Idaho Department of Water Resources

Open File Report

FLUORESCENT DYE TRACER TESTS
and
HYDROGEOLOGY
near the
MALAD GORGE STATE PARK
(Hopper well test)

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ABSTRACT

Through a cooperative effort between Idaho Power and the Idaho Department of Water Resources, two Fluorescein tracer tests were successfully completed near the Malad Gorge State Park during the spring of 2010. Dye was released in a domestic well located approximately 5,490 feet south of the Gorge. Springs along the river edge in the Gorge and selected domestic wells were monitored for the presence of dye. Fluorescein dye was used in a 'two phased' approach to determine the spatial distribution first and the travel time second. Results document that groundwater is flowing in a northwest direction from the injection well to the Gorge at an average linear flow velocity of 664 feet per day and a maximum flow velocity of 1,996 feet per day. Previous tracer tests in this area were completed by Farmer and Blew during 2009 using the Malad Gorge State Park picnic area well and then in 2010 using a domestic well for dye release. The information gained and techniques developed from the previous tests were applied during these tracer tests.

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Purpose and Objectives

A groundwater tracer test using fluorescent dye was implemented near the Malad Gorge State Park to track flow paths and define other baseline aquifer characteristics. Long-term goals for the tracer studies in the Eastern Snake Plain Aquifer (ESPA) are to provide additional information on aquifer flow characteristics of the ESPA starting in the discharge areas. This study is an additional step in developing information and technology to support an ongoing tracer program on the ESPA. Tracer studies could provide flow data for the application of practices to manage and enhance the aquifer.

Some of the goals for this test include an attempt to determine the following:

1. What is the flow path from the well to the springs in the Gorge?
2. What is the azimuth of the groundwater flow direction?
3. What is the groundwater flow velocity?
4. What is the spatial distribution or dispersion of the dye?
5. Will water quality be affected?
6. What is the optimal temporal and spatial sampling frequency?
7. How much dye is needed to obtain a significant and discernable response?
8. What will be the resurgent concentration of dye in the springs?
9. What are any potential biological impacts from the dye?
10. Will the test be an inconvenience for the well owner?
11. What is the cost of the test?

Geographic Setting

The Malad Gorge State Park is located approximately 90 miles southeast of Boise (Figure 1) and starts near where Interstate 84 crosses the upper part of the Gorge in Gooding County at T6S R13E, southern section 25 and northern section 36 (Figure 2). The Gorge in this area is about 225 feet deep with vertical walls of basalt and boulder talus slopes. Formation of the Gorge is attributed to cataract retreat of flood waters from the Bonneville Flood (Malde, 1991). No major landslides are discernable in this part of the Gorge. However, a bench about 20 feet higher than the river within a section of the talus slope extending from sample sites MG-1 to MG-5 may be the remnants of an old landslide. A domestic well (Hopper) located approximately 5,490 feet south and east of the Gorge was used for the injection of dye. The elevation of the well is 3,306.1 feet determined from 50 post processed readings using a Trimble GeoXT 2005 set on the highest precision option and NAD83 with a duel frequency L2 ProXRT receiver. On April 19th, 2010 the depth to water in the well was 182.15 feet or 3,123.9 feet elevation. The river and shoreline spring discharge elevations in the Gorge range from 3,015 to 3,040 feet.

Figure 1. General location of the dye tracer test at the Malad Gorge State Park.

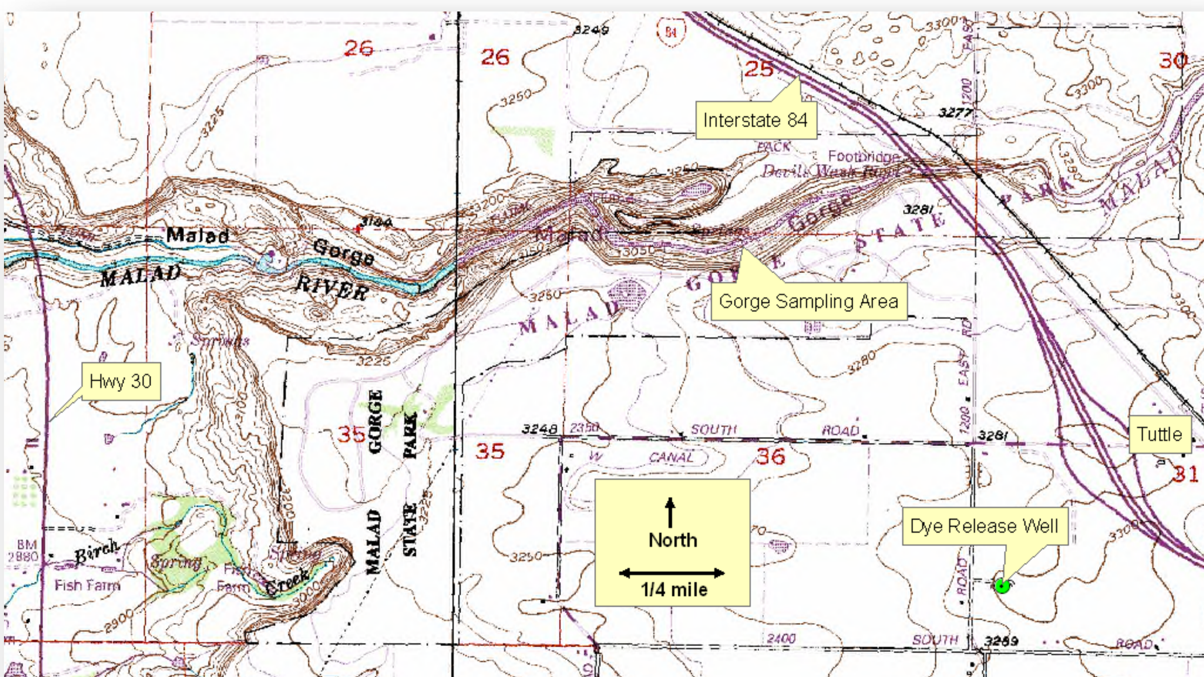

Figure 2. USGS topographic map of the site showing the dye release well southeast of the Malad Gorge.

Hydrogeologic Setting

The Snake River Plain is a major late Cenozoic tectonic/volcanic feature in the northern portion of the Basin and Range geologic region (Malde, 1991). The plain extends across southern Idaho for roughly 300 miles in a crescent shape. It is divided into two main sections identified as the western and eastern Snake River Plain. The western portion is about 40 miles wide, bounded by normal faults and has a northwest-southeast trend. Malde and Powers (1958) recorded at least 9,000 feet of displacement between the highlands to the north and the elevation of the plain today and concluded about 5,000 feet of displacement occurred in the early and middle Pliocene. The displacement started about 17 million years ago by rifting and down warping of the plain. The subsequent stretching of the crust produced a basin that began filling with sedimentary and volcanic rocks during the Miocene, Pliocene and Pleistocene (Malde, 1991).

The Bonneville Flood sculpted and augmented the Snake River Canyon from erosion and deposition approximately 15,000 years ago (Malde, 1991). It is theorized that several gorges were cut from the flood event through a process of cataract retreat. As with Niagra Falls, the plug pool erodes a less resistant lower level formation more easily than an overlying formation (Leet et al., 1978). Exposed at the mouth of the Malad Gorge is an in-situ outcrop of Glenns Ferry Formation (GFF) at an elevation of 2,934 feet. The cataract that formed the Gorge eroded a partially unconsolidated pillow rubble zone and probably the GFF which caused the overlying basalt to collapse. Springs in the canyon emerge from boulders and talus slopes near the edge of the Malad River. The actual outlets of springs are covered, except for a few locations. Each spring was selected based upon observed higher flow rates than adjacent springs, position for an even distribution and access to the sample sites.

A simple geologic model described in a previous dye tracer report by Farmer and Blew (2009) is used to provide the framework to assist hydrologic and tracer test interpretation. A cross section of three wells and the canyon are provided in Figure 5 to show the geology and levels of dye release relative to the water table. The well log for the dye release well is also provided in Appendix A with cinders noted from 198–204 feet depth or about 3,100 feet elevation. This description and elevation correlate to the top of a pillow basalt and associated brecciated material which is interpreted to be the same pillow zone and general geologic environment as described in Farmer and Blew (2009). Pillows and brecciated rubble are highly permeable and capable of transmitting and discharging large volumes of groundwater at high velocities. The brecciated zone of the pillow layer, which maybe up to 45 feet thick in the Gorge and extend for up to 2 miles based on nearby well drilling logs, may be more homogeneous and isotropic than the basalt flows. When considering the overall aquifer at a larger scale of many miles and the full thickness of the basalts overlying the GFF, the pillow brecciated zone creates greater heterogeneity in the flow system.

Harold T. Stearns (1936) describes that nearly all the large springs are discharging from pillow lava features and a ‘peculiar glassy breccia’. He also notes how 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. 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 small drainage containing water, pillow features and associated breccia were formed creating highly permeable zones for groundwater flow. Later authors such as Covington and Weaver (1991), Ralston (2008) and Farmer (2009) also describe the same geologic phenomena as Stearns did in 1936.

Farmer (2008) also identified structural features such as faults and folds that also play a role in the spring flows and distribution from Thousand Springs northward to Malad Gorge. In addition to the 'cut and fill' process and structural deformation, there is evidence supporting a 3-layer hydrostratigraphic model for the general area between Hagerman and Wendell which is composed of Quaternary basalt overlying Glenns Ferry Formation overlying deeper basalts. A 600-foot deep USGS well located 3 miles east of the Curren Tunnel (T7S, R14E, sec.35) documents a similar '3-layer' hydrogeology and a deep basalt aquifer is supported at this location based on water levels and temperature data (Figures 3 and 4).

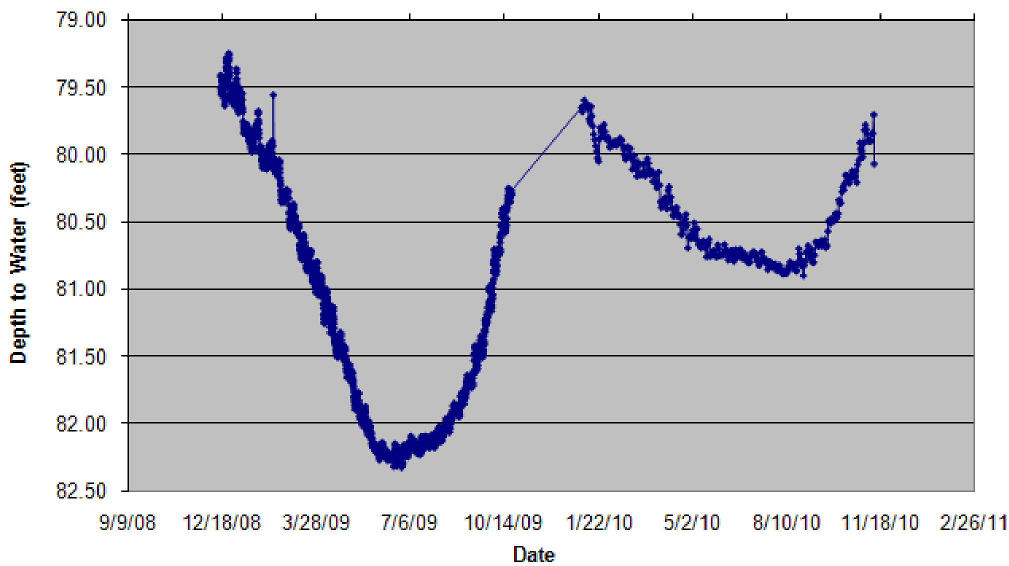

Figure 3. Hydrograph for USGS 'Henslee' well completed in the lower basalt.

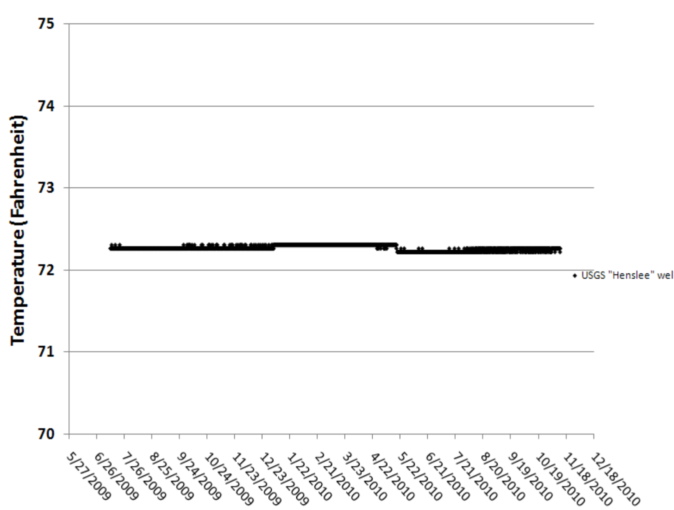

Figure 4. Temperature data for USGS well (Henslee) showing 72 degree Fahrenheit water.

During GPS surveying, coordinates were collected at bench marks for control usually at the start and finish of the survey. The depth to water in the dye release well #30 (Hopper) was measured at 182.40 feet on May 21st, 2010 which equates to an elevation of 3,123.7 feet. The river pool elevation at sample site MG-3 is 3,028 feet but a spring that flows across a bench about 20 feet above the river level is 3,048 feet for a difference between the well and bench of approximately 76 feet. Using the bench spring elevation and distance of 5,490 feet would equate to a groundwater hydraulic gradient of 0.014.

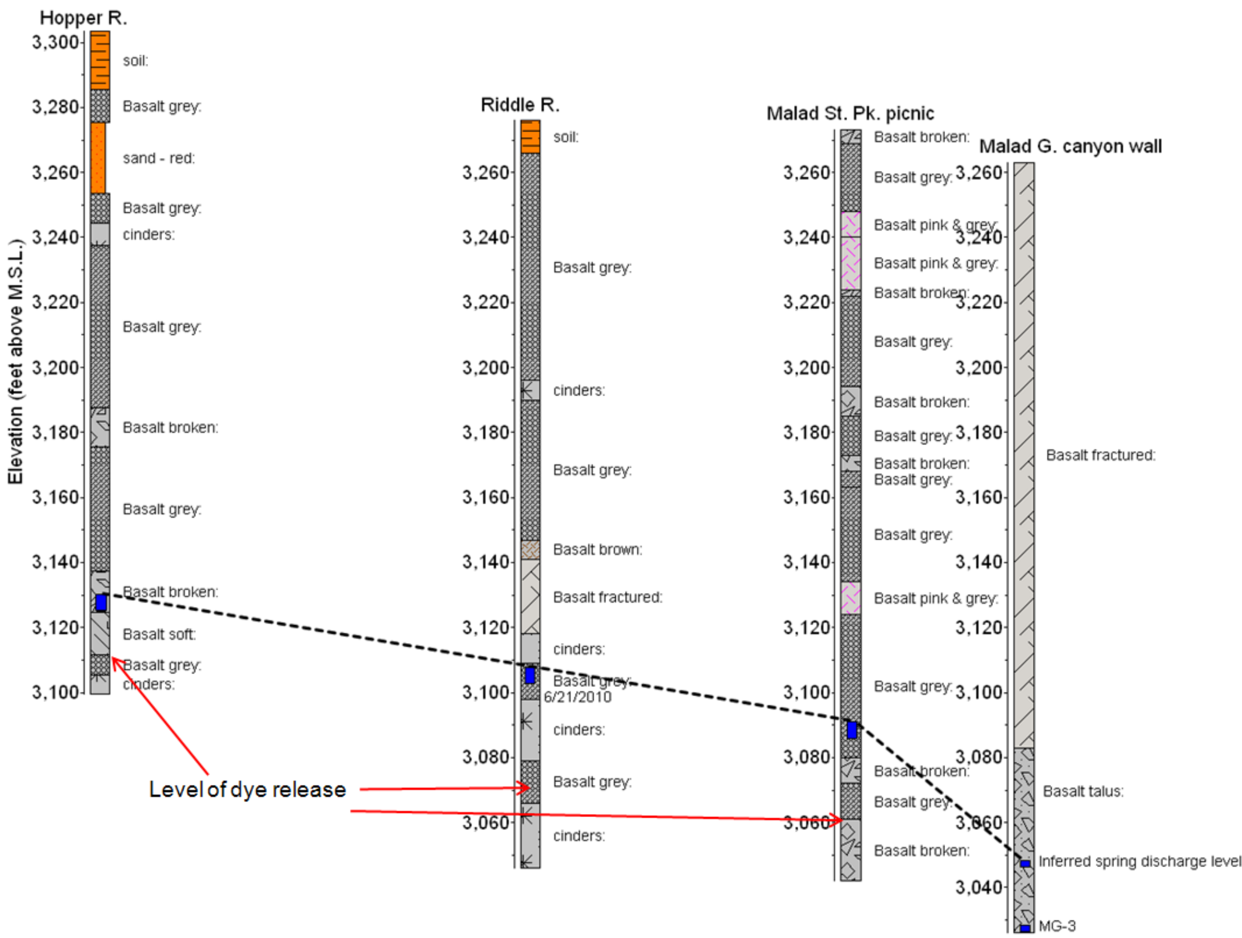

Figure 5. Geologic cross section of three wells and the Gorge wall showing elevations of dye release related to the geology.

A water table map shown in Figures 6 and 7 suggest curved flow paths possibly influenced by surface water from the Malad River east of Interstate 84 entering the groundwater flow system as the river cuts down through about 100 feet of basalt flows and contacts. As the river water ‘stair steps’ down through this zone through a series of falls and pools it may inundate approximately four to six basalt flow contacts that would allow for water to flow laterally to the south and mix with ESPA water only to flow back into the Gorge from the springs. This may explain a difference in water temperature for selected springs in the Gorge (Figure 8). The temperature shifts about 2 degrees Fahrenheit from MG-5 to MG-7 which also seems to be a dividing line noted in tracer tests performed in the Malad Gorge Park picnic area well verses a trace done at the Riddle domestic well #26. Also, water was clearly heard cascading within the R. Conklin well suggesting an elevated aquifer in this area.

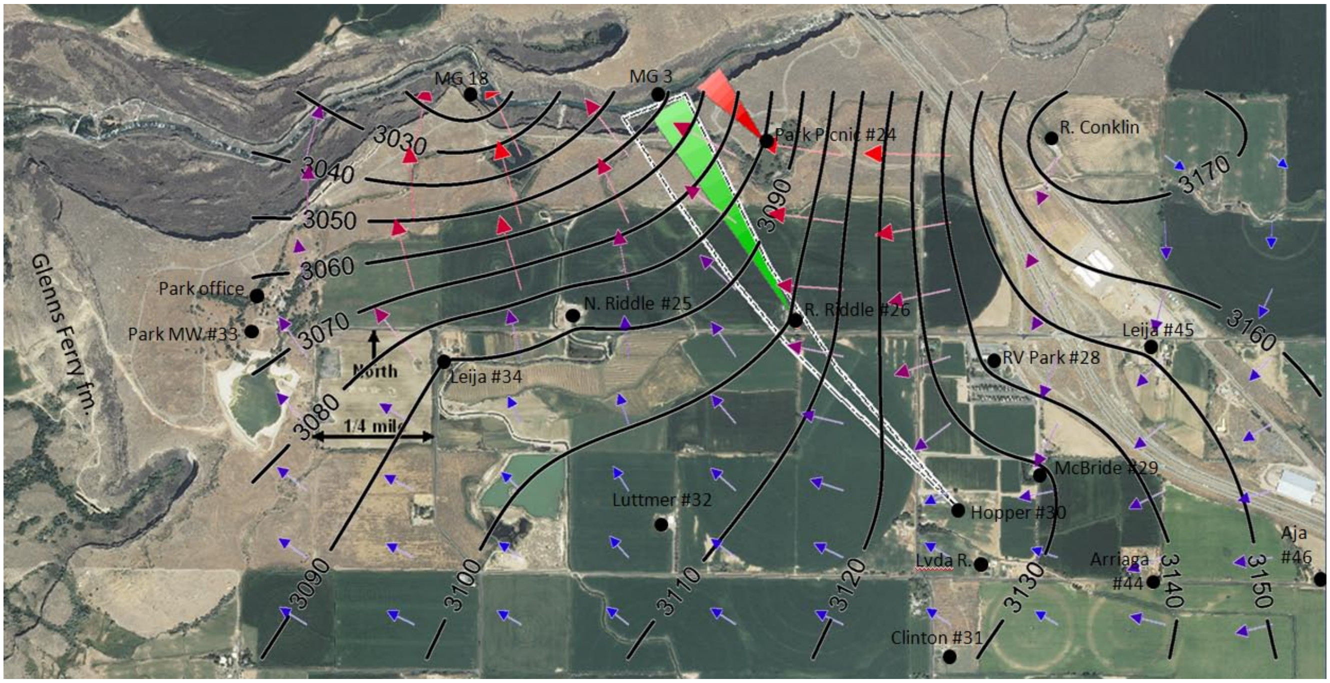

Figure 6. Water table contours (10 foot interval), hydraulic gradient vectors and approximate tracer flow path noted with the white dashed line. Measured wells are noted with black circles.

Figure 9 shows the location map for the geologic cross section in Figure 10 which extends from the Bruneau Plateau eastward to the Malad Gorge State Park picnic area well then north to the Hooper well. This well should not be confused with the Hopper well to the south where the dye was released. The geology on the west side of the Snake River is defined from outcrop mapping by the U.S. Geological Survey (Malde, 1972), a hydrostratigraphic model and numerous hydrogeologic studies that compared, contrasted, summarized and listed in Farmer (1998). Numerous wells, tracer tests, paleontology and sedimentological studies since the late 1930's also help define the subsurface architecture of this area.

The east side of the Valley is also defined by an in-situ outcrop of GFF mapped by the U.S. Geological Survey (Malde, 1972), in-situ outcrop of pillow lavas, and the subsurface geology from numerous wells. Well drilling geologic logs and the GFF outcrop support the model that Lake Idaho sediments extend eastward under the upper basalt flows with a possible graben from faults. The possible fault located at the Snake River is supported more by outcrops and geologic information than the possible fault located north of the Gorge. The contact between the GFF formation and overlying basalt rises in elevation near Woody's Cove creating a barrier to groundwater flow of the ESPA and effectively 'diverts' the flow of water northward into the Malad Gorge.

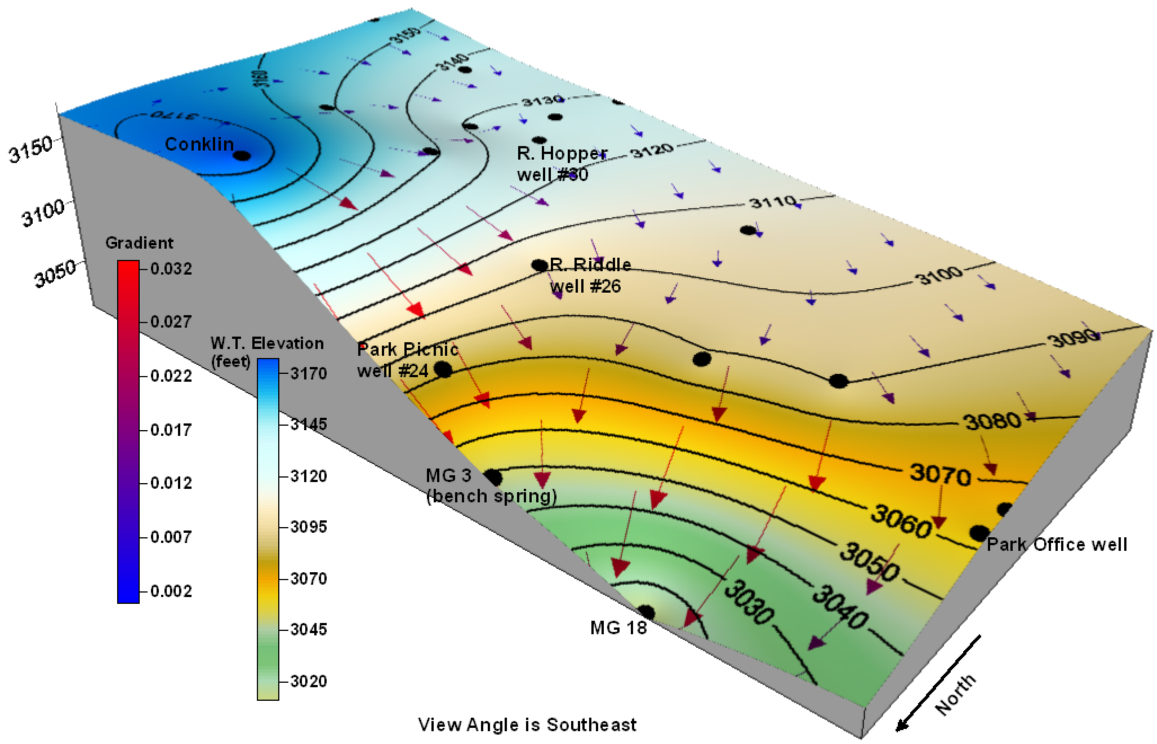

Figure 7. 3-D water table and vector map showing hydraulic gradient direction and magnitudes which range from about 0.002 to 0.032. View angle is to the southeast.

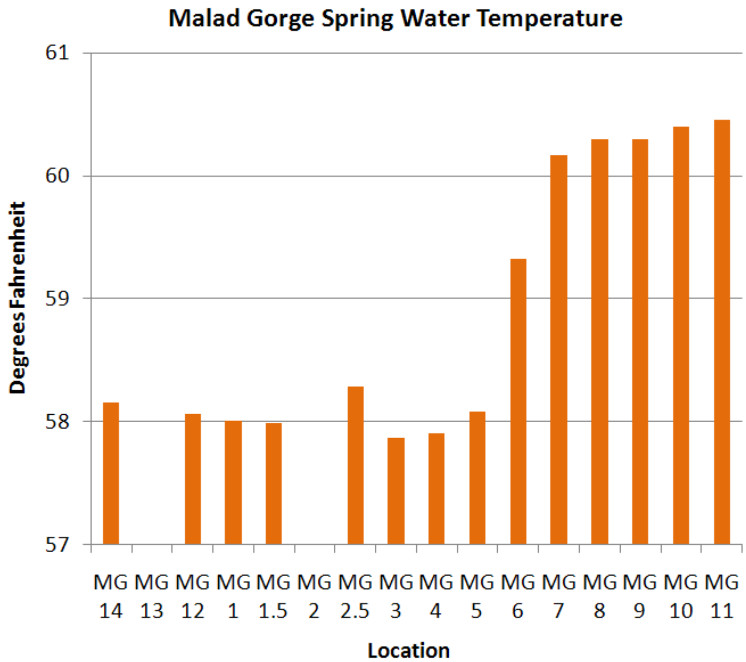

Figure 8. Spring water temperature for some sites in the Malad Gorge. Note the 2 degree change from MG-5 to MG-7 (see figure 9 for locations of springs).

The hydrogeologic model is consistent with and helps interpret the groundwater table map in Figures 6 and 7. This would also explain why there are low discharge seeps, similar in nature to the anthropogenic springs on the west valley side; or no springs at all immediately north and south of Woody's Cove along the slope of the Valley. The association of landslides and an outcrop of the GFF also support the existence of sediments under the rim area. Woody's Cove may be located in an ancient erosional topographic low area, possibly reflecting an old stream or river channel cut into the GFF before the deposition of the overlying basalt flows or flowing through a paleo sand channel within the GFF (Farmer and Nagai, 2004). Much of the groundwater discharging from Woody's Cove might be flowing through sand or small gravels deposited within this low area which might explain the lower spring flow rate than springs in the Malad Gorge. The L. Woody well drilled in 1974 (Figures 9 and 10) apparently had such low yield that it was abandoned according to a discussion and site visit with a local landowner.

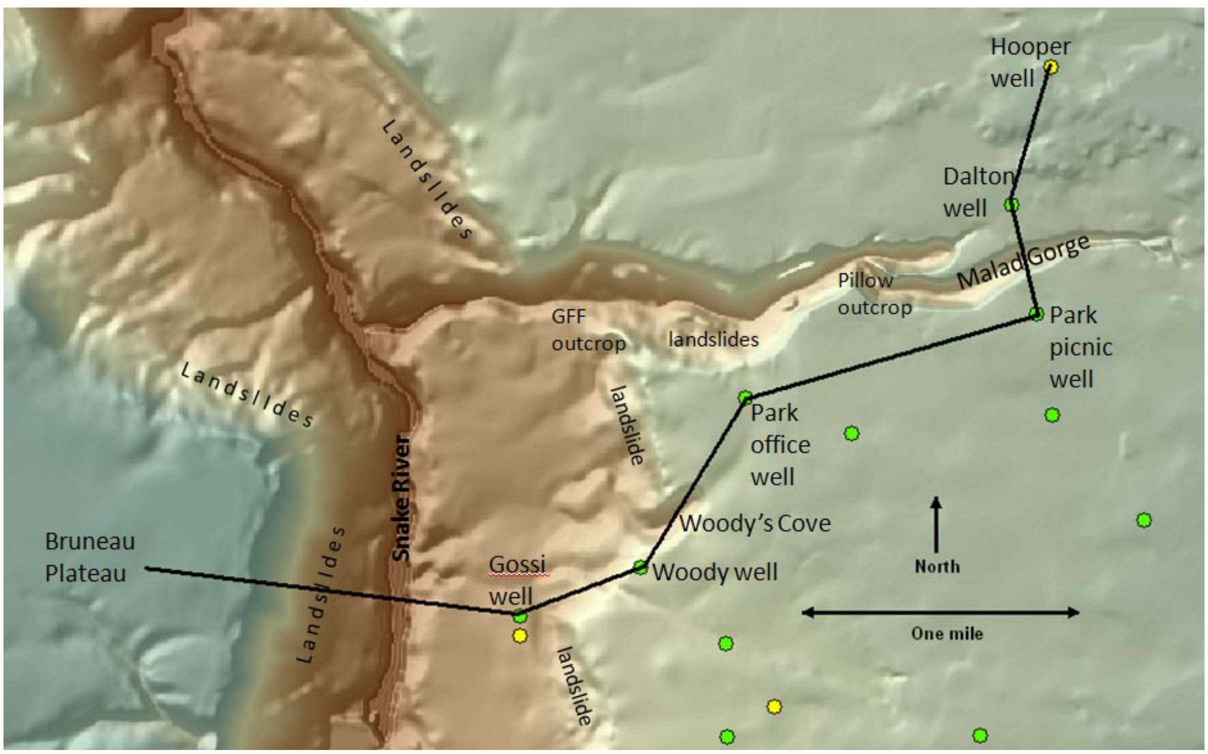

Figure 9. Shaded relief location map for a geologic cross section from Bruneau Plateau east then north to Malad Gorge (black line).

The lower basalt likely has an aquifer but its hydrogeologic characteristics are unknown. If the L. Woody well would have continued about another 100 feet it may have encountered the deeper basalt with a possible confined aquifer and pressure head. The P. Gossi well may have water flowing upward from the deep basalt and exiting the well through the screen located at an elevation of 2,850 feet. At this level, there is a 'valley fill basalt' identified by Gillerman et al. (2005) as the Pleistocene Epoch Notch Butte Basalt where it outcrops at land surface just a few hundred feet west. A blue triangle notes the water level in the well. Field evidence and mapping by Idaho Geological Survey (Gillerman et al, 2005) support the concept that lava flowed down the inclined relay ramp at Thousand Springs and spread into the Hagerman Valley.

A simple dye trace within the well bore of the Gossi well would confirm the flow of water within the borehole by releasing dye at about 2,750 feet elevation and monitoring with a submersible fluorometer at an elevation of 2,850 feet. This would help confirm the presence of an upward gradient and a deep aquifer that may be discharging into the Snake River along a fault. A borehole camera survey would also be of benefit.

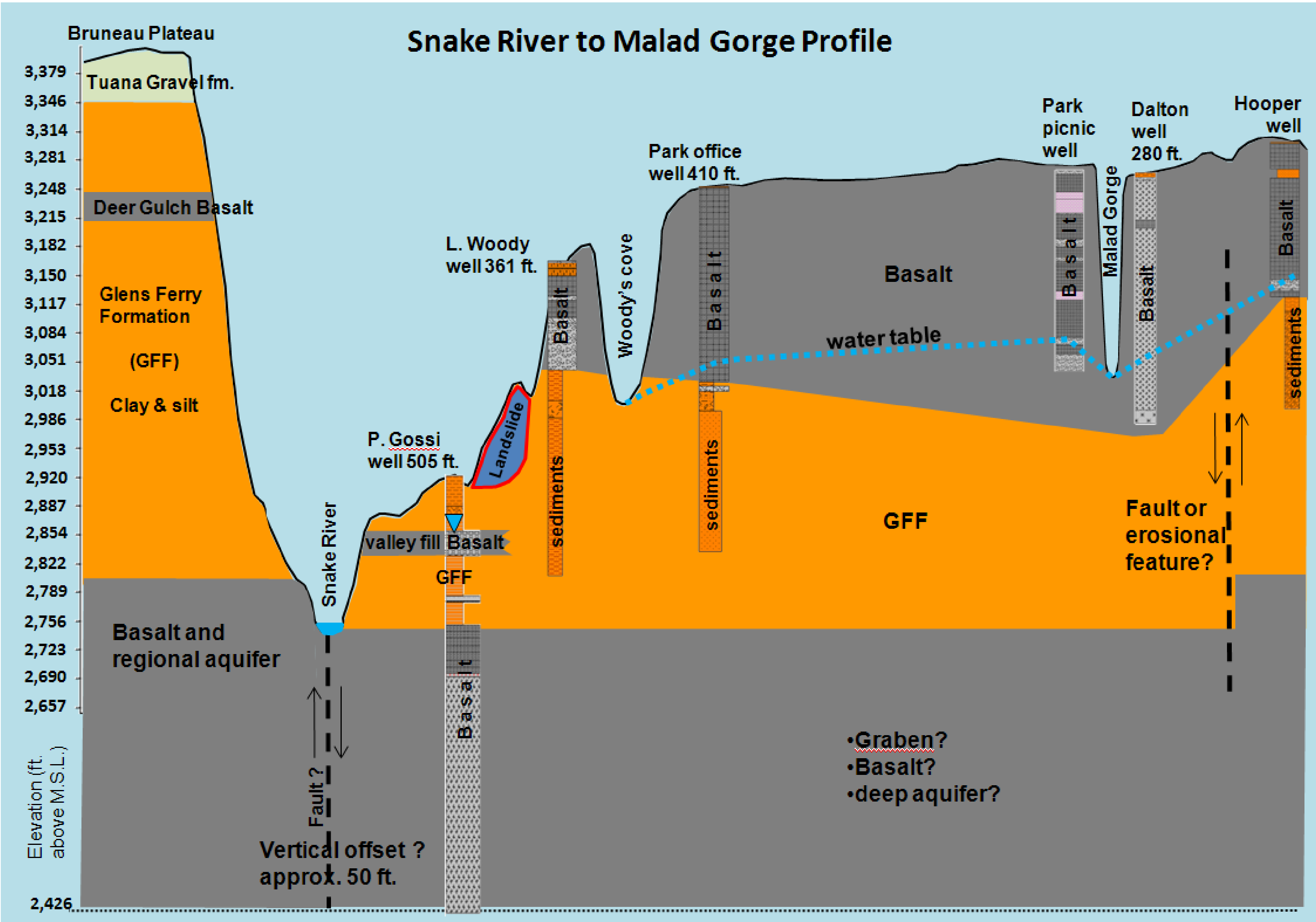

Figure 10. Geologic model cross section showing well geology, water table and possible faults. The diagram is accurate for vertical and horizontal scale using ArcGIS Profile with a DEM. Elevations were converted from cm to feet units.

GENERAL PROCEDURE AND METHODS

The following general approach proved efficient for time, supplies, and sampling/analysis costs. A Turner Designs C3 instrument provided a high resolution breakthrough curve on a ½ hour frequency that is essentially impossible if done manually. The dye best suited for this study was Sodium Fluorescein which is a green colored fluorescent dye first synthesized by Adolf von Baeyer in 1871 and used since 1882 for groundwater studies (Dole, 1906). It's the most commonly used dye for groundwater tracing studies for the past 128 years. Below is an excerpt copied from Dole, R.B. (1906) page 75 stating the uses of Fluorescein dye in groundwater tracing near Paris.

> HISTORY
>
> Probably the first coloration experiments to establish the water origin of typhoid fever were made by Dr. Dionis des Carrières[a] in 1882, during a severe epidemic at Auxerre, a city about 85 miles southeast of Paris. Since that time the use of various dyes has been frequent for studying the underground movements of water. In 1887 fluoresceïn was used in the valley of the Avre.[b] M. Trillat in 1899 conducted elaborate investigations into the delicacy of certain dyes for flow indicators and the effect on them of passage through common soils.[c] The fluoroscope invented by him and perfected by M. Marboutin[d] is capable of detecting minute traces of fluoresceïn, and has made possible the extensive studies of ground flow now being conducted with that material. The work has assumed such proportions that the so-called sanitary analysis of water plays a rather subordinate rôle in the consideration of the springs. Under the direction of the Montsouris commission geologists, hydrologists, chemists, physicians, and other skilled professional men make a detailed study of the region in order to ascertain the purity of the water and the means for preventing avoidable pollution. Their work embraces a study of the water flow and of the geology of the formations, determination of the supply basin, inquiry into epidemics and hygienic conditions on the watershed, as well as the study of the water itself as regards chemical and bacteriological condition, discharge, temperature, etc. From the results of all these researches a definite decision concerning the availability of the supply and its chances of pollution can be made.

Sodium Fluorescein (Acid Yellow 73 – CAS # 518-47-8) can be detected in a fluorometer at low concentrations of 0.01 parts per billion (ppb) or 10 parts per trillion. Fluorescein is also known as Drug and Cosmetic Yellow 8 which is an ingredient in some consumer products. A two phase approach similar to and consistent with previous tests was used at this site due to accessibility issues matched with sampling frequency needs (Farmer and Blew, 2009).

Test #1 used Fluorescein dye to delineate the spatial distribution of the dye cloud as well as the location with the greatest amount of dye resurgence. Phase two also used Fluorescein dye with additional charcoal samplers placed to increase the resolution of the spatial distribution from the first test. A Turner Designs C3 submersible fluorometer and datalogger was deployed during Test #2 at the sample site where the greatest amount of Fluorescein dye was detected from Test #1. The C3 recorded the concentration of dye with time to provide a concentration breakthrough curve which was then used to determine the travel time as well as the character of the dye cloud as it passed out of the spring. A groundwater velocity was then calculated using the linear distance between the dye release well and the sample site/spring. The dye was also detected during Test #1 from a well (Riddle #26) located halfway between the springs and the dye release well (Hopper #30). During Test #2, an auto sampler was installed at Riddle well #26 with a flow through design to collect water samples every 12 hours for lab analysis.

Phase I Description

The well selected for injection was based upon several factors. A previous tracer test of one-half mile had been completed in March of 2010. The data from that test showed a relatively quick resurgence of dye at the target spring. Based upon this data a one mile test was proposed as part of a stepped approach of a larger ongoing tracer study program. The objective is to select wells for tracer studies within the inferred flow path based on previous traces, and show brecciated or fractured zones on the well drilling report. It's also an aim to select wells with no nearby down gradient wells and be available for injection. The Hopper well met these qualifications and was selected for injection. The Hopper well is a six-inch domestic well completed in 1992 to a depth of 204 feet. During the period of the test the home was vacant and the well was not pumped.

The Phase I tracer test started on April 19^{th} 2010. Prior to the release of dye, water samples were collected from nearby wells and springs in the Malad Gorge. Pre-test sampling was done to ensure Fluorescein from previous testing or other source of fluorescent material was not present prior to initiation of the test. Water sample collection consisted of 50 mL grab samples, and the analysis was done with a bench top fluorometer, Turner Designs model TD700, and calibrated with factory solution standards. Charcoal packets were also placed in toilet tanks of eight homes (ground water monitoring location) and 19 spring locations. Figure 11 shows the location of the sample sites as green circles noted as MG-1, 1.5, 2, 2.5, 3, 4, 5, 7, 8, 9, 10, 11, then MG-12 through 19, and 8 wells for a total of 27 sample sites. Spring sample sites number 20 through 23 were not sampled. The charcoal packets were placed at locations with high spring or groundwater discharge flowing into the river. Groundwater discharge was observed at other locations but at lower rates. Nine grams of coconut shell activated carbon (#10 mesh size, Calgon, Cas #7440-44-0) were placed inside each packet made from fiberglass screen which is similar to Ozark Underground Laboratory's method noted on page 1 (Aley, 2003). Charcoal packets serve as 'sentries' that are constantly immersed in water and will absorb dye as it passes through the packet during the test period. This means the information gained from the charcoal packets is integrative over the test period.

Dye release occurred at approximately 10:30 a.m. on April 19, 2010. The release included 4.84 pounds of Fluorescein dye mixed with 7.75 gallons of water (7.5% concentration) and injected into Hopper well #30 through polyethylene tubing at 192 feet below top of the casing (T.O.C.). The tubing could not be lowered any further due to impedance perhaps due to collapsing cinders. Power to the pump was disconnected during the duration of the test and no water was withdrawn from the well. The water level in the well was 182.15 feet below T.O.C.

Throughout the tracer test water samples were periodically taken from the eight ground water monitoring locations. On May 7^{th} the last water sample was taken from the eight ground water monitoring locations and at the spring sample sites. Charcoal packets from all locations were also retrieved on the same date. Both water samples and charcoal packet eluted solutions were analyzed with the TD700. Factory calibration solutions were used according to the standard operating procedure for the Turner Designs model TD700 lab fluorometer configured for Fluorescein with a detection limit of 0.01 ppb. The concentration of standards used for Test #1 were 0.1, 1.0, 10 ppb and deionized water as a blank. The instrument is operated and maintained in accordance with the manufacturer's manual. The calibration solutions, water samples and eluted charcoal samples were allowed to equilibrate to room temperature overnight before analysis or use. The fluorometer was set on 'direct concentration mode' which uses an averaging process before the final value is displayed. The same culture tube is used for each water sample and rinsed 3 times with deionized water.

Results of the pre- and post-test water samples collected at spring sites are shown in Table 1. Most pre-test results were at or near 0 ppb Fluorescein indicating no residual fluorescence in the water. For those spring water samples collected 18 days post dye release only sites MG 2, 2.5 and 3 showed residual of dye cloud.

Figure 11. Tracer test sample sites with green circles and general path of dye as the white dashed line. The previous dye trace locations are noted as the red and green triangles. Sites #20-23 were not monitored.

Elution of dye from the charcoal samplers was done in accordance with the SOP outlined on page 7 from the document titled 'Procedures and Criteria Analysis of Fluorescein and Rhodamine WT Dyes in Water and Charcoal Samplers' (Aley, 2003). Fifty mL of the solution is poured over the charcoal in a glass container and capped for 24 hours (Figure 12). The solution was then poured through a fiber filter into a 50 mL culture tube and then inserted into the fluorometer. Two controls, one unused charcoal soaked in deionized water and the second of unused charcoal soaked in eluting solution (Figure 13) resulted in a fluorescence of -0.1 ppb. The negative value is due to fine particles of charcoal and eluting solution absorbing or blocking some of the emission light.

Figure 13 shows that MG-2.5 and MG-3 received the largest amount of dye with progressively less concentrations lateral to these two sites with a roughly bell shaped pattern. Slightly elevated levels of 2.73 and 2.22 were observed at MG-7 and 8 but it is unclear if these are responses to the dye or changes in background fluorescence. The natural background fluorescence or ‘noise’ for most of the spring sample sites ranged from about 1 to 2 ppb charcoal samples. There was no discernable dye detection in any of the wells except Riddle well #26.

	19-Apr	7-May
MG-1	0.00	0.00
MG-1.5	0.01	0.00
MG-2	0.00	0.03
MG-2.5	0.01	0.05
MG-3	0.00	0.04
MG-4	0.00	0.00
MG-5	0.00	0.00
MG-7	0.00	0.00
MG-8	0.00	0.00
MG-9	0.00	0.00
MG-10	0.00	0.00
MG-11	0.00	0.00
MG-12	0.00	0.00
MG-13	0.00	0.00
MG-14	0.01	0.00
MG-15	0.02	0.00
MG-16	0.00	0.00
MG-18	0.00	0.00
MG-19	0.00	0.00

Table 1. Pretest water samples results in ppb from springs on April 19th and post test results on May 7th. Note some residual dye in sites 2, 2.5 and 3.

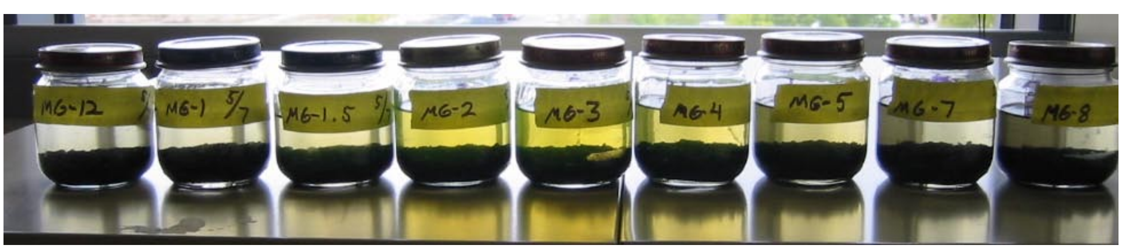

Figure 12. Charcoal soaking in eluting solution from Fluorescein Test #1 visually showing dye in MG-1.5 through 5.

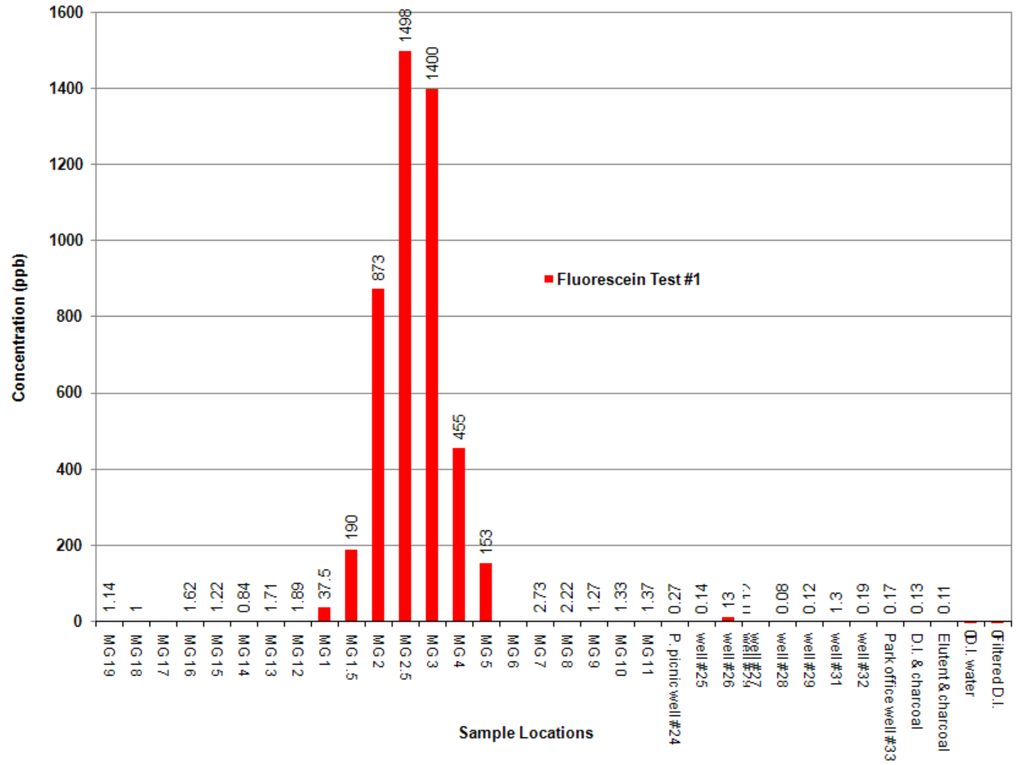

Figure 13. Data from charcoal packet analysis for Fluorescein. Dye was detected at spring sites MG-1 through 5 and Riddle well #26.

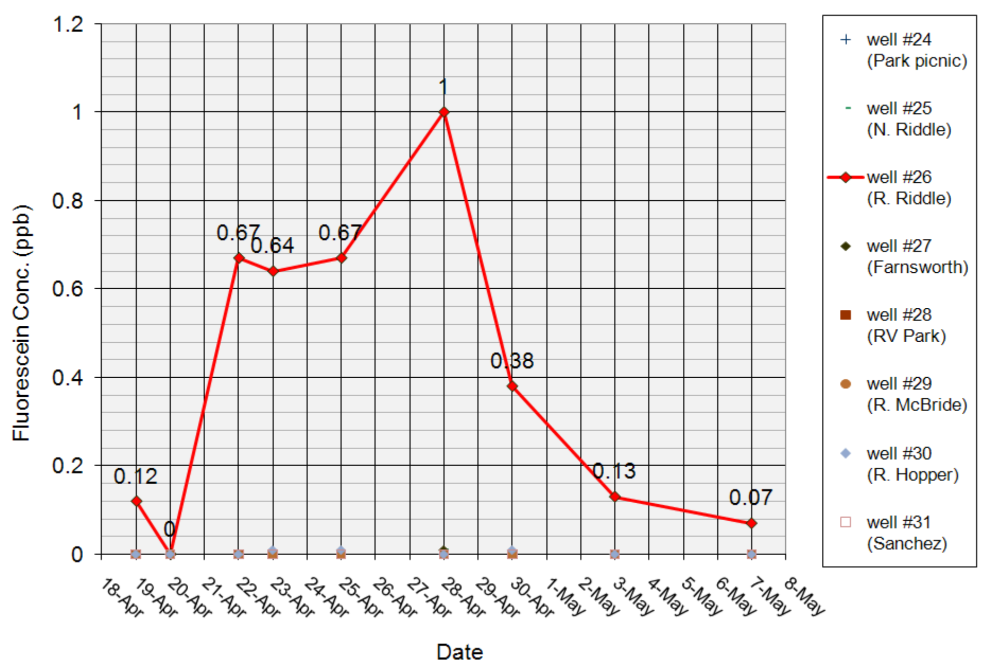

Figure 14. Results from well water samples taken a ground water monitoring locations with only well #26 (Riddle) showing a positive response for dye.

Figure 14 illustrates the results of water samples taken from the eight ground water monitoring locations. Those samples were collected opportunistically during Phase I as conditions and schedules permitted. The results of these water samples confirm the finding of the charcoal packets deployed in toilet takes at the ground water monitoring locations. Only well #26 showed a positive result for the presence of dye. This positive result provide a clear indication that the dye cloud had passed through this well. It also gave rise for the need to provide additional monitoring during subsequent tracer tests.

<u>Phase II Description</u>

Data from Phase I indicated the preferred flow path through the aquifer emerged at or near the spring locations designated as MG-3 or MG-2.5. Based on this information on May 21, 2010 a Turner Designs 'C3' submersible fluorometer was deployed at spring sample site MG-3 and calibrated using deionized water and factory calibration solution of 10.0 ppb Fluorescein. Prior to deployment, the C3 was programmed to record dye concentration and turbidity every ½ hour. The unit was inserted into 4-inch diameter black plastic pipe with holes drilled to allow water to flow through but shade the optics from sunlight. It was secured in a shady area of high spring flow at MG-3 about 3 feet in elevation above the stage of the river. Charcoal samplers were placed at sites MG-13, 12, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 7, and 8 during Phase 2.

Dye was released in the target well on May 21st, 2010 at approximately 12:30 p.m. The injectate included 5.01 pounds of Fluorescein active ingredient mixed with 8 gallons of water. The release occurred approximately two weeks after the last traces of dye were detected from test #1. The dye was released using the same methods and level in the well as in Test #1. The depth to water in the well was measured at 182.40 feet below T.O.C for a drop in water level of 0.25 feet (3 inches) from the previous test about one month earlier.

On June 16, 2010 the charcoal samplers were retrieved from the spring locations, chilled, and taken to the lab for analysis as shown in Figures 15 and 16. Processing the charcoal samplers for Fluorescein used the same lab methods as described in the previous section. The Fluorometer was 'blanked' with deionized water, and factory calibration solution standards of 0.1, 1.0 and 10.0 ppb were used. Deionized water was poured through a particulate filter into a 50 mL culture vial and analyzed with a result of 0.0 ppb fluorescence. The results indicate that most of the dye passed by spring sample sites MG-1 through MG-5 with MG-2.5 having the highest concentration. The rise and fall pattern is consistent with the Test #1 and shows a steady progression and then a regression in concentrations.

Dye was detected in Riddle well #26 from both the charcoal packet and water samples collected during Test #1 (Figure 13 and 14). During Test #2 an ISCO automated sampler (Figure 17) was installed with a constant flow through design that collected 500 mL samples every 12 hours. Flow was measured at 273 mL per minute which would refill approximately 350 times every 12 hours or 90-100 gallons between samples. In addition, the residence was occupied during the trace with normal water usage patterns for 1 to 2 persons. Samples from the ISCO samples were poured into 50 mL containers and transferred to the lab for analysis Results of the samples are shown in Figure 18 as the green diamond symbols. The yellow diamond symbol in Figure 18 represents the center of mass calculated and interpolated between data points to be at 5 p.m. on

May 28th or 7.2 days after the release of dye. The general shape and timing of the dye cloud is consistent with the grab water samples from Test #1 shown as the red square symbols and line (Figure 18). The distance between the dye release well #30 and the Riddle well #26 with the auto sampler is 2,640 feet which equates to an average linear velocity of 367 feet per day. One main assumption for this scenario and velocity is that the well is located in the center of the dye cloud. It is probably the edge of the dye cloud passed by this well and that the center, or main flow path, passed by earlier in time and lateral to this location as conceptualized in Figure 19. This would explain the timing of dye arrival when compared to spring site MG-3 and the peak concentrations that are nearly the same (Figure 22).

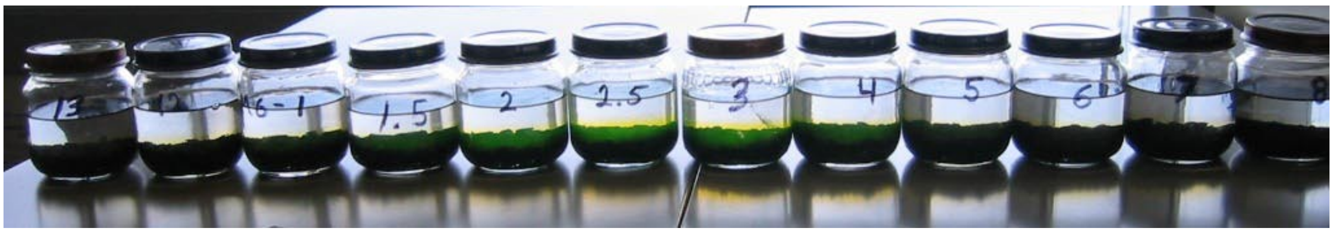

Figure 15. Charcoal soaking in eluting solution visually showing dye in MG-1.5 through 4.

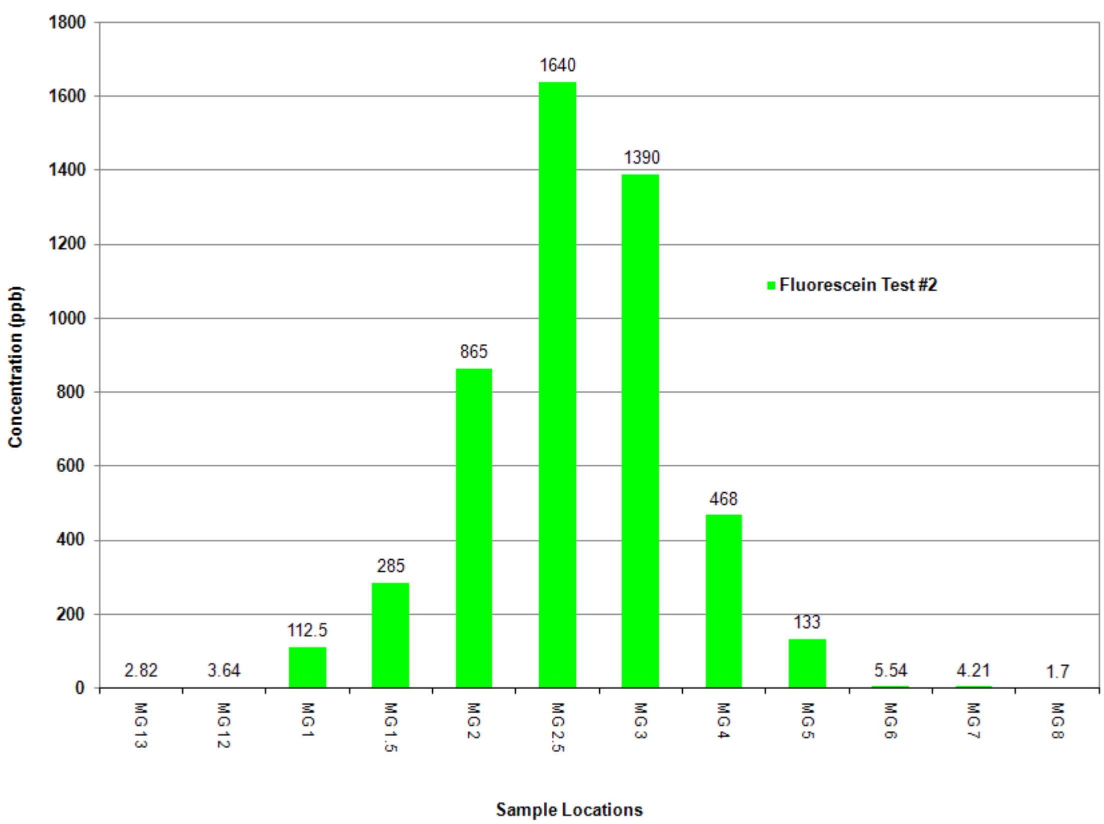

Figure 16. Concentrations of Fluorescein for Test #2 from charcoal packet samplers. Dye was detected in spring sample sites MG-1 through MG-5.

Figure 17. ISCO auto sampler deployed at Riddle well #26 programmed to collect 500 mL samples every 12 hours from a constant flow through container.

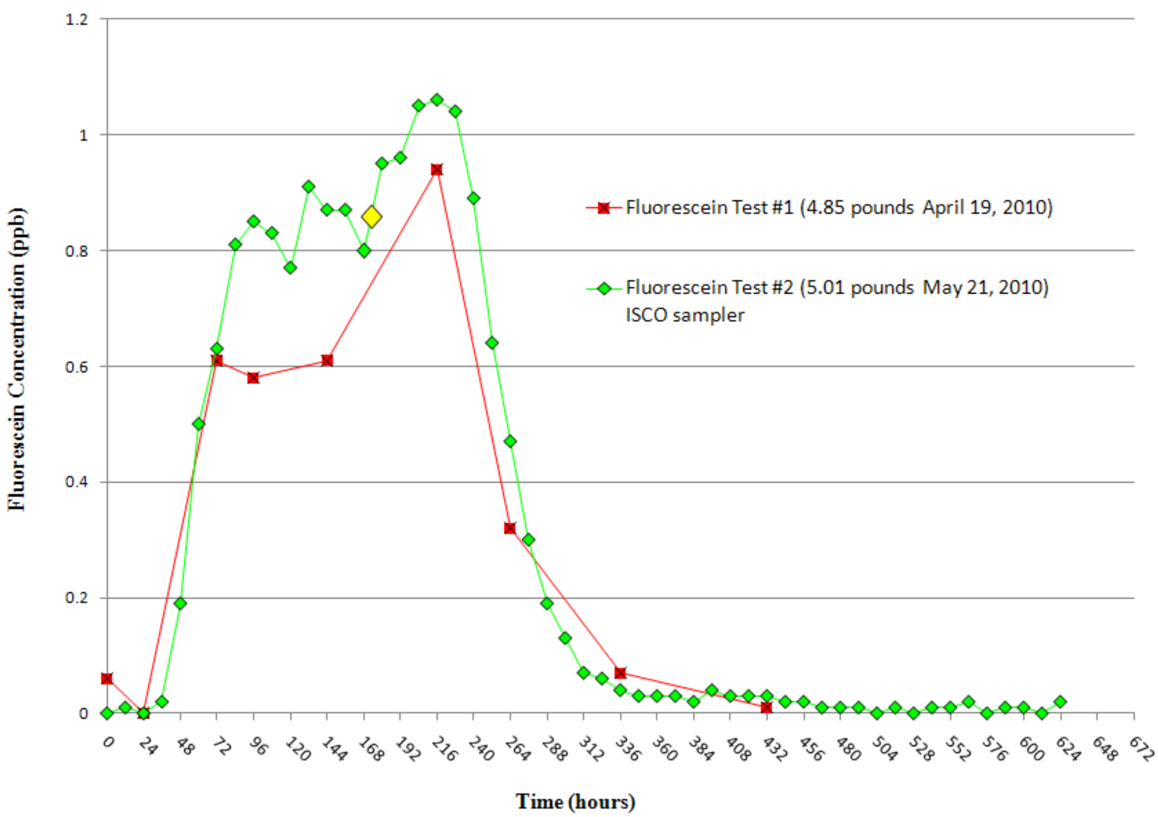

Figure 18. Riddle well #26 water sample concentration breakthrough curves from Test #1 and #2 showing sharp rising and recession limbs. The yellow diamond notes the interpolated center of mass from Test #2 at 5/28/10 5 p.m. or 7.2 days after dye release.

Figure 19. Conceptual dye cloud showing how Riddle well #26 may have intersected the edge of the cloud thereby effecting the timing and magnitude of concentration measured at this location.

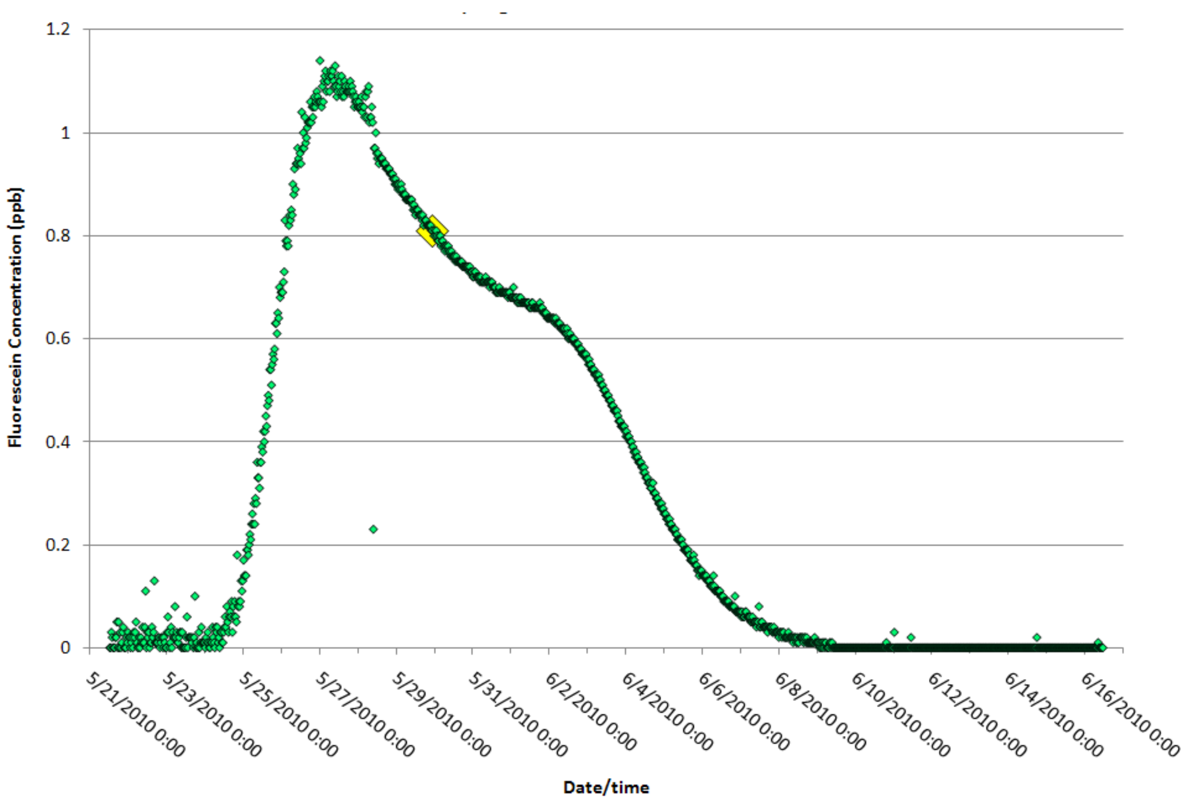

Figure 20. Concentration breakthrough curve for Fluorescein Test #2 at MG-3 showing a slight double peak response with a 'sharp' interface of the rising limb indicative of a conservative tracer. The yellow diamond symbol notes the center of mass at 5/29/10 at 18:30 hours or 8.27 days from dye release.

Figure 20 shows the response breakthrough curve at spring site MG-3 for dye with a maximum concentration of about 1.1 ppb. A few spikes occurred in the data but they are insignificant and the trend is clearly defined. On May 28^{th}, at 9:30 a.m., the C3 was removed from the water to ensure it was turning on at the programmed time interval, and it was. The data point recorded during that event is due to the instrument being out of the water. Entrained air bubbles were observed from some turbulence where the C3 was positioned prior to May 28^{th} so it was repositioned with the sensor located in the water column with less bubbles. Repositioning the unit appears to have reduced background noise which is attributed to bubbles affecting the optics. Air bubbles likely caused some noise in the data prior to May 28^{th} but the curve exhibits a classic shape with a steeper rising limb and a more gradual recession limb with a slight change in slope at June 2nd. The slope of the recession limb and character of the tail suggest that longitudinal dispersion and sorption were low and the slug was well constrained. The time of passage for the dye cloud was approximately 16 days with the initial breakthrough occurring on May 24^{th} at 6 a.m. or 2.75 days (66 hours) after dye release. The center of mass, based on the mean concentration, occurred on May 29^{th} at 6:30 p.m. or 8.27 days (198 hours) after release which provided a time of travel to calculate the average linear velocity of 664 feet per day.

Aquifer hydraulic conductivity can be better quantified using tracer data with the insignificant caveat that approximately 4% of the linear flow path distance may be through talus slope. The effective porosity is estimated from professional judgment and assumed to be nearly the same as porosity obtained from published literature.

Using the equation $K = P_e * V_{ave} / I$ where:

- "P_e" is effective porosity estimated from field observation and from published literature (Dominico and Schwartz, 1990) (Fetter, 1988) (Kruseman and Ridder, 1991) at 15% and then 30%.
- "V_{ave}" is average linear velocity based on the center of mass from the dye cloud at 664 feet per day.
- "I" is the hydraulic gradient from dh/dl = 0.014.

Therefore:

- If P_e is 15% then K is approximately 7,000 feet per day.

  or,
- If P_e is 30% then K is approximately 14,000 feet per day.

<u>Results and Discussion</u>

The charcoal sample results from both Test #1 and #2 show consistent patterns and concentrations as shown in Figure 21. Sites MG-2.5 and 3 received the most dye ranging from 1,400 to 1,600 ppb Fluorescein and the lateral distribution was from MG-1 through MG-5. This suggests that MG-2.5 and 3 are on a direct flow path from Hopper well #30 to the Malad Gorge. The distance between sites MG-1 and MG-5 is 718 feet and the distance between the well and site MG-3 is 5,490 feet which equates a mechanical dispersivity ratio of approximately 7.6. The angle of dispersion measured from the well between MG-1 and 5 is approximately 8 degrees. The main flow path is assumed to be based on the azimuth between the dye release well #30 and MG-3 to 2.5 which is 323 degrees. It is interpreted that the dye was transported through a cinder rich brecciated pillow zone and the 'bell' shaped response curve is consistent with this concept.

Figure 22 shows two breakthrough curves, one for Riddle well #26 and the other for spring site MG-3. The rising limbs for both curves have nearly the same slope angle along with the relatively sharp recession limbs which suggest little retardation of the tracer from sorption and indicative of a conservative tracer. The May 28th peak for MG-3 is probably more representative of conduit flow paths and the slight second peak for MG-3 on June 3rd is possibly associated with flow through breccia or cinder particles. The highest peak for Riddle well #26 on May 31st may have more association with the flow path for the second MG-3 peak on June 3rd which is additional evidence that the well was not centered in the highest concentration flow path of the dye cloud. The term dye cloud is used loosely to help the reader visualize the fundamental movement of the tracer. The actual shape of the tracer plume is undefined and the flow regime might be more accurately described as intertwining network of conduits surrounded or incased within breccia and cinders. The dye may be flowing through both conditions producing the double peak response curve.

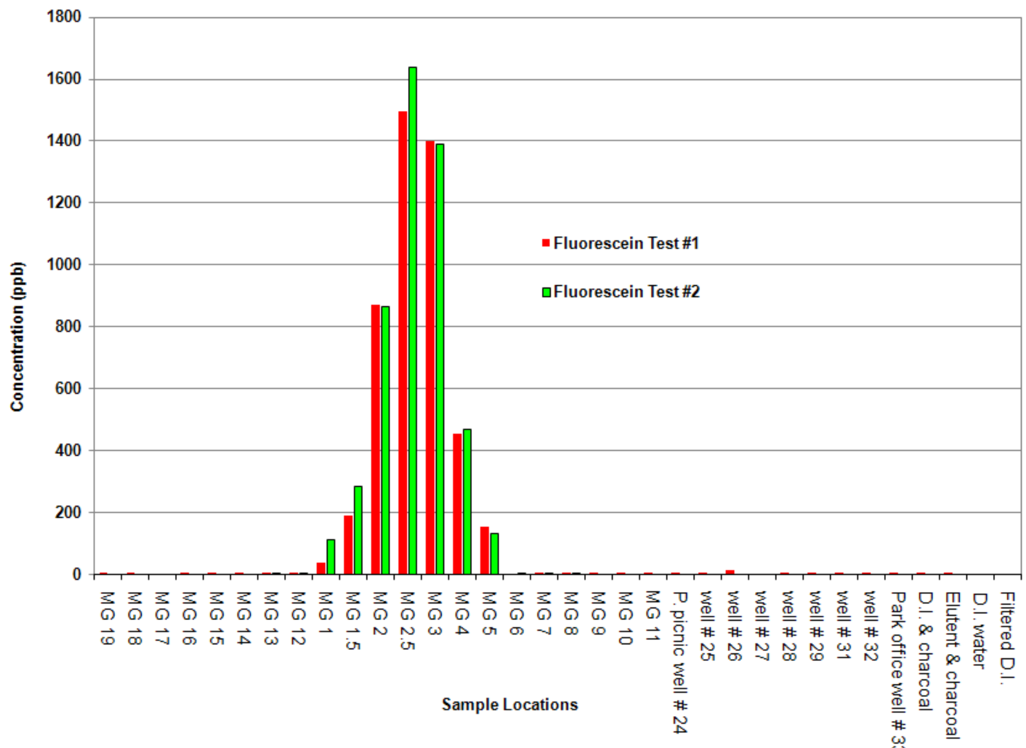

Figure 21. Combined charcoal results from Test #1 and #2 showing consistent reproducibility.

The results from Test #1 allowed for targeting the placement of the C3 in Test #2. The results from Test #2 were consistent with Test #1 data and provided a greater refinement of dispersion, travel time, dye break through characteristics, center of mass response, what amount of dye injected results in concentrations at the spring, how fast the dye moves out of the well, and provided quantitative data to calculate aquifer parameters. The first arrival of Fluorescein dye at MG-3 spring was 2.75 days post injection and the center of mass of the dye cloud was determined to be 8.27 days. Using the recorded travel times of the dye cloud, the average linear water velocity was 664 feet per day and most of the dye had passed out of site MG-3 by about 16 days. The velocity from this test is consistent with two previous tracer test velocities and shows a decreasing trend with increasing scale and a lower gradient (Table 2). Note the distances have roughly doubled between each test. Harold 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.

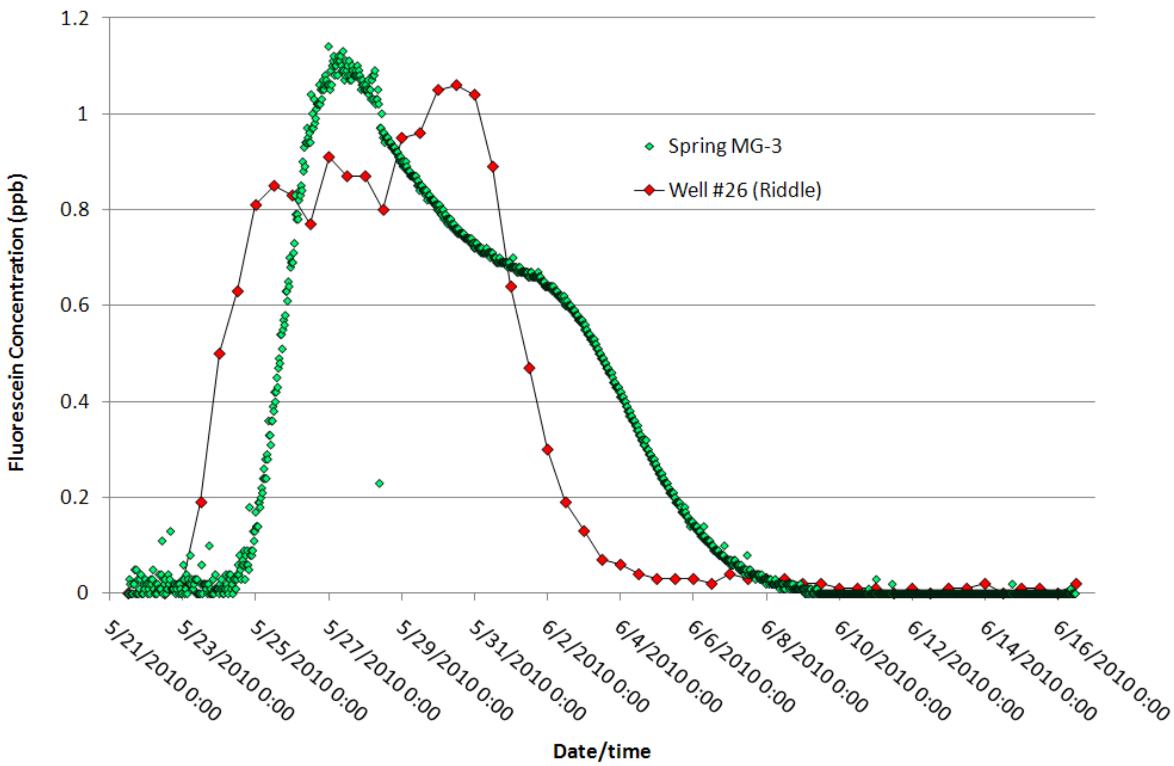

Figure 22. Two dye breakthrough curves from second Fluorescein test for Well #26 and spring MG-3.

Dye Test Location/Name	Distance/scale (feet)	Average GW Velocity ft./day	Maximum GW Velocity ft./day	GW Gradient
Park Picnic Well	1,100	880	5,640	0.04
Well #26 (Riddle)	2,865	800	2,455	0.024
Well #30 (Hopper)	5,490	664	2,000	0.014

Table 2. Relation between distance, gradient and groundwater velocities of three dye traces.

The ESPA Groundwater Model cell (SP037016) at this location has the following aquifer parameter of transmissivity (T) = 336,544 ft.^{2}/day and saturated thickness (b) = 200 feet. This would equate a hydraulic conductivity (K) of 1,683 ft./day. This cell has a calibration target (7508) located within it as shown in Figure 23 with a pink triangle. Using information from

Figure 5 and other nearby wells and outcrops, the aquifer in this cell may have a saturated thickness closer to 125 feet in the basalt overlying the GFF than 200 feet. If this is the case, then the model data would calculate a K value of approximately 2,700 ft./day compared to the 7,000 to 14,000 from this tracer test. The tracer test data would then calculate a T= (b) 125 ft.* (K) 10,500 ft./day (ave.) or 1,312,500 ft.^{2}/day.

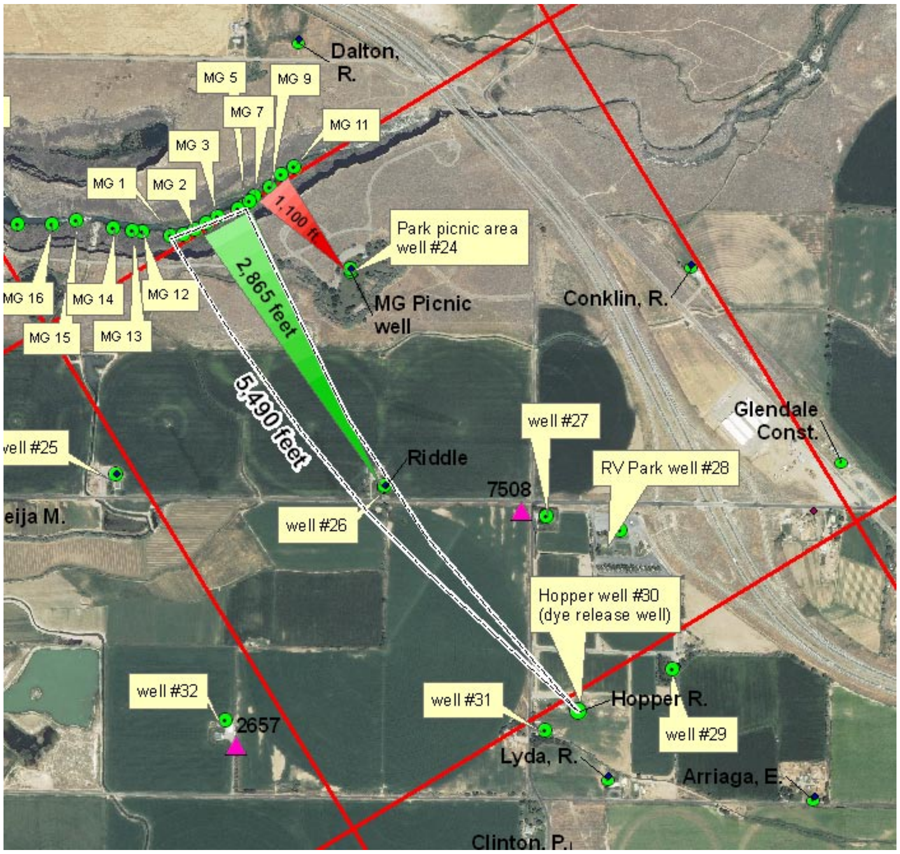

Figure 23. ESPAM cell with calibration target shown as pink triangle.

This 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 this test will provided a solid foundation to gauge decisions for larger scale tests with invaluable support from the following. Thank you.

Idaho Department of Water Resource staff who assisted with the project include Hal Anderson, Brian Patton, Rick Raymondi, Sean Vincent, Dennis Owsley, Craig Tesch, Mike McVay, Allan Wylie and Taylor Dixon. Idaho Power employees who assisted with project were Kresta Davis-Butts and Tim Miller. Tom Aley with Ozark Underground Laboratories (OUL) provided volunteer support for project planning with guidance and recommendations for implementation. 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 over $10,000 worth of instruments, without which this project may not have occurred. The Idaho State Health Lab provided technical assistance from Beth Orde (Principal Chemist) and Jim McKean (Research Geomorphologist) with the U.S. Forest Service provided access to lab space to process samples. We also appreciate the support from Boise State University Hydrology Professor Dr. Jim McNamara for loan of equipment.

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. 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.

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

6. 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).

7. 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.

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

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

10. 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.

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

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

13. 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.

14. 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.

15. 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.

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

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

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

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

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

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

22. 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.

23. 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.

24. 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.

25. 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.

26. 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.

27. 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.

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

29. 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.

30. 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, v. K-2.

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

32. 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.

33. 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.

34. 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.

35. 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.

36. 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.

37. 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.

38. 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.

39. 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.

40. Ralston, D., 2008, Hydrogeology of the thousand springs to Malad reach of the enhanced snake plain aquifer model, I.D.W.R. report, 20.

41. 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.

42. 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.

43. 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.

44. 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.

45. 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.

46. 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.

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

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

49. 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.

50. 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 – Well Drillers Report for Dye Release Well

Form 238-7 8/80

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

WELL DRILLER'S REPORT

USE TYPEWRITER OR BALLPOINT PEN

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name: Roy Hopper
Address: 2382 Ritchie Rd Hagerman
Drilling Permit No. 36-92-S-063-000
Water Right Permit No. ______

2. NATURE OF WORK

☒ New well ☐ Deepened ☒ Replacement
☐ Well diameter increase
☐ Abandoned (describe abandonment procedures such as materials, plug depths, etc. in lithologic log)

3. PROPOSED USE

☒ Domestic ☐ Irrigation ☐ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other ______ (specify type)

4. METHOD DRILLED

☒ Rotary ☒ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other ______

5. WELL CONSTRUCTION

Casing schedule: ☒ Steel ☐ Concrete ☐ Other ______

Thickness	Diameter	From	To
.250 inches	6 inches	+ 1 feet	19 feet
inches	inches	feet	feet
inches	inches	feet	feet
inches	inches	feet	feet

Was casing drive shoe used? ☐ Yes ☒ No
Was a packer or seal used? ☐ Yes ☒ No
Perforated? ☐ Yes ☒ No
How perforated? ☐ Factory ☐ Knife ☐ Torch ☐ Gun
Size of perforation ______ inches by ______ inches

Number	From	To
perforations	feet	feet
perforations	feet	feet
perforations	feet	feet

Well screen installed? ☐ Yes ☒ No
Manufacturer's name ______
Type ______ Model No. ______
Diameter ____ Slot size ____ Set from ______ feet to ______ feet
Diameter ____ Slot size ____ Set from ______ feet to ______ feet
Gravel packed? ☐ Yes ☒ No ☐ Size of gravel ______
Placed from ______ feet to ______ feet
Surface seal depth 19 Material used in seal: ☐ Cement grout ☒ Bentonite ☐ Puddling clay ☐
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☒ Overbore to seal depth
Method of joining casing: ☐ Threaded ☐ Welded ☐ Solvent Weld ☐ Cemented between strata
Describe access port: Sanitary Well Cap

6. LOCATION OF WELL

Sketch map location must agree with written location.

N / W / E / S — 31

Subdivision Name ______
Lot No. ______ Block No. ______

County: Gooding
SW ¼ SW ¼ Sec. 31, T. 6 N☐ S☒, R. 14 E☒ W☐

7. WATER LEVEL

Static water level 174' feet below land surface.
Flowing? ☐ Yes ☒ No G.P.M. flow ______
Artesian closed-in pressure ______ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature ~85 °F. Quality ______
Describe artesian or temperature zones below.

8. WELL TEST DATA

☐ Pump ☐ Bailer ☐ Air ☐ Other ______

Discharge G.P.M.	Pumping Level	Hours Pumped

87331

9. LITHOLOGIC LOG

Bore Diam.	Depth From	Depth To	Material	Water Yes	Water No
8	0	18	Top Soil + br Sand		X
8	18	19	Bl Lava		
6	19	23	" "		
	23	30	Red Sand		
	30	57	Gray Lava		
	57	66	Red + bl Cinders		
	66	116	Gray Lava		
	116	117	Soft bl Lava Loose Rock		
	116	128	Soft Gray Clay		
	128	166	Gray Lala		
	166	179	Crack bl Lava Loose Rock		
	179	192	Soft bl Lava + Br Sand	X	
	192	198	Bl Lava	X	
	198	204	Cinders		

RECEIVED
APR 1992
Department of Water Resources
Southern Region Office

RECEIVED
DEC 01 1992

10. Work started 3-31-92 finished 4-1-92

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name: Eaton drilling Firm No. 26
Address: Wendell Date 4-5-92
Signed by (Firm Official) [signature]
and
(Operator) Dave [signature]

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

APPENDIX B – Miscellaneous Information

The NSS Bulletin - ISSN 1090-6924
Volume 46 Number 2: 21-33 - October 1984
A publication of the National Speleological Society

A Review of the Toxicity of Twelve Fluorescent Dyes Used for Water Tracing

P.L. Smart

Abstract

Toxicological information is reviewed for twelve fluorescent dyes used in water tracing, Fluorescent Brightener 28, Tinopal CBS-X, Amino G Acid, Diphenyl Brilliant Flavine 7GFF, Pyranine, Lissamine Yellow FF, Fluorescein, Eosine, Rhodamine WT, Rhodamine B, Sulphorhodamine B and Sulphorhodamine G. Mammalian tests indicate a low level of both acute and chronic toxicity. However, only three tracers could be demonstrated not to provide a carcinogenic or mutagenic hazard. These were Tinopal CBS-X, Fluorescein and Rhodamine WT. Rhodamine B is a known carcinogen and should not be used. In aquatic ecosystems, larval stages of shellfish and algae were the most sensitive. Persistent dye concentrations in tracer studies should not cause problems provided they are below 100 μg/l.

http://www.caves.org/pub/journal/PDF/V46/v46n2-Smart.htm

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

Division of Kingscote Chemicals

WATER TRACING DYE
FLT YELLOW/GREEN PRODUCTS

TECHNICAL DATA BULLETIN

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

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

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

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

Site	X (meters)	Y (meters)
MG 1	2429484	1296373
MG 1.5	2429519	1296376
MG 2	2429548	1296389
MG 2.5	2429582	1296406
MG 3	2429614	1296423
MG 4	2429668	1296444
MG 5	2429687	1296455
MG 6	2429698	1296464
MG 7	2429714	1296477
MG 8	2429738	1296494
MG 9	2429755	1296504
MG 10	2429787	1296538
MG 11	2429822	1296560
MG 12	2429405	1296383
MG 13	2429380	1296384
MG 14	2429328	1296391
MG 15	2429227	1296411
MG 16	2429158	1296401
MG 17	2429067	1296403
MG 18	2428995	1296436
MG 19	2428989	1296445
MG 20	2428850	1296535
MG 21	2428667	1296436
MG 22	2428489	1296375
MG 23	2428431	1296316
Well 24 Park picnic area	2429972	1296268
Well 25 N. Riddle	2429314	1295699
Well 26 R. Riddle	2430064	1295676
Well 27 Farnsworth	2430509	1295605
Well 28 RV Park	2430713	1295557
Well 29 R. McBride	2430866	1295183
Well 30 R. Hopper	2430597	1295074
Well 31 Sanchez	2430503	1295020
Well 32 S. Luttmer	2429625	1295018
Well 33 Park office	2428265	1295650