Idaho Department of Water Resources

Open File Report

FLUORESCENT DYE TRACER TESTING at the LSRARD Shoshone Aquifer Recharge Site

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ABSTRACT

Managed aquifer recharge in Southern Idaho is an important component of water resource management. East Snake Plain Aquifer water levels have been dropping for the last half century. The Shoshone recharge site, a spreading basin near Shoshone, Idaho, was one of the first constructed recharge sites in the area. The Lower Snake River Aquifer Recharge District (LSRARD) started developing this site in 1982. The site has been available for use since that time when water was available for recharge. The Idaho Water Resource Board (IWRB) started a full-scale managed aquifer recharge (MAR) program to rebuild aquifers in the region in 2014. A key part of the program was developing the appropriate monitoring to assess the potential impacts from the MAR program. Conducting groundwater dye tests have proven to be an effective and efficient method for obtaining essential data for characterizing the recharge sites and developing effective site monitoring programs. Two dye tests were conducted at the Shoshone site, the first on June 15, 2017 and the second on April 4, 2019, using 59 pounds of Fluorescein dye in both tests. Two traces allow for comparison, reproducibility and refinement of data and results. Utilizing nearby monitor wells and domestic supply wells surrounding the recharge site, the results from both traces were consistent. The tracer results demonstrate the majority of the dye and recharge waters are flowing southwest of the recharge site. The dye was detected in domestic wells 3.2 miles distant with a maximum groundwater velocity of 1,800 feet per day. This information was used to adjust the water quality monitoring for the recharge site to include these domestic wells and essential data for the placement of new water quality monitoring wells. Information from the dye tests also provided invaluable data on water movement through the vadose zone and the unconfined East Snake Plain Aquifer (ESPA) providing an improved understanding of the aquifer response to recharge events.

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INTRODUCTION AND BACKGROUND INFORMATION

The Shoshone Recharge Site tracer test is part of an ongoing effort by the tracing program to further the knowledge and understanding of the East Snake Plain Aquifer (ESPA). Dye tracing provides data and information for stakeholders and policy makers for the application of practices to manage the ESPA. The tracing program was initiated as part of the Swan Falls Re-affirmation Agreement for ESPA studies. The goals of the tracing program are to enhance the understanding of spring discharge, aquifer flow, and the geologic framework of the aquifer. Since the conception of the program in 2009, 24 dye traces have been completed. Many of the traces have been conducted near major spring outlets like Malad Gorge, Box Canyon, Banbury Spring, Briggs Spring and Clear Springs. Four traces have been conducted at aquifer recharge sites approximately 20 to 30 miles distant from the springs. The studies have been completed through a cooperative effort between the Idaho Department of Water Resources, Idaho Power, Idaho Water Resources Board and the Lower Snake River Aquifer Recharge District. Previous tracer study reports are available in IDWR Technical Reports at https://idwr.idaho.gov/press/technical-publications.html for years 2009-2014.

The Shoshone/LSRARD aquifer recharge basin is located in south central Idaho at Township 5 South, Range 17 East section 22; Lincoln County or 2.7 miles north by northwest of the city of Shoshone, Idaho and east of the City of Gooding by 14 miles (Figure 1). The recharge basin name is referenced by the proximity to the city of Shoshone and the organization that initiated it, the Lower Snake River Aquifer Recharge District (LSRARD). The area surrounding the recharge site is mostly desert land with thin or no soils where recent basalt flows are present. Vegetation is primarily sagebrush, cheat grass and crested wheat grass. Annual natural precipitation is about 10 inches and dominantly occurs in the winter and spring months (NOAA, 2020). Geographically the site is located between the Big and Little Wood Rivers. The Big Wood River is located less than a mile north of the site and it is ephemeral with flows being controlled by the upstream Magic Reservoir. The Little Wood River is a perennial river located approximately 1.5 miles to the south. The Recharge site is located next to a large capacity canal which can convey water directly from the Snake and the Little Wood Rivers; and indirectly from the Big Wood River. The basin is naturally 'closed' with no flow outlet at the current high pool level allowing for a maximum hydraulic head to build improving recharge capacity. The basin features are all natural and there has been no modification to enhance recharge into the rocky outcrops.

The recharge site is located on Bureau of Land Management property which authorized recharge prior to the general area being designated as a Wilderness Study Area. The site has been used sporadically for aquifer recharge since 1984 with more frequent use in the last 10 years. Recent peak measured flow rates into the basin is approximately 175 cfs at a steady state condition.

REGIONAL AND SITE HYDROGEOLOGY

Land surface of the recharge basin area is composed of a recent basalt flow which has been dated at 10,130 years old (Kauffman, et. al., 2005). Little to no soil covers the basalt and pressure ridges with gaping fractures are common. The subsurface geology near the recharge basin is inferred from a well, LSRARD North Monitor Well (Figure 1&2), drilled 1,300 feet south of the basin. The well was originally drilled in year 1984 April 18th and Dr. Marvin Strope, a Geologist with the College of Southern Idaho, logged the geology of the well.

Data from the LSRARD North Monitor Well (MW) are obtained from drill cuttings and video which provides an indication of the subsurface geology in the area. There is a Basalt zone overlaying a clay unit within the first 80 feet below land surface (bls) followed by Basalt for at least the next 250 feet shown in Figure 3. The clay layer starts at about 40 feet bls and is approximately 26 feet thick which is somewhat thicker than typical interbedded soil horizons observed across the ESPA in this area. The clay unit is believed to be locally extensive between the well and the basin, considering the thickness of the unit and evidence of perching water during recharge events on top of the unit in the LSRARD North MW. If the elevation of the clay layer is the same under the recharge basin as it is in the monitor well this would place the clay unit 34 feet below the floor of the recharge basin.

For years after the LSARD North MW was completed IDWR staff, and both authors of this report, observed water cascading into the well from an inadequate seal during recharge events. After recharge events, the well would go dry when it was measured and videoed during other times of the year. It is interpreted that a perched aquifer would temporarily form on top of the clay unit and spread horizontally toward the monitoring well. The clay may be from lacustrine origin, possibly from lava damming of either of the two rivers that flow in this area. If this is the case, along with observations from well cameras, and hydrologic responses from water level loggers in the perched aquifer at this well, then this provides indications that the clay unit underlies the recharge basin 1,300 feet north.

The LSRARD North MW was re-built in 2016. The old casing was pulled out and the well was enlarged to 16-inch diameter and deepened from the original depth of 215 feet down to 324 feet. This large diameter allowed for a 5-inch annular seal down to 96 feet and a 3-inch annular seal down to 239 feet. The well is open hole from 239 feet down to 324 feet. The clay unit was videoed from approximately 44 feet down to 70 feet depth. The thick annular bentonite and long length of 6-inch casing creates a robust seal from land surface down to 239 feet depth which effectively stopped the interconnection of the perched system to the regional water table. Since 2016, there have been no observations of the perched aquifer spilling into the new well. Water sample results prior to 2016 and after 2016 should take into consideration the reconstruction of the well. The design changes that have occurred in the well ensures that water quality samples and dye samples are taken from the regional aquifer and not from or mixed with the perched system.

In the direction of groundwater flow to the southwest, the closest well is located 3.2 miles distant at Township 5S, Range 17E, and Section 31AAA (Brossy Bunkhouse well) shown on Figure 1. After the results from dye test #1, two new monitor wells were drilled, Brossy MW1 and Brossy MW2, and their location is shown on Figure 2. The geologic log for the Brossy Bunkhouse well provides a detail description of the representative subsurface geology at this location and it is similar to nearby wells (Figure 4). The drillers report notes cinders, sand and clay layer from 160 feet to 181 feet depth or approximately 20 feet thickness. The well is cased to 218 feet and then open hole showing basalt related rock types to the bottom of the well at 280 feet depth. A video log completed on April 3, 2019 confirms the well construction and geologic features below the casing. The clay recorded in this well log is over 200 feet lower in elevation than the clay encountered in the LSRARD North MW next to the recharge basin. Considering the distance and change in elevation it is not believed that the clay layers are connected.

The cross section in Figure 5 shows the general geology below the water table from wells in the Brossy area. The cross section is oriented from West to East for a distance of approximately 5 miles and parallels the Little Wood River. Fine grained sediment layers were recorded in some wells and typically range in thickness from approximately 10-20 feet thick. The remaining rock type in the well logs are recorded by drillers as having basalt related rock type characteristics. The general well construction is shown but well drilling reports were not available for a few of the wells.

The regional groundwater table in the area dips to the southwest as depicted in Figure 1 (IDWR, 2018). An aquifer gradient of 0.005 was calculated utilizing water levels obtained May 2, 2019 from the LSRARD North MW (3776.2 feet elevation) and the Brossy Bunkhouse (3688.3 feet elevation) over a horizontal distance of 16,900 feet. Utilizing the year 2018 groundwater contours, results in a similar gradient demonstrating the regional aquifer has not changed significantly between year 2018 and 2019.

When the recharge site was constructed it was used intermittently, however, in recent years the site has been used more frequently and for longer periods of time. Reported flow rates into the basin from early years of the site use were around 400 cfs but there is no record of how these rates were determined or if they were during steady state conditions. Flow rate measurements from recent recharge events have been made during steady state conditions using ADCP technology supporting the capacity of the site to be around 175-200 cfs range. There are a number of possible reasons for an apparent reduction in the basin leakage rates but one may be attributed to the clay unit encountered in the North MW at approximately 40 feet below land surface, estimated to be only 34 feet below the bottom of the basin. As the site is used more frequently at higher volumes, the inferred water level rise in the perched aquifer may be causing a reduction in leakage rates. There is evidence of decreased leakage rates during recent usage. Infiltration of water is readily observed flowing into the fractured basalt located on the sides of the basin as well as some locations in the floor of the basin. Fine grained sediment has settled out in the quiescent parts of the basin based on field observations. These areas act as traps and help remove sediment before water flows into basalt fractures. However, sediment may also be accumulating in the subsurface and depositing on top of the inferred clay layer along horizontal and vertical openings in the basalt.

TRACING PROCEDURE AND METHODS

<u>Trace #1 Description</u>

Trace #1 was started on June 15, 2017 by releasing 59 pounds of powder form Fluorescein (FL) dye into the recharge basin. Dye was poured from several containers into the water at the recharge site turn out structure and completed within minutes. A pressure transducer was deployed into the basin to record water depths and temperature. The basin received water starting on March 16, 2017 and on April 6th, 2017 flows were measured at 181 cfs. The basin pool level was at a typical level of 5.5 foot depth until May 25th, 2017. The basin was dry May 25th through June 12th. Recharge started again on June 12th and continued through June 20th at the 4 foot pool depth level. The canal company reported a diversion rate of 197 cfs on June 15th and held steady for during the event. The diversion rate was determined by subtracting the difference between two gauges on the canal. When dye was released, the basin pool depth was 4 feet which is 1.5 feet below a typical high basin level of 5.5 feet depth. Basin water temperature was 62 degrees Fahrenheit and groundwater temperature was 55-56 degrees.

As a result of the scarcity of wells in the project area, potential dye sample sites were limited to twenty-one wells (Figure 1 and Table 1). Sampling locations were selected by availability of wells in the area, homeowner cooperation and proximity to the trace. As can be seen in Figure 1, there were significantly more wells available for sampling along the Little Wood River to the south of the recharge site than to the north along the Big Wood River. The first sampling point west of the recharge basin is the Toon's stock well located nine miles distant. Southwest of the Brossy wells for approximately 15 miles, there is an absence of wells across the desert.

Charcoal samplers, grab water samples and a field fluorometer were used for dye monitoring. Charcoal samplers (packets) were deployed at all of the sample sites. These samplers act essentially as sentry samples, representing an integrated value over the time period of deployment. Having sentry samples assists in guaranteeing that no dye is missed in-between the discrete sampling events by the trace staff. Charcoal samplers can also detect dye that may be under the detection limits for grab water samples or field fluorometer. A new packet was swapped for the collected packet during sampling events.

In addition to charcoal samplers, grab water samples were collected as part of the sampling plan at the following sites of LSRARD North MW, LSRARD South MW, Newell, Hunting Lodge, Brossy Bunkhouse, Brossy Home, Brossy Rockhouse, Arkoosh, and Keale. Grab water samples provide instantaneous dye concentrations of the water at the time of collection. Grab water samples can provide a duplicate sample at the same site to support the charcoal packet samplers. At many locations, site conditions are not conducive for the deployment of field instruments so grab water samples are an alternative detection method. Grab samples analyzed in a lab also allow for a lower detection limit of dye than field instruments.

A calibrated Cyclops-7 Fluorometer was deployed into the LSRARD North MW on June 15, 2017 and a second fluorometer on June 20 at the Brossy Bunkhouse. The fluorometer at the Brossy Bunkhouse was installed in a flow-through cell. These wells were selected to deploy fluorometers because the LSRARD North MW was the closest well to the basin and the Bunkhouse well had the greatest dye concentration of wells 3 miles south of the basin. No other fluorometers were available to deploy at other sampling locations. Additionally, the adjacent wells configuration would not allow for fluorometer deployment. The data from the fluorometer deployed at the Brossy Bunkhouse was not usable due to difficulties maintaining a constant flow through the chamber housing the instrument.

The LSRARD North and South monitor wells were pumped using a generator to collect grab water samples from dedicated pumps. Grab water samples and packets from all sampled wells were shipped overnight to Ozark Underground Labs which specializes in dye sample analysis. The detection limits of the lab's instruments are reported at 0.002 parts per billion (ppb) (or 2.0 parts per trillion) for water samples and 0.025 ppb for charcoal packets.

Trace #1 Results

On the morning of June 16th at 8:30 am, about 12 hours after dye release, a basin water sample was collected. Lab results show the sample contained 160 ppb FL as shown in Figure 6. Figure 1 shows the locations of all of the wells sampled in Trace #1. Brossy Monitor Wells #1 and #2 were not sampled in Trace #1 since they were drilled after Trace #1 was completed. Green symbols in Figure 1 denote the wells where dye was detected. Red symbols denote where dye was never detected. Table 1 lists the results of sampling showing the dates, time periods and type of sampling.

Dye was detected from both grab water samples and a packet sampler collected on July 13th and 14th, 2017 at Brossy Bunkhouse, Brossy Home and the Hunting Lodge sites. These results represent the first detection of dye but not the first arrival of dye at those sites which likely occurred prior to July 13th. Positive dye detections in the LSRARD North MW from Charcoal packets occurred on July 13th and September 6th, 2017 and again on April 3rd, 2018. No dye was detected for a packet deployed between April 3 and October 18th, 2018 in the North MW (see Table 1). All of the water samples from the North MW were non-detect because the dye concentrations were below detection limits. This is consistent when extremely low concentrations of dye are present that are below the lab detection limit of 2 parts per trillion.

The bulk of the dye appears to have passed the Brossy Bunkhouse, Brossy Home, and the Hunting Lodge wells based on dye concentration data collected through November of 2017 (Figure 7). The last detection of dye for Trace #1 was from a charcoal packet collected on April 3, 2018 from the LSRARD North MW. Dye was not detected at any of the remaining sample sites including the South LSRARD MW, Newell and Lockwood wells. The sampling period for all of the wells with no detection of dye was from June 15th, 2017 through June 9th, 2018.

Dye Trace #1 Discussion

Dye Trace #1 was the first trace at the LSRARD Shoshone Recharge Basin documenting the direction and general magnitude of flow from the recharge site. The dye flowed southwesterly from the recharge site 3.2 miles where it was detected in three domestic wells shown on Figure 7. The movement of dye into these wells is likely dominated by advective flow. Dye was also detected in the LSRARD North MW but only in charcoal packets, as dye concentrations in the water samples were likely below detection limits. Dye was not detected in any other sample sites.

The LSRARD North MW received little dye relative to its proximity to the recharge basin. This is an indication that this well has little flow communication with the recharge basin, and dye movement to the well may be through a chemical diffusion process. It also supports that the newly designed and sealed well is working. Dye was never detected in the LSRARD South MW indicating this well does not have flow communication from the basin. This is not surprising considering the well is 90 degrees to the groundwater gradient which dips to the southwest. This well was originally installed to ensure that recharged water would not impact the City of Shoshone to the south.

This dye trace shows the recharged water flowing to the southwest with the greatest water sample dye concentration detected at the Brossy Bunkhouse of 0.478 ppb (Figure 8). The peak dye concentrations decreased lateral to the Bunkhouse well with peak concentration to the west at the Brossy Home well, at 0.028 ppb occurring in September, and to the east at the Hunting Lodge well site, at 0.022 ppb occurring in July (Table 1). Figure 9 suggests the center of the dye cloud and water flow from the recharge site was approximately 0.4 miles east of the Brossy Bunkhouse well and a peak dye concentration in water at that location might have been over 1.0 ppb. This projection would also align the flow path to a more perpendicular orientation with the 2018 groundwater contours.

The results from this dye trace suggest the recharge water flows to the southwest and by 3.2 miles it has a lateral spread of at least 1.2 miles. This is the distance between the Brossy Home and the Hunting Lodge well and perpendicular to the flow path. Data interpolation between the wells shows the lateral dispersion of the dye cloud at 3.2 miles down gradient from the recharge site to be approximately 1.6 miles. The authors have been able to measure the lateral dispersion of dye for another trace from the Milepost 31 recharge site (Farmer and Blew, 2016). The lateral dispersion of dye for the Mile Post 31 Trace at 8 miles distance was measured at 4.5 miles width which is comparable to the Shoshone Trace. The Shoshone trace lateral dispersion of 1.6 miles and the Mile Post 31 lateral dispersion of 4.5 miles have a comparable ratio at the different scales. Data from another unpublished trace (Farmer and Blew, 2013) by the authors, near the Clear Springs area shows a lateral dispersion of approximately 1.2 mile width 3 miles down the dye cloud flow path. All three traces have similar lateral dispersion at approximately a 3 mile distance down the flow path.

The Trace #1 result from the Brossy Bunkhouse well located 3.2 miles (16,900 feet) from the recharge site produced the best data set and it was used to calculate a groundwater velocity for this trace. As shown in Figure 8, using the peak concentration detected that occurred on July 13th, or 28 days post dye release, then a dominant velocity would equate to approximately 600 feet/day based on the highest concentration detected. If the peak occurred earlier in time then the velocity would be calculated higher than 600 feet/day.

Trace #1 provided the foundation for planning to increase resolution and sampling efficiency for Trace #2. Additionally, in 2018 after Trace #1 was completed and before Trace #2 started, two new monitor wells were drilled north of the Little Wood River (Figure 2) along a straight line between the recharge basin and the Brossy Home and Bunkhouse wells.

<u>Trace #2 Description</u>

Dye trace #2 started on April 4, 2019 by releasing the same amount of dye (59 lbs.) using the same delivery method and type of dye as Trace #1 into the Recharge Basin at 6pm (Figure 10). The basin pool level was similar as it was in Trace #1 at about 4 foot depth at the turnout basin which is shown in Figure 10. Recharge waters had been discharging into the basin for 3 days prior to dye release and continued for five days post dye release and the flow in the canal and gates to the recharge basin were constant during this period. Pre-wetting the basin and subsurface promotes a steady state flow condition out of the basin and into the subsurface. A water sample collected at the time of dye release in the recharge basin (Figure 10) was lab tested at 848 ppb FL concentration but this sample was collected directly downstream of the release point and may not represent an overall basin concentration.

The sampling plan was altered to reflect the results from Trace #1 for improved efficiency and better resolution. The changes to the sampling plan included:

- Adding the two new monitor wells, Brossy MW #1 and #2 (Figure 2) along with video logs of the new wells and the Bunkhouse well.
- Downhole Fluorometers were deployed prior to dye release in the Bunkhouse well, Brossy MW #1 and Brossy MW #2.
- Sample sites that were non-detect in Trace #1 were not sampled in Trace #2 with the exception of LSRARD South MW.
- Grab water samples were not collected in the LSRARD North MW as all grab water sample from Trace #1 were non-detection. However, charcoal packets were deployed into the LSRARD North and LSRARD South MW's.

To ensure there was no residual dye from Trace #1 grab water samples were collected at 4 wells downgradient at the Brossy Bunkhouse, Brossy Home, Brossy MW #1, and Brossy MW #2 prior to dye release. There was no detection of dye in any of the wells during this antecedent sampling. The 'Hunting Lodge' well was not accessible for sampling during Trace #2. The same standard procedure was in place for Trace #2 for analysis of grab water samples and charcoal samplers submitted to and analyzed by Ozark Underground Labs.

<u>Trace #2 Results</u>

Similar to Trace #1, there was no detection of dye from water samples and charcoal samplers in the LSRARD South MW or at the Brossy Rock house well. The level of and open interval for the Rockhouse well is roughly the same as the Brossy Bunkhouse well (Figure 5). Access to the Hunting Lodge well was not available and other wells further east, Newell and Lockwood, did not have any dye detection from Trace #1. There is no well log for the Newell well but the Lockwood well open interval and level is roughly the same as the Brossy Bunkhouse well (Figure 5). The horizontal or lateral spread of the dye cloud were defined from Trace #1 data. The water levels depicted on Figure 5 were determined from hand measurements made on May 2, 2019. Well elevations were obtained from Trimble Geo7x cm edition with external antenna and post processed using the Jerome base station according to GPS Standard Operating Procedure on file at IDWR.

The well closest to the site, LSRARD North MW, showed similar results to the first trace. A charcoal packet collected on May 2, 2019 had a concentration of dye at 21.9 ppb which was higher concentration than from Trace #1. The concentrations at this well showed a steady decline to 1.69 ppb (May 23), 1.74 ppb (July 2) and no detection in charcoal packets collected on Sept. 11th and Dec. 9th. Dye was never detected in the LSRARD South MW which is the same results from Trace #1. The open interval from 3,740 feet to 3,650 feet elevation, or approximately 90 feet of water, is similar to the North well and other domestic wells as discussed later in this section.

A graph of the results from grab water samples for Trace #2 are shown in Figure 11 from the Brossy area sample sites. The Bunkhouse well showed the greatest response (blue circles) consistent with Trace #1 data (red squares Figure 8). The first detection of dye at the Bunkhouse well was 9.37 days post dye release on April 14th 12:00 am based on field instrument data shown in Figure 12 as green circles. The peak concentration was 0.379 ppb from a grab sample on April 30th which is similar to Trace #1 peak of 0.478 ppb. In Trace #2, a Cyclops Fluorometer was deployed down the Bunkhouse well which produced high resolution 10 minute frequency data. Figure 12 depicts the data from the fluorometer (green dots) along with grab samples from Trace #1 (red squares) and Trace #2 (blue circles). The data from grab samples and from the Cyclops exhibit a similar shape and magnitude. The peak concentrations from the Trace #2 grab samples and the fluorometer are off by 0.1 ppb this can be attributed to the difference between lab equipment and field equipment resolution capabilities and calibration.

Figure 11 shows the dye response curve from the Brossy Home well as black circles. It has a distinctly different flattened or plateau shape than the Bunkhouse response curve. The first detection of dye occurred on April 21, 2019 at 12:00 pm or 16.7 days post dye release. The distance is approximately 3.3 miles which equates to a maximum velocity of 1,040 feet per day. The interpolated first arrival of dye is on April 20, 2019 or 15.7 days or 1,100 feet per day. The peak concentration detected was on May 10th at 0.029 ppb FL or 35.7 days post dye release for a dominant velocity of 490 feet per day. The time of passage for approximately 90% of the dye at this location occurred by November 2019 or 7 months post dye release.

Figure 12 shows data from grab water samples collected at the Brossy Bunkhouse well from both Trace #1 (red squares) and Trace #2 (blue circles). There is a slight difference of approximately 0.1 ppb but the recession limb for both data sets are similar as well as the timing. The Trace #2 peak occurs at 25 days post dye release which equates to a dominant velocity calculated at 675 feet/day. Dominant velocity is calculated using the peak concentration from the breakthrough curve and it is the best representative of the bulk of the flow system characteristic as it passes by the Bunkhouse well. There is not a significant difference with the Trace #1 dominant velocity of 600 feet/day.

Figure 12 shows the field fluorometer data as green dots with 10 minute frequency, and the timing, shape and magnitude provide a good correlation with the lab results. Fluorometer data documents a single peak breakthrough curve and shows the dye arriving at the well between grab samples at the 225 hour or 9.37 days post dye release, documenting the first detection of dye from the field instrument. The first arrival of dye defines the maximum groundwater velocity which is calculated at 1,800 feet/day. The peak concentration is off by 0.1 ppb which is attributed to calibration variable for the field instrument. Ninety percent of the dye passed this well in 100 days since the first arrival of dye in the well. On the recession limb, from approximately 70 to170 days there is variance in the instrument data of approximately 0.03 ppb which is near the resolution limit of 0.02 ppb of the fluorometer. The breakthrough curve similarity between both traces supports that this is a unique solution outcome.

The cross-section depicted in Figure 5 also demonstrates the open intervals for wells Arkoosh (35 ft.), Brossy Rockhouse (12 ft.) and Lockwood (76 ft.) which have similar elevations to the Brossy Bunkhouse well (62 ft.). The open interval below the water table for wells with no detection of dye from Trace #1 had a range from 35 feet to 100 feet and an average of 65 feet. The other wells shown in Figure 5 (Brossy Home, Newell and Hunting Lodge) did not have a well drilling log but it is expected that the Brossy Home well and the Hunting Lodge wells have a similar open interval elevation since all of the well construction logs reviewed from the IDWR construction database for this local area and the sample sites have similar design and depths.

The only exception are the two new monitor wells. The open intervals for Brossy MW's #1 and #2 wells are noticeably higher in elevation and they are close to the river. Brossy MW #1 is 480 feet and Brossy MW #2 is 280 feet away from the river. If there is localized mounding of the water table along the river corridor this may induce a local gradient and flow from the river toward the shallow monitor wells. This may explain why dye was not detected in either of these two wells. Figure 5 shows some fine-grained sediment displayed as orange layers but it is unknown if they are continuous. Brossy MW #2 did not encounter a fine-grained layer at the same horizon as the layer in Brossy MW #1. Most of the fine-grained layers are vertically offset from other wells and any correlation between them is questionable.

Dye Trace #2 Discussion

The Brossy Bunkhouse well showed the greatest dye response in both traces. Figure 11 depicts the dye concentrations over time for wells sampled in Trace #2 in the Brossy area. The breakthrough curve from the Bunkhouse well shows a single peak response. A pronounced single peak response that demonstrates a sharp rise and fall in concentrations indicates a high groundwater flow connection, whereas, the Brossy Home well received dye later in time, lower in concentration and shows a plateaued breakthrough curve. A plateaued breakthrough suggest a greater hydrodynamic dispersion of the dye than the results from the Bunkhouse well. One explanation is the Home well may be completed in a lower hydraulic conductivity zone such as dense basalt or even a fine sediment layer. The Bunkhouse response curve is steep and narrow exhibiting a less intense dispersion while the Home well is exhibiting a strong dispersion characteristic (Kass, 2009; Davis, 1985).

A similar dye test response to the Brossy Home well occurred in the West Monitor Well for the Mile Post 31 tracer test (Farmer and Blew, 2016). The arrival of dye was delayed and the peak concentration was low relative to its proximity to the dye release location and the shape of the dye breakthrough curve was similar with a flattened or plateau appearance. The West Monitor Well at Mile Post 31 has demonstrated a greater drawdown while being pumped and a slow recovery. The log for this well indicates the screened open interval is located in 'hard grey rhyolite' and geophysics on this well indicating dense rock at depth. The data gathered at the MP31 West MW demonstrating low conductivity geology and a similar dye test response serves as an analog for the Brossy Home well.

Dye was not detected in either of the newly drilled monitor wells. One potential explanation is the wells are not deep enough to intercept the regional aquifer and are completed in a localized water table mound associated with water leaking from the Little Wood River. A river leakage test was performed in year 2006 (Blew and Scheidt, 2006) that showed the channel between

Shoshone and Gooding had a leakage rate of approximately 20%. As can be seen in Figure 5, Brossy MW#1 and MW#2 the water levels are higher in elevation than observed in the Brossy Bunkhouse well.

Conclusions and Discussion

The two traces were conducted under similar conditions such as nearly identical pool levels, similar inflow rates into the recharge basin during and after dye release, similar temperature, lengthy pre-wetting conditions of the basin and associated vadose zone, and the same amount of dye was used. The two traces also started during similar times of the year, Trace #1 in April and Trace #2 in June. Considering the similar conditions, it is not surprising that the results are nearly identical. The water from the recharge site flows to the southwest with a similar lateral dispersion compared to the Mile Post 31 and Strickland Traces that also occur in fractured basalt aquifers.

Dye was detected the earliest in time and the highest concentrations at the Brossy Bunkhouse well than any of the other sampling locations. The dye breakthrough curve for the Brossy Bunkhouse well demonstrated a single peak response which shows the dye cloud moving through the subsurface in a single mass with no major alternate flow paths. More dye and/or more water would likely not change the results much based on traces at MP 31 Recharge Site. The Trace #2 results at MP31 were essentially the same as Trace #1 despite releasing twice as much dye and water into the recharge basin. Multi-peak dye breakthrough curves are typically a function of multipath flow systems (Kass, 2009). The dye response curves from these tests do not show much evidence of multi-pathway flows. However, the different shapes of dye breakthrough curves seen in these tests are typically a result of heterogeneities in the aquifer i.e. a sharp rise and fall compared to a plateaued pattern.

The center of the dye cloud was likely about 0.4 miles east of the Brossy Bunkhouse well and this would represent the main flow path for dye and recharge water, but there are no wells located in this area. A review of the available well drilling report lithology descriptions and well videos for the Brossy Bunkhouse well, the LSRARD North and South wells show typical geologic features below the water table of fractured basalt, porous basalt, some massive basalt, minor fine grained interbeds etc., which have been observed with borehole camera's in the area of the plain since 2008 by the authors.

The dye test indicates the groundwater in this region has relatively high velocities with a range of 1,800 feet per day maximum and approximately 675 feet per day dominant based on the results from the Brossy Bunkhouse well. The generally high velocity of advective ground water flow influences the longitudinal and lateral shape of the dye clouds simply by limiting residence time and the chemical diffusive spread of dye. The results from the tracer test showed limited dye detected in the LSRARD North MW and that will need to be considered when analyzing data related to recharge activities.

Two new monitor wells, Brossy MW1 and MW2, were drilled in line with flow directions determined from the first trace. However, results from the second trace demonstrated no detection of dye in either of these wells. Both new monitoring wells have open intervals that occur at a higher elevation than wells where dye was detected. The new monitoring wells could be completed at a level within a localized mounding sourced from leakage from Little Wood River; and is not representative of the regional aquifer.

The studies completed at the Shoshone recharge site proves the value of tracer studies in refining monitoring plans and aquifer management practices. The studies also show that tracers are an effective tool for tracing recharge plumes within the ESPA. Tracer tests also provide additional evidence that the construction of monitoring wells must take into account not only horizontal positioning but the vertical completion of the well when dealing with complex aquifers and potential perching conditions. These studies have proven to be useful tools in providing insight into the physical characteristics related to how an aquifer behaves such as the homogeneity of the aquifer and preferential flow may be present in parts of the aquifer but multipeak dye breakthrough curves would be present if preferential flow were prevalent.

The tracer studies provide insight not only to the spatial scale for monitoring but the temporal scale as well. High ground water velocities have been documented from the tracer tests and the temporal scale for monitoring needs to take this into account. Due to the limited residence time within the aquifer, timely monitoring of influent to the recharge basin is an important safeguard. Further work would benefit the body of knowledge in this area.

ACKNOWLEDGEMENTS
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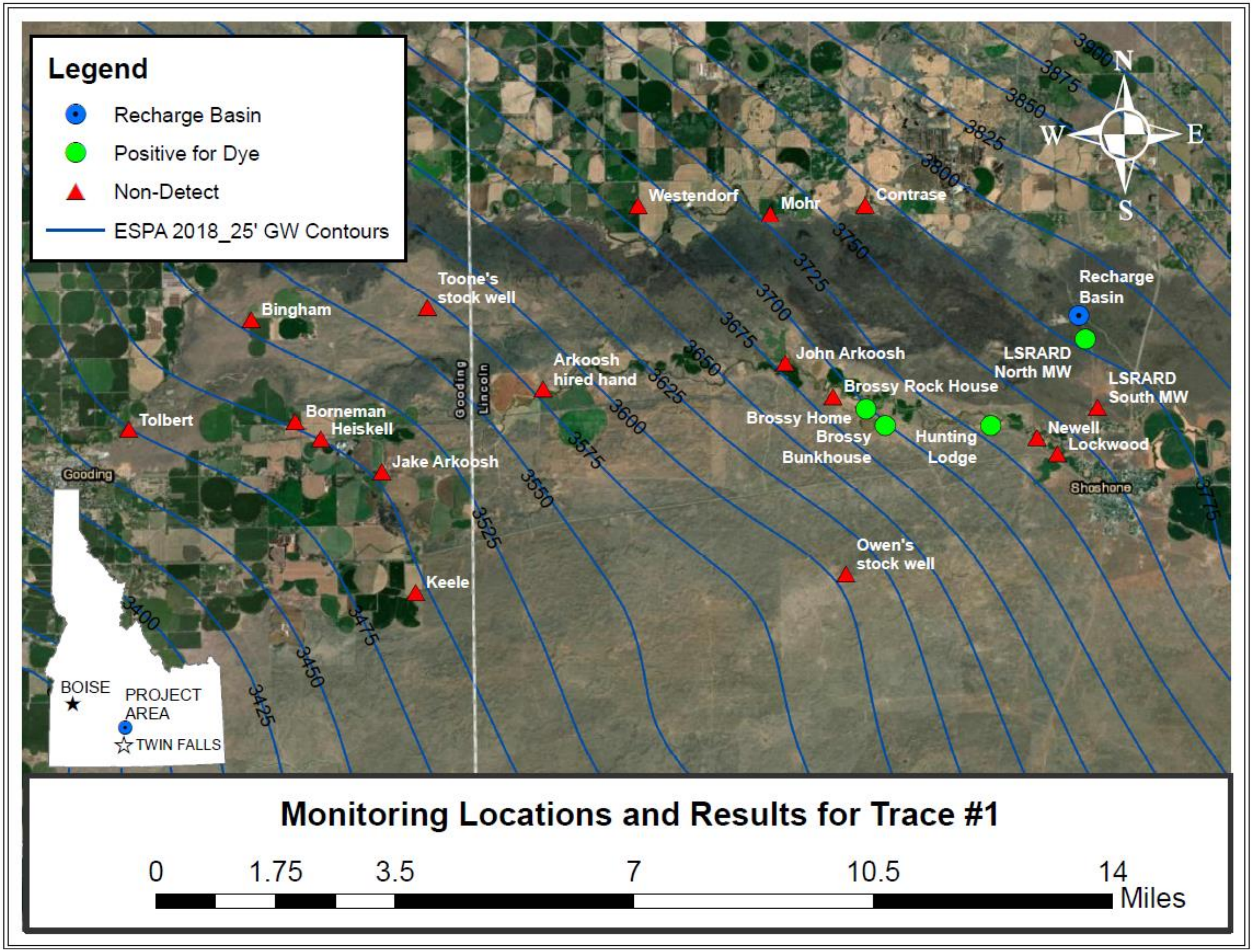

Figure 1. Location of the LSRARD/Shoshone Recharge Site and dye trace sample sites for Trace #1.

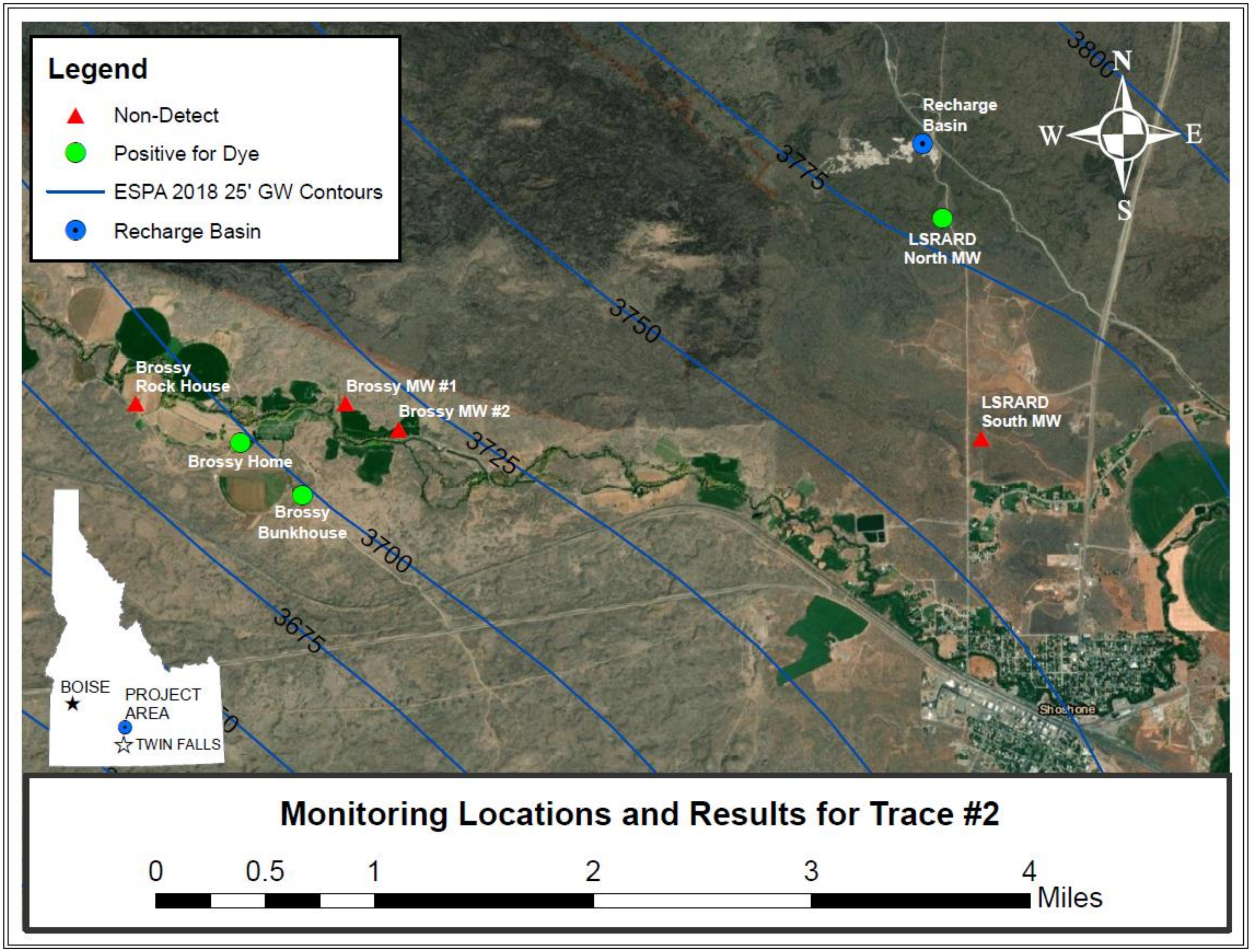

Figure 2. Location of the LSRARD/Shoshone Recharge Site and dye trace sample sites for Trace #2.

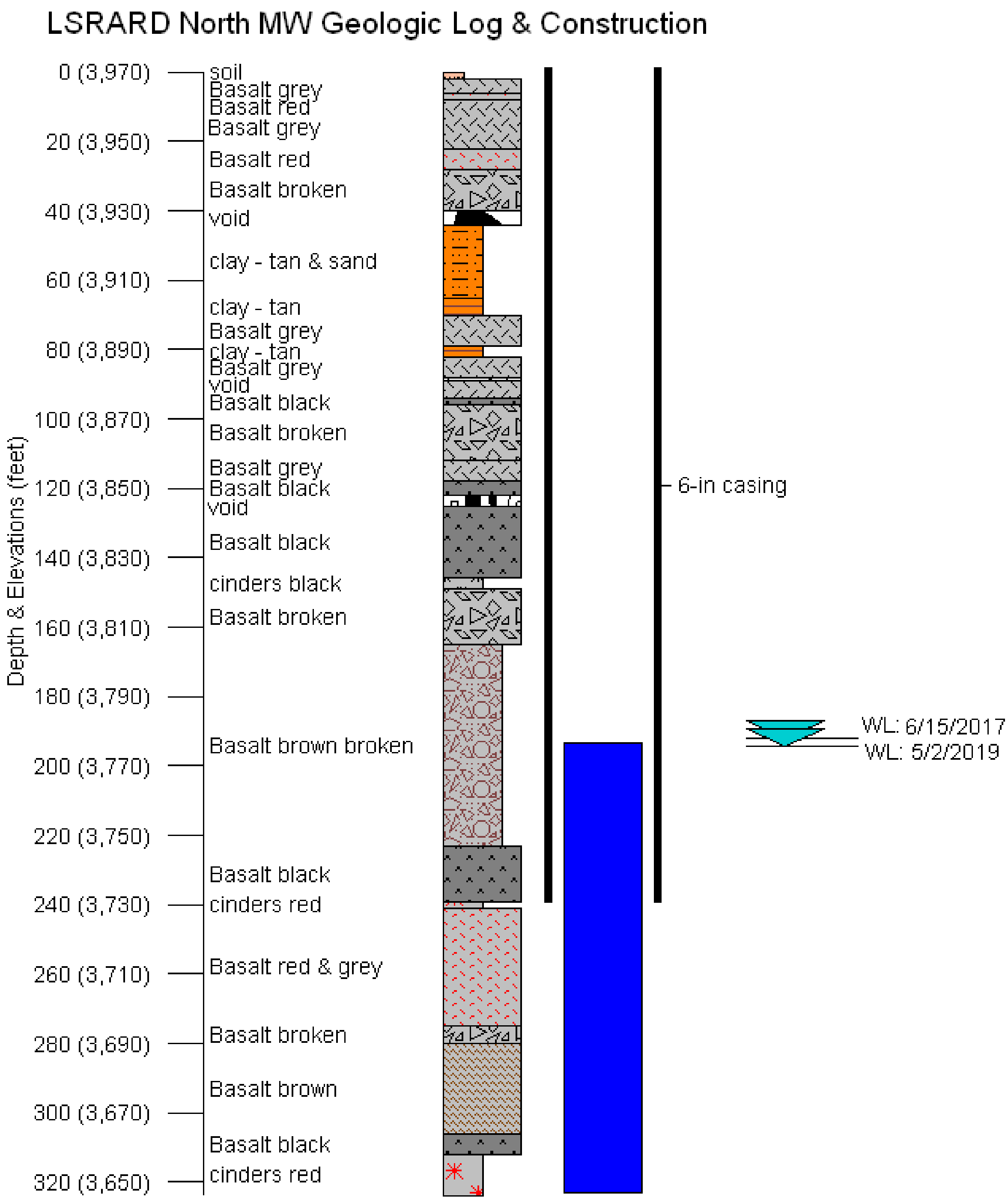

Figure 3. LSRARD North Monitor Well Geologic Log, Construction and Water Levels.

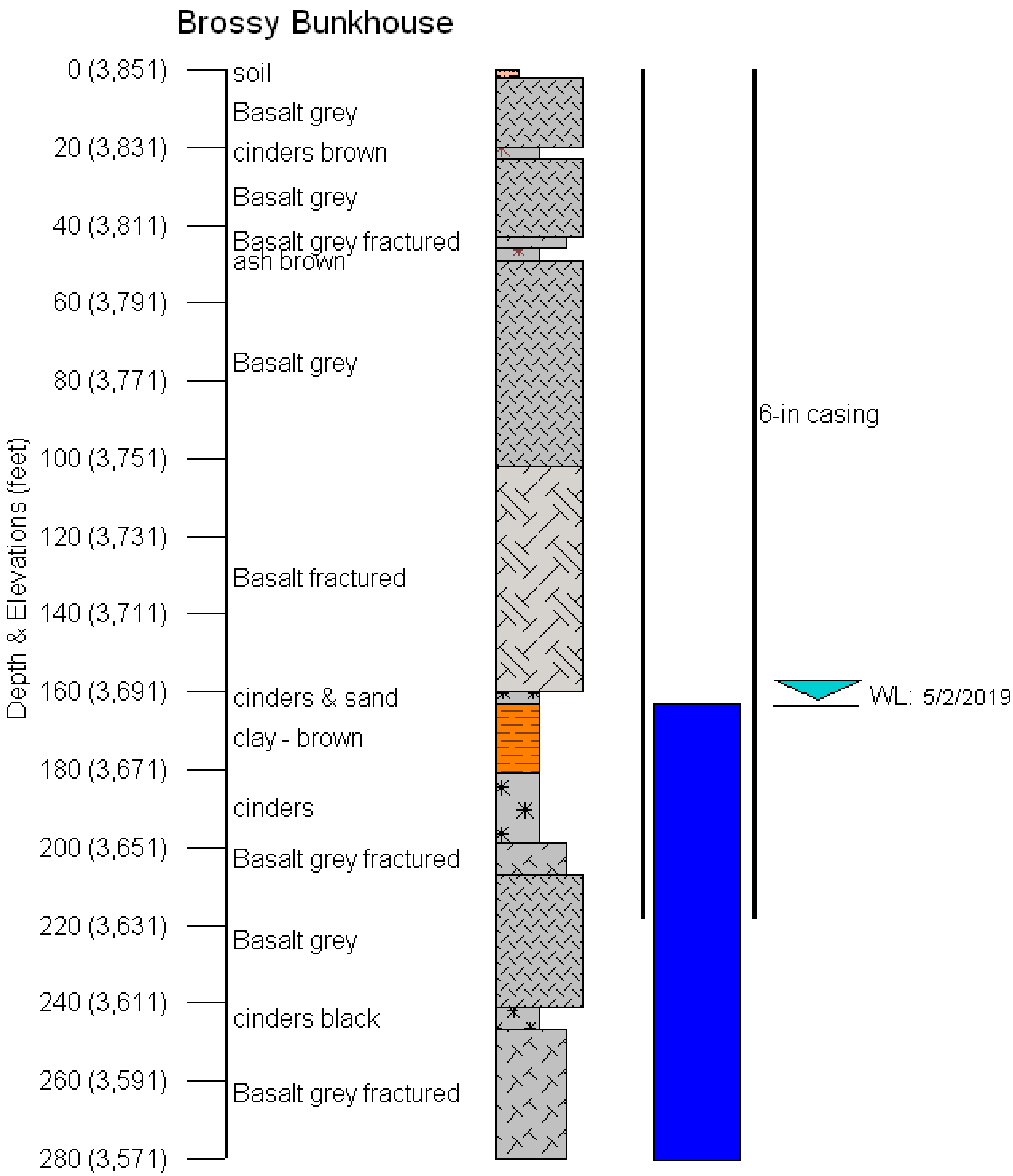

Figure 4. Brossy Bunkhouse Well Geologic Log, Construction and Water Levels. There were no water levels measured in 2017 for this well.

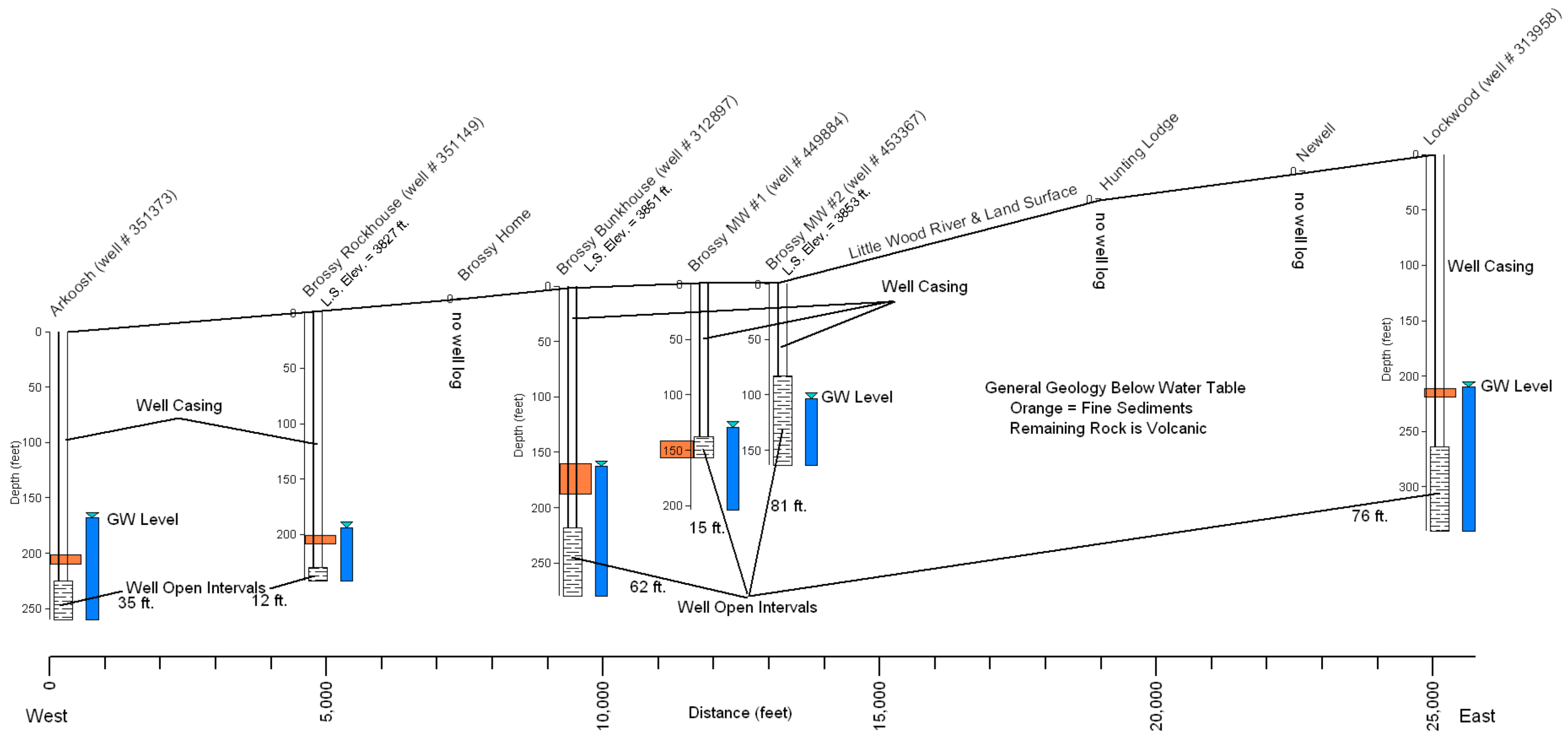

Figure 5. Cross Section of wells in the Brossy area from west to east for a distance of approximately 5 miles.

Figure 6. Photo is from June 16, 2017 12 hours after dye was released (Trace #1) with a concentration of 160 ppb. View is to the north with the turnout structure in the upper right corner.

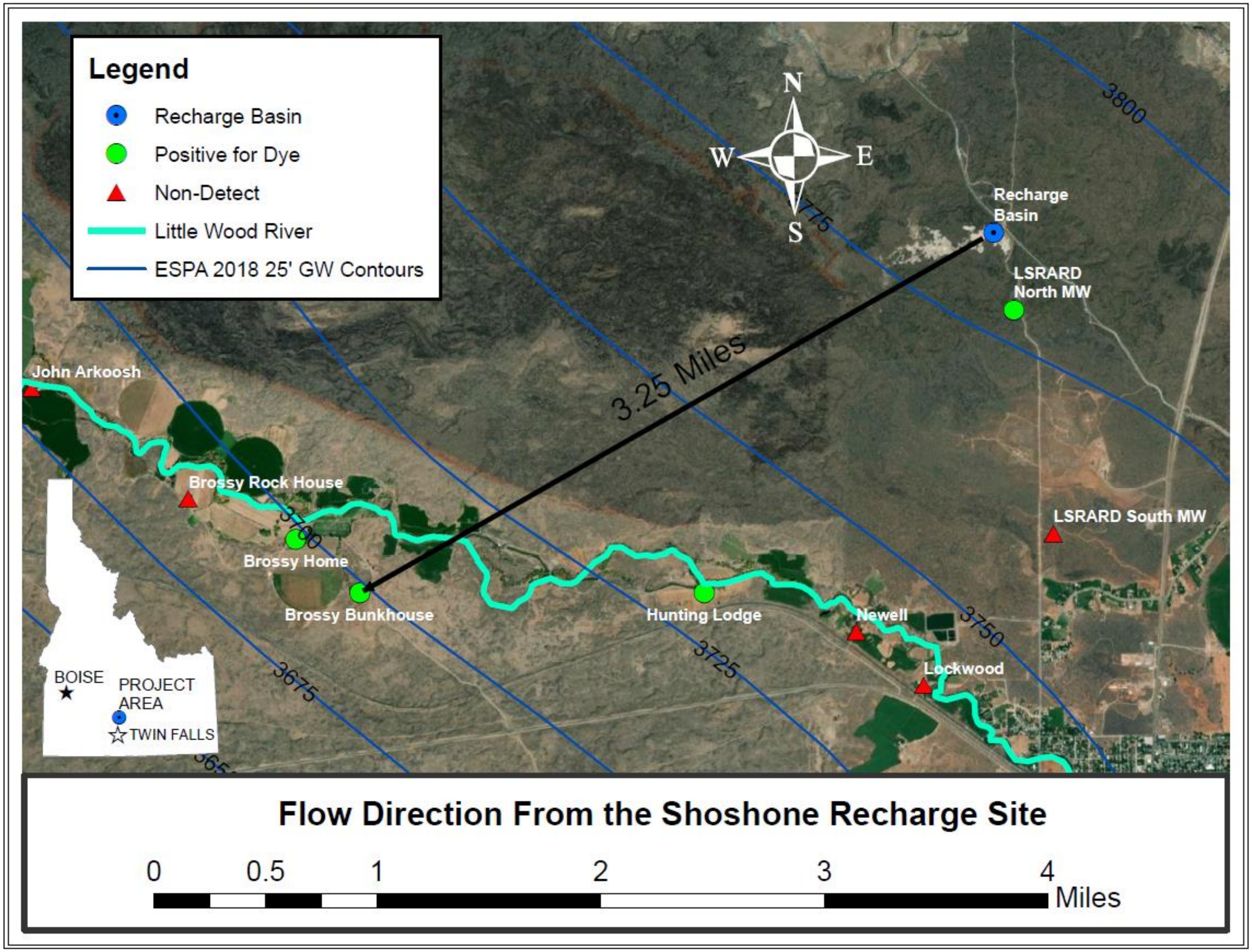

Figure 7. Trace #1 Sample Sites and Dye Flow Path from the Recharge Site.

Name	Jun15 2017	Jun16 2017	Jun21 2017	Jun23 2017	Jun27 2017	Jun29 2017	Jul13 2017	Jul14 2017	Aug9 2017	Aug22 2017	Sep6 2017	Sep21 2017	Oct4 2017	Nov1 2017	Nov3 2017	Jan25 2018	Apr3 2018	May16 2018	May30 2018	Jun7&9 2018	Aug9 2019	Oct18 2018
Contrase	p = deployed							p=ND (end)														
Mohr	p = deployed							p=ND										p = owner discarded (end)				
Lockwood	p = deployed						p=ND													p=ND (end)		
Newell	p = deployed						p=ND, w=ND		w=ND		p=ND							p=ND (end)				
Brossy Home	p = deployed						p=0.421, w=0.016		w=0.016	w=0.020	p=2.15	w=0.028	w=0.022	w=0.016 (end)								
Brossy Bunkhouse	p = deployed						p=26.5, w=0.478		w=0.188	w=0.087	p=18.1	w=0.038	w=0.019	w=0.012 (end)								
John Arkoosh	p = deployed						p=ND		w=ND		p=ND								p=ND (end)			
Arkoosh hired hand	p = deployed						p=ND													p=ND (end)		
Jake Arkoosh	p = deployed						p=ND											p=ND (end)				
Borneman			p = deployed					p=ND										p=ND (end)				
Bingham			p = deployed					p=ND										p=ND (end)				
Heiskell			p = deployed					p=ND										p=ND (end)				
Westendorf					p = deployed			p=ND										p = owner discarded (end)				
Toone's stock well					p = deployed									p=ND (end)								
Tolbert					p = deployed		p=ND											p=ND (end)				
LSRARD North MW	w=ND, p = deployed	w=ND	w=ND, w=ND	w=ND	w=ND	w=ND	p=0.685	w=ND	w=ND		p=ND, w=ND					p=3.84	p=0.255	p=ND				p=ND (end)
LSRARD South MW	w=ND, p = deployed						p=ND	w=ND	w=ND		p=ND, w=ND			p=ND		p=ND	p=ND	p=ND				p=ND (end)
G. Arkoosh stockwell						p = deployed						p=ND			p=ND		p=ND				p=ND (end)	
Hunting Lodge	p = deployed							p=2.22, w=0.022	w=ND	w=ND	p=3.80				p=0.290 (end)							
Brossy Rock House	p = deployed						w=ND		p=ND, w=ND	w=ND	p=ND	w=ND	w=ND, p=ND	w=ND (end)								
Keale											w=ND, p = deployed					p=ND		p=ND (end)				

Table 1. Trace #1 Results for both Charcoal Packets (p) and Water Samples (w). ND=non-detect for dye.

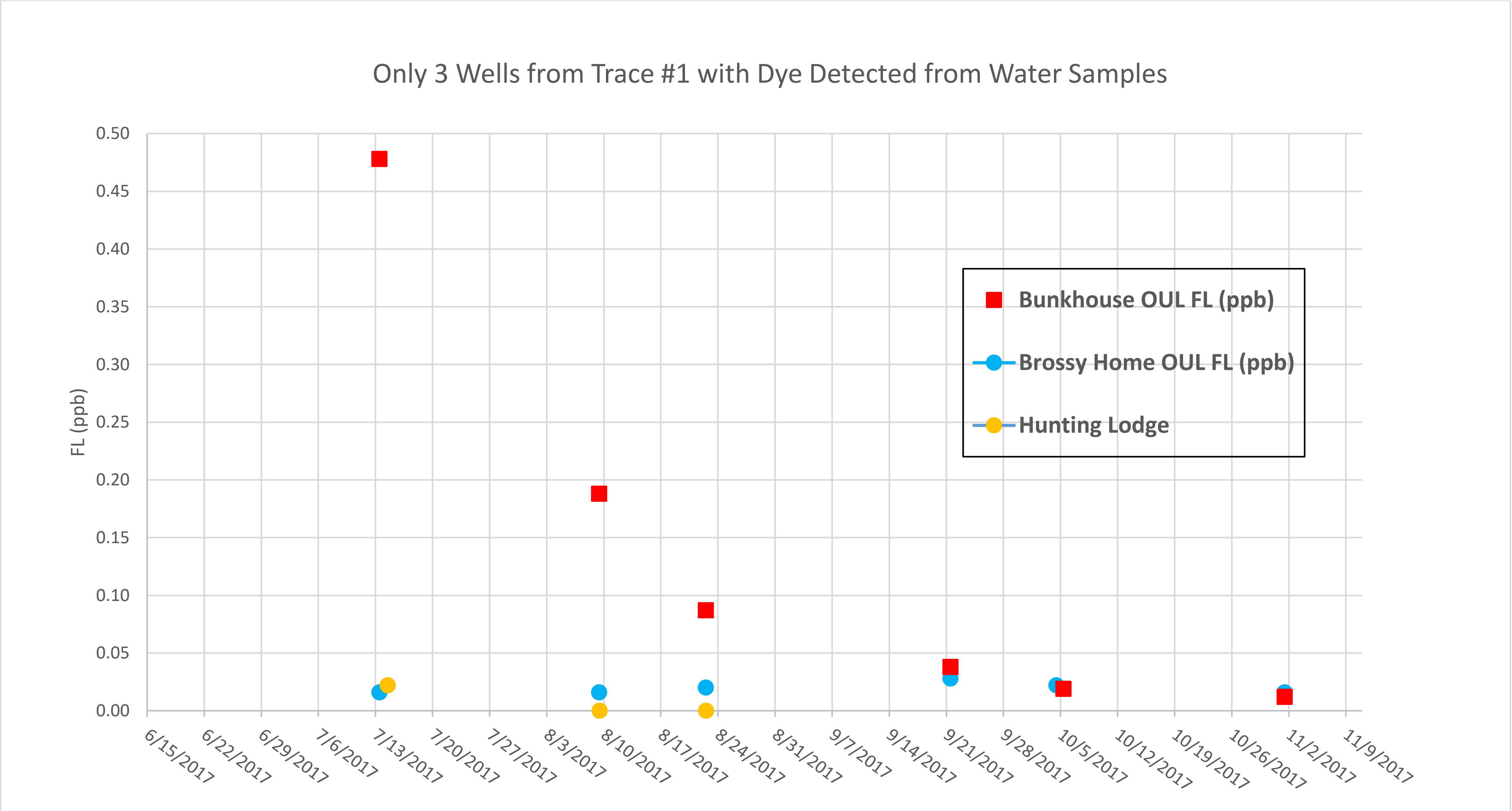

Figure 8. Chart showing results from the only 3 wells that dye was detected in water samples from Trace #1.

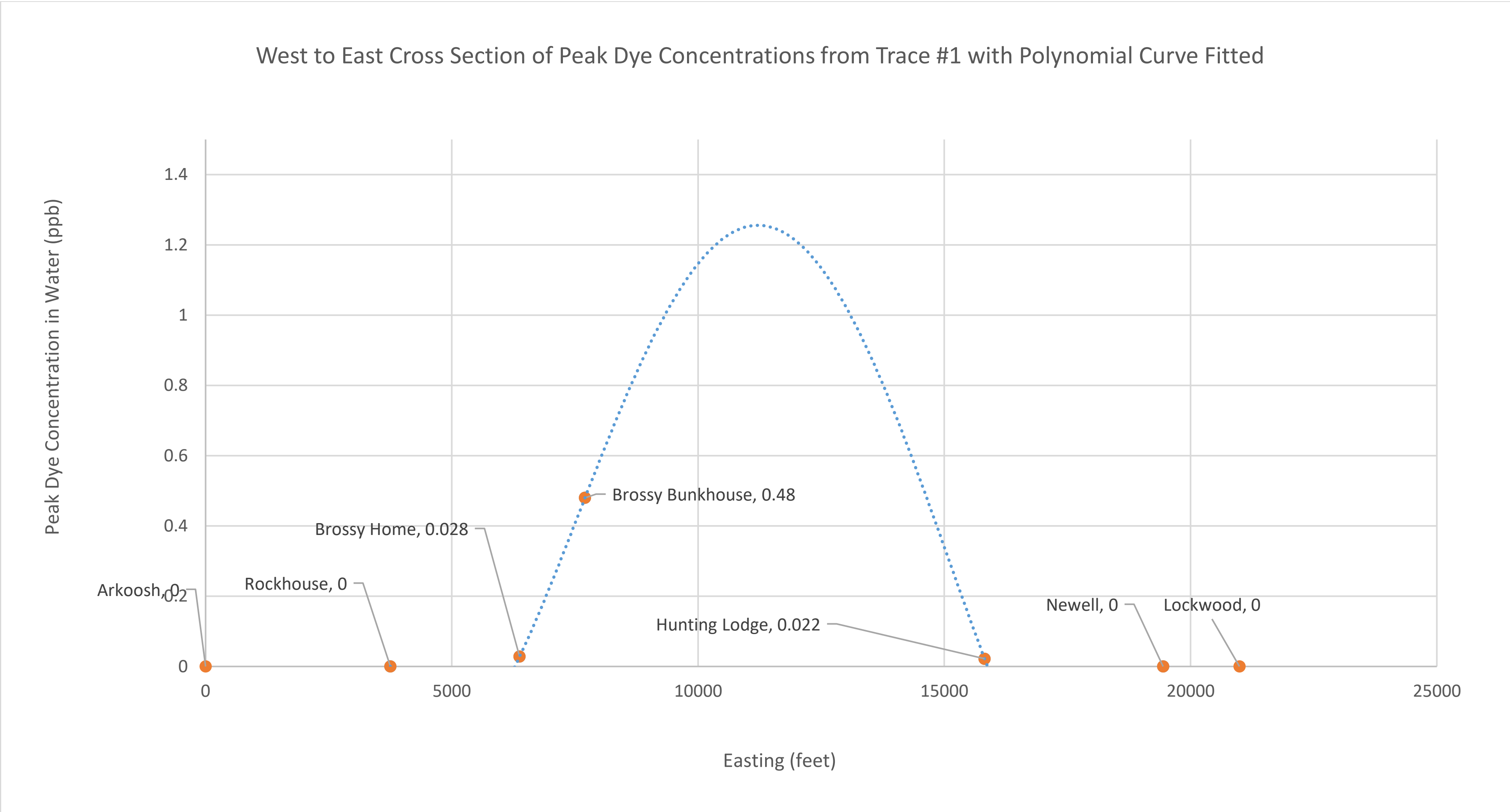

Figure 9. Peak water concentrations for a west to east section of wells and a polynomial curve fit for estimation for the center of the dye cloud and flow path.

Figure 10. Photo is during dye released on April 4, 2019 with a concentration of 848 ppb FL. Both dye releases occurred at the canal turn out structure seen in the upper right hand corner and view angle is to the North.

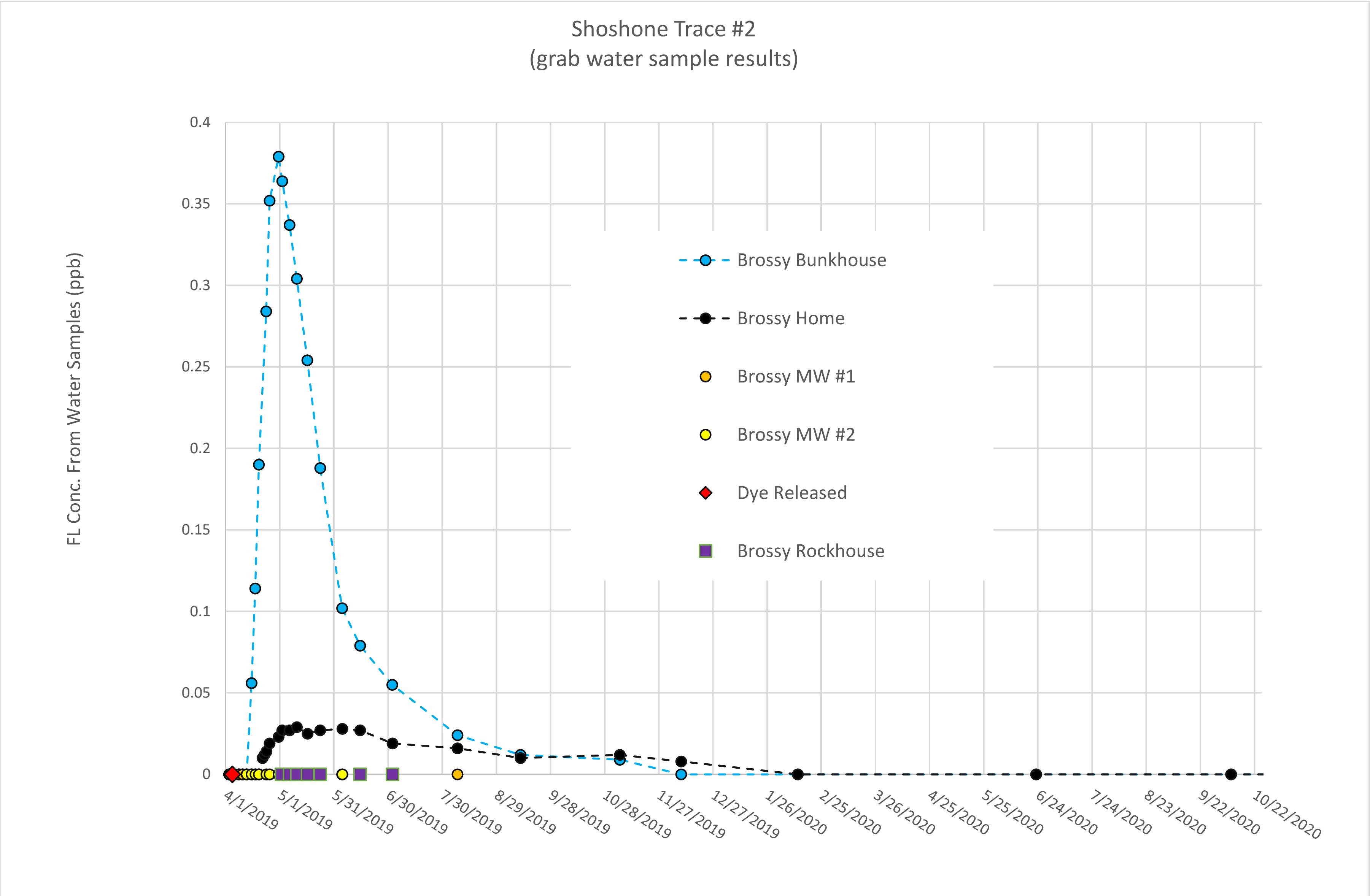
Shoshone Trace #2
(grab water sample results)
FL Conc. From Water Samples (ppb)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
4/1/2019
5/1/2019
5/31/2019
6/30/2019
7/30/2019
8/29/2019
9/28/2019
10/28/2019
11/27/2019
12/27/2019
1/26/2020
2/25/2020
3/26/2020
4/25/2020
5/25/2020
6/24/2020
7/24/2020
8/23/2020
9/22/2020
10/22/2020
Brossy Bunkhouse
Brossy Home
Brossy MW #1
Brossy MW #2
Dye Released
Brossy Rockhouse

Figure 11. Dye concentration breakthrough curves from grab water samples for selected monitoring sites.

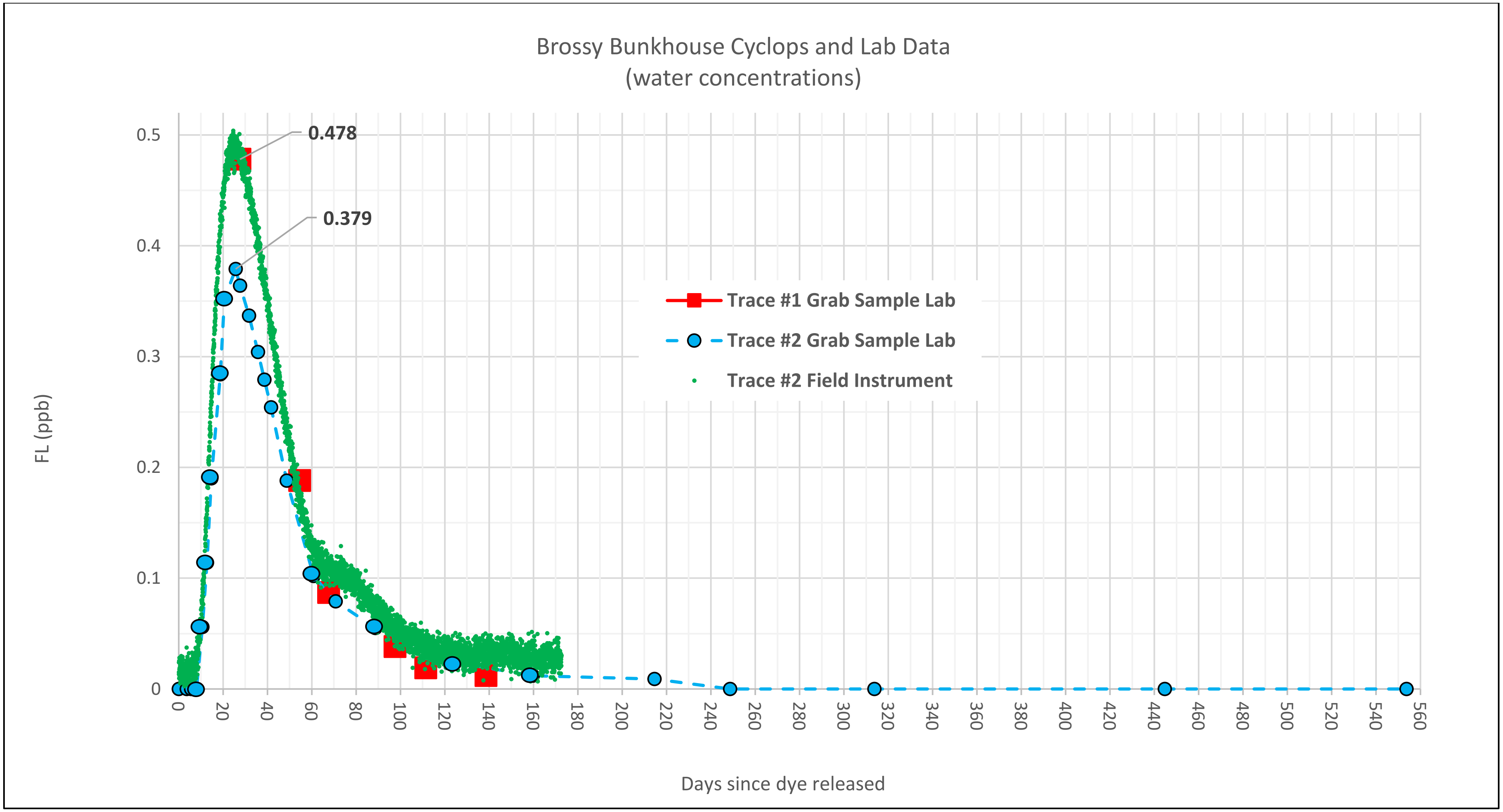

Figure 12. Dye Concentrations for the Bunkhouse well from Trace #1 and Trace #2 suggesting a unique solution outcome.

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