Idaho Department of Water Resources

Open File Report

FLUORESCENT DYE TRACER TESTS AT THE MALAD GORGE STATE PARK

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September 30, 2009

ABSTRACT

Through a cooperative effort between the Idaho Parks and Recreation Department, Idaho Department of Water Resources, Idaho Power, Lower Snake River Aquifer Recharge District, and the Middle Snake Water Resource Commission three tracer tests were successfully conducted at the Malad Gorge State Park during the spring of 2009. A thorough literature search for any groundwater tracing done in the ESPA for the area from Idaho National Lab (INL) to Hagerman was made along with inquiries to various federal and state agencies and organizations to determine if tracing has been previously done but none were found. If this is true, then the first documented successful groundwater tracer test was completed at Malad Gorge. Dye was injected into a well located in the park picnic area. Springs along the river edge in the Gorge were monitored for the dye. Fluorescent dyes were used in a ‘two phased’ approach to determine the spatial distribution first and then 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 873 feet per day with the caveat that 18% of the distance is through talus slope.

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Purpose and Objectives

A pilot-scale groundwater tracer test was implemented at Malad Gorge State Park to determine the feasibility and viability of using fluorescent dyes to assist with baseline aquifer characterization. Long-term goals for the tracer studies for 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 important 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. For example, water quality can be better monitored from aquifer recharge if flow directions are delineated which would enhance public safety. Some of the site specific goals included an attempt to determine the following:

1. What is the hydraulic communication between the picnic well and 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 cone of dispersion of the dye?
5. How fast will the dye flow out of the well?
6. How long does the pump need to be turned off during the test?
7. What will be the residual dye concentration in the well when the pump is turned back on?
8. Will water quality be affected?
9. What is the optimal sampling temporal frequency and spatial frequency?
10. How much dye is needed to obtain a significant and discernable response?
11. Is it possible to access the sample locations in the Gorge given the terrain and vegetation?
12. What will be the resurgent concentration of dye in the springs and the river?
13. What are any potential biological impacts from the dye?
14. Will the injection method of using polyethylene tubing work?
15. Is the level of injection in the well appropriate?
16. Will the test be a burden or inconvenient for the park operations?
17. Can the dye be detected downstream after the Malad River and other spring discharge areas have diluted it?
18. 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 elevation of the park picnic area well head is 3,273 feet determined from 100 post processed readings using a Trimble GeoXT 2005 set on the highest precision option and NAD83. On March 20, 2009 the depth to water in the well was 191.76 feet or 3,081 feet elevation. The river and spring discharge elevations range from 3,030 to 3,040 feet elevation using the same technique. The Gorge in this area is about 225 feet deep with vertical walls of basalt and talus slopes. Formation of the Gorge is attributed to cataract retreat of flood waters from the Bonneville Flood. No major landslides are located in this part of the Gorge. However, a bench about 20 feet higher than the river within a section of the talus slope may be the remnants of an old landslide.

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

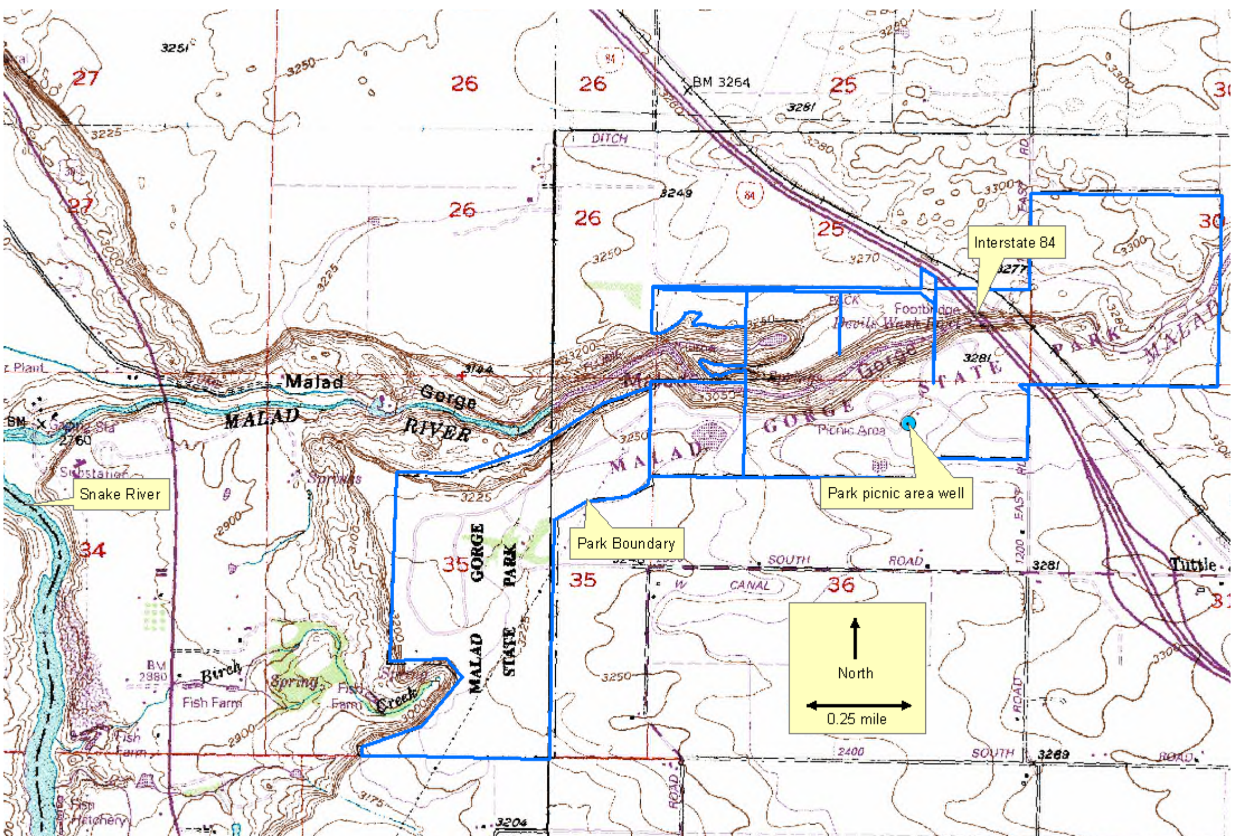

Figure 2. USGS topographic map of the site showing the park boundary as the blue colored line.

Geologic 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 walls of the Gorge are identified as Madson Basalt dated at 404,000 years old (Figure 3). The cataract that formed the Gorge eroded the partially unconsolidated pillow rubble zone and probably the GFF which caused the overlying basalt to collapse. Downstream in the Gorge, landslides (Qls in Figure 3) are also slipping or failing in the saturated GFF and they likely failed during the recession of the Bonneville Flood.

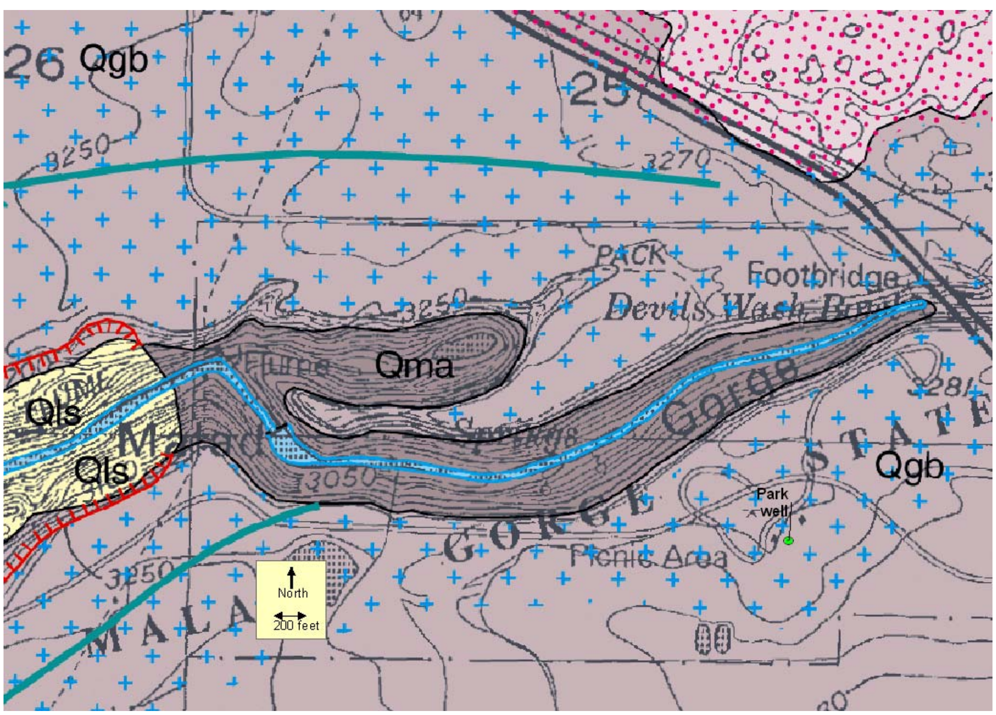

Figure 3. Geologic map showing the upper section of Malad Gorge Pleistocene age basalts Madson (Qma) and Gooding Butte (Qgb) (Gillerman et al, 2005). See Appendix A.

GEOLOGIC MODEL OF TRACER TEST SITE

A simple geologic model is inferred from the site specific geologic map, well logs, and outcrops in context with inspections of geology in the Hagerman Valley area. The geologic model provides a framework to assist hydrologic and tracer test interpretation. A general chronology of events that formed the Gorge geology would entail:

1.) Lake Idaho deposits fluvial and flood plain sediments from about 5 to 1.5 million years ago (Malde, 1958).
2.) Lake Idaho drained about 1.5 million years ago and erosion of the sediments takes place with rivers and streams cutting canyons into the sediments up to about 404,000 years ago.
3.) A volcanic eruption occurred approximately 404,000 years ago and filled the canyon with lava and pillows; then repeated basalt flows fill the canyon (Gillerman et al, 2005).
4.) The Malad River probably was flowing in this area when 15,000 years ago the Bonneville Flood cut the Gorge through erosion and cataract retreat.
5.) Landslides occur in the lower sections of the Gorge possibly during the recession of flood water.

Located near Idaho Power's upper diversion is an in-situ outcrop of pillow lava exposed in the canyon wall that is at least 30 feet thick, although the base is not exposed (Figure 4). The location of Cross-section A-A' is shown in Figure 5 noting some relevant geologic outcrops and the deepest wells in the area. The elevation of this pillow zone correlates to the inferred contact between the GFF and overlying Madson (Qma) basalt based on additional information in well logs of the Park Office and Hooper wells and L. Woody borehole (Figure 6). Individual logs can be found in Appendix B. Note the close elevation correlation between the pillow outcrop, site MG-7 and the lowest geologic notation for the park picnic well as 'broken basalt'. Groundwater flows from the base of the brecciated pillows which is similar to other spring locations in the Hagerman Valley with exposed pillows and groundwater discharge. Field inspection at several nearby spring sites show a geologic pattern of a massive 'cap' of basalt overlying a pillow/brecciated rubble zone typically with groundwater discharging from it, and underlying the pillows is the GFF. This general geology has been observed at the Curren Tunnel, Three Springs, Big Springs, an outcrop 1 mile south of Rangen (dry), and at Spring Creek. All four well logs note "broken basalt" at this contact and it is interpreted to be the pillow/rubble deposit. Pillows and associated rubble are highly permeable and capable of transmitting or discharging large volumes of ground water.

An idealized vertical cross section model is shown in Figure 7 that is not to scale, and the exact subsurface geologic architecture is not well defined. The units, contacts and orientation are inferred from outcrops, mapping and well logs. Numerous well logs and outcrops indicate the GFF contact appears to rise in elevation both north and south of this area and there is an approximately 47 foot elevation change from the water level in the well to the river/spring elevation in the Gorge.

Figure 4. Thick layer of pillow basalt with groundwater discharge located at Idaho Power Company's upper diversion dam.

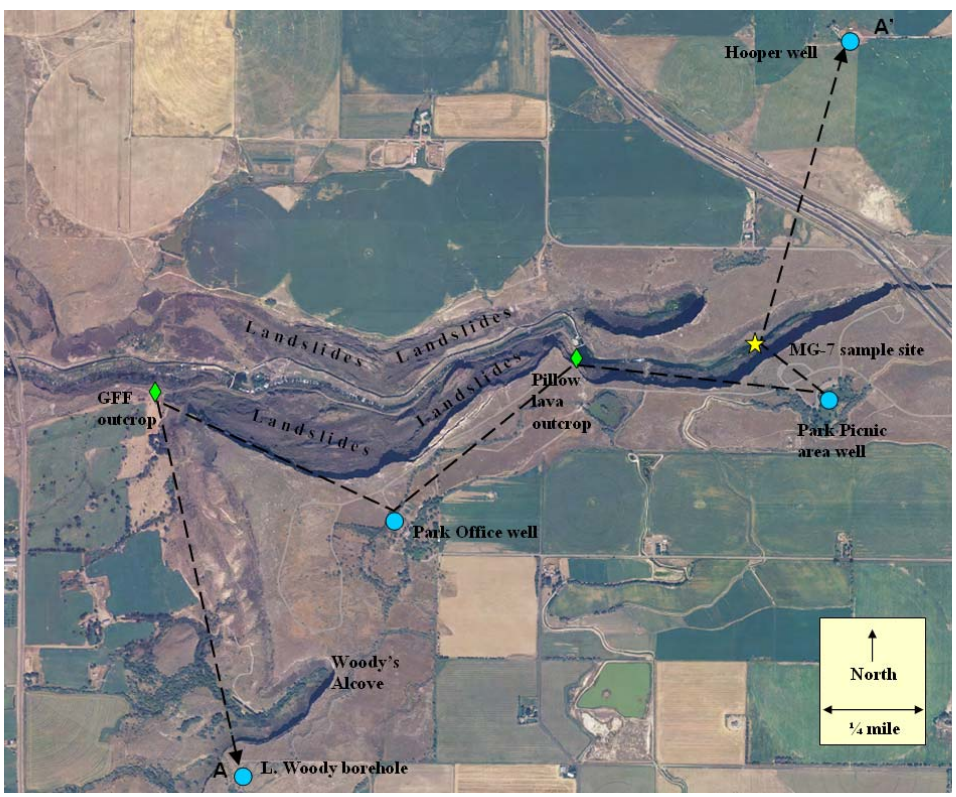

Figure 5. Location of geologic cross section line A-A' with wells noted as blue circles, outcrops as green diamonds and sample site MG-7/Malad River as yellow star.

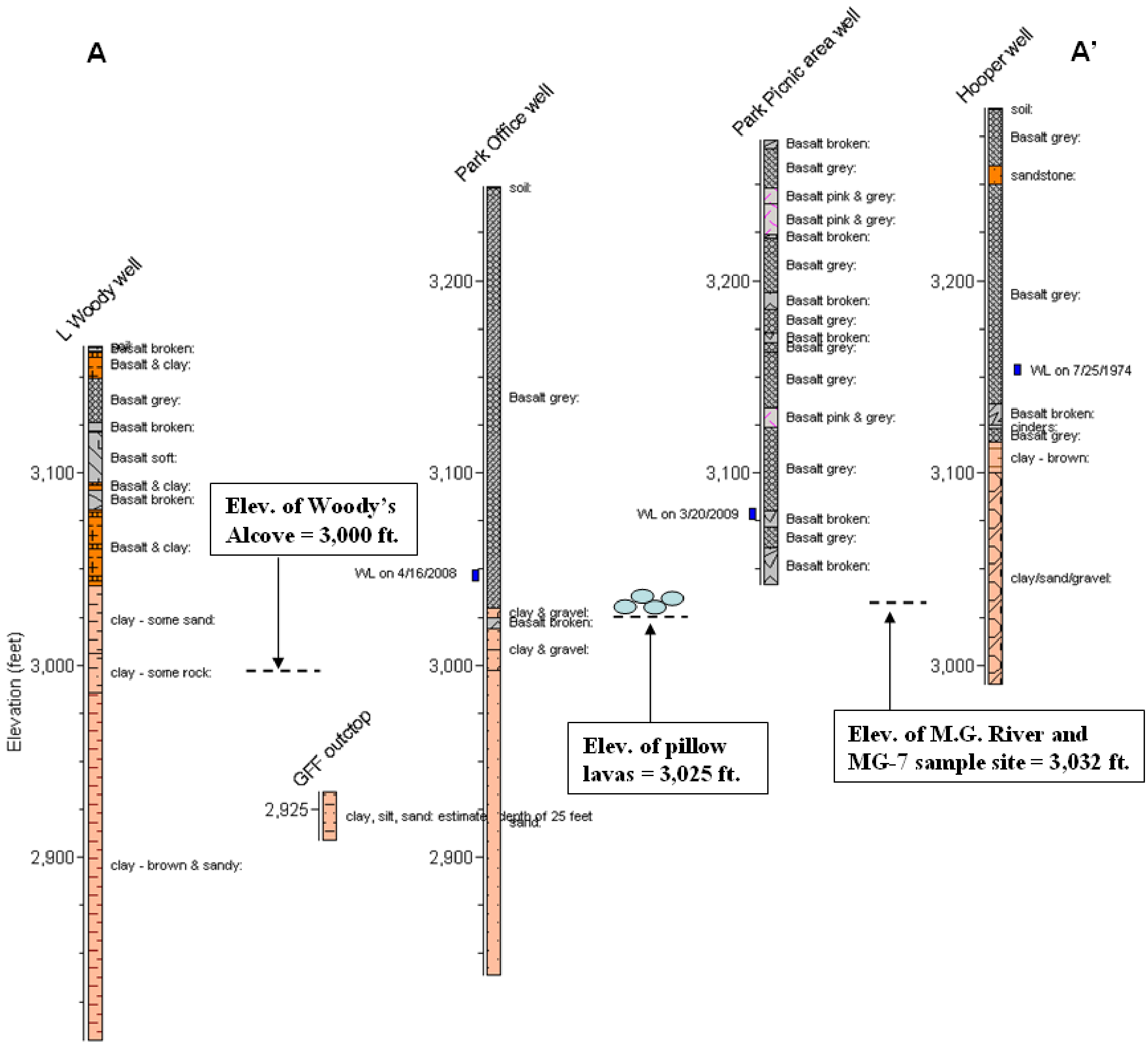

Figure 6. Geologic cross section A-A' noting sediments as orange colored background and basalt related rock type as grey colored background patterns. Elevations of Woody's Alcove, pillow basalt outcrop and the Malad Gorge River/sample site MG-7 are also shown. Tick marks are every 25 feet. Well water levels are shown with dates.

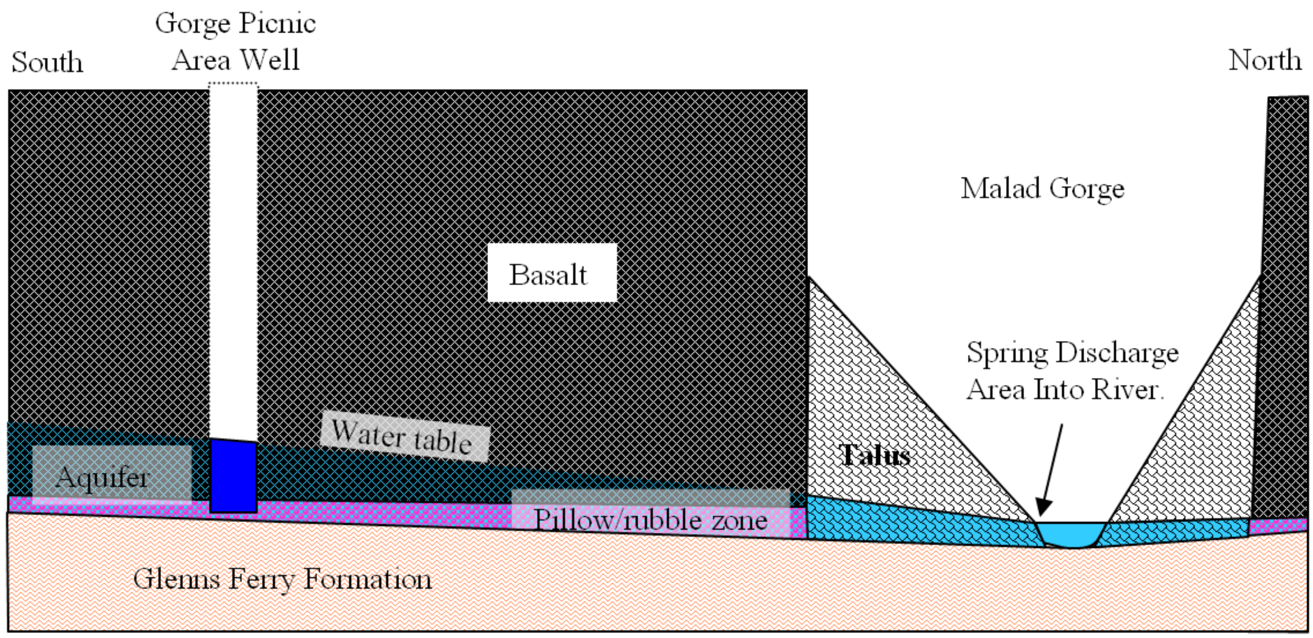

Figure 7. General conceptual cross section geologic model for the tracer test area (not to scale).

BACKGROUND OF DYE TRACING

A literature review and inquiry was made to Universities, state and federal agencies to determine if any tracer tests have been performed, documented and made available to the public on the Lower Eastern Snake Plain Aquifer (LESPA) southwest of INL but no previous investigations were found. The groundwater tracer test completed at Malad Gorge appears to be the first documented successful tracer test in the LESPA that is readily available to the public.

The dye of choice for this study was Sodium Fluorescein and Rhodamine WT. Fluorescein, a green colored fluorescent dye, was first synthesized by Adolf von Baeyer in 1871 and it is the most commonly used dye for both surface and groundwater tracing studies. Sodium Fluorescein (Acid Yellow 73 – CAS # 518-47-8) can be detected in a fluorometer at very low concentrations of 0.1 parts per billion (ppb). Fluorescein is also known as Drug and Cosmetic Yellow 8 which is an ingredient in some consumer products. Fluorescein is widely used in medical treatments for humans in the United States and it is given to about a million people a year. Dye tracing has been used for the analysis of blood circulation within various parts of the human or animal body. For example, fluorescent angiography, a technique of analyzing the circulation in the retina, is used for diagnosing various eye diseases.

The toxicity of any tracer is dependent upon several factors including the concentration present and the environment into which the dye is released (Field et al 1995). Additionally, some organisms may be more susceptible than others to the introduction of a tracer. Several authors have investigated health and ecological impacts of Fluorescein. Field (with U.S. EPA) et al

1995, evaluated several dyes including Fluorescein. They reported finding little concern for human health or environmental impacts “if dye concentrations are maintained below the minimum (easily visible to the naked eye) at approximately 1-2 mg/L (1,000-2,000 micro grams per liter) for 24 hr. at the point of groundwater withdrawal or discharge.” Walthall and Stark (1998) evaluated the acute and chronic toxicity of fluorescein to *Daphnia pulex*. They concluded that Fluorescein is “not likely to pose a significant threat to natural populations.” Their results indicated that concentrations required to elicit even sublethal doses were quite high (LC50 337 mg/l and LC90 721 mg/l). Pouliquen et al (1995) as cited by Noga and Udomkusonsri (2002) stated that turbot (*Scophthalmus maximu*) exposed to concentrations of 700 mg/l (700,000 ug/l) Fluorescein was not lethal. Smart (1984) concluded that persistent (long-term) exposure to dye concentrations below 100 ug/l should not cause environmental or health problems. Smart also states that while developmental stages of shellfish appear more sensitive to Flourescein than fish, short-term (48 hours) exposure to concentrations of 1 mg/l can be endured. In conclusion, the use of Fluorescein for tracer studies does not appear to create health or environmental problems if target concentrations are low at the point of ground water discharge into surface water environments.

Human health and safety are addressed and the MSDS sheets are provided in the appendices. Safety of both Fluorescein and Rhodamine WT has been documented in numerous scientific studies during the past 50 years. The EPA approves both of these dyes to be used in public drinking water supplies and notes the dyes as “non-toxic” (see reference sources) which also conform to the ANSI/NSF Standard 60 for potable water as set forth by the EPA in the Clean Water Act. The FDA has also approved the use of Fluorescein in ‘over the counter’ consumer products. The dye is biodegradable and photodegradable with decomposition products of carbon dioxide, water and a trace amount of sodium.

Fluorescent dyes make excellent tracers for a variety of reasons, including:

1. They are approved for use in public drinking water supply systems.
2. There are no harmful effects (MSDS) and have extremely low toxicity ratings. The absence of toxicity from Fluorescein is documented in the following reference by Smart (1984).
2. They are water soluble.
3. They are highly detectable (some below 1 part per trillion).
4. They are inexpensive.
5. They are fairly stable in a normal water environment.
6. They have been used successfully for tracing for over half a century even at locations where there are endangered or sensitive species and public drinking water supplies.
7. They are not naturally found in aquifer systems and therefore no background interference like other tracers can be like bromide.
8. Sampling procedure is simple and inexpensive.

Planning for a tracer test includes the development of the conceptual design, identifying potential down gradient receptors such as humans, aquaculture industry and endangered species, transient hydrologic barriers such as canal recharge, selection of initial mass of tracer or its concentration, target concentrations at collection points, observation wells, sampling schedule and locations, and monitoring. The type of tracer selected for a tracer test is dependent on many factors including the purpose of the study. For example, if information such as the velocity of the ground water, porosity, and the dispersion coefficient are of interest, then a conservative tracer should be used. Other factors include type of medium, available funds, the stability of the tracer, detectability of tracer, difficulty of sampling and analysis (availability of tracer, ease of sampling and availability of technology for analysis), physical/chemical/biological properties of tracer and public health considerations (Davis et. al., 1985). For tracer tests at springs in the Thousand Springs area, the following components were considered and evaluated: the conceptual design, down gradient receptors, aquaculture industry and endangered species, transient hydrologic barriers such as canal recharge, selection of initial mass of tracer or its concentration, observation wells, sampling schedule and locations, and monitoring. The 1986 USGS report titled “Fluorometric Procedures for Dye Tracing” by Wilson et al. served as a principal guidance document.

The transport of a conservative tracer is primarily controlled by advection with effects of dispersion. Advection is the movement of the solute due to general ground water motion. Dispersion is a phenomenon by which a solute is mixed and becomes reduced in concentration at the pore level and different strata flow paths. Since no fine grained sediments of silt or clay are present along with high ground water flow velocities; then dye tracers serve as a conservative tracer. The rate of the flowing ground water can be evaluated based on Darcy’s Law. Tracer migration due to advection is assumed to occur at the same rate as the average linear velocity of the ground water (Fetter, 2001). It is important to realize that not all solute will travel at the same rate as the ground water. Some solute will move slower than the mean velocity and some will move faster than the mean velocity. This mechanical mixing together with ionic diffusion results in hydrodynamic dispersion and spreading of the solute. Dispersivity has been determined to be scale-dependent (Davis et.al., 1985), meaning that values of longitudinal dispersivity generally increase with increasing distance between the injection point and sampling locations (i.e. dispersivity increases as the plume migrates down gradient) (Anderson and Woessner, 1992). In fractured, non-soluble aquifers, Leibundgut and Wernli (1986) estimated about 1% of the dye introduced is typically recovered (Aley, 2002) but recovery of tracer can vary. For example, in a tracer study performed in a perched basalt aquifer under the Bell Rapids Irrigation District in Twin Falls County by Dallas (2005), up to 28% of the dye was recovered.

PROCEDURE/METHODS

Prior to making an application for a permit to inject the dye, numerous meetings and discussion occurred between IDWR, Idaho Power, Parks and Recreation, and the U.S. Fish and Wildlife Service. A two phase approach was developed at this site due to accessibility issues matched with sampling frequency needs for desired results. Phase one used Fluorescein dye to delineate the spatial distribution of the dye cloud as well as the location with the greatest amount of dye passing. Phase II used Rhodamine dye with a submersible fluorometer and datalogger (SCUFA) deployed at the sample site where the greatest amount of Fluorescein dye was detected from Phase I. The SCUFA recorded the concentration of dye with time to provide a concentration breakthrough curve which was then used to determine the travel time. A ground water velocity was then calculated. The approach proved very efficient for time, supplies, and sampling/analysis costs. It also provided a high resolution breakthrough curve on a one minute frequency that is essentially impossible if done manually without a SCUFA instrument.

Phase I Description

Fluorescein dye was injected in phase I with charcoal packets used as dye collectors along with 50 mL water samples. Figure 8 shows the location of the sample sites as yellow circles and noted as MG-1 through MG-11. They were placed at high spring/groundwater discharge flowing into the river. Ground water discharge was observed at other locations but at reduced rates. It was anticipated that the dye would discharge at MG-4, 5, and 6 and that is why there is a slightly higher density of sample sites. Coconut shell charcoal packets purchased from Ozark Underground Labs (OUL) were deployed at each sample site in the spring water and also at the Idaho Power diversion. 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.

- On March 20, 2009 sample sites were scoped, selected and georeferenced using a Trimble GeoXT 2005 with 100 readings post processed and NAD83 IDTM.

- On Tuesday April 7 charcoal packets were deployed and pre-test water samples collected. The SOP for collecting water samples consists of rinsing the 50 mL containers provided by OUL three times with sample water before collection. Then the water samples were placed in a cooler with blue ice for transport back to the lab. There was no detection of dye from these water samples collected before the dye was injected using a calibrated Turner Designs fluorometer model TD 700. At 5:10 pm 1 pound of Fluorescein powder that is 75% dye equivalent was mixed with 3 gallons of potable water and injected into the Park picnic area well through polyethylene tubing (Figure 9) that extended down to 213 foot depth. This level, approximately 22 feet below the water surface, is noted as "broken basalt" in the well log (see Appendix B) and interpreted to be pillow basalt.

- On Saturday April 11 an inspection was conducted of the springs and river from the rim. Water from the park restrooms and from the Idaho Power diversion was inspected, and water samples collected. No dye was visible to the unaided eye at any locations, and the river was clear of sediments. The water samples from the river and restrooms were tested in the lab using the TD 700 with no detection of Fluorescein dye indicating that no dye was being discharged from the aquifer after 4 days. The Fluorescein dye probably flowed completely out of the well in just a few hours after release.

- Protocols also called for monitoring of the park well for the presence of Coliform bacteria after the test. Park staff reported a lab result of "absence" for total Coliform bacteria from the well water sample before service to the restroom.

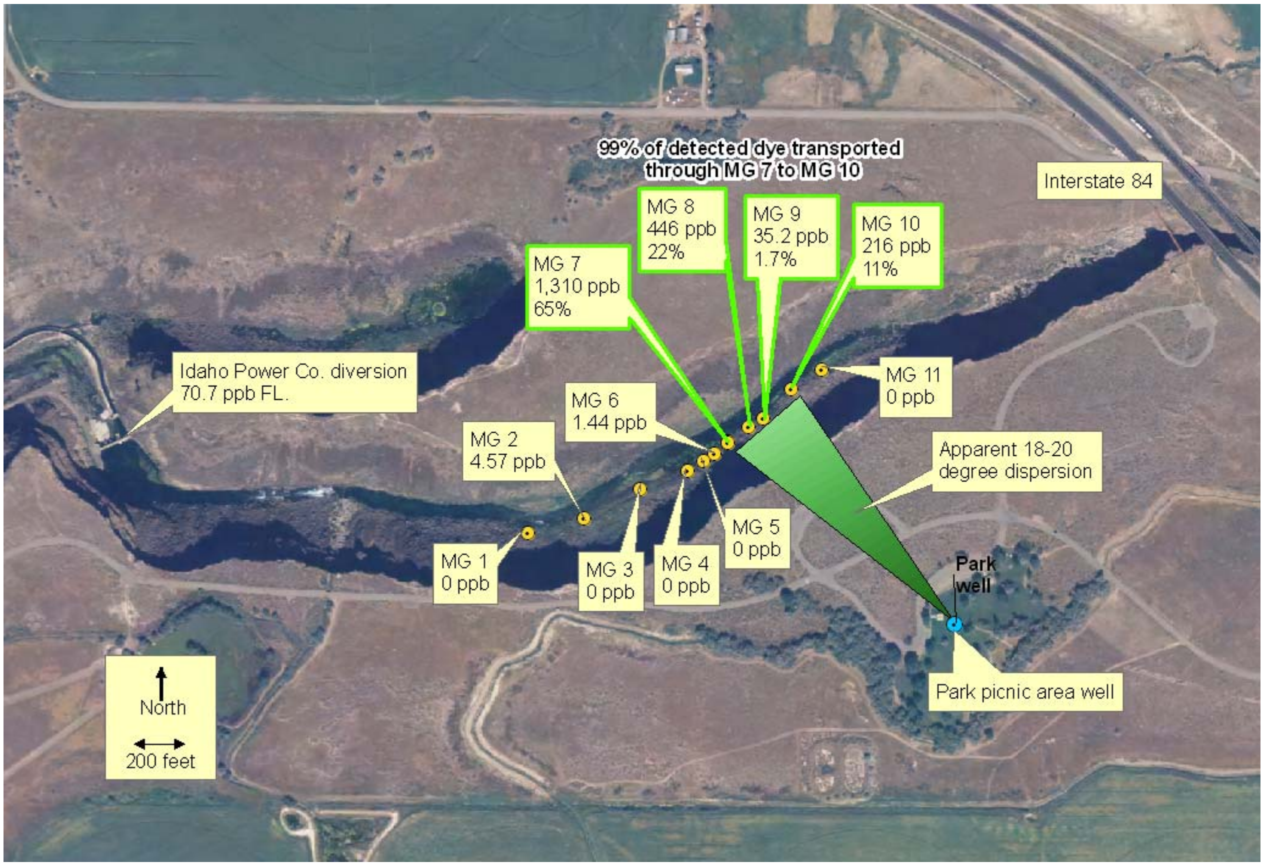

Figure 8. Air photo showing Fluorescein tracer test sample sites with yellow circles and the dye injection well in the Park picnic area with a blue circle. The majority of the detected Fluorescein dye passed by sites MG 7, 8, 9 and 10.

Figure 9. Polyethylene tubing deployed down well to the 213 foot depth level.

- On Tuesday April 14th water samples were collected, charcoal packets retrieved and replaced with new ones at all sample sites. These samples were shipped to Ozark Underground Labs for analysis with a table of results provided in Appendix C.

Phase Two Description

Once the preferred hydraulic pathway was determined from Phase I, one gallon of 2.5% concentration active ingredient (approximately 0.2 pounds) Rhodamine WT (RWT) dye was injected into the park well on June 23, 2009 with deployment of a Turner Designs "Self Contained Underwater Fluorescent Apparatus" or SCUFA at sample site MG-7. The SCUFA was programmed to record fluorescence data once per minute. The SCUFA provides a concentration breakthrough curve and travel time of the dye cloud; from which a velocity can be calculated.

The SCUFA unit was calibrated using deionized water and 4.0 ppb RWT solution, and it measures the water concentration of dye directly. The SCUFA also measures and records turbidity. The unit was inserted into 3-inch diameter black plastic pipe with holes drilled at an angle to allow water to flow through but block sunlight. Direct sunlight on the optics can produce noise and erratic readings. The unit was secured under a rock in a shady area of high flow at MG-7 (see following photos).

Figure 10. Location of sample site MG-7 in the red circled area as viewed from the canyon rim. Note the boundary of clear groundwater discharging into murky Malad River water.

Figure 11. Closer view of MG-7 showing the high flow out into the river.

Figure 12. IDWR staff, Dennis Owsley, assisting with deployment of the SCUFA. Note the strong current from the spring discharge.

Prior to and after the June 23rd deployment of the SCUFA, cool wet weather occurred and farmers stopped diverting irrigation water. High return flows into the Malad River and increased sediment load resulted. On the 23rd, the pool level of the river rose about 6 inches but may have been even higher at other times. It is unknown if this had any effect on the spring flows or water quality, but there were some unusual cycles in the fluorescent data recorded by the SCUFA (Figure 13) that correlate to turbidity.

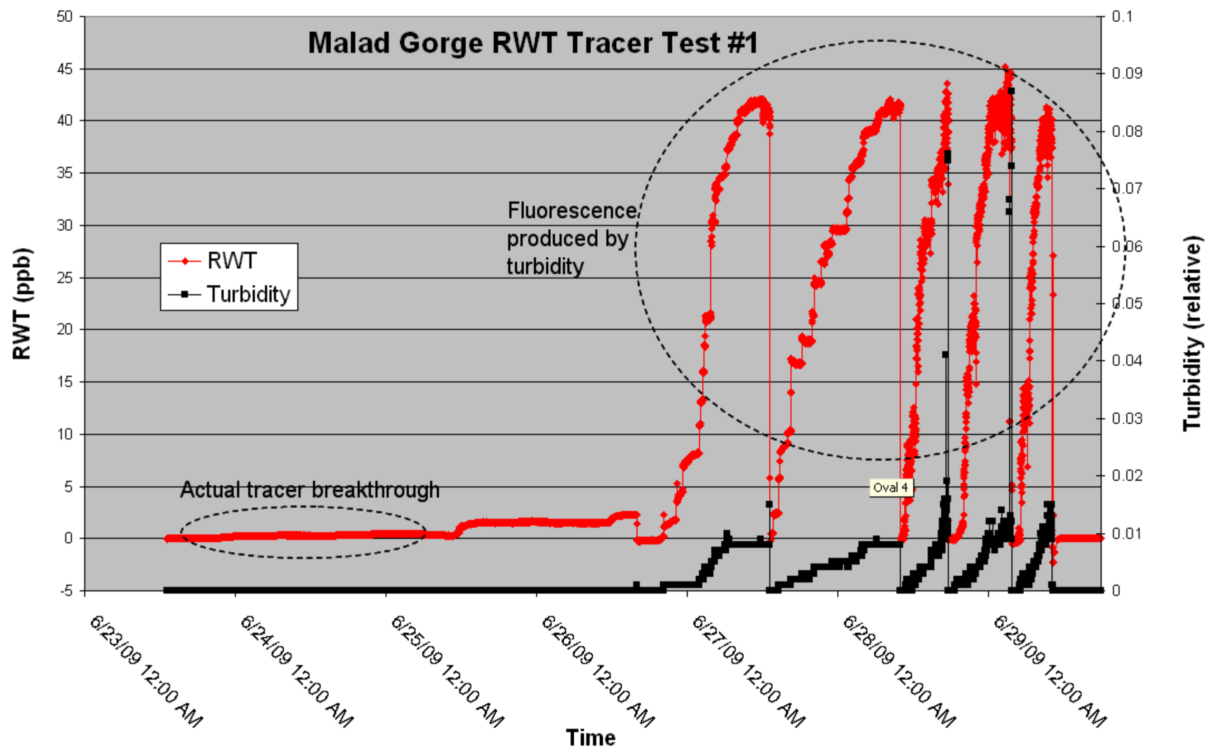

Figure 13. RWT test #1 concentration breakthrough curve from SCUFA. Fluorescent spikes correlate to turbidity spikes.

After evaluating the data from tracer test #1, a decision was made to repeat the test using the same mass of dye, sample point, injection level, etc. with the goal to obtain data with less "noise" (i.e. turbidity). Clearly, some natural events affected the data and produced large repeated cycles as seen in Figure 13. Data shifts are also noted in Figure 14. An incomplete recession limb made calculating the center of mass of the dye cloud and interpreting the results difficult. The data shift of approximately 0.05 ppb are near the detection limit of the instrument (0.04 ppb) therefore the shifts might not be real. The data shifts were removed from the red line to form the green line noted in Figure 14 and probably represents a more realistic trend. By removing the shifts the line slope angles and timing of the peak is not affected.

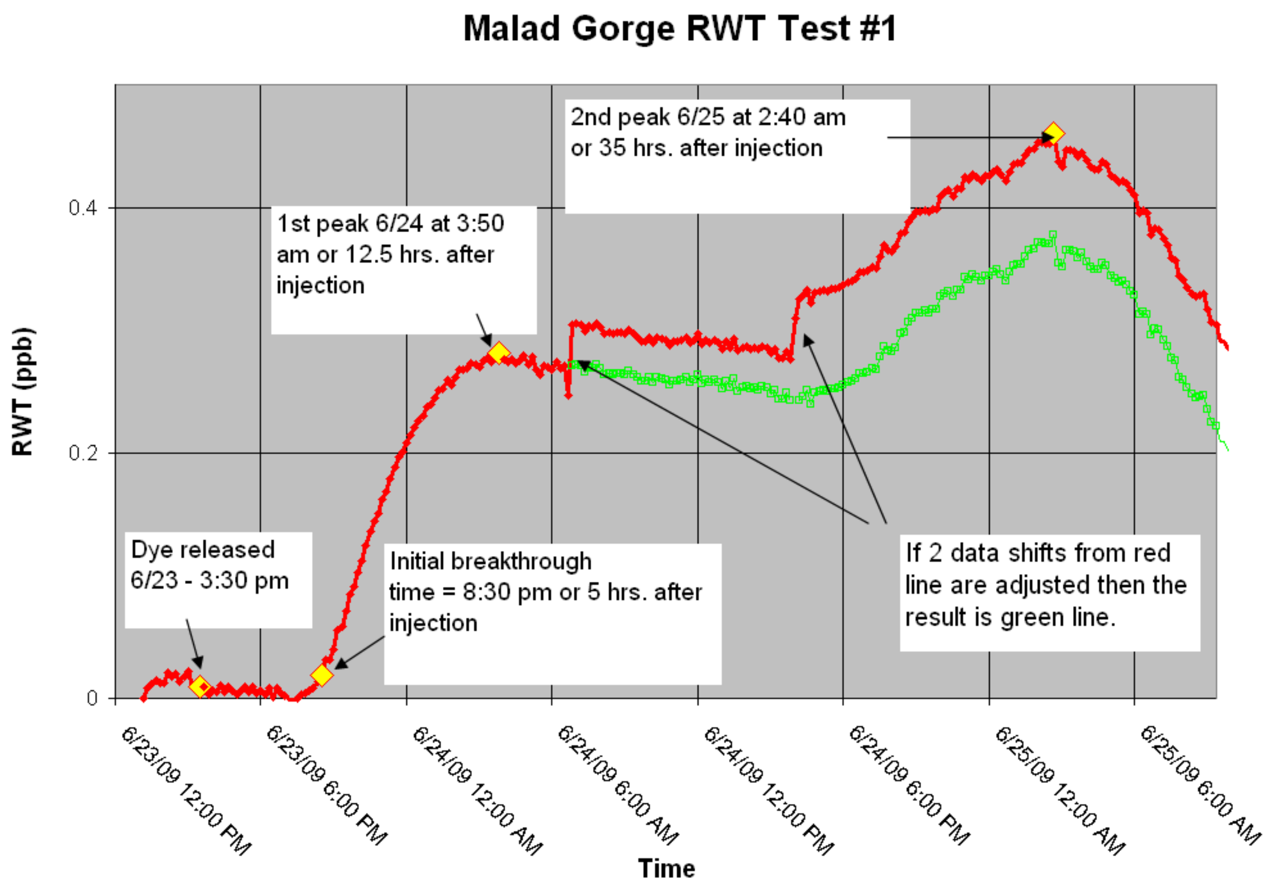

Figure 14. Expanded view of the oval shaped circled data in Figure 13 concentration breakthrough curve. Note the two peaks and temporal pattern for comparison with the second RWT test. Two data shifts occurred and if adjusted then the green line would be the resultant curve.

On Monday June 29th, a second repeat RWT test was performed. The SCUFA was immersed into two calibration solutions to check for drift, and the readings were within 0.5 ppb of the original calibration. After the test, the data (Figure 14) was downloaded from the SCUFA and evaluated. The SCUFA was then recalibrated to 25 ppb because at the time it was unknown if the high concentration cycles were dye or not and 25 ppb is roughly half of the peak of 45 ppb. Figure 15 shows better results because the turbidity (or other) disturbances were not present. At the time of the second test, typical spring weather patterns prevailed in southern Idaho. Irrigation activities resumed with a corresponding decrease in flows in the Malad River. In short, the hydrologic system 'settled down' or resumed back to a more stable character or baseflow condition.

Figure 15 shows a classic, nearly 'text book shaped', RWT concentration breakthrough curve with a sampling frequency of 10 minutes. In comparing Figures 14 and 15, it is evident, that the initial breakthrough, first peak and second peak are all within 1 hour of the each other. With a more complete recession curve, it was possible to calculate the center of mass of the dye at about 30 hours after injection. The two peaks can be explained by a simple 'double flow path' model

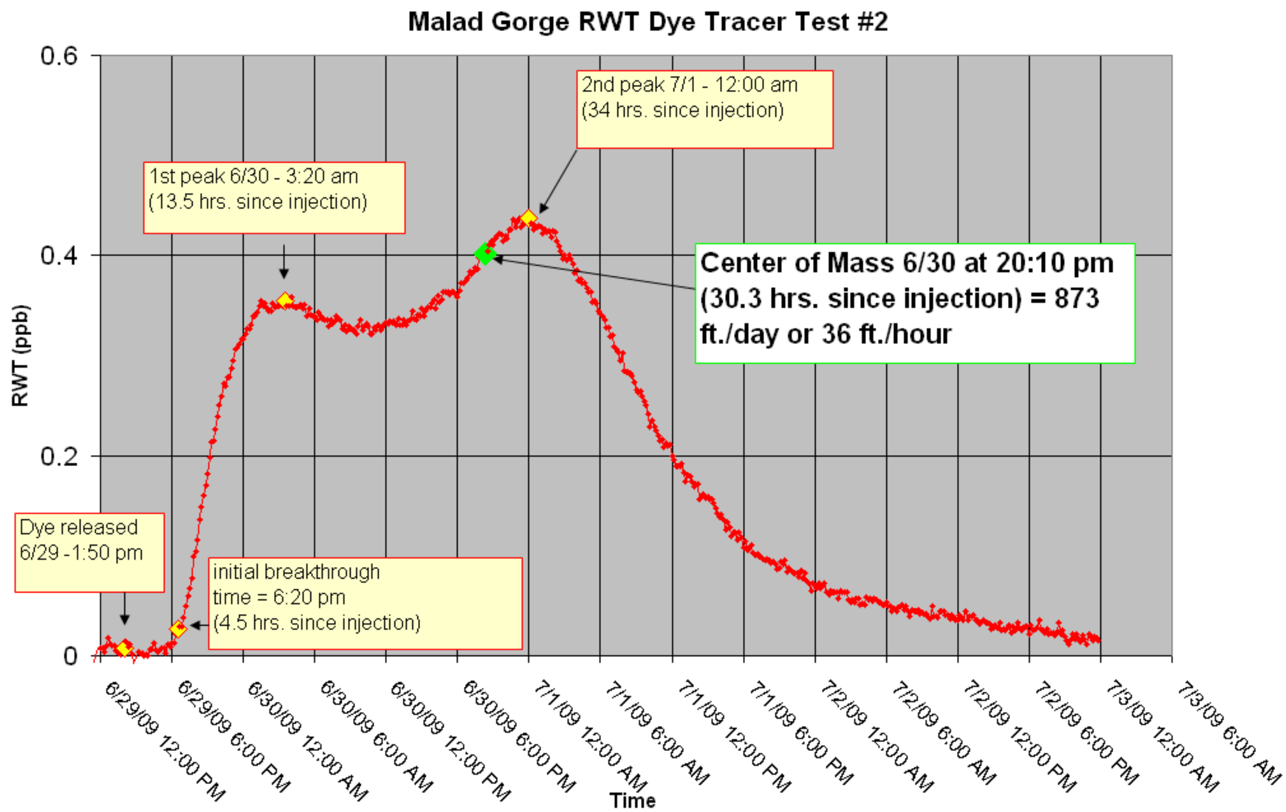

Figure 15. Dye concentration breakthrough curve for 2nd RWT test. Note the same two peak pattern as in test #1 confirming reproducibility.

for this specific site with each path having its own unique breakthrough curve as conceptualized in Figure 16 as black circles and squares. The two flow paths are combined or integrated at sample site MG-7 as one graph (Figure 15) as the red symbol line. The first peak demonstrates relatively higher hydraulic conductivity in the flow path but received slightly less dye. The second peak demonstrates a slower flow path that received slightly more dye. The double peak may have been initiated within the well from the slug injection which was not evenly mixed within the borehole water column. A mixing pump placed within the water column may have eliminated this pattern. In order to deploy a mixing pump, it would have been necessary to pull the supply pump at a cost of $500 while further delaying the use of the pump for park water supply.

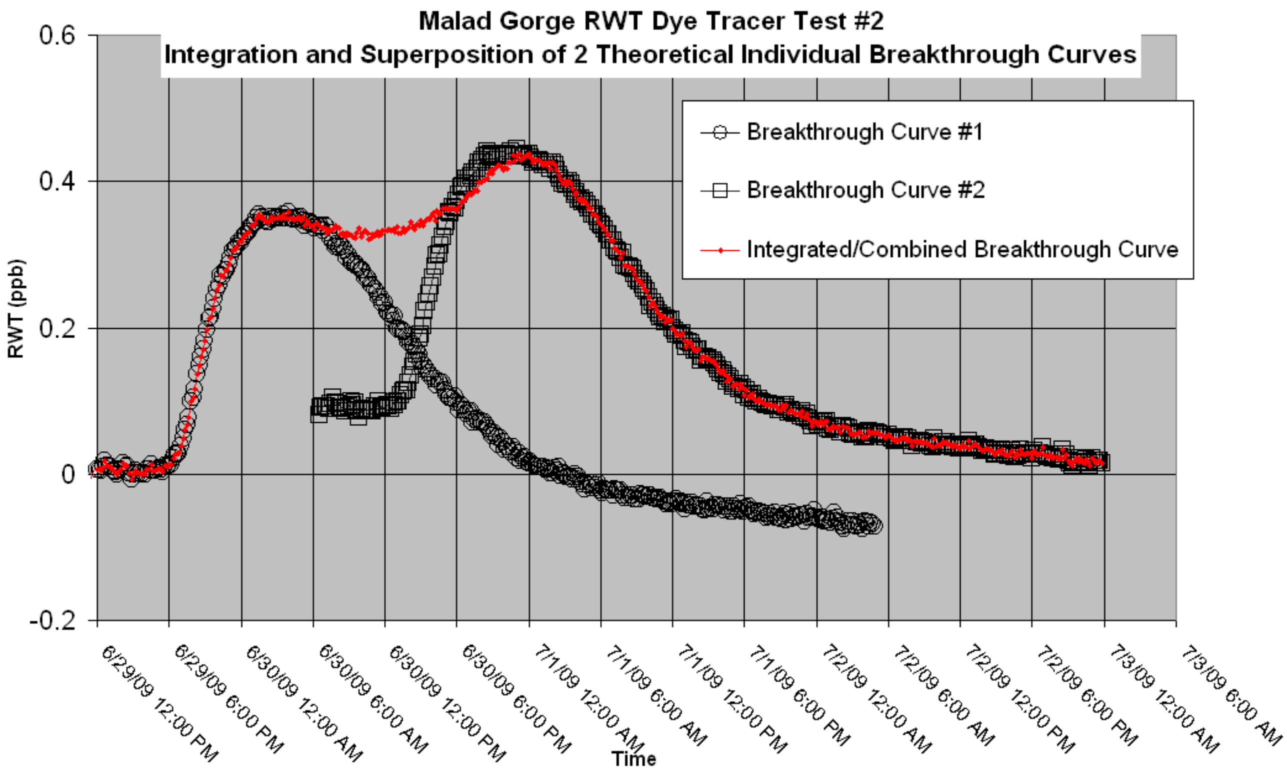

Figure 16. A general combination of two individual conceptualized concentration breakthrough curves noted in black with circles for Curve #1 and squares for Curve #2. The integration of these two black symbol curves would have the shape of the red symbol line.

Figure 17 shows a plot of both tests on the same relative time axis starting with the dye injection. The data shifts from the first test were adjusted to produce a consistent line colored red which allows for a better visual comparison of the two breakthrough curves. The curves show a consistent pattern between both tests with essentially the same slope angles on the rising limbs and recession limbs as well as the timing of the peaks. The vertical difference between the two graphs is probably from the calibration of 4 ppb for the first test and 25 ppb for the second test causing a slight change in the measured values. The horizontal shift of the peaks of about 1 hour may be due to slightly different water levels in the well and resulting in different flow hydraulics. The water level in the well on March 20th was 191.76 feet below T.O.C. and at the time of injection for the first RWT test on June 23 it was 191.06 feet below T.O.C. Unfortunately, a water level was not collected during the second RWT test on June 29th.

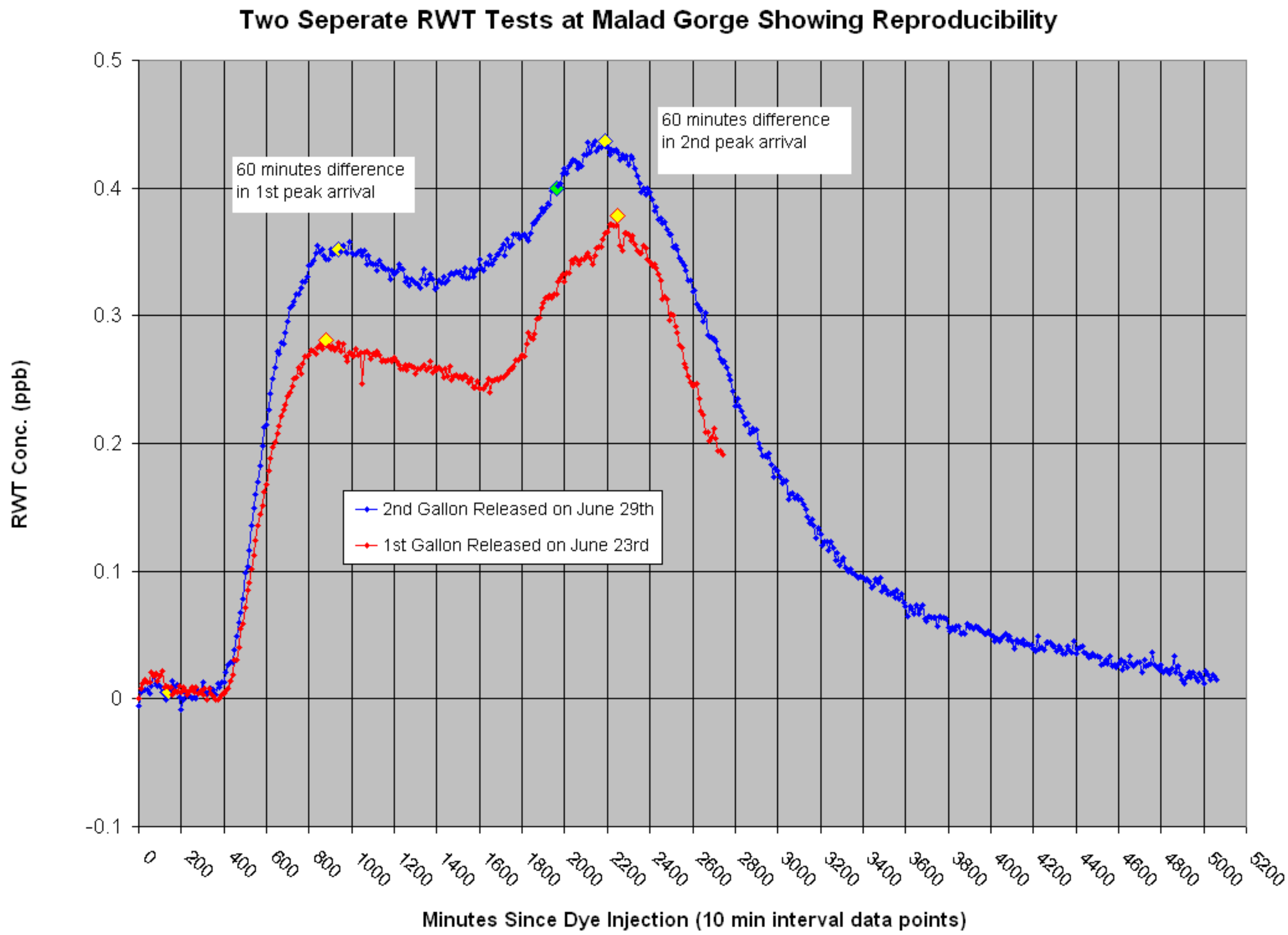

Figure 17. Reproducibility of both RWT tests demonstrating similar patterns with a strong correlation.

Aquifer hydraulic conductivity can be estimated using tracer data with the caveat that approximately 18% of the linear distance is 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 $K = P_e * V \div I$ 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" is average linear velocity based on the center of mass from the dye cloud at 873 feet per day.
- "I" is the hydraulic gradient from dh/dl = 0.04 derived from a "dh" of 47 feet vertical change based on GPS Trimble GeoXT 2005 with multiple 100 readings averaged with a vertical accuracy averaging +/- 3.5 feet when checked against a known USGS benchmark. This level of accuracy was deemed sufficient given the unknown nature of

the insitu level of aquifer discharge hidden under the talus slope. “dl” is based on the linear distance from the injection point to the spring of 1,100 feet using GIS and GPS.

Therefore:

If Pe is 15% then K is approximately 3,275 feet per day.
Or,
If Pe is 30% then K is approximately 6,550 feet per day.

Results and Discussion

Results from Phase 1 Fluorescein test demonstrate that 99% of the detected dye in charcoal packets passed by sample sites MG-7, 8, 9, and 10 with a minor amount at MG-2 and MG-6 (Figure 8). Site MG-7 received the highest concentration of dye of 1,310 ppb (from the charcoal packet) or 65% of the detected dye and therefore it is assumed this site has the best hydraulic communication with the well. MG-8 received the next highest charcoal packet concentration of 446 ppb or 22% of the detected dye. Sites MG-9 and MG-10 also received high dye concentrations. MG-3, 4, 5, and 11 did not receive any dye and only a small amount (1.44 ppb) at MG-6. This pattern indicates the dye was well constrained between MG-7 through MG-10 with little or no lateral migration of dye into adjacent sites of MG-6 or MG-11. The horizontal spatial dimension was delineated from the ‘spread’ of the dye cloud with a cone of dispersion measured at approximately 18-20 degrees. Taken as a whole (sites MG-7 through MG-10), the distribution apparently indicates a high level of homogeneity in the aquifer at this scale and location. This might be attributable to the highly broken, fractured and rubble nature of the pillow zone which diffuses the flow more than a non-pillow zone. The caveat to this is that each individual site may have multiple flow paths which is supported by Phase II of the test. The main flow path is based on the azimuth between the well and MG-7 which is nearly due northwest at 310 degrees. Dye was also detected at about 71 ppb from the charcoal packet located at the Idaho Power diversion and appears to have been diluted by both the Malad River inflow as well as other groundwater springs flowing into the river with no dye.

The results from Phase I allowed for the targeting and placement of the SCUFA in Phase II. The results of the Phase 2 were consistent with Phase I data and provided greater refinement of travel time, dye break through characteristics, center of mass response, amount of dye injected produces what concentration at the spring, how fast the dye moves out of the well, and provides quantitative data to calculate aquifer parameters. The first RWT dye detected in the spring was 4.5 to 5 hours post injection and the center of mass of the dye cloud was determined to be 30 hours. Using the travel times, the average linear velocity was 873 feet per day and the maximum linear velocity is 220-250 feet per hour. No dye was detected by the SCUFA approximately 3.5 days post injection of the dye.

The results from Phase I and II were consistent for direction and travel times from the park well to the Malad Gorge. This data will be used to develop additional studies utilizing additional wells farther from the Gorge. It also provides data on water movement within the ESPA and can potentially be used to help refine ground water models. The studies also provide legitimacy to the use of fluorescent tracers for studying ground water 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 practice application that can improve aquifer levels and increase spring discharge. Knowledge gained not only from the results of these studies but also the techniques develop can lead to a better understanding of water movement through the aquifer.

ACKNOWLEDGEMENTS

From both a personal and professional view, I have enjoyed this project immensely and it will provide for additional knowledge about the ESPA. The data from this test has also provided a solid foundation to gauge decisions for larger scale tests. Although this may be a small step for the ESPA, it is a huge leap for tracer studies.

Idaho Power provided solid support with planning and implementation of the project as well as financial, logistical and report writing support. Tom Aley with Ozark Underground Laboratories (OUL) provided invaluable volunteer support for project planning with guidance and recommendations for implementation. Other Idaho Department of Water Resource staff that assisted with the project includes Hal Anderson, Brian Patton, Rick Raymondi, Sean Vincent, Dennis Owsley, Craig Tesch, Mike McVay and Allan Wylie. Staff with the Idaho Parks and Recreation were especially accommodating and without their assistance the project would not occurred or been as successful as it was. 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. Generous financial contributions from both the Lower Snake River Aquifer Recharge District and the Middle Snake Water Resource Commission were greatly appreciated. The Idaho State Health Lab provided technical assistance from Beth Orde (Principal Chemist) to mix calibration standards and Jim McKean (Research Geomorphologist) with the U.S. Forest Service provided access to lab space to mix solutions and process samples.

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