Idaho Department of Water Resources

Open File Report

FLUORESCENT DYE TRACER TESTS
and
HYDROGEOLOGY
near the
MALAD GORGE STATE PARK
(Meyer, Conklin and Riddle wells)

By

Neal Farmer
Idaho Department of Water Resources

and

David Blew
Idaho Power

ABSTRACT

Through a cooperative effort between Idaho Power and the Idaho Department of Water Resources, five natural gradient dye tracer tests were successfully completed near the Malad Gorge State Park during the winter of 2010/2011 through September 2011. At the Meyer well, two traces occurred where dye was released in a domestic well located 2 ¼ miles southeast of the Gorge. Springs along the river edge in the Gorge and selected domestic wells were monitored for dye. Results document that groundwater is flowing in a northwest direction from the dye release well to the Gorge at average linear flow velocity of 400 feet per day (mean value) and 517 feet per day based on the peak dye concentration and a maximum flow velocity of 1,100 feet per day (1st detection). Previous tracer tests in this area were completed by Farmer and Blew in 2009 using the Malad Gorge State Park picnic area well located ¼ mile from the Gorge; then in 2010 using a domestic well (Riddle, ½ mile) and the Hopper well (1 mile) for dye release. This test extends the same flow path to 2.25 miles from the Gorge which may be controlled by the presence of an ancient buried canyon hypothesized by geologists with the U.S. Geological Survey. A mass water level measurement was completed in November of 2011 with a shared effort between IDWR and Idaho Power from Crystal Springs to Malad Gorge. Water table maps support both the results from tracer tests but also information from U.S. Geological Survey reports.

TABLE OF CONTENTS

Title Page 1
Abstract 2
Table of Contents 3
List of Illustrations 3
Tables 4
Background 5
Tracing Related Information 10
Tracing Procedure and Methods 12
Meyer Well Dye Trace 12
    Trace #1 12
    Trace #2 14
N. Riddle Well Dye Trace 18
Conklin Well Dye Trace 21
Discussion 23
Acknowledgements 25
References and Sources of Information 26
Appendix A – Miscelaneous Information 32
Appendix B – GPS Coordinates of Sample Sites 42
Appendix C – Grid Information for Contoured Data 44

LIST OF ILLUSTRATIONS

Figure 1 Location of Study 45
Figure 2 USGS Harold Stearns formation of ancient canyons 46
Figure 3 USGS Harold Malde map of ancient canyons 47
Figure 4 Geologic logs for Vader Grade area 48
Figure 5 Hydrographs for shallow domestic well and deep USGS well 49
Figure 6 Temperature for shallow domestic well and deep USGS well 50
Figure 7 Geologic logs of wells used in tracing 51
Figure 8 Water table contour lines 52
Figure 9 3-D plot of water table contour lines 53
Figure 10 Recent water table contour lines compared to 1938 USGS map 54
Figure 11 Wells and springs temperature map 55
Figure 12 3-D of wells and springs temperature map 56
Figure 13 Electrical conductivity map of well water and spring water 57
Figure 14 November 2011 mass groundwater measurement contour map 58
Figure 15 Map of dye traces to date, wells and springs 59
Figure 16 Charcoal in eluting in solution from Meyer Trace #1 60
Figure 17 Bar chart of charcoal packet concentrations from Meyer Trace #1 & #2 61
Figure 18 Bar chart of charcoal packet concentrations from Meyer Trace #1 & #2 62
Figure 19 Visual results of dye from charcoal soaking in elutant for Meyer Trace #2 ... 63
Figure 20 3-D plot of dye concentrations during midpoint for Meyer Trace #2 64
Figure 21 Dye breakthrough curves for two springs from Meyer Trace #1 & #2 65
Figure 22 Map of results for RWT trace at N. Riddle well 66
Figure 23 Bar chart of results for RWT trace at N. Riddle well 67
Figure 24 Map of traces, contour lines and geologic cross sections 68

Figure 25 Geologic cross section A-A' 69
Figure 26 Gelogic cross section B-B' 70
Figure 27 Model of relay ramp fault system compared to Thousand Springs................. 71
Figure 28 Fluorescein dye released in Conklin well from poly-tubing 72
Figure 29 Charcoal packet visual results from Conklin well Trace #1............................ 73
Figure 30 Bar chart of results for Conklin well Traces #1 and #2.................................. 74
Figure 31 Charcoal packet visual results from Conklin well Trace #2............................ 75
Figure 32 Dye breakthrough curve from Conklin well Trace #2..................................... 76

Table 1 List of wells sampled 20 days after dye release during Meyer Trace #1............ 13
Table 2 Comparison of water sample dye concentrations 13
Table 3 Dye release well water concentrations after turning pump back on 14
Table 4 Spring and well locations with presence of dye detected in water samples 15
Table 5 Comparison of FL dye concentrations from selected springs............................. 15
Table 6 Dye release well #25 RWT water concentrations after turning pump on........... 19
Table 7 Comparison chart of attributes for all traces.. 77

BACKGROUND

Thirteen groundwater tracer tests have been successfully implemented 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. Typically, each test is an iterative process where two traces are performed at each well so that the results of the first trace can be confirmed by the second trace and adjustments made to the second one to optimize the results. Not only are the traces reproduced at each well but each well location is also part of the iterative and reproducible progression up a flow path. In other words, two reproducible traces at a well located ½ mile from the spring supports the two reproducible traces at the next well located 1 mile away and then 2.25 miles. Tracing groundwater is fallible thus the iterative process helps correct misjudgments like sampling locations and frequency; it also helps refine the accuracy and precision of the data sets which affect process improvement. Figure 1 shows the locations of wells where data was collected for this report and the locations of three wells used for dye releases. The GPS methods, geologic model, geography, well construction, 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). Tracer studies could provide data and information for the application of practices to manage and enhance the Eastern Snake Plain Aquifer. The tracing program also improves the understanding of the nature of spring discharge, aquifer flow, geologic framework and a geologic history of the Snake River Plain.

Previous authors provided evidence on the factors that may control spring discharge from the ESPA. USGS geologists Harold Stearns, Harold Malde and H. Covington described how ancient canyons were filled and buried by volcanic eruptions (Stearns, 1936; Malde, 1971; Covington, 1985) that occurred on the Snake River plain. Even earlier USGS investigations shed light on this phenomenon by I.C. Russell (1902), L. Crandall (1918), and O.E. Meinzer (1927). Meinzer (1927) stated, "It may be that the underlying surface which holds up the water is a former land surface and that the principal subterranean streams which supply the springs flow down the valleys of this ancient surface". The results of the current tracer studies are starting to define convergent flow paths around high spring discharge areas, numerous groundwater divides, high horizontal velocities and high vertical flow velocities through numerous beds of basalt. The current tracer tests appear to be verifying or validating early theories and works by previous investigators.

Harold T. Stearns in 1928 was asked by the U.S. Geological Survey to conduct a geologic and groundwater survey of the East Snake Plain Aquifer. The project was a collaborative effort between the State of Idaho Bureau of Reclamation, Bureau of Mines and Geology, private irrigation projects and Idaho Power (Stearns, 1983). The State of Idaho stopped supporting funds to the project in 1930 due to the Depression and the long-term cooperative plan collapsed. In 1938, Stearns and his support team, created a groundwater table map which shows similar patterns to recent groundwater contours generated from a cooperative effort between the Department of Water Resources and Idaho Power.

Stearns (1936) describes that nearly all of the large springs on the Snake River plain are discharging from pillow lava features and a 'peculiar glassy breccia'. He also notes how at least six paleo-canyons of the ancestral Snake River filled with basalt from volcanic eruptions in a sequential manner that displaced the river to new locations, typically in a southward migration (Figure 2). This process explains why the Snake River does not lie in the central part of the east Snake Plain. When the basalt lava flowed into a canyon or other drainage containing water, pillow features and associated breccia were formed creating highly permeable zones for groundwater flow. Stearns (1936) also describes one paleo-canyon having a base lower than the present day Snake River which may provide a pathway for aquifer water to discharge into the base of the Snake River. Stearns (1936) further describes the ancient filled canyons as "…extensive collecting systems for underground water…that act as great underground drains…and one such canyon could be 50 miles in length".

Malde (1971) mapped the location and orientation of these ancient canyons (Figure 3) and at one location west of Bliss he notes the pillow lava is 500 feet thick in the Pleistocene age (Othberg and Kauffman, 2005) McKinney Basalt that filled both the ancestral Snake River and the Wood River canyons. The resulting lava dam created a deep lake (Lake McKinney) that extended far upstream from the Hagerman Valley and created thick pillow lava features as the lava poured into the lake. Silty sediments of the Yahoo Formation were deposited in the lake and they are mapped from the Buhl area to Bliss (Malde, 1982). These ancestral canyons are located north of the Snake River and none have been identified on the south side of the river. Stearns (1936) stated this may explain why there are high water table conditions on the south side while the north side is well drained.

Later authors such as Covington and Weaver (1985), Ralston (2008) and Farmer (2009) also describe the same geologic phenomena as previous investigators. Farmer (2008) identified structural features such as 'relay ramp' faults at the Thousand Springs complex and potential folds that play a role in the spring flows and distribution. In addition to the ancient canyon 'cut and fill' process and structural deformation, there is evidence supporting a 3-layer hydrostratigraphic model down to approximately 600 feet depth for the general area between Hagerman and Wendell. The gross hydrostratigraphic units are Quaternary basalt overlying Glenns Ferry Formation (GFF) overlying deeper basalts (Farmer, 2009). The traces in this report occur in the upper shallow basalt but there is groundwater also flowing through the GFF and underlying basalt.

Additional information about the subsurface geologic architecture is from a 602-foot USGS well (T7S, R14E, sec.35) located 3 miles east of the Curren Tunnel and several domestic wells near Vader Grade document a similar '3-layer' hydrogeology (Figure 4). A deep basalt aquifer is identified at the USGS well based on the geologic log, water levels and temperature data (Figures 5 and 6). The 6-inch casing open interval is from 447 to 520 feet below land surface in the upper portion of the deep basalt. The bottom hole temperature is 72.3 degrees Fahrenheit (F) at 600 feet compared to 59 degree (F) (Figure 6) at the water table aquifer in a 123 foot domestic well located 60 feet south of the USGS well. This equates to a geothermal gradient of approximately 3 degrees (F) per 100 feet. Iceland's geothermal energy is typically from areas where the gradient is greater than 2.2^{o}F/100 ft. (Enotes, 2011).

Ring fault systems associated with the collapsing caldera in the Twin Falls volcanic field may provide pathways for upward migration of thermal water. Based on the location of the caldera's margin in the Hagerman Valley (Bonnichsen et. al., 2002), the faults may dip eastward and could be intersected with deep wells. The heat signature is probably erased by the high flow rates in the upper cold water of the ESPA making this area "hidden" to exploration of geothermal resources. Fine-grained sediments of the Glenns Ferry Formation (GFF) may be functioning to insulate or suppress the upward migration of heat flow. The 'relay ramp' (Farmer 2008) noted previously at the Thousand Spring complex may be related to the caldera subsiding along the ring fault systems.

Figure 5 shows the two hydrographs for the deep USGS monitor well and the shallow domestic 'Nunez' well 60 feet away. Both hydrographs show typical cycle magnitudes and timing for the ESPA (Farmer 2011, unpublished data). During the summer months the water level in the deep well is higher than the water level in the shallow well suggesting an upward gradient and a good well seal. Then during the winter months the levels reverse where the shallow water level is higher than the deeper one. The inflection point of the troughs and peaks are similar suggesting a hydraulic connection between aquifers. The slope angles of both the rising and recession limbs are similar. The amplitude of the deep well hydrograph (~2 feet) is approximately half of the shallow well of about 4 feet which may indicate good storage, porosity and therefore permeability and yield. The deeper aquifer appears to be responding to the same factors that affect water levels in the shallow ESPA aquifer.

A 1,123 foot exploration well northeast of Wendell by 5 miles (T7S R15E sec. 12 NE) encountered similar gross stratigraphy of (Whitehead and Lindholm, 1985):

- basalt 0-400 feet
- sediments 400-590 ft. (GFF)
- basalt 590-1,070 ft. (high permeable zone from 620-700 ft.)
- sediments 1,070-1,123 ft.

The report notes a deep zone from 620-700 feet below the sediments as "…very porous cinder zone with high hydraulic conductivity" from a gamma-gamma log and drill cores. This well documents the potential for good aquifer yield below the Glenns Ferry Formation. But, the lower part of this deep basalt is described as few fractures or vesicles. Whitehead and Lindholm (1985) further states "If the sediment unit (Glenns Ferry Fm.) is areally extensive and extends to the canyon, it may be a major control on the elevation of springs and groundwater movement".

Groundwater movement southeast of the Malad Gorge is being delineated by tracer tests which support an unconfined aquifer flow regime. The main trace flows northwest from the 'Meyer' well into the Malad Gorge (Figure 1). Figure 7 shows the geologic logs for all of the wells where dye was released along this same flow path and the level of dye release. All four wells along this flow path show a trend of more dense basalt above the water table and more broken, fractured, caverns and cinders below the water table. It is possible the wells end in the upper portion of a rubble breccia zone that extends downward to at least the elevation of the in-situ pillow basalts exposed in outcrop at the upper diversion dam in the Malad Gorge at an elevation of about 3,016 feet above m.s.l. This outcrop of pillows show foreset bedding with an apparent dip to the northwest which is the same direction as the tracer flow paths. The contact below the pillow zone is covered and it is inferred to be located at a greater depth. Based on information from previous investigators regarding ancient canyons, it is inferred that the base level of the former ancient canyon may extend down to 2,900 - 2,800 foot elevation range. If the ancient canyon has a gradient similar to the existing canyon of today, then the base of the ancient canyon below the 'Meyer' dye release well may be another 200 to 300 feet below the bottom of this well, if the well is centered above the 'thalwag' of the canyon.

Water levels, temperature and electrical conductivity were collected in April 2011 from fifty-four wells and five spring sites for water elevation data (Figure 8). Temperature and electrical conductivity were not collected on all wells because of variable field conditions where collecting all three parameters was not possible. Below are some additional field observations made during the April measurement:

- There was no irrigation occurring during this period but towards the end of April the W-canal started to flow with water and spilling into the Malad Gorge.
- The W-canal near the Malad Gorge spill had a water temperature of 44.4^{o} F and an EC of 231 µS on April 22nd.
- The Malad River upstream of the Gorge east of Interstate 84 on April 28th was 53^{o}F and an EC of 337 µS.
- The river temperature at the upper diversion dam in the Gorge was 56^{o}F with an EC of 345 µS on April 28th.

All of the data for water levels, temperature, and electrical conductivity maps were modeled using Surfer software and the Kriging option with a cell spacing of 33 meters so that only one data site is within a grid cell. A water table map shown in Figure 8 and the 3-D version in Figure 9 is consistent with the location and orientation of an ancient canyon described by Malde (1991) (Figure 3). It is also consistent with water levels collected in January 2011 for a previous tracer report. The second round of water levels in April 2011 also suggest converging flow paths around the Malad Gorge as noted in a previous tracer report. The contour lines show a trough-like depression in the water table with the same long axis orientation of northwest/southeast as the tracer test flow path shown with a white dashed line in Figure 8. The location of this water table depression fits near where Malde (1971) mapped it. If the ancient canyon exists here, and has highly permeable pillow rubble zones at depth, then in effect the subsurface mega-scale feature is acting like a drain (Stearns, 1936) that captures the ESPA water and routes it down the ancient canyon towards the Malad Gorge.

Figure 10 shows one contour line highlighted in red from Stearns (1938) with recent contour lines overlain on top of it. Note the same pattern is seen in the red contour line as the recent contour lines. If there is an ancient canyon at this location and if the contour lines are influenced by the canyon, then Stearns identified the canyon in his water table map but may not have been aware of it. It is important to note that not all of Stearns' water level data is entered into the USGS groundwater database. One USGS location, 424537114471901 at 08S 14E 02CBB1 has only one water level in the database where the Stearn's report shows four water levels were measured. High groundwater flow velocities determined from tracing may follow an ancient canyon filled with higher permeable matrix such as breccia or pillows and may explain why the water table exhibits a 'trough' feature. The other control is the depth that the Malad Gorge has cut into the ancient canyon. Based on information from tracer tests, the groundwater velocity in this area appears to exceed the Reynolds number for laminar non-turbulent flow. Therefore, the steep groundwater contours in Figure 8 are interpreted to be a function of high groundwater velocities with a strong vertical flow component through basalt flows (described later in the Conklin dye trace) into and down the ancient canyon suggesting an unconfined aquifer flow regime.

The area southeast of the Meyer well in sections 10 and 15 may be where the ancient canyon turns east but since there are no wells in this area it is difficult to discern this based on water levels. But, temperature data plotted in Figure 11 suggests a cold water trough (shown as dark blue lines) turning east in this area. Figure 12 shows a 3-D view from an east view angle that has warmer water south and north of the cooler zone. The area east of this cold water trend is desert land for 5 miles to State Highway 46 then more desert further east that has no irrigation. This area would not provide the warmer irrigation water to recharge the aquifer like adjacent irrigated lands do to the south and north; therefore the groundwater could simply have a cold water signature from this desert land area rather than a function of the ancient canyon orientation.

Another possibility is that the canyon may continue southeast along the edge of the steep water table contours which would be consistent with Malde's (1991) map in Figure 3. The steep contours (yellow and light blue in Figure 8) just east of the water table depression exhibit the same orientation as the groundwater trace flow paths and the trough depression in the water table and Malde's map. The steep contours may be a result of the hydraulic effect from the ancient canyon to groundwater flowing from the east and "spilling" into the canyon sized drain.

Figure 13 shows the electrical conductivity contours with high values of blue and green colors and lower values in red. The trends are much less discernable and it is difficult to make conclusions from this data set.

Evidence for an unconfined flow regime is reported by Farmer and Owsley (2009) where a pond leakage trace was conducted through the vadose zone northeast of Wendell at the pilot aquifer recharge site near the W-canal (Figure 14). The average vertical leakage rate was approximately 7 to 10 feet per day and took about 3 weeks to travel 150 feet vertical through numerous basalt flows and 150 feet horizontal through the vadose zone where it was detected. The dye may have arrived even earlier (as short as 1 to 2 weeks directly below the pond) but there was no way to determine this since there were no wells completed under the pond. The expediency of the dye travel time indicates little if any significant barriers to vertical flow through 150 feet of vadose zone basalt. In fact, it was determined from multiple onsite slug and packer tests in boreholes that this site was not suitable for a recharge site because it had too low of permeability and thus would not accept recharge water at a high enough rate. This indicates that despite the dense basalt in the vadose zone the dye moved through it relatively fast. Therefore, it could be concluded that in other areas of the plain where the basalt has more fractures and permeability, then the rate of leakage may be even higher than at the W-canal site. This also supports the concept that the center of basalt flows may not pose as great of a confining character as theorized. If the character of the basalt at the W-canal Site continues below the water table and given the empirical field tracing data; then the theoretical concept of the center of the basalt flows creating confining conditions may not be valid.

Grey colored and permeable basalt has traditionally been interpreted by many geologists to be a thin veneer that extends to shallow depths and rests on rhyolite across most of the ESPA; and the cold water ESPA having a thin depth as well. But, a recently cored exploratory borehole 16 miles north of Paul (Minidoka Co.) documents the cold water aquifer of the ESPA extends to approximately 3,200 feet below land surface with a temperature at this depth of 62.6^{o} F (onsite personal communication with Dr. Shervais and sample inspection by Farmer, 2010). Basalts dominate the entire depth of the hole down to at least 6,000 feet (about as deep as the Grand Canyon) with the exception of a few minor interbeds of sediments. Geophysical logs record porous features in the basalt down to about 3,200 feet below land surface and then the density increases and the formation of secondary fracture filling minerals (Shervais et. al., 2011). The location of this exploration well is also near one of Malde's (1991) mapped ancient canyons #4 (Figure 3) but it is difficult to locate the well and Malde's canyon from his Figure.

TRACING RELATED INFORMATION

Use of fluorescent dyes for groundwater tracing constitute the most analytically sensitive, most versatile, non-toxic, and least expensive water tracers available (Quinlan, 1990), but experimental design is typically more important than a refinement or precision of equipment used for analysis. Therefore, a hypothesis has been developed for each tracer test in the past couple of years using all available information and then testing the theory from multiple locations with varying concentrations using two different dyes, different levels of injection, different equipment, different lab techniques, real time in-situ measurements verses static integrated charcoal packet measurements, different times of the year, repetition of traces by doubling injection concentrations and the resulting increases in dye discharge concentrations and use of independent labs for analysis of duplicate samples. Systematic observation, measurement and testing provide for modification to the working hypothesis. These factors have been employed to build a sound scientific practice to demonstrate the results are not from some random haphazard event but are easily reproducible with a high confidence level of predicted outcome. To date there have been six well locations traced and all have produced not only duplicate data set patterns, timing and consistent with nearby traces; but as dye injection concentrations increase, the corresponding spring concentrations increase documenting cause and effect.

In 2007, Martin Otz and Nicholas Azzolina presented at the Geological Society of America fall meetings on their findings from hundreds of groundwater dye traces. They state the following,

> "Fluorescent dye-tracing (FDT) tests show that ground-water seepage velocities can be orders of magnitude faster than calculated by Darcy's Law. FDT data show that classical assumptions of groundwater flow are often wrong! "Real-world" conditions mandate the use of tracing techniques to determine accurate flow paths & seepage velocities. One example of a trace in a fluvial geologic environment, the groundwater flowed 350 times faster than the Darcy equation calculates. A second example in fractured bedrock the dye trace was 650 times faster than what the Darcy equation shows and in a clayey unconfined aquifer setting the dye travelled 110,000 times faster than the Darcy calculation. Otz and Azzolina note that the average difference between Darcy calculations and FDT results are 450%. More than 75% of all tracer tests show that

> ground water movement moves faster than the Darcy velocity and does not move in the direction of the hydraulic gradient."

Groundwater gradient maps are partly a function of data resolution within any given scale. The dye flow azimuth for the Meyer 2.25 mile trace is approximately 20-25 degrees off from the 2008 synoptic groundwater contours suggesting that groundwater is not following the direction of gradient as noted in the last statement above by Otz and Azzolina (2007). But, high resolution data and the resulting groundwater gradient map created from water levels measured in April and November of 2011 support the contrary that indeed groundwater flow (based on tracing) is following groundwater gradients. In fact, when all 13 traces to date are evaluated relative to the recent high resolution groundwater contour maps, they're all in alignment with the gradient. Therefore, if a contaminant transport model such as WhAEM uses low resolution water level data (ex.-2008 synoptic) as an input, then the results may have low resolution accuracy especially within a few miles of spring discharge areas where the high resolution contours are nearly 90 degrees from the lower resolution contours.

Figure 14 shows a high resolution groundwater table contour map from data collected in November 2011 through a cooperative effort between Idaho Department of Water Resources and Idaho Power. One hundred ninety-six wells and 39 springs were visited to collect water levels, temperature and conductivity although not all parameters could be measured at all sites. The main springs are labeled and each one was GPS'd except the head of Box Canyon at the plunge pool where the elevation was obtained from Lidar sourced from NASA. The spring elevations were based on the highest point of emergence for visible free water. Most of the remaining red circles that are not labeled are wells. The contour interval is 10 feet and the arrows denote azimuth of gradient and do not necessarily suggest groundwater flow paths. One theory is that groundwater can flow in a different direction than the gradient. The exception to this theory is that all 13 groundwater traces south of Malad Gorge are in alignment with the groundwater gradient and arrow directions. Details of this mass synoptic water level project are forthcoming in a subsequent report but a few general observations are noted here.

There are at least six groundwater divides shown on Figure 14 (generally located by arrows with opposing direction) which means if a numerical flow and transport computer model honors the field data then the computer grid cell size needs to be at least ¼ mile in size for several miles away from the spring area. Note that in the Southeast corner, there is a 'trough' in the water table and the gradient slopes northward from the rim of the canyon into the trough then westward towards Niagra and Crystal. This 'trough' area is located where Malde (1991) in Figure 3 mapped two ancient canyons. The groundwater gradient has high definition south of Malad Gorge with spring elevations from insitu exposed discharge. The gradient south of Malad Gorge is similar to the gradient at other spring areas such as Niagra and Crystal Springs where the highest point of emergence from the talus slope was used for the spring elevation. Also note the groundwater gradient 'ramp's' down the Thousand Springs complex between 'Ten' spring and 'Len Lewis' spring which is consistent with the 'relay ramp' geologic structure. This supports the theory that the Thousand Springs complex is controlled more by structural deformation architecture than by erosional processes of canyon-filling lavas such as the Malad Gorge area.

TRACING PROCEDURE AND METHODS

The traces described in this report were performed at three different wells which are referred to as the Meyers, Conklin, and N. Riddle wells shown in Figure 15 which also shows several other previous tracing locations. The Meyer and Conklin wells had two traces completed while the N. Riddle well had one trace; but all used the same methods, equipment, and dyes as previous traces done in this area.

Meyer Well Dye Trace

Trace #1 Description

This well (Tag #D0023742) was selected because it is located in the trend of the flow path from previous dye traces and it has a recent well construction with a drillers log noting "lava breaks and cinders" from 191 to 220 feet below land surface. A camera was lowered down the well to inspect and confirm geologic conditions with a large cavern observed at 205 feet below the top of casing (TOC). This well was also selected because the nearest wells down the flow path are approximately 1 mile distance from this well. It is a six-inch diameter domestic well completed in year 2003 to a depth of 220 feet and it is located at 07S R14E, section 5, SE, SE.

On December 12, 2010 charcoal packets were deployed at springs in the Malad Gorge at locations MG-1, 2.5, 3, 4, 5, 6, 7, 12, 15, 16, 18, 19, and the Bench Spring (Figure 15). Nine grams of coconut shell activated carbon were placed inside each packet made from fiberglass screen which is similar to methods described by Aley (2003). Two Turner Designs C3 submersible fluorometers were calibrated and programmed to record hourly readings and placed at the Bench Spring and MG-4. Prior to the dye release water samples were collected at all sampling locations and they tested negative for the presence of Fluorescein dye. Charcoal packets were deployed in toilet tanks on December 16th, 2010 in nearby wells mapped in Figure 15.

On December 17, 2010, eight pounds of Fluorescein dye in powder form with a 75% concentration procured from Ozark Underground Lab was mixed with sterile water for a total volume of 15 gallons. It took 35 minutes to inject the dye through poly-tubing at 205 feet below TOC and the pump was turned off for 48 hours after injection. The water level in the well was 180.78 feet below top of casing. A water sample was collected before the injection from an outside spigot on November 5th, 2010 and tested for fecal coliform with a result of "Absent". On Sunday December 19th (48 hours after injection), the pump was turned on and tested for presence of dye. Samples were collected about every 2 minutes for 30 minute period and tested on site which resulted in no detection of dye in any of the samples except one at 12 minutes which tested at 0.05 ppb FL. A bacteria sample was collected from the outside spigot on a windy day, which may have contaminated the sample. Testing of the sample resulted in a positive for the presence of fecal Coliform. The well was subsequently disinfected and the water was re-sampled with a result of negative.

On January 6th, 2011 (20 days post dye release) water samples were collected from 13 wells down gradient and tested for dye with the results listed in Table 1. Dye was detected in well #43 Burrell at a concentration of 0.37 ppb and the remaining values represent natural background fluorescence at or near the detection level of the instrument which is 0.01 ppb. Field water samples typically have some background fluorescent noise but in the dye release well #48 there might have been residual dye. A minute amount of dye can drip from the poly tubing onto the face of the well borehole as the tubing is retrieved and then condensation can carry this residual back down the well.

Well I.D.	FL concentration ppb	Well I.D.	FL concentration ppb
#47 Goolsby	0.01	#28 RV Park	0.02
#40 Palmer	0.00	#46 Aja	0.02
#25 Riddle, N.	0.00	#44 Arriaga	0.00
#MG Park picnic area	0.01	#33 MG Park office	0.02
#43 Burrell	**0.37**	#29 McBride	0.01
#38 Boyer	0.01	#48 Meyer	0.03
#34 Leija	0.02		

Table 1. List of wells sampled 20 days after dye release during Trace #1at Meyer well #48. All show natural background fluorescence except well #43 Burrell.

On January 21, 2011 (35 days post dye release) two water samples were collected from springs in the Malad Gorge at sites MG-4 and the 'Bench Spring' both of which had submersible fluorometers instruments deployed. Table 2 shows a comparison of results between the field instruments, TD-700 lab instrument and a private lab results. The private lab uses different instrumentation and methods to determine dye concentrations to a higher accuracy and precision.

Site	Submersible Fluorometers	TD-700 Instrument	Private Lab
MG-4 spring	0.19	0.21	0.229
Bench Spring	0.23	0.27	0.333

Table 2. Comparison of water sample analysis for Fluorescein dye concentration in ppb units.

On March 4, 2011 (77 days post dye release) the charcoal packets were retrieved from the Gorge springs and on March 8th packets were collected from the toilet tanks. The packet at spring site MG-3 shifted to a location where it was not in the water and the analysis shows only natural background levels of fluorescence but dye was identified in springs on both sides of MG-3 as can be seen in Figure 16. Dye is visually confirmed at MG-1, 2.5, Bench Spring and MG-4 in Figure 16 but charted in Figures 17 and 18 as black bars along with Trace #2 charcoal packet data shown with green bars. Natural fluorescent background level responses are confirmed through independent analysis at a private lab and typically range from about 2 to 4 ppb. The charcoal packet result for spring MG-1 appears to be higher than the trend or pattern associated with this area from previous tracer tests and also in comparison with results from the subsequent trace at this well and maybe attributed to lab error.

No dye was detected in charcoal packets at the springs named Birch Creek, Willow Creek, Indian Creek (Deakin Spr.), or the Alcove spring north of Malad Gorge located in Figure 19. There was no detection of dye (confirmed by a private lab) for Indian Creek and Birch Creek shown with the pink colored bars in Figure 17. There was also no detection of dye by the private lab for spring MG-11. There is a general pattern in the charcoal packet results shown in Figure 17 black colored columns at the springs in the Malad Gorge showing a lower slope angle from MG-12 up to the peak at MG-4 as the concentration increases; then a steeper concentration slope down to MG-7. This pattern is repeated more clearly in the subsequent Trace #2 (green columns). Note that Trace #1 was started during extreme field conditions similar to the photo in Figure 16 and therefore fewer sites were monitored due to limited accessibility.

Trace #2 Description

On March 15th, 2011 pre-trace water samples were collected at Indian Creek Spring, Willow Creek Spring, and Birch Creek in Woody's Cove and analyzed with results of no detection of dye in the water. On March 22nd, charcoal packets were placed in toilet tanks in homes with domestic wells. On March 23, charcoal packets were placed and water samples collected in the Gorge at spring sites MG-1, 1.5, 2, 2.5, Bench Spring, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18 & 19. All of the spring water samples tested absent for presence of fluorescein using the TD-700 fluorometer.

On March 25th, a water sample was collected from the dye release well #48 and analyzed at a private lab which resulted in an absence for bacteria. Fourteen pounds of 75% active ingredient Fluorescein dye (1.75 times more than Trace #1) mixed with potable water for a total volume of 14 gallons was released through poly tubing at the same level as Trace #1 from 2:15 to 3:00 pm. The mixing tank and poly tubing was rinsed with 7.5 gallons of potable water and released in the well. The water level in the well on April 13th was 183.21 feet below the top of casing. On March 27th (48 hours post dye release), the well pump was turned on and water samples were collected for both bacteria and dye. The State Lab results for both Total Coliform and E. coli were "Absent". Table 3 shows the results of the onsite dye testing from a 2 minute frequency.

March 27, 2011 Time a.m.	FL concentration	March 27, 2011 Time a.m.	FL concentration
11:25	0.02	11:31	0.01
11:27	0.00	11:33	0.00
11:29	0.01	11:35	0.01

Table 3. Dye release well water concentrations after turning pump back on indicating all of the dye had flowed out of the well.

On April 12, (18 days post release) water samples were collected at the springs and wells shown in Figure 19. Spring locations listed in Table 4 show positive results for presence of Fluorescein that has the typical bell shaped concentration pattern with the peak concentration near the Bench Spring at 0.42 ppb. The analysis results were negative for the remainder of spring sample sites and wells as denoted with values of '0' in Figure 19. The grab water samples were analyzed in the lab using a TD-700 fluorometer and those results were consistent with the results recorded by both submersible fluorometers (Table 4). The width of the dye cloud is estimated to be approximately 1,200 feet wide near Well #30 but only about 500 feet wide at the springs. This suggests, for a time of travel of 18 days, the leading edge of the dye cloud had reached the springs and it was more narrow than the main body of the cloud which lagged behind. The purpose of sampling on April 12th was to collect a snap shot of the 'spread' of the dye with concentrations about halfway during the trace which is roughly shown in Figure 19. At the location of well #26 (Figure 19) there is a lower density of wells to sample from so the dye cloud only appears to be wide at this location when in fact it is more likely an artifact of contouring sparse data.

The mass of dye used in Trace #2 was 1.75 times greater than Trace #1. However, as plotted in Figure 17 and listed in Table 5, the concentration of dye at three sites (MG 2.5, Bench & 4) did not increase by a factor of 1.75. Site MG-12 did increase by a factor 1.7 and MG-6 increased by a factor of 2 (Table 5). This demonstrates the charcoal packet results have some variability but still produce meaningful trends.

Spring I.D.	**FL concentration ppb**	**C3 concentration ppb**
MG-1	0.09	
MG-1.5	0.17	
MG-2	0.37	
MG-2.5	0.42	
Bench Spr.	0.42	0.41
MG-3	0.33	
MG-4	0.19	0.21
MG-5	0.08	
Well I.D.	**FL concentration ppb**	
#26 R. Riddle	0.60	
#30 Hopper	0.92	
#31 Sanchez	0.39	
#42 Evers	0.04	
#43 Burrell	0.69	
#53 Lyda	0.22	

Table 4. Spring and well locations with presence of dye detected in water samples collected on April 12^{th} or 18 days after dye was released. Note the consistent results between the in-situ C3 instrument measurements compared to the grab samples measured in the lab. Other springs and wells had no detection of dye.

Spring I.D.	**Concentration from Trace #1 (8 lbs. FL)**	**Concentration from Trace #2 (14 lbs. FL)**	**Increased Factor**
MG-12	8.51	14.62	1.7
MG-2.5	312	360	1.2
Bench sp.	403	533	1.3
MG-4	489	744	1.5
MG-6	8.49	17.00	2

Table 5. Comparison of FL dye concentrations from charcoal packets at selected springs from Trace #1 to Trace #2.

The presence and concentration of dye was confirmed during Trace #2 at locations MG-14, MG-13, Bench spring, MG-4, MG-6 and MG-7 from an independent commercial lab which also shows a rough bell shaped curve with low concentrations at MG-14 and MG-7 and higher concentrations in between these sites. Figure 20 shows a visual confirmation of dye eluted from charcoal packets. The distance between MG-14 and MG-7 is 1,300 feet which appears to be the width of the dye cloud upon emergence in the springs. Figures 15 and 20 indicate that the dye is not spreading laterally as much as the theory of transverse dispersion might predict as the distance increases from 1 mile to 2.25 miles (Fetter, 1993; Anderson, 1979; Klotz et al. 1980). Based on Figure 2.14 in Fetter (1993), the ratio of longitudinal to transverse dispersivity is visually estimated to be in the range of 10 to 20. This may be another indicator that the dye is flowing down an ancient canyon and there is subsurface architecture that might be constraining the spread or horizontal dispersion of the dye. The horizontal spread of the dye is also interpreted to be about the same distance of 1,200 feet at the halfway distance of 1 mile down the flow path from the Meyer well trace. This suggests that the dye is not spreading much from the 1 mile distance on down to the springs in the Gorge. An application of this knowledge is for water quality monitoring. If the exact flow path is not known then the chances of a monitor or sampling well to be intercepted by a contaminant is low.

Figure 21 shows 4 dye breakthrough curves at two springs, the Bench Spring and MG-4. The horizontal distance between the two sites equipped with submersible fluorometers is about 350 feet. The two submersible fluorometers were programmed to record a direct in-situ water concentration hourly resulting in approximately 260 pretest samples being measured prior to the first arrival of dye. First arrival of dye at the Bench Spring occurred on April 4th, at 21:00 hours or approximately 10 days and 6 hours later. Dye concentrations at the Bench Spring returned to background levels on May 15 at 13:00 hours for a 'time of passage' for the cloud of 977 hours or 40.7 days. The breakthrough curve for Trace #1 (8 lbs. FL) at the Bench Spring is shown with a yellow line and a red line for Trace #2 at the same spring. Note the similar shape and pattern to the two curves but a fluorescent disturbance occurred during the period before dye arrived during Trace #1 (yellow line) exhibited by high spikes at 2, 12 and 13 days in elapsed time. This is not interpreted to be dye but rather an erratic perturbation moving through the system. This phenomenon has been observed before and it is absent during subsequent traces.

The background fluorescent levels ranged from 0.00 to 0.01 ppb and the peak dye concentration recorded during this study was 0.59 ppb which equates to a dye concentration that is approximately 59 times the background level of fluorescence. The goal of this study was to achieve a peak concentration in the springs approaching 1.00 ppb or about 100 times (2 orders of magnitude) higher than the background fluorescence. This goal helps keep the peak dye concentration 2 orders of magnitude below visual and aesthetic levels (about 100 ppb), 1 order of magnitude below 10 ppb USGS protocol. Peak dye concentrations from 1 to 5 ppb are optimal for conditions in the ESPA near this location and probably at other spring/groundwater locations; but receptors in between the point of dye release and springs such as domestic and public water supply wells need to be considered.

The peak concentration for Trace #1 at the Bench Spring is 0.37 ppb at approximately 22 days after dye release. The curve has a typical steep rising limb and lower angle recession limb defining a positive skew. The first time of arrival for dye is at 260 hours (10.83 days) after dye release over a distance of 11,900 feet (2.25 miles) which equates to a maximum flow velocity of 1,102 feet/day.

The red colored line shows the break through curve for Trace #2 (14 lbs. FL) at the Bench Spring with no spikes or disturbances that were exhibited in Trace #1. This curve also has a typical steep rising limb and lower angle recession. The peak concentration reached 0.59 ppb FL at approximately 23 days with a factor of 1.6 increase from Trace #1 peak even though the mass of dye released was 1.75 times more. The peak arrived about 12 to 24 hours later possibly due to a lower water table and thus a slightly lower gradient. The water level dropped from Trace #1 on Dec. 17, 2010 to April 13th, 2011 (20 days after Trace #2) by 2.43 feet. The first time of arrival for dye is at 261 hours (10.87 days) after dye release which equates to a maximum flow velocity of 1,095 feet/day. Averaging both maximum velocities together equates to 1,098 feet/day or rounded to 1,100 feet/day.

Both breakthrough curves at the Bench Spring (yellow and red lines) exhibit a slight bimodal character at 34 to 35 days after dye release on the recession limbs. The slope angle is lower before and then breaks to a steeper decent at this point in time which indicates a secondary flow path influencing the curves. It probably is no coincidence that at days 31 and 32 is also when the peak arrives at spring MG-4 and starts to decline in concentration. Conversely, the rising limbs of both breakthrough curves from spring MG-4 (blue and green lines) show a bimodal character at day 20 and 21 which correlates to start of the concentration inflection of the peaks at the Bench Spring. In addition, both traces for the Bench Spring (yellow and red lines) have a positive skew so that the bulk of the values are left of the mean shown with a yellow diamond symbol located at the 28th day on the red line. Conversely, both traces for spring MG-4 have a negative skew right of the mean shown with a yellow diamond symbol located at the 30th day on the green line. It is unclear why the dye breakthrough curves at spring MG-4 have a negative skew but it may be due to an integration of dye from the Bench Spring flowing into dye at MG-4 with a lag time involved. Evidence of this shows as an inflection point in both trace breakthrough curves at MG-4 at the same time that the Bench Spring peaks in concentration. It is interpreted that the breakthrough curves for spring MG-4 is an integration of two contributions of dye after about day 22.

It appears there is some overlap of dye and thus hydraulic connection between the Bench Spring and spring MG-4. This 'flip-flop' phenomenon between the two springs is probably affecting the mean for each curve individually so an average of the two means might be more useful and applicable. The average linear velocity for the Bench Spring from Trace #2 mean is 426 feet/day and for spring MG-4 it is 393 feet/day and both averaged and rounded equate to 410 feet/day which may be too many significant digits and thus a value of 400 feet/day may be more appropriate for the average linear velocity. It is interpreted that some water from the Bench Spring is spilling over into spring MG-4 since the water on the bench is slightly higher in elevation by approximately 10 feet than where the C3 was set up at spring MG-4. Also, the peak concentration at spring MG-4 is about 8 days later than the Bench Spring for both Trace #1 and #2 which is enough to indicate two flow paths; even though in the discharge area they intermingle or overlap to some degree affecting each other's breakthrough curve. This indicates the slower flow path is about 3,000 feet behind the faster flow path using an average linear velocity of 400 feet/day and eight days. In summary, there could be a blending of dye in the spring discharge area and/or a blending of dye from two separate but dominate flow paths in the groundwater.

N. Riddle Well #25 Dye Trace

A qualitative trace was performed using Rhodamine WT at well #25 N. Riddle located in Figure 22. The trace used only charcoal packets and the flow path is shown as an orange narrow triangular shaped polygon. The house was vacant during the trace period and thereafter for some time. On June 7th, 2011 packets with 9 grams of coconut shell charcoal were deployed in the Gorge at spring sites MG-1, 1.5, 2, 2.5, Bench Spring, 3, 4, 12, 13, 14, 15, 16, 17, 17.5, 18, 19, 20, 21, 22, and 23 (Figure 21). Pre-trace water samples were also collected at these sites and analyzed with the TD-700 lab fluorometer with negative results for RWT at all locations. The top of casing for the well was GPS'd using a Trimble ProXRT receiver for an elevation of 3,262 feet above mean sea level. The elevation of the springs in the area of MG-19 were GPS'd at 3,018 feet. The water level in the well was measured at 172.10 feet below the top of casing which equates to a water table elevation of about 3,089.9 feet. The springs are about 72 feet lower in elevation than the level of dye release and water table in the well which equates a gradient of 0.027.

It is 0.59 miles or 3,100 feet distance from the dye release well #25 to spring MG-20 and 2,660 feet to MG-19 which is about the same distance as several traces done at the R. Riddle well #26 to spring MG-3 at a distance of 2,865 feet. The information learned from the R. Riddle well traces in year 2010 provided a basis for planning the mass of dye, spatial sampling sites, and frequency for this trace. The spread of dye for the R. Riddle trace (Figure 22 green triangle area) may have been greater extending from MG-2 through MG-7 but there is a high resolution of sampled springs at this location compared to a lower concentration of springs near MG-20.

The pump was turned off for two days and two 16 ounce containers of 20% concentration RWT (purchased from Ozark Underground Labs) was released 172 feet below the top of the casing at the level of the water table which was measured at 172.10 feet on June 7th at 11:30 am. The tubing would not continue below this level due to an obstruction and a well log could not be located nor was the pump pulled to camera the down-hole conditions. When the pump was turned back on (June 9th) and water samples collected there was very little to no detection of dye (Table 6) for a total pumped volume of about 100 gallons. Therefore, it is reasonable to assume the bulk of the dye migrated out of the well bore. The total mass of dye released was 0.46 pounds or 208 grams which is the least amount of dye released from any traces to date and 4.4 times less RWT than released at the R. Riddle well in 2010. Two pounds active ingredient of RWT was released in the R. Riddle well #26 to the east of the N. Riddle well during March 2010 with a peak water concentration detected at spring MG-3 of 1.9 ppb (see Figure 9 in that report). No dye was detected from the well water when the pump was turned back on at the R. Riddle well but the well drilling report showed a broken zone at the level the dye was released. During the 2010 traces at R. Riddle's well #26 the first arrival of dye was 28 hours after release, the peak was at about 3 days and total time of passage of dye was approximately 12 to 14 days.

Time a.m.	RWT conc. (ppb)	Time a.m.	RWT conc. (ppb)
11:40	0.00	11:49	0.00
11:41	0.00	11:51	0.00
11:42	0.02	11:53	0.04
11:43	0.04	11:55	0.02
11:44	0.01	11:57	0.01
11:45	0.00	11:59	0.03
11:47	0.03	12:01	0.00

Table 6. Dye release well #25 RWT water concentrations after turning pump back on two days (June 9th) after dye release. Flow rate was measured at 5 gallons per minute from a frost free hydrant.

On July 11th, 2011 (35 days after dye released) the charcoal packets were collected at the spring sites with the exception of MG-23 which was missing. The packets were processed in with the same methods as previously described in earlier reports and analyzed with the same lab instrument TD-700 configured with filters and lamp for RWT, then calibrated to blank, 0.04, 0.4, 4.0 and 40.0 ppb RWT standards obtained from a commercially available stock solution of 400 ppb and then diluted. The instrument was re-calibrated to analyze for samples from MG-18, 19 and 20 with a blank, 4.0, 40.0 and 80.0 ppb standards. The results are graphed in Figure 23 with positive detection of RWT dye at spring sites MG-18, 19 and 20. Based on the concentration trend in Figure 23, it is possible that dye may have discharged out springs between sites MG-20 and MG-21. Due to the geometry of the canyon, it is less likely much dye discharged between MG-18 and 17.5.

The trend of the packet results suggests a stronger constraint on the horizontal spread than previous traces in this area and possibly a more fracture flow regime within a more massive portion of the basalt flow. Conversely, springs at MG-17.5, 18 and 19 all discharge from undisturbed in-situ thick exposed pillow lava outcrop. A borehole camera survey could help with the interpretation of this trace. The 0.46 pounds of dye released produced a maximum detected concentration of 76.75 ppb from packets at MG-19 at nearly the same distance as the 2010 trace at R. Riddle well #26 which released 2 pounds of RWT and produced a maximum concentration from spring site MG-3 charcoal packet of 388 ppb. The decrease in mass by 4.4 times produced a concentration of 5 times lower. This relation suggests that all of the dye cloud passed through the system based on the time of passage and other characteristics from the R. Riddle well traces in 2010. The high charcoal packet concentration of 76.75 ppb RWT relative the very low mass released of 0.46 pounds and travel distance of 0.56 miles strongly supports that RWT is readily transported in the basalt aquifer, easily absorbed by the charcoal and easily eluted from the charcoal.

Conklin Well #52 Dye Trace Background Information

A well east of Interstate 84 was selected for a new trace based on information from previous tracer tests and water level contours discussed previously shown in Figures 8 and 9 on a small scale of about 1:62,000. Figure 24 shows the same groundwater contours at a larger scale of 1:12,500 as red lines. The green dashed lines show the main tracer flow paths which are roughly perpendicular to the contour lines supporting field observations that flow paths are following the contour lines down gradient. If there was a higher density of wells in this area the flow paths might be more accurate in relation to the contour lines. Some hydrogeologists theorize that groundwater flow does not always follow the hydraulic gradient displayed as water table contour lines and therefore flow can occur at different directions independent of the gradient. Presently, the empirical evidence shows that all 13 traces to date have followed the contour lines down gradient. This is one reason the Conklin well #52 (Tag # 0043236) was selected for a trace to demonstrate how the contour lines that were generated during the spring of 2011 could assist with tracer planning efforts and increase the field operations efficiency. The trace was designed with an expected outcome of resurgence of dye upstream (east) of springs MG-7 based partly on water table contour lines and a more intense effort was made to identify springs upstream of MG-11 whereby spring MG-11.5 and before the second trace MG-11.7 were identified. Conditions in the Gorge are made finding these springs even more difficult than all of the downstream sites in part due to more rapids in the river. On December 8th, when the river flows were very low, these upper springs could be seen from the north rim of the Gorge but nearly impossible to identify earlier in the year when the river had higher flow rates.

The Glenns Ferry Formation (GFF) is exposed as in-situ outcrop at six known locations east of the Snake River – 1) old Bliss Grade, 2) mouth of the Malad Gorge, 3) Vader Grade, 4) the top of Blind Canyon Grade, 5) a small exposure (in-situ?) northeast of Big Springs, 6) Blind Canyon springs. It is possible that sediments noted in the bottom 30 feet of the drilling log for the Conklin well may be part of this formation. Geologic cross section A-A' mapped in Figure 24 and illustrated in Figure 25 shows geologic logs from well drilling reports. Basalt related rock types are have grey colored background symbols while clastic sediment related rock types (sand, silt, clay, gravel) have orange colored background symbols. 125 feet of sediments are noted in the lower portion of the Hooper well which clearly exceeds a typical thickness of any paleosol in the ESPA. Most of the remaining wells in cross section A-A' also encounter sediments at about the same elevation of 3,100 feet.

In comparison, cross section B-B' (Figure 26) shows no sediments encountered in the wells next to the Gorge down to at least 100 feet deeper than the sediment contact (about 3,100) in cross section A-A'. The geographical trend is from northwest to southeast which roughly parallels the steep groundwater contour lines shown in Figures 8, 9, and 24; and roughly the same orientation of the Meyer well trace that flowed from southeast to northwest. Field evidence suggests a rise in the Glenns Ferry Formation just east of the Malad Gorge with a northwest to southeast orientation. If this model is correct, the rise in the GFF might represent the east "wall" of a paleo-canyon described previously in this report by multiple USGS researchers in the last 80 years. The west "wall" of this paleo-canyon may parallel the east side of the Hagerman Valley extending from Malad Gorge, along Billingsly Creek and down to Thousand Spring's area where a possible "relay ramp" geologic structure controlled by faults forms the Thousand Spring's complex. This "west wall" of sediments likely plays a significant macro-scale hydrogeologic feature. The ancient canyons are essentially acting as subsurface 'French drains' to the ESPA. Stearns (1936), who studied hydrogeology in southern Idaho for the U.S. Geological Survey, used a hydrograph from Blue Lakes Spring to estimate that ground water was flowing at an average rate of 750 feet per day between Wilson Lake and this spring. His methods are unclear but appear to be consistent with our velocities except at a larger scale. If the area from Blue Lakes to Wilson Lake are traced this may provide direct confirmation of his estimate.

In the area south of Malad Gorge, the westward flow of the ESPA may be partially diverted into paleo-canyons which then flow northwesterly and discharge into the Gorge. These canyons will likely become less evident further east because to two factors. The land surface rises to the east along with the water table which means typically wells don't penetrate deep enough to encounter the sediments. In addition, faulting and subsidence of the Twin Falls volcanic field (Bonnichsen and Godhaux, 2002) likely plays a role in lowering in elevation, erasing and/or shifting from faults the position of the sediments.

These two large aquifer discharge areas, Thousand Springs and Malad Gorge, are controlled by two different geologic phenomena. The geologic subsurface architecture that controls the springs in the Malad Gorge appear to be a function of erosion that forms a canyon and then deposition of basalt that fills and buries the canyon. The geologic architecture of the Thousand Springs complex (Figure 27a) is probably controlled by extensional faulting which formed a relay ramp feature generally described by Faulds and Varga (1998). Figure 27b shows a lab model rift zone and associated relay ramps (McClay et. al, 2002). Figure 27c shows the tilted water deposited sediment exposed in the wall behind the Thousand Springs power plant. The relay ramp provides an exit to the ESPA water at this location. Relay ramps provide a soft link between developing faults through ductile strain mechanisms in rift valleys (McClay et. al., 2002). The Hagerman Valley is located on the edge of the Twin Falls volcanic field within the larger Snake River Plain rift valley where extensional forces have occurred. It is also possible that there is a combination of ramp structures influencing the position and architecture of ancient canyons that have been buried by volcanic eruptions.

Conklin Well #52 Trace Description

On July 11th, 2011, charcoal packets were deployed at springs the Gorge for MG-1, 2, 2.5, Bench Spr., 3, 4, 5, 6, 7, 8, 9, 10, 10.5, 11, 11.5 sample sites. No instruments were deployed in the springs or water samples collected for Trace #1. Then from 1:30 to 2:00 p.m. on the same day, 3 pounds of 75% concentration powder form Fluorescein dye was mixed in 3 gallons of water and released through poly-tubing into the Conklin well just above the pump (Figure 28) or 164 feet below the top of the casing. The Conklin well water was tested for FL dye the next day on July 12th which resulted at 0.02 ppb FL residual. On July 7th, a borehole camera was lowered down the well and recorded the following from the top of casing:

- 21.5 feet - bottom of casing.
- 115 feet – groundwater discharging from a large fracture and cascading down well.
- 137 feet – turbulent water table.
- 164 feet – top of the pump column.
- 200 feet – bottom of well (from drilling log).

The camera could not pass by the pump but the drilling log notes a 200 foot deep well with cinders from 164 to 170 feet, then clay sediments encountered from 170 to 200 feet (Figure 25). There was a strong downward gradient which is consistent with the steep groundwater contours mapped in this area (Figure 24). Water is flowing down the well bore transporting air bubbles along with it from the cascading water. The smaller bubbles are easily carried down through the water column, while the medium sized bubbles tend to ‘hover’ and the large air bubbles (discharged from the poly-tubing) travelled back up the borehole against the flow. The flow is great enough that it gently moves the pump around inside the borehole. If all of the sediments are clay in the bottom of the well, then essentially all of the downward flow of water in the well must be exiting through the cinder zone from 164-170 feet. The elevation of the well casing is 3,295 feet above sea level and the water level is at 3,180 feet. MG-11 is 3,034 feet elevation and 3,653 feet horizontally from the well which equates a gradient between the water level in the well and MG-11 at 0.040.

On August 4th, 2011 (24 days since dye released) the charcoal packets were retrieved from Trace #1 and analyzed with the same methods and equipment as previous traces with visual results shown in Figure 29. The results from Trace #1 are also plotted as red colored bars in Figure 30. Dye was detected from spring MG-7 upstream to spring MG-11.5. There is a consistent but more gradual increase in concentrations from MG-7 to the peak at MG-11, then a steeper decrease in concentrations to MG-11.5. This pattern was seen in the Meyer trace too and may be a function of the direction of groundwater flowing northwesterly with the canyon oriented essentially east/west. The Malad Gorge Park picnic area well was the only well sampled but no dye was detected in the well. Water samples were also collected at the springs and two springs had some residual FL dye (MG-10.5 and 11 at 0.03 ppb) but the rest were at or below the detection limits.

On August 17, 2011, spring MG-11.7 was located and charcoal packets were deployed at sites MG-1, 2, 2.5, 3, 4, 5, 6, 7, 8, 9, 10, 10.5, 11, 11.5, 11.7. A C3 instrument was calibrated and deployed at spring MG-11 and programmed to record hourly readings. Six pounds (twice the amount of Trace #1) of powder form FL dye with 75% active ingredient was mixed with 6 gallons of water and injected at 10:35 a.m. on August 19th at 163 feet below the top of casing which took 7 to 8 minutes with the domestic pump turned off. Then 5 gallons of rinse water was injected, then the pump was turned back on after ½ hour. The water was sampled for total coliform which resulted in an “absent” lab analysis and tested for FL dye which was also not detectable.

On September 28th, (40 days after dye released) the charcoal packets and C3 were retrieved. The packet at MG-1 was lost and there was no packet placed at the park picnic well, Bench Spring or MG-1.5 for Trace #2. Visual confirmation of the FL dye can be seen in Figure 31 in sites MG-8 through MG-11.5. But, after some changes in natural lighting the dye could be visually seen in MG-7 as shown in Figure 31 comparison. The left image of MG-7 is resting on a brown file cabinet next to a window with natural sunlight and the right image it is resting on a stainless steel cart in the same light conditions. The steel cart produces improved visibility of the dye in direct sunlight.

The results after lab analysis are plotted on the graph in Figure 30 as the green bars. Note the same general trend as in Trace #1 is evident but with a higher concentrations. Also note that dye passed by site MG-11.7 which was not known about during Trace #1. Trace #2 had the same downstream spatial distribution with dye passing by MG-7 during both traces. It was surprising that by doubling the mass of dye from 3 pounds to 6 pounds the packet concentration only increased by a factor ranging from about 1.3 to 1.7 times.

Figure 32 shows the FL dye breakthrough curve from the C3 instrument deployed at MG-11. The curve has a smooth character with no background noise showing a classic single peak with a positive skew. The straight line distance from the well to MG-11 is 3,653 feet or 0.69 miles. The initial breakthrough occurred at 30 hours since dye release for a calculated maximum velocity of 122 feet/hour or 2,922 feet/day. The mean concentration occurred at 122 hours after dye release for a calculated average linear velocity of 29.94 feet per hour or 720 feet/day rounded. The dominant flow regime velocity is based on the peak dye concentration that occurred at 82 hours since dye released which equates to a groundwater flow velocity of 1,069 feet/day. The total time of passage for the dye cloud was about 900 hours or about 38 days. This means that the packets from Trace #1 were probably collected about 14 days too soon for the total mass of dye to pass out of the system but effectively about 97.6% of the mass had passed by 24 days or 576 hours which would be insignificant for the effects on the charcoal packet results.

The fact that dye passed through in a single, well constrained peak indicates little longitudinal dispersion despite having to flow vertically through 146 feet of inferred basalt. At least 100 feet of basalt is exposed insitu from the wall of the canyon above the talus slope. The dominant flow regime is not a function of the maximum groundwater velocity nor the average linear velocity but rather the peak of the concentration break through curve which equates to 1,069 feet per day. Considering the well log geology, outcrop geology, tracer breakthrough characteristics, velocity, and likely flowing vertically through 146 feet of basalt or approximately 5 to 6 individual basalt flows/contact zones, this suggests excellent vertical flow through the basalts and supports that the ESPA at this location is strongly unconfined in nature.

Discussion

Dye tracing is one of the most powerful tools available to hydrologists because it has been demonstrated to be viable, feasible and an efficient method of understanding an aquifer. The charcoal sample results from all traces described in this report are consistent with all previous dye traces in this area. Table 7 shows the attributes of these trends in chronological order for comparison between traces. The empirical field data collected to date is consistent with early hydrogeological models of ancient canyons buried from volcanic eruptions. Field evidence, hydrologic evidence and reference documents support a ‘relay ramp’ structure as a dominant control of aquifer discharge in the Thousand Springs complex. A higher temperature (72^{o} F) aquifer exists about 600 feet below land surface between Wendell and Thousand Springs area but the heat signature is effectively erased by the high flow of the cold water ESPA. An addition to this report, is the concept that dominant groundwater flow regime is defined by the peak concentration of the breakthrough curve (Kass, 2009).

High resolution groundwater contours are important when comparing tracer flow paths and hydraulic gradient directions. Flow and transport computer models should use high resolution groundwater contours near spring areas for model input to achieve optimal results. Numerous groundwater divides are present in the spring areas as evident from the contour maps and additional traces will aid in the body of knowledge about the divides which are important for transport models such as the U.S.-E.P.A. Whaem. A future recommendation is to repeat the mass water level measurement but generally keep the boundary between Interstate 84 and the rim of the Snake River and extend the area east to Highway 93 and northwest to capture the north side of Malad Gorge. The dye cloud ‘time of passage’ documents how expedient water soluble contaminants can travel through the aquifer and how short their residence time might be. Even information about how fast 14 pounds of dye migrates out of the well bore is useful regarding contaminant residence time. The fast moving flow system has implications for the temporal component of water quality sampling and the transverse dispersion has implications for the spatial component of water quality sampling. Steep vertical gradients and tracer test results near the Malad springs support the aquifer is unconfined in this area.

These data will be used to develop additional studies utilizing wells that are farther from the Gorge. It also provides data on water movement within the ESPA and can potentially be used to help refine groundwater models applied at the local scale. The studies also provide legitimacy to the use of fluorescent tracers for studying groundwater on the ESPA. The knowledge gained here is also being exported to other sites on the ESPA where additional tracer studies are currently 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 may also help in refining water quality monitoring sites for aquifer recharge projects to ensure the protection of groundwater resources. They may also aid in determining sources of contamination at some spring complexes.

ACKNOWLEDGEMENTS

This project is supported with financial assistance and personnel from Idaho Power and the Idaho Department of Water Resources. The data from these tests will provide a solid foundation to gauge decisions for larger scale tests with invaluable support from the following. Thank you.

Idaho Department of Water Resource staff that assisted with the project includes Brian Patton, Rick Raymondi, Sean Vincent, Dennis Owsley, Mike McVay, Allan Wylie and Taylor Dixon. Idaho Power employees who assisted with project were Kresta Davis-Butts and Tim Miller. Home/well owners were especially accommodating. The Idaho Department of Parks and Recreation were helpful by providing staff assistance and access to Park wells. Also, imperative to the project was the significant support from Larry Martin with the Water Resource Division of the U.S. National Park Service for the generous loan of instruments. Jim McKean (Research Geomorphologist) with the U.S. Forest Service provided use of lab space and equipment to process samples.

REFERENCES AND SOURCES OF INFORMATION

1. Aley, T., 2002, Groundwater tracing handbook, Ozark Underground Labs, 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 Labs, 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. Bonnichsen, B., and Godchaux, M.M., 2002, Late Miocene, Pliocene, and Pleistocene Geology of Southwestern Idaho With Emphasis on Basalts in the Bruneau-Jarbidge, Twin Falls, and Western Snake River Plain Regions; Tectonic and Magmatic Evolution of the Snake River Plain Volcanic Province, Idaho Geological Survey, Bulletin 30, 482 p.

8. Bonnichsen, B., McCurry, M., and White, C.M., 2002, Tectonic and Magmatic Evolution of the Snake River Plain Volcanic Province, Idaho Geological Survey Bulletin 30, 482 p.

9. 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).

10. Covington, H.R., and Weaver, J. N., 1991, Geologic maps and profiles of the north wall of the Snake river canyon, Thousand springs and Niagra springs quadrangles, Idaho, U.S. Geological Survey, Miscellaneous Investigation Series, Map I-1947-C.

11. Covington, H.R., Whitehead, R.L., and Weaver, J.N., 1985**,** Ancestral canyons of the Snake River; geology and geohydrology of canyon-fill deposits in the Thousand Springs area, south-central Snake River Plain, Idaho: Geological Society of America Rocky Mountain Section, 38th Annual Meeting, Boise, Idaho, 1985, Composite Field Guide, Trip 7, 30 p.

12. Crandall, L., 1918, The springs of the Snake River canyon, Idaho Irrigation, Engineering, and Agriculture Societies Joint Conference Proceeding, pp. 146-150.

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

14. 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.

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

16. 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.

17. Domenico P.A. and Schwartz F.W., 1990, Physical and chemical hydrogeology, John wiley & sons, 824 p.

18. Enotes, 2011, web site address: http://www.enotes.com/earth-science/geothermal-gradient

19. 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.

20. 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.

21. 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.

22. 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.

23. 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.

24. Farmer N., 2008, Traffic jams occur in nature too – geologic architecture of Hagerman valley spring discharge areas, Idaho Water Resource Research Institute Ground Water Connections Conference, Sept. 23 & 24, Boise, Idaho, Session 4 Research.

25. Farmer N., and Kathren, R.L., 2008, Radioactivity in fossils at the Hagerman fossil beds national monument, Journal of Environmental Radioactivity, Aug; 99(8):1355-9.

26. Farmer, C.N., and Nagai, O., 2004, Non-native vegetation growth patterns as a tracer for development of human caused perched aquifers in landslide areas, Journal of the Japan Landslide Society, vol. 41, no. 3 (161), 12 p.

27. Farmer N., 1998, Hydrostratigraphic model for the perched aquifer systems located near Hagerman fossil beds national monument, Idaho, University of Idaho thesis, 106 p.

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

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

30. Faulds, J. E., and R. J. Varga, 1998, The role of accommodation zones and transfer zones in the regional segmentation of extended terranes, *in* J. E. Faulds and J. H. Stewart, eds., Accommodation zones and transfer zones: the regional segmentation of the Basin and Range province: Geological Society of America Special Paper 323, p. 1–46.

31. 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.

32. 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.

33. 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.

34. Gillerman, V.S., J.D. Kauffman and K.L. Othberg, 2005, Geologic Map of the Thousand Springs Quadrangle, Gooding and Twin Falls Counties, Idaho: Idaho Geological Survey digital web map 49.

35. Gillerman, V.S., J.D. Kauffman and K.L. Othberg, 2005, Geologic Map of the Tuttle Quadrangle, Gooding and Twin Falls Counties, Idaho: Idaho Geological Survey digital web map 51.

36. Gillerman, V.S., J.D. Kauffman and K.L. Othberg, 2005, Geologic Map of the Hagerman Quadrangle, Gooding and Twin Falls Counties, Idaho: Idaho Geological Survey digital web map 50.

37. 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.

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

39. 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.

40. 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.

41. 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.

42. Leet, D., Judson, S. and Kauffman, M., 1978, Physical Geology, 5th edition, ISBN 0-13-669739-9, 490 p.

43. 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.

44. Malde, H.E., 1991, Quaternary geology and structural history of the Snake River Plain, Idaho and Oregon in Morrison, R.B., ed., Quaternary nonglacial geology; conterminous U.S.: Boulder, CO, Geological Society of America, The Geology of North America, vol. K-2.

45. Malde, H.E., 1982, The Yahoo Clay, a lacustrine unit impounded by the McKinney Basalt in the Snake River canyon near Bliss, Idaho, in Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 617-628.

46. Malde, H.E., 1972, Stratigraphy of the Glenns Ferry Formation from Hammett to Hagerman, Idaho: U.S. Geological Survey Bulletin 1331-D, 19 p.

47. Malde, H.E., 1971, History of Snake River canyon indicated by revised stratigraphy of Snake River group near Hagerman and King Hill, Idaho, Shorter contributions to general geology; Geological Survey professional paper, 644-F, 21 p.

48. Malde, H.E., and Powers, H. A., 1958, Flood-plain origin of the Hagerman Lake Beds, Snake River Plain, Idaho (abs.): Geological Society of America Bulletin, v. 69, 1608 p.

49. 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.

50. McClay, K.R., Dooley, T., Whitehouse, P., and Mills, M., 2002, 4-D evolution of rift systems: Insights from scaled physical models, AAPG Bulletin, V. 86., no. 6 (June 2002), pp. 935-959.

51. Meinzer, O.E., 1927, Large springs in the United States, USGS Water Supply Paper 557, library number (200) G no.557, 94 p.

52. 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.

53. 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.

54. Othberg, K.L. and Kauffman, J.D., 2005, Geologic map of the Bliss quadrangle, Gooding, and Twin Falls counties, Idaho, Idaho Geological Survey map #53.

55. 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.

56. 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.

57. 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.

58. 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.

59. 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.

60. 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.

61. Ralston, D., 2008, Hydrogeology of the thousand springs to Malad reach of the enhanced snake plain aquifer model, Idaho Department of Water Resources report, 20 p.

62. Russell, I.C., 1902, Geology and water resources of the Snake river plains of Idaho, USGS Bulletin 199, library number (200) E no.199, 192 p.

63. Shervais, J., Evans, J.P., Lachmar, T.E., Christiansen, E.J., Schmitt, D.R., Kessler, J.E., Potter, K. E., Jean, M.M., Sant, C.J., Freeman, T.G., Project hotspot – the Snake river scientific drilling project: a progress report, Geological Society of America Rocky Mountain 63rd Annual meeting and Cordilleran 107th Annual meeting May 18-20, 2011, Abstracts with Programs, Vol. 43, No. 4, p. 5.

64. 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.

65. 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.

66. 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.

67. 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.

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

69. Stearns, H.T., 1983, Memoirs of a geologist: from Poverty peak to Piggery gulch, Hawaii Institute of Geophysics, 242 p.

70. Stearns, H.T., Crandall, L., Steward, W.G., 1938, Geology and ground-water resources of the Snake River plain in southeastern Idaho; U.S. Geological Survey Water Supply Paper 774, 268 p.

71. Stearns, H. T., 1936, Origin of large springs and their alcoves along the snake river in southern Idaho, The Journal of Geology, vol. 44, No. 4, 429-450 p.

72. 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.

73. Taylor, C.J., and Alley, W.M., 2001, Ground-water-level monitoring and the importance of long-term water-level data, U.S. Geological Survey Circular 1217, 68 p.

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

75. U.S. Bureau of Reclamation Water Measurement Manual, 2001, http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/

76. 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.

77. 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

WATER TRACING DYE
FLT YELLOW/GREEN PRODUCTS

BRIGHT DYES
Division of Kingscote Chemicals

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.

To our best knowledge the information and recommendations contained herein are accurate and reliable. However, this information and our recommendations are furnished without warranty, representation, inducement, or license of any kind, including, but not limited to the implied warranties and fitness for a particular use or purpose. Customers are encouraged to conduct their own tests and to read the material safety data sheet carefully before using.

[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

FLUOROMETRIC FACTS
Bulletin No. 104
Fluorescent Tracer Dyes

Rhodamine WT has been approved as a tracer dye in potable water in the United States (1).

Rhodamine WT is related to rhodamine B, a tracer in common use in the 1960s. It was developed to overcome a disadvantage of rhodamine B, absorption on suspended sediment. The same modification was expected to reduce toxicity, and limited testing bore this out.

Rhodamine WT was an immediate success as a tracer in marine systems and in wastewater. While it was also used in potable water, such use was occasionally forbidden on the grounds that it did not have formal Federal approval for such use. Rhodamine WT is now approved for such use. A brief history follows.

While the EPA has sole responsibility for identifying those substances which may be used a tracers (2), the Food and Drug Administration (FDA) does issue policy statements. The FDA did issue such a policy statement on 22 April 1966 concerning rhodamine B (3). A temporary tolerance limit for ingestion of rhodamine B was set at 0.75 mg per day. Based on normally expensed water consumption, the tolerance would not be exceeded unless the concentration approaches 370 parts per billion (PPB). Noting that 30 PPB may be detected visually in a glass of water, and 10 PPB is visible in larger volume such as a clear reservoir, the FDA pointed out that if the dye is not visible, the tolerance would not be exceeded. The USGS, a large user of fluorescent dye tracers, directed that the concentration should not exceed 10 PPB at the intake of a water supply (4). The visual and instrumental detectability of rhodamine WT, based on active ingredient, is about the same as rhodamine B (rhodamine WT is supplied as a 20% aqueous solution).

Ten parts per billion may not sound like much to the uninitiated, but it is a thousand times the limit of detectability guaranteed by Turner Designs on its Model 10 Series Fluorometers (5). Background fluorescence caused by fluorescent materials in the water being studied usually limits detectability. But even so, measurements can be made to 0.1 part per billion of rhodamine WT (active ingredient), in raw sewage!

On April 10, 1980, Dr. Joseph A. Cotruvo of the U.S. EPA issued a memo stating that the EPA considers rhodamine WT to be equivalent to rhodamine B (1). More recently, the following policy letter was sent to Crompton and Knowles:

United States Environmental Protection Agency
Washington, D.C. 20460
Aug 2 1988

Office of Water Ms. Janice Warnquist Chemical Safety Manager Crompton and Knowles Corporation

P.O. Box 341 (500 Pear Street)
Reading, Pennsylvania 19603

Dear Ms. Warnquist:

The Criteria and Standards Division (Office of Drinking Water) has reviewed the available data on chemistry and toxicity of Rhodamine dyes. We would not anticipate any adverse health effects resulting from the use of Rhodamine WT as a fluorescent tracer in water flow studies when used with the following guidelines.

-A maximum concentration of 100 micrograms/liter Rhodamine WT is recommended for addition to raw water in hydrological studies involving surface and ground waters.

-Dye concentration should be limited to 10 micrograms/liter in raw water when used as a tracer in or around drinking water intakes.

-Concentration in drinking water should not exceed 0.1 micrograms/liter. Studies which result in actual human exposure to the dye via drinking water must be brief and infrequent. This level is not acceptable for chronic human exposure.

-In all of the above cases, the actual concentration used should not exceed the amount required for reasonably certain detection of the dye as required to accomplish the intended purpose of the study.

The Criteria and Standards Division recommends that Rhodamine B not be used as a tracer dye in water flow studies.

This advisory supersedes all earlier advisories issued by EPA on the use of fluorescent dyes as tracers in water flow studies. This advisory is granted on a temporary basis only.

EPA is terminating its voluntary additives advisory program as announced in the Federal Register (53 FR, 25586, July 7, 1988). A copy of the Federal Register Notice is enclosed for your convenience. All EPA advisory opinions issued within the framework of the additives program will expire on April 7, 1990.

Our opinion concerning the safety of this tracer dye does not constitute an endorsement, nor does it relate to its effectiveness for the intended use. If this letter is to be used in any way, we require it to be quoted in its entirety.

Sincerely,

Arthur H. Perler, Chief Science
and Technology Branch Criteria
and Standards Division

Enclosure

REFERENCES

1. Cotruvo, J. A., RHODAMINE WT AND B, Memo to P. J. Traina, dated April 10, 1980

2. Letter from A. D. Laumback, FDA, to George Turner, dated 7 June 1977

3. POLICY STATEMENT ON USE OF RHODAMINE B DYE AS A TRACER IN WATER FLOW STUDIES, Department of Health, Education and Welfare, dated 22 April 1966

4. Kilpatrick, F. A., DOSAGE REQUIREMENTS FOR SLUG INJECTIONS OF RHODAMINE BA AND WT DYES, U. S. Geological Survey, Prof. Pater 700-B, B250-253 (1970)

5. FIELD FLUOROMETRY, Monograph available at no charge from Turner Designs

Division of Kingscote Chemicals ®

WATER TRACING DYE

FWT RED PRODUCTS

TECHNICAL DATA BULLETIN

Bright Dyes FWT Red products are specially formulated versions of Rhodamine WT dye for convenient use in water tracing and leak detection studies. This bright, fluorescent red dye is certified by NSF International to ANSI/NSF Standard 60 for use in drinking water. It may be detected visually, by ultraviolet light and by appropriate fluoremetric equipment. Today it is most often used visually. Visually the dye appears bright pink to red, depending on its concentration and under ultraviolet light as bright orange.

The dye is resistant to absorption on most suspended matter in fresh and salt water. However, compared to Bright Dyes FLT Yellow/Green products it is significantly more resistant to degradation by sunlight and when used in fluoremetry, stands out much more 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 (200)	Powders
Detectability of active ingredient [1]	Visual <100 ppb	Visual <100 ppb	Visual <100 ppb
Maximum absorbance wavelength [2]	550/588 nm	550/588 nm	550/588 nm
Appearance	Dark red convex 1.6cm diameter	Clear dark red aqueous solution	Dark red fine powder
NSF (Max use level in potable water)	0.3 ppb	0.8 ppb	0.1 ppb
Weight	1.05 gms ± 0.05		
Dissolution Time [3]	50% < 3 minutes 95% < 6 minutes		50% < 3 minutes 95% < 6 minutes
Specific Gravity		1.15 ± 0.05 @ 25° C	
Viscosity [4]		4.3 cps	
pH		10.6 ± 0.20 @ 25° C	

Coverage of Products	One Tablet	One Pint Liquid	One Pound Powder
Light Visual	604 gallons	250,000 gallons	467,000 gallons
Strong Visual	60 gallons	25,000 gallons	46,700 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. To our best knowledge the information and recommendations contained herein are accurate and reliable. However, this information and our recommendations are furnished without warranty, representation, inducement, or license of any kind, including, but not limited to the implied warranties and fitness for a particular use or purpose. Customers are encouraged to conduct their own tests and to read the material safety data sheet carefully before using.

[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.

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		
Well #48 Meyers, R.	2432081.1	1293736.0
Well #40 Clinton, P.	2430569.0	1294595.0
Well #44 Arriaga, E.	2431239.0	1294829.0
Well #46 Aja, R.	2431796.9	1294839.9
Well #53 Lyda, R.	2430677.0	1294882.9
Well #30 Hopper R.	2430596.2	1295073.8

Well #34 Leija M. stock	2428903.1	1295573.7
Well #26 Riddle, R.	2430065.1	1295680.0
Well #24 MG Picnic well	2429973.9	1296268.8
Well #52 Conklin, R.	2430904.0	1296282.9
Well #31 Sanchez/Rosales	2430526.2	1295025.4
Well #50 Riddle (rental)	2431272.4	1293740.9
Well #37 Stoffel	2429296.8	1294056.4
Well #39 Riddle, Len	2430462.1	1294486.3
Well #25 Riddle, N.	2429331.0	1295709.2
Well #36 Anderson, T.	2428956.7	1294837.6
Well #35 Loveland	2428838.2	1295055.1
Well #33 MG Park MW	2428264.6	1295651.1
Well #38 Boyer	2430568.5	1293950.6
Well #47 Goolsby	2432174.6	1294516.0
Well #51 O'shea, B.	2431990.0	1294695.9
Well #29 McBride, R.	2430865.7	1295184.2
Well #43 Burrell	2430752.4	1294868.3
Well #41 Umek	2430465.9	1294750.6
Well #42 Evers	2430425.0	1295006.4
Well #28 RV Park	2430711.0	1295556.1
Well #45 Glendale Construction	2431315.2	1295751.5

Appendix C – Grid Information for Contouring Data south of Malad Gorge.

Wed Sep 21 11:11:03 2011

Grid File Name:	D:\data\Dye Tracing\Areas\Malad Gorge Site\Spring 2011 WL's, EC, FL, & Temperature Data\Master of WL's for Contouring (9-2-11).grd
Grid Size:	327 rows x 290 columns
Total Nodes:	94830
Filled Nodes:	94830
Blanked Nodes:	0

Grid Geometry

X Minimum:	2428174.241
X Maximum:	2437725.34
X Spacing:	33.048785467128
Y Minimum:	1288894.74
Y Maximum:	1299656.005
Y Spacing:	33.010015337423

Grid Statistics

Z Minimum:	3016.0546019335
Z 25%-tile:	3147.553150745
Z Median:	3197.6431881216
Z 75%-tile:	3239.9559454305
Z Maximum:	3265.0743206667
Z Midrange:	3140.5644613001
Z Range:	249.01971873317
Z Interquartile Range:	92.40279468552
Z Median Abs. Deviation:	46.511716864884
Z Mean:	3188.7516191368
Z Trim Mean (10%):	3192.4772840293
Z Standard Deviation:	57.65756377529
Z Variance:	3324.3946605017
Z Coef. of Variation:	0.018081547471201
Z Coef. of Skewness:	-0.64343487710616
Z Root Mean Square:	3189.2728455258
Z Mean Square:	10171461.283208

Figure 1. Shaded relief map of the tracer test site showing the 'Meyer' dye release well southeast of the Malad Gorge by 2.26 miles. Higher elevations are shown as blue tones, mid levels as yellow tones and lower elevations as brown tones. Nearby wells shown with black symbol.

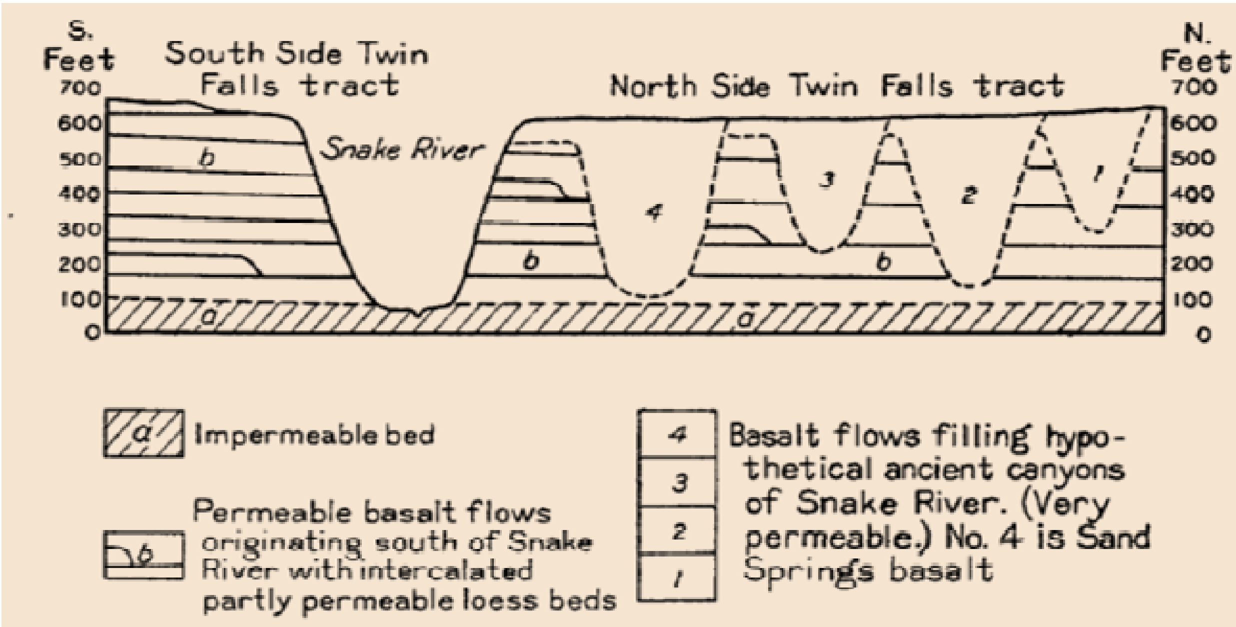


Figure 10.—Diagrammatic section showing postulated conditions beneath the North Side Twin Fall tract.

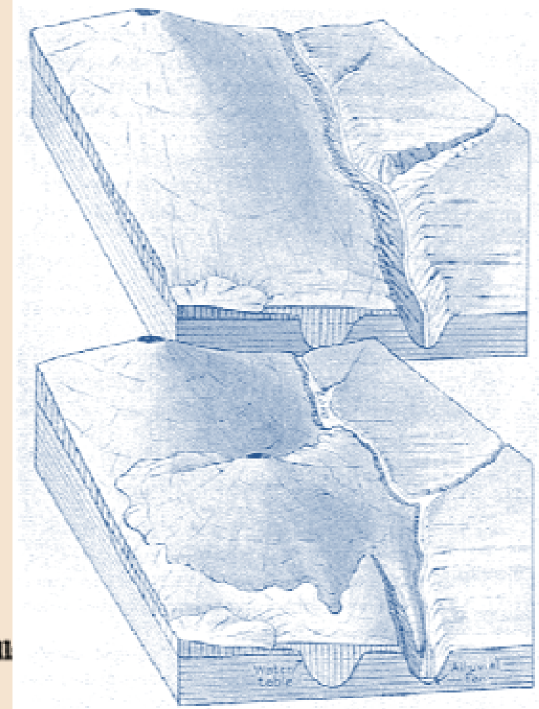


Fig. 6.—Diagram showing displacement of Snake River by lava flows

Figure 2. Diagrams from Stearns and others (1938) showing how the present Snake River and Canyon have been displaced in a southward progression by volcanic eruptions filling the canyon and displacing the river only to re-cut a new canyon.

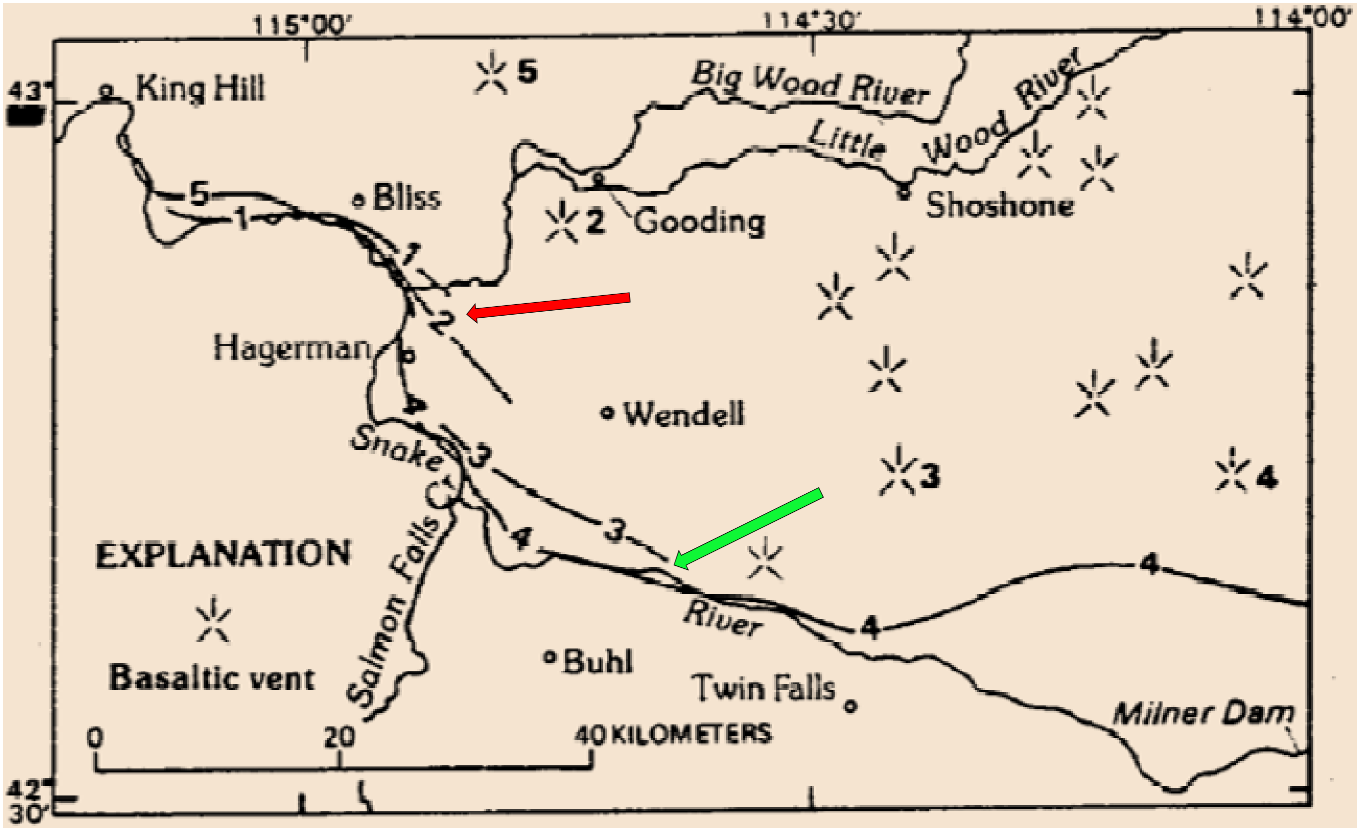


Figure 3. Map from Malde (1991) showing the approximate location of each ancestral canyon numbered 1 through 5 from oldest to youngest. Canyon #1 may be a major control for the dye traces south of Malad Gorge. Note the flow paths of the traces have the same azimuth as both Canyon #1 and #2. The canyons near the green arrow correlate with the depressed water table in the southeast corner of the contour lines in Figure 14.

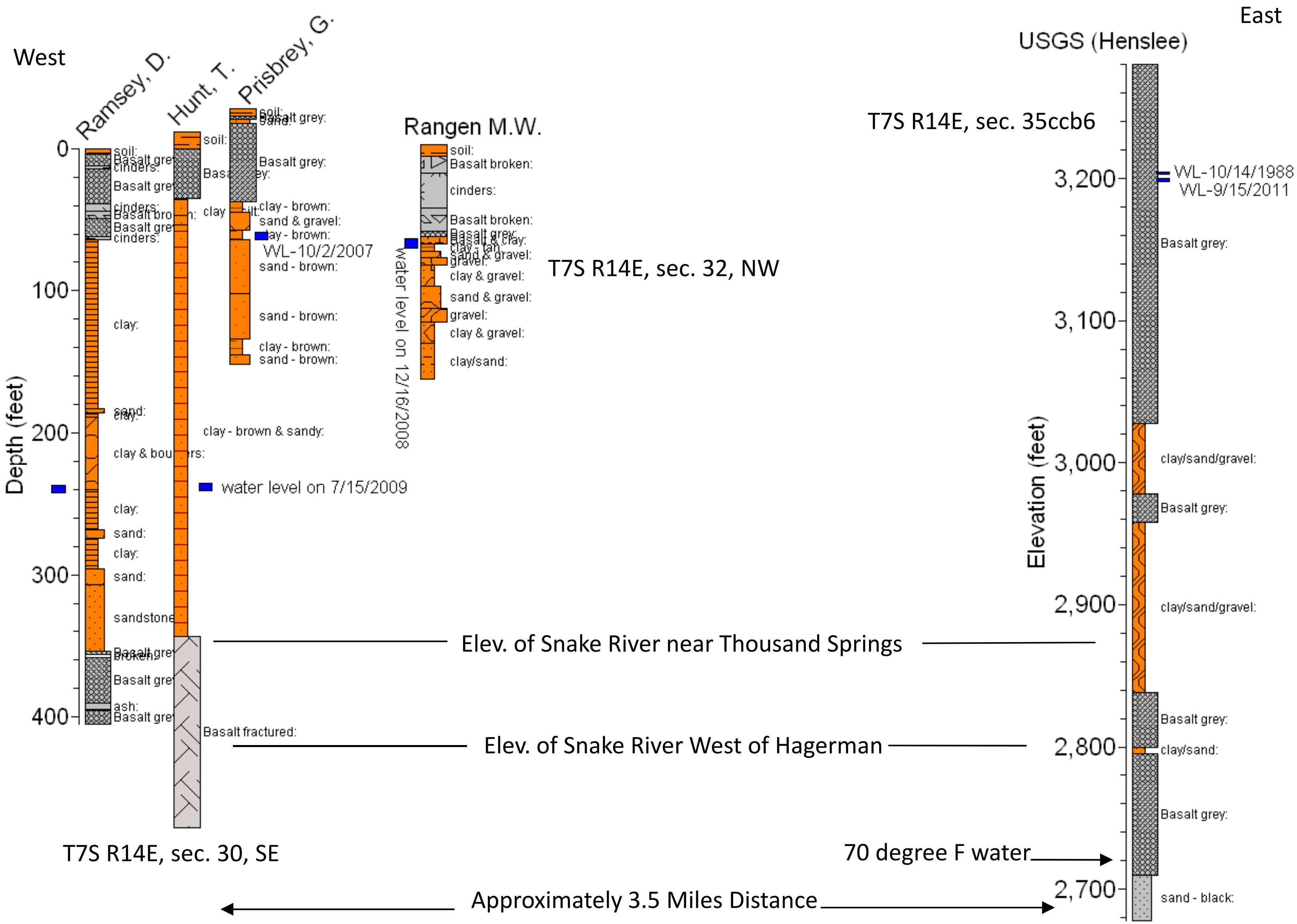


Figure 4. Geology of Vader grade area and USGS ‘Henslee’ well

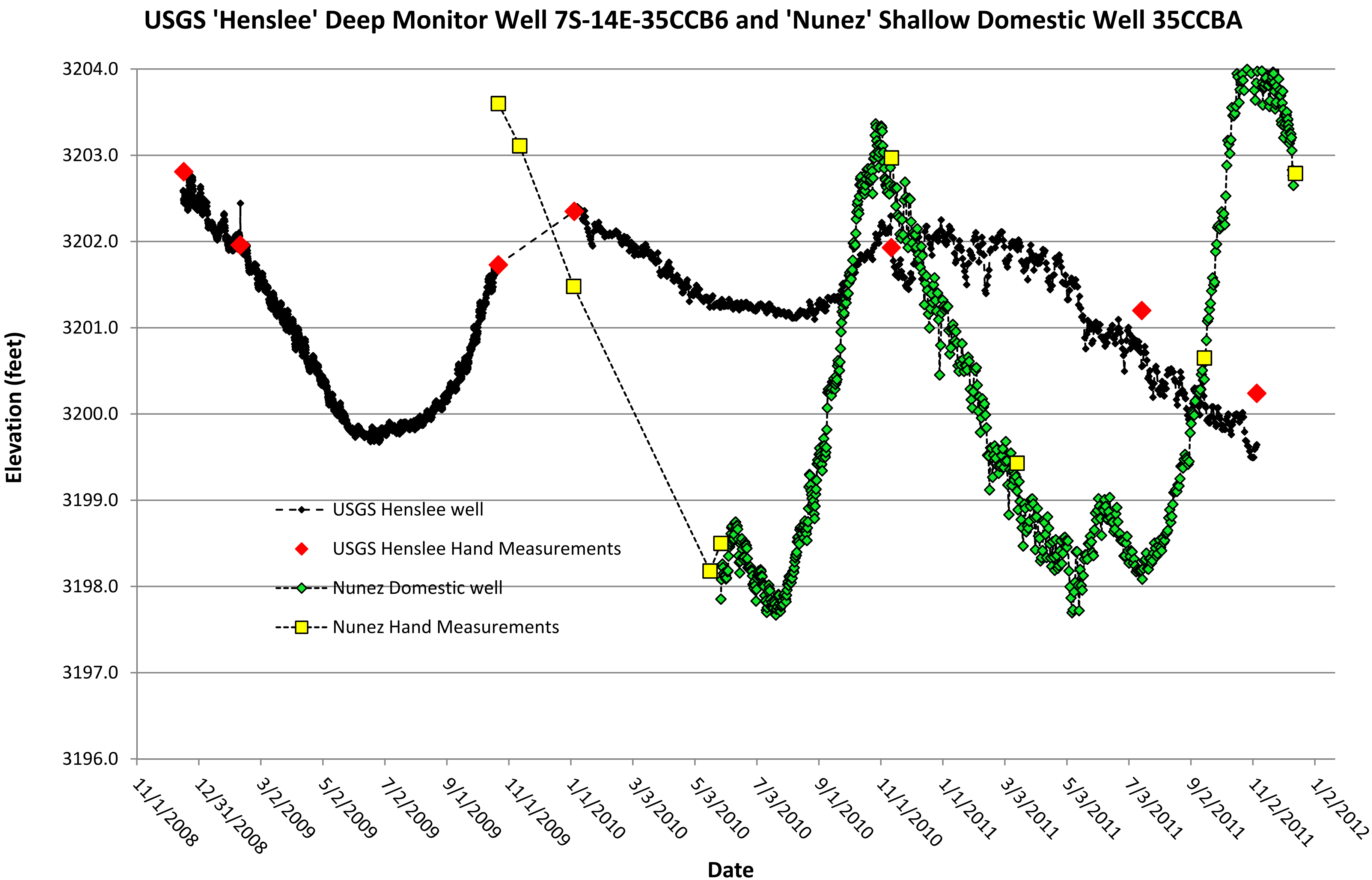


Figure 5. Hydrograph for USGS 'Henslee' well completed in the lower basalt.

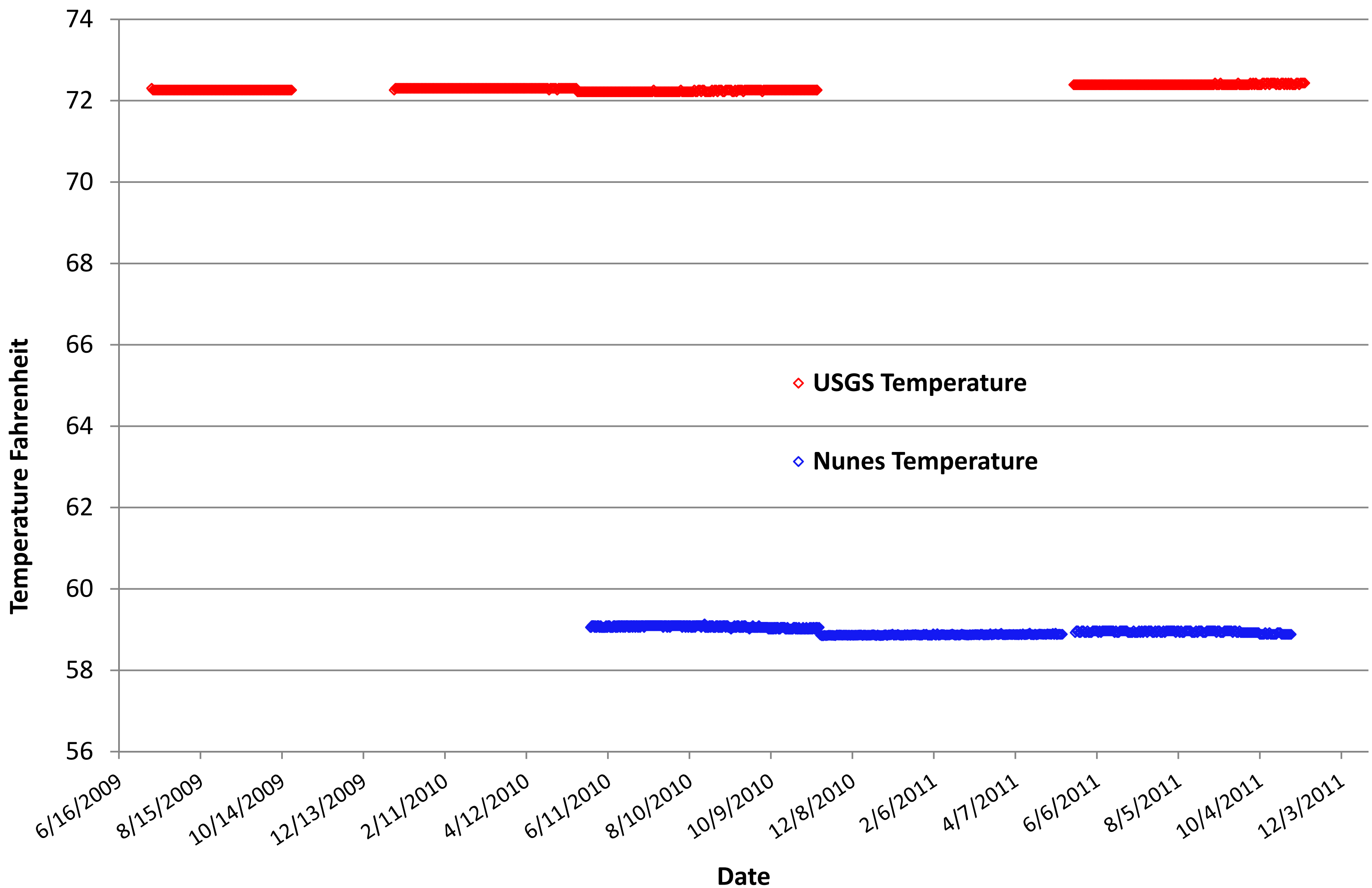


Figure 6. Temperature data for USGS Henslee well showing over 72 degree Fahrenheit water at 600 foot depth and the temperature for the 123 foot deep domestic well (Nunes D0023382) 60 feet south of the USGS well.

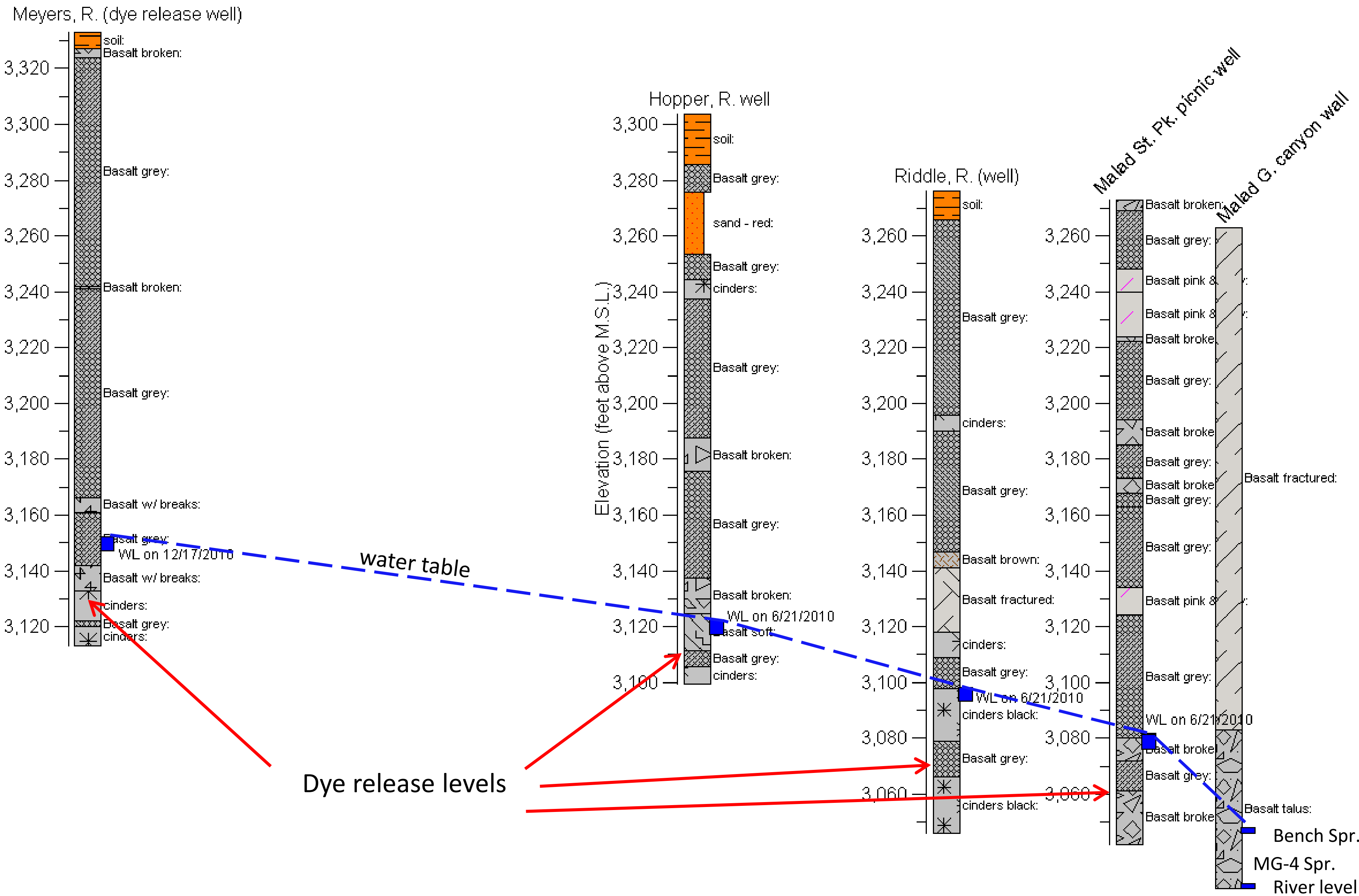


Figure 7. Geologic cross section of four wells and the Gorge wall showing elevations of dye release related to the geology and water table. The distance between the Meyer well and the Gorge is 2.26 miles. The Hopper well is about 1 mile and Riddle well about ½ mile.

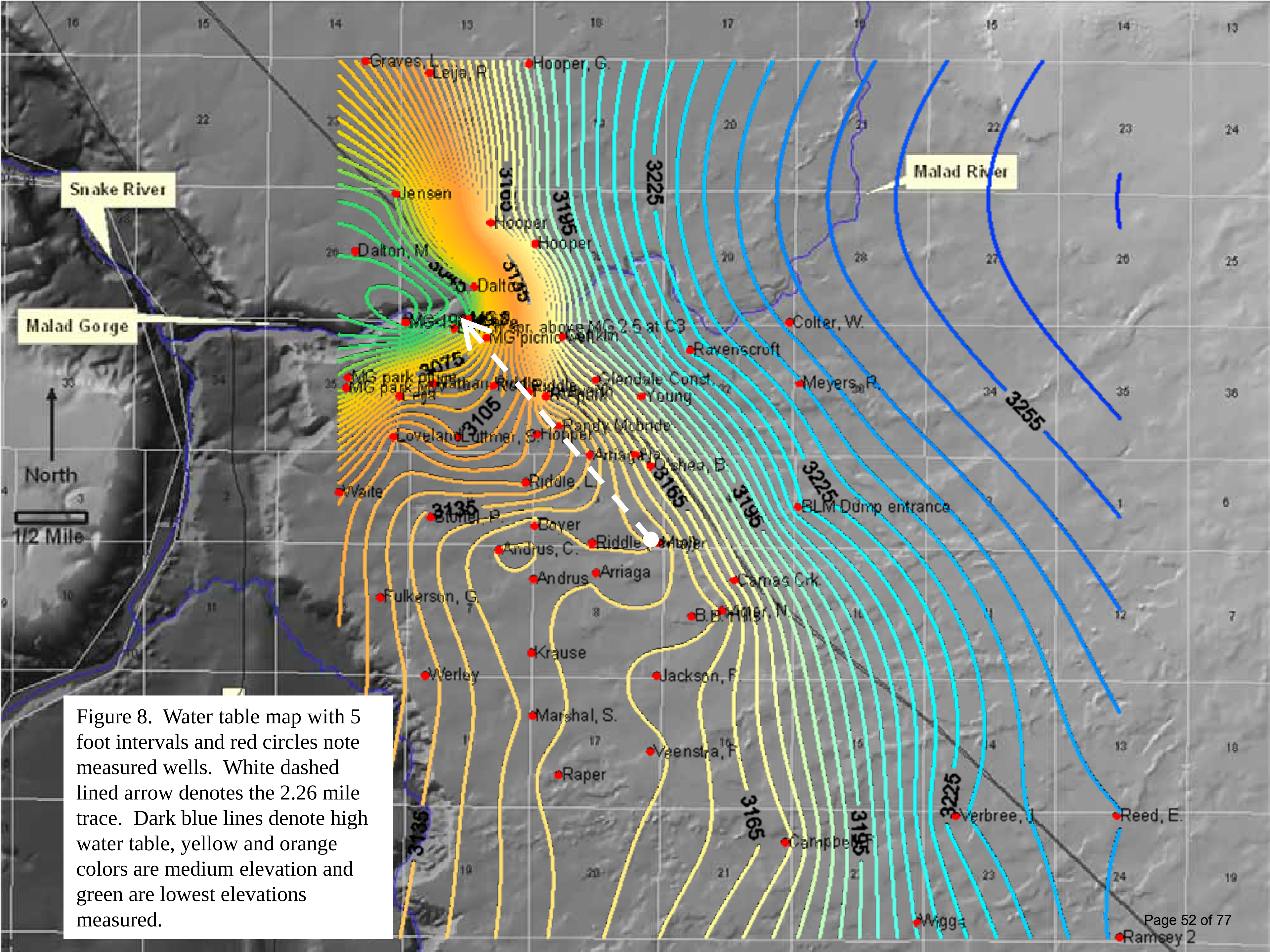


Figure 8. Water table map with 5 foot intervals and red circles note measured wells. White dashed lined arrow denotes the 2.26 mile trace. Dark blue lines denote high water table, yellow and orange colors are medium elevation and green are lowest elevations measured.

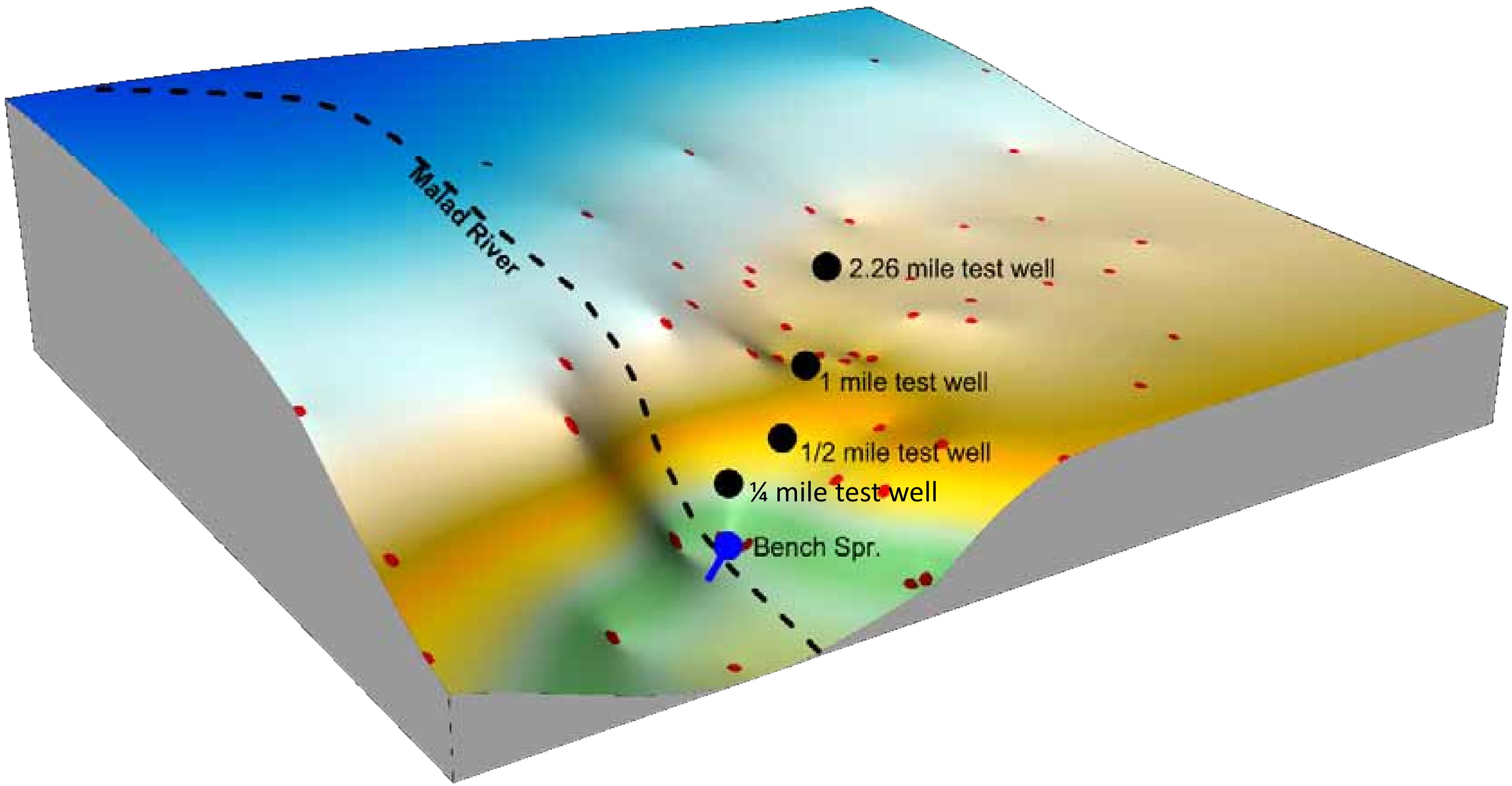


Figure 9. 3-D water table map with locations of tracer test wells in the same flow path. Note the steep water table around Malad Gorge where the 'Bench' spring is located. View angle is to the southeast.

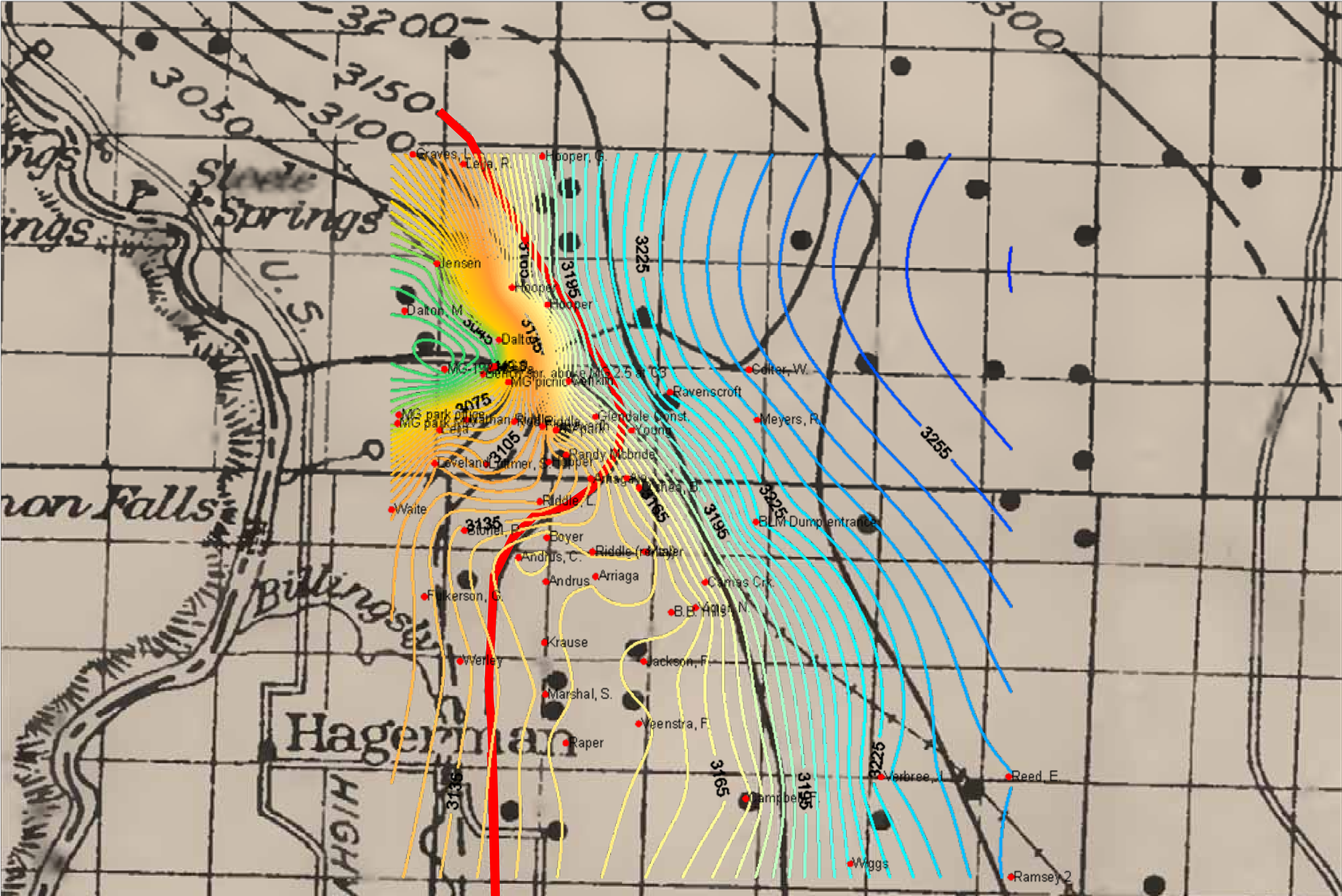


Figure 10. Groundwater contours from April 2011 shown with the color gradient overlain onto H.T. Stearns 1938 map. Note the concave then convex shape of the red highlighted contour from Stearn’s map compared to the same patterns of the high resolution contours.

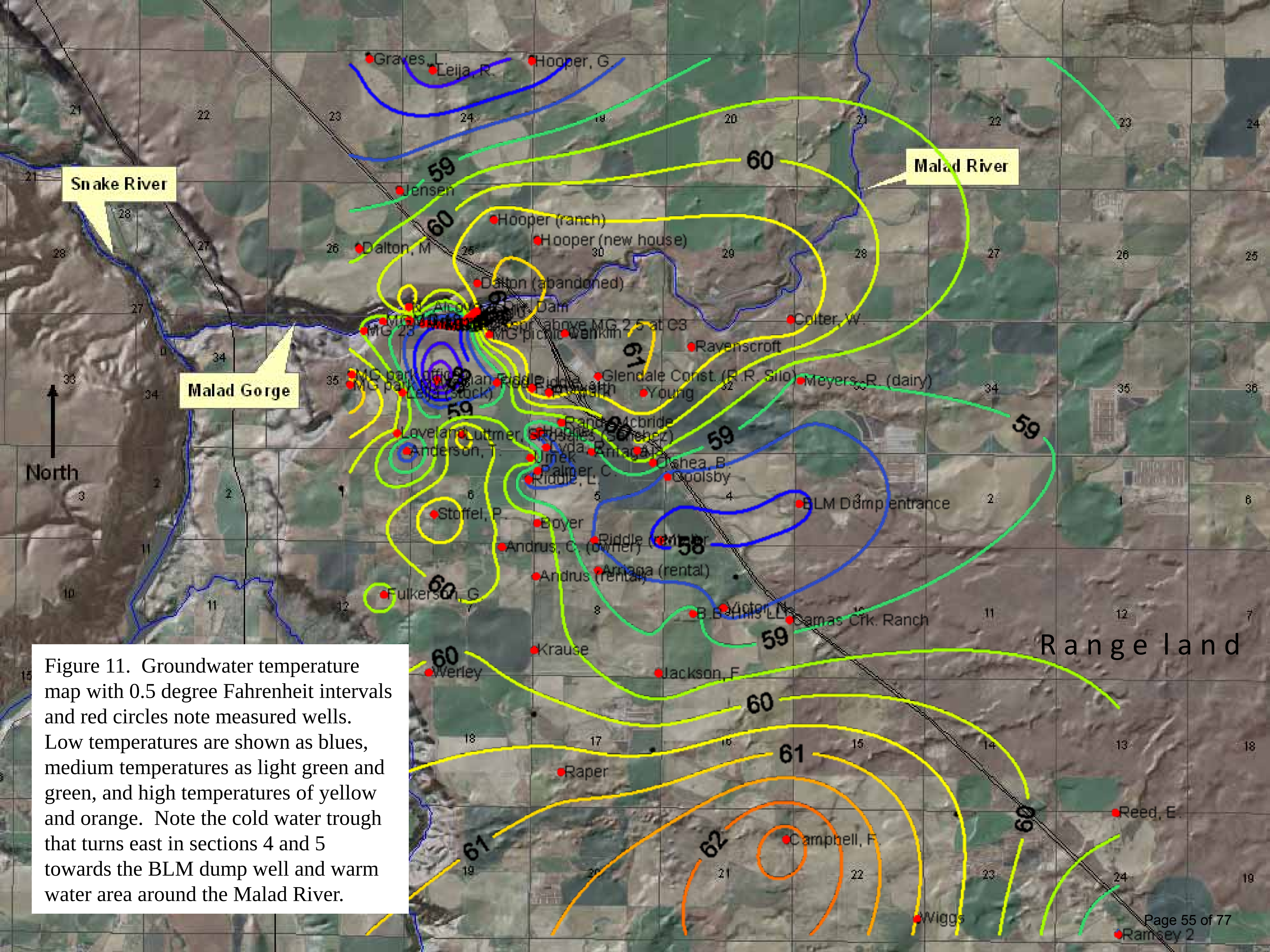


Figure 11. Groundwater temperature map with 0.5 degree Fahrenheit intervals and red circles note measured wells. Low temperatures are shown as blues, medium temperatures as light green and green, and high temperatures of yellow and orange. Note the cold water trough that turns east in sections 4 and 5 towards the BLM dump well and warm water area around the Malad River.

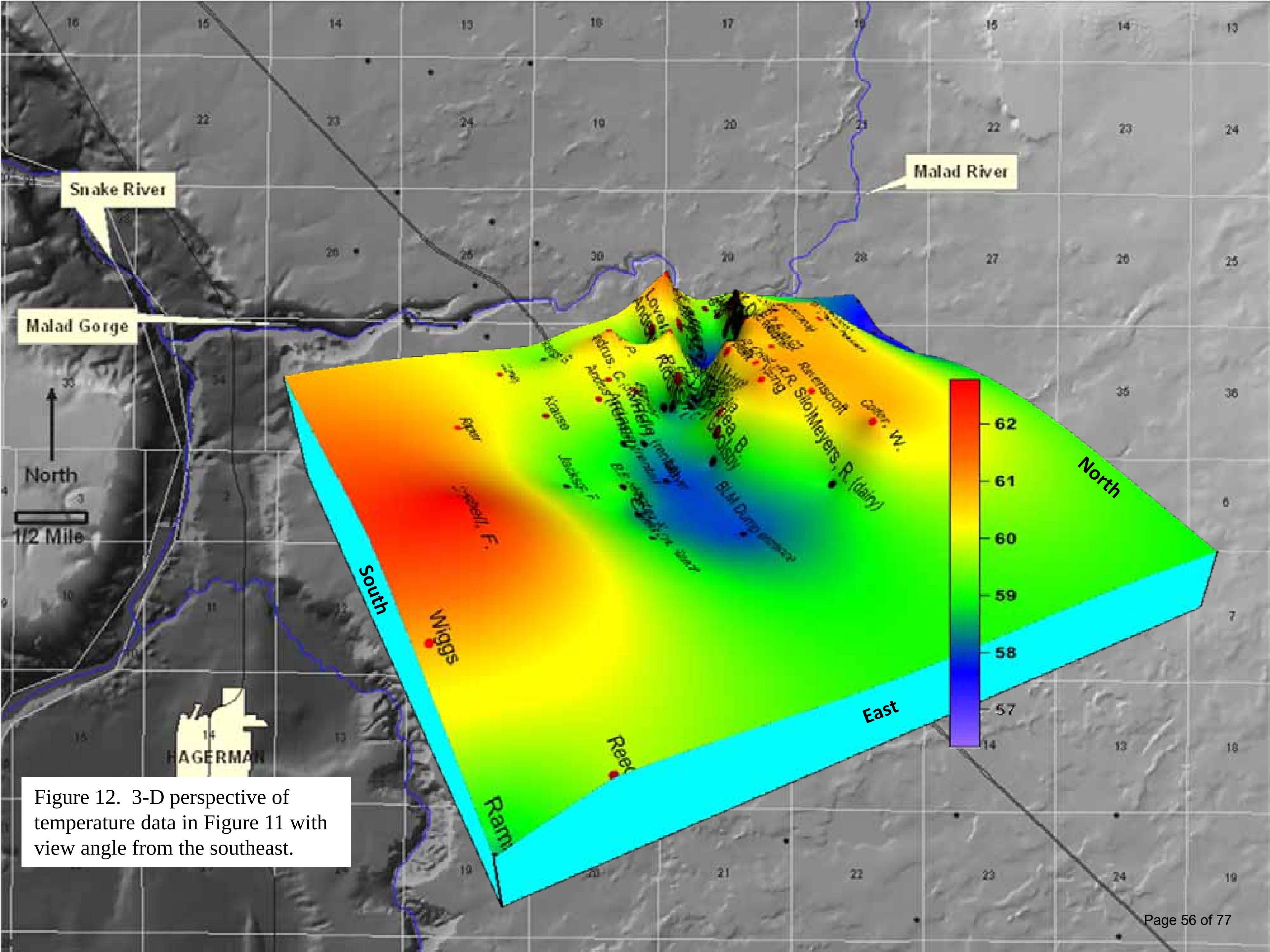


Figure 12. 3-D perspective of temperature data in Figure 11 with view angle from the southeast.

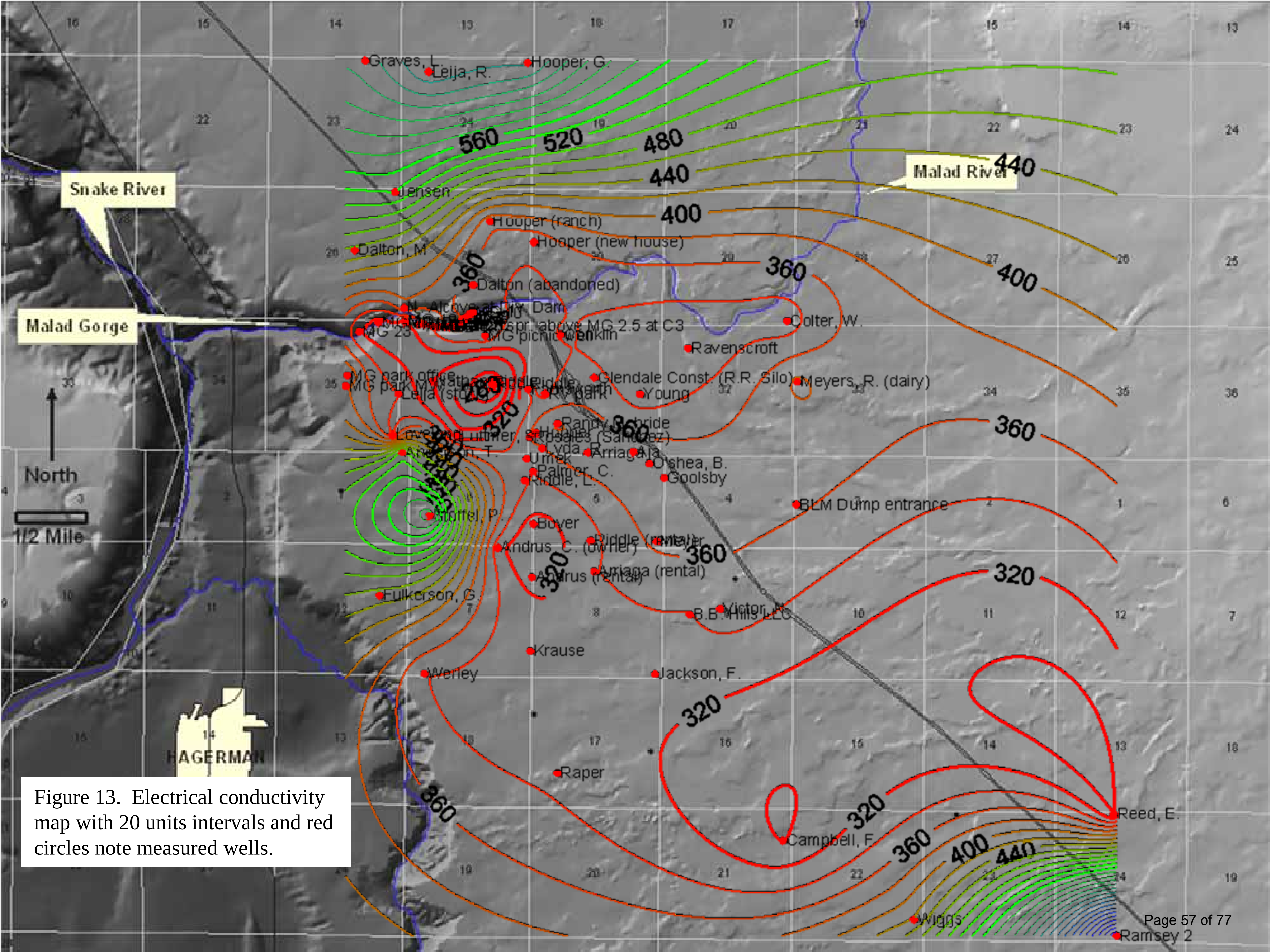


Figure 13. Electrical conductivity map with 20 units intervals and red circles note measured wells.

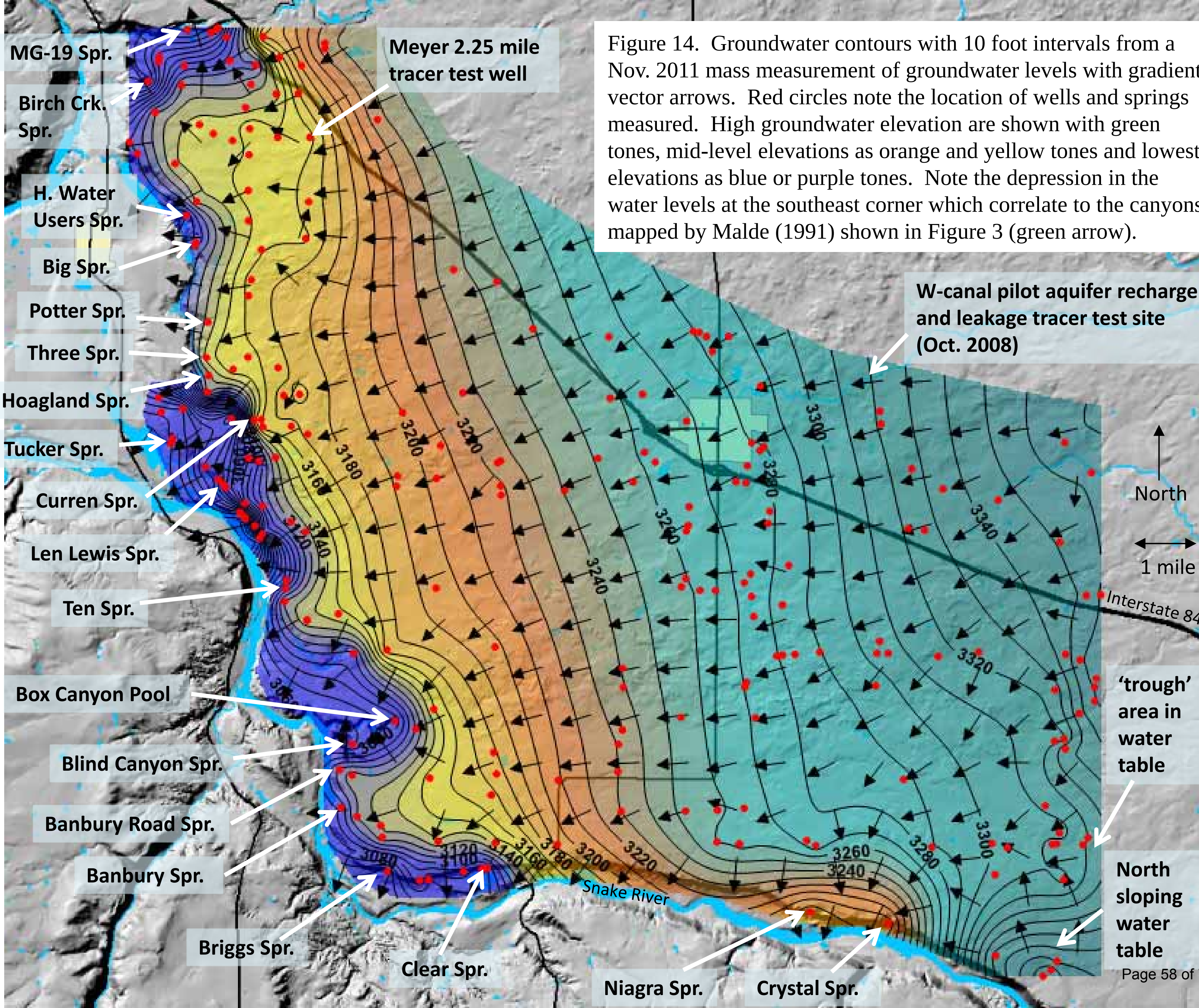


Figure 14. Groundwater contours with 10 foot intervals from a Nov. 2011 mass measurement of groundwater levels with gradient vector arrows. Red circles note the location of wells and springs measured. High groundwater elevation are shown with green tones, mid-level elevations as orange and yellow tones and lowest elevations as blue or purple tones. Note the depression in the water levels at the southeast corner which correlate to the canyons mapped by Malde (1991) shown in Figure 3 (green arrow).

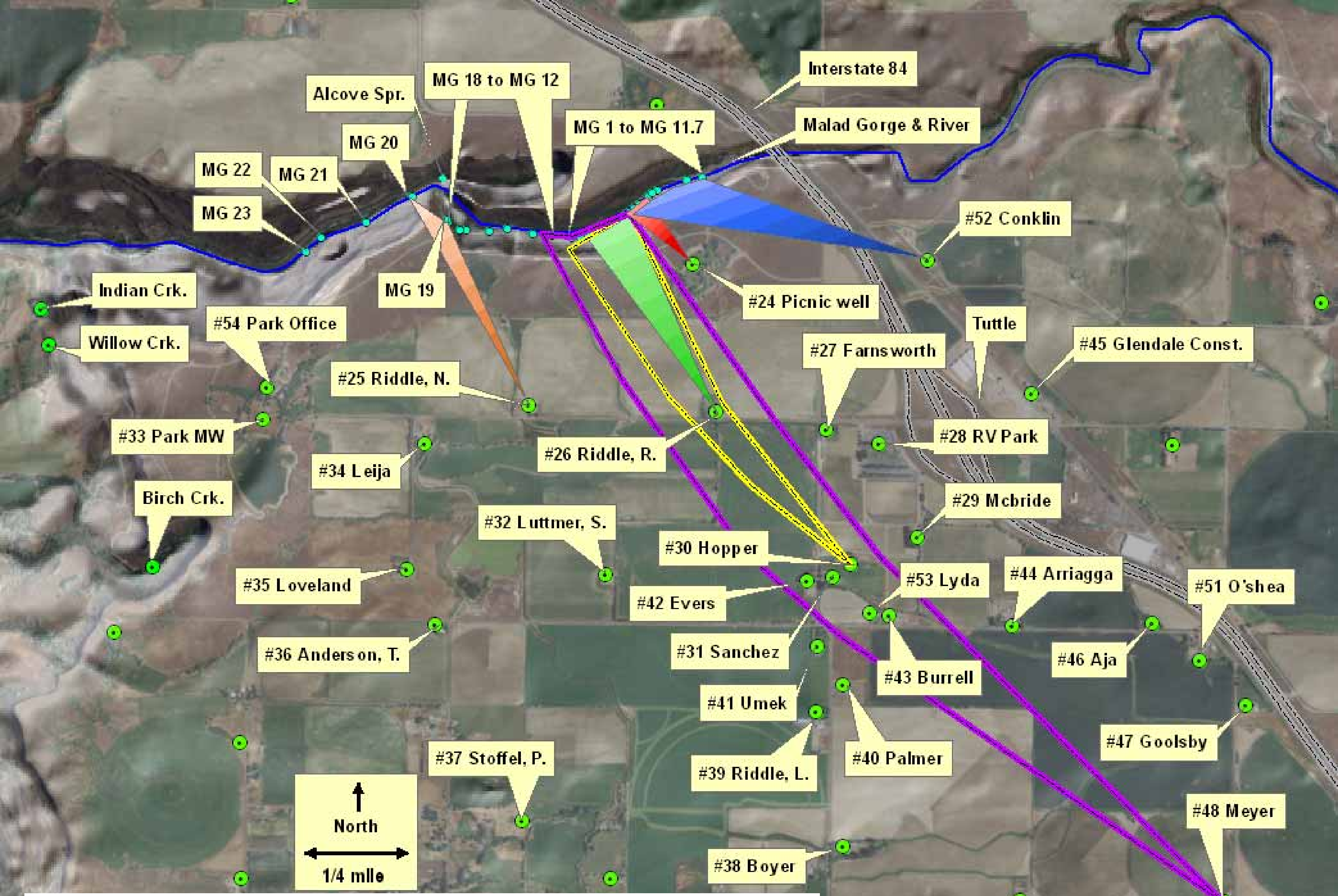


Figure 15. Map of dye traces to date delineated with different colored triangular shaped polygons and monitoring locations . Wells are represented with green circles and springs with light blue circles.


Malad Gorge in Winter Conditions

Figure 16. Visual results of charcoal packet analysis from Trace #1 showing Fluorescein dye in MG-1, 2.5, 4 and the Bench Spring. The packet at MG-3 had shifted out of the water. Trace #1 was started during winter conditions in the Gorge.

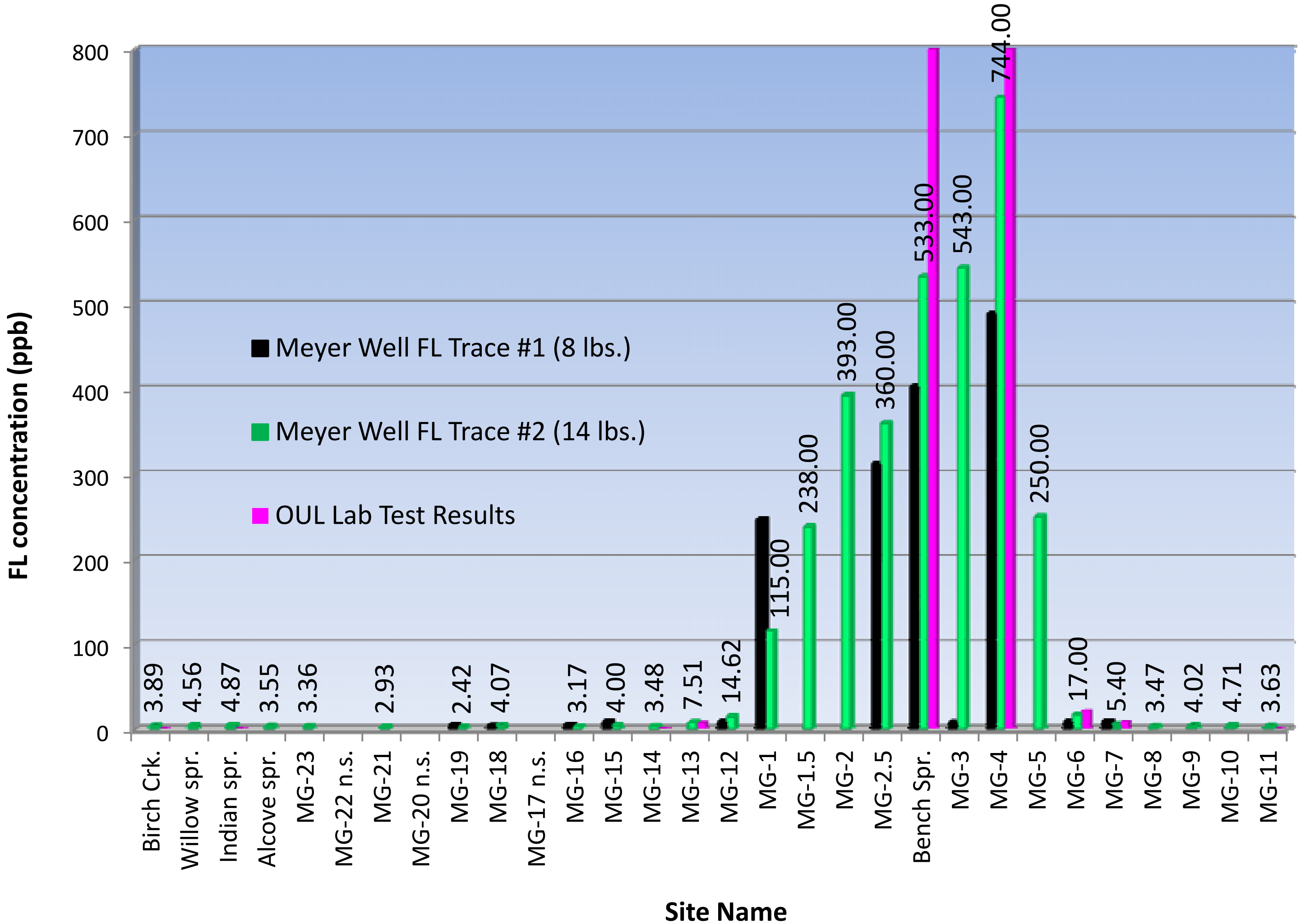


Figure 17. Charcoal packet results from springs in the Gorge and other nearby springs for both Meyer Well #48 traces along with lab analysis results (pink bars) from the second test. Note the increase in concentrations in the springs that correspond to an increase of dye released from 8 pounds to 14 pounds. MG-1 appears to have a lab error. Numerical values shown on graph are for Trace #2 results only.

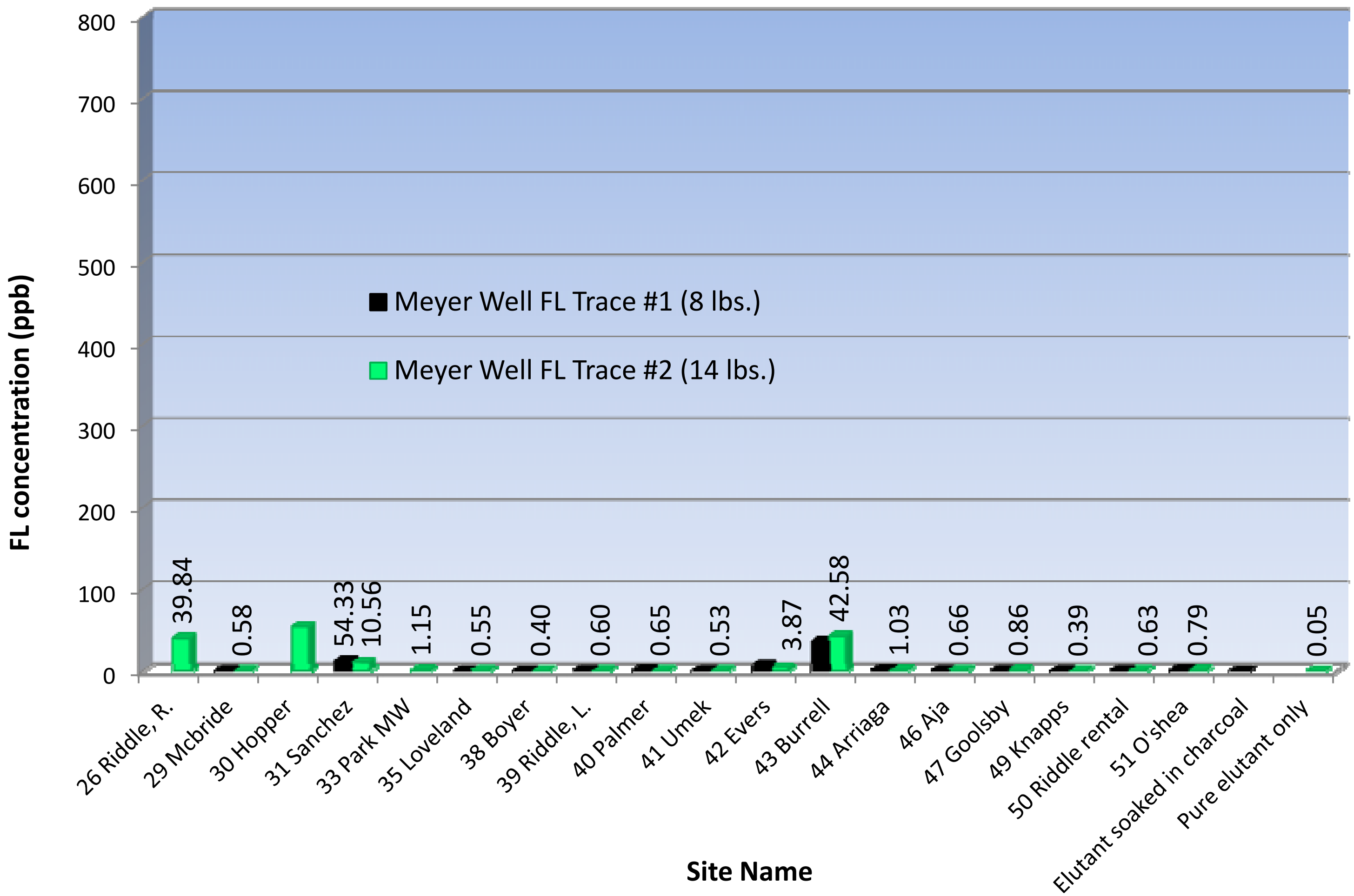


Figure 18. Charcoal packet results from toilet tanks (essentially wells) for both Meyer Well #48 traces. Note the increase in concentration in the charcoal packet at well #43 Burrell which corresponds to an increase in dye released from 8 to 14 pounds of dye released. Toilet use patterns, storage in the pressure tank and delivery pipe, and depth to pump intake all effect the results of toilet tank methods of detection with charcoal packets. Raw numerical values for Trace #2 are shown on the same vertical scale as Figure 16 and they are not adjusted to the pure elutant tested after soaking in unused charcoal.

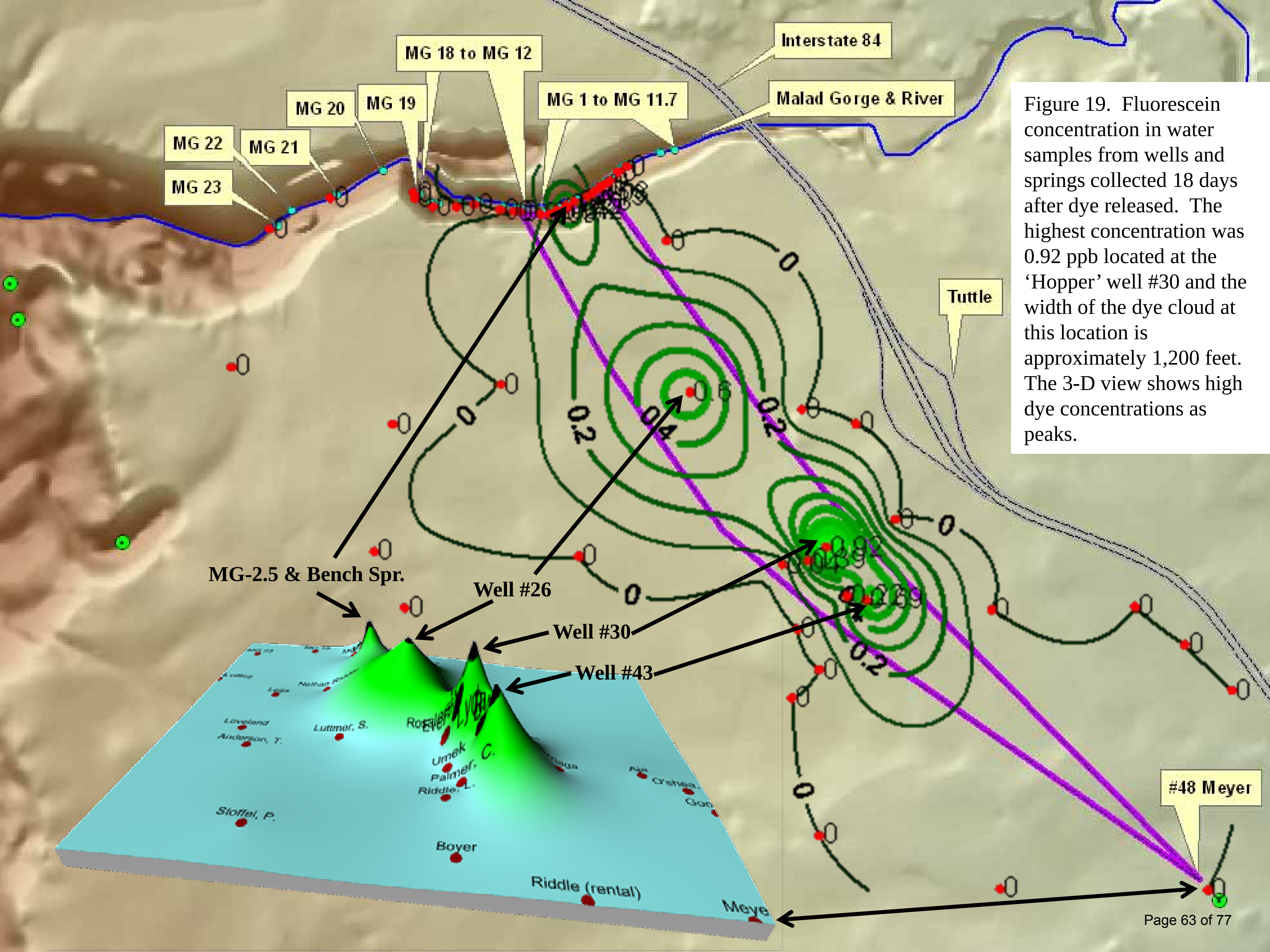


Figure 19. Fluorescein concentration in water samples from wells and springs collected 18 days after dye released. The highest concentration was 0.92 ppb located at the ‘Hopper’ well #30 and the width of the dye cloud at this location is approximately 1,200 feet. The 3-D view shows high dye concentrations as peaks.

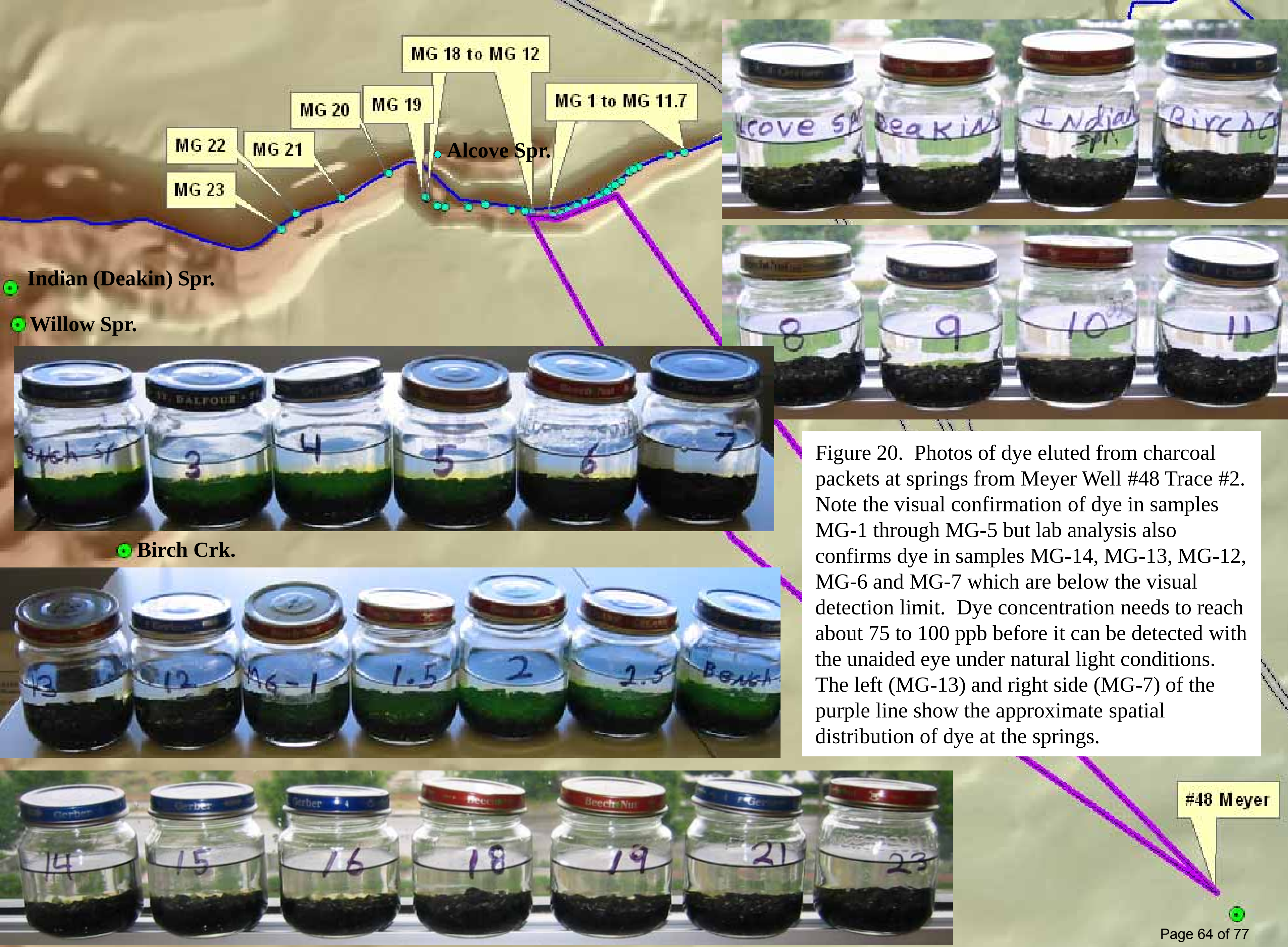


Figure 20. Photos of dye eluted from charcoal packets at springs from Meyer Well #48 Trace #2. Note the visual confirmation of dye in samples MG-1 through MG-5 but lab analysis also confirms dye in samples MG-14, MG-13, MG-12, MG-6 and MG-7 which are below the visual detection limit. Dye concentration needs to reach about 75 to 100 ppb before it can be detected with the unaided eye under natural light conditions. The left (MG-13) and right side (MG-7) of the purple line show the approximate spatial distribution of dye at the springs.

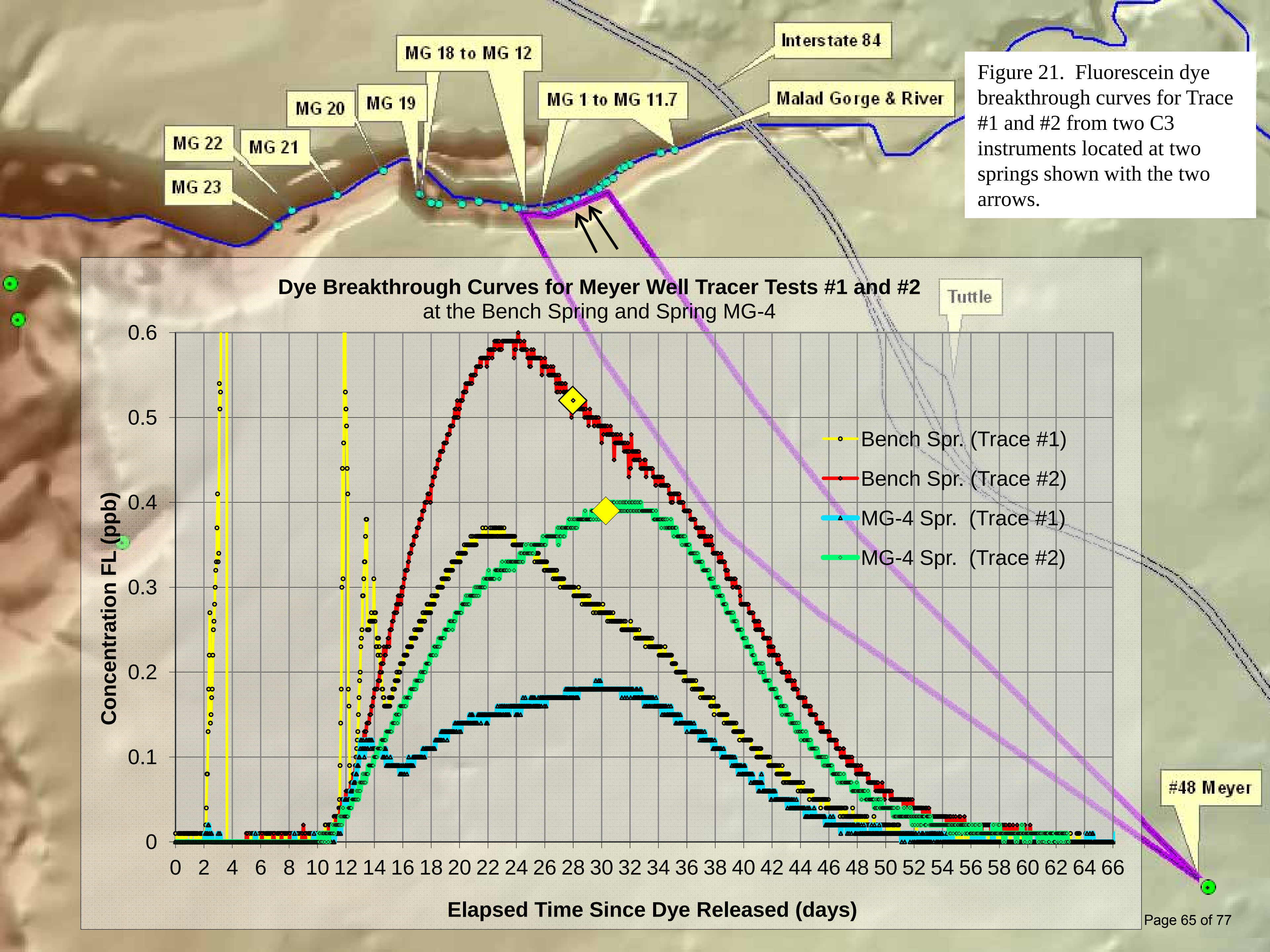


Figure 21. Fluorescein dye breakthrough curves for Trace #1 and #2 from two C3 instruments located at two springs shown with the two arrows.

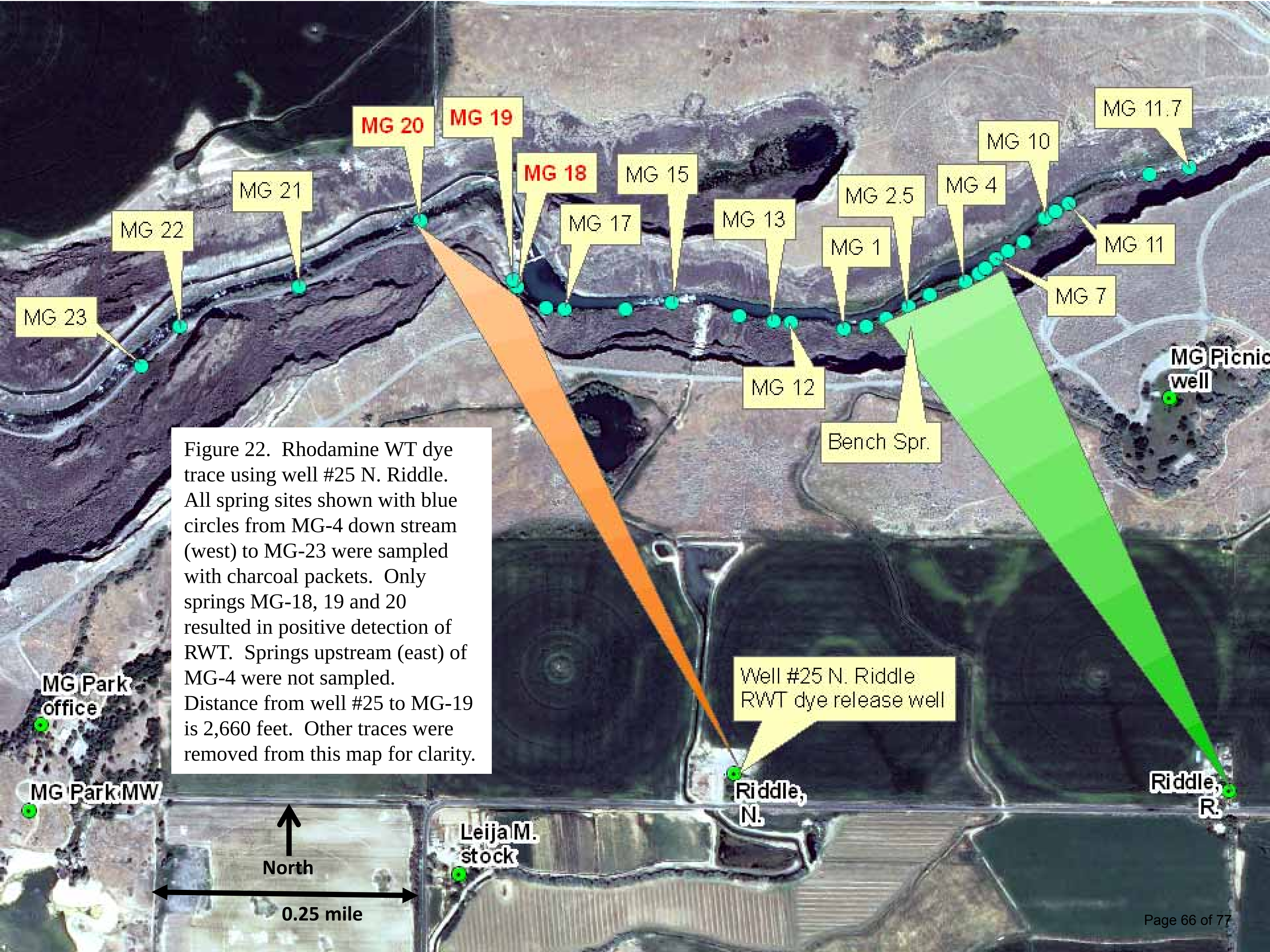


Figure 22. Rhodamine WT dye trace using well #25 N. Riddle. All spring sites shown with blue circles from MG-4 down stream (west) to MG-23 were sampled with charcoal packets. Only springs MG-18, 19 and 20 resulted in positive detection of RWT. Springs upstream (east) of MG-4 were not sampled. Distance from well #25 to MG-19 is 2,660 feet. Other traces were removed from this map for clarity.

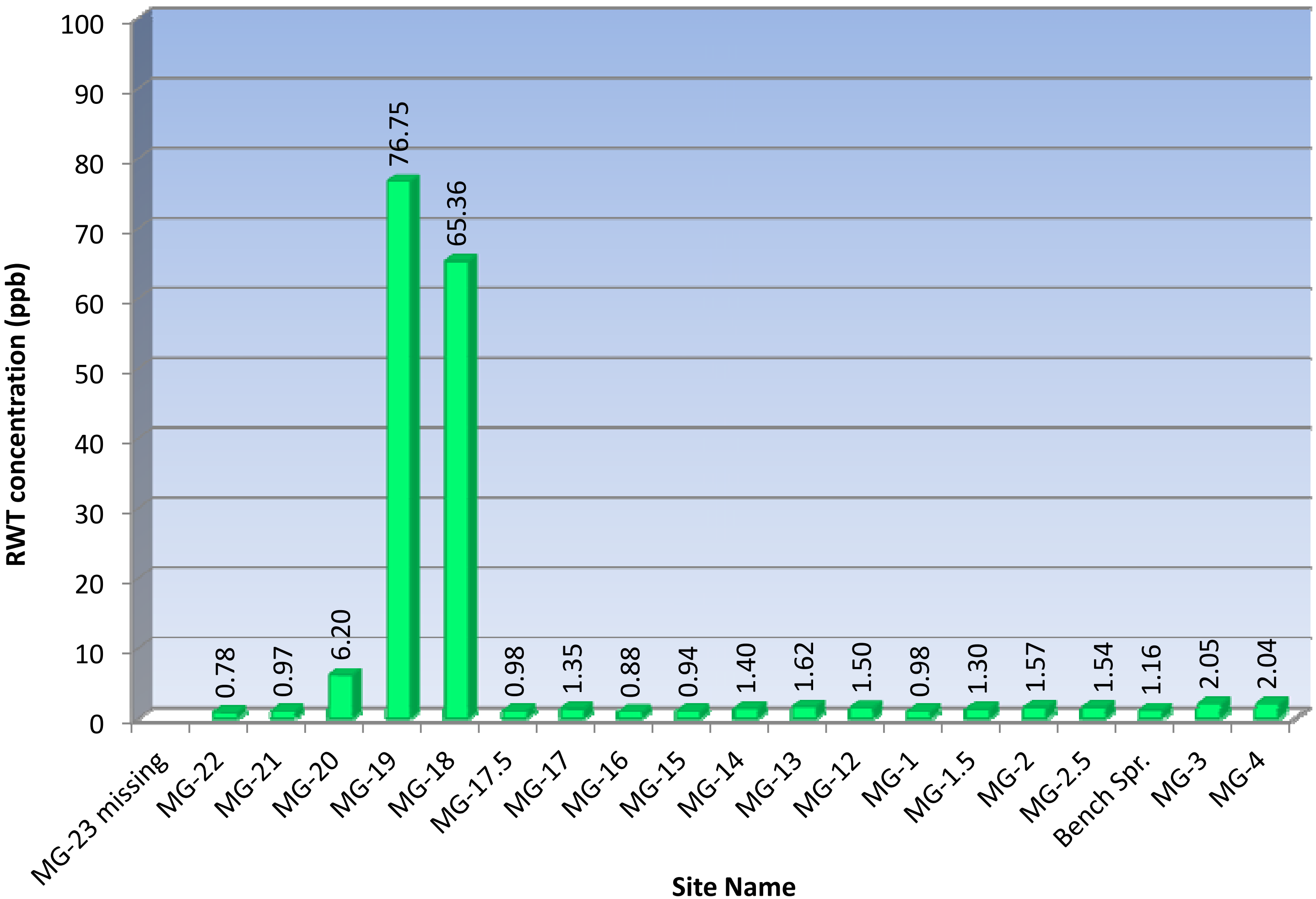


Figure 23. Graph of results from charcoal packets for N. Riddle well #25 Rhodamine WT trace. Dye was detected with positive results at sites MG-18, 19 and 20 at about 50 to 70 times above the ambient background fluorescence with the remaining sites negative. MG-23 was missing.

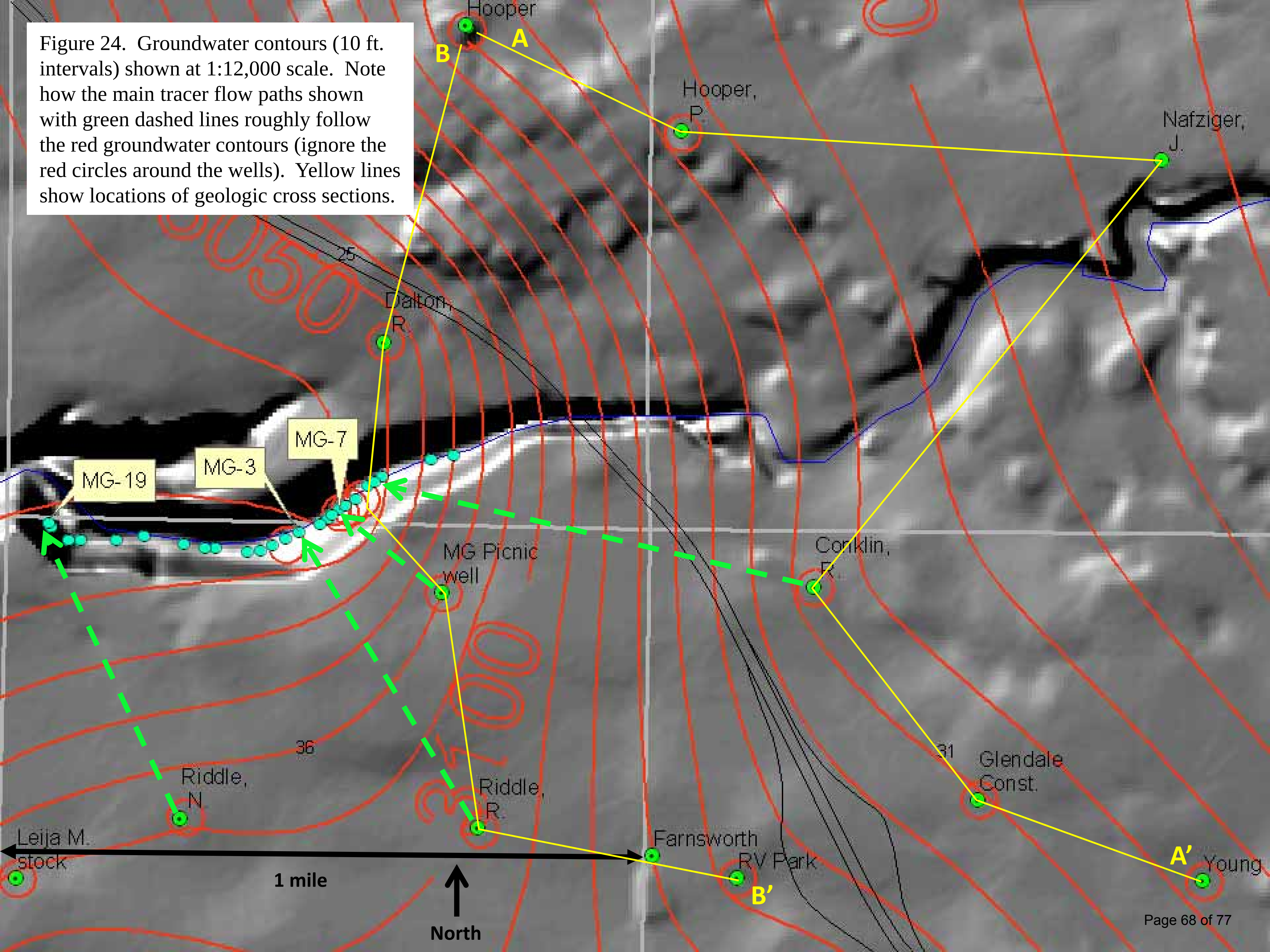


Figure 24. Groundwater contours (10 ft. intervals) shown at 1:12,000 scale. Note how the main tracer flow paths shown with green dashed lines roughly follow the red groundwater contours (ignore the red circles around the wells). Yellow lines show locations of geologic cross sections.

Geologic Cross Section A-A’

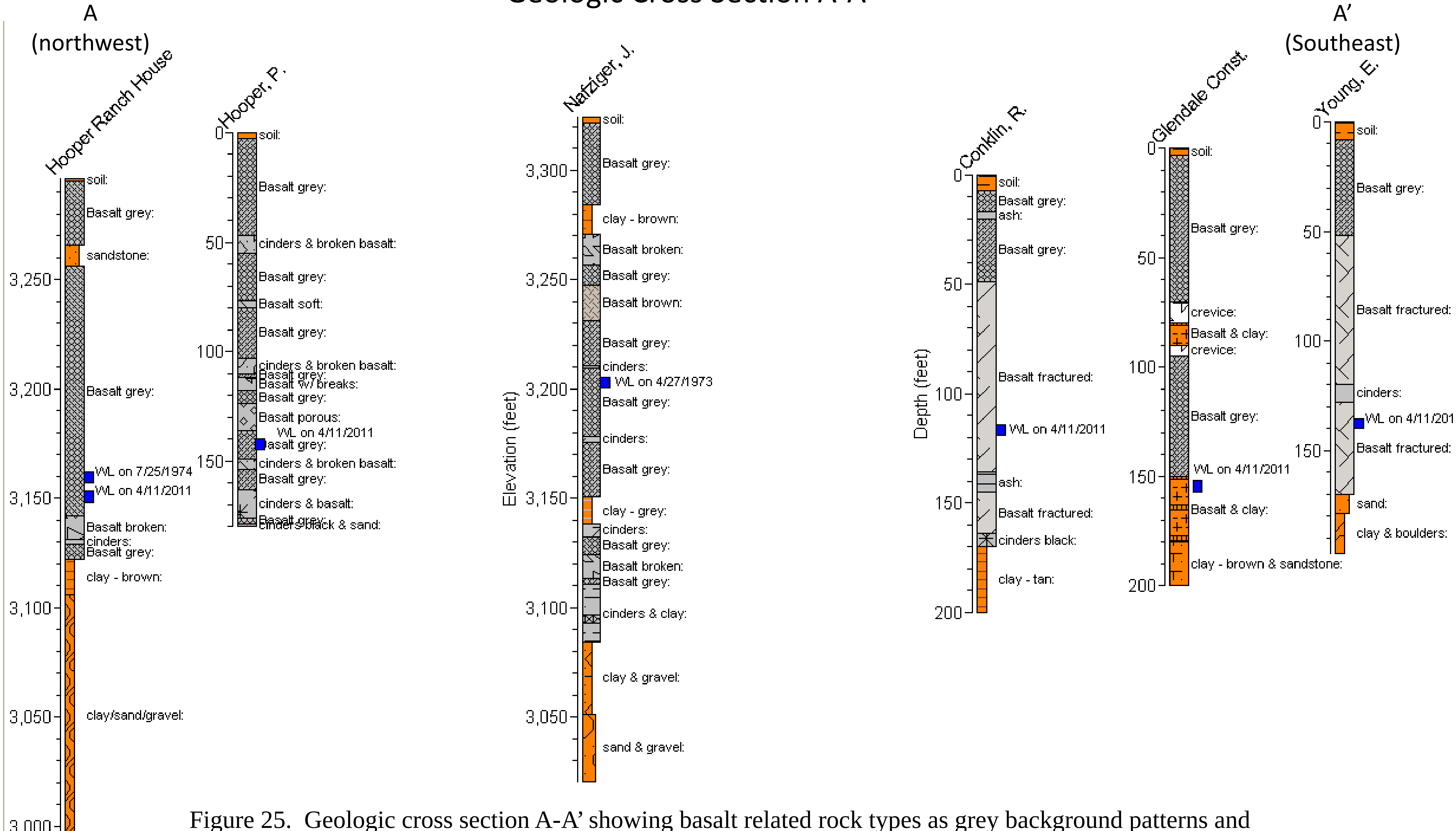


Figure 25. Geologic cross section A-A’ showing basalt related rock types as grey background patterns and sediment related rock types as orange background patterns. Water levels symbols are blue. Note the thickness of the sediments in the lower levels of the wells ranging from about 50 to 120 feet which would be atypical for paleosol interbeds and suggest this is the top of the Tuana Gravel and/or Glenns Ferry Formations.

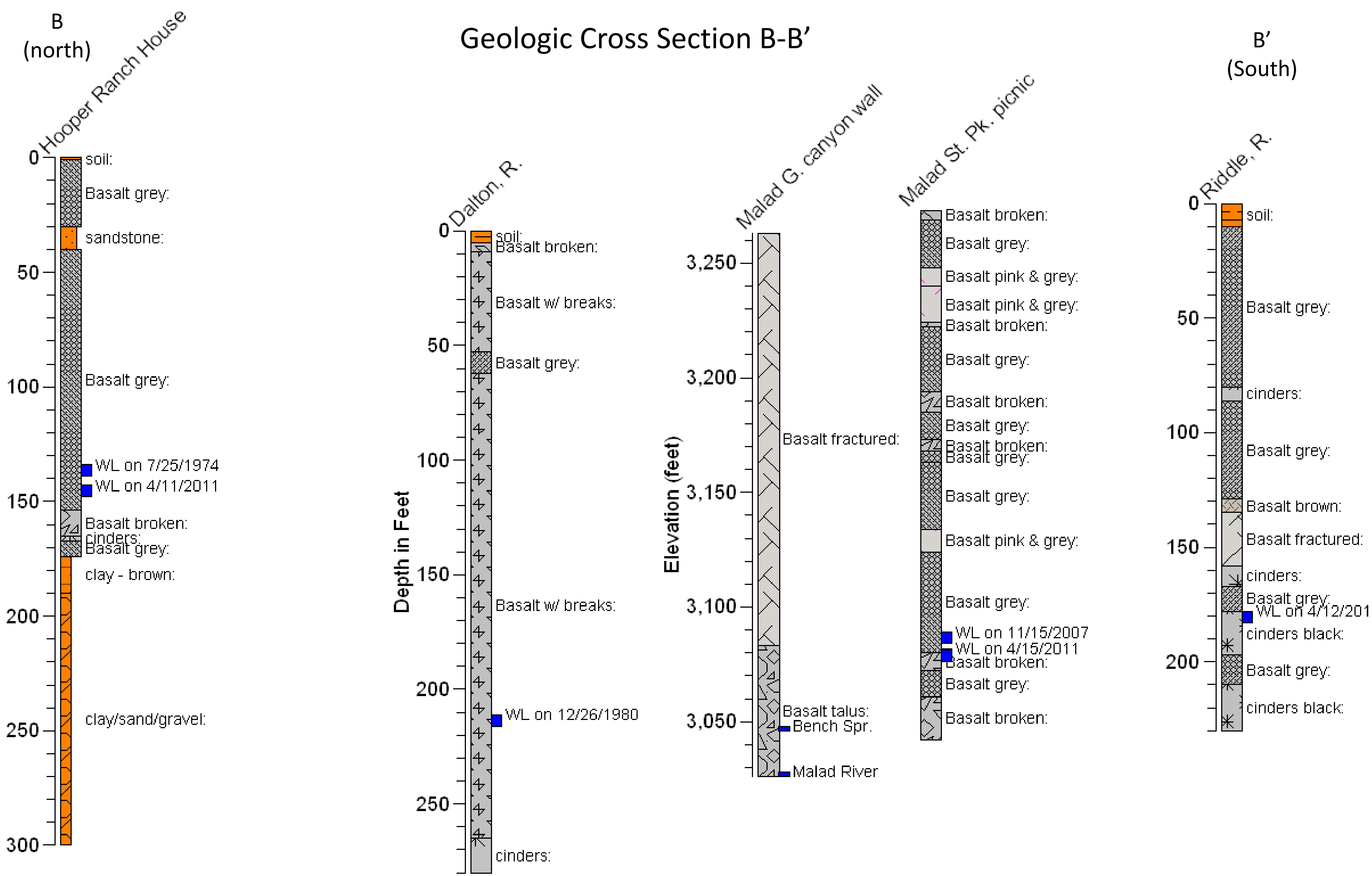
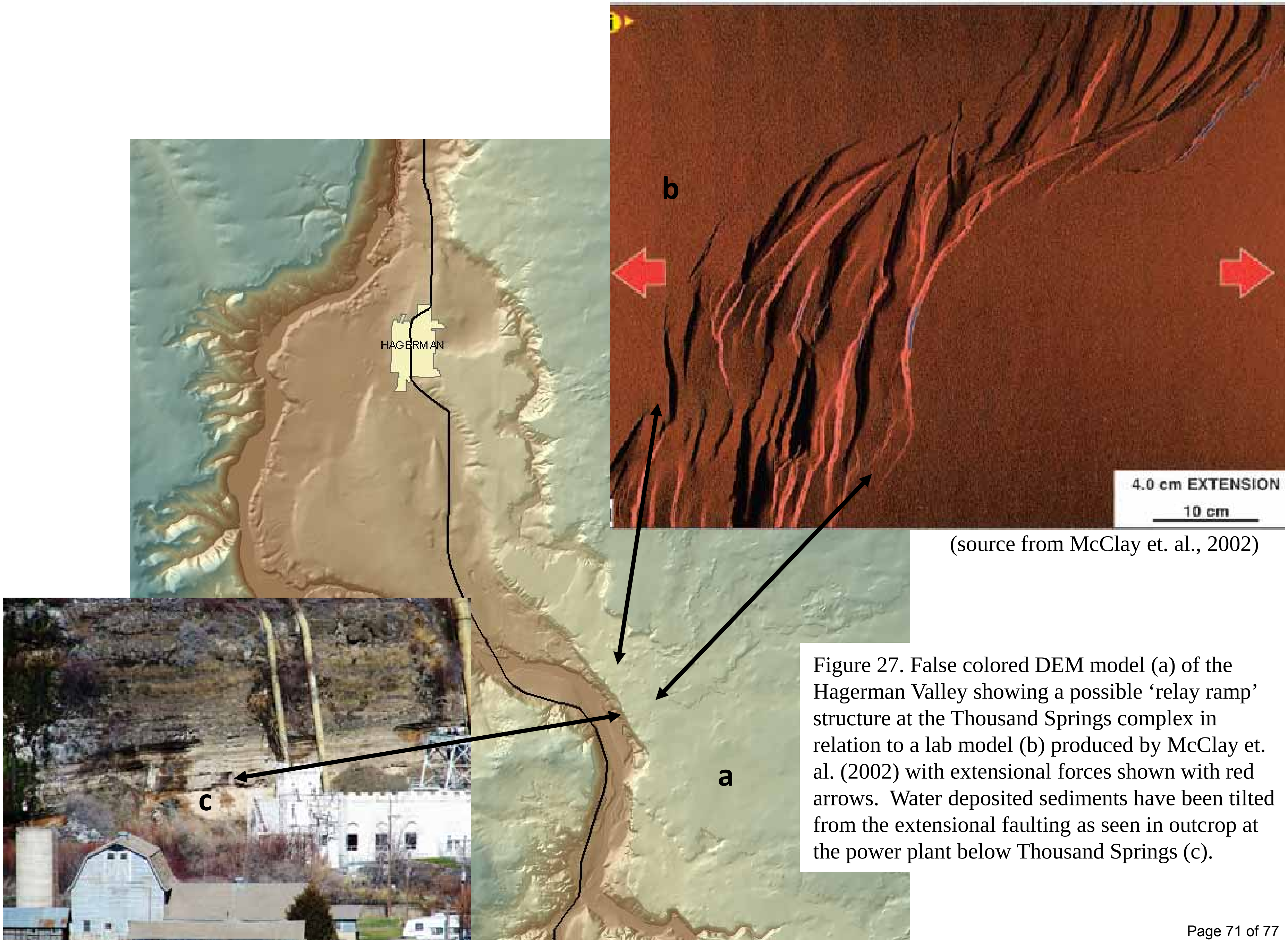


Figure 26. Geologic cross section B-B’ showing basalt related rock types as grey background patterns and sediment related rock types as orange background patterns. Water levels symbols are blue. Note the lack of sediments near the Malad Gorge at these depths compared to cross section A-A’ east of the Gorge.



(source from McClay et. al., 2002)

Figure 27. False colored DEM model (a) of the Hagerman Valley showing a possible 'relay ramp' structure at the Thousand Springs complex in relation to a lab model (b) produced by McClay et. al. (2002) with extensional forces shown with red arrows. Water deposited sediments have been tilted from the extensional faulting as seen in outcrop at the power plant below Thousand Springs (c).

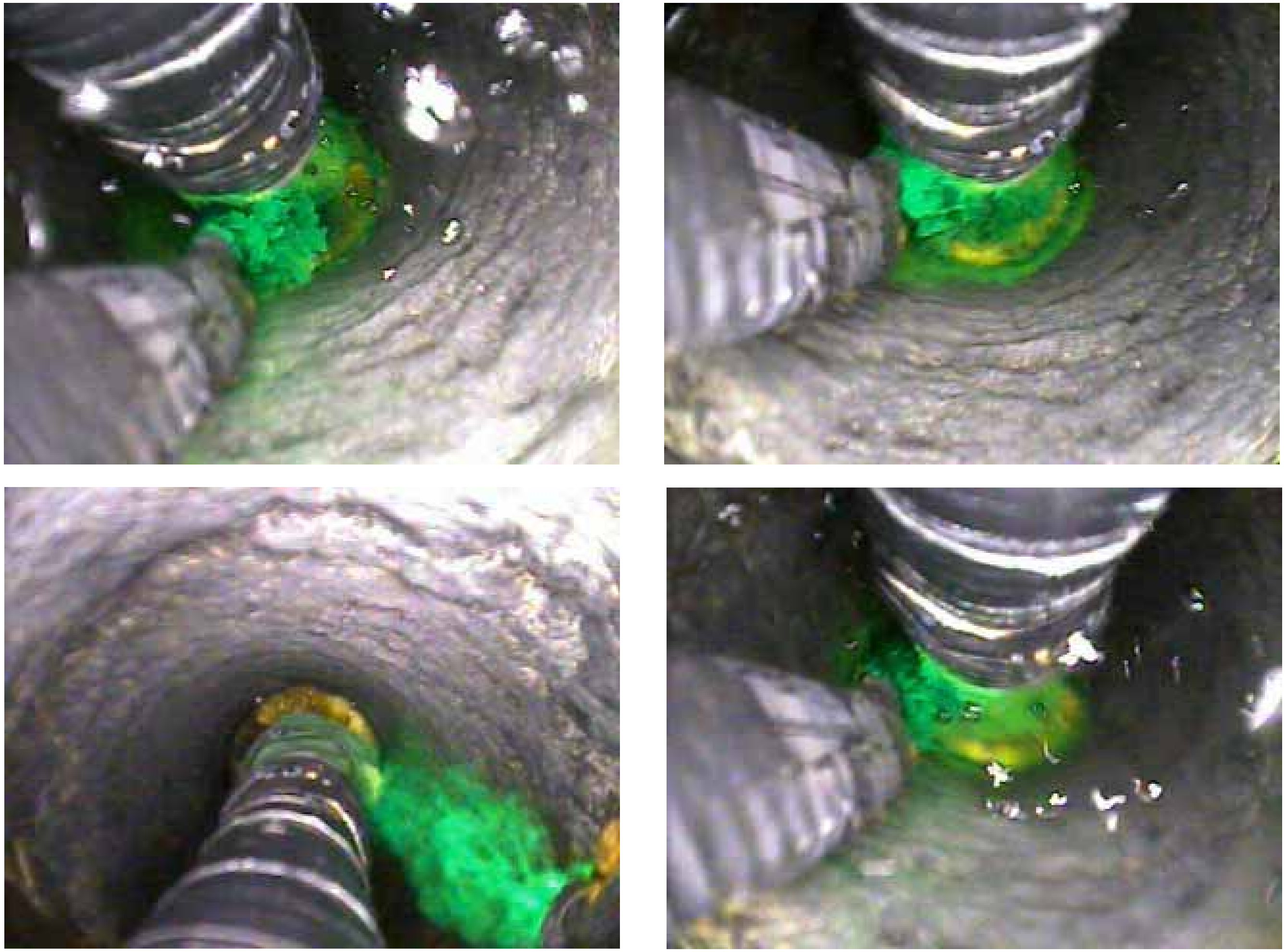


Figure 28. Fluorescein dye being released in the Conklin Well #52 through poly-tubing with the top of the pump column visible. The well is 6 inches in diameter and the dye release tubing is about ½ inch in diameter. Due to the strong downward flow in the well the dye was carried past the pump and out of the well. Large air bubbles traveled up the well, medium sized bubbles hovered and small bubbles were carried down with the flow.

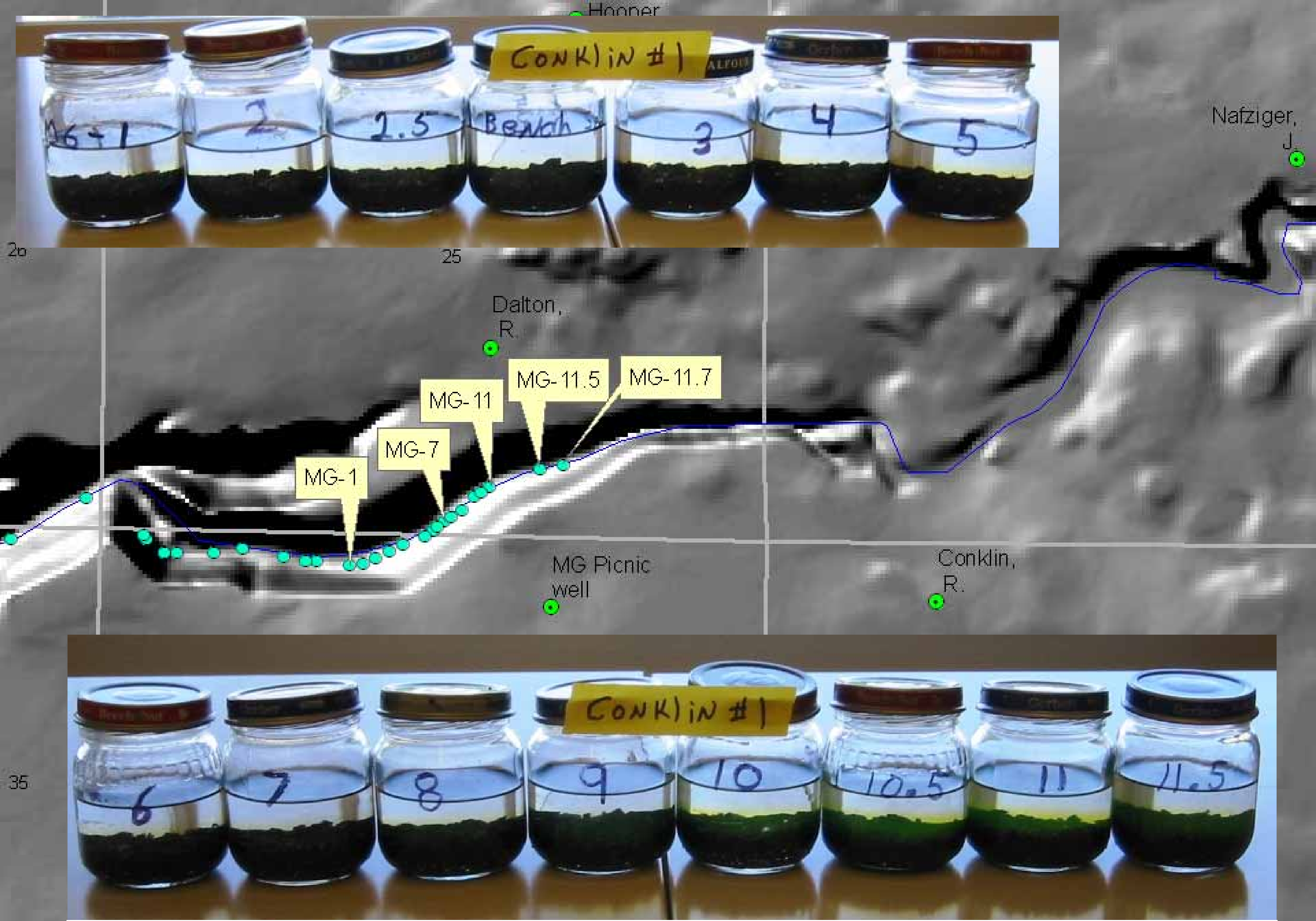


Figure 29. Charcoal packet results for Conklin well #52 Trace #1 showing visual green dye in MG-9 through 11.5.

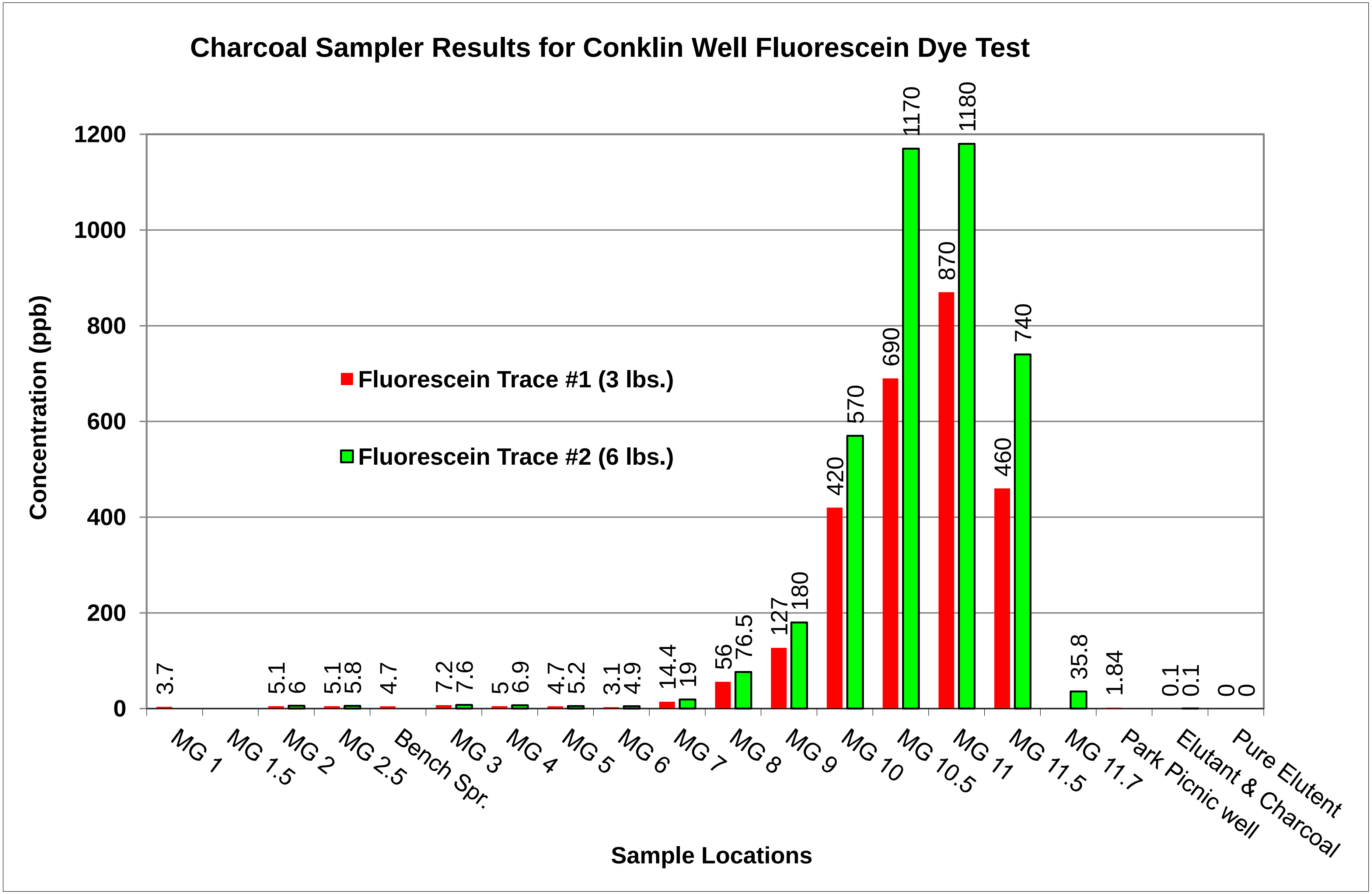


Figure 30. Charcoal packet results for Conklin well #52 Trace #1 and #2 the Gorge springs.

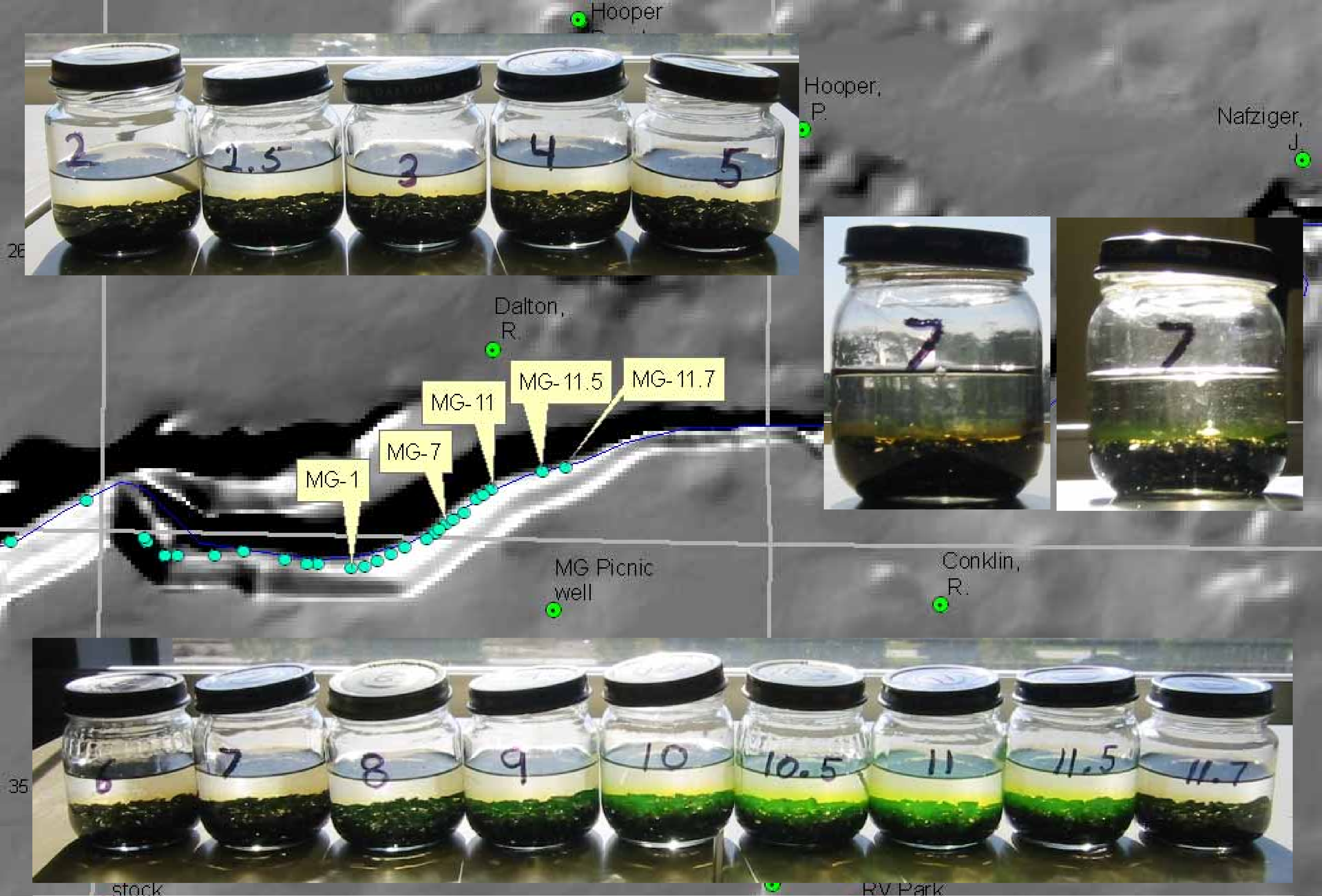


Figure 31. Charcoal packet results for Conklin well #52 Trace #2 visually showing green dye in MG-7 through 11.5. Placing the samples on a stainless steel surface improves visibility of the dye as seen in the right image of sample #7 comparison.

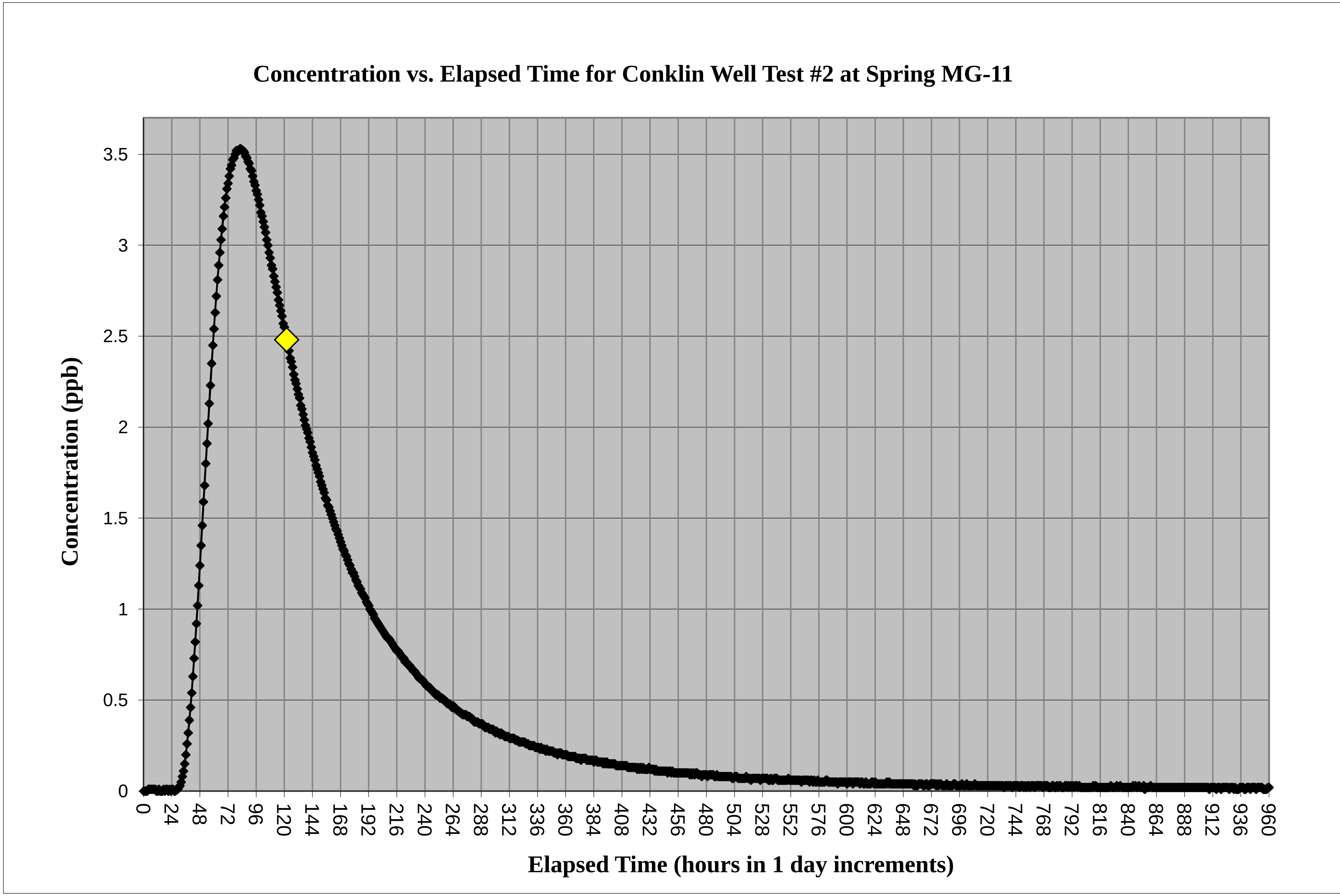


Figure 32. Dye breakthrough curve for Trace #2 from spring MG-11. Six pounds of 75% concentration FL dye was release from the Conklin well #52.

Date	Name	Distance (feet)	Dye (type & mass)	Volume of dye mixture released (gallons)	Max GW Velocity ft./day	Ave. GW Velocity ft./day	Dominant Flow Velocity ft./day	Approx. Time of Passage (days)	Peak Water Conc. (ppb)	Peak Charcoal Packet Conc. (ppb)	Gradient
April 7, 2009	Park picnic well #24	1,100	1 lb. FL (75% conc.)	3	n.a.	n.a.	n.a.	n.a.	n.a.	1,310 @ MG-7	0.04
June 23, 2009	Park picnic well #24	1,100	0.21 lb. RWT (100% conc.)	1 (2.5% conc.)	5,640	n.a.	Same as below	n.a.	0.37 @ MG-7	n.a.	0.04
June 29, 2009	Park picnic well #24	1,100	0.21 lb. RWT (100% conc.)	1 (2.5% conc.)	5,640	880	Same as below	4.2 estimated	0.43 @ MG-7	n.a.	0.04
Sept. 22, 2009	Park picnic well #24	1,100	0.63 lb. RWT (100% conc.)	3 (2.5% conc.)	5,640	880	1st peak = 2,037 2nd peak = 791	4.2	0.91 @ MG-7	n.a.	0.04
Oct. 20, 2009	R. Riddle well #26	2,865	3 lb. FL (75% conc.)	6	n.a.	n.a.	n.a.	n.a.	n.a.	8,160 @ MG-3	0.024
March 1, 2010	R. Riddle well #26	2,865	2 lb. RWT (100% conc.)	4	2,455	800	868	11	1.8 @ MG-3	388 @ MG-3	0.024
April 19, 2010	Hopper well #30	5,490	4.84 lb. FL (75% conc.)	7.75	n.a.	n.a.	n.a.	n.a.	n.a.	1,498 @ MG-2.5	0.014
May 21, 2010	Hopper well #30	5,490	5.01 lb. FL (75% conc.)	8	2,000	664	958	16	1.10 @ MG-2.5	1,640 @ MG-2.5	0.014
Dec. 17, 2010	Meyer well #48	11,900	8 lb. FL (75% conc.)	15	1,102	n.a.	n.a.	40	0.37 @ Bench spr.	489 @ MG-4	0.010
March 25, 2011	Meyer well #48	11,900	14 lb. FL (75% conc.)	14	1,095	410	517	41	0.59 @ Bench spr.	744 @ MG-4	0.010
June 7, 2011	N. Riddle well #25	2,660	0.46 lb. RWT (100% conc.)	0.25	n.a.	n.a.	n.a.	n.a.	n.a.	76.75 @ MG-19	0.027
July 11, 2011	R. Conklin well #52	3,653	3 lb. FL (75% conc.)	3	n.a.	n.a.	n.a.	30	n.a.	870 @ MG-11	0.040
Aug. 19, 2011	R. Conklin well #52	3,653	6 lb. FL (75% conc.)	6	2,922	720	1,069	30	3.53 @ MG-11	1180 @ MG-11	0.040
1936	H. Stearns					750					

Table 7. Table of selected attributes for all traces with H.T. Stearns (1936) estimate for an area extending from Blue Lakes to Wilson Lake .