 2016. Unfortunately, just before the work in this report was completed, Microsoft announced that it no longer supports Mac Excel 2016 and their marketing widget complains several times a day that you need to change to either Excel 2019 or else start paying $100/year rent to use their new Excel available only on the Cloud. Excel 2019 won't run on my 12-year old Mac unless I hack the OS, and Cloud solutions don't run well at the Fort Stanton Field House. (I hope to update my Mac to the new M1 silicon that can talk to a pair of large monitors at the same time. My 2008 desktop can multi-task and is extremely useful when analyzing this volume of data on two MSW documents at the same time working on four different MSE files.)
4. The main purpose of this work was to better understand the cross-correlation between a multiple of data logging sites 10-15 miles apart. It is my expectation that others will look closely and identify new avenues of analysis and will use some of these charts to identify the exact data files. These files, which are now all in (.xlsx) format, are listed in Appendix 12.

Summary

The “flat statements” listed below may now seem to be obvious to some, so in those cases the data in this report is now offered as “proof”. It is hoped that by looking at the data set as a whole and being able to easily compare graphical information both at a single site, and between multiple sites, including the surface, that additional ideas will emerge among the interested hydrologists and cavers with more extensive experience in the cave over the past decade.

1. The air temperature at TJ is ~ 1.7 Deg. C warmer than in the Main Corridor at 20-Steps.
2. The air temperature at the Wash Tub Room varies significantly, due to the proximity of the entrance and the effects of the “cold trap”.
3. The water temperature at SPL is cooler than the temperature of a flowing Snowy River by ~ 1 Deg. C. Is this enough to detect the relatively slow “leakage” from SPL into Snowy River?
4. The range of variance of Baro air loggers beyond the Hobbit Door seems to increase, likely caused by the constrictions of the two known connecting passages.
5. There appears to be a time delay in the compensating barometric pressure as the distance of the water logger sites from the Turtle Junction Baro units increases. Smoothing of shallow channel data logging sites seems to require a closer baro unit for best performance (like we see in the vented BLM Solinst logger pairs).
6. The Snowy River water temperature appears to be a function of the water temperature near the potential insurgence site (s). Changes in the water temperature are colder during the first quarter of the year, probably due to snowmelt.

Temperature Comparisons: The first chart below was made by averaging the quarterly temperature of the water loggers, both “no flow” (or air temperature) cases and “standard flow”, from Finger Lake all the way South to Crystal Spring. The yellow boxed numbers represent an “eyeball estimate” of the air temperature when Snowy was not flowing, and the aqua colored numbers represent the temperature (degrees C) during a water flow. Blank areas are where we have no logger data. The main anomaly is the Mud Lizard sump area, which seems to rise after the Bobbitt’s-to-Snowy River Spring flows.

Location / H2O or Air	Station	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14	1Q15	2Q15	3Q15	4Q15	1Q16	2Q16	3Q16	4Q16	1Q17	2Q17	3Q17	4Q17	1Q18	2Q18	3Q18	4Q18	1Q19	2Q19	3Q19	4Q19	1Q20	2Q20	3Q20	4Q20
Finger Lake	SRS535	13.9	14.0	13.9	14.0	14.0	13.9	13.3	13.0	12.3	12.6	12.8	12.5	12.3	12.8																	
Floating Islands	SRS374	13.9	13.8	13.7	13.6																		14.0	13.7	13.1	12.8	13.6	13.8	13.6	12.3	13.6	
Eggshell Trai	SRS318																											13.8	13.1	12.7	13.7	
Mt. Airy	SRS227																											13.9	13.5	13.0	13.8	
Bobbitt's Blvd	SRS171	13.8	13.9	13.8	13.8	13.8	13.9	13.6															13.8	13.9	13.5	13.0	13.7	13.8	14.0	13.0	13.8	
Mud Lizard	SRS141	13.6	13.7	13.6	13.6	13.7	13.7	13.9															13.6	13.5	13.5	12.8	13.4	13.4	13.3	12.8	13.3	
Snowy River Spring	SRS125	13.7	13.7	13.7	13.8	13.7	13.7	13.9															13.5	13.9	13.5	13.9	13.5	13.5	13.8	13.1	13.5	
Plunge Pool	SRS31	13.2	13.3	13.3	13.2	13.2	13.3	13.8				13.5	13.3	13.3	13.5	13.7	13.5	13.3	13.4	13.3	13.7	13.5	13.5	13.8	13.6	13.1	13.4	13.5	13.8	13.1	13.5	
Turtle Junction	SRS23	13.2	13.2	13.2	13.1	13.2	13.3	13.6		13.4	13.5	13.4	13.2	13.4	13.3	13.7	13.5	13.5	13.4	13.3	13.7	13.4	13.4	13.8	13,7	12.7	13.5	13.5	13.9	13.3	13.6	
Core Hole	SRS19																						13.3	13.8	13.7	13.2	13.4					
P-7 Landing	SRS10																						13.5	13.9	13.7	13.2	13.5					
Window Passage	SRN08																		13.4	13.3	13.7	13.5	13.2	13.7	13.6	13.1	13.3					
Swimming Pool	SRN53	13.2	13.2	13.2	13.2	13.2	13.2	13.6															13.4	13.7	13.6	13.3	13.4					
Crystal Spring	SRN80	13.2	13.1	13.1	13.1	13.1	13.2	13.6	13.2	12.0	12.0												13.2	13.4	13.5	13.1	13.3					
Government Spring	GS1										13.2											13.2	13.4	13.4								

The 2nd chart simply replaced the data upstream from Turtle Junction with data from the 20-Steps and Sewer Pipe Landing sites. Two-degree (C) colder water is appearing beneath the cave floor at 20-Steps, but warms to about a one-degree (C) difference at SPL, compared to Snowy River.

Location / H2O or Air	Station	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14	1Q15	2Q15	3Q15	4Q15	1Q16	2Q16	3Q16	4Q16	1Q17	2Q17	3Q17	4Q17	1Q18	2Q18	3Q18	4Q18	1Q19	2Q19	3Q19	4Q19	1Q20	2Q20	3Q20	4Q20
20-Steps TH3	TH3a										11.5	11.4	11.5	11.6	11.6	11.7	11.8	11.6	11.8	11.8	11.6	11.5	11.5	11.7	11.6	11.4						
Sewer Pipe Landing	SW1									11.8	12.0	12.1	11.9	11.9	12.2	12.3	12.6	12.6	12.7	12.8	12.4	12.5	12.6	12.5	12.4	12.3						
Turtle Junction	SRS23	13.2	13.2	13.2	13.1	13.2	13.3	13.6		13.4	13.5	13.4	13.2	13.4	13.3	13.7	13.5	13.5	13.4	13.3	13.7	13.4	13.4	13.8	13,7	12.7	13.5	13.5	13.9	13.3	13.6	
Core Hole	SRS19																						13.3	13.8	13.7	13.2	13.4					
P-7 Landing	SRS10																						13.5	13.9	13.7	13.2	13.5					
Window Passage	SRN08																		13.4	13.3	13.7	13.5	13.2	13.7	13.6	13.1	13.3					
Swimming Pool	SRN53	13.2	13.2	13.2	13.2	13.2	13.2	13.6															13.4	13.7	13.6	13.3	13.4					
Crystal Spring	SRN80	13.2	13.1	13.1	13.1	13.1	13.2	13.6	13.2	12.0	12.0												13.2	13.4	13.5	13.1	13.3					
Government Spring	GS1										13.2											13.2	13.4	13.4								

Both temperature charts are probably too coarse to pull out new information based on water temperature, but perhaps in the future a more focused analysis might yield additional clues.

Currently most of the hydrology team believes that the major part of the Snowy River water is an insurgence from Eagle Creek, and that it exits from Government Spring.

But there are still other hydrological questions:

1. What is the relationship between surface water in the Eagle Creek insurgence area and area wells and the assumed aquifer reservoir?
2. When, where and why does the Rio Bonito connect to the Main Corridor?
3. When, where and why does the Rio Bonito connect to the HOTP Passage?
4. When, how and what feeds the Sand Boil, which is probably now no longer active? We are STILL waiting for the date from the BLM charcoal samples we took several years ago.
5. When, where and how does the Conrad's Branch water join the Snowy River flow?
6. Does any of the FSC water exit at other known springs just upstream from Government Spring?
7. Where do the other known regional springs get their water? Do we know their temperatures?
8. How can we determine if the water trickling out of the Lincoln's Bathtub breakdown is different from that coming out of Crystal Spring, which appears to be essentially at the lowest year-around level of Crystal Lake, and therefore very close to the relative level of Government Spring?
9. When, where and how can we determine if there is any insurgence from Little Creek?

Perhaps the answer to some of these questions can be obtained from the Midnight Junction area, and we may finally be able to access that part of the cave in 2021. Other questions may be answered by continued survey and exploration upstream of Midnight Junction.

Since the answer to some of these questions may only appear during a "Standard Snowy River Flow", we will probably have to rely on data loggers. In this case, perhaps the value of this "standard flow" might be some sort of weighted average of all the current Turtle Junction measurements, of course throwing out any obvious errors in water depth during flow. Without more precision data loggers available that can detect dye or other contaminates in the water, we are left to 20th century dye tracing methods where we rarely understand the "when" of dye passing past a measurement point. What works for the Mammoth Cave Basin where there are 100's of insurgence possibilities and a continuously flowing Green River Base Level, does not apply for dry New Mexico where all three major surface streams are low-flow, and intermittent.

Is there new technology that can detect dyes or other materials introduced in the Eagle Creek area, packaged in a data logger format, that can log data for up to a year in the cave? Detection of salt and common components of yard fertilizer that are probably already now leaching into the upstream insurgence to Snowy River come to mind. Can we gain additional data from conductivity data loggers? Is there a DNA data logger available yet for this purpose?

References

The web page at [http://fscsp.org/science/bibliography.html] lists some of these hydrology-related reports and many other reports on the cave and Snowy River.

-Christenson, S. & Lindsley, P., 2019. *Science Team Trip Report 2019-05-05*, (Parts included in FSCSP May 2019 Expedition Report by Steve Peerman, Rev 2.4, 7-28-19), 29 pages.

-Darr, Michael J., Rattray, McCoy, Gordon W., Kurt J., and Durall, Roger A.; *Hydrogeology, Water Resources, and Water Budget of the Upper Rio Hondo Basin, Lincoln County, New Mexico, 2010*, USGS Scientific Investigations Report 2014–5153; Prepared in cooperation with Lincoln County, New Mexico; File *sir2014-5153.pdf*; 9-25-2014. (Sub watersheds figure from p. 19 of this USGS publication.)

-Davis, D. G., 2007. Water Returns to Fort Stanton Cave. *Rocky Mountain Caving* 24(2), Spring 2007, p. 8-9.

-Davis, D. G., 2007. *Fort Stanton Cave Water References*, July 9, 2007, 2-page unpublished report.

-Davis, D. G., 2008c. Understanding Fort Stanton's Snowy River, *Rocky Mountain Caving* 25(4), Autumn 2008, p. 14-16

-Fort Stanton Cave Study Project, **2017**. ***12 Miles From Daylight, Fort Stanton Cave and the Snowy River Discovery***. Edited by Pete Lindsley and Lee H. Skinner, assisted by a great team of authors, writers, editors, and published with the help of numerous donations from our supporters, June 2017. ISBN 978-0-939748-83-9; 9 x 12-inch format, sc, 306 pages, over 350 maps, graphics and photos.

-Kimble, J., Spilde, M. N., Northup, D. E., 2017. *Fort Stanton Cave-Snowy River National Conservation Area White-Nose Syndrome and Ferromanganese Deposit Research Agreement 13-0484. Phase III Final Report,* University of New Mexico, July 2017, 29 pages.

-Land, L., 2007. *Preliminary results of surface and subsurface water chemistry sampling in the vicinity of Fort Stanton Cave, Lincoln Co.,* NM, *National Speleological Society-Southwest Region, Winter Technical Meeting*, Las Cruces, NM, Abstracts with Programs, December 3, 2011.

-Land, L., **2009.** *World's longest speleothem: New results from radiometric dating and hydrologic observations*, *GSA Abstracts with Programs*, v. 41, no. 7, p. 399.

-**Land, L., Polyak, V. & Newton, B. T., 2010**. *The Snowy River formation in Fort Stanton Cave, New Mexico: Results from Radiometric Dating and Hydrologic Observations of the World's Longest Speleothem, in* Eaton, M. & Landres, P, compilers, *Decade of Discovery in the National Landscape Conservation System*, May 24-28, 2010, Albuquerque, NM: Proceedings RMRS-P-000. Fort Collins, CO: U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station, p. ??

-Land, L., Polyak, V. & Newton, B. T., 2010. *The Snowy River Formation in Fort Stanton Cave, NM: Results from radiometric dating and hydrologic observations of the world's longest speleothem*, *in New Mexico Geological Society, Proceedings* Volume, 2010 Annual Spring Meeting, Socorro, New Mexico, p. 23.

-Lindsley, P. & Frederickson, T., **2010**. *Initial Water Level Logging at Turtle Junction*, Manufacturer's Case Study of EL-USB-3 Voltage Logger, Lascar White Paper.

-Lindsley, P., 2011, *Snowy River Water Flow*, Unpublished paper by Fort Stanton Cave Study Project, June 7, 2011. 15 pp.

-Lindsley, P., 2012. *Trip report from Sandy River charcoal collection*, (with D. Davis, W. Walker & R. Harris), April 26, 2012.

-Lindsley, P., **2014.** *Rainfall in the Fort Stanton – Snowy River Cave Area;* 6 pp, Unpublished paper by Fort Stanton Cave Study Project September 9, 2014.

-Lindsley, P., 2014. *Tracking the Hydrology of Fort Stanton Cave*, Presented at the NSS Southwestern Region Winter Technical Conference, Las Cruces, NM, December 6, 2014, 30 slides.

-Lindsley, P., 2015, *Investigations at Government Spring*, pp 8-14, FSCSP Expedition Report July 25-30, 2015; Steve Peerman Editor.

-**Lindsley, P. and Corcoran, J., 2015**. *Hydrology Plan for Fort Stanton Cave*, Power Point Presentation; October 23, 2015; 36 pp.

-Lindsley, P., 2016. *April Trip Report Details from the Spring 2016 Expedition*, (Various Government Spring comments).

-Lindsley, P., 2017. *Precision Hydrology Survey Proposal for 2017*; (Excerpt 2 pp.), 1-6-2017; Bucket Model is described.

-Lipinski, R. J., 1982. *A Model for Boiling and Dryout in Particle Beds*, Sandia National Laboratories, Albuquerque, NM, NUREG/CR-2646, SAND82-0765, 1982, https://www.osti.gov/scitech/biblio/5114771-model-boiling-dryout-particle-beds-lmfbr

-Lipinski, R. J., 1984. "A Coolability Model for Post-Accident Nuclear Reactor Debris", *Nucl. Tech.*, v65, pp 53-66, Apr 1984, http://www.ans.org/pubs/journals/nt/a_33373 .

-Lipinski, R. J., 2018. *Recommended Locations for Water Level Data Loggers to Infer the Time-Dependent Snowy River Discharge North of Floating Islands*, Unpublished paper by Fort Stanton Cave Study Project, March 25, 2018. 9 pp.

-Lipinski, R. J., 2020. *Caver Quest, A Computer Simulation of Fort Stanton Cave*, Version 6.7.1. Notes and challenge questions on various hydrogeology aspects of Fort Stanton Cave, free versions available at [http://fscsp.org/CQ6/].

-Newton, T. and L. Land, 2009. Trip Report in *Fort Stanton Cave / Lincoln Plateau Study Area Summary of Activities: Sept 26 – Oct 4, 2009*, J. J. Corcoran III ed., Fort Stanton Cave Study Project, 2009.

-Newton, B. T., **2017**. *Snowy River Fill and Spill Model*, Included (Snowy_river_fill&spill_model.xlsx), Email to Hydrology Working Group, 7-11-2017.

-Newton, B. T., 2020. *(Four Snowy River Flow Characteristics),* Private email communication October 20, 2020, 1p. Reproduced in the section for the Floating Island logger data elsewhere in this report.

-Peerman, S., 2010. *Fort Stanton Cave Study Project Trip Report – Water Monitoring Trip*, June 22, 2010, 3 pages.

-Peerman, S., 2016. *A different model for the Eagle Creek -- Snowy River relationship.* Unpublished email to the FSCSP BoD and others, December 29, 2016.

-Peerman, S., 2017. Turtle Junction Timing Studies, various informal charts published in multiple FSCSP Expedition Reports.

-Peerman, S., **2019**. *Snowy River Data Logger Analysis*, October 2019 Expedition Report, Appendix D, 11-25-2019, pp 31-41.

-Spilde M. N., Northup D.E., Polyak V.J., Boston, P.J., Clement, A. & Huges K. J., **2009**. *Snowy river: A new discovery from an old cave*. *Geological Society of America Abstracts with Programs, v41, n7, p399.*

Appendix 1 – Additional History

Additional History: Thanks to the support of the BLM, the Fort Stanton Cave Study Project (FSCSP) was able to design a more extensive array of data loggers for about a dozen locations along Snowy River and actually deploy the loggers between Midnight Creek 10 miles upstream from Turtle Junction, all the way North to Crystal Spring about a mile downstream in 2013.

But then, after the Little Bear Fire significantly changed the parameters of the surface runoff, large rainfalls contributed to a change in the surface dynamics of the hydrogeological system before we were able to install a proper logger at the resurgence of Snowy River at Government Spring. A homemade plywood weir at Government Spring was washed out after 4 years of casual documentation of spring flow by the flooding Rio Bonito, which also deposited around 35 cm of hard-packed mud and ash over the previously open spring vent. The Snowy River Passage continued to flow for another four years.

As more loggers were installed in both the Main Corridor section and the Snowy River Passage the logger array in the cave more than doubled as we occasionally had access to the cave for logger maintenance. The initial logger locations in Snowy River were primarily in dry pools where we expected the potential water depth to yield the best information on future Snowy River flows, which based on available flow information in 2013 were most likely to last for perhaps 9 months at a time. Elementary volume flow estimates of Snowy River and the closely associated Government Spring were around 2 CFS.

As the first results from the Snowy River loggers were obtained, we began to realize that there was a significant safety issue at Two-Way Hill and Mud Lizard because of the restriction caused by the breakdown blockage of a flowing Snowy River. When the lower level Mud Lizard crawl sumps, water is backed up for a significant amount of time creating a condition that could trap a cave team for months, and even years depending on the surface insurgence. The outlet for this backed up flow is Snowy River Spring, but the significant restriction at this location creates a more uniform flow all the way to Crystal Spring in the North end of the cave, where again the water level can increase several feet do to the next constriction between Crystal Lake and Government Spring.

As more data was obtained from the loggers available between flow events, it became apparent that the next step in the hydrogeological analysis was to place additional loggers in more uniform channel locations (instead of in pools) where we could begin to collect data that would result in a better volume flow analysis. (A future goal is to improve the flow analysis in hopes that additional insurgencies to the "normal Snowy River flow" could be identified. There still remains the question of how the much smaller flow in the Main Corridor interacts with the Snowy River flow, both of which are currently assumed to exit at Government Spring.) A clue to this interaction is suggested by the data in this report and real-time temperature measurements, which show the temperature of the water in the Main Corridor is about 2 Degrees C warmer than in the Snowy River flow.

The primary parameter of Steve Peerman's logger analysis at Turtle Junction is the water depth. Usually the Snowy River flow goes from no-flow to "almost" full flow in about an hour. But using non-vented In-Situ loggers for most of the data loggers requires either subtracting an "average barometric pressure” or better yet, a “precise” barometric pressure from the water logger data to compute the apparent water depth at each site. Obviously, the ever-changing barometric pressure creates a noise level on the plots, but when the proper “precise” barometric pressure is used to compensate the variance, a more desirable “textbook” graph result. The best results are achieved by using the In-Situ Baro Merge software with an associated baro logger during the same time period.

During the initial temperature study, it became obvious that the temperature of the water in Snowy River varies several tenths of a degree depending on the time in the cave, the temperature of the water entering the cave on the South end of the study area. In fact, the temperature variance is probably a better indicator of changes in the flow state and can be related to both the uncompensated and compensated calculations of actual water depth.

If we are to be successful in monitoring the actual flow volume, the temperature will become part of the analysis, but also it will be imperative to improve the coverage of Baro loggers, which will offer a more accurate water depth. Ron Lipinski authored a paper in 2018 that suggested adding several new locations for water loggers in more uniform channels where the theoretical analysis would be useful once the local area slope and channel cross section was measured. A previous attempt to accurately measure the flow volume at Turtle Junction by Lewis Land and Talon Newton using an ADV unit on 5-6-2010 failed because the Snowy River water was “too clean”. Without tiny particles in the water, the data obtained was unusable. A simple mechanical flow meter would be required.

In 2018 the author obtained a Rickly Pygmy flow meter which was sent to the factory for maintenance and calibration. Operation of the Pygmy flow meter involves counting the mechanical revolutions of a low friction spinning wheel as the device is moved across a stream channel at a precise depth. This compact unit fits inside a small Pelican box, which also had room for a simple “clicker” circuit. Adapting a 2-section wading rod (provided by John McLean) for non-destructive use on the delicate calcite crystal floor of the stream channel, completed an appropriate light weight “Pygmy cave kit”. Scott Christenson and Pete Lindsley compared the Pygmy flow meter data in several Sandia area streams with two other modern calibrated USGS flow meters. Scott Christenson and Talon Newton were able to measure the very low flow of Snowy River in May 2019, and also compared the data with the Government Spring exit flow into the Rio Bonito the next day.

At the time of this writing, we have In-Situ data loggers installed in semi-permanent well points at three surface locations. The Eagle 1 location is several miles downstream from the USGS 08387600 site, about a mile upstream from the suspected insurgence area to Snowy River. This stretch of Eagle Creek was well documented in 2010 as a “losing stream”. Another site of interest is on the Rio Bonito, across from the Field House. This stretch of the Rio Bonito was a site used in the past with just a six-foot staff gauge installed in the intermittent stream bottom. (These gauges were consistently washed away every time the Rio Bonito experienced floods before and after the Little Bear Fire.) The third surface location is in Government Spring, where Michael McGee has a project installing a flume to measure a calibrated flow rate up to about 10 CFS. Data from a logger installed in a well point at the spring is included in this report.

Appendix 2 – Correlation With Surface Flows

Correlation With Surface Flows:

Snowy River, when discovered in September, 2001, was dry. The original explorers did not venture onto Snowy River until two years later, after long discussions and planning of how to best walk on the white crystal surface without damage. Questions were posed asking “where did the water come from, probably 100’s of years before, and where did it go?” After a few trips heading both upstream and downstream from the Priority 7 Landing discovery point, initial surveys revealed that the end of what was called the Mud Turtle Passage was under the Don Sawyer Memorial Hall (DSMH) and plans were made to dig into Snowy River at that point, thereby avoiding the tight and dangerous Priority 7 breakdown area.

Once the new Access Shaft was extended 44 feet down from DSMH the cavers were awarded with the first view of a flowing Snowy River on July 1, 2007. Later that year, during the October expedition, the Snowy River flow was found to be no longer flowing. The following year during the August, 2008 expedition, the 2nd Snowy River flow was observed and a wooden weir was installed at Government Spring. Various data loggers were positioned at Turtle Junction ranging from homemade units to a professional Schlumberger water logger with associated baro logger. This 2nd flow stopped at Turtle Junction on January 4, 2009. It appeared that the flow probably lasted several months and could be related to the rains sometimes experienced during the New Mexico “Monsoon Season”. The 3rd flow event started on April 22, 2010, and ended on December 21, 2010. Using data from the Schlumberger unit at Turtle Junction, we correlated the very sharp start of the Turtle Junction flow, two following “peaks”, and a steady falloff of the flow with the KSRR weather data from the wunderground.com site. It appeared that the travel time for the surface water to reach Turtle Junction was between 72 and 80 hours. At that time, we had no idea the cave would be pushed several years later to a point at the southern edge of the NCA and that we would discover an even better correlation point at the USGS Eagle Creek gauging station. Furthermore, we discovered a USGS publication that reported a “losing stretch” of Eagle Creek, which was measured and verified by Scott Christenson and Steve Peerman in 20XX.

The USGS Gauging Station (USGS 08387600 on Eagle Creek) is an important resource for analysis of the Snowy River flows. As mentioned in the USGS report in 2014 (sir2014-5153.pdf), it is an important part of the hydrogeology study of the Upper Rio Hondo Basin, and the study itself is a major report for the hydrology of this area. USGS 08387600 is unique in the area as it covers 29 years of Eagle Creek flow data, much longer than the other water gauging resources that would influence the flows in Snowy River. Most of the recent flow modeling between USGS 08387600 and the Snowy River Turtle Junction site has been based on this unique data, and the calibration of the USGS site is checked and updated periodically.

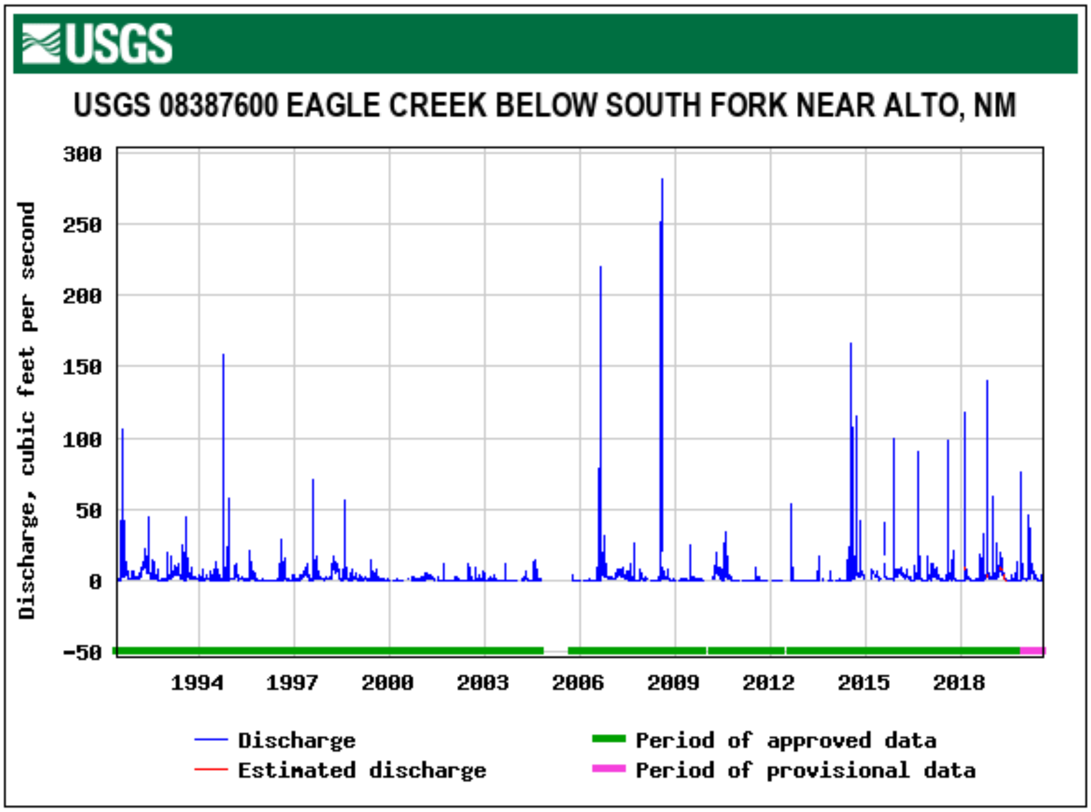
Future Dye Testing to Improve Hydrology Models

Conrad's Branch water most likely comes out of Gov. Spring, or perhaps upstream springs. But exactly "how" this happens is still an unknown. We have 150+ years of observation, but the documentation is very poor. The dye test Buzz Hummel did was apparently only a visual trace to a flooded main corridor, probably done in April, 1983. That path apparently took 2-3 days. Unfortunately, the USGS Eagle Creek record does not go back 38 years. The FSCSP web site shows periodic opportunities for Eagle Creek flows to possibly cause Snowy river to flow after that time. [http://fscsp.org/science/hydrogeology/Eagle%20Creek%20Flows.html]

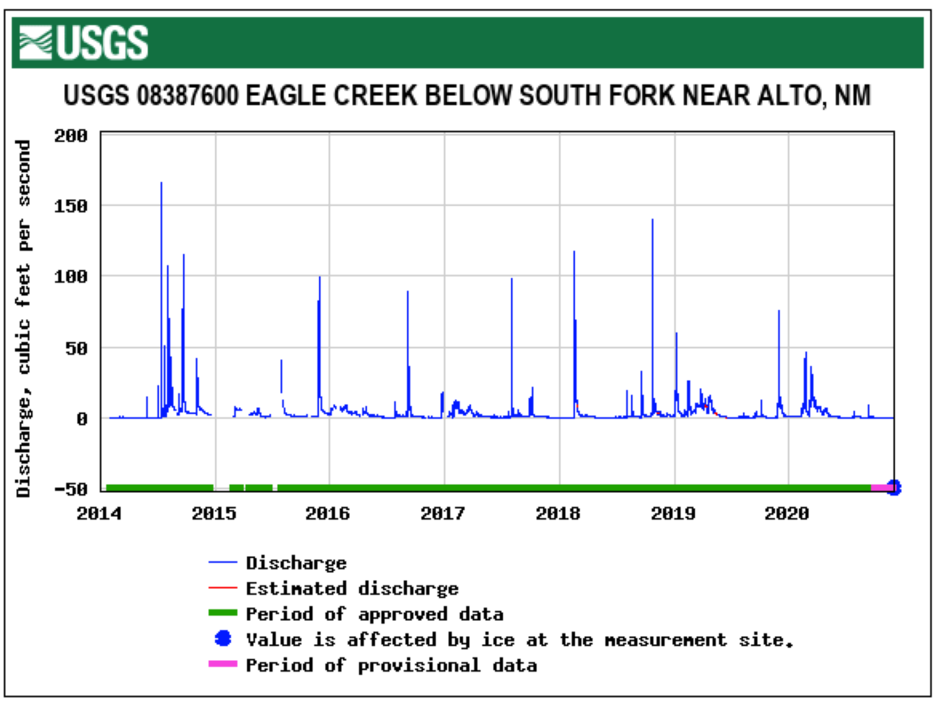
But there are still comments and questions that one might ask:
1. Did Buzz use charcoal "bugs" in Government Spring?
2. Dye placed in the Rio Bonito most certainly flows down to Government Spring, even at low flow. At high flow (perhaps when Buzz did the dye test, although the photo on page 4 seems to indicate otherwise), the Bonito flows into Government Spring, but I don't think it flows all the way into Crystal Lake at SRN80. One time recently it appeared that water flowed from the HOTP passage, across the Wash Tub Room (past our logger) and then on into the Circle Route which feeds the Main Corridor. Was this the only route for the Hummel dye, or did it come through a more direct route?
3. Did anyone make a visual observation of green dye in Government Spring? If it took 2-3 days to arrive in the Main Corridor, it could have taken many months or even years to arrive at Government Spring. Dye would likely have passed Government Spring in the Bonito prior to the Wash Tub Room.
4. Since the Main Corridor was apparently flooded, one might assume that Snowy River was probably also flowing, at least that is what we have seen for the recent 2014-2018 records from our own data loggers. We will get a better idea of the Conrad's Branch drying when we retrieve the SPL data logger this spring.
5. From Donald's references, one might assume that the Main Corridor was flooded for about 10 years starting about the time Buzz introduced the dye into the Rio Bonito. Steve Peerman has a proposal to identify Main Corridor water lines for this flooding period, based on a few photos.
6. What we really need is some rainfall records for the 1980-2000 period.
7. With the recent acquisition of an appropriate Pygmy meter for measuring the exact flow of the Rio Bonito during future flows, perhaps we can better identify if there is a "loosing" section of the Rio Bonito near where we suspect Buzz introduced the dye, or downstream.
8. After we extract our data logger from the new Rio Bonito site this spring, we may get a better idea of any correlation with the USGS station on Eagle Creek, for which we now have very good correlation with the SR flow at TJ.
9. The exact correlation with water in Conrad's Branch with either Snowy River or Government Spring remains a mystery. Data loggers in place now may give us temperature, water depth and timing information to help answer this mystery, but I suspect that it is more likely to take some better chemical / DNA analysis at Sewer Pipe Landing, Turtle Junction and Government Spring to fully resolve "some" of this mystery.
10. Fortunately George Veni is now working on a plan for a future dye test that could occur during a future Snowy River flow event. If it ends up involving more than "just" an Eagle Creek-to-SR-to-Government Spring test, we now have very good timing information for 8 miles of the downstream SR path. The challenge may also involve Little Creek and Rio Bonito insurgences and the small springs upstream from Government Spring along the Rio Bonito.

Appendix 3 – USGS Eagle Creek Flow Charts

USGS Eagle Creek Flow Charts: The chart below is directly from the (USGS 08387600 on Eagle Creek) web site and shows the flow over the 29-year period from 1991 until 2020.



When first discovered in September 2001, Snowy River was dry. A similar expanded chart that covers 2014 thru 2020 is shown on the right.

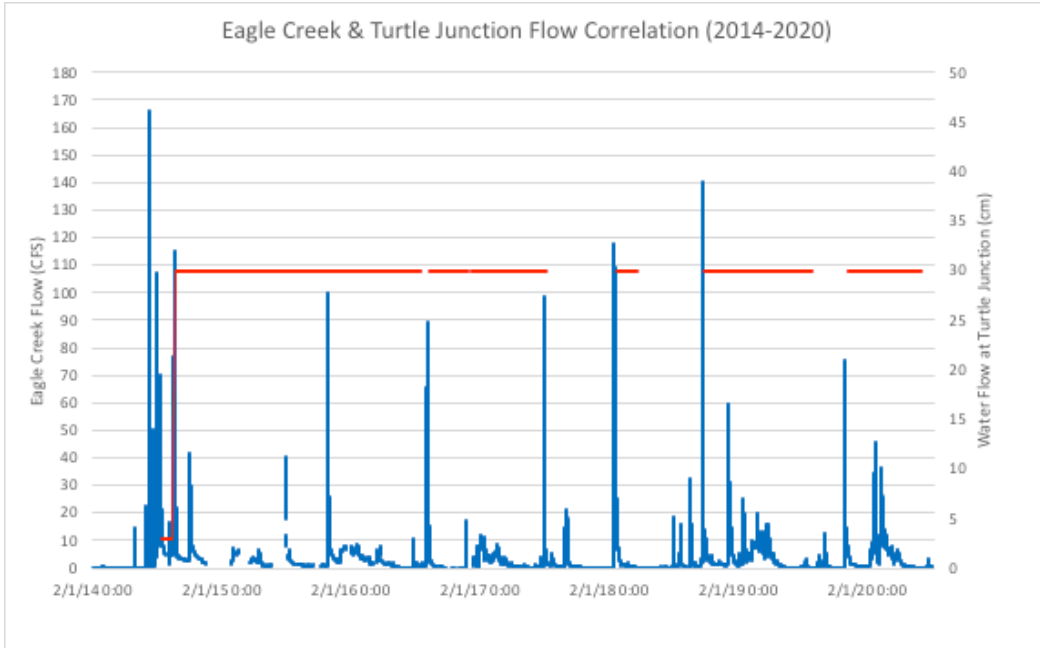


This chart covers the majority of the data loggers discussed in this report, starting in mid 2014 with the significant rainfall that continued for several months and resulted in a new Snowy River flow during the fall of 2014.

(The URL for this USGS site is shown below.

[https://nwis.waterdata.usgs.gov/nwis/uv?cb_00060=on&format=gif_default&site_no=08387600&period=&begin_date=2014-01-01&end_date=2020-12-01]

The next chart shows just the 6-year 2014-2020 Eagle Creek flow period (blue trace) with the actual measured flows at Turtle Junction shown in red. This chart, by Steve Peerman, is a continuation of a study started with the goal of correlating the flows at Turtle Junction with the same USGS gauge shown in previous charts. Steve Peerman's analysis now uses a spreadsheet that allows arbitrary sizing of a hypothetical underground reservoir



between the USGS station flow data and the measurement point at Turtle Junction where we have been able to obtain data logger data since 2010. This allows the assumed reservoir to start filling with the surface flow in Eagle Creek, and then at a certain value this flow begins to start the flow in Snowy River until it reaches Turtle Junction and beyond. As we are able to evaluate the timing of these flows at various data logger sites south of Turtle Junction, the variables in the analysis can be optimized to better match the predicted arrival time of a flow at Turtle Junction.

Appendix 4 – Area Hydrology & Watershed Map

Area Hydrogeology and Watershed Map:

Hydrogeology, Water Resources, and Water Budget 19

The figure on the right is a watershed map for the Upper Rio Hondo Basin. It is found on page 19 from the *sir2014-5153.pdf* file and the sub watersheds for the Fort Stanton Cave Snowy River karst area are shown in the numbered sections 6, 7, 10, 11 and 13. An adjacent sub watershed, number 8, also feeds the Rio Bonito (section 7), which we currently believe is responsible for feeding the Main Corridor flows, which appear to join the Snowy River flow just upstream from Government Spring.

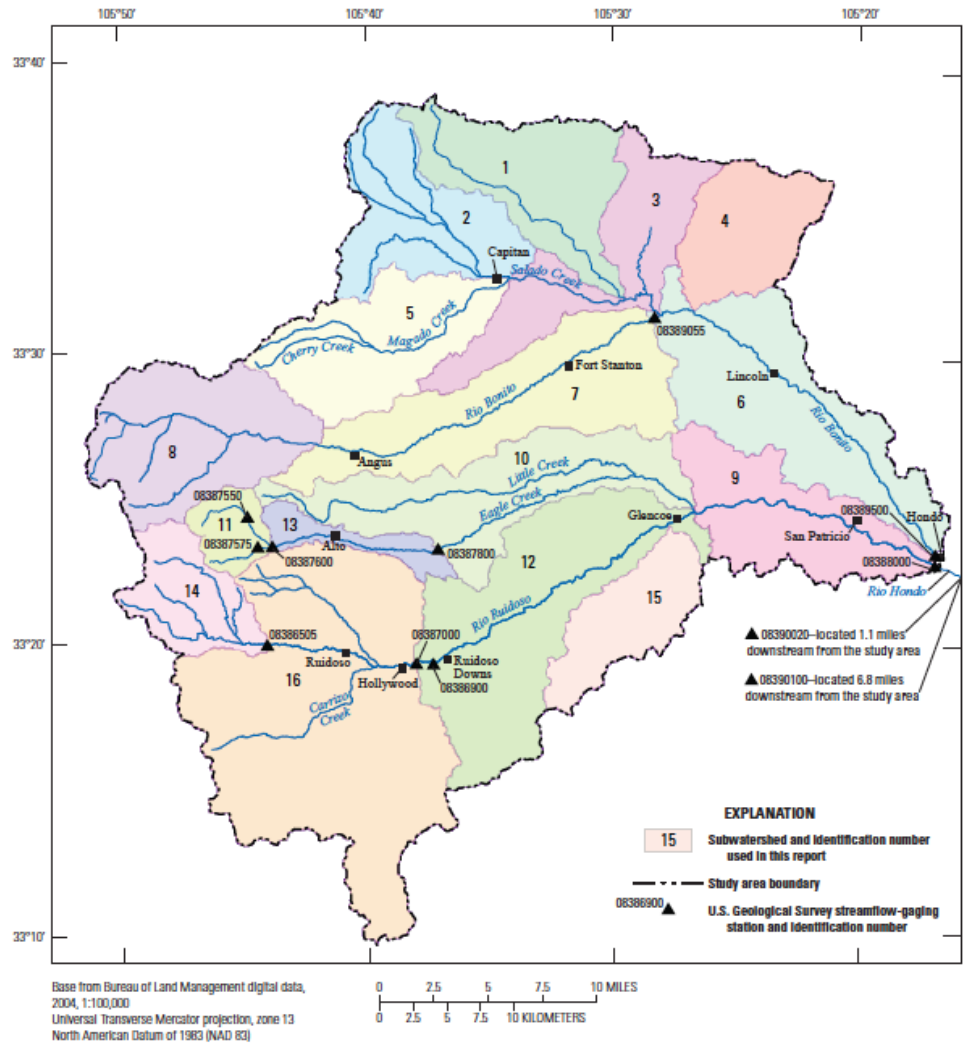


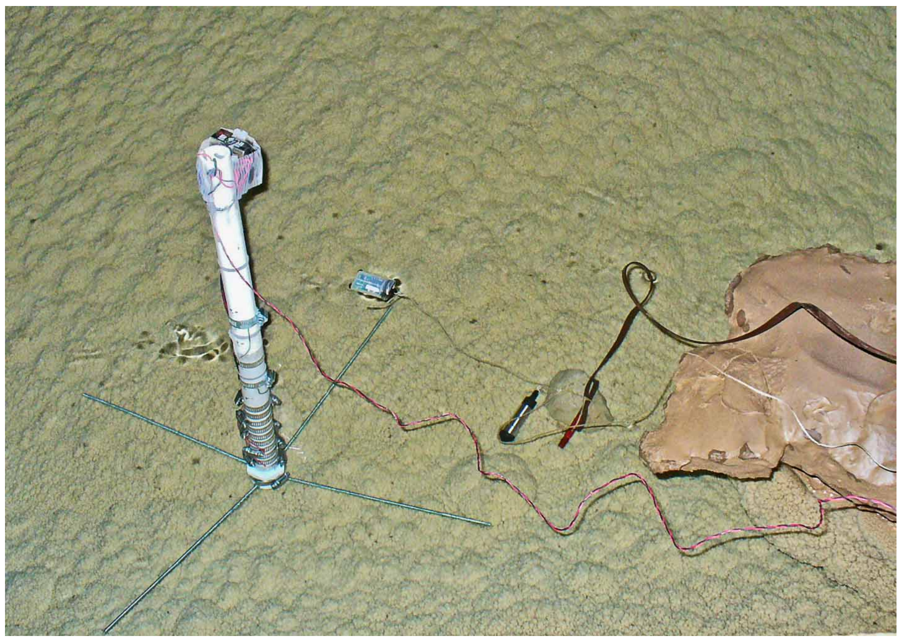
Figure 9. Subwatersheds and streamflow-gaging stations in the upper Rio Hondo Basin study area and on the Rio Hondo, Lincoln County, New Mexico.

Appendix 5 – Choice of Data Loggers

Choice of Data Loggers:

John Corcoran's Schlumberger Mini-Diver was the first commercial FSCSP logger at the Turtle Junction location and recorded the 2010 flow. Also shown in the photo below with the Mini-Diver are home-made loggers by Lindsley & McLean installed at Turtle Junction on 8-8-2008. (Photo: J. McLean #0086))

In 2008, shortly after the access shaft was connected to the Mud Turtle passage, it was discovered that Snowy River was flowing. The word went out and by August we were able to install three data loggers at Turtle Junction. Lindsley fabricated a crude "water sensor" and attached a LASCAR data logger, McLean assembled a better unit from his parts stash, and Corcoran beat us all with the purchase of a professional Schlumberger baro and water level data logger. The success of the Schlumberger unit in recording the 2010 Snowy River flow was outstanding and would lead the team into an evaluation study to identify the most appropriate data logger for Snowy River.



After an extended discussion with several hydrologists and considering the special requirements of the deep cave survey teams (Strong & Light or S&L teams), the logger requirements focused on the In-Situ loggers. These had been used successfully by the Texas Edwards Aquifer hydrologists covering an extended field area. They were non-venting, which required a couple of extra baro loggers for compensation of the barometric pressure, but in the long run we could acquire almost twice as many units for twice as many sites using our limited funds. Without cables, they were more rugged, and the relatively larger diameter housed a longer life battery as compared to the Mini-Diver unit. The size and weight of the units were more than the S&L cavers wanted to deal with since at the time they were making extremely long trips (30-40 hours) without camping. But since future maintenance could be accomplished simply by taking in four replacement loggers to exchange with four units in the cave, only a single 1 x 6-inch logger had to be carried by each team member. The ability to clean each logger coming out of the cave and not having to deal with unreliable computers and cables were positives. With the help and suggestions from several professional hydrologists (Geary Schindel, George Veni and others) in addition to the BLM support in a 2012 Assistance Agreement, by May 2013 we were prepared to deploy the first array of In-Situ loggers along the length of the then known Snowy River Passage complex. The team carefully selected the 10 best Snowy River logger sites to answer our main questions on the water source.

Appendix 6 – Compensation Considerations

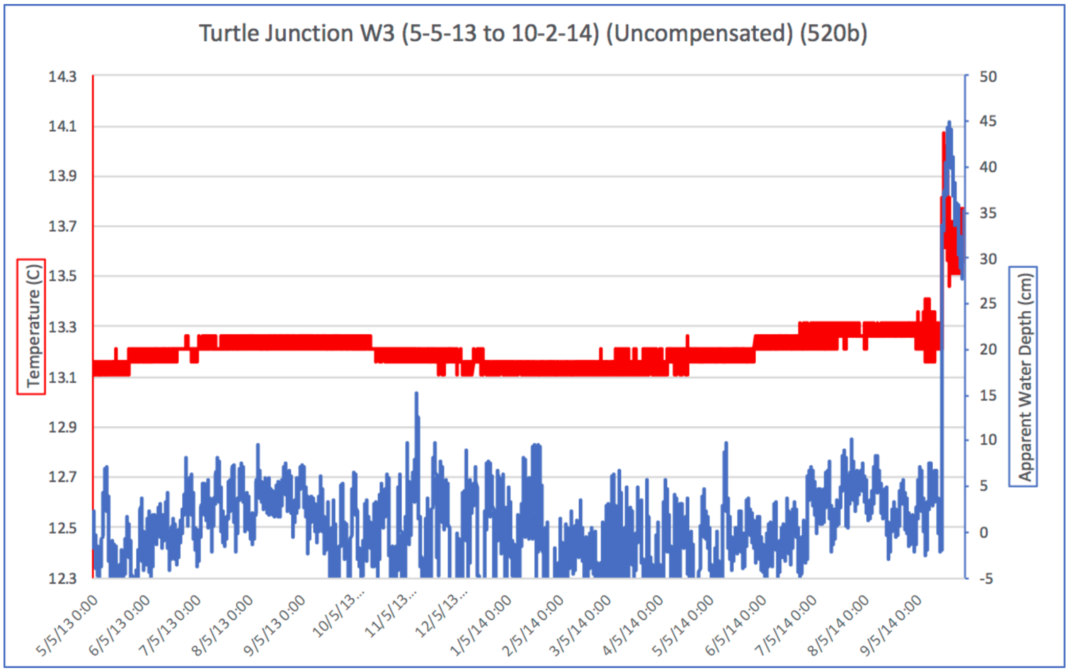
Water Depth Compensation Considerations:

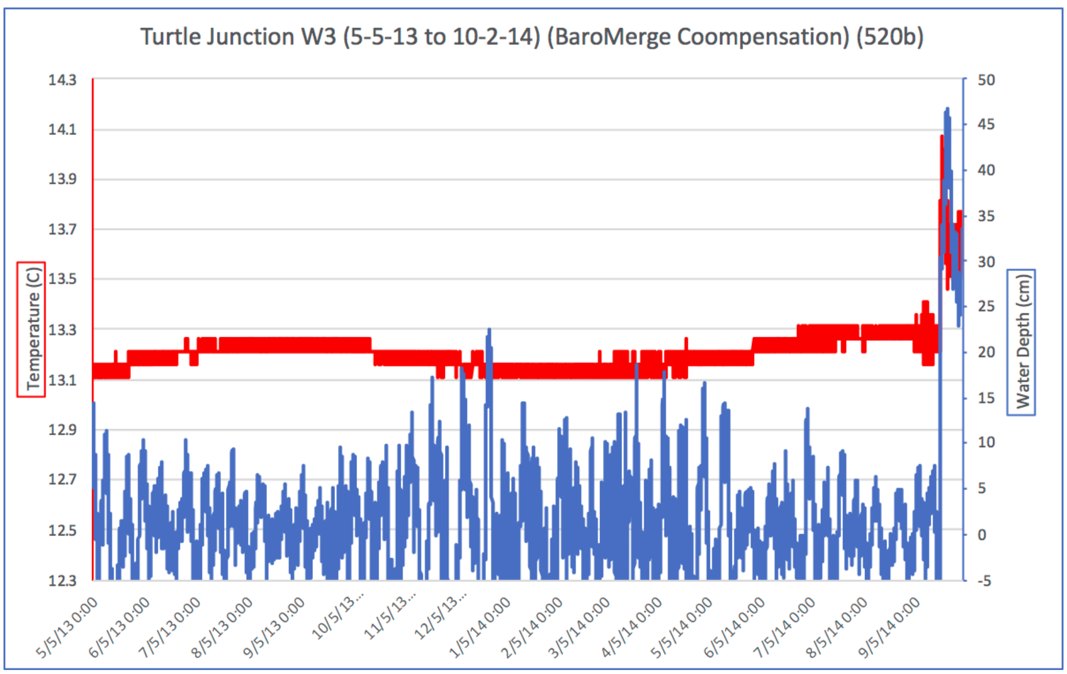
The change in barometric pressure also changes the apparent water pressure, and the simple correction is to subtract the (barometric pressure) from the (water + barometric pressure). Normally a baro logger will be deployed at the same time as a set of water loggers, and one baro unit can "sort of" take care of a number of water loggers within a set distance, depending on the precision desired. In 2013 available documentation and suggestions from the "local rep" suggested a baro could cover an area with a radius of ~ 10 miles. This may be appropriate for above ground corrections, but we have found that in the cave this distance is much shorter, and may depend on the cave characteristics. In 2018, using some "home brew" barometric data loggers for measuring relative elevations in the cave, we measured a significant pressure drop at the Mud Turtle air lock door. This "door" still allows air to leak between the DSMH Access Shaft and Turtle Junction. A mile and a half upstream from Turtle Junction the Two-Way Hill breakdown also apparently the timeline on changes in the barometric pressure.

A major difference between the BLM Solinst vented data loggers, which are set in pairs that also include a local baro data logger for each site, can be observed in the charts in this report. Although the Solinst units provide a much smoother water level value, the cost per site is about 3-4X higher than the non-vented In-Situ Rugged Troll 100 units that the FSCSP is using in the cave. The overall reliability of data taking with the In-Situ units due to the lack of cables in the cave and the practice to download the units outside the cave was important in the choice of data logger units. It was decided that it was more important to obtain hydrological data at 3-4X the number of sites for the amount of funding that was available. The other factor in the choice of the In-Situ units was the ~10-year battery life and more compact size when transported over 2 miles into the cave, with some sites being 11 miles from the entrance.

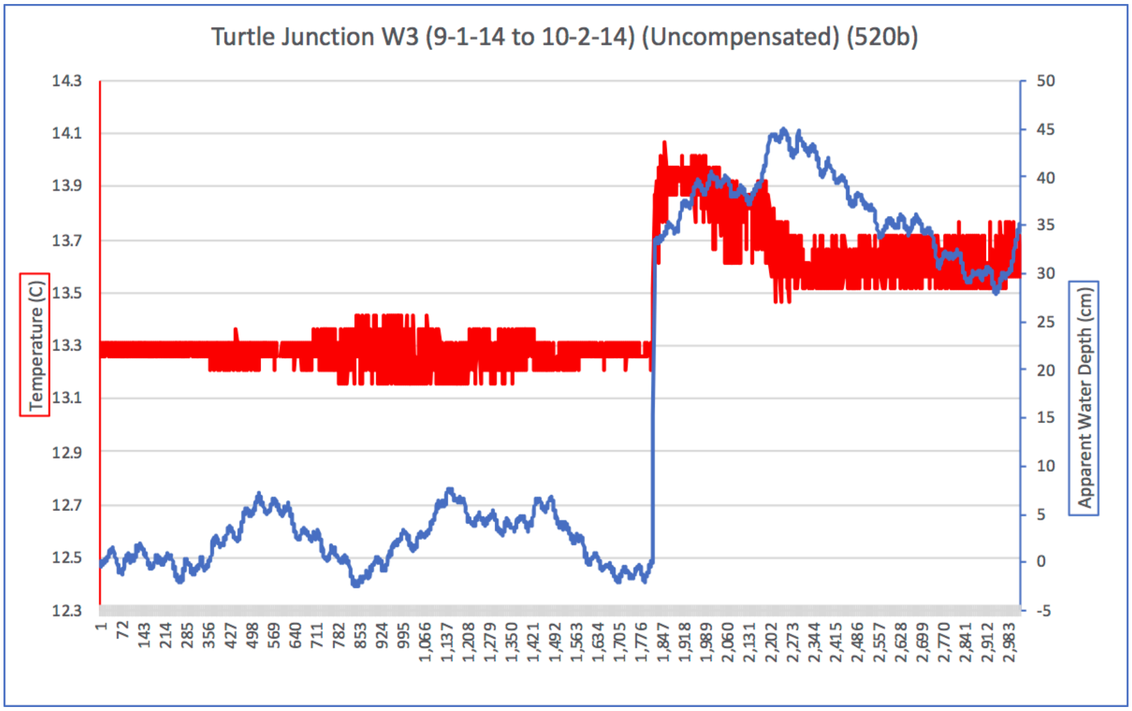
In addition to the choice of location for the baro units, it is now considered very important to set both the baro loggers and the water loggers for the same sample rate. In the 2013 deployment it was decided to program the two baro units for a 1-hour interval. The 10 water logger units were programmed for a 2-hour interval, but were also set in an event-sensing mode to monitor any change in the water pressure of more than 2 cm of water that would change the interval to 15 minutes. Due to mis-information, the units of pressure change were incorrect and the first 10 water loggers took data in 15-minute intervals for the first 16 months until the unit memory filled. Previous duration of the observed Snowy River flows had been 9 months, but in 2014 a most unusual Snowy River flow lasted 4+ years. The lesson learned from the 2013 deployment and over the next 6 years, plus the ROM update on the units that doubled their data point capacity, resulted in the 2020 decision to program both the water loggers and the baro units for 30-minute intervals, which will provide data for 7+ years.

The four charts in this appendix show a non-ideal compensation of a baro at Turtle Junction with 1-hour increments when used to correct the water level of a water logger at Turtle Junction using the In-Situ BaroMerge program. For this example, the BaroMerge correction is not an improvement over the "simple un-corrected" chart where only a nominal site area pressure value was subtracted from the raw water logger data, which placed the average "dry" water depth near a zero-water depth value.

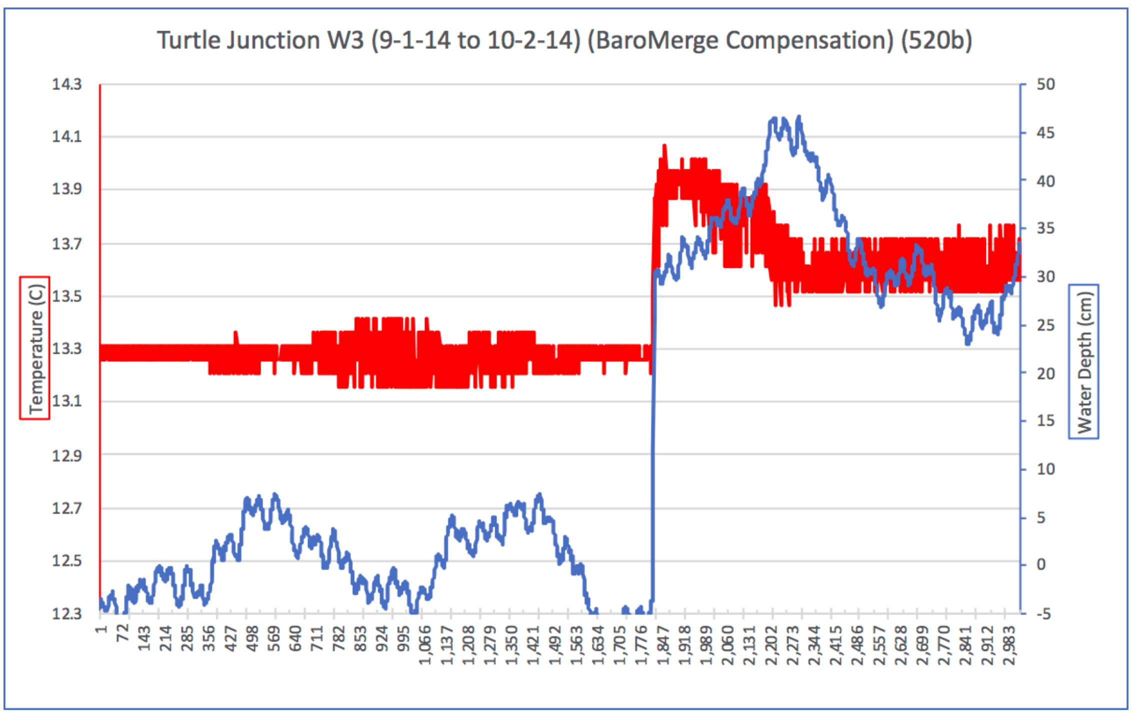




These two charts show the effect of the water level calculation when the start of the 2014 Snowy River flow starts. It is likely that some of the noise on the blue water level plot is caused both by barometric change and also the internal processing of the In-Situ BaroMerge program.



Do the differences really matter? The "yes" answer may only come from the scientist trying to determine a smoother flow volume from these stage measure-



ments, and the ripple would likely have a greater effect for shallower stage measurements. The arrival time calculation for the start of the flow would probably not significantly change since the temperature change in most cases would be an easier identifier than the first change from zero to 1 cm in water depth.

Appendix 7 – Post Processing & Charting Process

Post Processing and Charting Process:

If doing a lot of processing from past data sets, start with the list of loggers sorted by location, and logger end date. Check to see that any site information in the file name matches the actual location as determined from the in-cave logger exchange data sheet. Determine the approximate end date for each site and determine which, if any, are duplicates of other files. In-Situ duplicates occur when a data logger is downloaded more than once using the PC software (Win-Situ 5, v5.7.6.1). If there is an appropriate associated baro logger on the same PC doing the water logger download, also run the Baro Merge PC program, which will automatically compute the water logger compensation for barometric pressure variations. If not available, perhaps the compensation can be done at a later time using manual Excel processing.

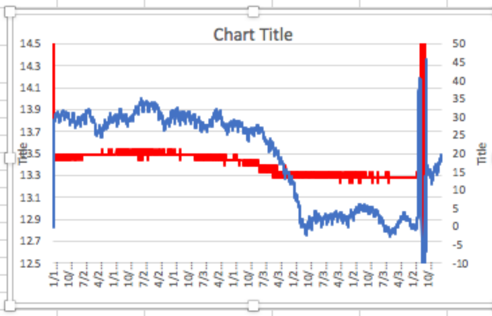
1. Download logger using In-Situ app (Win-Situ 5, v5.7.6.1). File is saved on a PC under the user's name. Export CSV file.
2. If a corresponding Baro file is available, you can also process a BaroMerge operation (Win-Situ Baro Merge, v 1.4.5.1) and also save a CSV file.
3. Transfer both the .wsl and the .csv files to project management computers for archive and also post-processing during the expedition.
4. Open the CSV files using MSE (Microsoft Excel) or equivalent. (Steve has his own undocumented process that combines the In-Situ data logger data with post processing from the USGS data from (USGS 08387600 on Eagle Creek). See Appendix 3. This data is often presented in a chart in the expedition report.)
5. Pete has his own process as documented in this report.
6. Double click the CSV file to open it in MSE. Copy the latest parameter correction table into the new MSE file at approximately G55. Enter the logger short name near the table for future reference. If the short name is not in the header of this file, determine the correct logger name using a serial number reference chart.
7. Select the 3h x 4w cells that are the last two column headers plus two additional two cells to the right. Text wrap and center text these 12 cells. You will be plotting the Temperature (C) column and the adjacent Water Depth (cm) column, so insert a blank column to the right of the Temperature column as required. Add the Water Depth (cm) header to the blank column next to the Temperature column. Add the Pressure (cm H2O) header to one of the new blank columns. Fill this new Pressure column using the data logger pressure reading and the appropriate multiplier from the table. Fill the Water Depth (cm) column computed by subtracting the "Area Pressure Compensation" from the newly filled Pressure column. (Note: the compensation number can be changed in the table later after the graph is completed to "balance" the zero pressure for zero, or other, actual water depth.)
8. Graph the two adjacent columns for the whole data record. Look closely to detect data records not of interest, such as logger "turn-on" before the logger is at the designated site; or on the other hand extra data on the "tail end" of the records after the logger is removed from the designated site. Modify the graph to show only the legitimate data from the designated site.

9. Use the Chart Template feature of MSE (or equivalent) choosing the particular site or closest equivalent template. If no template is available for your particular chart, modify the chart by hand and be sure to save a new template for future use.

Post Processing Logger Data Example:

52						
53	Log Notes:					
54	Date and Time	Note				
55	7/1/16 23:24	Used Battery: 0% Used Memory: 3% User Name: John				
56	9/14/16 12:55	Log Download - Used Battery: 1% Used Memory: 6% User Name: caverpete				
57						
58						
59	Log Data:					
60	Record Count	7108				
61						
62	Sensors	1				
63						
64		1	449799		Pressure/Temp PSIA (9m/30ft)	
65						
66	Time Zone: Mountain Daylight Time					
67						
68			Sensor: Pres(A) 30ft		Sensor: Pres(A) 30ft	
69		Elapsed Time	SN#: 449799		SN#: 449799	
70	Date and Time	Seconds	Temperature (C)	Water Depth (cm)	Depth (ft)	Pressure (cm H2O)
71	7/2/16 12:00	0	26.811	2.38	27.473	837.38
72	7/2/16 12:15	900.001	24.772	2.13	27.465	837.13
73	7/2/16 12:30	1800.001	22.765	1.95	27.459	836.95
74	7/2/16 12:45	2700.001	21.731	1.62	27.448	836.62
75	7/2/16 13:00	3600.001	21.187	1.55	27.446	836.55
76	7/2/16 13:15	4500.001	20.89	1.95	27.459	836.95
77	7/2/16 13:30	5400.001	20.642	1.71	27.451	836.71
78	7/2/16 13:45	6300.001	20.344	1.98	27.46	836.98
79	7/2/16 14:00	7200.001	19.946	0.88	27.424	835.88
80	7/2/16 14:15	8100.001	19.498	3.29	27.503	838.29
81	7/2/16 14:30	9000.001	18.399	0.67	27.417	835.67
82	7/2/16 14:45	9900.001	17.697	0.00	27.395	835.00
83	7/2/16 15:00	10800.001	17.546	0.73	27.419	835.73
84	7/2/16 15:15	11700.001	17.345	1.04	27.429	836.04

Corrected Conversions (Rev2)	
7.5006161	kPa to mmHg
0.7500616	mBar to mmHg
70.3069578	psi to cm H2O
1.019716	mBar to cm H2O
10.197162	kPa to cm H2O
1.35951	mmHg to cm H2O
835	Area Pressure Compensation



Describe the process shown above to produce a collection of similar charts between In-Situ, Solinst and Schlumberger data loggers now displayed in uniform units.

Appendix 8 – Drain-Down in Snowy River Pools

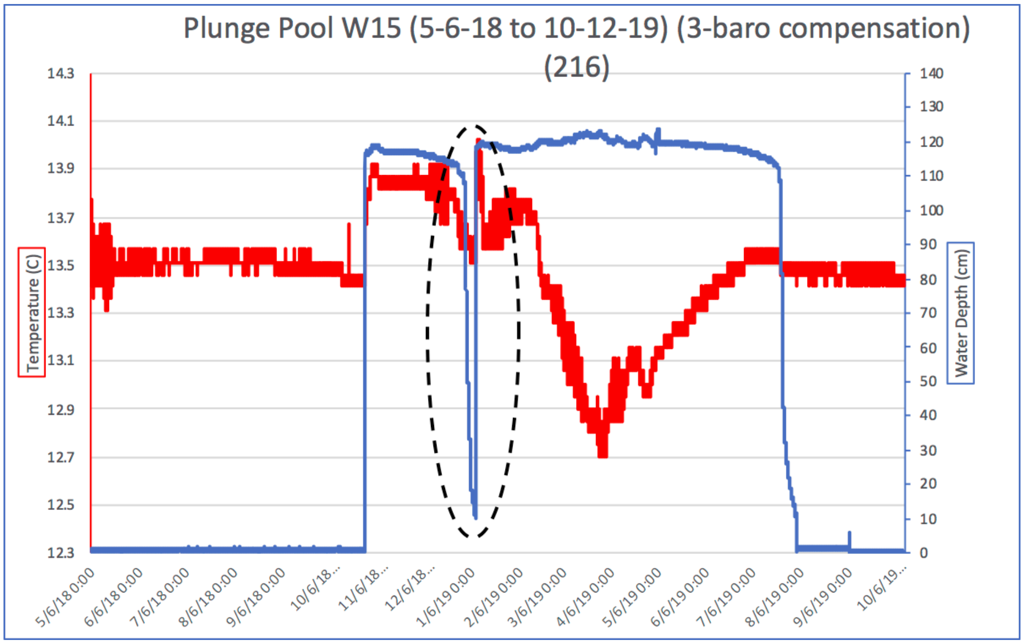
Drain-Down in Snowy River Pools:

A continuing discussion of Snowy River Hydrogeology is focused on what material is available under the calcite floor area. Tell-tale markings such as ripples are visible in several places, including the Plunge Pool, seem to indicate there could be some sort of gravel or sand bank under the calcite, a floor surface that was already in place in this major stream channel passage that seems to have pirated the upper levels of the cave in numerous locations. Perhaps a closer look at the stratigraphy in the cave, compared to what is visible on the surface as well as possible information from well logs will provide more information in the future. Dr. Lewis Land did some of the earliest work on the calcite surface material that is likely part of the pool drain-down characteristics. Lewis and his team are shown below on the initial core hole drilling. Talon Newton also made cross section measurements at these initial core hole sites. Check out the References section at the end of the main report for additional related data.

For several years the discussion has involved the idea of lower aquifer levels being able to both transmit water in these levels up to the calcite surface due to increased head pressure in the aquifer, and also to more rapidly drain down pools along the Snowy River route. By incorporating temperature data in the charts presented in this report I believe now we may be able to show an example of the former process that occurred at the Floating Island site. This appendix will add some newly processed charts that may also show a difference in the drain-down process. There may be other sites that can be studied for possible contributions to drain-down characteristics that we can pursue in the future.

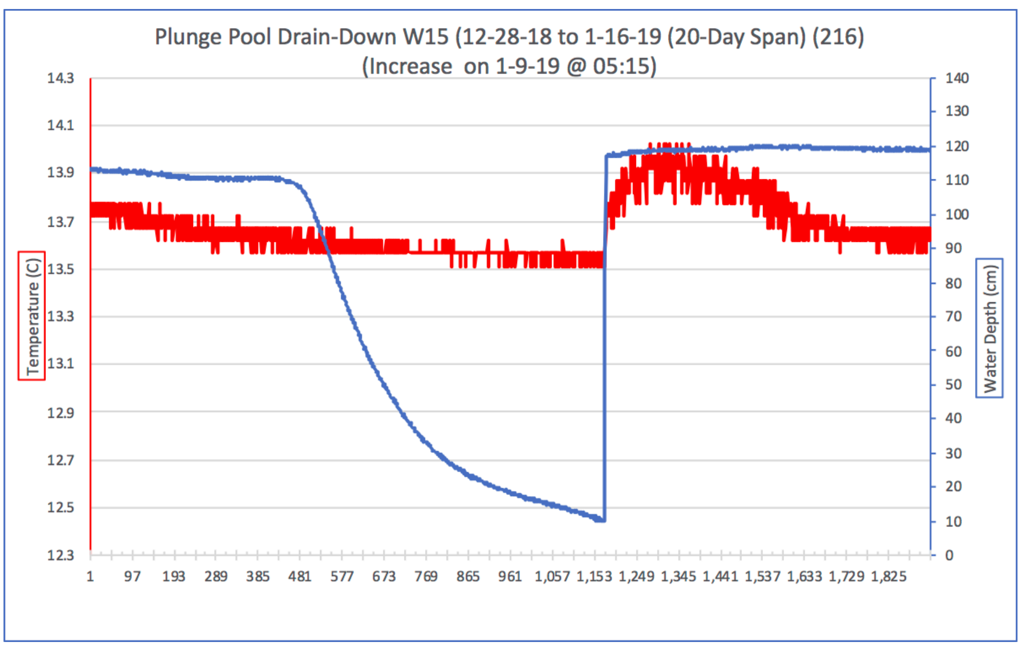
(Photos: R. Harris #0042 & #0049)

Plunge Pool: Since water pressure at the floor will impact the rate of a drain-down process, we would expect to see some sort of non-linear curve shape that will differ as a function of the pool depth in addition to the characteristics of the material beneath the calcite. Another function of the drain-down process might be the saturation of water in the floor material. Looking closely at some of the charts in this report may lead to differences in drain-down rates after a 9-month Snowy River flow versus a 4-year flow. This became apparent by just looking at the pooled water shortly after the primary stream channel flow ceased. One year there was a 6 cm deep pool at Turtle Junction and no water pooled at the Plunge Pool. Observations during another year following a multi-year flow showed a pool depth at the Plunge Pool site with about a 15 cm depth (shown in the photo below), but there was no standing water at the Turtle Junction site just downstream. This appendix will also show some drain-down charts at the SRS19 core hole just downstream from Turtle Junction, plus data from the deep pool near Turtle Junction, the Plunge Pool (SRS31), and another deep pool, the Swimming Pool at SRN53, which is about halfway to the final deep pool where Snowy River sumps just before the resurgence at Government Spring. In particular, the above data illustrates just the Snowy River flow between May 2018 and October 2019.



The photos illustrate the remaining drain-down pool in the Plunge Pool on 8-19-17. When Snowy River starts to flow, it drops down about three feet into this large pool. It takes a while to fill the pool before it crests over the downstream floor and goes another 100 meters before reaching Turtle Junction. The logger is at the bottom of the folding engineering ruler, and the empty PVC tube was used to extract the red calcite-coated nylon string for depth analysis by Dr. Mike Spilde.

When the Plunge Pool passage was visited on 8-19-17 after a multi-year flow, the floor was obviously saturated. We noticed that the calcite coating the nylon logger string was significant, and possibly the thickness was a function of depth. We assume from the ripple marks at the exit of the Plunge Pool that there is probably sandy material over a hard limestone or clay floor. One of the Lewis Land core holes is just upstream from the drop into the Plunge Pool, and might offer a good measurement site in the future for a small data logger.



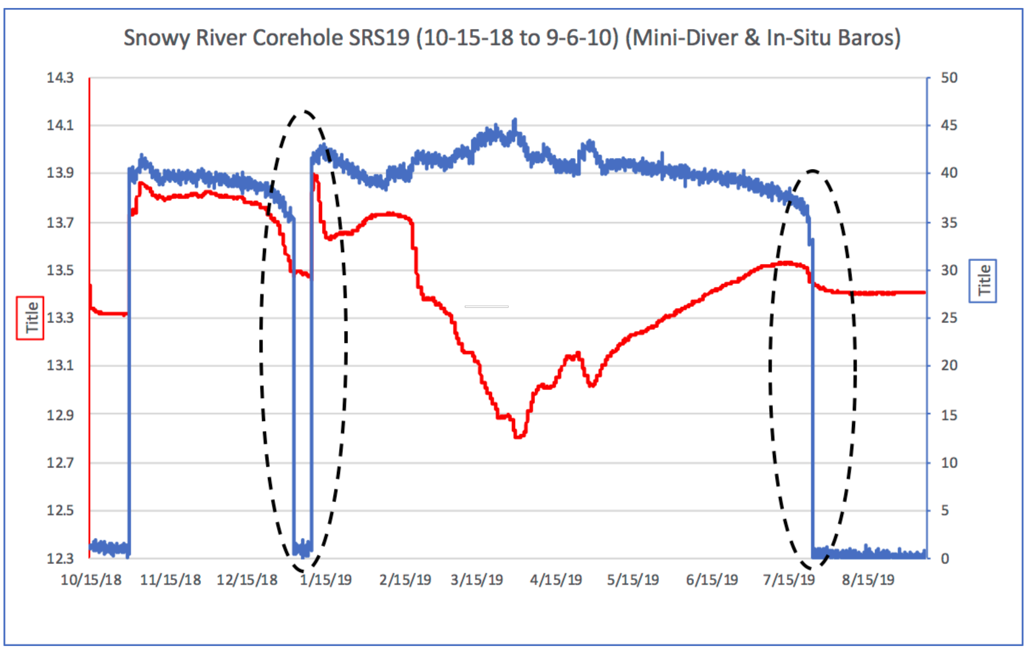
If we expand the previous chart for the Plunge Pool around the time of the sudden dip in water level in January 2019, we can start to see the drain-down characteristics. There are other charts in this report for the Plunge Pool and Turtle Junction area, but this particular chart illustrates that the Snowy River flow stopped several miles upstream (South), a characteristic that carried through to the other charts all the way downstream (North) to Crystal Spring.

The dip was caused by diminishing water in the Eagle Creek area, and it appears from the temperature associated with this dip a slight warming followed a few days later by much cooler water (shown on the previous chart) from a snowmelt event. Was this warmer temperature at the arrival time of the sudden water rise associated with the temperature of water in the aquifer? We currently have very little historical records of the surface temperatures, but perhaps in the future we can find a way to correlate these characteristics with surface temperatures.

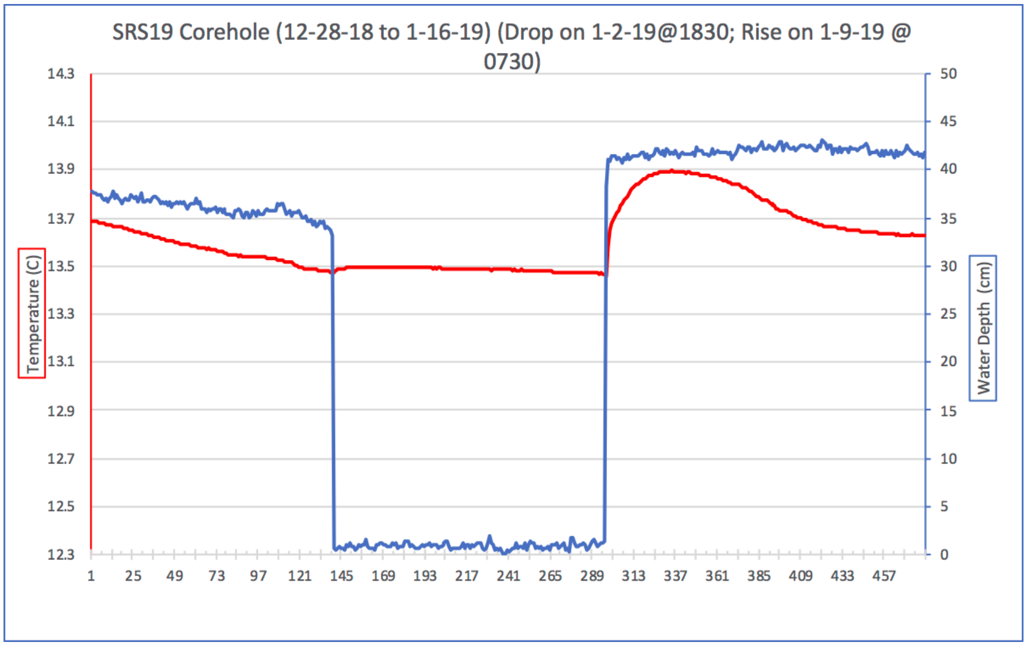
SRS19 Core Hole: Twelve survey stations downstream from the Plunge Pool is a small core hole that we hope might add to our understanding of the porosity of the Snowy River calcite. This core hole was smaller than the 1-inch diameter In-Situ Rugged Troll 100 data loggers featured in the majority of these Fort Stanton sites, but it was possible to insert a Schlumberger Mini-Diver (similar to what we first used at Turtle Junction in 2009). The photo shows this installation, and a more detailed report should be available that describes this USGS project (Dr. Johanna Blake, 2021).

Although Lewis Land and Talon Newton (Dr. Lewis Land, 2010) drilled a series of core holes in the calcite floor of Snowy River for dating purposes of the calcite layers, we have not made any specific hydrological measurements until this project. We know from this previous work that there are alternating white and brown layers in this calcite, which reached several inches thick in some areas. We assume the colored layers are due to past significant flow events. But now we have an opportunity to actually attempt to measure the water below the calcite.

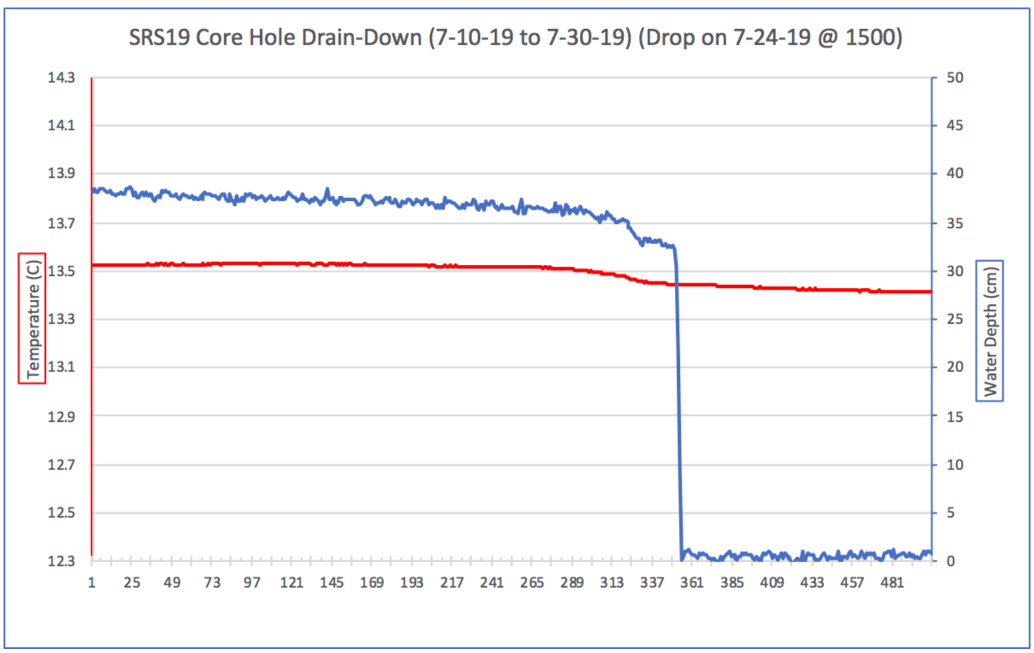
This particular flow had a somewhat unique characteristic in that a few months into the flow the water stopped flowing along parts of Snowy River, but then started up again and ran for another seven months before completely finishing the flow. The following charts show a unique flow stoppage followed by a flow startup when the calcite was likely completely saturated. Compared to other charts in this report, the water depth "fall time" for this shallow core hole was quite sudden. Of course, the other two sites in this appendix were both deeper pools (~120 cm deep compared the SRS19 site which was only 40 cm deep). It is of the opinion of this writer that this site should be used more in the future, perhaps with a slight modification of the core hole "sealing" and a deeper hole if possible. Expanding the chart over a similar 20-day period shows a more linear drain-down curve as compared with either the Plunge Pool or the Swimming Pool site.



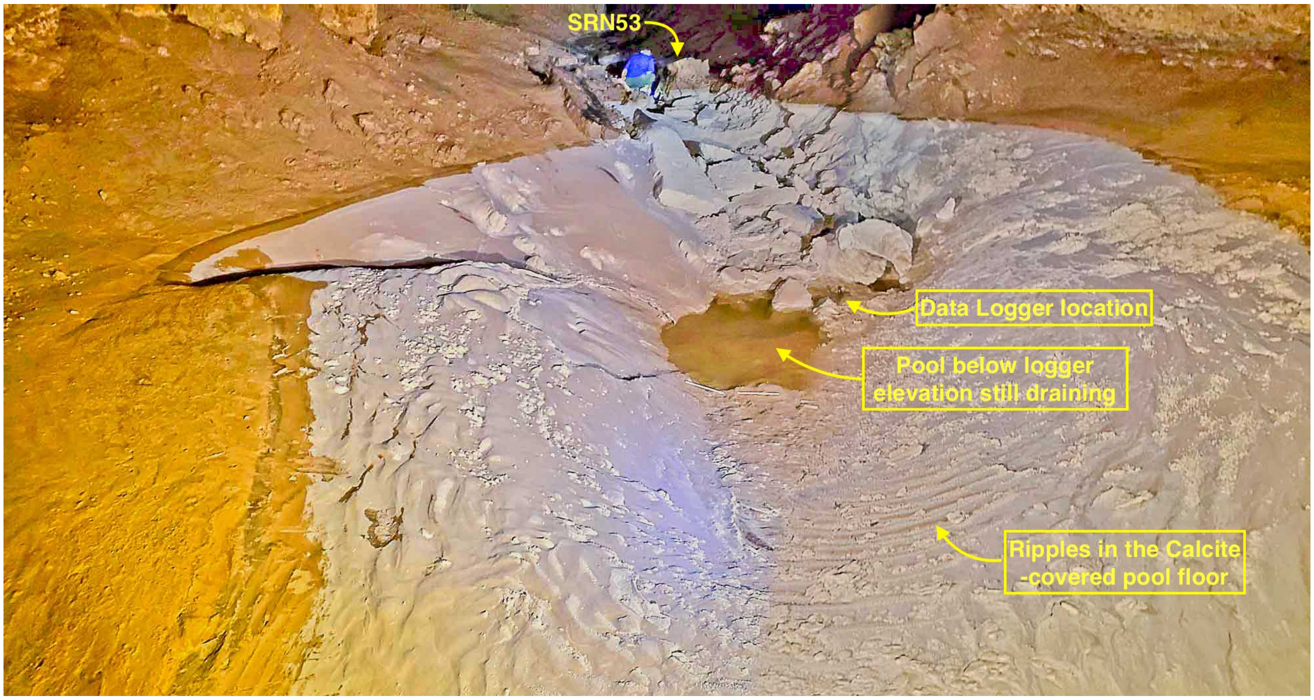
This next chart, shows a similar drain-down characteristic as the flow completely stops. Most of the other Snowy River sites in this report show a slower fall in the water depth. It is expected that the reader will take a close look at this characteristic at the other sites, most of which are shallower that the two deep pools featured in this appendix.



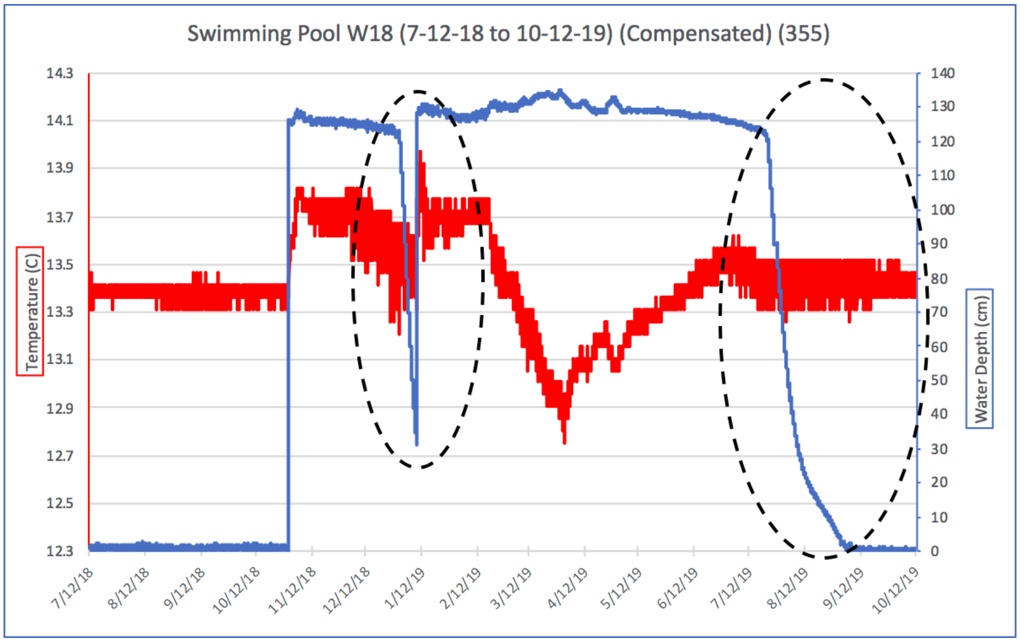
The next chart shows the tail end of this 2018-2019 flow. Again, we see a rather sudden drop, perhaps somewhat emphasized by the 1-hour sample rate of the Mini-Diver logger. A 15-minute sample rate in the future may provide additional data supporting analysis of the Snowy River Drain-Down rate.

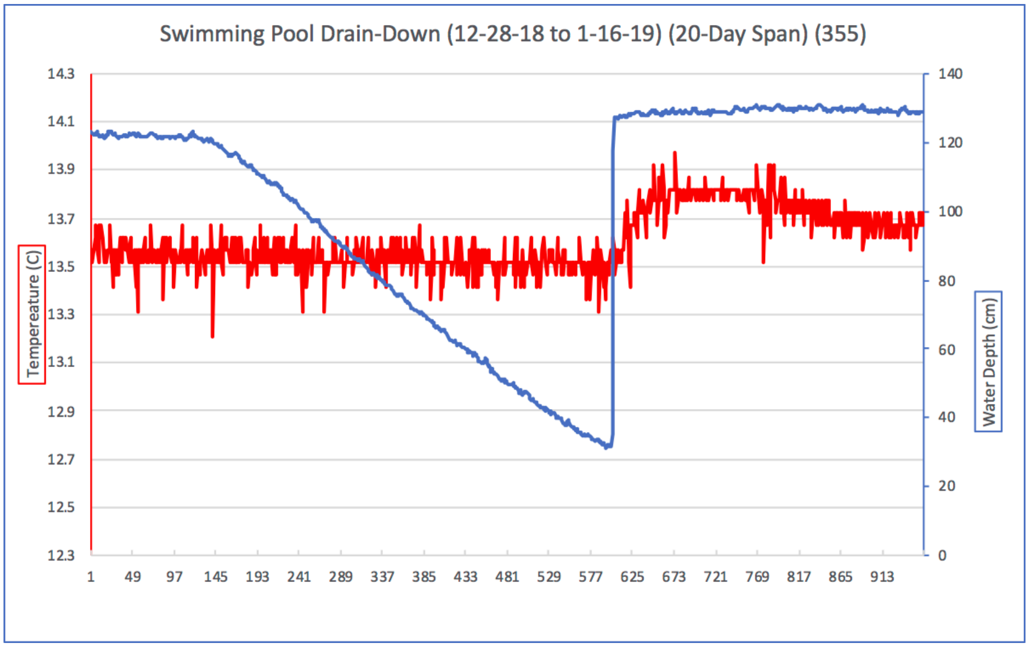


Swimming Pool: The third site featured in this appendix is at station SRN53, which is 53 stations north downstream from the Priority 7 Landing, the discovery location of the Snowy River complex in September 2001. Station SRN53 is on the boulder to the right of the caver in the blue shirt, in this Ron Lipinski stitched panorama. The logger was originally placed in 2013 just downstream from the boulder, and as this photo shows, the location is slightly above the draining pool level shown in this October 12, 2019 photo.



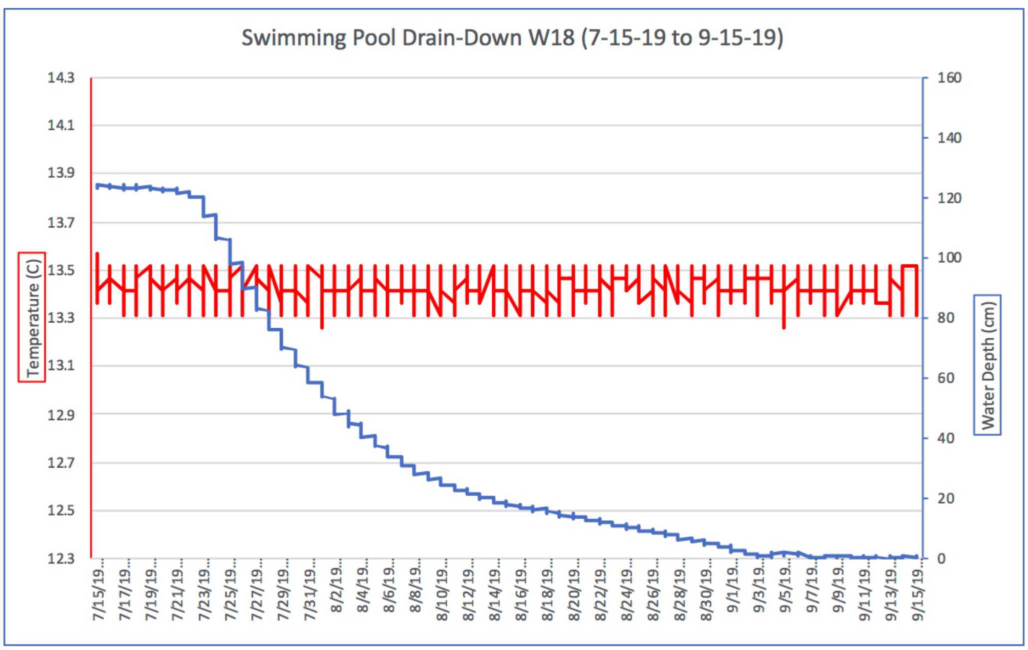
Looking closely at the above photo, one can see several floor ripples on the downstream end of the pool. The chart below shows a similar sudden rise at the start of the Snowy River flow at noon on 10-30-2018. On December 28 the pool level starts to decrease and we see a typical drain-down, which seems to be a sharp, almost linear decrease in the water level





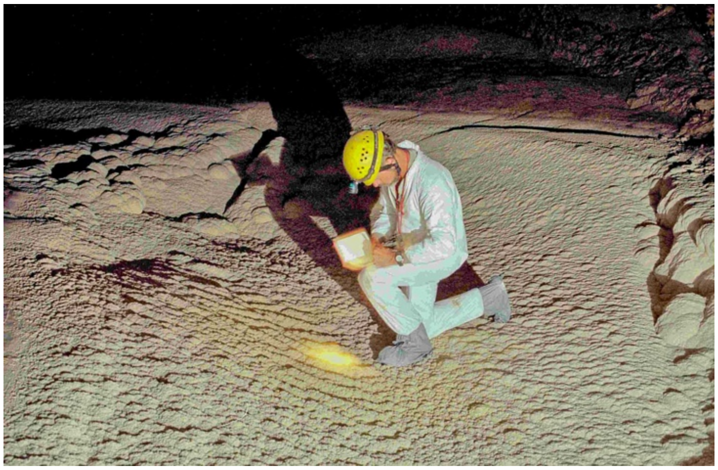
Th chart on the right shows that the pool level declined to about 31 cm until on 1-9-19 the Snowy River flow suddenly started again. This decline shape may be a function of both the (head) pressure from the ~ 4 ¼ feet of water (~1,85 psi) and the porosity of the calcite and the floor material below.

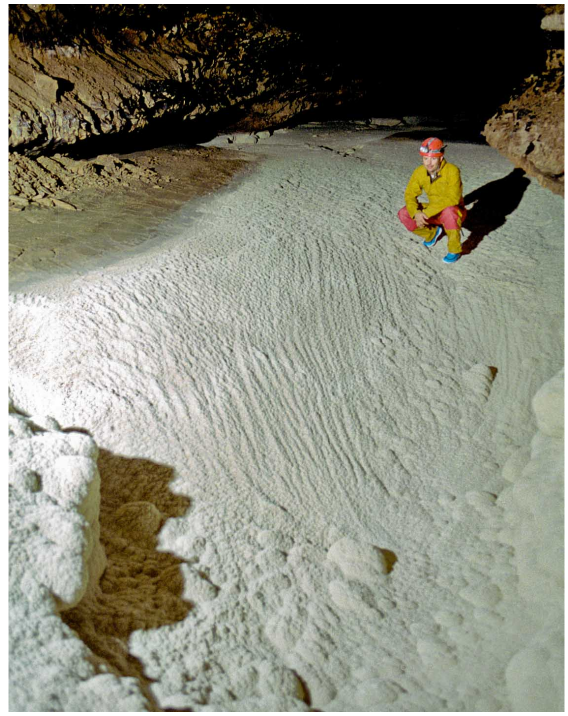
As expected, the final August drainage rate changes as the depth of the water in the pool decreases.



This is one reason it takes several months after a Snowy River flow before the calcite floor is dry enough, and strong enough to support careful travel by cave teams. Some of the deeper pools may be at risk for possible floor damage if the thickness of the calcite over a soft bottom is thinner in places. It is also possible that hardening of the floor calcite can be a function of the humidity and air flow.

Ripples: Both the Plunge Pool and the Swimming Pool sites show "ripples" in the calcite surface. Even on one of the first surveys, John Cochran named the area shown on the right in this photo "13 ripples pool SRS42". John's second photo below was named "Snowy River ripples in floor".





Other photos showing "ripples" correlate the "calcite ripples" as a coating over the top of more ancient clay and sand ripples that were likely formed prior to the past 750-year coating of the Snowy River calcite. Henry Schneiker's photo below on the left shows ripples on the clay bank above today's Snowy River Formation Top (SRFT). Note that there are also multiple "bathtub rings" above the SRFT where the local white calcite elevation is seen in the photo. The bottom photo on the right, by Wayne Walker, shows Knutt Peterson near the plunge pool during the first In-Situ logger deployment trips in April 2013. Side lighting shows the calcite formation over ripples that could indicate flow rates prior to the Snowy River calcite coating. Question: Is there a way that the black coatings (manganese?) at levels above the SRFT be dated?

Appendix 9 – Water Lines

Water Lines: The water level peaks seen on the charts in this report suggest there may be some correlations with various water lines observed in Fort Stanton Cave. During some major flows of Snowy River, we often see short duration peaks that suggests the surface of Snowy River may exceed the more obvious "normal levels" that is related to the Snowy River Formation Top (SRFT) which we are starting to use to correlate with newly installed precision elevation stations. In particular, where we are installing water data loggers at "almost level" sites, part of the data we are obtaining for these discharge sites involves the precision measurement of the local slope. This slope, plus the stream channel cross section, can be used to determine an approximate volume flow (in cubic feet per second) versus time which might lead to new predictions of undiscovered inflows to Snowy River from other passages.

On closer observation of the apparent SRFT elevations, some locations seem to have more significant "water lines" as evidenced by both white calcite lines and black lines above the white SRFT elevations. The calcite lines, which are mostly seen in the historic sections of the cave, particularly in conjunction to the water levels in Conrad's Branch, are likely caused by pooled water that is supersaturated with calcite which forms calcite on the surface of the pool. However, one such example, near the junction of the Mud Turtle passage with the Snowy River passage, may be related to the elevation of water prior to the actual formation of the Snowy River calcite. This suggests a future correlation of the dates of these layers by the proper lab tests.

Another example is seen at Sewer Pipe Landing, where the data logger site sometimes shows depths up to seven feet during a period of Main Passage flooding. There is a section where over two feet of varying water depth is seen on the passage walls, and this site often has calcite rafts floating on the surface of the pool extending from Sewer Pipe Landing back towards the entrance.

When one inspects the black manganese deposits in the Snowy River Passage there seems to be at least two processes depositing the manganese. The water lines above the white Snowy River calcite appear to be a part of a flowing water process.

At several Snowy River locations there are multiple black lines showing previous water levels above the present day "normal flow" levels. Victor Polyak's photo on Snowy River downstream from Turtle Junction shows Paula Provencio pointing at one of these areas. Another of Victor's photos shows Mike Spilde checking out the manganese on a wall above Snowy River.

Close observation of the manganese thickness in locations near Turtle Junction show that the upper wall levels appear to have a fairly equal thickness, at least in some areas. A number of manganese samples were collected at Turtle Junction in May, 2019, and are currently being evaluated by Mike Spilde. The closeup photo of a clay deposit on the wall about 4 feet above the SRFT seems to show layers, perhaps due to ancient deep flooding of the Snowy River trunk passage well before the current white calcite deposits. The cm scale of the photo taken in 2011 gives an idea of the thin outer black layer on the top of a clay deposit, likely deposited by muddy waters 100's of years ago.

This closeup of the edge of Snowy River appears to show multiple waterlines above the normal top of the white Snowy River calcite of different widths. Apparently, these black lines are probably manganese, but appear to be formed differently from the more common coating on the limestone walls and ceilings near the Snowy River Passage. Were they formed before or after the white calcite coating the floor of the current stream channel? (This might be an appropriate area of study for a graduate student looking for a cave-related project. A cross section with proper photography of a series of lines at different elevations above the SRFT level might show thickness differences. Perhaps the layers could be dated. It is unknown if such black lines are also located under the white calcite coating, which has been analyzed to be very "young", perhaps 700-800 years before present.)

Appendix 10 – Expanded Low Temperature Charts

Expanded Low Temperature Charts from In-Situ Data Loggers

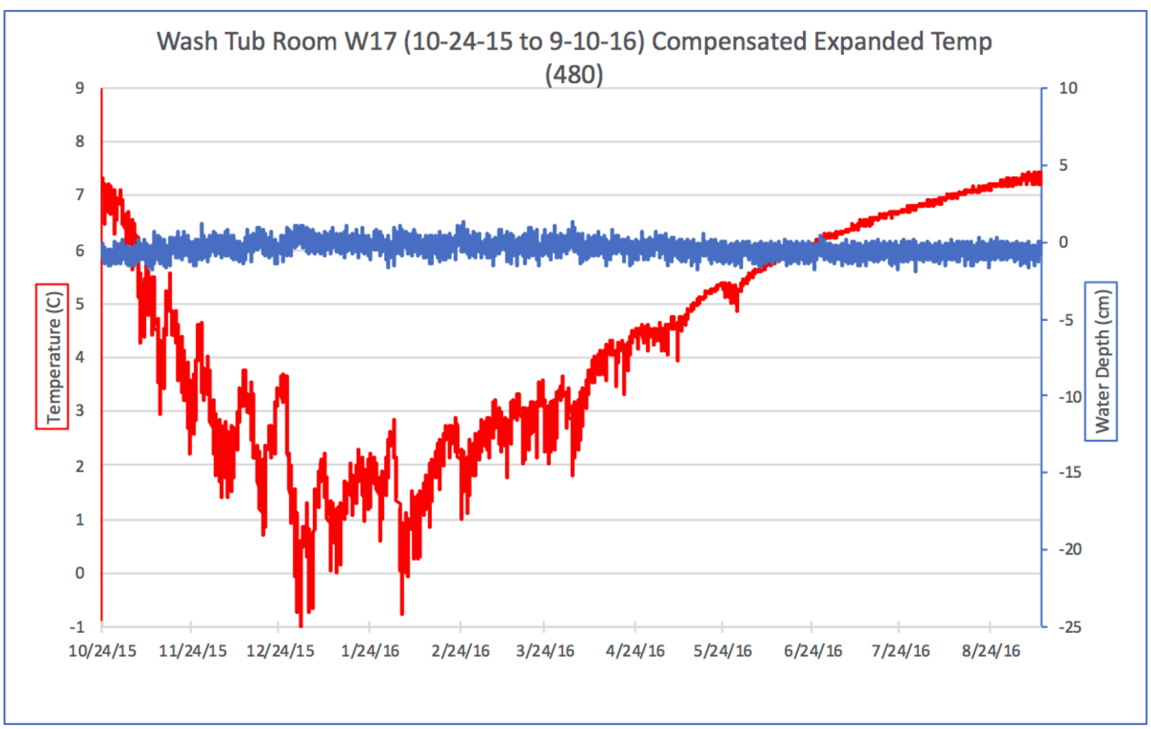
These charts are presented with the temperature scale expanded to cover -1.0 to +9.0 Degrees C in two locations. The primary location is in the entrance area of Fort Stanton Cave in the Washtub Room. This site is known to reach freezing temperatures during the winter, although usually for only a day or two. This "cold trap" area is important for the bats that hibernate in the cave, and numerous other data loggers have been deployed over the years by the bat researchers.

This particular set of charts is only from the In-Situ Rugged Troll 100 units, both water level loggers and the baro loggers used to compensate the water loggers by normalizing the varying atmospheric pressure. We also use the baro data to compensate the water depth charts for three surface logger sites. The data only covers the period up to the winter of 2019-2020 because the data for 2020-2021 winter is not yet available.

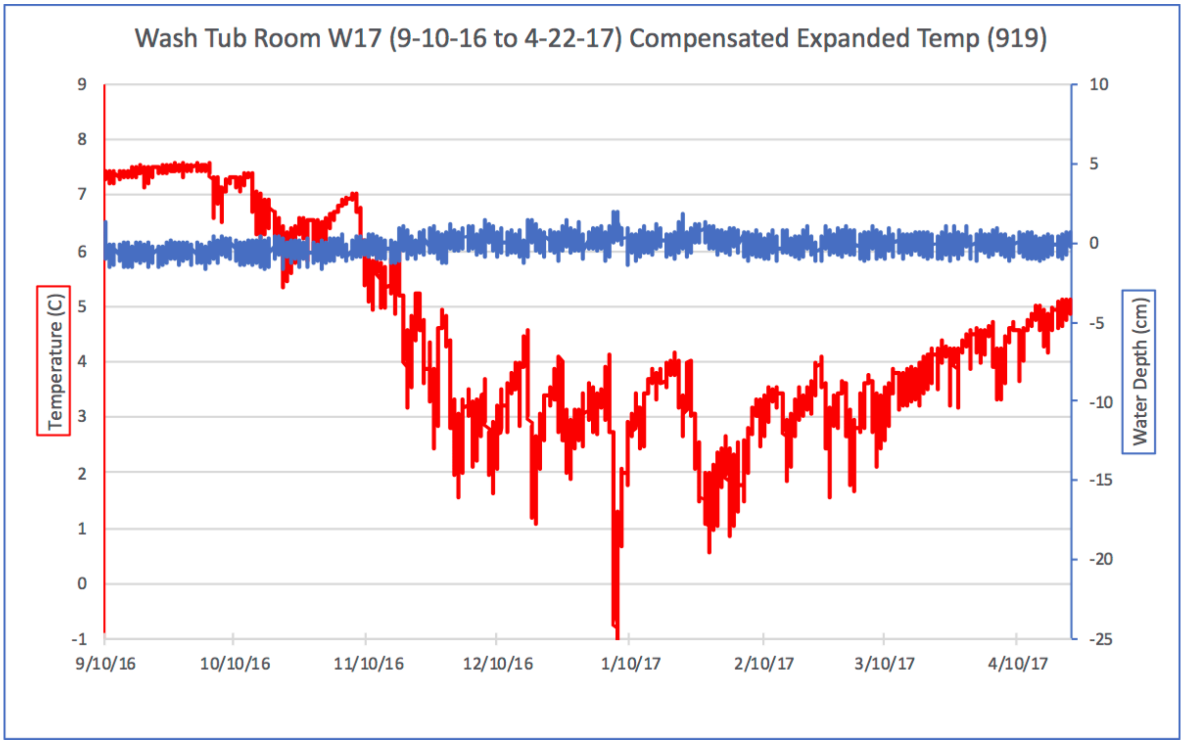
The first three Washtub Room loggers did not experience any water flow during deployment, so the water level is essentially zero. These loggers were resting on the floor of the dry stream bed where any flow continues on into the Circle Room, and finally the Main Corridor. So, this temperature is impacted by the ground temperature. The 4th chart shows an apparent water flow, so this temperature during the flow is impacted by the water temperature. (Although unusual, actual flows through the Washtub Room have been confirmed with Debbie Buecher who has visited this area in early spring during various bat research activities.)

A6, Washtub Room:

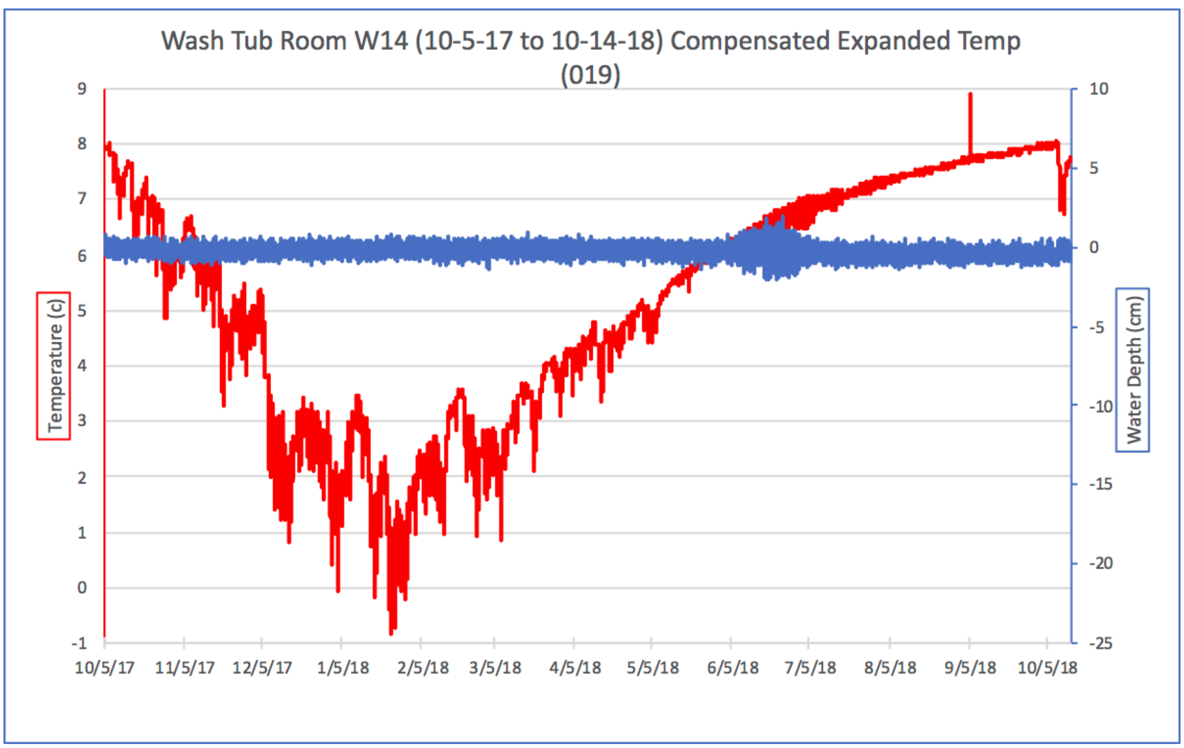
(480) (10-24-15 to 9-10-16)



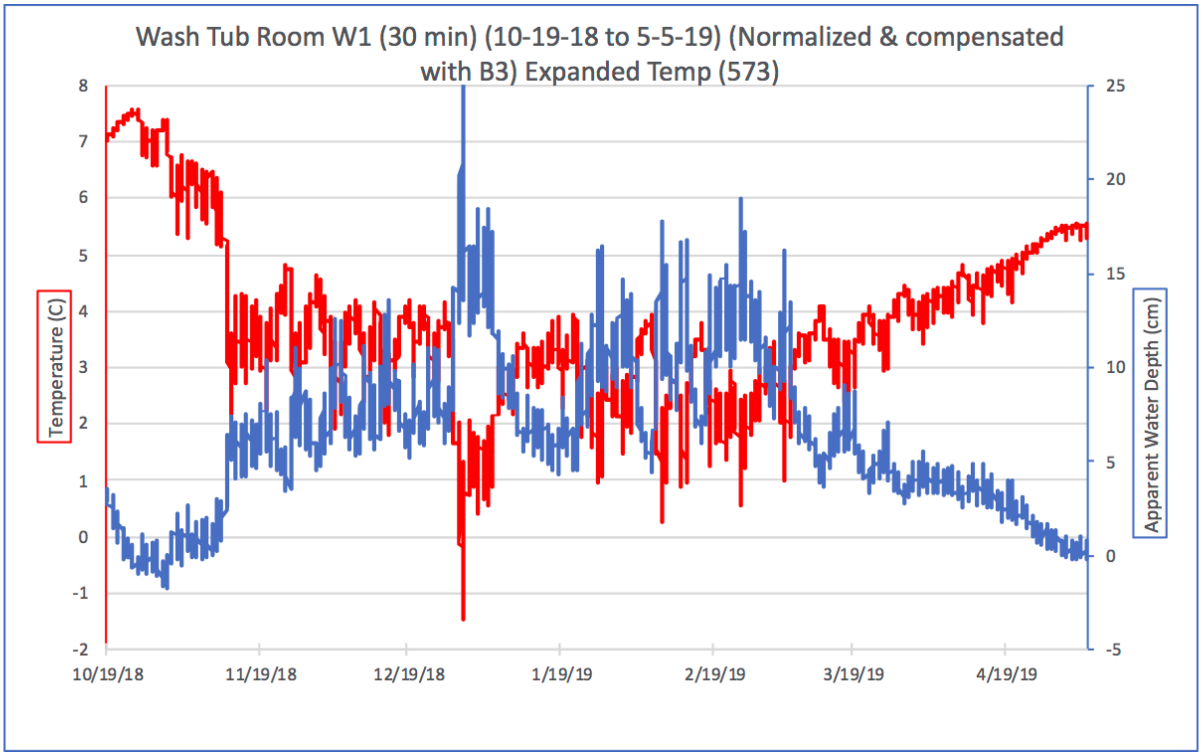
(919) (9-10-16 to 4-22-17)



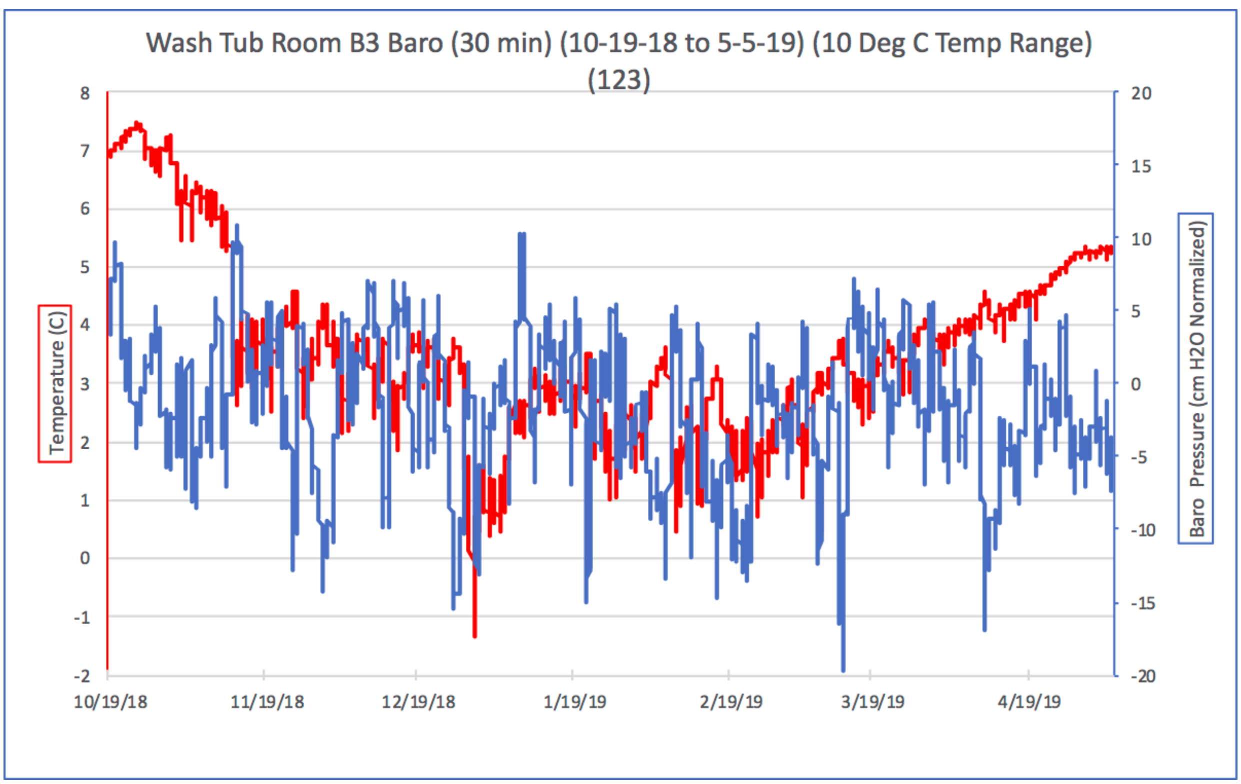
(019) (10-5-17 to 10-14-18)



(573) (10-19-18 to 5-5-19)



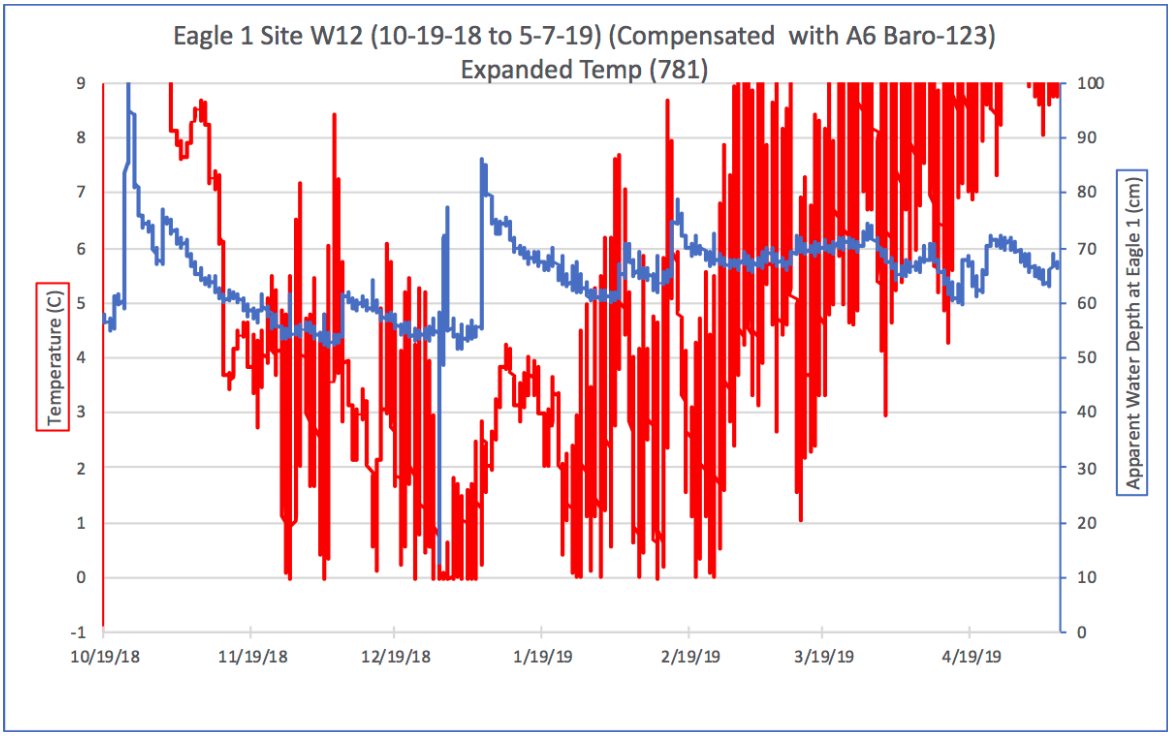
Normally, when compensating the water logger water depths, the water depth indicated above in the chart is much smoother. Since this is the first time a continuous flow in the Washtub Room floor channel has been recorded, several questions become apparent. Did the water flow only from the Hell of a Thousand Pinches (HOTP) passage, or did it also enter the entrance sink? The chart below shows the baro pressure normalized to a (cm H2O) pressure and explains some of the noise.



Surface Sites

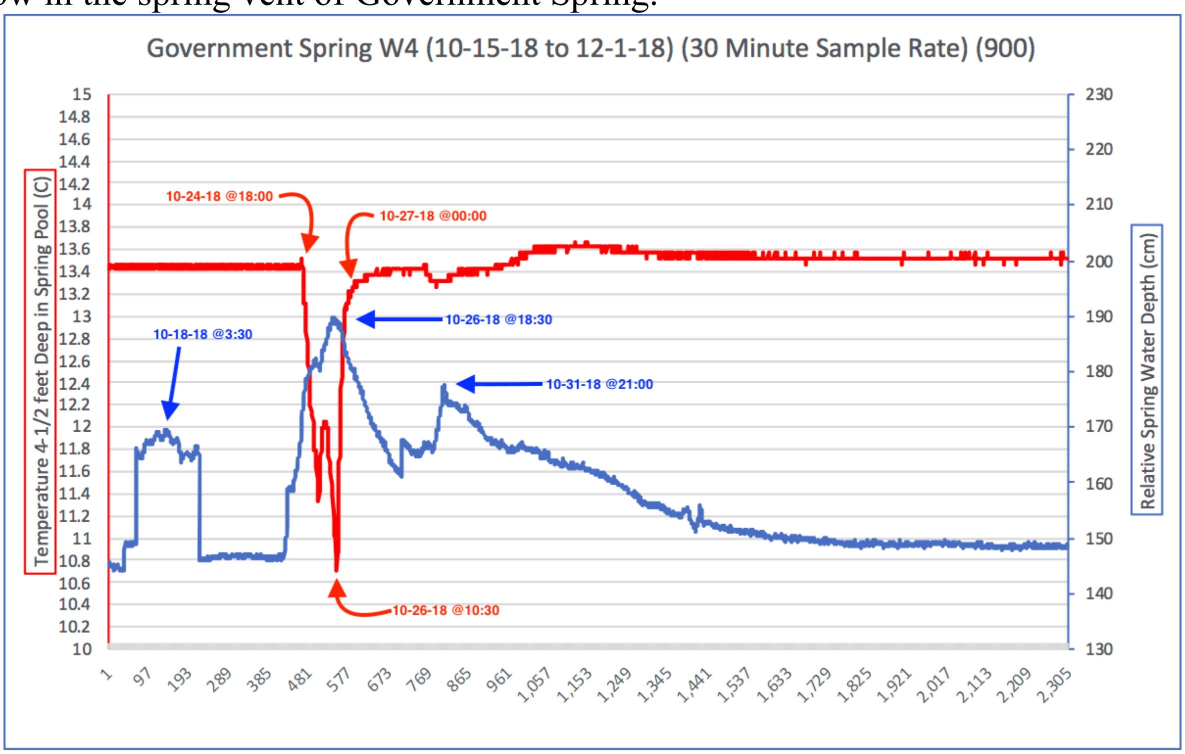
Eagle 1 (Eagle Creek) (781) (July 2018 to May 2019)

This water logger is approximately 38 cm below the rocky streambed, but still reaches almost freezing temperatures at times. The single point where the water depth appears to drop to about 10 cm may be due to ice formed at the logger or slightly above.



Government Spring (900) (10-15-18 to 12-1-18)

There is only a cooling affect from the Rio Bonito that reaches this logger 4+ feet below in the spring vent of Government Spring.



Appendix 11 – Author Bio & Water Caves

Author Bio & Water Caves

Pete Lindsley has a history of work in water caves going back to 1962. Adding to this hydrological interest is work with data loggers in the past, in particular work with iButton data loggers after being introduced to these compact data loggers by Bob Buecher. Official disclaimer: Lindsley is NOT a hydrologist. His previous employer (Texas Instruments and Raytheon Co.) hired him to design 45 years-worth of microwave antennas, which included some testing of sophisticated systems.

Several of the water cave activities are summarized below.

1. **Powell's Cave, TX**. This maze cave near Menard in central Texas first became known to the author in 1962 when members of the Dallas-Ft. Worth Grotto checked a lead that resulted in multiple Texas Region Projects over several decades. For several years the cave held the title of "longest cave in Texas". The maze of passages were about 60-80 feet under the surface, and were apparently formed from waters coming in via the "Egg Shaped Sinkhole" in a dry creek bed over a mile to the north. This dry passage was called the Crevice Passage and showed ancient calcite rafts and crystals on the floor. The Crevice ended to the south in a short section of a water passage. Going downstream the passage was pushed through a tiny hole into a room with a well pipe from an abandoned well. Wall signatures on an upper level indicated a historic entrance around 1900, which possibly coincided with stories about the locals dumping in cotton seed hulls that later appeared several miles away in springs along the San Saba River. Downstream from Powell's was a sump. Pushing upstream from the small room that ended the south end of the Crevice Passage, David McKenzie pushed through a low area and found the continuation of the upstream water. After several trips upstream, cavers surveyed over a mile heading towards the Egg-Shaped sink and an area called the Silver Mines. (J. Frank Dobie's book *Coronado's Children* had mentioned this area which was now a low-key operation by some secretive "silver miners" searching for Jim Bowie's lost mine.) Austin and Dallas cavers were allowed to venture into the "Silver Mine", which actually intersected cave passages about 60 feet down a shaft, and found that the cave passages actually led to what is probably the same water source, which disappeared into breakdown. A reference to yet another area north of the Silver Mine Cave reported a large underground lake at the bottom of a "meteor hole", which was likely a sinkhole leading down to possibly the same water source. No cave is visible now at the Meteor Hole which appears to be a small man-made pond. Suspecting that a water passage in Neal's Cave to the south likely connected with Powell's Cave, George Veni explored upstream towards Powell's using SCUBA gear and exited the sump at Powell's Cave. The point of this story is that little hydrological work has been done at Powell's Cave, and the stories of the features mentioned above go back over 100 years. This would be a good project for future hydrologists.

2. **Fitton Cave, Arkansas**. This cave was a favorite of Missouri, Texas, Oklahoma and Arkansas cavers since the 1950s. In the 1960s DFWG cavers worked closely with Jim Schermerhorn (Arkansas) to maintain a gate on one of the two entrances to the cave. The water in the cave was dye traced to Fitton Cave Spring on the Huchingson property in the mid 1960s. The cave became part of the first National Park Service Buffalo National River in 1972. In 1985 the

Cave Research Foundation (CRF) started a new survey of the cave, adding to the Schermerhorn map. This survey work is on-going and the 17-mile long cave is very similar to Fort Stanton Cave, prior to the Snowy River discovery. A spring near the top of the hill over Fitton Cave flows down the hillside and disappears into a rock pile near the valley floor and near the Bat Cave entrance of Fitton Cave. It is likely that this stream, which currently flows nearly year-long, is the primary force forming the multi-level passages in the cave. The stream flows over a 43-foot high waterfall in the Bat Cave passage, and quickly drops to the lowest levels of the known cave. There are several connections with other known upper level passages in the cave, and the stream finally drains into a tiny hole near the "end" of the cave. It reappears 1000 feet away at the end of Fitton Spring Cave, a mostly level 2000-foot long cave that exits just slightly above the elevation of the nearby Buffalo River. In parts of the lower level stream passage, about 20-25 feet above the current stream level, numerous charcoal bits are found that seem to indicate a major flood following a forest fire on the surface. Again, little hydrological work, including dating the charcoal, has been done and this cave would also be of interest to a hydrology student as a project.

3. **Bad Air Hole, Texas.** Located in San Saba County in central Texas, the small cave is usually filled with CO_2. A couple of 30-foot drops lead the visitor down to a stream level which appears to be running even during times of drought. The stream exits through a spring on the side of the Colorado River. Looking at a map, one notices that the river appears to detour around a large deposit of travertine that protrudes out to the edge of the Colorado River. Apparently the surface stream that forms Gorman Falls with a ~60 foot drop to the river below, (and is also about 100 feet from the bad air cave), contains a high percentage of calcite which cavers always assumed came from unknown caverns upstream in the surface creek which is also spring-fed. In the cave, the lower secondary stream leads to a small pool that is the surface of a larger underground lake. Cave divers venturing into this lake have discovered a funnel shaped water-filled room that leads to a small constriction with obvious upwelling of water that so far has prevented exploration. Another future study area.

4. **Gorman Cave:** Located about a mile downstream from Gorman Falls, the single entrance is a round tunnel coming out of the limestone cliffs and exits into the Colorado River both directly, and through lower level springs. The cave is about 2500 feet long and heads directly away from the river. It ends in a sump with standing water, but is known to flow several feet deep out to the river during times of flooding. Continuing over the path of the cave below for another mile leads to a large dry surface stream with a circular sinkhole in the floor of the streambed. We named this cave "Mack's Rain Drain" after Mack Yates, the owner. This cave apparently drains perhaps a square mile and inside the cave are large diameter tree trunks. This cave has several "gravel slopes" where the force of the flood waters has pushed small rocks up a slope during heavy flows. This effect is a reminder of the Sand Boil at the end of the Sandy River section of Snowy River, just upstream from the Crawl From Hell in Fort Stanton Cave.

5. **Mammoth Cave:** Well, you already know about that one. I just hit my BS page limit.

Appendix 12 -

List of Data Logger File Names in this report:

This list is provided for those interested in continuing this analysis without starting from the raw download files from the data loggers. For those interested is different compensation methods, different charts or needing more precise data on timing of events, these files may be available on request to qualified researchers. There were several duplicate files downloaded by various individuals that are not listed here. (Many of these files were processed, and determined to be duplicates.) These Microsoft Excel (Mac 2016) files will be available on request from the author.

Snowy River Area 3 (Deep Snowy River South):

Midnight Creek: W9 Water Logger
Need Midnight Junction Baro for best smoothing.

Snowy River South: W10 Water Logger
need MJ Baro for best smoothing.

Midnight Junction: B2 Baro Logger
Need this MJ Baro for best smoothing of water depths.

SRS535, Finger Lake:
[Finger Lake 1_2018-09-23_11-45-23-562.xlsx]
[1043983 SRS535 FINGERLAKE START 4_5_2014 STOP 7_16_2016 DATA-PL.xlsx]

Snowy River Area 2: (Floating Islands to Mud Lizard):

SRS374, Floating Islands:
[2001654 EGGSHELL BLM LEVEL START 10_20_2011 DATA-PL]
[W22, SRS374, Floating Islands_2019-10-09_22-52-53-658-BaroMerge.xlsx]
[W32, SRS374, Floating Islands_2020-09-23_12-42-29-966-BaroMerge.xlsx]

SRS318, Eggshell Trail:
[W34, SRS___, Garrett Mt. Airy Up_2020-10-06_15-17-33-141-BaroMerge.xlsx]

SRS227, Mt. Airy:
[W33, Garrett Mt. Airy upstream 1_2020-10-06_15-12-30-032-BaroMerge,xlsx]

Bobbit’s Blvd:
[Bobbit's Byway 1_2018-09-09_17-47-11-552-BaroMerge.xlsx]
[W21, SRS171, Bobbits Byway_2019-10-09_22-36-40-798-BaroMerge.xlsx]
[W31, SRS171, Bobbit's Blvd._2020-09-23_12-35-45-732-BaroMerge.xlsx\

SRS141, Mud Lizard:
[Mud Lizard 1_2018-09-10_17-58-35-554.xlsx]
[W20, SRS141, Mud Lizard_2019-10-09_21-57-21-404-BaroMerge.xlsx]
[W30, SRS141, Mud Lizard_2020-10-06_15-06-12-683-BaroMerge.xlsx]

***SRS125, Snowy River Spring**:*
[Below Snowy River Spring 1_2018-09-10_19-33-04-287.xlsx]
[W19, SRS125, Snowy River Spring_2019-10-09_22-19-04-159-BaroMerge.xlsx]
[W29, SRS125, Snowy River Spring_2020-10-06_14-56-28-605-BaroMerge.xlsx]

SRS107, Black Rock Bypass:
No data yet.

Snowy River Area 1: (Independence Hall to Crystal Spring):

SRS53, Independence Hall:
[1043930_SR Site 2_2009_09_24Compensated.xlsx]
[1043930 11-2-2009 to 4-30-2011-PL.xlsx]
[1043930_SR Site 2_2011_04_30Compensated.xlsx]

SRS31, Plunge Pool:
[Plunge Pool 1_2015-10-25_11-11-43-241.xlsx]
[SR-Plunge Pool_Append_2018-07-09_15-31-06-553.xlsx]
[SR-Plunge Pool_2017-08-20_19-32-19-938-BaroMerge.xlsx]
[W-17_2018-07-09_23-10-08-404-BaroMerge.xlsx]
[SRS31 May 2018_2019-10-15_09-31-22-216 (3-baro compensation).xlsx]
[W5, SRS31l 1.2 mBar event_2020-09-23_13-09-38-700-BaroMerge.xlsx]

SRS23, Turtle Junction:
[turtle junction_110430145031_F1559_Merge_testfile.xlsx]
[turtle junction_110430145031_F1559_Merge.xlsx]
[Turtle Junction 1_2015-06-27_19-45-45-520b.xlsx]
[TJ_2015_2016-07-03_16-48-15-172.xlsx]
[Turtle Junction_2016-09-14_13-02-35-531.xlsx]
[Turtle Junction_2017-04-24_11-03-05-402a.xlsx]
[W-16 Turtle Junction_2017-08-20_19-19-26-175-BaroMerge.xlsx]
[W-12_2018-07-09_22-56-05-639-BaroMerge.xlsx]
[Turtle Junction W-16_2019-05-07_06-57-18-471.xlsx]
[W27, Turtle Junction_2019-09-23_13-20-51-325-BaroMerge.xlsx]
[W2, SRS23, 1.2 mBar event_2020-09-23_13-18-18-849-BaroMerge.xlsx]
Conductivity Loggers:
[Solinst TJ 4-Yr Conductivity-PL.xlsx]

SRS19, Test Hole Snowy River North:
[Diver and baro logger data from core near TJ_PL.xlsx]

SRS10, Priority 7 Landing:
[P7 Landing Area W-11_2019-10-14_09-10-01-419.xlsx]

SRN08, Windows Passage:
[W-17_2018-05-07_09-19-19-845.xlsx]
[Metro Area W-17_2019-10-14_07-38-16-707a.xlsx]

SRN53, Swimming Pool:
[Hot Tub 1_2018-07-14_08-51-58-854.xlsx]
[Swimmiing Pool_2019-10-14_07-59-03-355.xlsx]

SRN80, Crystal Spring:
[1043934 11-2-2009 to 4-30-2011.xlsx]
[1043934 4-30-2011 to 7-10-2012.xlsx]
[1043934-Jul2012-CC.xlsx]
[1044761 Nov2009 Site3 CC.xlsx]
[Crystal Creek 1_2018-07-13_10-29-07-774-BaroMerge.xlsx]
[Crystal Spring_2019-10-14_07-49-58-311.xlsx]

Main Corridor Logger Array:

A6, Wash Tub Room:
[TJ or WT_2016-09-14_11-59-22-480-BaroMerge.xlsx]
[HOTP Entrance_2017-04-24_10-44-32-919-BaroMerge.xlsx]
[W-14 HOTP_2018-10-16_10-31-54-019-BaroMerge.xlsx]
[W-1, A6, Washtub_2019-05-07_07-48-39-573.xlsx]

20-Steps Pipe (TH3a):
[20-Steps_2015-10-18_18-52-26-998.xlsx]
[20 Steps Pipe_2016-07-03_16-16-04-603.xlsx]
[337660 20-Steps_2016-10-10_19-16-49-002.xlsx]
[20 Steps_2017-04-24_10-07-26-829.xlsx]
[W-18 20 Steps_2017-08-22_21-19-11-092-BaroMerge.xlsx]
[W-3_2018-10-16_10-16-37-976-BaroMerge.xlsx]
[W-2, v1.01, 20-Steps Pipe_2019-10-09_21-38-55-918.xlsx]

SW-1, Sewer Pipe Landing:
[MCW13_2015_2016-07-03_16-33-22-362.xlsx]
[Sewer Pipe Landing_Append_2016-09-14_12-52-32-875.xlsx]
[S-Pipe_2017-04-24_10-32-50-847.xlsx]
[W-15 Sewer Pipe Landing_2017-08-22_21-23-06-762-BaroMerge.xlsx]
[W-13_2018-10-16_09-42-35-559-BaroMerge.xlsx]
[W-5, v1.01, Sewer Pipe Landing_2019-05-07_07-29-52-717-BaroMerge.xlsx]

Surface Areas:

Eagle Creek at Eagle-1:
[Eagle Otey-1 W-12_2019-05-09_17-54-01-781-BaroMerge.xlsx]
[Eagle Otey-1 W-12_2019-05-09_17-54-01-781-BaroMerge-619.xlsx]
[Eagle Otey-1 W-12_2019-05-09_17-54-01-781-BaroMerge-123.xlsx]

Government Spring:
[337638 W-12 GovSpring Temps_2015-07-29_16-51-23-837.xlsx]
[W-4 2018_2019-05-11_10-06-02-900.xlsx]