Idaho Department of Water Resources

Open File Report

FLUORESCENT DYE TRACER TESTS from the VICTOR WELL south east of the MALAD GORGE STATE PARK

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ABSTRACT

Through a cooperative effort between Idaho Power and the Idaho Department of Water Resources, two additional dye tracer tests were successfully completed from a new well (Victor) located 3.1 miles southeast from the Malad Gorge. Trace #1 started on Sunday November 18, 2012 with 14 pounds of Fluorescein dye mixture in 14 gallons of drinking water which was injected into the Victor well. The dye was tracked in both space and time as it flowed through the basalt aquifer and intersected by numerous domestic wells before discharging into the Malad Gorge springs. Trace #2 started on Monday November 4th, 2013 with 21 pounds of dye mixture in 21 gallons of drinking water injected into the Victor well. The results from both traces are consistent with previous traces in this area and also document a mass balance that shows nearly all of the dye passed through the flow system and discharged into the Malad Gorge. The geology and other factors such as irrigation practices, date of release and depth of injection are essentially the same as in previous traces. The mass balance results from the Victor trace is directly applicable to previous traces for the 'Meyer' 2.25 mile, 'Hopper' 1 mile, 'Rod Riddle' ½ mile, 'Park' ¼ mile, 'Nathan Riddle' ½ mile traces.

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BACKGROUND

Fifteen groundwater tracer tests have been successfully completed south of the Malad Gorge since April 2009 in a cooperative effort between the Idaho Department of Water Resources, Idaho Power, land owners and numerous other entities. This report details the completion of two 3.1 mile distance tracer tests from the 'Victor' well with the first trace starting November 18, 2012 and the second starting November 4, 2013. Field and equipment conditions were optimal in trace #2 to compute the mass balance of the dye recovered during the trace. At least 4 previous traces (*Park Picnic, R. Riddle, R. Hopper and Meyer*) were completed within essentially the same flow path as the Victor traces and it is reasonable to assume these earlier traces produced a similar mass balance of greater than 84% recovery of dye. Two other traces (*R. Conklin and N. Riddle*) performed lateral to this flow path can also be inferred to have similar recovery rate. Figure 1 shows the locations of wells where data was collected for this report and Figure 22 shows the locations of the four wells used for previous dye releases that fall within the Victor trace flow path. The name for this trace is sourced from the original well owner's name Nolan Victor. The GPS methods, geologic model, geography, well construction (which was open hole below surface casing), tracing techniques, etc. are all essentially the same as in previous traces (Farmer and Blew, 2009, 2010, 2011). The traces presented in this report are an additional step in developing information and technology to support an ongoing tracer program on the Eastern Snake Plain Aquifer (ESPA).

TRACING PROCEDURE AND METHODS

<u>Victor Well Dye Trace #1</u>

This well was selected because it is located southeast and in the trend of the flow path extending from previous dye traces (Figures 1 and 22). The well construction details are shown in Figure 2 and the drillers log notes "cinders and soft lava" from 210 to 260 feet below land surface. The well was drilled April 4, 1992 and the log states Tuttle Farms as the well owner. Discussions with nearby neighbors confirmed the land, house and well were owned by Nolan Victor and the legal location is 7 South, 14 East, center of section 9, Gooding County. A camera was lowered down the well to inspect and confirm geologic conditions (Figures 2 and 3) with a large cavern observed just below the base of the pump which is at 245.5 feet below top of casing (BTOC). The cavern extends from 245.5 feet down to the bottom of the well at 253.5 feet (BTOC) or about 8 feet distance. Bulbous features are visible and appear to be pillow basalt which matches the drillers' description of cinders and soft lava. Figure 3 shows the difference between summer and winter conditions in the well. Cascading water is present during the summer and fall months, which is likely subsurface leakage from irrigation canals and laterals.

On November 15th and 16th 2012, charcoal packet samplers were placed in toilet tanks in residential dwellings supplied by wells named; Knapp, Jackson, Arriaga south, Turner, Len Riddle, Clinton, Umek, Hopper, Arriaga north, Burrell, and Evers (Figure 1). Also on November 16th, charcoal samplers were placed in the Malad Gorge springs from MG-1, 1.5, 2, 2.5, 3, 4, 5, 6, 7, Bench spring, MG-12, 14, 19, 21, 23 (Figure 11). A Turner Designs C3 submersible fluorometer (C3) was deployed at the Bench Spring on the 16th and calibrated using spring water as the blank and a 10 ppb fluorescein (FL) standard purchased from Turner Designs. On Sunday

November 18, 2012, poly-tubing was lowered down the Victor well to a depth of 243 feet below the top of casing (BTOC). A borehole camera was also lowered into the well to video the dye release. At the time of the dye injection, the water surface in the well was at 201.5 feet (BTOC). The domestic well pump was turned off prior to the injection and remained off for approximately three hours post injection. Fourteen pounds of 75% concentration Fluorescein (FL) dye purchased from Ozark Underground Laboratory was mixed with 14 gallons of drinking water in a large poly-tank. The injection rate was 1 gallon per minute, and dye started exiting the poly-tubing at 1:46:30 pm (Figure 4). The injection of dye was completed by 2:00 pm. On Monday November 19th, a water sample was collected from the well and delivered to a private lab to test for fecal coliform. A water sample was also taken to test for the presence of dye in the well. The samples tested absent for the presence of fecal Coliform, and no dye was detected in the well.

During the following 4 month time frame, grab water samples were collected from wells and wells and springs at about 1 to 2 week intervals and analyzed for dye. Grab water samples were analyzed using a table top TD-700 Fluorometer calibrated to a blank (de-ionized water), 1.0, and 10.0 ppb FL standards. Figures 5 and 6 show the water sample results and dates of sampling for wells and springs. On the right axis of Figure 5, the scale is forward in time starting on December 3, 2012 and ending on February 28th, 2013. Conversely, Figure 6 plots the time scale in reverse order so the reader can see the plotted results from both sides, otherwise some of the bars are hidden. On December 3, dye was first detected in a well named Turner shown as a red bar in Figure 5 at a concentration of 0.04 ppb. In addition to the grab water samples, a calibrated mobile C3 instrument was moved from spring to spring in the Gorge on December 18, 2012 from MG-14.5 upstream to MG-4 to obtain a real time test for presence of dye. All values were zero from the springs which is plotted in Figures 5 and 6 with light green bars. Water samples and standards were allowed to equilibrate to room temperature over night before analysis.

Figures 7a through 7k show a 3-D plot using the Kriging option in Surfer software to show the results of water samples collected during the 4 month time frame and the rise and fall in dye concentration as the dye cloud passes by wells. Unfortunately, winter conditions in the Gorge restricted access to sample springs due to snow and ice. Despite the limitations of grab sample frequency and distribution, the trends clearly show the dye cloud peaking in concentration at the Clinton Palmer well at 0.42 ppb at 46 days post dye release, and this well is 1.77 linear flow path miles from the Victor well. The 46 day travel time (Figure 7f) was calculated as the peak of the breakthrough curve at the Clinton Palmer well, since it is the average of the previous (39 day Figure 7e) and post samples (52 day Figure 7g) at this well. This equates to an approximate dominant flow velocity from the Victor well to the Clinton Palmer well of 9,370 feet/46 days or 204 feet/day dominant groundwater velocity through this interval or rounded to 200 feet/day integrated value over the 1.77 mile distance. First arrival of dye at the Clinton Palmer well is inferred to occur between December 3 (Figure 7a) and December 10 (Figure 7b) which would place it at approximately 19 days travel time equating to a maximum flow velocity between the Victor well and the C. Palmer well of 9,370 feet/19 days or 493 feet/day maximum groundwater flow velocity which was rounded to 500 feet/day.

On February 1, 2013, a calibrated C3 instrument was deployed in the Malad Gorge at spring MG-12. This date appears to have been close to the peak concentration of dye passing through the spring based on C3 instrument readings (Figure 8). The peak concentration was 0.30 ppb FL and the measurement frequency was hourly. The 'Meyer' Trace #2 used 14 pounds as well, with a peak spring water concentration of 0.59 ppb and a travel distance of 2.25 miles instead of 3.1 miles for this trace. The peak concentration in the spring was reduced by half when the distance extended by one mile. The peak is inferred to have occurred on February 2 or 96 days post dye release (consistent with Trace #2). The recession limb has a smooth slope, and the instrument was retrieved from the spring too early to record the full tail of the curve. The C3 located at the Bench Spring did not appear to record dye passing through (Figure 8) possibly due to concentrations below the detection limit of the instrument (0.01 ppb). Some dye did pass through this spring based on the charcoal sampler result of 7.66 ppb (Figure 9). Figure 8 suggests that most of the dye had exited the groundwater system via springs by the end of March 2013. This provided approximately 7 months to fully flush out residual amounts of dye by the start of second tracer test in November of 2013.

The charcoal packet sampler results for Trace #1 are graphed in Figure 9 showing a peak concentration determined from Ozark Underground Laboratory (OUL) of 468 ppb FL at spring MG-14. MG-12 had the next highest concentration of 291 ppb, and there is a progression of decreasing concentrations upstream of MG-4 (upstream edge of dye cloud) in the Malad River Canyon. Charcoal packet sampling during Tracer #1 was hampered by fluctuating river levels leaving some packets out of the water for a period of time and disturbance by animals. There were no samplers placed at MG-15 through MG-18. MG-19 produced a result of 0.22 ppb and based on information from Trace #2, it is now known better this is the downstream edge of the dye cloud. The charcoal sampler results from wells are shown in Figure 9. The highest concentration of dye is at the Clinton Palmer well which is consistent with the water sample results shown in Figures 5, 6 and 7g. The Turner well charcoal sampler result was 8.11 ppb which is also consistent with water sample results. It is important for the reader to understand that charcoal packet concentrations are not water concentrations. For example, a charcoal packet concentration of 8.11 ppb may mean that the peak water concentration was lower at perhaps 1.0 ppb FL.

In summary, the first trace at the Victor well utilized 14 pounds of 75% concentration Fluorescein dye mixed with 14 gallons of potable water injected into the bottom cavern zone of the well on November 18, 2012. The trace provided good resolution of the dye cloud as it passed by numerous domestic wells based on both charcoal samplers and approximately weekly to bi-weekly water samples. The water sample data is graphed in Figures 5 and 6 and stepped progressions are shown in Figures 7a-7k to illustrate the movement of the dye cloud. The tracer was also identified the spring zone with the greatest concentration and mass of dye providing the basis for a more focused and robust data collection design for Trace #2. One element not captured in the springs during Trace#1 was the time of first arrival of dye, which would ultimately hinder the design of Trace #2.

Victor Well Dye Trace #2

In preparation for Trace #2, on November 1, 2013, charcoal packet samplers were deployed in the Malad Gorge springs MG-1, 1.5, 2, 2.5, 3, 4, Bench Spring; then MG-12, 13, 14, 15, 16, 17.5, 18, 19, 19.5, 21, and 23 (Figure 10). C3 instruments were calibrated using spring water for the blank and 10 ppb FL standard calibration solution from Turner Designs. The instruments were deployed at spring sites MG-12 and MG-13 based on real-time spring water test results during Tracer #1 (Figures 5 and 6). MG14 had the highest charcoal packet concentration during Trace#1. Fluctuating river levels left the packet at MG12 out of the water for a period of time, and a packet was not placed at MG13. On November 4th, 2013 at 2:45 pm, fifty percent more dye (21 pounds) was injected during Trace #2 than in Trace #1 (14 pounds). The same method, equipment and depth of dye release was used in Trace #2 as Trace #1. Twenty one gallons of potable water was mixed with 21 pounds of 75% concentration Fluorescein dye and injected into the Victor well. There were no occupants living in the residence and the well was unused during the Trace #2 time period. The depth to water was measured at 203.71 feet from top of casing. Charcoal packet samplers were not deployed into domestic homes toilet tanks like in Trace #1; nor were weekly to bi-weekly water samples collected during Trace #2 from the wells or springs.

On November 25, 2013, a Turner Designs Cyclops-7 submersible fluorometer (Cyclops) was calibrated with purchased spring water and a 10 ppb FL standard solution from Turner Designs. The Cyclops was deployed in a concrete flume just upstream of Idaho Power's power plant (Figure 10). The flume is located downstream of all springs with resurgent dye concentrations. During the monitoring period the diversion into the flume captured all of the spring discharge known to contain dye. Flow in the flume ranged from approximately 650 cfs to 700 cfs and consisted almost exclusively of spring discharge. A grab water sample was collected during deployment of the Cyclops and sent to OUL for analysis. The dye concentration at the time of the Cyclops deployment was 0.012 ppb FL indicating the dye had recently started to discharge out of the springs and down the flume. The C3 instruments placed at MG13 and MG14 did not detect a first arrival of dye in the springs until about a week later on December 3 (Figures 14 and 15). It is possible that dye was discharging out of the springs MG-12 and 13 but below the 0.01 detection limit of the C3 instruments, and/or dye was discharging from springs not monitored.

Figure 11 shows that little to no Malad River water flowed into the Gorge during Trace #2 which means all of the water discharging from the spring site MG-19 and other springs upstream were captured by the diversion dam and routed into the Flume. There is a small amount of leakage through the dam gates. The Flume has a calibrated measurement device that records the flow rate every hour. The Cyclops instrument was programmed to record a Fluorescein measurement every hour. With little to no flow from the Malad River entering the Gorge, little sediment was introduced into the flow. These conditions existed except during a minor flow rate change starting at about February 13th shown in Figure 11. This flow event occurred during the tail end of the dye trace from approximately 2,400 hours through 3,192 hours (Figure 20). Therefore, to perform a mass balance with optimal conditions were present during Trace #2.

Figure 12 shows Fluorescein concentrations in charcoal packets from both Trace #1 (yellow bars) and #2 (red bars). Note the classic bell shaped curve of Trace #2 results from springs in the Gorge. The distribution of dye resurgence through spring locations can be seen in Figure 12. Detection of dye extended from MG-4 downstream to MG-18 for a lateral dispersion across the dye cloud of approximately 1,900 feet (Figure 10) over a trace distance of 16,350 feet (3.1 miles). Spring MG-13 tested at 2,230 ppb FL which was not equipped with a charcoal sampler during Trace #1. The bulk of the dye from Trace #2 passed through springs MG-12, 13 and 14 located on the map in Figure 10, and all of the dye appears to have been captured upstream of the diversion dam and routed down to the Cyclops sample site. No dye was detected at spring sample sites MG-19, 19.5, 21 and 23.

At spring sample site MG-13, a calibrated C3 instrument was placed before dye injection using the spring water as a blank and a 10 ppb FL standard from Turner Designs. The instrument was programmed to sample the spring discharge every 3 hours, and the data is graphed in Figure 13. The instrument was checked in the field on December 26, 2013 and re-positioned because data interference was evident. Air bubbles could be seen in the water where the instrument was originally deployed. It was re-located approximately two feet from its previous position in the same spring water with less bubbles. Figure 13 shows less interference after this change. On January 22, 2014, the battery was replaced in the instrument, but it failed to restart. It is unknown why it did not restart but the same procedure was done for the C3 at site MG-12 and that instrument did restart. The only apparent difference is that the C3 at MG-13 that did not restart had one large capacity battery (8 amp hour) and the C3 at MG-12 had two separate batteries of 4.5 amp hour each. We believe that when we unhooked the one large battery, the instrument lost all power. While changing the two batteries for the other C3 instrument one battery at a time was 'swapped' out, which meant the instrument had power even during the battery change out. We have observed this same phenomena while changing out batteries for previous traces. We plan to re-design all battery boxes to hold 2 batteries instead of one large one. Despite the loss of data during the recession limb of the breakthrough curve, the first arrival of dye and the peak concentration of 0.50 ppb FL was recorded in the data set. The C3 data set shows a single peak response curve based on comparison with other curves shown in Figure 15.

The C3 instrument deployed at spring sample site MG-12 produced a near perfect single peak breakthrough curve reaching a peak concentration of 0.55 ppb FL (Figure 14). The curve is slightly unusual in that it appears to be left skewed since the mean shown with a yellow diamond is left of the peak. The left skewed nature of the breakthrough curve was also evident in the Cyclops data located in the flume. Figure 15 illustrates the consistency between breakthrough curves at the spring sites from both Trace #1 and Trace #2. The peak concentration from Trace #1 was 0.30 ppb from 14 pounds of dye and increased up to 0.55 ppb from Trace #2 where 21 pounds of dye was injected.

Figure 16 illustrates the raw unadjusted hourly data from the Cyclops instrument deployed in the flume (Figure 10). The Cyclops was calibrated using purchased spring water as the blank and 10 ppb FL standard solution from Turner Designs. The zero point calibration using purchased spring water could account for the vertical shift at the start time for this instrument. The first obvious features are the large spikes that occur as individual points below and above the trend of the data set. These are likely due to noise introduced from particles of organic debris, moss, sediment or other 'contaminants' in the river/flume water. The spikes were removed by adjusting them to the trend based on pre and post data points. The next adjustment shifted the entire data set up by an increase of 0.01 ppb due to the -0.005 value of the initial data at the start time and based on the results of grab water samples sent to OUL for analysis (0.012 ppb FL). Additionally, on February 5th, 2014 (2,400 hours since dye injection) some additional noise was introduced and it appears to be correlated to cycles in flow rates caused by upstream hydropower plants on the Malad River (Figure 11).

Figure 17 shows the Cyclops data set with the spikes removed and adjusted to the trend. The entire data set was shifted vertically up by 0.01 ppb (from -0.005 to +0.005) which is also the detection limit of the instrument, any remaining negative values were changed to zero. Figure 17 also shows the grab water sample results (blue square symbols) and the longer period of interference patterns starting at about 2,400 hours. Anthropogenic changes in flow rate and runoff from rain events may have induced suspended sediment to flow through the Gorge and into the flume causing longer term interference in the data set than the individual spikes. OUL adjusts the pH value of their samples to maximize the fluorescent response and therefore the detection of dye, which may partially contribute to the disparity between the Cyclops data and the OUL grab sample results shown in Figure 17. A 25 point (+ or – 12 hours) moving average was applied to the Cyclops data set and graphed onto the original data set as shown in Figure 18. Figure 19 shows the spring MG-12 breakthrough curve, the Cyclops flume breakthrough curve and the OUL results. The arrival and detection of dye, peak of concentration of dye and the recession of dye correlate between the spring data, flume data and the OUL data. Figure 20 shows the 25 point moving average data set and the flow rate data. Note how the late time Cyclops data starting at about 2,400 hours (approximately February 5th) correlates to the fluctuations in the flow rates. The bulk of the dye (87% total measured by Cyclops) had already passed out of the aquifer, springs and down the flume past the Cyclops by the time the flow rate cycles started. The introduced noise had a minimal effect on the data analysis for mass balance which may have only affected approximately 13% of the remaining dye (2.73 lbs.) in the tail end.

Figure 21 shows the 25 point moving average curve used to calculate the mean and mass balance. Zero values were inserted prior to the start of the Cyclops instrument data back to time zero of the dye injection. The mass of dye recovered was calculated at 84.3% or about 17.7 lbs of the original mass of dye. The base balance calculation was also performed on the Cyclops data without the 25 point moving average shown in Figure 17 and the value was the same. The remaining 15.7% of dye could be attributed to when dye concentrations were below the detection limits of the Cyclops but still present and discharging from the springs at MG-12 and 13 at low levels. The Cyclops appears to have been deployed a little late based on indications from OUL results that a small amount of dye had started to discharge by the time the Cyclops started collecting data. Another factor is that the Cyclops has a 0.01 ppb detection limit so any dye passing by less than this concentration would not be detected by the Cyclops; therefore since dye was already starting to discharge out of the springs and flow down the flume before the Cyclops was deployed and since there was a very low amount still discharging from the springs when the equipment was retrieved (Figure 14 April 4, 2014). This fact would increase the mass recovered above 84.3% perhaps approaching 90% recovery.

Figure 22 shows the inferred dye flow paths from all of the traces south of Malad Gorge to date. The Victor Trace is shown with a black dashed line and effectively all of the springs upstream of the Diversion dam have been traced to a greater or lesser degree. Detailed water level contour maps of the area (Farmer and Blew, 2013) suggested convergent flow paths, the dye traces have confirmed this pattern. In all cases of 7 different tracing locations and 15 individual traces, the dye flow path has been directly down the hydraulic gradient with no deviations or surprises. It has been hypothesized that groundwater and dye could have flowed tangential to or at some odd angle to the gradient whereby some dye could have escaped from the flow path, travelled up and over a ‘ridge’ or groundwater divide west of these traces and then back down into Woody’s Cove and Birch Creek. The results of charcoal packet analysis from the Meyer and Victor traces showed this to be incorrect.

Discussion

The tracer results provide real world data on water movement within the ESPA and it will be used to develop additional hydrologic studies. The information can be used to help refine and assist with groundwater model input assumptions applied at a local scale. The studies also provide legitimacy to the use of fluorescent tracers for studying groundwater on the ESPA. To date all 19 traces have flowed down the hydraulic gradient and none have demonstrated flow tangential to the gradient so far. The results and conclusions are being exported to other sites on the ESPA where additional tracer studies are being planned. A long-term strategy to utilize tracer studies is being implemented to help guide and direct efforts that can improve aquifer levels and increase spring discharge. Knowledge gained not only from the results of these studies but also the techniques developed can lead to a better understanding of water movement through the aquifer. Tracers have helped in refining water quality monitoring sites for aquifer recharge projects to ensure the protection of groundwater resources. The trace results have been directly applied and used to assist with the permitting process for aquifer recharge by injection wells regarding water quality and public safety. They may also aid in determining sources of contamination at some spring complexes.

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REFERENCES AND SOURCES OF INFORMATION

1. Aley, T., 2002, Groundwater tracing handbook, Ozark Underground Laboratory, 44 p.

2. Aley, T., 2003, Procedures and criteria analysis of Fluorescein, eosine, Rhodamine WT, sulforhodamine b, and pyranine dyes in water and charcoal samplers, Ozark Underground Laboratory, 21 p.

3. Anderson, M. P. and Woessner, W. W., 1992, Applied groundwater modeling, Academic Press, San Diego.

4. Anderson, M.P., 1979, Using models to simulate the movement of contaminants through groundwater flow systems, Critical Reviews in Environmental Controls 9, no. 2: 97-156.

5. Aulenbach, D.B., Bull, J.H., and Middlesworth, B.C., 1978, Use of tracers to confirm ground-water flow: Ground Water, Vol. 16, No. 3, 149-157 p.

6. Axelsson, G., Bjornsson, G., and Montalvo, F., 2005, Quantitative interpretation of tracer test data, Proceedings World Geothermal Congress, 24-29 p.

7. Bowler, P.A., Watson, C.M., Yearsley, J.R., Cirone, P.A., 1992, Assessment of ecosystem quality and its impact on resource allocation in the middle Snake River sub- basin; (CMW, JRY, PAC - U.S. Environmental Protection Agency, Region 10; PAB - Department of Ecology and Evolutionary Biology, University of California, Irvine), Desert Fishes Council (http://www.desertfishes.org/proceed/1992/24abs55.html).

8. Dallas, K., 2005, Hydrologic study of the Deer Gulch basalt in Hagerman fossil beds national monument, Idaho, thesis, 96 p.

9. Davies, G.J., 2000, Lemon lane landfill investigation, Technical Note: Groundwater tracing using fluorescent dyes: interpretation of results and its implications, The Coalition Opposed to PCB Ash in Monroe County, Indiana, 24 p.

10. Davis, S., Campbell, D.J., Bentley, H.W., Flynn T.J., 1985, Ground water tracers, 200 p.

11. Dole, R.B., 1906, Use of Fluorescein in the study of underground waters, pg 73, USGS Water Supply Paper, #160, series 0, Underground Waters, 58, by Fuller M.L., 104 p.

12. Farmer N., and Blew D., 2011, Fluorescent dye tracer tests and hydrogeology near the Malad Gorge state park (Hopper well test), Idaho Department of Water Resources Open File Report, 41 p.

13. Farmer N., and Blew D., 2010, Fluorescent dye tracer tests near the Malad Gorge state park (Riddle well test), Idaho Department of Water Resources Open File Report, 36 p.

14. Farmer N., 2009, Review of hydrogeologic conditions located at and near the spring at Rangen inc., Idaho Department of Water Resources open file report, 46 p.

15. Farmer N., and Owsley, D., 2009, Fluorescent dye tracer test at the W-canal aquifer recharge site, Idaho Department of Water Resources Open File Report, 23 p.

16. Farmer N., and Blew D., 2009, Fluorescent dye tracer tests at Malad Gorge state park, Idaho Department of Water Resources Open File Report, 45 p.

17. Fetter, C.W., 1988, Applied hydrogeology, second edition, Macmillan publishing company, 592 p.

18. Fetter, C.W., 1993, Contaminant hydrogeology, Macmillan publishing company, 458 p.

19. Field, M.S., Wilhelm R.G., Quinlan J.F. and Aley T.J., 1995, An assessment of the potential adverse properties of fluorescent tracer dyes used for groundwater tracing, Environmental Monitoring and Assessment, vol. 38, 75-96 p.

20. Gaikowski, M.P., Larson, W.J., Steuer, J.J., Gingerich, W.H., 2003, Validation of two dilution models to predict chloramine-T concentrations in aquaculture facility effluent, Aquacultural Engineering 30, 2004, 127-140 p.

21. Galloway, J.M., 2004, Hydrogeologic characteristics of four public drinking water supply springs in northern Arkansas, U.S. Geological Survey Water-Resources Investigations Report 03-4307, 68 p.

22. Harvey, K.C., 2005, Beartrack mine mixing zone dye tracer study outfall 001, Napias creek Lemhi county, Idaho, Private Consulting Report by KC Harvey, LLC., 59 p.

23. Kass, W. et. al., 2009, Tracing technique in geohydrology, reprinted by CRC Press from year 1998 publishers A.A. Balkema, 581 p.

24. Kilpatrick, F.A. and Cobb, E.D., 1985, Measurement of discharge using tracers, U.S. Geological Survey Techniques of Water-Resources Investigations Report, book 3, chapter A16.

25. Klotz, D., Seiler K.P., Moser H., and Neumaier F., 1980, Dispersivity and velocity relationship from laboratory and field relationships. Journal of Hydrology 45, no. 3: 169-84.

26. Kruseman G.P. and Ritter N.A., 1991, Analysis and evaluation of pumping test data, second edition, International institute for land reclamation and improvement, 377 p.

27. Leibundgut, C. and H. R. Wernli. 1986. Naphthionate--another fluorescent dye. Proc. 5th Intern’l. Symp. on Water Tracing. Inst. of Geol. & Mineral Exploration, Athens, 167-176 p.

28. Marking, L., Leif, 1969, Toxicity of Rhodamine b and Fluorescein sodium to fish and their compatibility with antimycin A, The Progressive Fish Culturist, vol. 31, July 1969, no. 3. 139-142 p.

29. Mull, D.S., Liebermann, T.D., Smoot, J.L., Woosley, L.H. Jr., (U.S. Geological Survey), 1988, Application of dye-tracing techniques for determining solute-transport characteristics of ground water in karst terrranes; U.S. EPA904/6-88-001, 103 p.

30. Noga, E.J., and Udomkusonsri, P., 2002, Fluorescein: a rapid, sensitive, non-lethal method for detecting skin ulceration in fish, Vet Pathol 39:726–731 p.

31. Otz, M. H., and Azzolina, N.A., 2007, Preferential ground-water flow: evidence from decades of fluorescent dye-tracing, Geological Society of America fall meetings presentation, 19 slides.

32. Olsen, L.D. and Tenbus F.J., 2005, Design and analysis of a natural-gradient groundwater tracer test in a freshwater tidal wetland, west branch canal creek, Aberdeen proving ground, Maryland, U.S. Geological Survey Scientific Investigation Report 2004-5190, 116 p.

33. Parker, G.G., 1973, Tests of Rhodamine WT dye for toxicity to oysters and fish, Journal of Research U.S. Geological Survey, Vol. 1, No. 4, July-Aug., 499 p.

34. Putnam, L.D. and Long A.J., 2007, Characterization of ground-water flow and water quality for the Madison and minnelusa aquifers in northern Lawarence county, South Dakota, U.S. Geological Survey Scientific Investigation Report 2007-5001, 73 p.

35. Quinlan, J.F. and Koglin, E.N. (EPA), 1989, Ground-water monitoring in karst terrranes: recommended protocols and implicit assumptions, U.S. Environmental Protection Agency, EPA 600/x-89/050, IAG No. DW 14932604-01-0, 79 p.

36. Quinlan, J.F., 1990, Special problems of ground-water monitoring in karst terranes, Ground Water and vadose Zone Monitoring, ASTM STP 1053, D.M. Nielsen and A.I. Johnson, (Eds), American Society for Testing and Materials, Philadelphia, p. 275 -304.

37. Smart, C. and Simpson B.E., 2002, Detection of fluorescent compounds in the environment using granular activated charcoal detectors, Environmental Geology, vol. 42, 538-545 p.

38. Smart, P.L., 1984, A review of the toxicity of twelve fluorescent dyes used for water tracing, National Speleological Society publication, vol. 46, no. 2: 21-33.

39. Smart, P.L., 1984, A review of the toxicity of twelve fluorescent dyes used for water tracing, National Speleological Society publication, vol. 46, no. 2: 21-33.

40. Spangler, L.E., and Susong, D.D., 2006, Use of dye tracing to determine ground-water movement to Mammoth Crystal springs, Sylvan pass area, Yellowstone national park, Wyoming, U.S. Geological Survey Scientific Investigations Report 2006-5126, 19 p.

41. Stanovich, Keith E. (2007). How to think straight about Psychology. Boston: Pearson Education, 123 p.

42. Taylor, C.J., and Greene E.A., Hydrogeologic characterization and methods used in the investigation of karst hydrology, U.S. Geological Survey field techniques for estimating water fluxes between surface water and ground water, chapter 3, Techniques and Methods 4-D2, 71-114 p.

43. Turner Designs, Inc., A practical guide to flow measurement, www.turnerdesigns.com.

44. Walthall, W.K., and Stark J.D., 1999, The acute and chronic toxicity of two xanthene dyes, Fluorescein sodium salt and phloxine B, to Daphnia pulex, Environmental Pollution volume 104, 207-215 p.

45. Wilson, J.F., Cobb, E.D., and Kilpatrick F.A., 1986, Fluorometric procedures for dye tracing, U.S. Geological Survey Techniques of Water-Resources Investigations of the United States Geological Survey, Applications of Hydraulics, book 3, chapter A12, 43 p.

APPENDIX A – Miscellaneous Information

BRIGHT DYESMATERIAL SAFETY DATA SHEET
FLT YELLOW/GREEN LIQUID CONCENTRATE
PAGE 1 OF 3

MSDS PREPARATION INFORMATION

PREPARED BY:	T. P. MULDOON (937) 886-9100
DATE PREPARED:	1/01/05

PRODUCT INFORMATION

MAUNFACTURED BY:	KINGSCOTE CHEMICALS 3334 S. TECH BLVD. MIAMISBURG, OHIO 45342
CHEMICAL NAME	NOT APPLICABLE
CHEMICAL FORMULA	NOT APPLICABLE
CHEMICAL FAMILY	AQUEOUS DYE PRODUCT

HAZARDOUS INGREDIENTS

NONE PER 29 CFR 1910.1200

PHYSICAL DATA

PHYSICAL STATE	LIQUID
ODOR AND APPEARANCE	YELLOW/GREEN, WITH NO APPARENT ODOR
SPECIFIC GRAVITY	APPROXIMATELY 1.05
VAPOR DENSITY (mm Hg @ 25 ° C)	~23.75
VAPOR DENSITY (AIR =1)	~0.6
EVAPORATION RATE (Butyl Acetate = 1)	~1.8
BOILING POINT	100 degrees C (212 degrees F)
FREEZING POINT	0 degrees C (32 degrees F)
pH	8.0 OR ABOVE
SOLUBILITY IN WATER	HIGHLY SOLUBLE

FIRE HAZARD

CONDITION OF FLAMMABILITY	NON-FLAMABLE
MEANS OF EXTINCTION	WATER FOG, CARBON DIOXIDE, OR DRY CHEMICAL
FLASH POINT AND METHOD	NOT APPLICABLE
UPPER FLAMABLE LIMIT	NOT APPLICABLE
LOWER FLAMABLE LIMIT	NOT APPLICABLE
AUTO-IGNITION TEMPERATURE	NOT APPLICABLE
HAZARDOUS COMBUSTION PRODUCTS	NOT APPLICABLE
UNUSUAL FIRE HAZARD	NOT APPLICABLE

EXPLOSION HAZARD

SENSITIVITY TO STATIC DISCHARGE	NOT APPLICABLE
SENSITIVITY TO MECHANICAL IMPACT	NOT APPLICABLE

REACTIVITY DATA

PRODUCT STABILITY	STABLE
PRODUCT INCOMPATIBILITY	NONE KNOWN
CONDITIONS OF REACTIVITY	NOT APPLICABLE
HAZARDOUS DECOMPOSITION PRODUCTS	NONE KNOWN

TOXICOLOGICAL PROPERTIES

SYMPTOMS OF OVER EXPOSURE FOR EACH POTENTIAL ROUTE OF ENTRY:

INHALLATION, ACUTE	NO HARMFUL EFFECTS EXPECTED.
INHALATION, CHRONIC	NO HARMFUL EFFECTS EXPECTED.
SKIN CONTACT	WILL TEMPORARILY GIVE SKIN A YELLOW/GREEN COLOR.
EYE CONTACT	NO HARMFUL EFFECTS EXPECTED.
INGESTION	URINE MAY BE A YELLOW/GREEN COLOR UNTIL THE DYE HAS BEEN WASHED THROUGH THE SYSTEM.
EFFECTS OF ACUTE EXPOSURE	NO HARMFUL EFFECTS EXPECTED
EFFECTS OF CHRONIC EXPOSURE	NO HARMFUL EFFECTS EXPECTED
THRESHOLD OF LIMIT VALUE	NOT APPLICABLE
CARCINOGENICITY	NOT LISTED AS A KINOWN OR SUSPECTED CARCINOGEN BY IARC, NTP OR OSHA.
TERATOGENICITY	NONE KNOWN
TOXICOLOGY SYNERGISTIC PRODUCTS	NONE KNOWN

PREVENTATIVE MEASURES

PERSONAL PROTECTIVE EQUIPMENT

GLOVES	RUBBER
RESPIRATORY	USE NISOH APPROVED DUST MASK IF DUSTY CONDITIONS EXIST.
CLOTHING	PROTECTIVE CLOTHING SHOULD BE WORN WHERE CONTACT IS UNAVOIDABLE.
OTHER	HAVE ACCESS TO EMERGENCY EYEWASH.

PREVENTATIVE MEASURES (CONT.)

ENGINEERING CONTROLS	NOT NECESSARY UNDER NORMAL CONDITIONS, USE LOCAL VENTILATION IF DUSTY CONDITIONS EXIST.
SPILL OR LEAK RESPONSE	CLEAN UP SPILLS IMMEDIATELY, PREVENT FROM ENTERING DRAIN. USE ABSORBANTS AND PLACE ALL SPILL MATERIALS IN WASTE DISPOSAL CONTAINER. FLUSH AFFECTED AREA WITH WATER.
WASTE DISPOSAL	INCINERATE OR REMOVE TO A SUITABLE SOLID WASTE DISPOSAL SITE, DISPOSE OF ALL WASTES IN ACCORDANCE WITH FEDERAL, STATE AND LOCAL REGULATIONS.
HANDELING PROCEDURES AND EQUIPMENT	NO SPECIAL REQUIREMENTS.
STORAGE REQUIREMENTS	STORE AT ROOM TEMPERATURE BUT ABOVE THE FREEZING POINT OF WATER.
SHIPPING INFORMATION	KEEP FROM FREEZING

FIRST AID MEASURES

FIRST AID EMERGENGY PROCEDURES

EYE CONTACT	FLUSH EYES WITH WATER FOR AT LEAST 15 MINUTES. GET MEDICAL ATTENTION IF IRRITATION PERSISTS.
SKIN CONTACT	WASH SKIN THOROUGHLY WITH SOAP AND WATER. GET MEDICAL ATTENTION IF IRRITATION DEVELOPS.
INHALATION	IF DUST IS INHALED, MOVE TO FRESH AIR. IF BREATHING IS DIFFICULT GIVE OXYGEN AND GET IMMEDIATE MEDICAL ATTENTION.
INGESTION	DRINK PLENTY OF WATER AND INDUCE VOMITING. GET MEDICAL ATTENTION IF LARGE QUANTITIES WERE INGESTED OR IF NAUSEA OCCURS. NEVER GIVE FLUIDS OR INDUCE VOMITING IF THE PERSON IS UNCONSCIOUS OR HAS CONVULSIONS.

SPECIAL NOTICE

ALL INFORMATION, RECOMMENDATIONS AND SUGGESTIONS APPEARING HEREIN CONCERNING THIS PRODUCT ARE BASED UPON DATA OBTAINED FROM MANUFACTURER AND/OR RECOGNIZED TECHNICAL SOURCES; HOWEVER, KINGSCOTE CHEMICALS MAKES NO WARRANTY, REPRESENTATION OR GUARANTEE AS TO THE ACCURACY, SUFFICIENCY OR COMPLETENESS OF THE MATERIAL SET FORTH HEREIN. IT IS THE USER'S RESPONSIBILITY TO DETERMINE THE SAFETY, TOXICITY AND SUITABILITY OF HIS OWN USE, HANDLING, AND DISPOSAL OF THE PRODUCT. ADDITIONAL PRODUCT LITERATURE MAY BE AVAILABLE UPON REQUEST. SINCE ACTUAL USE BY OTHERS IS BEYOND OUR CONTROL, NO WARRANTY, EXPRESS OR IMPLIED, IS MADE BY KINGSCOTE CHEMICALS AS TO THE EFFECTS OF SUCH USE, THE RESULTS TO BE OBTAINED OR THE SAFETY AND TOXICITY OF THE PRODUCT, NOR DOES KINGSCOTE CHEMICALS ASSUME ANY LIABILITY ARISING OUT OF USE BY OTHERS OF THE PRODUCT REFERRED TO HEREIN. THE DATA IN THE MSDS RELATES ONLY TO SPECIFIC MATERIAL DESIGNATED HEREIN AND DOES NOT RELATE TO USE IN COMBINATION WITH ANY OTHER MATERIAL OR IN ANY PROCESS.

END OF MATERIAL SAFETY DATA SHEET

BRIGHT DYES
Division of Kingscote Chemicals

WATER TRACING DYE
FLT YELLOW/GREEN PRODUCTS

TECHNICAL DATA BULLETIN

Bright Dyes Yellow/Green products are specially formulated versions of Xanthene dye, certified by NSF International to ANSI/NSF Standard 60 for use in drinking water. This dye is the traditional fluorescent water tracing and leak detection material and has been used for labeling studies from the beginning of the century. It may be detected visually, by UV light and by appropriate fluoremetric equipment. Today it is most often used visually. This dye has been used by the military to mark downed pilots for search and rescue operations over large water bodies. Visually the dye appears yellow/green, depending on its concentration and under UV light as lime green.

Based on biochemical oxygen demand (BOD) studies, the dye is biodegradable with 65% of the available oxygen consumed in 7 days. The dye is resistant to absorption on most suspended matter in fresh and salt water. However, compared to Bright Dyes FWT Red products it is significantly less resistant to degradation by sunlight and when used in fluoremetry, stands out much less clearly against background fluorescence. As always the suitability of these products for any specific application should be evaluated by a qualified hydrologist or other industry professional.

General Properties	Tablets	Liquids	Powders
Detectability of active ingredient [1]	Visual <100 ppb	Visual <100 ppb	Visual <100 ppb
Maximum absorbance wavelength [2]	490/520 nm	490/520 nm	490/520 nm
Appearance	Orange convex 1.6cm diameter	Reddish, brown aqueous solution	Orange fine powder
NSF (Max use level in potable water)	6.0 ppb	10.0 ppb	1.0 ppb
Weight	1.35 gms $\pm$ 0.05		
Dissolution Time [3]	50% < 3 minutes 95% < 6 minutes		50% < 3 minutes 95% < 6 minutes
Specific Gravity		1.05 $\pm$ 0.05 @ 25° C	
Viscosity [4]		1.8 cps	
pH		8.5 $\pm$ 0.5 @ 25° C	

Coverage of Products	One Tablet	One Pint Liquid	One Pound Powder
Light Visual	605 gallons	125,000 gallons	1,200,000 gallons
Strong Visual	60 gallons	12,500 gallons	120,000 gallons

Caution: These products may cause irritation and/or staining if allowed to come in contact wit the skin. The use of gloves and goggles is recommended when handling this product, as with any other dye or chemical.

[1] In deionized water in 100 ml flask. Actual detectability and coverage in the field will vary with specific water conditions.
[2] No significant change in fluorescence between 6 and 11 pH.
[3] (One tablet, 1 gram of powder), in flowing deionized water in a 10 gallon tank.
[4] Measured on a Brookfield viscometer, Model LV, UL adapter, 60 rpm @ 25° C.

Kingscote Chemicals, 3334 S. Tech Blvd., Miamisburg, Ohio 45342
Telephone: (937) 886-9100 Fax: (937) 886-9300 Web: www.brightdyes.com

Bulletin No. 103
Fluorescein

INTRODUCTION

Fluorescein was the first fluorescent dye used for water tracing work[1] and is still used for qualitative (visual) studies of underground contamination of wells. In recent years, Rhodamine WT has almost completely replaced fluorescein for flow measurements[2] and circulation, dispersion, and plume studies[3]. Nonetheless, fluorescein has a role in such studies, and can be used for masking, hydraulic model studies, and underground water studies.

ADVANTAGES

Fluorescein has the following advantages over other tracer dyes:

- Its low sorption rate is far better than Rhodamine B, and comparable to Rhodamine WT.
- It has a temperature coefficient of only –0.36% per degree C, about one-eighth of the temperature coefficient of rhodamine dyes[2,4].
- It emits a brilliant green fluorescence, which gives an excellent visual or photographic contrast against the backgrounds normally encountered in water transport studies. Therefore it is easy to visualize the progress of an experiment.
- It is more aesthetic than the red dyes. This is psychologically important, especially in ocean areas subject to the blooms of certain dinoflagellates, called "red tides." Less public resistance will be encountered using a dye that does not resemble red tide[5].

DISADVANTAGES

Fluorescein has been replaced by other dyes, principally Rhodamine WT, for the following reasons:

- It is rapidly destroyed by sunlight. Reference 4 reports that a 50% loss occurred in three hours of sunlight exposure, with dye being held in an Erlenmeyer flask. Other tests in an flat, uncovered Pyrex dish showed an almost complete destruction in two hours[6].
- Many naturally occurring fluorescent materials have similar characteristics and thus interfere with measurement. When carefully chosen optical filters are used, the situation is better than that reported in Reference 4, but higher concentrations are required to overcome the effect of higher and more variable "blank" fluorescence.
- Fluorescein is more pH-sensitive than rhodamine dyes. Fluorescence drops very sharply at pH values below 5.5. For optimum results, pH should be between 6 and 10.

MASKING TECHNIQUES

In river, harbor, and ocean tests, fluorescein can be used to mask the objectionable color of the rhodamine dyes. Tests show that Fluorescein is an effective mask, subject to the following conditions[6]:

- The concentration of fluorescein should be at least five times that of the active ingredients in the Rhodamine B or Rhodamine WT concentrate.
- Where the receiving water is shallow, clear, and in full sunlight, the dyes must be dispersed quite rapidly. With slow dispersion, the photosensitive fluorescein will be destroyed before the masking effect is complete.
- Masking is subjective. Lower (hence less costly) amounts of fluorescein may be effective, depending on water clarity, bottom color, wave action, etc. Small scale addition of the mixed dyes to the receiving water should be made in advance

of a large scale test. This test should be made on a bright sunny day, if possible.

- Note that fluorescein is not the ingredient measured. The optical filter and light source in the fluorometer read only rhodamine dye[7].

HYDRAULIC MODEL STUDIES

Fluorescein may be used in hydraulic model studies in exactly the same way that Rhodamine WT is used (See Refs. 2 and 3 for details).

The major advantage of using fluorescein is its visibility; the green color can be seen as the test proceeds. The major disadvantage is fluorescein's light sensitivity. It can be destroyed by light entering the test area, both from windows and from indoor lights, especially fluorescent ones.

Containers used for dye destruction tests must be transparent to light at shorter wavelengths. Clear borosilicate glass baking pans are handy, since they transmit light at shorter wavelengths than window glass or the glass envelopes of fluorescent lamps.

Test samples must be at low concentrations (around 0.2 PPM) so that the fluorescein in the bottom of the pan is not protected from the incident light by absorption of the fluorescein in the top of the pan.

In certain cases, deliberate destruction of the fluorescein by sunlight may be a convenience instead of a problem. Hydraulic models often recycle water. With the very stable Rhodamine WT, the concentration of dye in the entire system will build up over a sequence of several tests, requiring replacement of the water. If a shallow holding tank can be placed outdoors, the degradation of fluorescein by sunlight may eliminate the need to replace the water.

UNDERGROUND WATER STUDIES

Fluorescein can be used quantitatively for underground tests, subject to limitations imposed by the higher background of naturally occurring fluorescent materials.

An advantage of fluorescein in underground studies is its light sensitivity. Should it reach an open receiving body of water, the color will be less of a problem because it will disappear rapidly in the sunlight.

FILTER AND LIGHT SOURCE SELECTION

Using fluorescein, the following light sources and filters are recommended (referenced part numbers are specific to Turner Designs products):

	10-AU-005
Optical Kit	10-086 (Lamp and all filters are included in this kit.)
Light Source	10-089 Blue Lamp
Reference	10-063
Excitation	10-105
Emission	10-109R-C

We have found that background fluorescence can be very high in natural systems with the fluorescein setup. In most cases, this background should be adequately suppressed using the 10-AU fluorometer. If, however, background cannot be suppressed, a mask (attenuator) may be added to the excitation filter holder to reduce its diameter and the amount of light scatter. Attenuation by a factor of 5 can be obtained with the 10-318R Attenuator Plate.

Fluorescein, known as "Acid Yellow 73", "Acid Yellow T", "DNC Yellow 7", etc., can be obtained from the following sources (addresses checked and confirmed June 1996):

Pylam Products
Company, Inc.
1001 Stewart Avenue
Garden City, NY 11530
516/222-1750

Tricon Colors, Inc.
16 Leliarts Lane
Elmwood Park, NJ 07407
201/794-3800

LISSAMINE FF

The properties of uses of Lissamine FF are reported in Reference 9. Its spectral characteristics are similar to those of fluorescein, but it does not decompose as rapidly in sunlight. Use the fluorescein filters detailed above with Lissamine FF. Pylam Products (address shown above) offers

Lissamine FF as "Brilliant Acid Yellow 8G" or "Brilliant Sulphoflavine FFA".

REFERENCES

1) Dole, R. B., *Use of Fluorescein in the Study of Underground Waters*, USGS Water Supply Paper 160, 73-85 (1906).

2) *A Practical Guide to Flow Measurement*, monograph by Turner Designs, 845 W. Maude Avenue, Sunnyvale, CA 94086.

3) *Circulation, Dispersion, and Plume Studies*, monograph by Turner Designs, 845 W. Maude Avenue, Sunnyvale, CA 94086.

4) (0047) Feuerstein, D.L., Sellick, R.E., *Fluorescent Tracers for Dispersion Measurements*, Journal of Sanitary Engineering, ASCE 89 (SA4), 1-21 (1963).

5) (0031) Murakami, Ken, Water Quality Section, Water Quality Control Division, Public Works Research Institute, 5-41-7, Shimo, Kita-Ku, Tokyo, 115, personal communication.

6) Turner Designs Laboratory Tests conducted July 23, 1975.

7) "Filter Selection Guide" for Turner Designs Fluorometers, by Turner Designs, 845 W. Maude Avenue, Sunnyvale, CA 94086.

8) (0413) Smart, P.L., Laidlaw, I.M.S., An *Evaluation of Some Fluorescent Dyes for Water Tracing*, Water Resources Research, 13 (1), 15-33 (1977).

TURNER DESIGNS
845 W.Maude Ave.
Sunnyvale, CA 94085
www.turnerdesigns.com
Telephone 408-749-0994
Toll Free 877-316-8049
Fax 408-749-0998

APPENDIX B – GPS Coordinates of Sample Sites in IDTM NAD83
(collected using a Trimble ProXRT and GeoXT 2005 set at maximum precision)

Site	X (meters)	Y (meters)
mg 1	2429484.4	1296372.7
mg 1.5	2429519.0	1296376.0
mg 2	2429548.4	1296388.9
mg 2.5	2429581.9	1296406.2
mg 3	2429613.7	1296423.1
mg 4	2429667.6	1296443.6
mg 5	2429686.7	1296455.2
mg 6	2429697.9	1296464.0
mg 7	2429713.9	1296477.4
mg 8	2429731.2	1296490.1
mg 9	2429755.0	1296504.0
mg 10	2429786.7	1296538.0
mg 10.5	2429803.2	1296549.7
mg 11	2429821.9	1296559.8
mg 11.5	2429943.6	1296603.8
mg 11.7	2430002.0	1296614.6
mg 12	2429404.9	1296383.0
mg 13	2429380.2	1296384.2
mg 14	2429327.7	1296391.2
mg 15	2429226.6	1296411.2
mg 16	2429157.6	1296401.3
mg 17	2429066.8	1296402.6
mg 17.5	2429038.8	1296404.2
mg 18	2428994.9	1296435.6
mg 19	2428989.3	1296444.6
mg 20	2428849.9	1296534.6
mg 21	2428667.3	1296435.5
mg 22	2428488.6	1296375.3
mg 23	2428430.7	1296315.8
wells		
Meyers, R.	2432081.1	1293736.0
Clinton, P.	2430569.0	1294595.0
Arriaga north	2431239.0	1294829.0
Arriaga south	2431316.6	1293369.0
Lyda, R.	2430677.0	1294882.9
Hopper R.	2430596.2	1295073.8

Riddle, R.	2430065.1	1295680.0
Sanchez/Rosales	2430526.2	1295025.4
Riddle (rental)	2431272.4	1293740.9
Riddle, Len	2430462.1	1294486.3
Riddle, N.	2429331.0	1295709.2
Boyer	2430568.5	1293950.6
Burrell	2430752.4	1294868.3
Umek	2430465.9	1294750.6
Victor	2432862.5	1292889.0
Knapp	2432148.0	1293629.0
Jackson	2432060.0	1292105.1
Turner	2431367.0	1293654.0
Evers	2430425.0	1295006.4

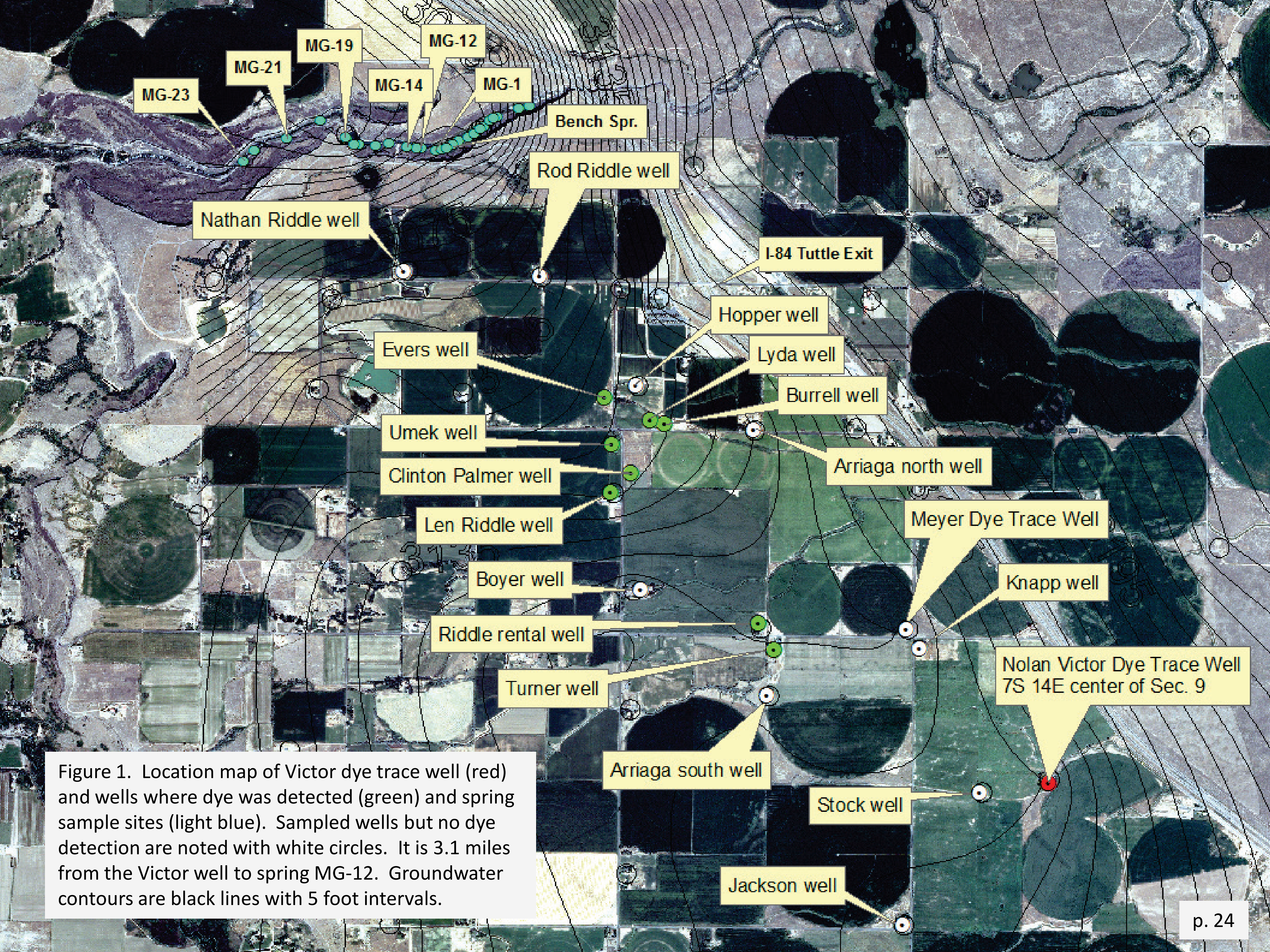


Figure 1. Location map of Victor dye trace well (red) and wells where dye was detected (green) and spring sample sites (light blue). Sampled wells but no dye detection are noted with white circles. It is 3.1 miles from the Victor well to spring MG-12. Groundwater contours are black lines with 5 foot intervals.

Figure 2. Screen capture images of the borehole video from the Victor well at 248 feet and 251.5 feet (BTOC) showing cavernous basalt with ragged bulbous features consistent with pillow basalt characteristics. The diameter of the smallest constriction in the images is at least 6 inches and probably greater. This is the level of dye release within the well.

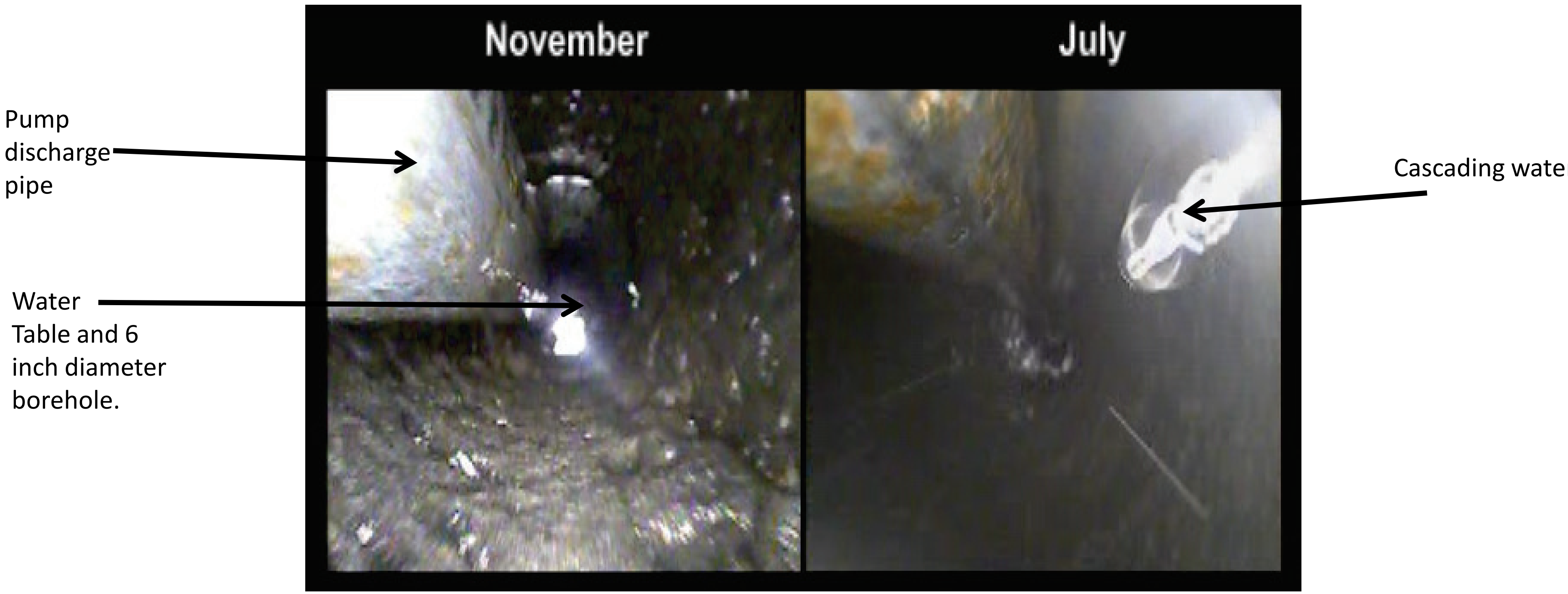


Figure 3. These images were taken during November on the left and July on the right side showing the water table in both. There was water cascading into the well during the summer and little to no water cascading into the well in November.

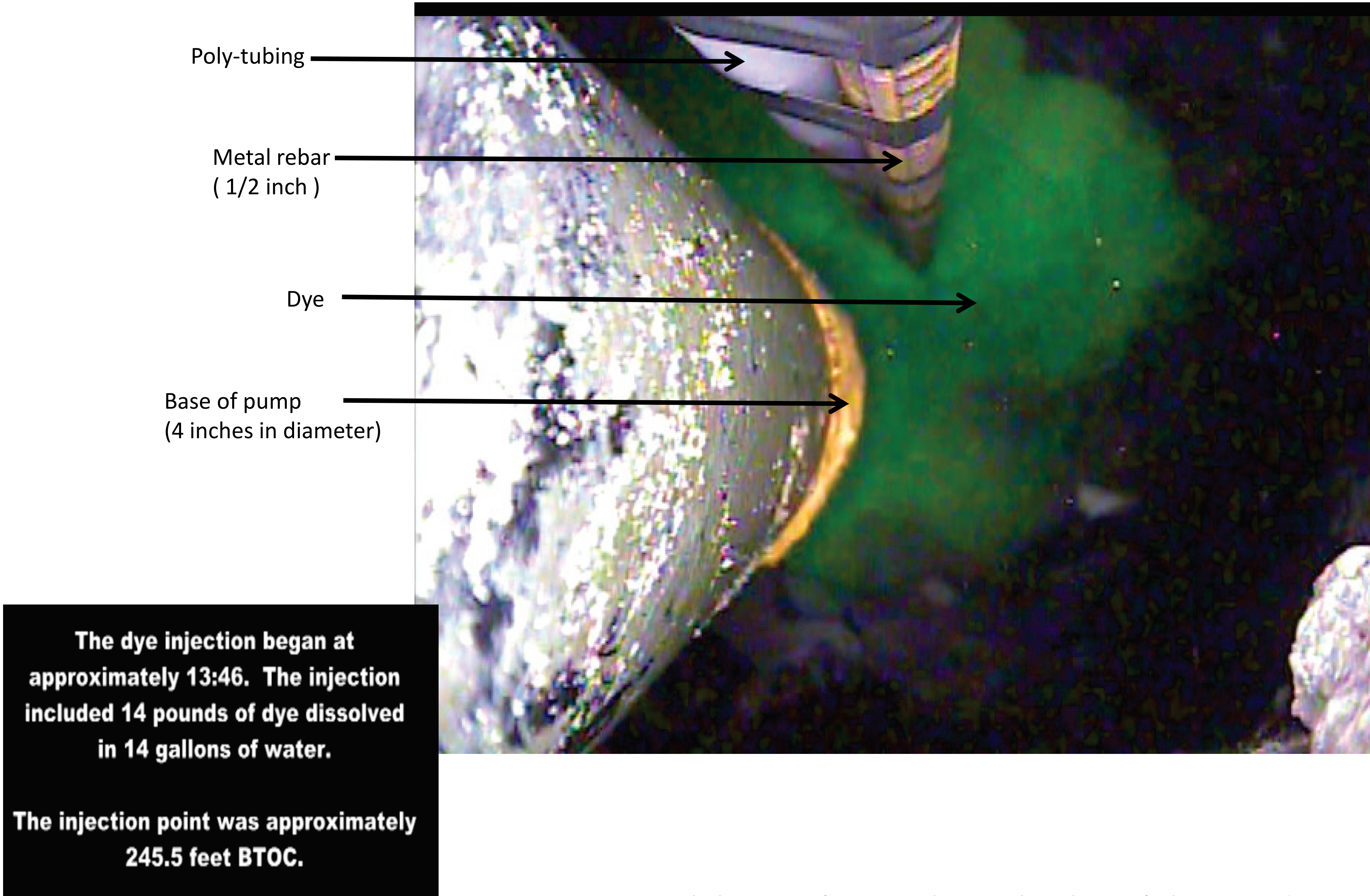


Figure 4. Borehole image of Trace #1 showing the release of Fluorescein dye from the poly-tubing (243 ft. BTOC) and below the base of the pump (242 ft. BTOC). A downward flow of water kept the dye from rising up the borehole.

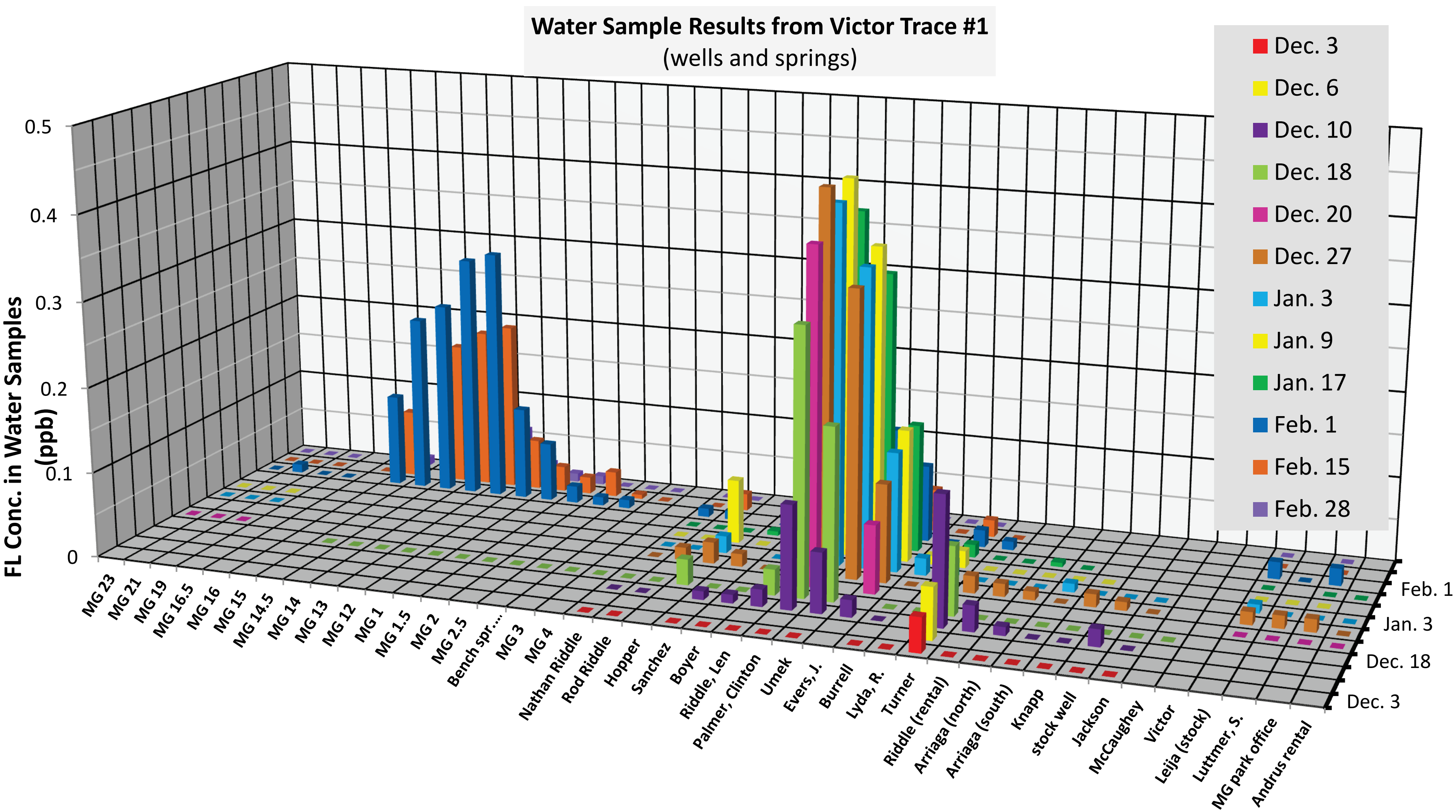


Figure 5. Chart of FL dye concentrations from water samples collected about a weekly frequency for wells and springs organized with earliest in time along front row. The highest well water concentration detected occurred at the Clinton Palmer's well with 0.44 ppb FL on Dec. 27, 2012 (brown column) but also 0.44 ppb on Jan. 9, 2013 (yellow column).

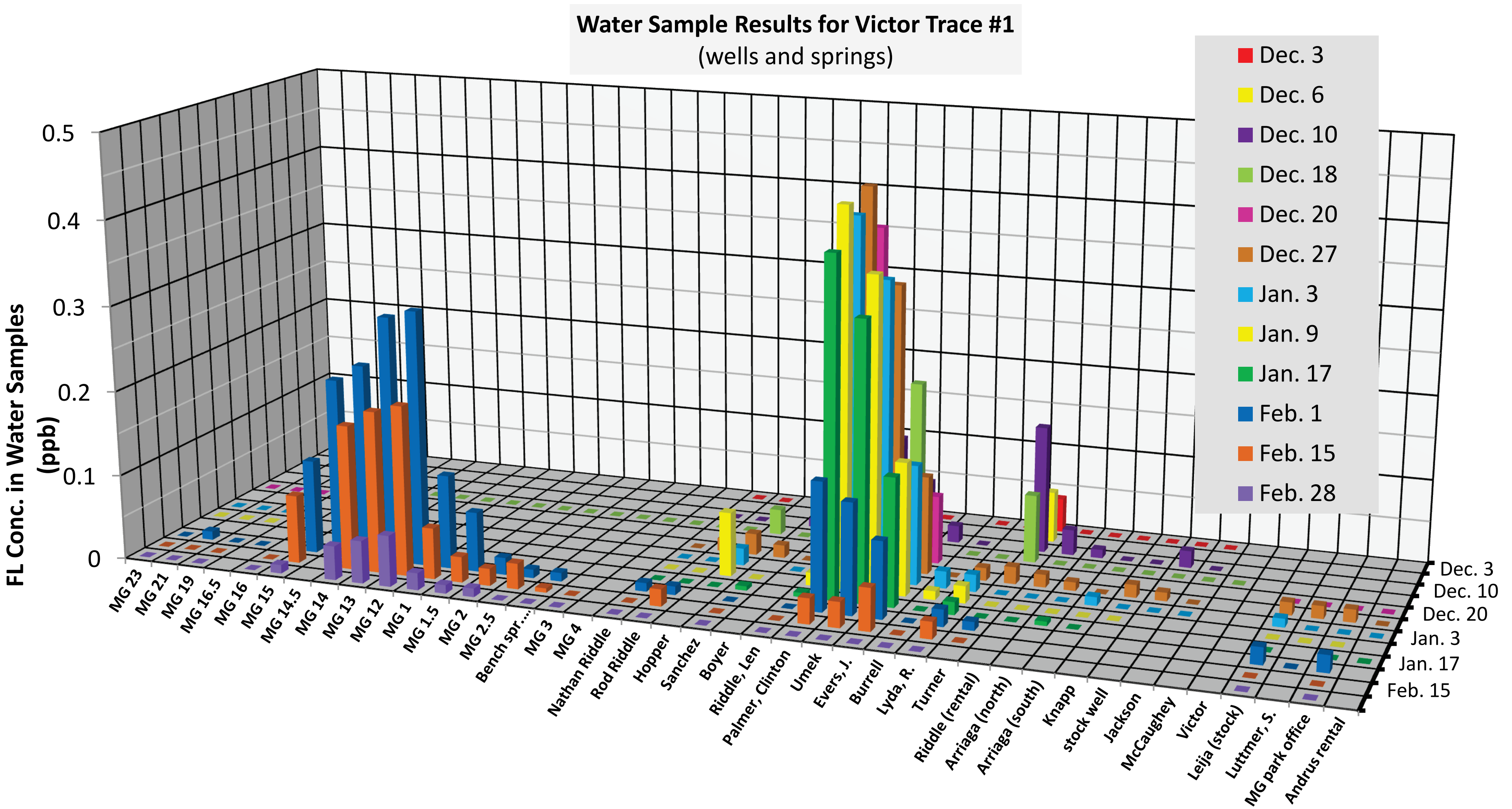


Figure 6. Chart of FL dye concentrations from water samples collected about a weekly frequency for wells and springs organized with latest in time along front row. The highest well water concentration detected occurred at the Clinton Palmer's well with 0.44 ppb FL on Dec. 27, 2012 (brown column) but also 0.44 ppb on Jan. 9, 2013 (yellow column).

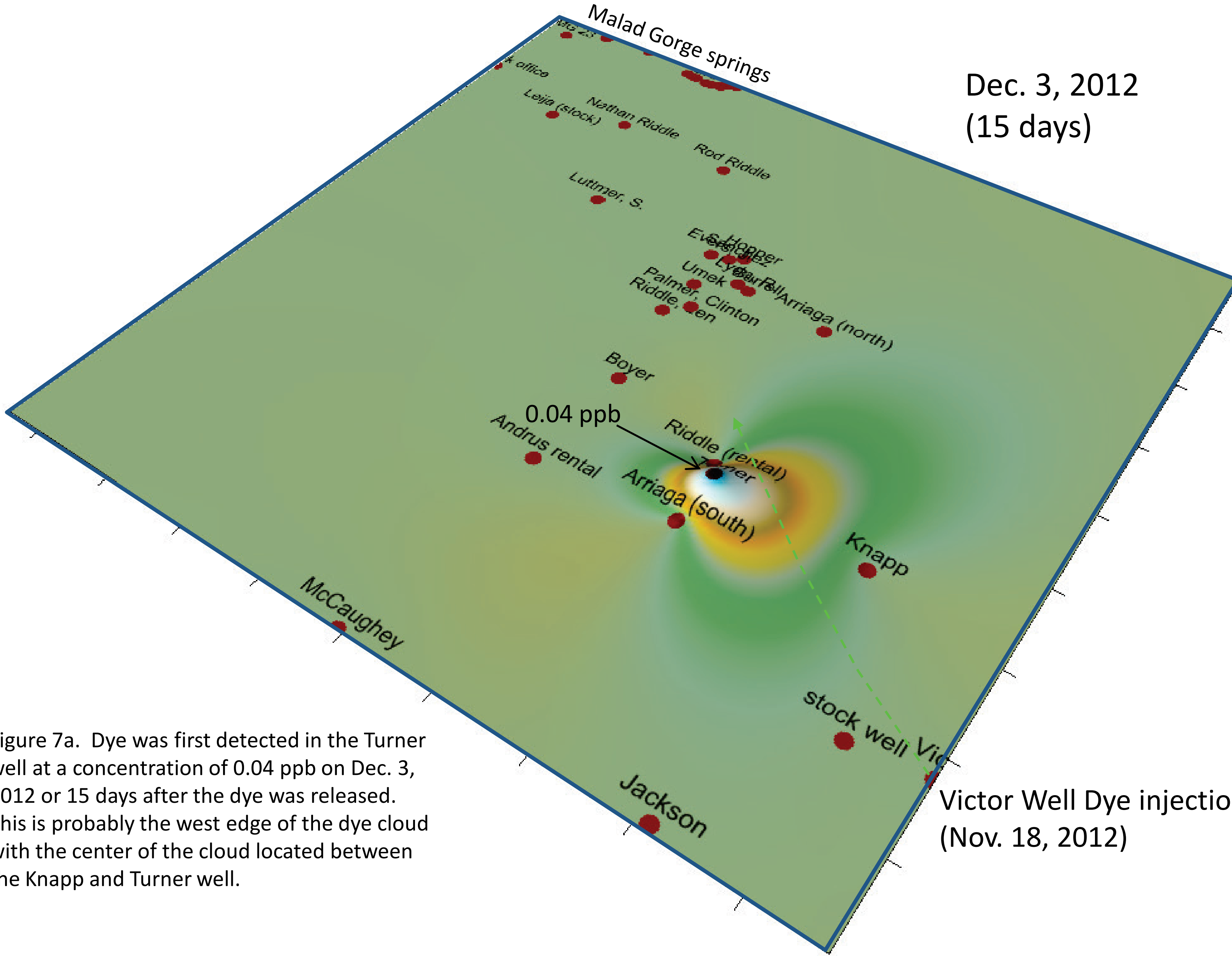


Figure 7a. Dye was first detected in the Turner well at a concentration of 0.04 ppb on Dec. 3, 2012 or 15 days after the dye was released. This is probably the west edge of the dye cloud with the center of the cloud located between the Knapp and Turner well.

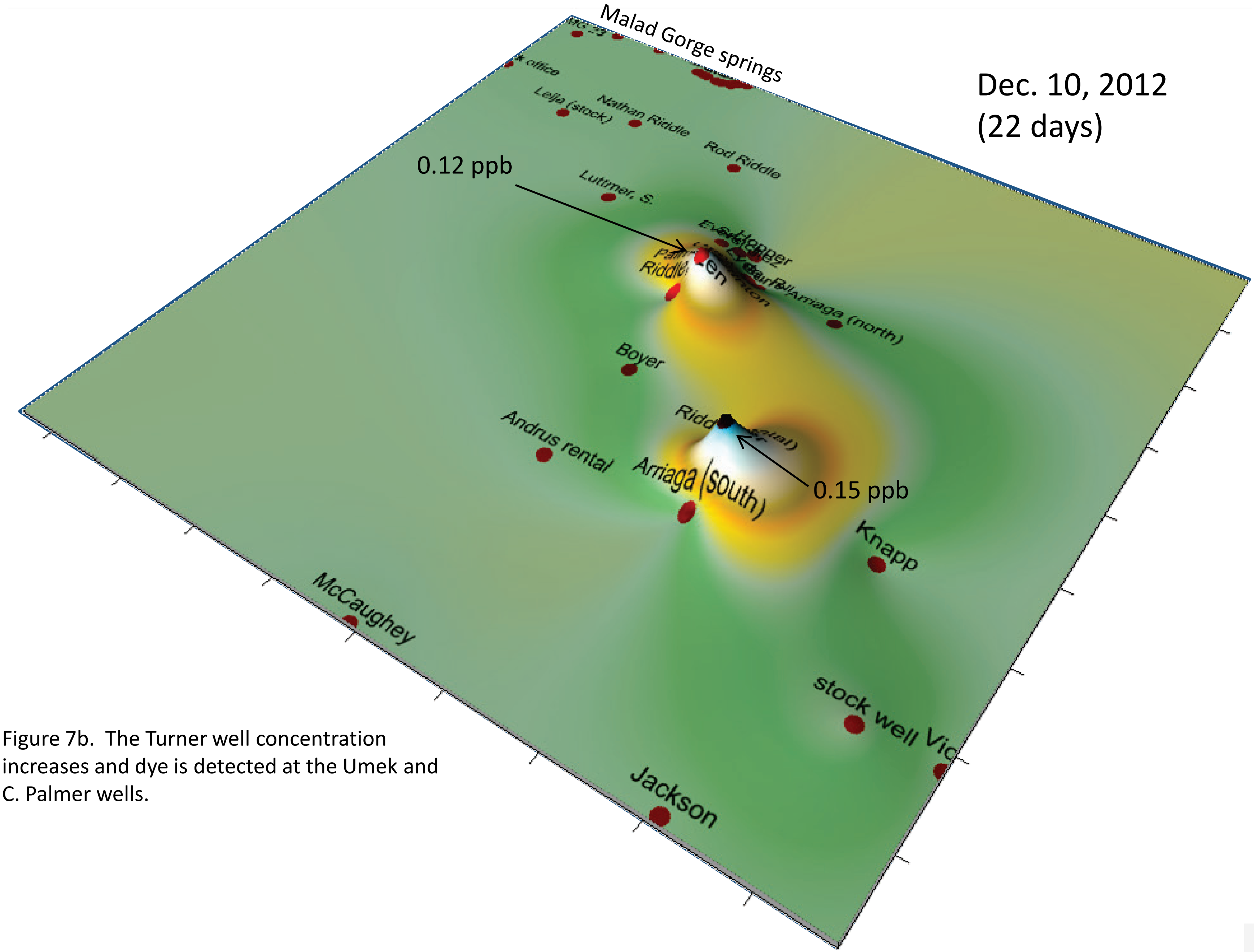


Figure 7b. The Turner well concentration increases and dye is detected at the Umek and C. Palmer wells.

Dec. 18, 2012
(30 days)

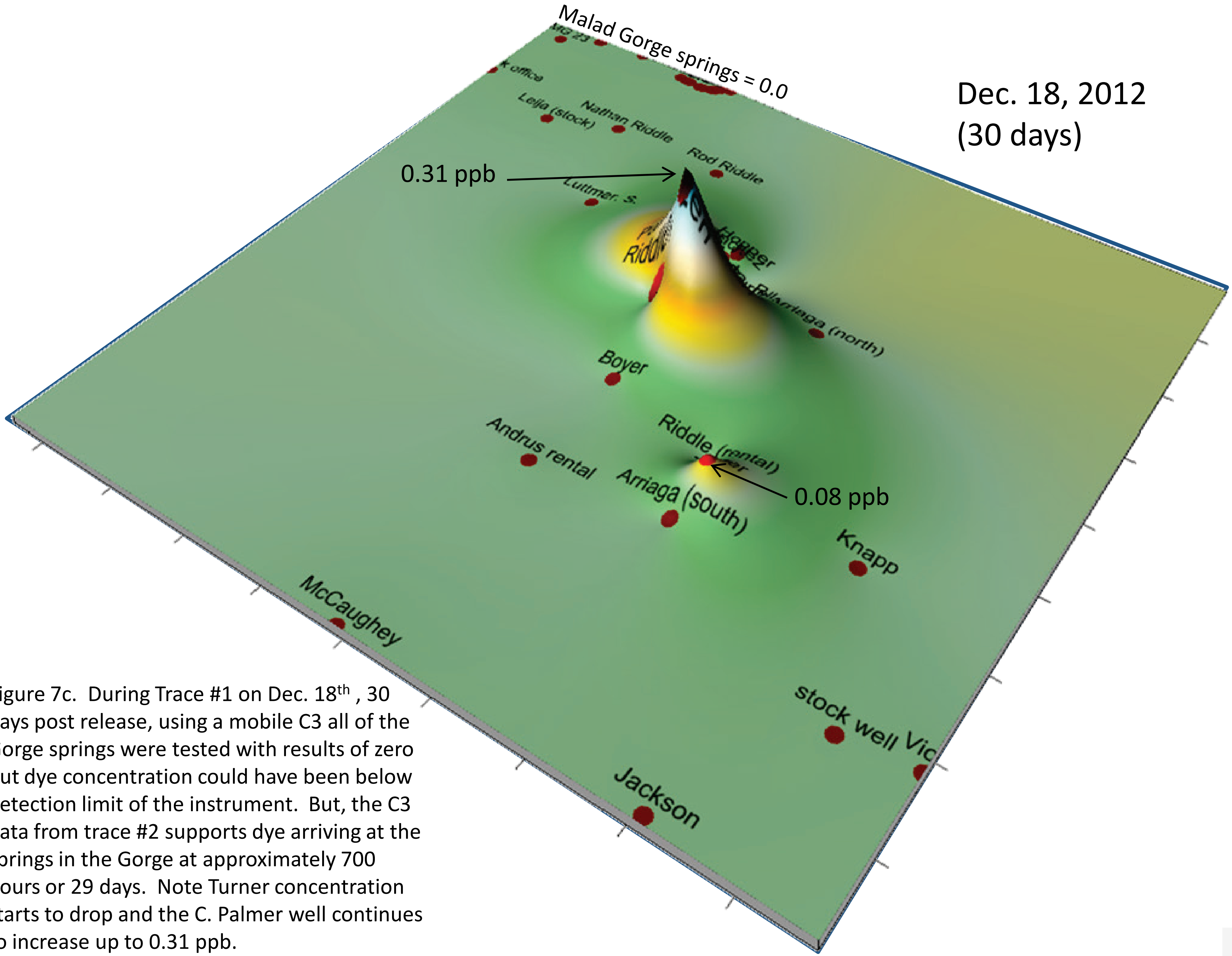


Figure 7c. During Trace #1 on Dec. 18th , 30 days post release, using a mobile C3 all of the Gorge springs were tested with results of zero but dye concentration could have been below detection limit of the instrument. But, the C3 data from trace #2 supports dye arriving at the springs in the Gorge at approximately 700 hours or 29 days. Note Turner concentration starts to drop and the C. Palmer well continues to increase up to 0.31 ppb.

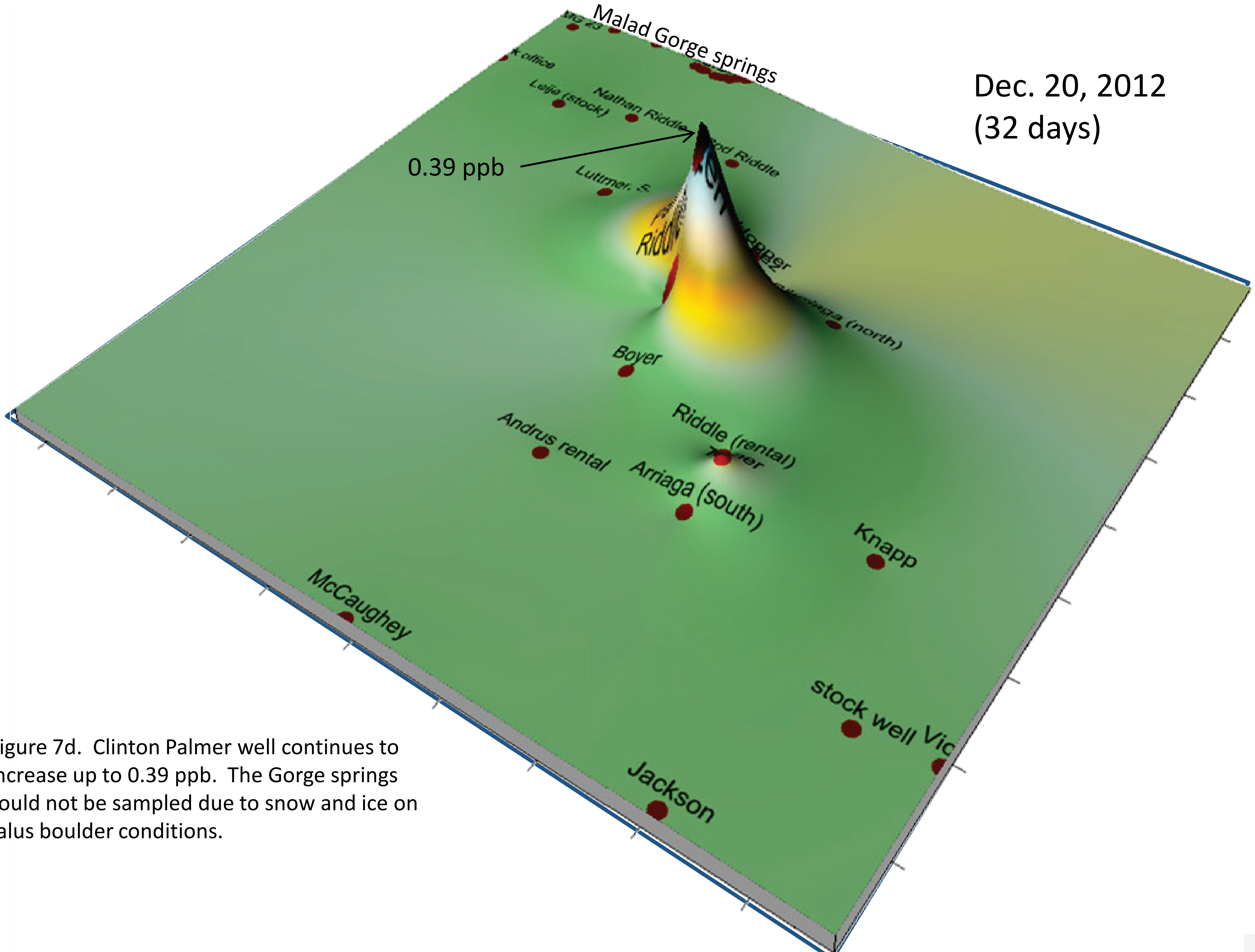


Figure 7d. Clinton Palmer well continues to increase up to 0.39 ppb. The Gorge springs could not be sampled due to snow and ice on talus boulder conditions.

Dec. 27, 2012
(39 days)

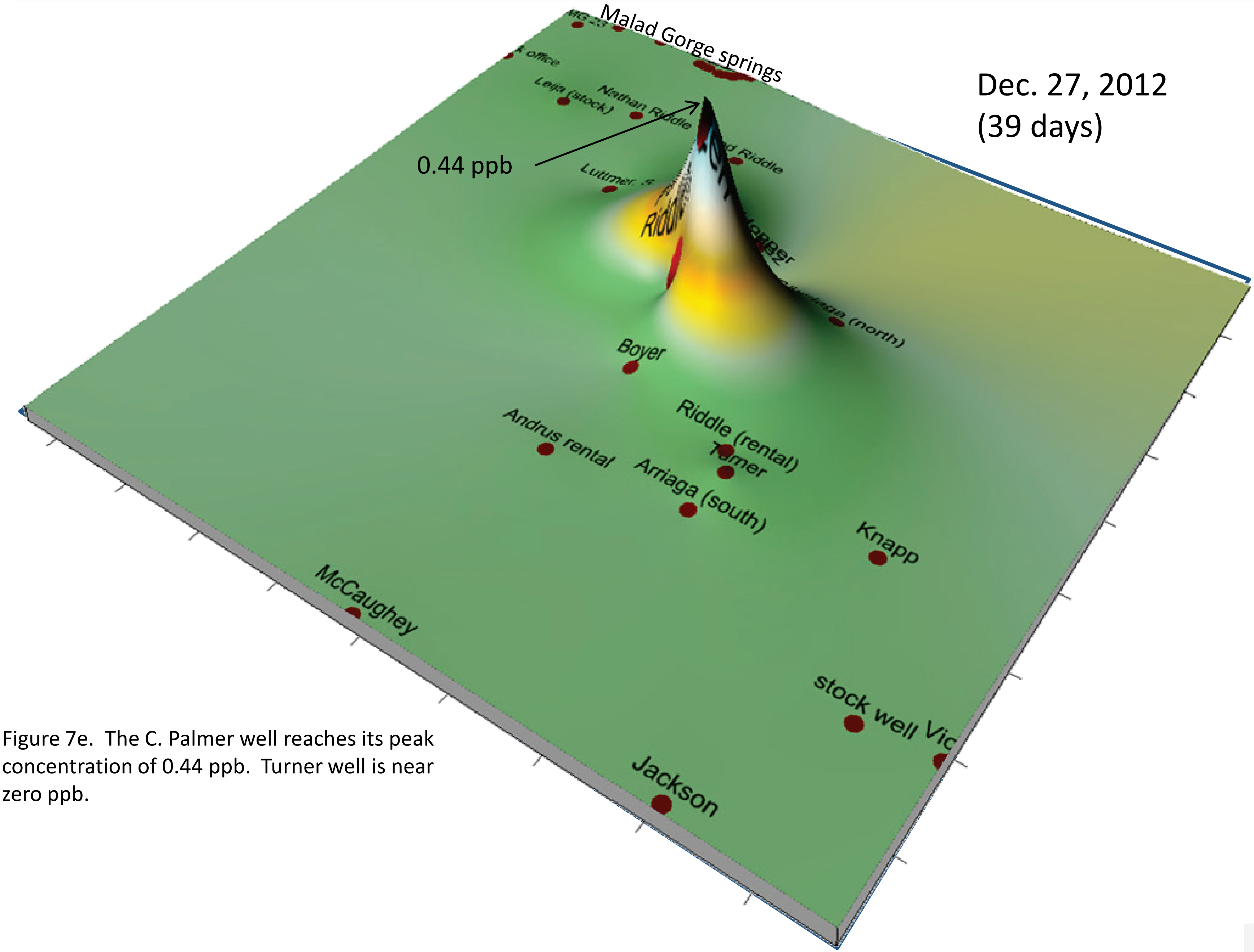


Figure 7e. The C. Palmer well reaches its peak concentration of 0.44 ppb. Turner well is near zero ppb.

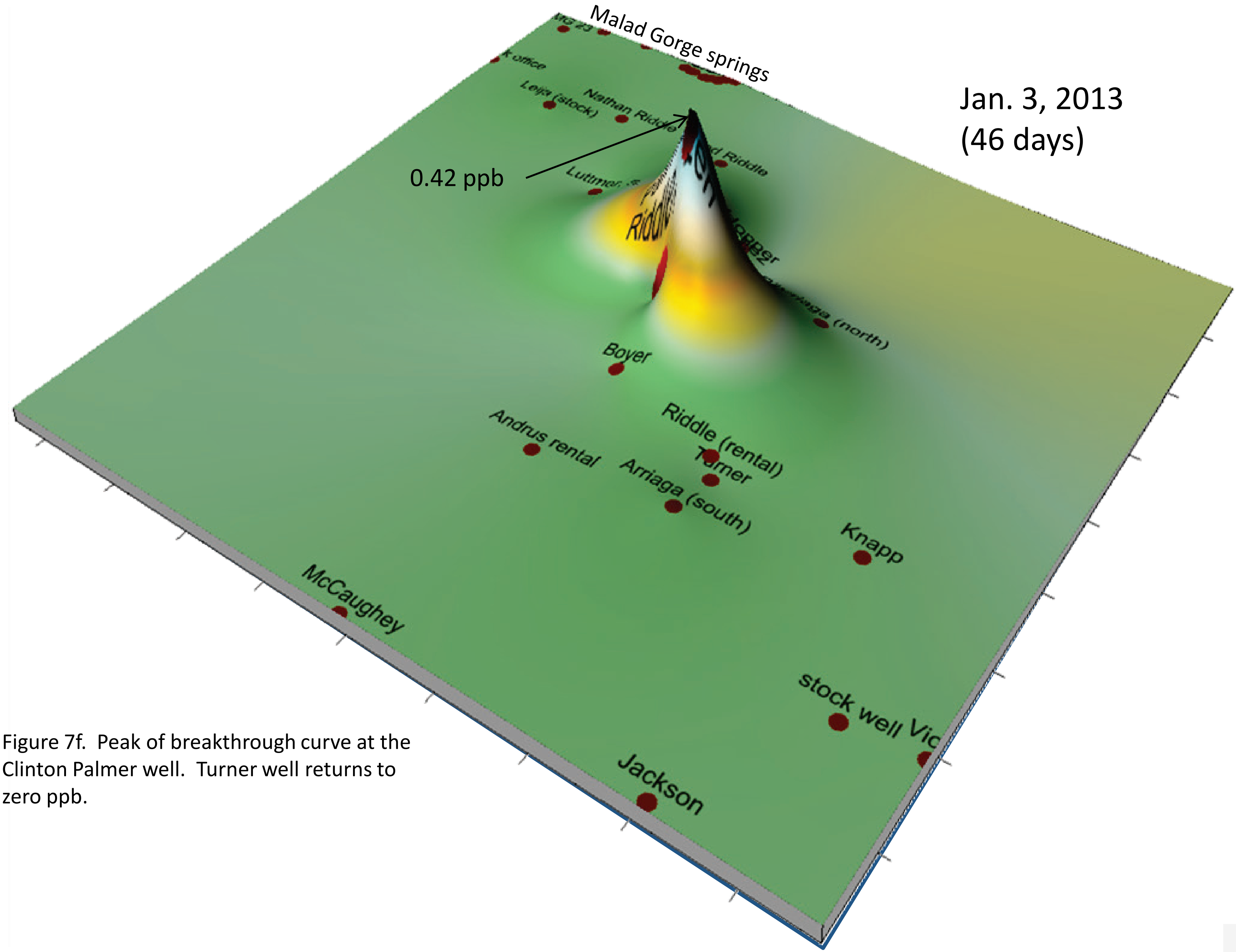
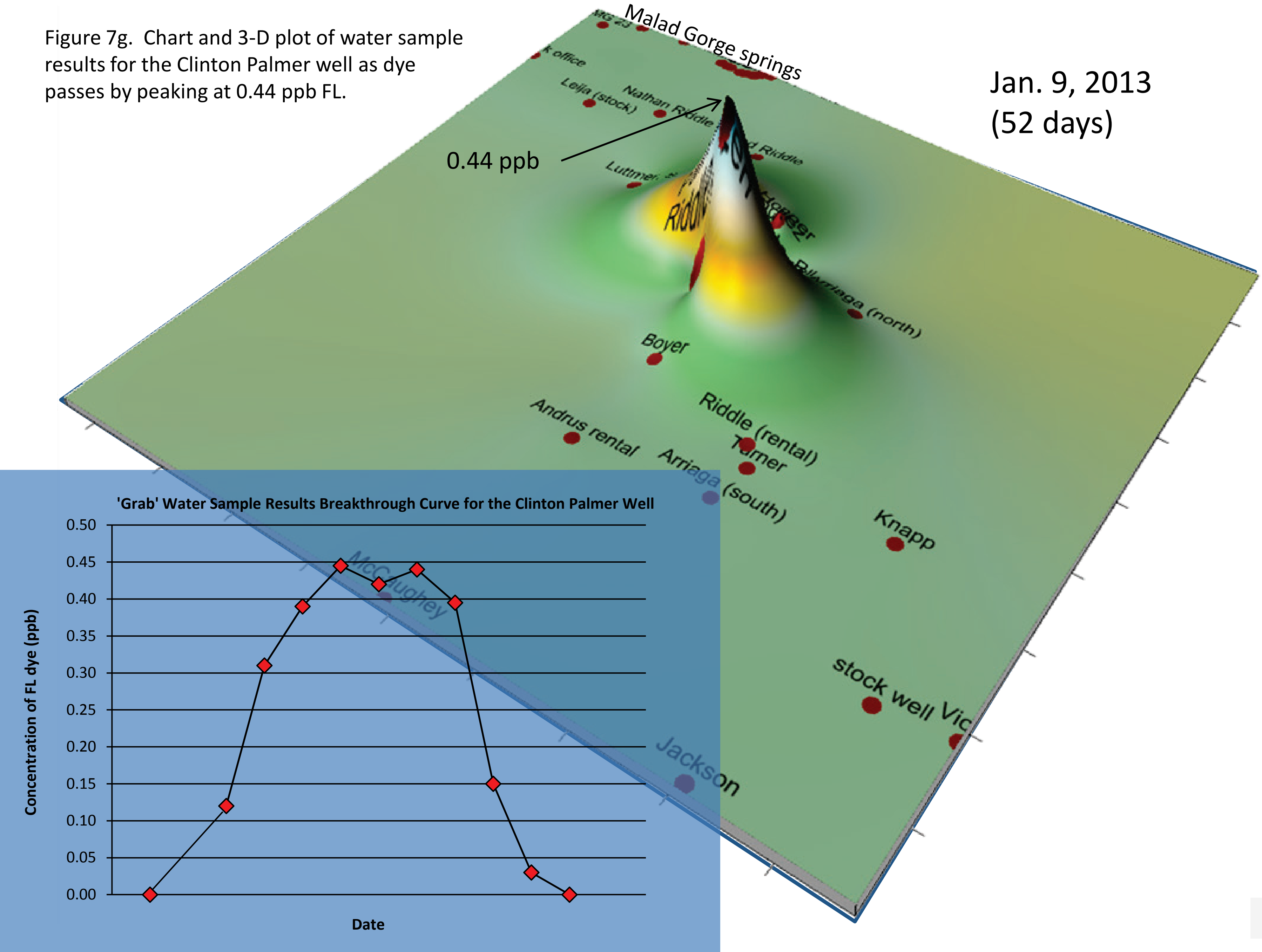


Figure 7f. Peak of breakthrough curve at the Clinton Palmer well. Turner well returns to zero ppb.

Figure 7g. Chart and 3-D plot of water sample results for the Clinton Palmer well as dye passes by peaking at 0.44 ppb FL.

Jan. 9, 2013
(52 days)



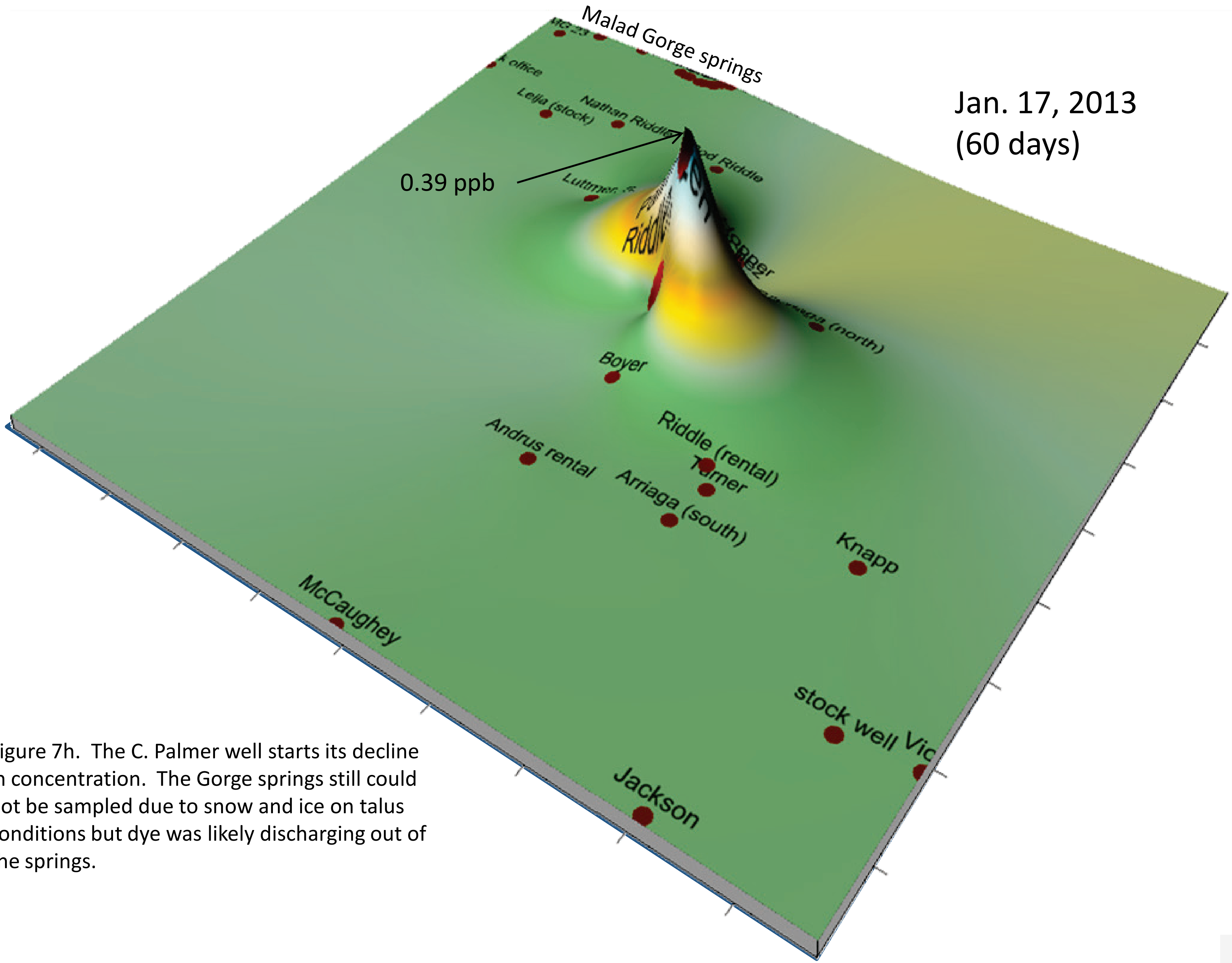


Figure 7h. The C. Palmer well starts its decline in concentration. The Gorge springs still could not be sampled due to snow and ice on talus conditions but dye was likely discharging out of the springs.

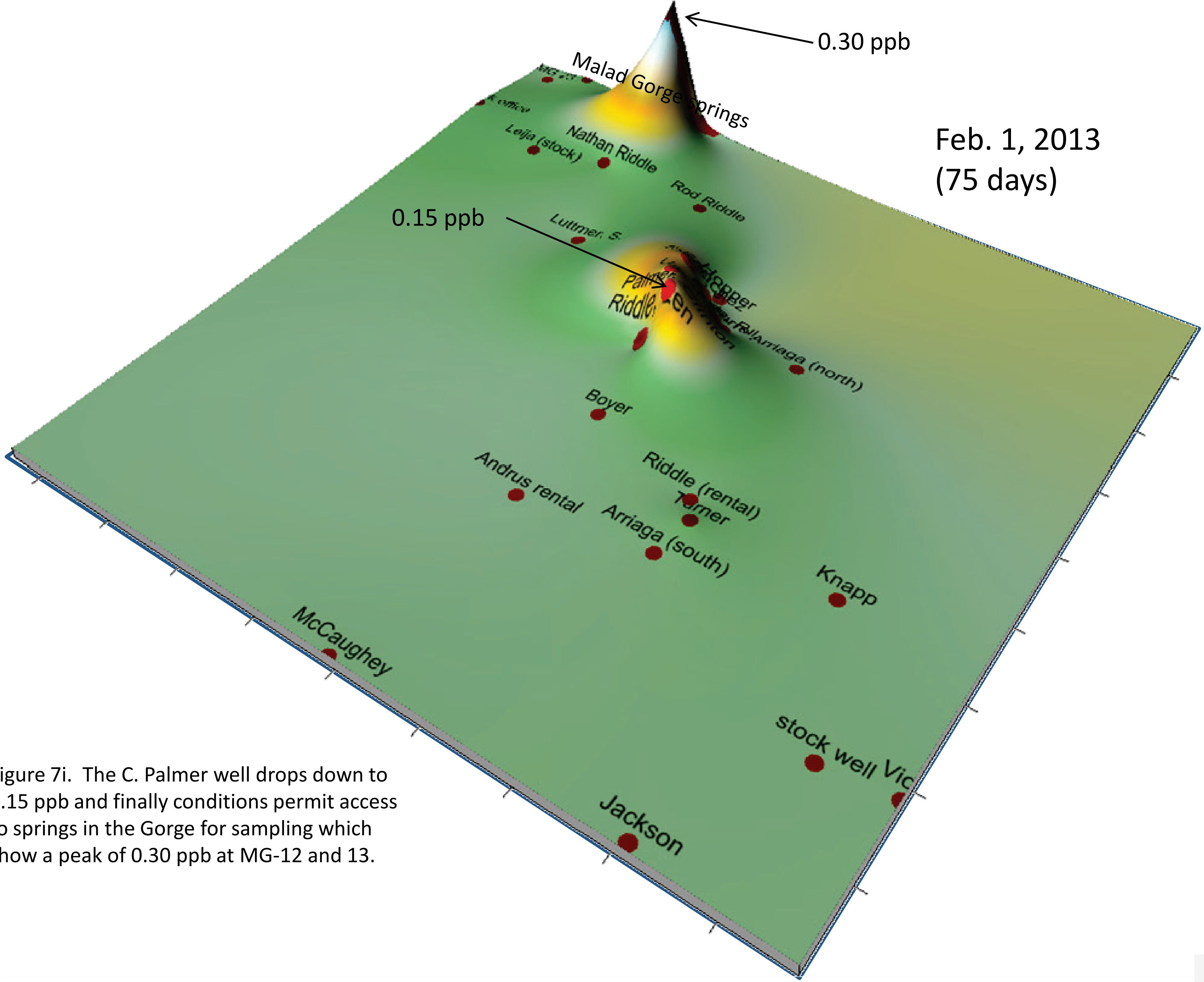


Figure 7i. The C. Palmer well drops down to 0.15 ppb and finally conditions permit access to springs in the Gorge for sampling which show a peak of 0.30 ppb at MG-12 and 13.

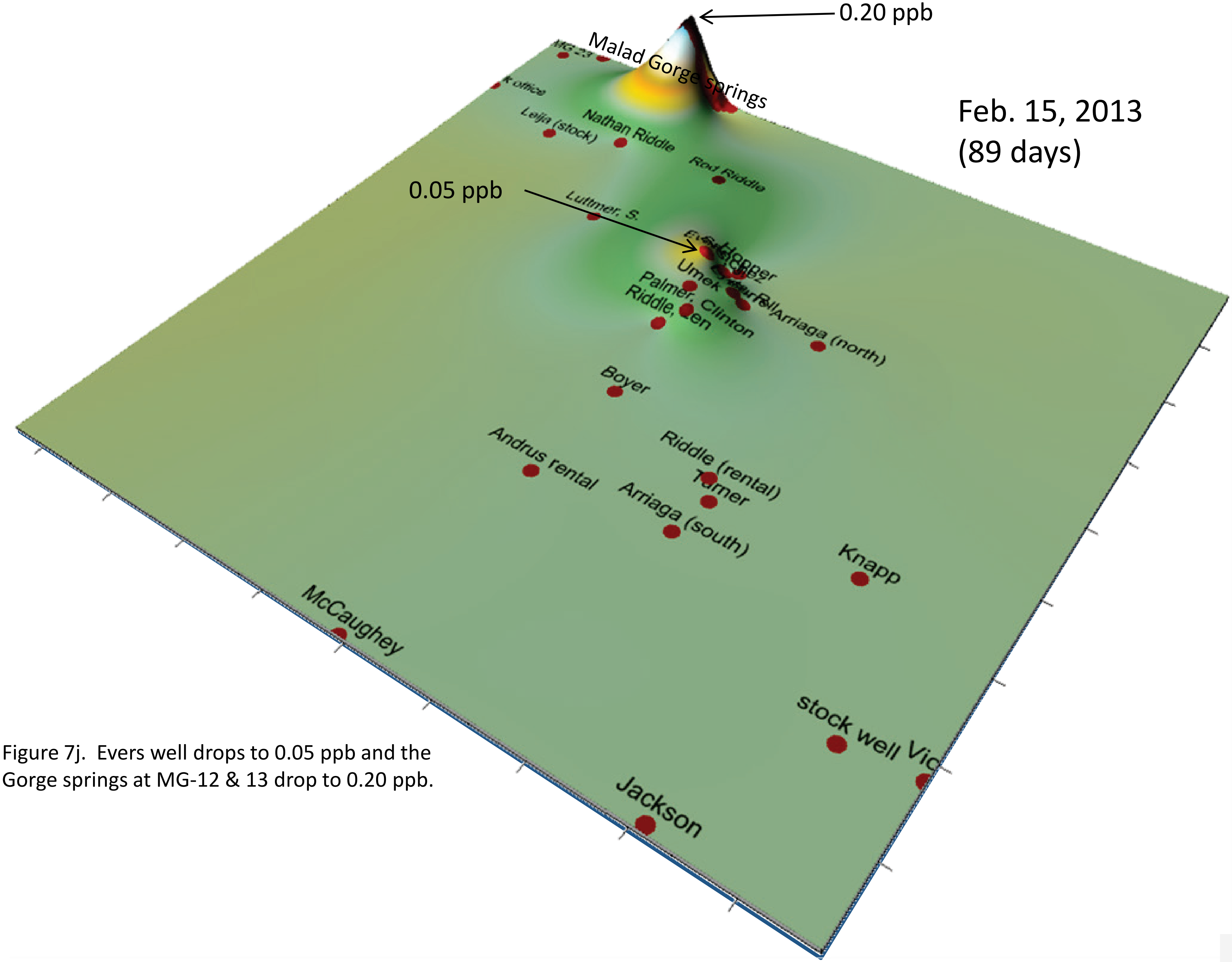
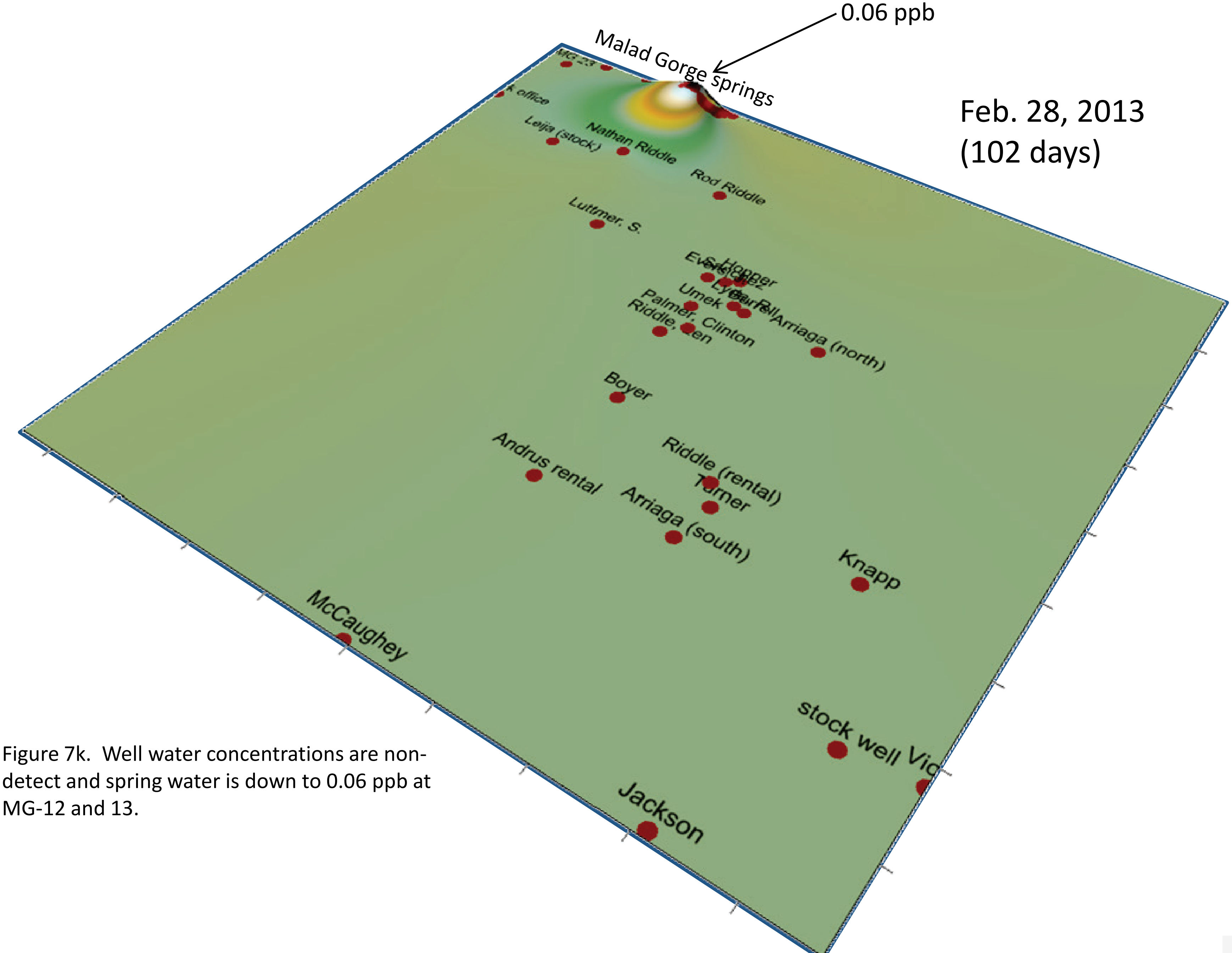


Figure 7j. Evers well drops to 0.05 ppb and the Gorge springs at MG-12 & 13 drop to 0.20 ppb.



Feb. 28, 2013
(102 days)

Figure 7k. Well water concentrations are non-detect and spring water is down to 0.06 ppb at MG-12 and 13.

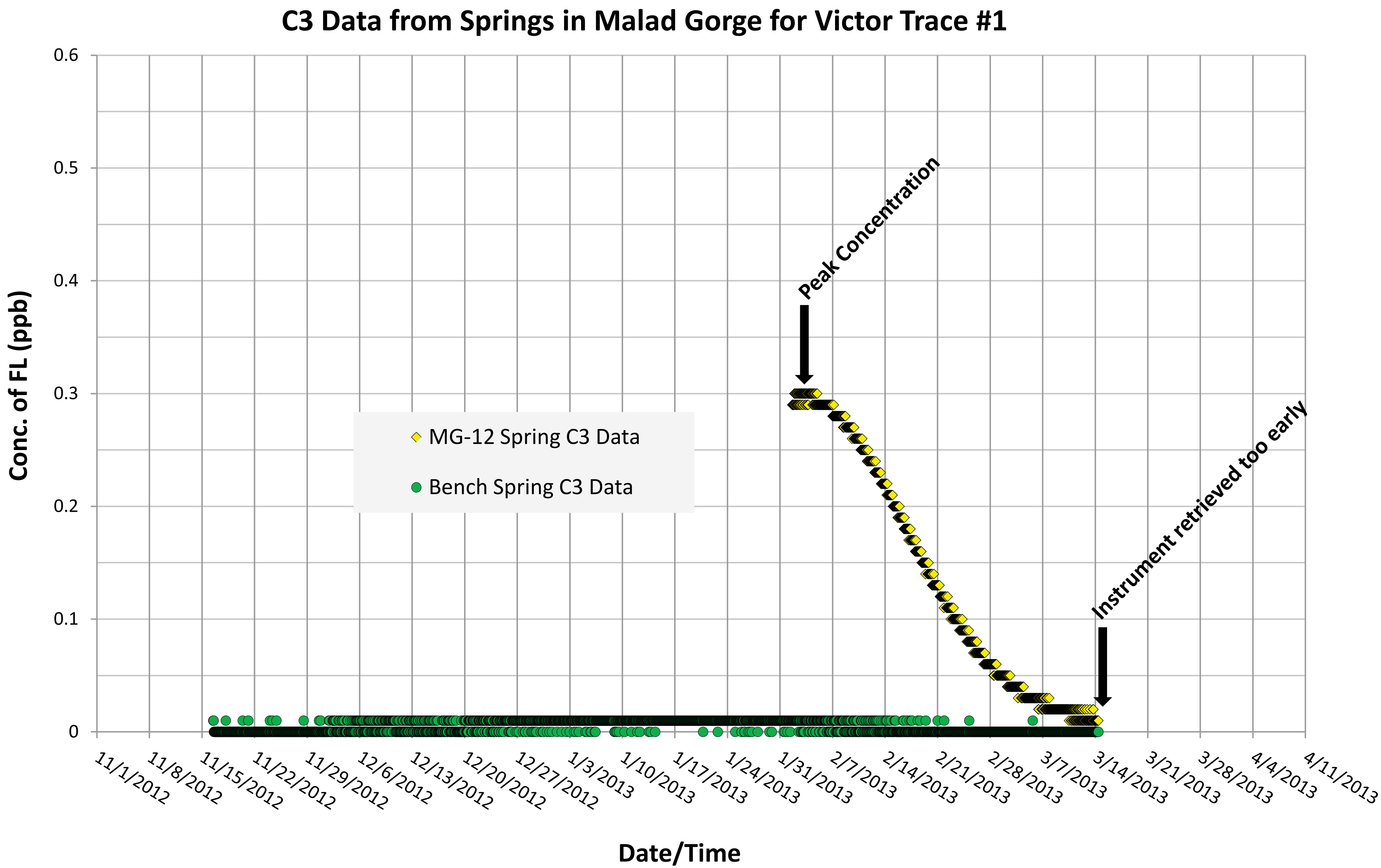


Figure 8. C3 instrument data sets from Victor trace #1 at spring MG-12 and the Bench Spring. The C3 at MG-12 was not deployed until February 1, 2013 when it was determined dye was exiting this location from a mobile C3.

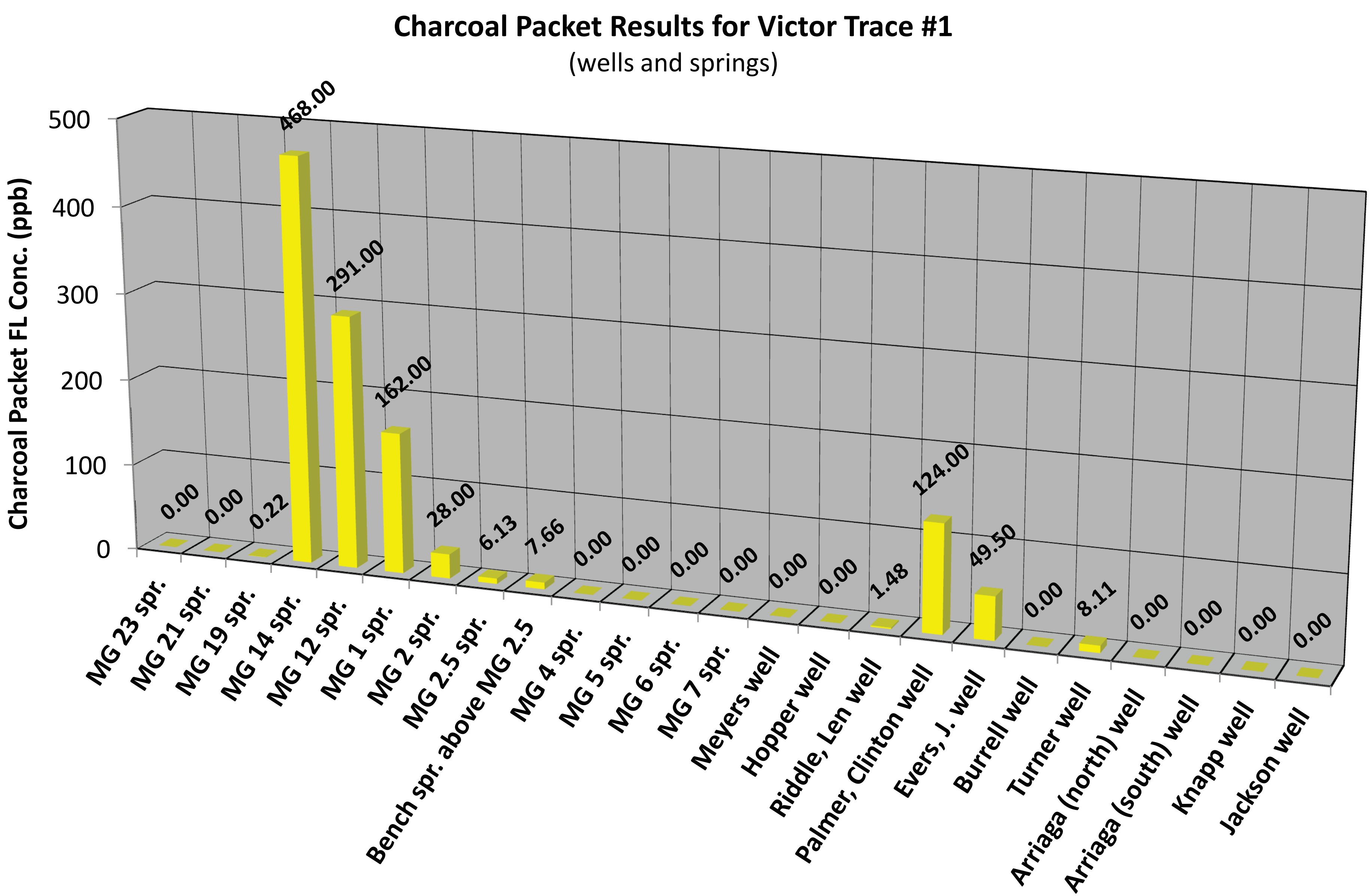


Figure 9. Charcoal packet sampler results for wells and springs for Victor Trace #1. Note MG-14 site had the highest concentration from charcoal packets but MG-12 and 13 had the highest water sample concentrations.

Charcoal Sampler Results Map for Trace #2

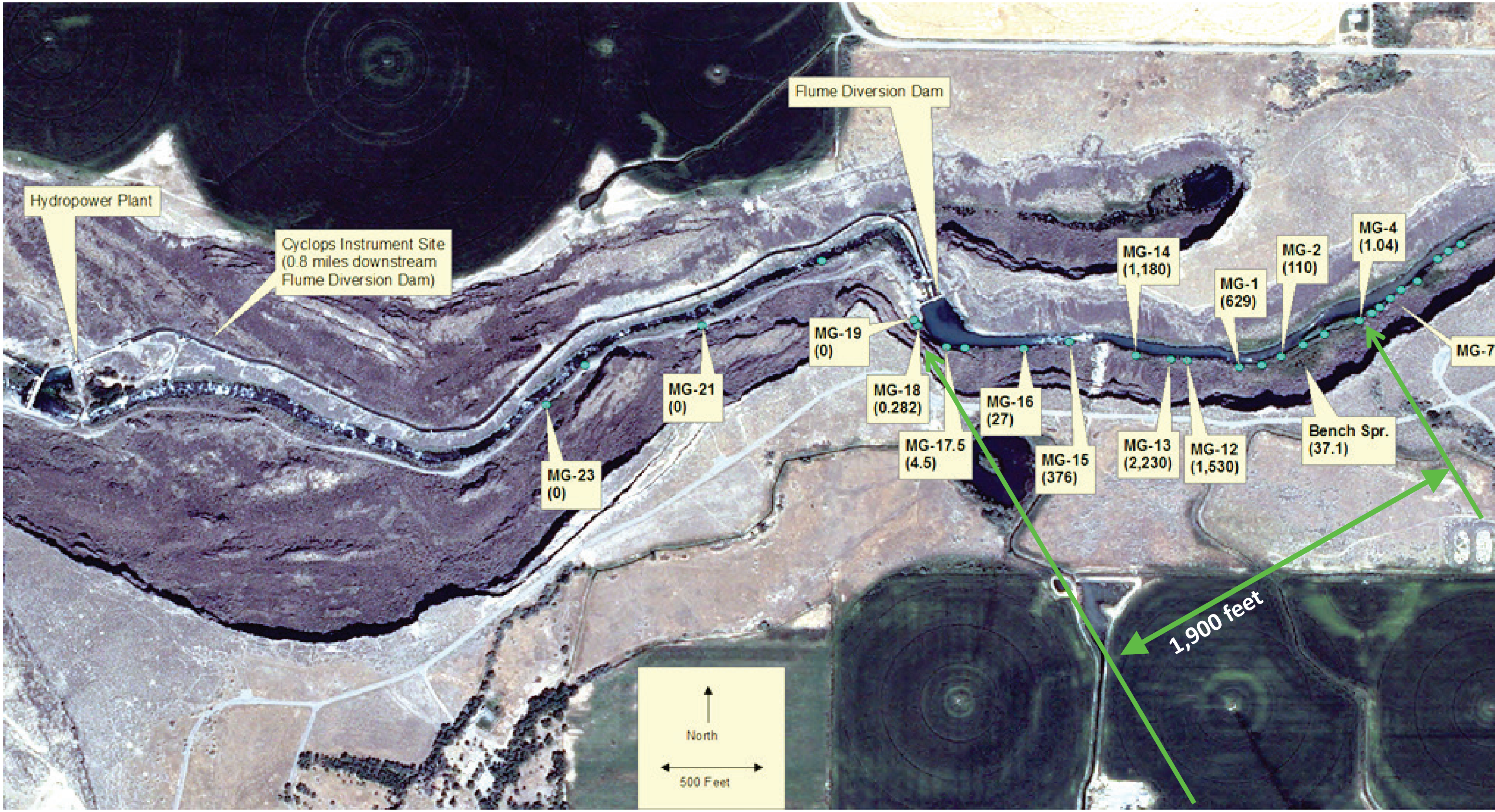


Figure 10. Spatial distribution of dye and concentration in parenthesis is ppb units for charcoal packet samplers from Trace #2. The later dispersion or spread was measured at approximately 1,900 feet from MG-18 upstream to MG-4. Note the location of the flume diversion dam and the location for the Cyclops instrument used for mass balance calculations.

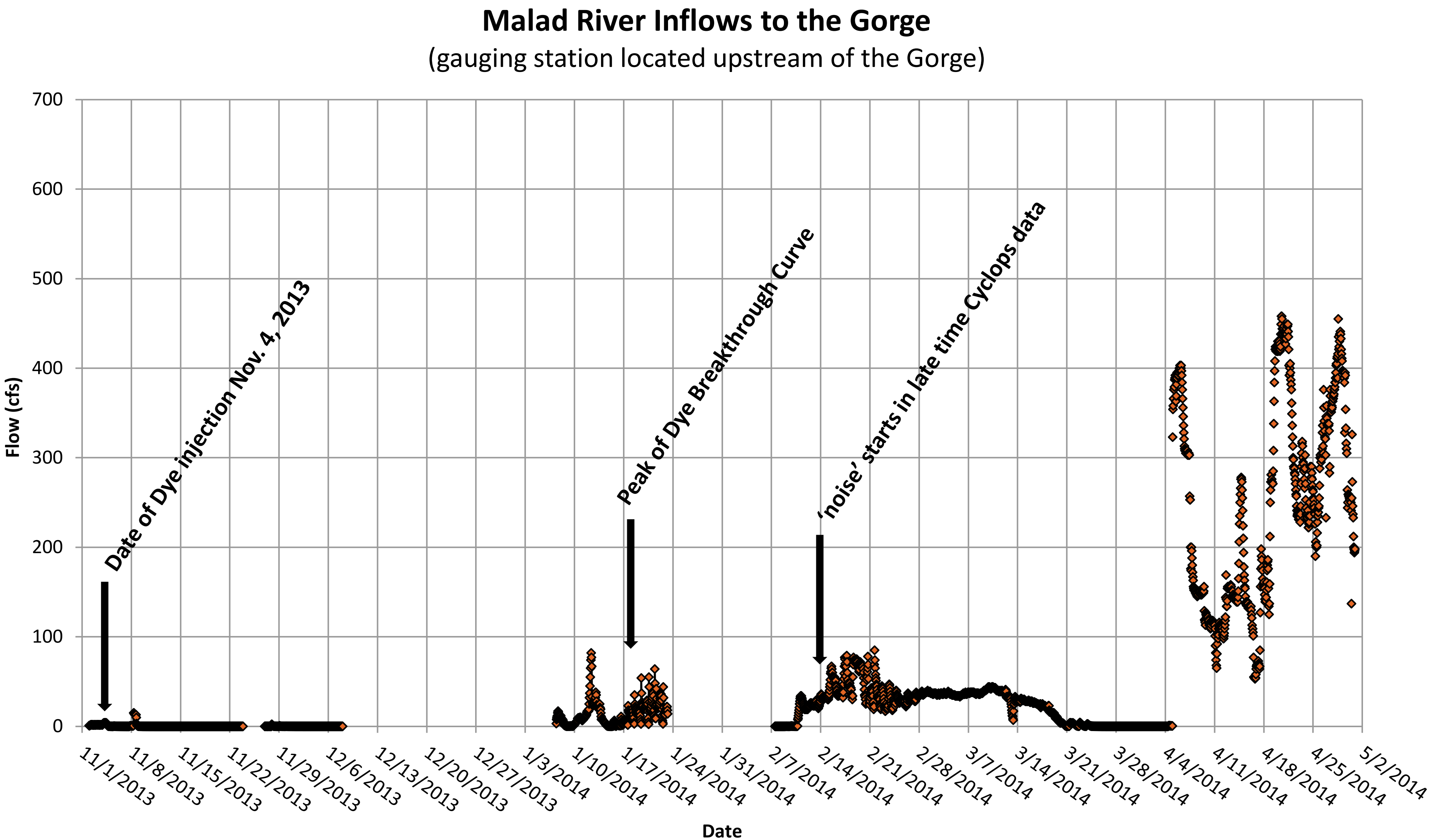


Figure 11. Malad River flows in cfs recorded upstream of the Gorge by several miles. Note that nearly no upstream river water flowed into the Gorge during the bulk of the tracer test or approximately 87% of the dye had passed through by February 14, 2014. (data from USGS).

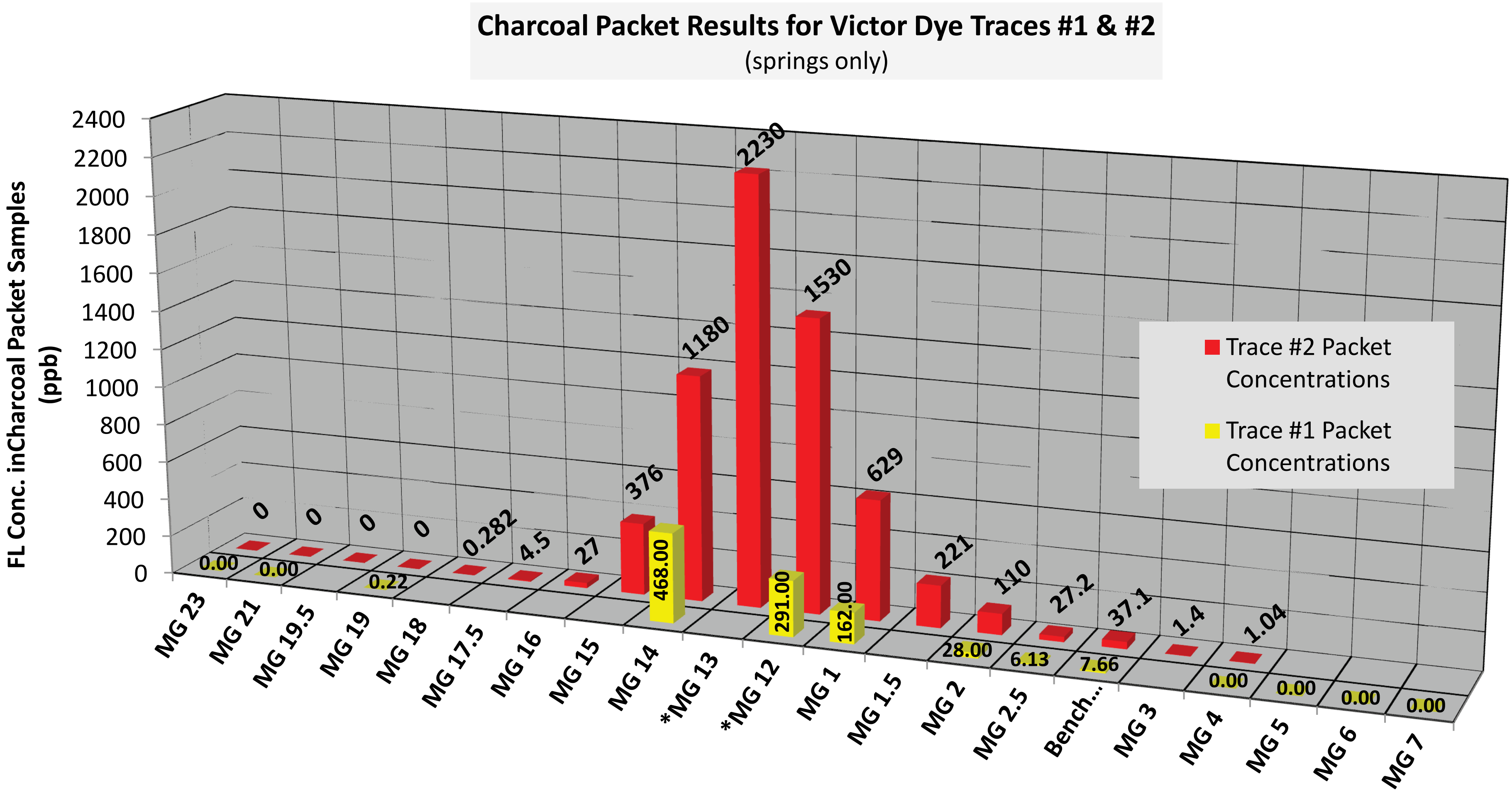


Figure 12. The bar chart shows the charcoal packet results from both Trace #1 and #2 and illustrates how the refinement of monitoring and analysis improves with the 2nd trace method strategy. Results from Trace #2 show a typical bell shaped curve documented numerous times from previous traces. This pattern supports that dye is not "splitting" off into numerous isolated flow paths that come out at many different locations like many believe fracture flow produces, but rather a fairly homogenous well constrained lateral and longitudinal dispersion of the tracer, similar to what occurs in a sand matrix.

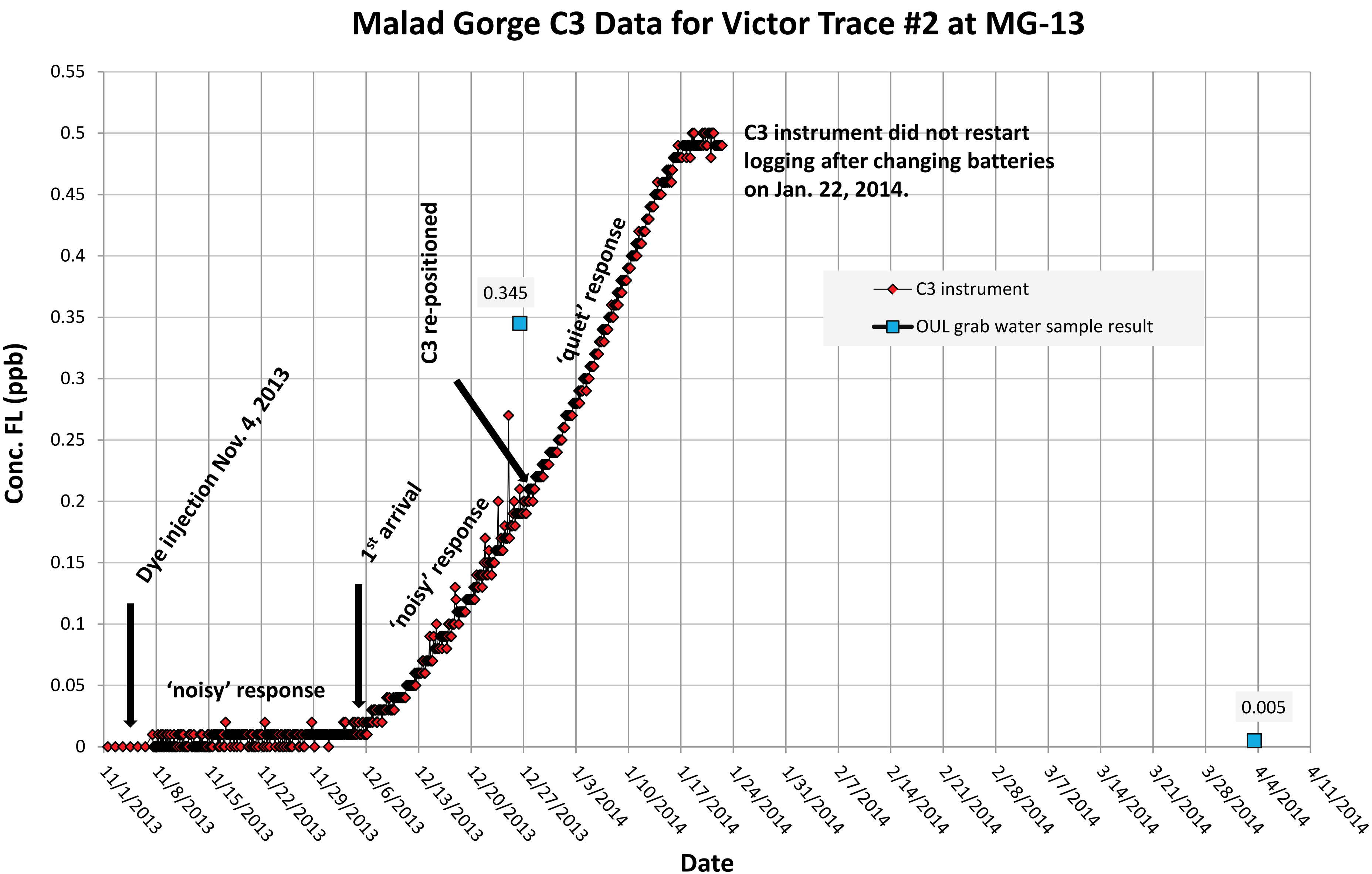


Figure 13. C3 data set from the Gorge spring site MG-13 at 3 hour sampling intervals. Small bubbles were causing some noise in the data so the instrument was repositioned in the same spring on Dec. 26, 2013 where there were fewer bubbles and resulted in less 'noise'. It is unknown why the C3 did not restart logging after changing with fresh batteries on Jan. 22, 2014. The blue square symbols are grab water sample results from OUL which show that residual dye was still discharging out of this spring on April 4th, 2014 but below the detection limit of the 'Flume Cyclops' used for mass balance.

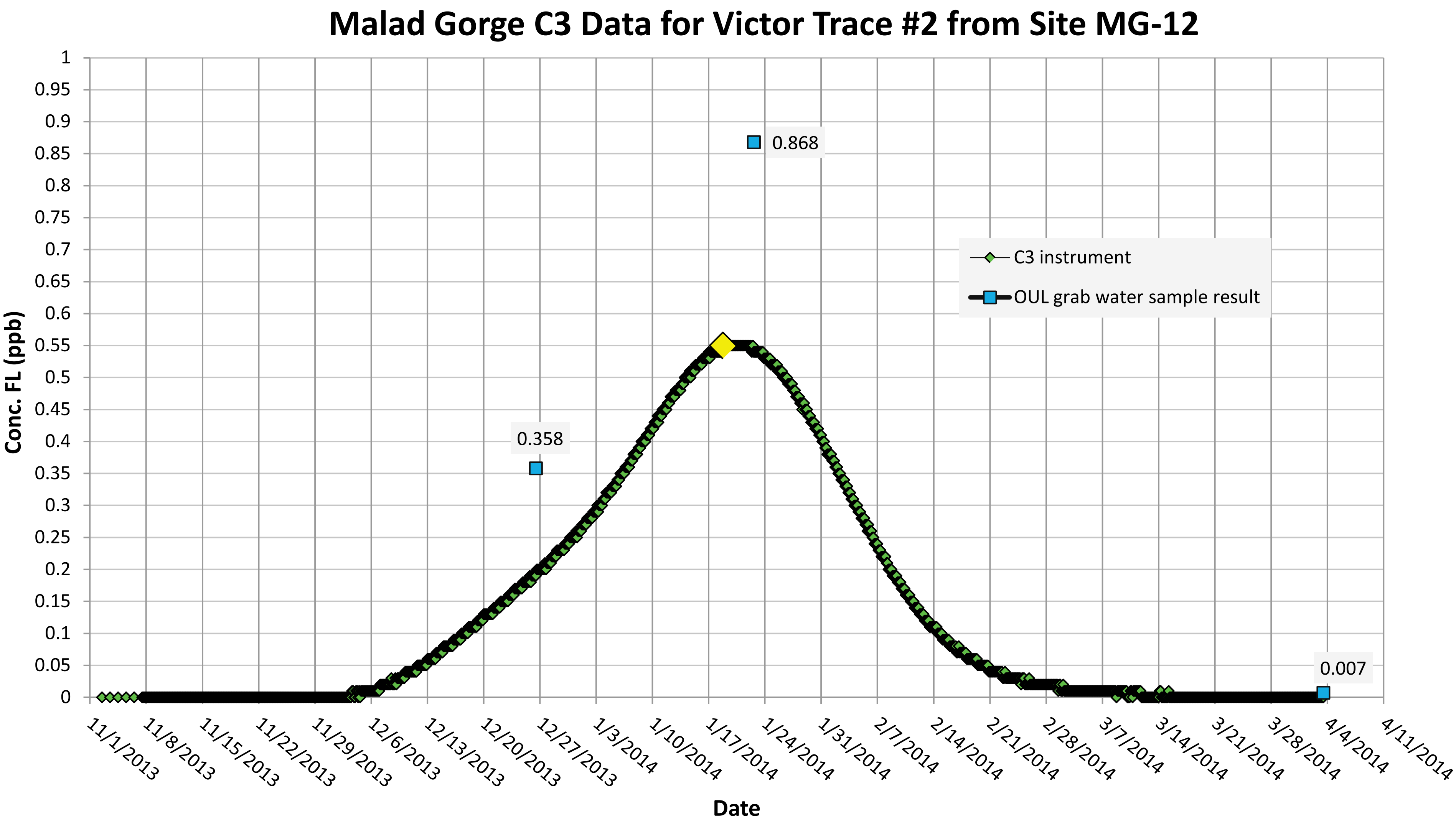


Figure 14. A left skewed dye breakthrough curve from Trace #2 at spring site MG-12 showing a single peak curve that has been the typical response pattern of numerous dye traces in the Malad Gorge and consistent with a homogenous equivalent porous media flow environment. The data frequency is every 3 hours and the Mean is shown with a yellow diamond symbol and occurs just before and left of the center of the peak. The blue square symbols show the OUL lab results from a grab water samples. The April 4th, 2014 value of 0.007 ppb is below the detection limit of the C3 which recorded zero values. This water sample documents dye was still flowing out of spring MG-12 but below detection limits of the 'Flume Cyclops' instrument used for mass balance.

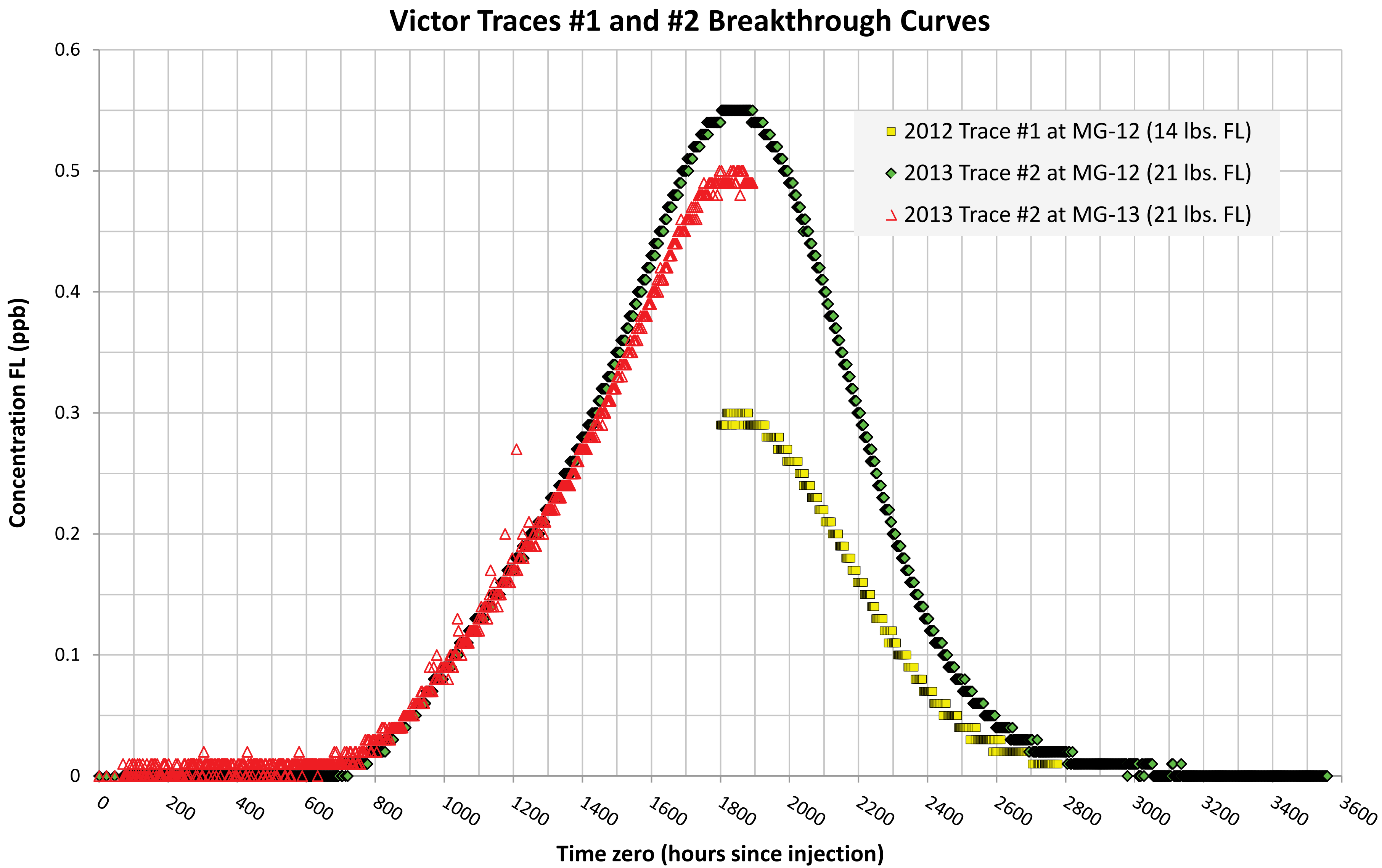


Figure 15. Breakthrough curves from both Trace #1 and Trace #2 showing the similar results between both traces and the increase in spring concentration from about 0.3 ppb from Trace #1 up to 0.55 ppb from Trace #2 as the mass of dye increased by 50%. Note how the horizontal or temporal response of the two traces is also in alignment.

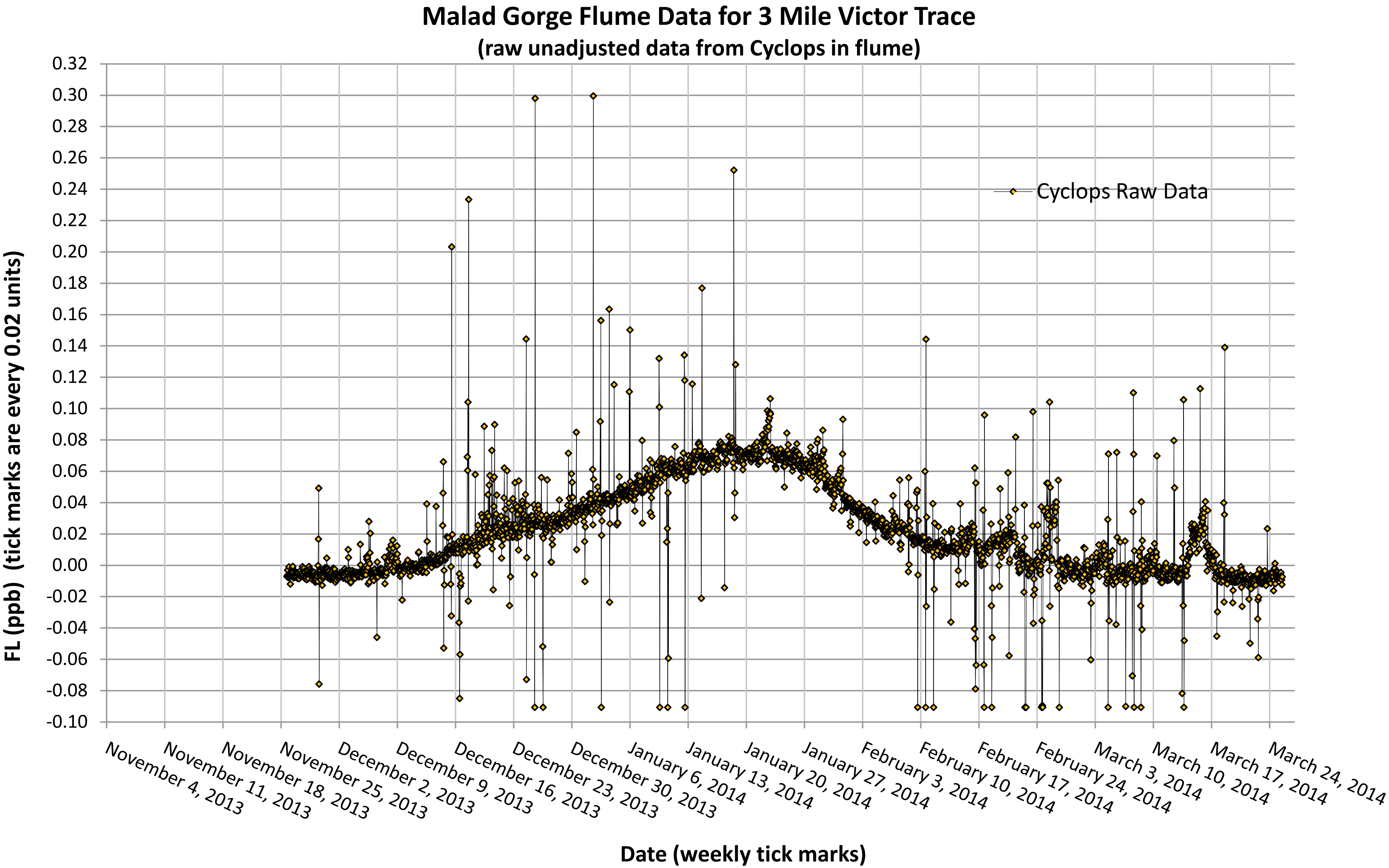


Figure 16. Raw data breakthrough curve from the Cyclops instrument located in the Flume. Note the “noise” spikes which are not real dye concentrations especially the negative values. Data frequency was set at 1 hour intervals. One source of noise started at about February 14th (2,400 hours) when flow rates started cycling in the Flume likely due to private hydropower plants upstream on the Malad River.

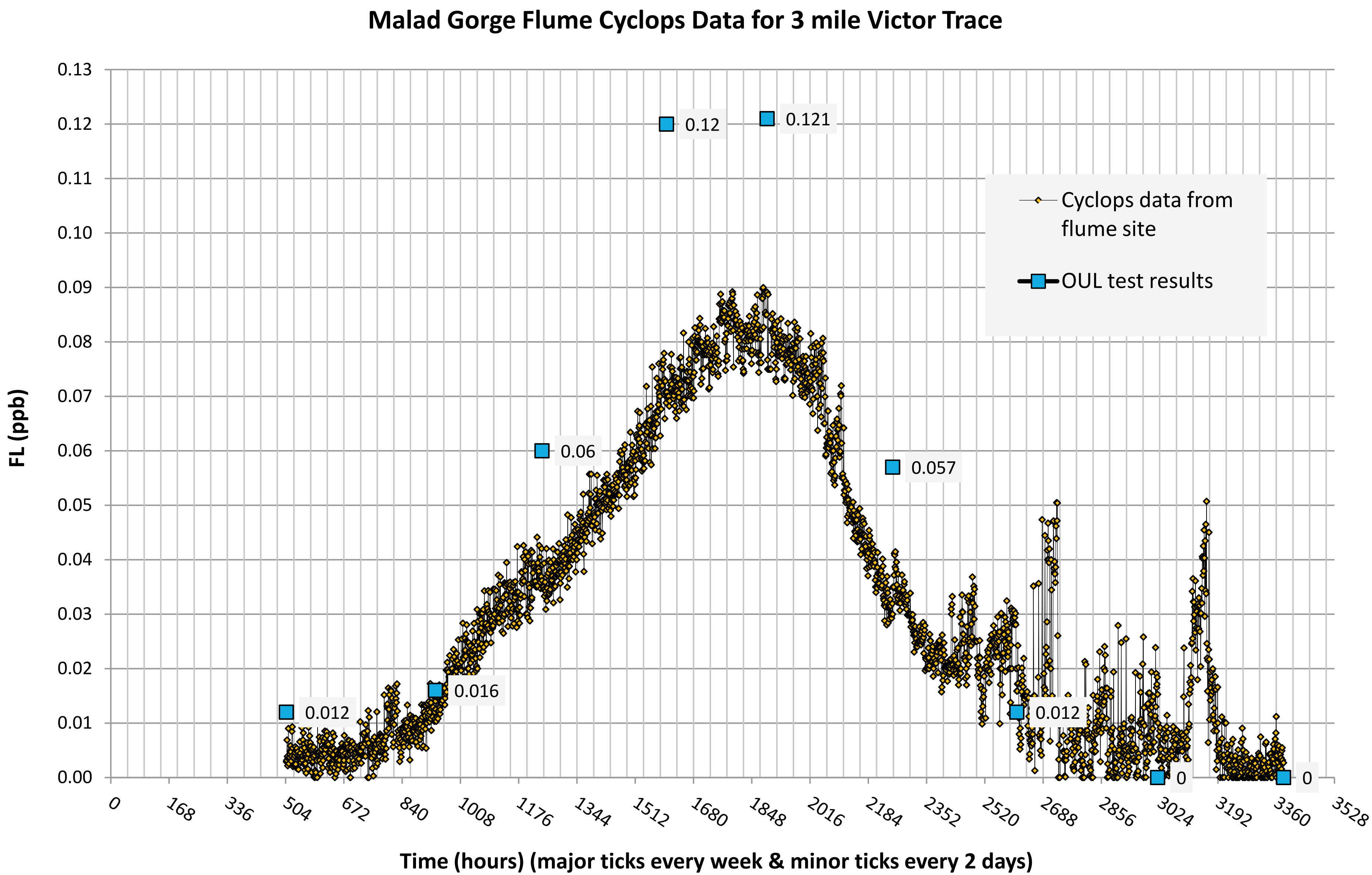


Figure 17. Hourly Cyclops data edited for 1) large spikes averaged to fit trend, 2) upward vertical shift of 0.01 ppb, 3) remaining negative values changed to zero. Grab water sample results shown with blue square symbols were analyzed at OUL labs. OUL labs adjusts the pH of samples to maximize the fluorescent response which may account for the difference between the in-situ Cyclops data and lab results.

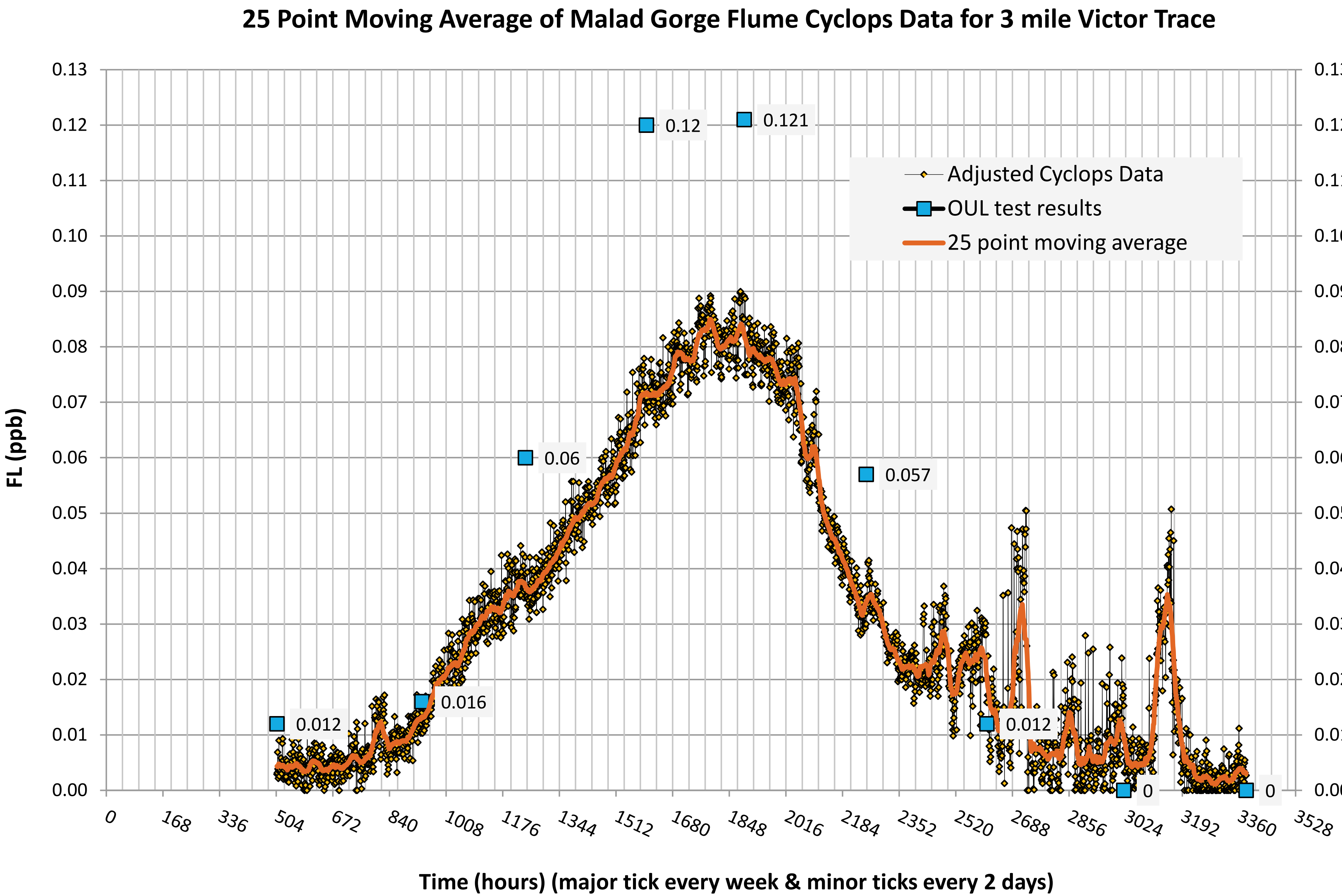


Figure 18. Overlay of a 25 point moving average (orange line) onto the data set which shows a good match in the trends.

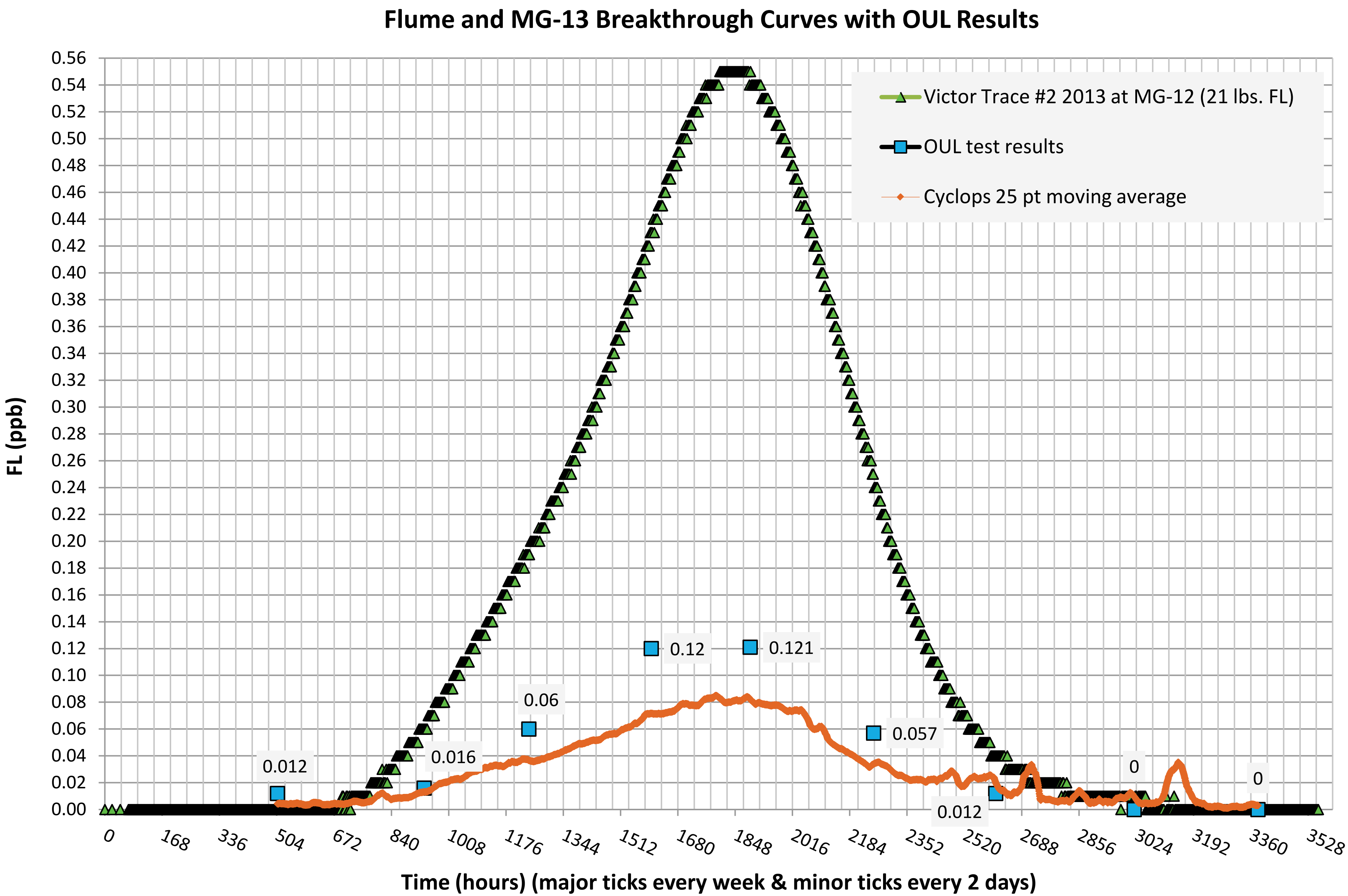


Figure 19. Breakthrough curves from spring MG-13, Cyclops in the flume, and OUL water grab samples showing a consistent correlation between the first arrival, peak and recession of dye in both the flume and the springs from both in-situ instruments and lab tests.

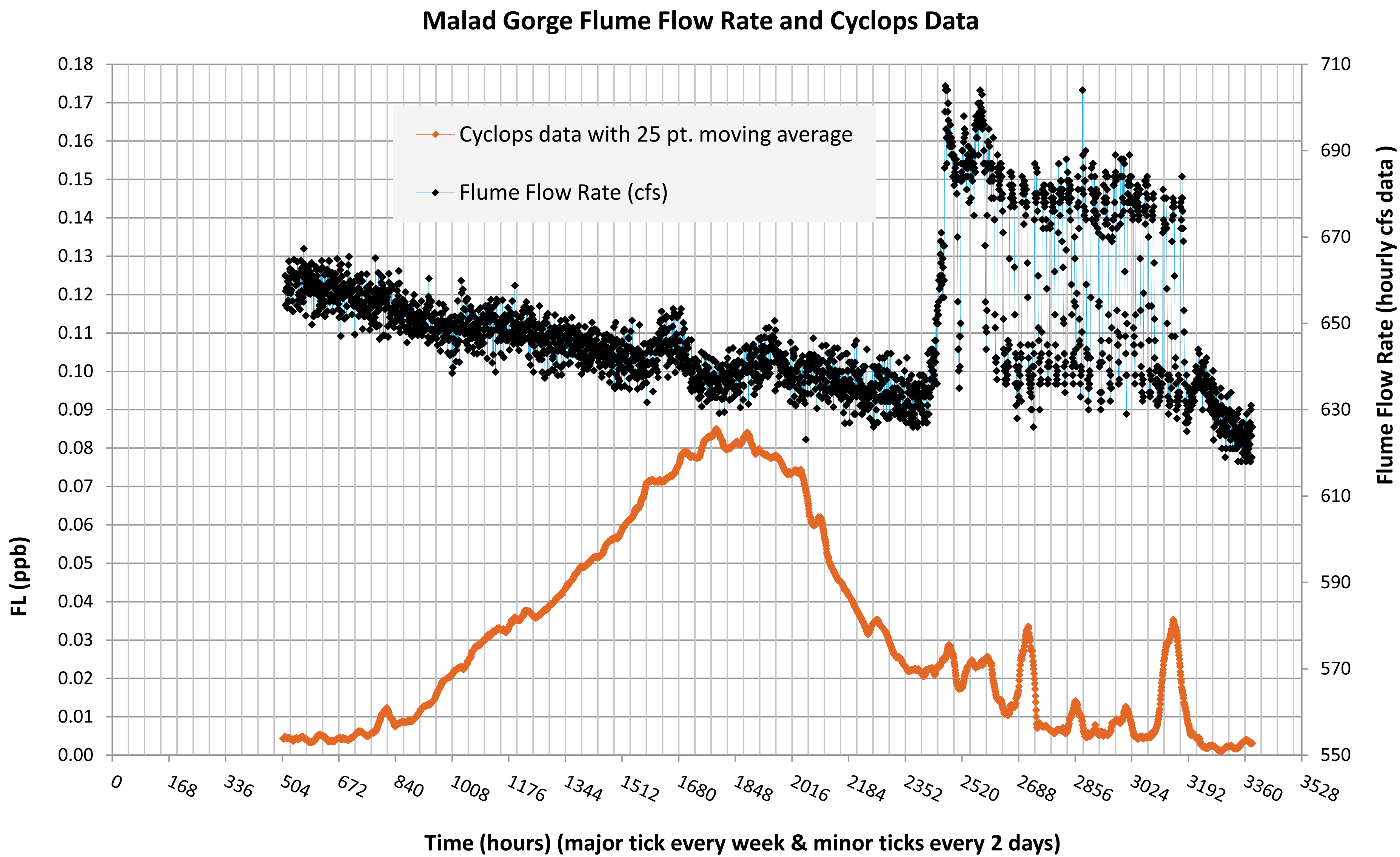


Figure 20. The blue lined data set represents hourly flow rates (source: Idaho Power) in the flume with a downward trend but also obvious anthropogenic cycles starting at about 2,400 hours and ending about 2,688 hours. Note how the flow rate cycles cause noise in the Cyclops data. All of the spring water was captured and routed down the flume for the entire trace duration.

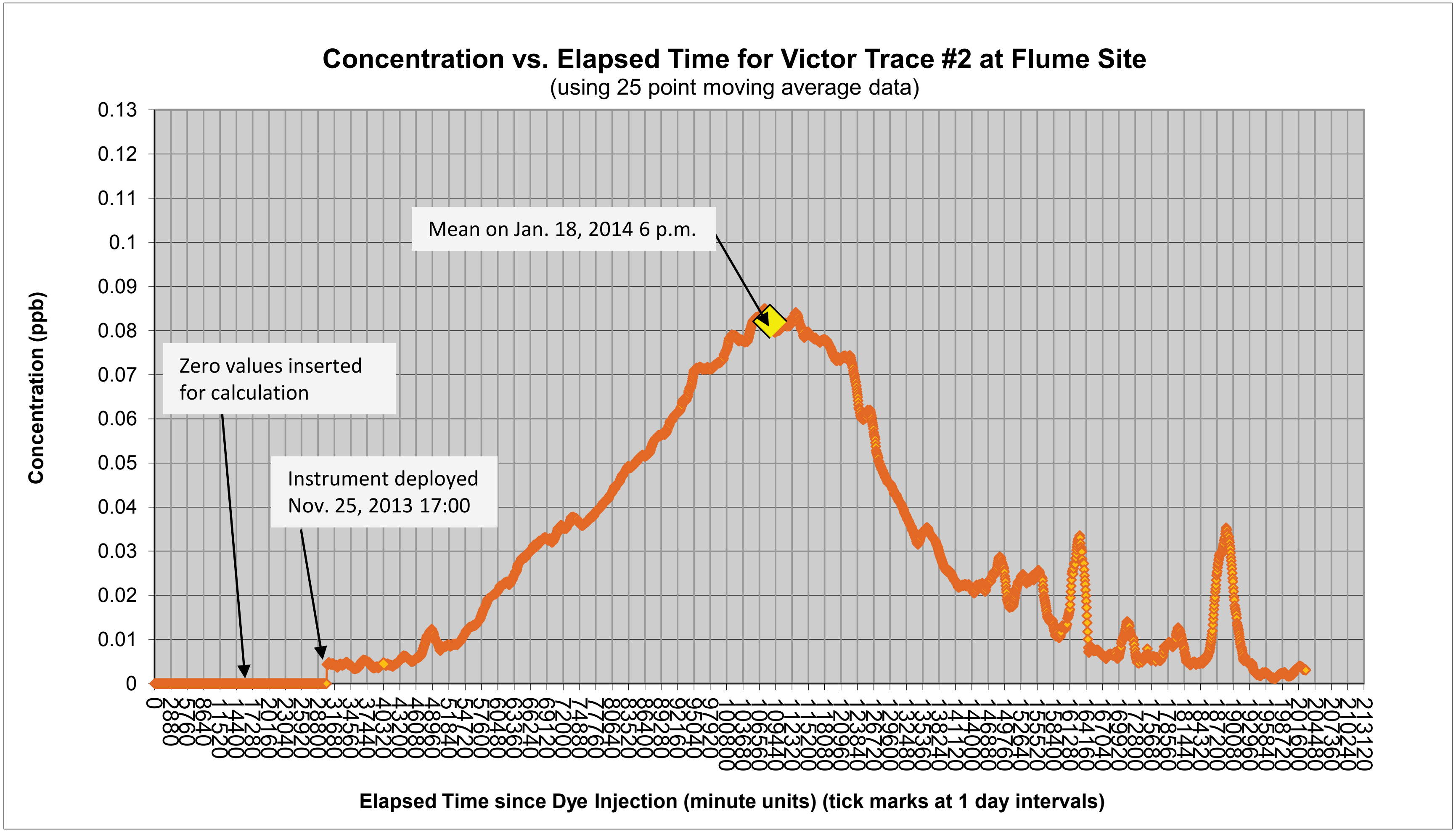


Figure 21. Using the flow rate data and Cyclops 25 point moving average data, a mass balance was performed and a calculations show a minimum of 84.3% of the original mass of dye was recovered. The remaining 15% can be accounted for by the fact that small amounts of dye were still discharging out of spring sites MG-12 & 13 when the trace was ended and equipment retrieved. This small amount of dye was diluted down to non-detectable levels by both the Cyclops and OUL lab analysis in the Flume. Also, some dye had already passed through the aquifer and was in the water when the instrument was deployed. The mean is shown as a yellow diamond symbol which appears to be slightly left skewed consistent with the C3 results at the spring discharge locations. The mass recovery of greater than 84% is directly applicable to previous traces in the Malad Gorge and represents an important addition to tracing.

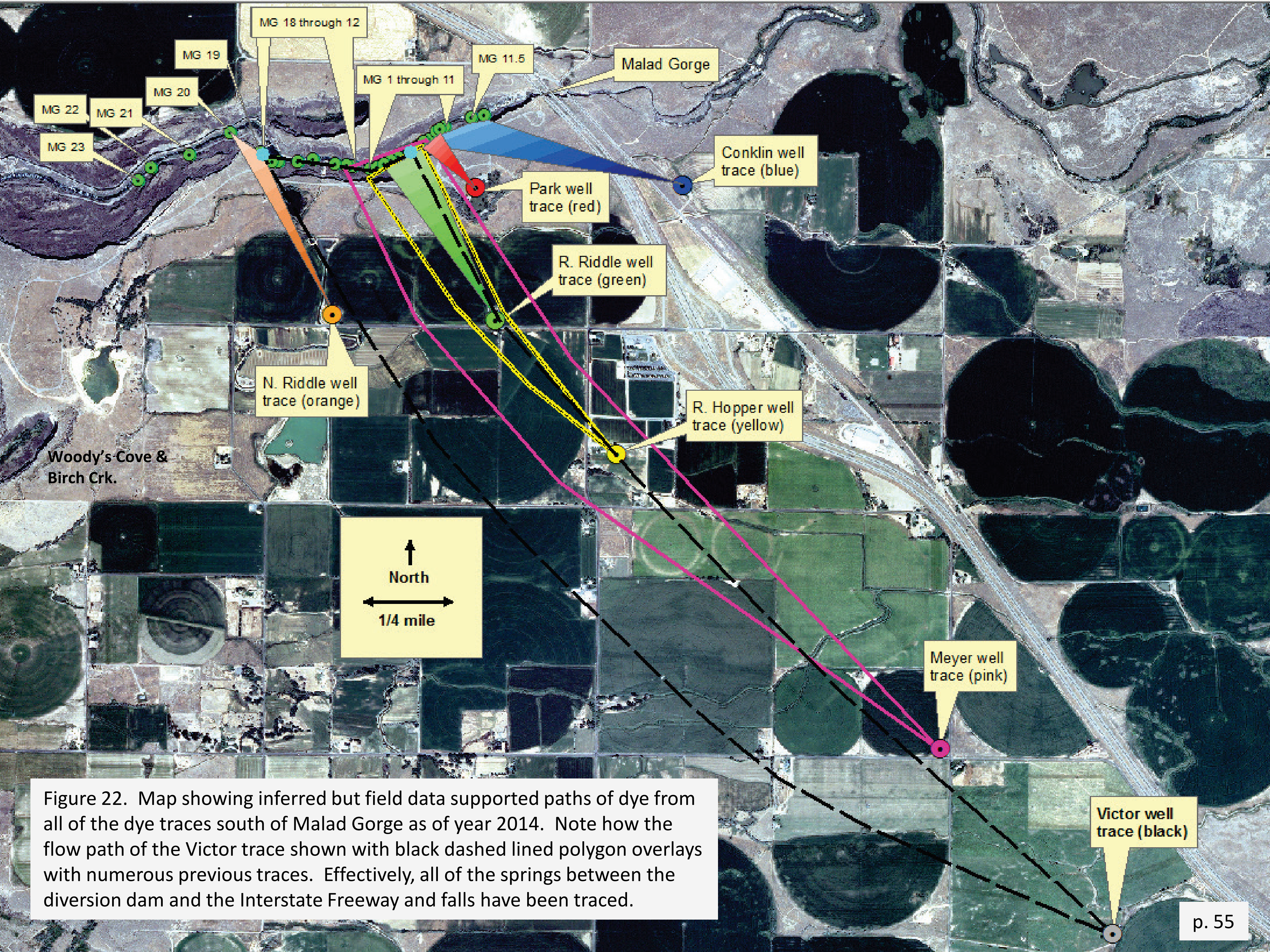


Figure 22. Map showing inferred but field data supported paths of dye from all of the dye traces south of Malad Gorge as of year 2014. Note how the flow path of the Victor trace shown with black dashed lined polygon overlays with numerous previous traces. Effectively, all of the springs between the diversion dam and the Interstate Freeway and falls have been traced.

Date	**Time**	**Trace Name**	**Elev. of well TOC MP** (RTK GPS'd in feet)	**Depth to Water** (feet below TOC MP)	**Elev. Of Water Table** (feet a.m.s.l.)	**Depth of Dye Injection** (below T.O.C.)	**Straight Line Distance** (feet)	**Dye** (type & mass)	**Volume of dye mixture released** (gallons)	**Mass Recovered (%)**	**Time to First Dye Arrival** (hours)	**Max GW Velocity** (ft./day)	**Time to Mean Concentration** (hours)	**Ave. GW Velocity** (ft./day)	**Time to Peak Concentration** (hours)	**Dominant Flow Velocity** (ft./day)	**Measured Transverse Dispersivity** (feet)	**Measured Longitudinal Dispersivity** (feet)	**Interpolated Longitudinal Dispersivity** (feet)	**Approx. Time of Passage** (days)	**Peak Water Conc.** (ppb)	**Peak Charcoal Packet Conc.** (ppb)	**Elev. of Peak Conc. Sample Site**	**Elev. of highest spr. Water**[b]	**Effective Porosity** (estimate) 'Pe'	**Reynolds number 10 met at Passage Way Diameter** (inches or larger & based on dominant velocity)	**Gradient** (at highest spr.)	**Gradient** (Increase Spr. Elv. by 25 ft.)[b]	**Hydraulic Conductivity** K=(Pe*Vave)/I Pe=0.20	**Hydraulic Conductivity** (higher elev. spr.) K=(Pe*Vave)/I Pe=0.20
April 7, 2009	5:10 PM	Park picnic	3275.46	n.a.	n.a.	215	1,100	1 lb. FL (75% conc.)	3	84[c]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	450 (MG 6-10.5)	n.a.	n.a.	n.a.	n.a.	1,310 @ MG-7	3031	3046	0.2	n.a.	n.a.	n.a.	n.a.	n.a.
June 23, 2009	3:31 PM	Park picnic 1	3275.46	191.06	3084.4	210	1,100	0.21 lb. RWT (100% conc.)	1 (2.5% conc.)		5	5,280	n.a.	n.a.	12.5 & 35	1st peak = 2,112 2nd peak = 754	n.a.	n.a.	n.a.	4.2 (estimated)	0.37 @ MG-7	n.a.	3031	3046	0.2	0.07	0.035	0.0258	n.a.	n.a.
June 29, 2009	1:52 PM	Park picnic 2	3275.46	n.a.	n.a.	210	1,100	0.21 lb. RWT (100% conc.)	1 (2.5% conc.)		4.5	5,867	30.3	871	13.5 & 34	1st peak = 1,955 2nd peak = 776	n.a.	n.a.	n.a.	4.2 (estimated)	0.43 @ MG-7	n.a.	3031	3046	0.2	0.07	0.035	0.0258	4977	6752
Sept. 22, 2009	2:30 PM	Park picnic 3	3275.46	190.28	3085.18	210	1,100	0.63 lb. RWT (100% conc.)	3 (2.5% conc.)		4.5	5,867	30.3[b]	871[b]	13 & 33.5	1st peak = 1,955 2nd peak = 788	n.a.	n.a.	n.a.	4.2	0.91 @ MG-7	n.a.	3031	3046	0.2	0.07	0.036	0.0265	n.a.	n.a.
Oct. 20, 2009	12:30 PM	R. Riddle 1	3279.69	178.13	3101.56	205	2,865	3 lb. FL (75% conc.)	6	84[c]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	700 (MG 2-7)	n.a.	n.a.	n.a.	n.a.	8,160 @ MG-3	3029	3046	0.2	n.a.	0.019	0.0166	n.a.	n.a.
March 1, 2010	2:30 PM	R. Riddle 2	3279.69	177.95	3101.74	203	2,865	2 lb. RWT (100% conc.)	4		28	2,456	86	800	82	839	700 (MG 1-6)	n.a.	n.a.	16	1.8 @ MG-3	388 @ MG-3	3029	3046	0.2	0.15	0.019	0.0167	8219	9596
April 19, 2010	10:45 AM	R. Hopper 1	3306.57	182.15	3124.42	192	5,490	4.84 lb. FL (75% conc.)	7.75	84[c]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	850 (MG 1-5)	>2865	4177	n.a.	n.a.	1,498 @ MG-2.5	3028	3046	0.2	n.a.	0.014	0.0130	n.a.	n.a.
May 21, 2010	1:00 PM	R. Hopper 2	3306.57	182.4	3124.17	192	5,490	5.01 lb. FL (75% conc.)	8	84[c]	66	1,996	198	665	139	948	850 (MG 1-5)	>2865	4177	17	1.10 @ MG-2.5	1,640 @ MG-2.5	3028	3046	0.2	0.13	0.014	0.0130	9347	10267
Dec. 17, 2010	2:35 PM	Meyer 1	3334.55	180.78	3153.77	205	11,900	8 lb. FL (75% conc.)	15	84[c]	260	1,098	626	456	528	541	1140 (MG 7-13)	>6320	9185	40	0.37 @ Bench spr.	489 @ MG-4	3033	3046	0.2	n.a.	0.009	0.0080	10075	n.a.
March 25, 2011	3:00 PM	Meyer 2	3334.55	183.21	3151.34	205	11,900	14 lb. FL (75% conc.)	14	84[c]	261	1,094	671	426	552	517	n.a.	>6320	9185	41	0.59 @ Bench spr.	744 @ MG-4	3033	3046	0.2	0.25	0.009	0.0078	9617	10853
June 7, 2011	11:30 AM	N. Riddle 1	3266.5	172.1	3094.4	171	2,660	0.46 lb. RWT (100% conc.)	0.25		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	300 (MG 18-20)	n.a.	n.a.	n.a.	n.a.	76.75 @ MG-19	3026	3026	0.2	n.a.	0.026	0.0163	n.a.	n.a.
July 11, 2011	2:00 PM	R. Conklin 1	3297.86	137.5	3160.36	166	3,653	3 lb. FL (75% conc.)	3	84[c]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	600 (MG 7-11.7)	n.a.	n.a.	30	n.a.	870 @ MG-11	3034	3046	0.2	n.a.	0.031	0.0277	n.a.	n.a.
Aug. 19, 2011	10:50 PM	R. Conklin 2	3297.86	137.5	3160.36	166	3,653	6 lb. FL (75% conc.)	6	84[c]	30.5	2,874	122.5	716	82.5	1063	n.a.	n.a.	n.a.	30	3.53 @ MG-11	1,180 @ MG-11	3034	3046	0.2	0.12	0.031	0.0277	4572	5159
Nov. 18, 2012	2:09 PM	N. Victor 1	3363.55	205	3158.55	243	16,350	14 lb. FL (75% conc.)	14	84[c]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1200 (estimated MG 16-3)	n.a.	n.a.	110 (estimated)	0.3 @ MG-12	468 @ MG-14	3031	3046	0.2	n.a.	0.007	0.0063	n.a.	n.a.
Nov. 4, 2013	2:45 PM	N. Victor 2	3363.55	203.71	3159.84	243	16,350	21 lb. FL (75% conc.)	21	> 84	696	564	1803	218	1848	212	1,900 (MG 17.5 - 4)	11,000	13,000	100	0.55 @ MG-12	2,230 @ MG-13	3031	3046	0.2	0.61	0.007	0.0064	6262	6687
Dec. 13, 2012	11:29 AM	Ashmead 1	3240.20	97.00	3143.20	147	2,170	2 lb. FL (75% conc.)	4		17.5	2,976	n.a.	n.a.	31.5	1653	600 (CL 300-401)	n.a.	n.a.	5	6 @ CL-404	1,120 @ CL-400	3056	3078	0.2	n.a.	0.030	0.0185	n.a.	n.a.
Jan. 31, 2013	12:35 PM	Ashmead 2	3240.20	95.50	3144.70	147	2,170	1 lb. FL (75% conc.)	4		17	3,064	40	1302	32.5	1602	n.a.	n.a.	n.a.	5	2.61 @ CL-404	n.a.	3056	3078	0.2	0.08	0.031	0.0192	8472	13551
Oct. 25, 2013	10:57 AM	Ashmead 3	3240.20	95.70	3144.50	147	2,170	0.5 lb. (75% conc.)	4		17	3,064	38.5	1353	32	1628	n.a.	n.a.	n.a.	4	1.35 @ CL-404	n.a.	3056	3078	0.2	0.08	0.031	0.0191	8828	14147
Nov. 14, 2013	3:16 PM	Strickland 1	3267	60.89	3206	108	18,500	6 lb. FL (75% conc.)	6		576	771	n.a.	n.a.	792	561	5,000	13,000	n.a.	63	0.105@Briggs spr.	119 Banbury spr. south side	3093	3093	0.2	0.23	0.006	0.0048	18356	23571
Stearns, Harold (USGS 1936)														750																

a = used dominant flow velocity in calculation
b = estimated
c = inferred from Victor Trace #2 data
*This table of data was updated Oct. 2, 2014 and data presented earlier is superseded by this information.
*It is up to the user to evaluate for significant digits but some data such as elevation was achieved to 2 decimal places from base/rover gps.