

# Dye Tracing Studies for a Land Application Disposal (LAD) System for Constantine Mining

Palmer Project - Haines, Alaska

4/13/2022

Thomas Aley and Trevor Osorno  
Ozark Underground Laboratory, Inc.

A project for Constantine Mining LLC, 800 West Pender Street, Suite 320, Vancouver,  
BC. V6C 2V6, Canada.

### **Authors**

Thomas Aley is Senior Hydrogeologist and President, Ozark Underground Laboratory, Inc. He is licensed as a Professional Geologist in Missouri, Arkansas, Kentucky, and Alabama and holds national certification as a Professional Hydrogeologist from the American Institute of Hydrology. He has specialized in groundwater tracing studies for over 50 years and has designed and conducted numerous tracing projects in Alaska. Trevor Osorno is Senior Hydrogeologist with the Ozark Underground Laboratory, Inc. and specializes in contaminant hydrogeology.

## Table of Contents

Authors.....	1
Table of Contents .....	2
List of Figures .....	4
List of Tables .....	5
1. Introduction.....	6
1.1 Background.....	6
1.2 Units.....	8
2. Phase 1 Tracer Study .....	9
2.1 Hydrogeological Setting .....	9
2.2 Phase 1 Dye Trace Aquifer.....	10
2.3 Objectives of the Phase 1 Dye Tracing Study .....	11
2.4 Phase 1 Methods.....	12
2.4.1 Construction of Trenches for Dye and Water Introductions.....	12
2.4.2 Tracer Dyes and Quantities Used .....	14
2.4.3 Introduction of Tracer Dyes and Water, Phase 1 Tracer Study .....	17
2.4.4 Sampling for Tracer Dyes.....	19
2.4.5 Study Schedule.....	22
2.4.6 Dye Analysis Methods.....	23
2.4.7 Flow Rate Measurements in Glacier Creek .....	27
2.4.8 Precipitation Measurements.....	28
3. Phase 2 Tracer Study .....	29
3.1 Hydrogeological Setting.....	29
3.2 Phase 2 Dye Trace Aquifer .....	30
3.3 Objectives of the Phase 2 Dye Tracing Study.....	31
3.4 Phase 2 Methods.....	32
3.4.1 Construction of Trenches for Dye and Water Introductions.....	32
3.4.2 Tracer Dyes and Quantities Used .....	33
3.4.3 Introduction of Tracer Dyes and Water .....	35



---

3.4.4 Sampling for Tracer Dyes .....	35
3.4.5 Study Schedule.....	35
3.4.6 Dye Analysis Methods.....	36
3.4.7 Flow Rate Measurements in Glacier Creek .....	39
3.4.8 Precipitation Measurements.....	40
4. Results.....	41
4.1 Infiltration Rates in the Tracer Study Areas.....	41
4.2 Groundwater Gradients in Tracer Study Area.....	42
4.3 Dye Tracing Results .....	43
4.3.1 Phase 1 Results .....	43
4.3.2 Phase 2 Results .....	47
4.4 Flow Rate Measurements in Glacier Creek.....	48
4.5 Water Level and Temperature Measurements in Monitoring Wells .....	50
5. Summary and Findings .....	54
5.1 Phase 1 Tracer Study.....	54
5.2 Phase 2 Tracer Study.....	56
5.3 General Discussion.....	57
6. Conclusions.....	59
7. References.....	60
Appendix A. Ozark Underground Laboratory Procedures and Criteria Document.....	
Appendix B: Dye Tracing Results .....	
Appendix C: Phase 1 and Phase 2 Precipitation Data.....	

## List of Figures

Figure 1. Map showing the general location of the Palmer Project site. ....	6
Figure 2. Map showing the locations of the LAD configurations for the Phase 1 and Phase 2 study locations. ....	7
Figure 3. Location of monitoring wells relative to the Conceptual LAD for Phase 1 Study.....	10
Figure 4. Location of dye introduction trenches for the Phase 1 tracer study. Trenches are T-1, T-2, and T-3. ....	13
Figure 5. Preparation of staff gauges. ....	13
Figure 6. Mixing powdered dye with water at Big Nugget camp.....	16
Figure 7. Fluorescein dye introduction at Trench T-1. Note blue water diffuser in bottom of trench.....	18
Figure 8. Fluorescein dye introduction into Trench T-2.....	18
Figure 9. Eosine dye introduction into Trench T-3.....	19
Figure 10. Attachment of activated carbon sampler at MW-02.....	20
Figure 11. Locations of Phase 1 dye sampling stations relative to the 2019 proposed LAD configuration. ....	22
Figure 12. Location of Phase 2 dye introduction trenches T-101, T-102, and T-103. ....	31
Figure 13. Fluorescein dye introduction into Trench T-102.....	34
Figure 14. Locations of Phase 2 dye sampling stations. ....	37
Figure 15. Map showing streamflow measurement stations along Glacier Creek and tributaries. ....	40
Figure 16. Carbon samplers recovered at Station 9 on February 10, 2020.....	45
Figure 17. Oblique view of the Phase 1 and Phase 2 test Study Areas. ....	46
Figure 18. Water levels and water temperatures in MW-01. The Phase 1 tracer study period is shown with a white background and the Phase 2 study period is highlighted with a gray background.....	51
Figure 19. Water levels and water temperatures in MW-02. The Phase 1 tracer study period is shown with a white background and the Phase 2 study period is highlighted with a gray background.....	52
Figure 20. Water levels and water temperatures in MW-03. The Phase 1 study period is shown with a white background and the Phase 2 study period is highlighted with a gray background. ....	53

## List of Tables

Table 1. Locational information on Phase 1 tracer study dye introduction trenches. Coordinates and ground surface elevations at the north end of each dye introduction trench is shown. Measurements made with a Trimble GeoHX 6000. Coordinates NAD 83.....	14
Table 2. Locational information on Phase 1 tracer study dye introduction trenches. Distances (feet) from trenches to streams and MW-01.....	14
Table 3. Locations of Phase 1 dye sampling stations. ....	20
Table 4. Study schedule, Phase 1 tracer study. Modifications and actual dates of accomplishment are shown in italics. Day numbers 0 through 42 are 2019; Day 275 is July 30, 2020.....	23
Table 5. RF-5301 Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein and eosine in water and elutant samples.....	25
Table 6. Phase 2 Dye Trace trench dimensions. ....	32
Table 7. Locational information on Phase 2 dye introduction trenches. Coordinates and ground surface elevations are the center of each dye introduction trench. Coordinates are NAD 83, UTM Zone 8N. Measurements from Tundra (2020). ....	33
Table 8. Locations of dye sampling stations for Phase 2 Dye tracer study. ....	36
Table 9. Phase 2 study schedule. Modifications and actual dates of accomplishment are shown in italics. Day numbers 0 through 130 are 2020; Day 350 is August 8 <sup>th</sup> , 2021...	38
Table 10. Monitoring well and groundwater elevation data. ....	42
Table 11. Flow rate measurements on Glacier Creek at Stations 8 and 9 for Phase 1 of Dye tracer study (see Figure 9 for station locations). 1 cubic foot/second (cfs) = 448.8 gallons per minute = 1,700 liters/minute.....	49
Table 12. Flow rate measurements on Glacier Creek and tributaries during the Phase 2 of Dye tracer study. 1 cubic foot/second (cfs) = 448.8 gallons per minute = 1,700 liters/minute.....	49

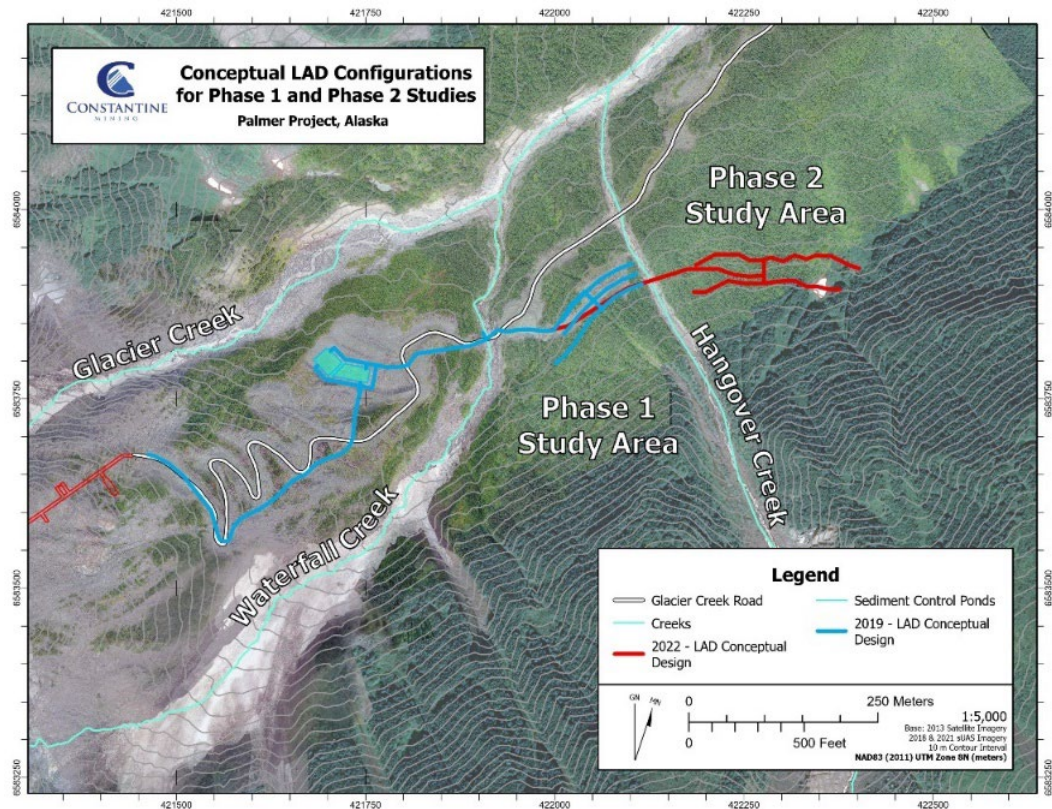
## 1. Introduction

### 1.1 Background

The Palmer Project is a copper-zinc-gold-silver-barite exploration project located 34 miles northwest of Haines, Alaska (Figure 1). Constantine Mining LLC (Constantine) has a permit to develop an underground exploration ramp to support underground drilling with water disposal infrastructure located in the overburden on the southeast valley flank of Glacier Creek. Treated wastewater generated from the permitted activities will be first treated in a wastewater treatment facility and then disposed of through a Land Application Disposal system (LAD) or (Lower Diffuser), with most of the water being disposed of through a diffuser system. The Lower Diffuser is now designed to accommodate a steady state flow of 700 gpm and temporary flows of 900 gpm. This provides a 1.9 factor of safety of above the anticipated base-case flows of 360 gpm as well as accommodating the unlikely flows of 500 gpm and the extremely unlikely flows of 700 gpm. The diffusers will be a system of buried perforated pipes that will allow subsurface discharge of the treated water after it has discharged from the water treatment facility and from a secondary control pond. This report details two groundwater tracing studies where tracer dyes were introduced in two separate, but adjacent, areas where the LAD diffuser system or systems might be located (Figure 2).



Figure 1. Map showing the general location of the Palmer Project site.



**Figure 2. Map showing the locations of the LAD configurations for the Phase 1 and Phase 2 study locations.**

The Phase 1 tracer study involved the introduction of two tracer dyes in the Phase 1 tracer study area. This area is approximately 650 feet uphill of Glacier Creek and is bounded by Waterfall Creek to the west and Hangover Creek to the east. Groundwater flow throughout the Phase 1 tracer study area is generally towards north-northwest towards Waterfall Creek to the west and Glacier Creek to the north (KCB Consultants Ltd., 2022). Hangover Creek separates the two study areas, Phase 1 and Phase 2 and provides a surface expression that loosely demarcates the transition in the groundwater flow direction to a more dominantly north-northeastern flow direction (KCB Consultants Ltd., 2022) in the Phase 2 tracer study area, east of Hangover Creek.

Sampling for tracer dyes from the Phase 1 tracer study area was conducted at all sampling stations (Stations 1-9) during the period from October 28, 2019, to December 10, 2019. Sampling at these stations ended on December 10, 2019, because of snow conditions and a high avalanche risk. Sampling at Station 9, the furthest downstream station on Glacier Creek for the Phase 1 tracer study, continued until July 7, 2020. Stations 1, 2, 5, 6, and 8 were sampled intermittently between December 10, 2019, and May 28, 2020. These stations were sampled routinely along with Station 9 from May 28, 2020, to the end of Phase 1 sampling on July 30, 2020 (Table 4).



The Phase 2 tracer study was conducted in an area on the opposite (east) side of Hangover Creek from the Phase 1 tracer study area. The Phase 2 tracer study area is approximately 1,000 feet southeast of the confluence of Hangover Creek and Glacier Creek and approximately 300 feet east of Hangover Creek. Groundwater flow throughout the Phase 2 tracer study Area is generally towards the northeast, away from Hangover Creek down-valley obliquely towards Glacier Creek (KCB Consultants Ltd., 2022).

Sampling for tracer dyes from the Phase 2 tracer study was conducted at 13 of the 17 sampling stations (Stations 101, 103-104, 106-110, 112, 114-117) for the period August 17, 2020, to August 7 and 8, 2021. Sampling at 3 of the 17 sampling stations (Stations 102, 111, 113) ended on November 23 or 24, 2020. Sampling for one of the 17 sampling stations (Station 105) ended on January 5, 2021 (Table 9).

This report discusses the Phase 1 and Phase 2 Tracer Studies separately. After these discussions the study results are summarized and conclusions are identified.

## **1.2 Units**

Some of the reports cited gave measurements in the metric system. For convenience our report lists those values and their equivalents in the English system. Measurements made in this study are mainly reported in English units; in most cases metric equivalents are not indicated.

---

## 2. Phase 1 Tracer Study

### 2.1 Hydrogeological Setting

BGC Engineering (2018) describes the hydrogeologic setting of the Phase 1 tracer study area as follows:

“The proposed LAD [Lower Diffuser] is located on an alluvial fan comprised of poorly sorted sandy gravel, on the west side of the site between Waterfall Creek and another glacial outwash valley, Hangover Creek. The alluvial deposits and colluvial material are mainly derived from glacial till and have been deposited in a relatively high energy environment. The Hangover Area is characterized by poorly sorted and poorly stratified mixtures of silt, sand, gravel, cobbles and boulders. With frequent and episodic flood, debris flow and avalanche events creating the surface deposits, the fan is generally interlayered with finer materials (lower permeability) and coarser material (higher permeability) up to boulder sizes.”

Based on data collected in a recent geophysical survey, the planned 2019 Lower Diffuser system as shown in Figure 3 is located in an area of alluvial and colluvial deposits that are 165 - 210 feet thick (Logic Geophysics, 2021). Similarly thick deposits of alluvium and colluvium are expected to extend from the 2019 Lower Diffuser area where the dyes were introduced, to and beneath the valley floor of the area southeast of Glacier Creek indicated in the subsequent overburden drilling following the Phase 2 study (ranging from 167 to 262 feet deep, as reported in the KCB Consultants Ltd. 2022 Report).

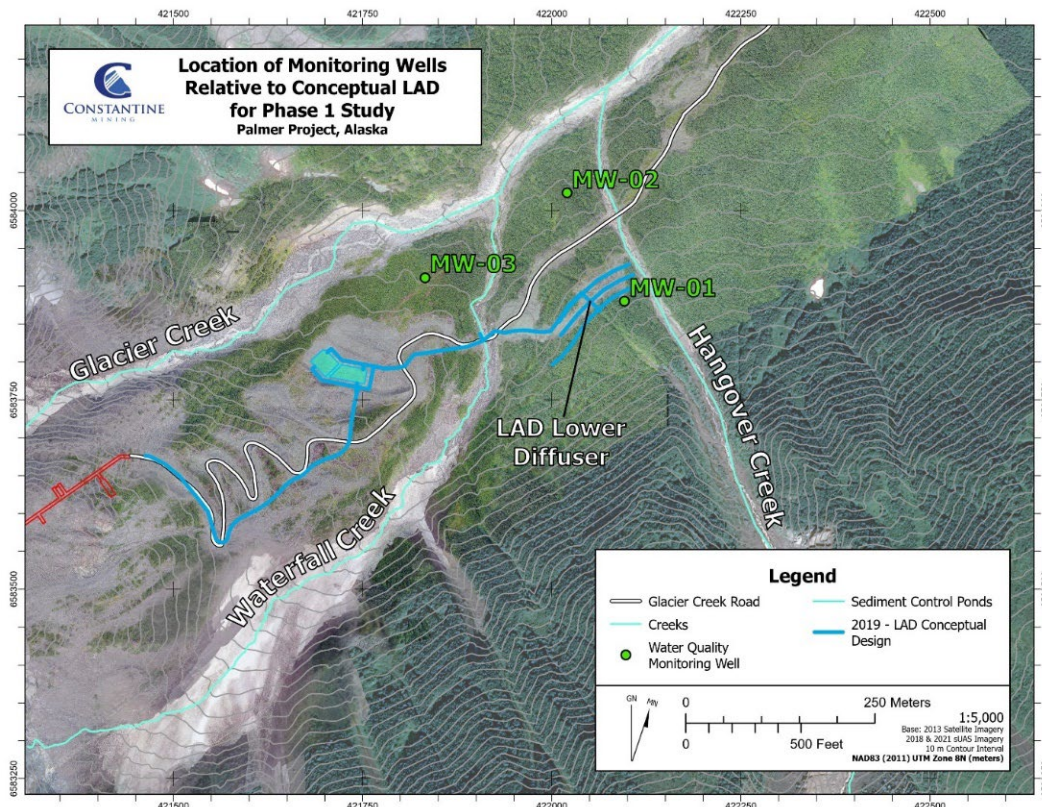
Logic Geophysics (2021) noted that bedrock maps from geophysical studies show the potential existence of a paleochannel on the southeast side of Glacier Creek. Such a paleochannel, if present, could provide a preferential groundwater flow route with high permeability that would roughly parallel the present channel of Glacier Creek.

Three monitoring wells were constructed in late August, 2018 (Tundra Consulting, 2018). These wells provide useful information on seasonal water levels and groundwater temperatures in the unconsolidated sediments in the vicinity of the tracer study areas. Data from monitoring wells MW-01 and MW-02 are the most relevant. The well locations and the initially planned LAD are shown on Figure 3. Additional monitoring wells were installed in 2021, east of Hangover Creek (KCB Consultants Ltd., 2022). Although the expanded network was installed within the Phase 2 tracer study area, the general interpretation of the overburden sediments is consistent to those from the three monitoring wells described below. A more detailed description of the stratigraphy and the additional monitoring well installations can be found in Tundra Consulting (2018) and KCB Consultants Ltd. (2022).

Based on water level measurements made between 2018 and 2021 the annual measured range in the depth to the water table from the land surface in the three monitoring wells was as follows:

- MW-01. 45.8 to 51.4 feet.
- MW-02. 36.6 to 59.4 feet.
- MW-03. 19.98 to 29.6 feet.

Figure 3. Location of monitoring wells relative to the Conceptual LAD for Phase 1 Study.



## 2.2 Phase 1 Dye Trace Aquifer

As planned in the 2019 configuration, the Lower Diffuser system shown in Figure 3 would discharge to a high gradient and relatively small aquifer. For designing a monitoring program to detect tracer dyes introduced for the Phase 1 tracer study the OUL made the initial assumption that the aquifer associated with this 2019 Lower Diffuser would be lower in elevation than the 2019 Lower Diffuser and generally bounded by Waterfall Creek, Hangover Creek, and Glacier Creek. This encompasses an area of approximately 15 acres. Note, the design and location of the 2019 Lower Diffuser configuration is different than that of the 2022 LAD configuration. The 2022 LAD configuration is entirely located east of Hangover Creek as described in Section 3, below, and is the focus of the Phase 2 study.

Data from MW-01 and MW-02 indicate that, without any unnatural addition of water to the aquifer, the depth to the water table in the southeastern half of this area is about 50 feet below land surface and slopes steeply toward Glacier Creek. There are no wells in the northwestern half of the aquifer from which to estimate the depth to the water table. Given the lower gradient of the surface topography and the presence of Glacier Creek in our experience the depth to the water table in the northwest half of the aquifer is unlikely to average more than approximately 30 feet below land surface. This is loosely evidenced by the relatively shallow groundwater table observed at MW-03 (MW18-03) during October 2021 measurements where groundwater was observed at 24.27 feet below ground surface.

The OUL estimates water storage capacity in this aquifer at 18% of the volume of earth materials. In groundwater literature the volume of water that can be extracted from an aquifer under the force of gravity is a percentage known as Specific Yield. For purposes of this discussion storage capacity and Specific Yield are equivalent. Driscoll (1986, p. 67) provides a table of representative Specific Yield ranges for selected earth materials and shows sand and gravel at 15 to 25%. The aquifer material at the Palmer project contains silt which would decrease the specific yield of the alluvium as compared with sand and gravel. Furthermore, the alluvium at the Palmer site is derived from glacial till and till has porosity percentages that range from 10 to 20% whereas sand and gravel mixed and shown in the same table by Fetter (1980, p. 64) varies from 20 to 35%. The selection of 18% specific yield was made by Tom Aley, senior author of this report, and is based on his education and experience, the technical literature, and his personal examination of the trenches used for the dye introductions and his personal examination of the excavated materials from the trenches.

### **2.3 Objectives of the Phase 1 Dye Tracing Study**

The study plan for this investigation was prepared by the OUL on October 24, 2019 (Aley, 2019). Objectives for the study were:

- To develop a general understanding of groundwater movement downgradient of the proposed location of the 2019 LAD's Lower Diffuser configuration by conducting a groundwater tracing study. Note, the 2019 LAD Lower Diffuser configuration has since changed and does not reflect the current (2022) LAD Diffuser configuration located entirely east of Hangover Creek.
- To determine, with the introduction of a total of about 15,000 gallons of water and dye into trenches in the 2019 Lower Diffuser configuration, if there is a hydrologic connection with lower Waterfall Creek, Hangover Creek, and/or Glacier Creek.
- If there is, to determine the approximate travel time for first dye arrival at creek sampling points, and to determine the approximate travel time for peak concentrations to arrive at creek sampling points.
- To determine into which stream segments this water discharges (assuming it does).
- To determine which cell of the 2019 Lower Diffuser configuration is reporting to surface water (assuming it does)

- To quantify the concentration of introduced dye(s) in Glacier Creek (assuming it reports to surface water).

## **2.4 Phase 1 Methods**

### **2.4.1 Construction of Trenches for Dye and Water Introductions**

Constantine is analyzing the disposition of treated wastewater by discharging it into a system of perforated pipes buried in the 2019 Lower Diffuser configuration area. Under the 2019 configuration, the LAD was designed to accommodate a discharge rate up to 500 gallons per minute (gpm). The OUL concluded that excavating three trenches and then introducing tracer dyes and about 5,000 gallons of water to each of the three trenches would be an appropriate approach for assessing underground transport of water into and through the groundwater system from the Lower Diffuser area. Figure 4 shows the locations of the three trenches.

All three trenches were constructed on October 11, 2019 and were located along the contour lines of the sloping hillside. Slopes in the vicinity of the trenches are about 30 to 35%. Each trench was about 11 feet deep (on the uphill side), and approximately 30 feet long at the bottom and 45 inches wide at the bottom. A laser level was used to ensure that the bottoms of all trenches were within 2 inches of being level along their entire lengths. At the tops trenches T-1 and T-2 were 56 feet long and T-3 was 50 feet long. The study plan (Aley, 2019B) specified that each trench be about 30 feet long, about three feet wide, and at least 8 feet deep. The trenches were slightly wider than initially planned because of the width of the bucket on the excavator and the trenches were slightly deeper than the minimum amount specified. These differences were beneficial to the study as there was no concern that water might overflow a trench. Small amounts of slumping into the trenches occurred after excavation but this created no problems for the study. Staff gauges were constructed from lumber and one staff gauge was placed in each trench with marks at one-foot intervals. Figure 5 shows preparation of the staff gauges.

Trench T-1 was located near the northeastern margin of the proposed 2019 Lower Diffuser. The bottom of the trench extended for about 30 feet. Trench T-1 was used for fluorescein dye introduction.

Trench T-2 was located near the central, northern margin of the proposed 2019 Lower Diffuser. The bottom extended for about 30 feet. It was used for a fluorescein dye introduction.

Trench T-3 was located near the center of the proposed 2019 Lower Diffuser. The bottom extended for about 30 feet. It was used for the eosine dye introduction.



Figure 4. Location of dye introduction trenches for the Phase 1 tracer study. Trenches are T-1, T-2, and T-3.

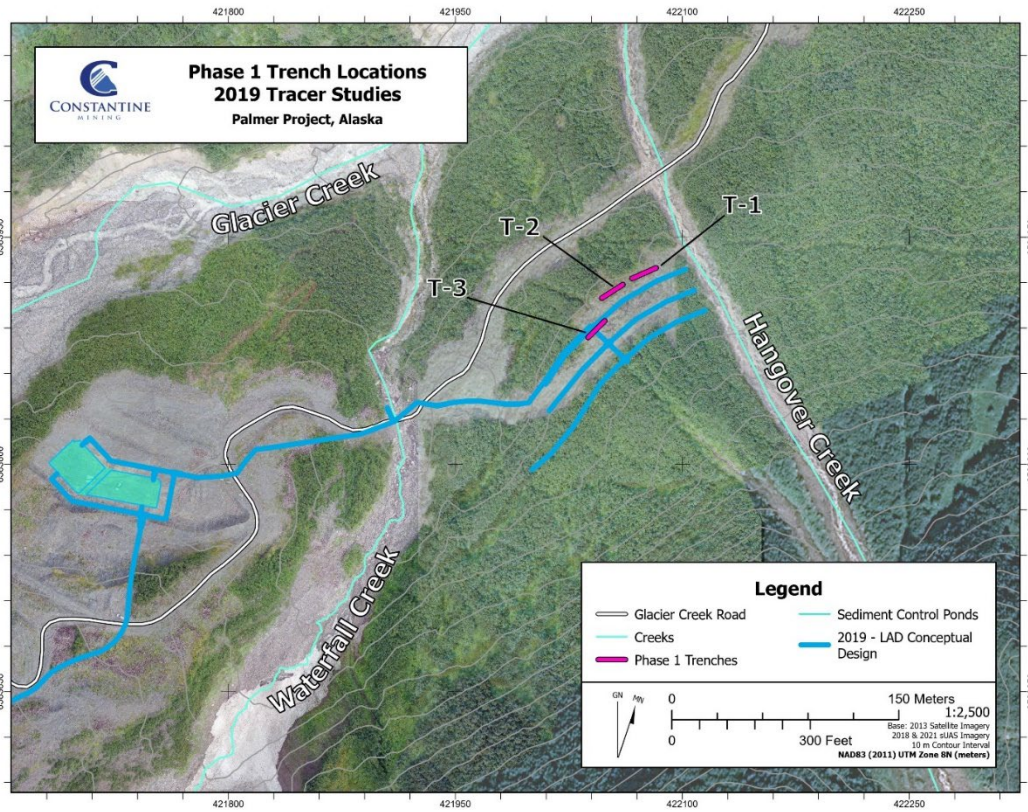


Figure 5. Preparation of staff gauges.



Coordinates and ground surface elevations at the northeast ends of each trench are shown in Table 1. Table 2 shows some important distances in the area.

Constantine (2019, page 8) reported that preliminary infiltration rates observed near Hangover Creek were 45 inches per hour with a head of 8 feet. Given this infiltration rate and the size of the trenches 5,000 gallons of water could easily be introduced into each trench without any risk of the trench overflowing.

**Table 1. Locational information on Phase 1 tracer study dye introduction trenches. Coordinates and ground surface elevations at the north end of each dye introduction trench is shown. Measurements made with a Trimble GeoHX 6000. Coordinates NAD 83.**

Trench	Easting	Northing	Elevation (meters)	Elevation (feet)
Trench T-1-Northeast end	422082.4	6583930	570.30	1,870.6
Trench T-2-Northeast end	422060.9	6583919	570.07	1,869.8
Trench T-3-Northeast end	422049.1	6583894	575.66	1,888.2

**Table 2. Locational information on Phase 1 tracer study dye introduction trenches. Distances (feet) from trenches to streams and MW-01.**

From	To			
	Waterfall Cr.	Hangover Cr.	Glacier Cr.	MW-01
N. End Trench T-1	497	97	607	159
N. End Trench T-2	425	180	561	157
N. End Trench T-3	399	239	585	143

#### 2.4.2 Tracer Dyes and Quantities Used

The dyes used for both the Phase 1 and Phase 2 Tracer Studies were mixtures containing fluorescein and eosine. Both fluorescein and eosine are highly detectable in water and in elutants from activated carbon samplers. Both of these dyes are commonly used in groundwater tracing investigations, and both are harmless to the environment and highly mobile in groundwater (Field et al., 1995).

Fluorescein, also known as uranine, is more specifically known as Acid Yellow 73, Color Index Number 45350. Three pounds of this dye mixture was introduced into Trench T-1 and another 3 pounds was introduced into Trench T-2. Eosine, is more specifically known as Acid

Red 87, Color Index Number 45380. Six pounds of this dye mixture was introduced into Trench T-3. Both dyes were mixtures containing approximately 75% dye equivalent and the remainder a diluent used as a standardizing agent and to assist in the mixing of dye with water. The diluent in both dye mixtures was sodium sulfate, commonly known as Glauber's Salt. All dye concentrations mentioned in this report are based on the as-sold mixture of the dye.

The dye mixtures are powders that are mixed with water prior to introduction for groundwater tracing. The dyes were shipped from the OUL to Haines in three 15-liter Nalgene® carboys; each carboy was packed inside a separate cooler. Water from the adjacent stream was added to all three carboys at the Big Nugget camp (see Figure 6). After dyes were introduced to the trenches, the carboys and their shipping coolers were returned to the OUL.

Fluorescein is a highly visible dye. Under field conditions it is visible to the general public at concentrations at or above 140 parts per billion (ppb) (Aley, 2019A).

Eosine is a pink or green color depending upon its concentration. Under field conditions eosine is visible to the general public at concentration at or above 13,500 ppb. In the experience of the OUL it was considered unlikely that there would be any dye visible in the water of the creeks. However, in the event field personnel noted colored water they were instructed to examine the edge of the stream to identify and mark with survey ribbons any points where colored water was visibly entering the creek. None was noted.



Figure 6. Mixing powdered dye with water at Big Nugget camp.



Groundwater in the study area does not freeze during winter and there was no frozen ground in the bottoms of the dye introduction trenches. Temperature loggers that record values every six hours are in place in all three monitoring wells and these data were reviewed by the OUL for the period October 2018 through March 2019. This is the part of the year equivalent to the period used for the groundwater tracing. A review of the monitoring well groundwater temperature data from these wells indicated that the temperature range of groundwater in these wells during the period October 2018 through March 2019 was as follows:

- MW-01. 2.141 to 4.343 °C. Surface elevation 1,891 feet.
- MW-02. 2.851 to 2.949 °C. Surface elevation 1,750 feet.
- MW-03. 3.565 to 3.578 °C. Surface elevation 1,796 feet.

The lowest temperatures recorded at MW-01 were associated with snow melt periods rather than winter conditions (Figure 18).

### **2.4.3 Introduction of Tracer Dyes and Water, Phase 1 Tracer Study**

All three trenches were excavated on October 11, 2019 and dye and water were introduced on October 29, 2019. The first set of activated carbon samplers for detecting tracer dyes was placed on October 28 except for Station 9 which was placed on the morning of October 29 prior to any introduction of dye and water into trenches. All water was pumped out of Waterfall Creek and transported through a system of hoses to the trenches. Water and dye introductions proceeded from Trench T-1 (Figure 7) to Trench T-2 (Figure 8) and then to Trench T-3 (Figure 9).

At each trench a small amount of water was pumped into the trench to moisten surfaces. Earth materials in the bottoms of the trenches were not frozen. Next, dye was poured out of the carboy in which it was mixed and into each trench from three or four points along the top of the trench. Each carboy was rinsed with a couple of gallons of water to get all dye out of the carboy; the rinse water was also added to the trench. Next, water was pumped into each trench through a diffuser until the total volume of water introduced into each trench equaled 5,000 gallons. Volumes were measured with a flow meter installed near the end of the waterline. A section of hose about 20 feet long extended from the flow meter to a diffuser at the end of the water line. The diffuser was placed in the bottom of the trench at a point about midway along the length of the trench. The depth of water in the trenches was occasionally noted based on the staff gauges; depths were interpolated between the marks made at every foot.

Figure 7. Fluorescein dye introduction at Trench T-1. Note blue water diffuser in bottom of trench.



Figure 8. Fluorescein dye introduction into Trench T-2.





Figure 9. Eosine dye introduction into Trench T-3.



#### 2.4.4 Sampling for Tracer Dyes

Sampling for the dyes was conducted using activated carbon samplers and grab samples of water. Detailed specifics on the sampling methods and analysis methods, including QA/QC considerations, are outlined in Appendix A, the OUL's Procedures and Criteria document. The OUL trained personnel to do the sampling using the proper sampling methods.

Each carbon sampler contains 4.25 grams of activated charcoal. Manufacturer's data indicates that the carbon in each sampler has a surface area in excess of one acre. Fluorescein and eosine dyes are readily adsorbed onto activated carbon when the sampler is anchored in the flow of a stream, spring, or monitoring well. Carbon samplers are continuous samplers for the presence of tracer dyes including fluorescein and eosine and accumulate dye from the passing water. For streams and springs, the dye concentration recovered from carbon samplers during laboratory analysis is routinely at least two orders of magnitude greater than the mean concentration in the passing water for carbon samplers in place for periods of about a week (Aley, 2017). The ratio is smaller for wells, especially if there is very little water flow through the well. Given the permeability of the material in which Monitoring Well-02 is located, there would expect to be a reasonable amount of water flow through this well over the time interval that a carbon sampler was in place.

Two independently anchored carbon samplers were placed at each stream sampling point during this tracing study. Monitoring Well-02 is located downgradient of the 2019 Lower

Diffuser area and was sampled with one carbon sampler suspended in the middle of the saturated zone within the well. Figure 10 shows how the sampler is anchored to the top of a dedicated well bailer. The well bailer is used to collect water samples from the well.

Carbon samplers were periodically collected and replaced with new samplers at all sampling locations. Each time carbon samplers were collected a grab sample of water was also collected at the sampling station. Sampling protocols are specified in Appendix A. Sampling stations used for this study are identified in Table 3 and shown in Figure 11.

An initial concern in the study was the possibility that dyes introduced into the Phase 1 Dye Trace Aquifer might discharge into nearby portions of Waterfall Creek and/or Hangover Creek. Sampling locations were selected to test for this case. Samples were collected more frequently in the first three weeks of the study than later in the investigation.

**Figure 10. Attachment of activated carbon sampler at MW-02.**

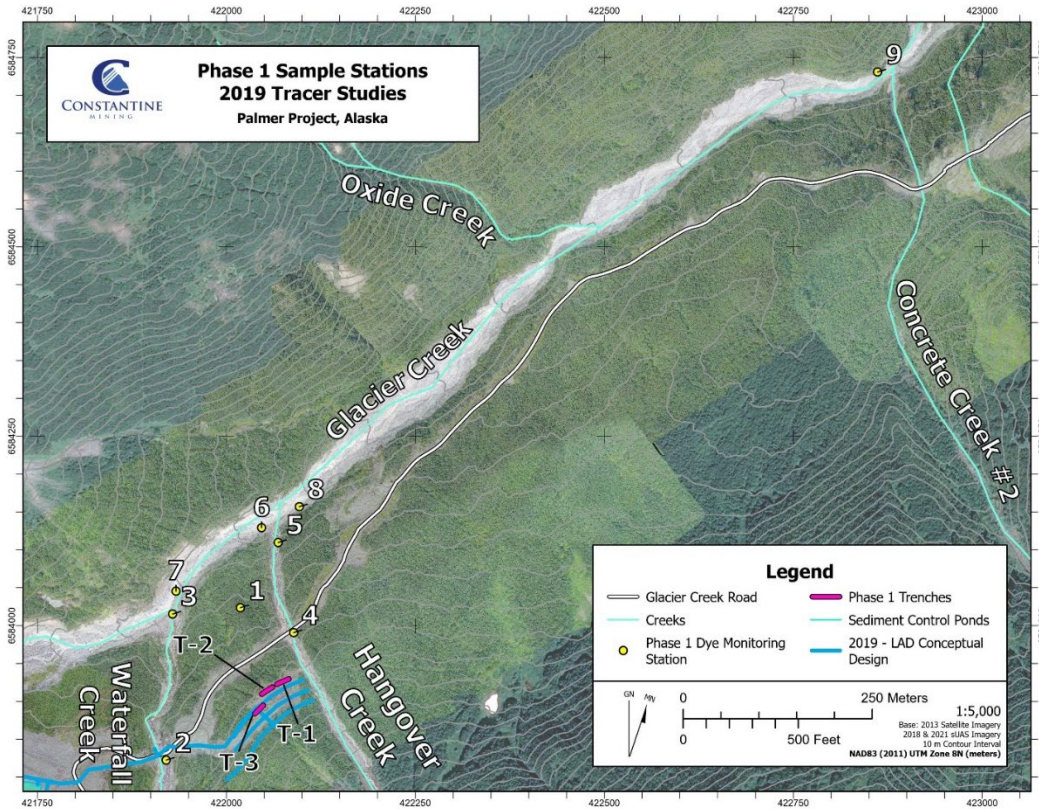


**Table 3. Locations of Phase 1 dye sampling stations.**

<b>Station Number</b>	<b>Station Name</b>	<b>Station Location</b>
1	MW-02 (Monitoring Well 02)	Between Waterfall Creek and Hangover Creek.
2	Waterfall Creek at Access Rd.	Immediately upstream of the access road and upstream of any point where runoff from the access road enters the creek (at Constantine's water quality sampling point P25).
3	Waterfall Creek upstream of Glacier Creek	Immediately upstream of the mouth of Waterfall Creek
4	Hangover Creek at Access Road	Immediately upstream of the access road and upstream of any point where runoff from the access road enters the creek (at Constantine's water quality sampling point P26)
5	Hangover Creek upstream of Glacier Creek	Hangover Creek immediately upstream of the mouth of Hangover Creek
6	Glacier Creek upstream of Hangover Creek	Glacier Creek immediately upstream of the mouth of Hangover Creek
7	Glacier Creek ~100 feet downstream of Waterfall Creek	Glacier Creek at a point where flow from Waterfall Creek has thoroughly mixed with the flow of Glacier Creek.
8	Glacier Creek ~100 feet downstream of Hangover Creek	Glacier Creek at a point where flow from Hangover Creek has thoroughly mixed with the flow of Glacier Creek.
9	Glacier Creek - midpoint	Glacier Creek midpoint downstream (at Constantine's water quality sampling point P27).



Figure 11. Locations of Phase 1 dye sampling stations relative to the 2019 proposed LAD configuration.



### 2.4.5 Study Schedule

The study schedule was designed to provide guidance and was to be used approximately as outlined. It was intended that the actual schedule could be modified for logistical reasons, weather, or other appropriate reasons. Table 4 shows the planned study schedule as well as the schedule actually followed.

## 2.4.6 Dye Analysis Methods

All collected samples were shipped to the Ozark Underground Laboratory at 1572 Aley Lane, Protem, Missouri 65733 for analysis. The dye analysis used a Shimadzu RF-5301 spectrofluorophotometer operated under a synchronous scan protocol. The protocol is specified in the OUL's Procedures and Criteria document attached as Appendix A. Sampling for the Phase 1 tracer study lasted for 275 days after dye introduction and ended on July 30, 2020.

**Table 4. Study schedule, Phase 1 tracer study. Modifications and actual dates of accomplishment are shown in italics. Day numbers 0 through 42 are 2019; Day 275 is July 30, 2020.**

Day Number	Activity
	Place carbon samplers at all sampling locations prior to introducing any dye. Stations 1 through 8 installed 10/28/19; Station 9 installed 10/29 prior to any dye introduction. The trenches were constructed <i>on 10/11/19</i> .
0	Introduce dye and water into all three trenches. <i>All dye and water introduction completed on 10/29/19.</i>
1	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. <i>All work conducted on 10/30/19.</i>
2	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. <i>All work conducted on 10/31/19</i>
4	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. <i>All work conducted on 11/2/19</i>
7	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. <i>All work conducted on 11/5/19.</i>
10	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. <i>All work conducted on 11/8/19.</i>
14	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. <i>All work conducted on 11/12/19.</i>
17	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. <i>All work conducted on 11/15/19.</i>
21	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. <i>All work conducted on 11/19/19.</i>



Table 4 continued. Study Schedule	
Day Number	Activity
28	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. Conduct flow measurement at Stations 8 and 9. While this was the end of the planned study, new samplers were left in place as a precaution, in the event that it appeared prudent to collect samplers at some time in the future. <i>All work conducted on 11/26/19. Constantine elected to extend the test program.</i>
35	Used samplers and grab water samples collected and new samplers placed on 12/3/19. Stream flow measured at Stations 8 and 9.
42	Used samplers and grab water samples collected and new samplers placed on 12/10/19. Stream flow measured at Stations 8 and 9.
104	Used samplers and grab water sample collected and new samplers placed on 02/10/2020 at Station 9. Stream flow measurements dropped due to snow cover. Other stations not accessible.
116	Used samplers and grab water sample collected and new samplers placed on 02/22/2020 at Station 9. Other stations not accessible.
140 – 141	Used samplers and grab water samples collected and new samplers placed on 03/17/2020 and 03/18/2020 at Stations 2 and 9. Other stations not accessible.
174	Used samplers and grab water sample collected and new samplers placed on 04/20/2020 at Station 9. Other stations not accessible.
196	Used samplers and grab water samples collected and new samplers placed on 05/12/2020 at Stations 8 and 9. Other stations not accessible.
212	Used samplers and grab water samples collected and new samplers placed on 05/28/2020 at Stations 1, 2, 8 and 9. Other stations not accessible.
227	Used samplers and grab water samples collected and new samplers placed on 06/12/2020 at Stations 1, 2 and 9. Stream flow measurements dropped due to high (unsafe) flows. Other stations not accessible.
233–234	Used samplers and grab water samples collected and new samplers placed on 06/18/2020 at Station 1 and on 06/19/2020 at Stations 2, 5, 6, 8 and 9. Other stations not accessible.
252	Used samplers and grab water samples collected and new samplers placed on 07/07/2020 at Stations 1, 2, 5, 6, 8 and 9. Other stations not accessible.
275	Used samplers and grab water samples collected on 07/30/2020 at Stations 1, 2, 3, 4, 5, 6, and 8. Other stations not accessible.

One carbon sampler from each sampling location was analyzed for each round of sampling. Extra carbon samplers were stored in the event they might be needed. Duplicates were analyzed for at least 5% of total samples.

If dye was detected in a carbon sampler from a station, then the water samples from that station for the beginning and end of the period that the carbon sampler was in place were also analyzed. All water samples are pH adjusted to a pH of greater than 9.5 prior to analysis; the approach is specified in Appendix A and does not change the volume of the sample. The Shimadzu RF-5301 analysis determines the emission peaks and concentrations of dye present in the samples.

The OUL has established normal acceptable emission fluorescence wavelength ranges for each of the dyes described in this document. These values are derived from actual groundwater tracing studies conducted by the OUL. The range equals mean values plus and minus two standard deviations.

The detection limits are based upon concentrations of dye necessary to produce emission fluorescence peaks where the signal to noise ratio is 3. The detection limits are realistic for most field studies since they are based upon results from actual field samples rather than being based upon values from spiked samples in a matrix of reagent water or the elutants from unused activated carbon samplers. In some cases, detection limits may be smaller than reported if the water being sampled has very little fluorescent material in it. In some cases, detection limits may be greater than reported; this most commonly occurs if the sample is turbid due to suspended material or a coloring agent such as tannic compounds. Turbid samples are typically allowed to settle, centrifuged, or, if these steps are not effective, diluted prior to analysis.

The normal emission wavelength ranges and detection limits for eosine and fluorescein when analyzed on the OUL's RF-5301 are shown in Table 5.

**Table 5. RF-5301 Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein and eosine in water and elutant samples.**

Fluorescent Dye Mixture	Normal Acceptable Emission Wavelength Range (nm)		Detection Limit (ppb)	
	Elutant	Water	Elutant	Water
Fluorescein	514.1 to 519.2	505.9 to 509.7	0.025	0.002
Eosine	539.3 to 545.1	532.5 to 537.0	0.050	0.015

Note: Detection limits based on as-sold weight of the dye mixtures used by the OUL.

The OUL has established the following criteria for determining positive fluorescein dye detections. For determining fluorescein dye detections in elutants from charcoal samplers the following criteria apply:

**Criterion 1.** There must be at least one fluorescence peak in the range of 514.1 to 519.2 nm in the sample.

**Criterion 2.** The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. The fluorescein detection limit in elutant samples is 0.025 ppb, thus this dye concentration limit equals 0.075 ppb.

**Criterion 3.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

**Criterion 4.** The shape of the fluorescence peak must be typical of fluorescein. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the narrower and symmetrical fluorescence peaks typical of fluorescein. In addition, there must be no other factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work.

For determining fluorescein dye detections in water samples, the following criteria apply:

**Criterion 1.** In most cases, the associated charcoal samplers for the station should also contain fluorescein dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

**Criterion 2.** There must be no factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work. The fluorescence peak should generally be in the range of 505.9 to 509.7 nm.

**Criterion 3.** The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our fluorescein detection limit in water samples is 0.002 ppb, thus this dye concentration limit equals 0.006 ppb.

**Criterion 4.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

The OUL has established the following criteria for determining positive eosine dye detections. For determining eosine dye detections in elutants from charcoal samplers the following criteria apply:

**Criterion 1.** There must be at least one fluorescence peak in the range of 539.3 to 545.1 nm in the sample.

**Criterion 2.** The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. The eosine detection limit in elutant samples is 0.050 ppb, thus this dye concentration limit equals 0.150 ppb.

**Criterion 3.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

**Criterion 4.** The shape of the fluorescence peak must be typical of eosine. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of eosine. In addition, there must be no other factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work.

For determining eosine dye detections in water samples the following apply:

**Criterion 1.** In most cases, the associated charcoal samplers for the station should also contain eosine dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

**Criterion 2.** There must be no factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work. The fluorescence peak should generally be in the range of 532.5 to 537.0 nm.

**Criterion 3.** The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our eosine detection limit in water samples is 0.015 ppb, thus this dye concentration limit equals 0.045 ppb.

**Criterion 4.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

#### 2.4.7 Flow Rate Measurements in Glacier Creek

Streamflow was measured at Stations 8 and 9 in Glacier Creek, concurrent with dye sample collections. Measurement of various hydrologic parameters during dye tracing studies is critical as it provides important data on hydrologic conditions for which the results of the tracer study are representative. If conditions change significantly from those under which the test was conducted, the results may no longer be representative. Additionally, streamflow measurements are critical in estimating the magnitude of dilution, in surface waters, during the period of dye detections.

Streamflow measurements were made manually with a Hach F950 flowmeter, and measured at 60 percent water depth with an automatic top-setting wading rod along a transect perpendicular to streamflow. Multiple measurements at vertical cross sections were made; the total number and spacing of measurements depended on stream width at the time of data collection. Data were recorded on field forms. Data collected included stream depth, width, and velocity. Total instantaneous discharge was calculated using methods described in USDA Forest Service's Stream Inventory Handbook. Stream flow measurements are found in the "Results" portion of this study.

Streamflow measurements were made in the event that dye reached Glacier Creek. If dye reached this stream, the amount of dye in the creek could be estimated by simple mass balance

calculations. The amount of dye introduced into the trenches is known. The amount of dye in the stream (if present at detectable concentrations) would be calculated from the concentration of dye measured in the grab water samples collected at stations where it was present and streamflow measurements. No dye was detected in any water samples from the Phase 1 Study.

#### **2.4.8 Precipitation Measurements**

Hourly precipitation during the study period was measured at a site in Glacier Creek Valley (near the Glacier Creek Laydown). The resulting data are included in Appendix C.

### **3. Phase 2 Tracer Study**

Following Phase 1 of the dye tracer study, Constantine Mining requested an additional dye tracer study be conducted in an area east of Hangover Creek and east of the Phase 1 tracer study. The purpose of the Phase 2 tracer study was to better understand the groundwater flow behavior in the area of this proposed 2022 configuration of the Lower Diffuser.

#### **3.1 Hydrogeological Setting**

The Phase 2 tracer study was conducted east of Hangover Creek and to the east and southeast of the dye introduction trenches used for the Phase 1 tracer study. The hydrogeology in the region east of Hangover Creek is similar to that described in Section 2.1. In particular, the subsurface tested during the Phase 2 tracer study is comprised of elongated lenses of poorly sorted mudflow deposits with somewhat to moderately sorted alluvial deposits creating an alluvial sediment deposit imposed on the mudflow deposits (Tundra, 2020). No monitoring wells have been installed in the area east of Hangover Creek at the time of the study. A subsequent site investigation conducted by KCB Consultants Ltd. installed 12 boreholes throughout the Phase 2 tracer study area. The overburden stratigraphy east of Hangover Creek was described to be very similar to that found by BCG throughout the Phase 1 tracer study area. A detailed description of the individual stratigraphic units that were identified is described by KCB Consultants Ltd. (2022). These overburden deposits are underlain by basalt bedrock (KCB Consultants Ltd., 2022).

Detailed hydraulic testing of both the overburden drill holes and monitoring wells were completed as a part of Constantine's 2021 Site Investigations. Representative hydraulic conductivity estimates for the twelve new boreholes is described by KCB Consultants Ltd. (2022).

Similar to the sediments described within the Phase 1 Study area, the alluvial and colluvial deposits located within the Phase 2 Study area are 165 - 210 feet thick (Logic Geophysics, 2021). The results of the geophysical survey were subsequently confirmed via overburden drilling following the Phase 2 study (ranging from 167 to 262 feet deep, as reported in the KCB Consultants Ltd. 2022 Report).

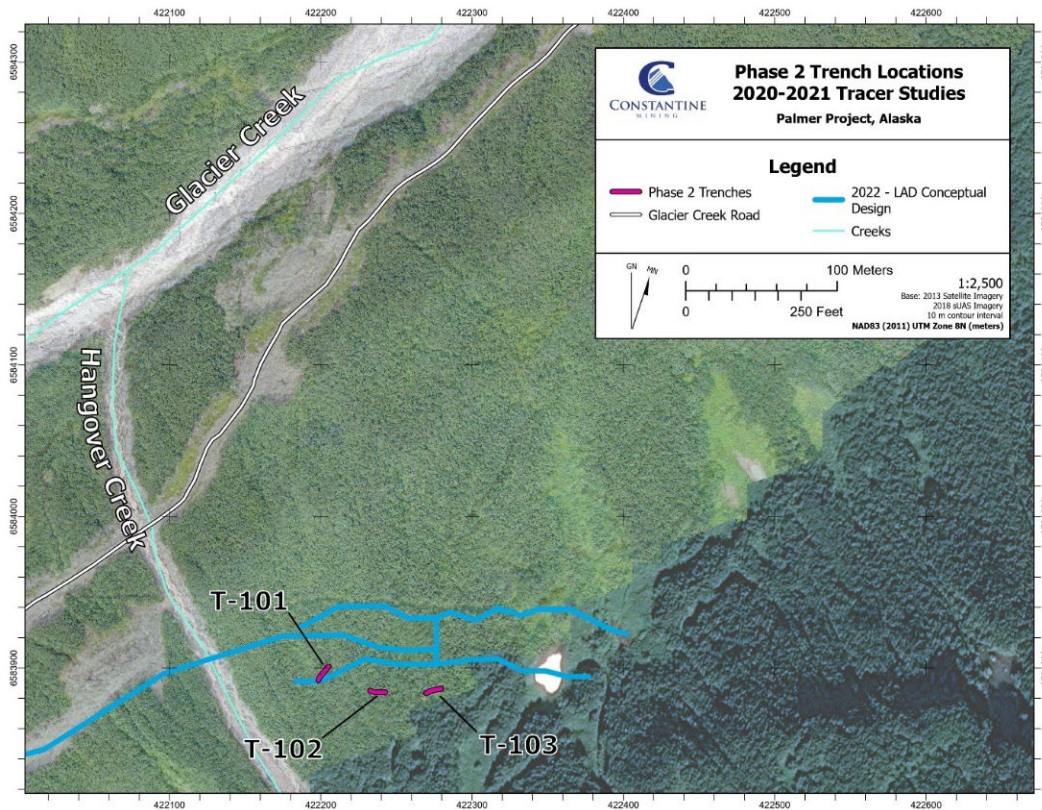
### **3.2 Phase 2 Dye Trace Aquifer**

The 2020 dye introductions for the Phase 2 tracer study were located adjacent to the high gradient Phase 1 Dye Trace Aquifer. The new LAD Diffuser will now be entirely east of Hangover Creek, and contained entirely within the Phase 2 Dye Trace Study Area. In this discussion we will call the aquifer that would be impacted by the treated wastewater disposed in the proposed 2022 LAD Diffuser configuration, the Phase 2 Dye Trace Aquifer.

At the time of the study, there were no monitor wells in the new proposed Study Area. Since the completion of the study, the 2021 site investigation report describes an additional twelve monitoring wells that were installed throughout the Phase 2 Dye Trace Aquifer, described above. The water table elevations throughout the Phase 2 Dye Trace Aquifer range from about 70 feet below ground surface near the dye introduction trenches to about 30 to 50 feet in the proximity of Glacier Creek (KCB Consultants Ltd., 2022). Given the similarity in subsurface sediments and water table elevations, the same storage capacity of 18% estimated in Section 2.2, is used as the estimated storage potential for the Phase 2 Dye Trace Aquifer.

Results from the Phase 1 tracer study demonstrated that Hangover Creek did not provide an eastern boundary for the Phase 1 Dye Trace Aquifer. As a result, sampling stations for the Phase 2 Trace Study were extended further down the Glacier Creek basin than those used for the Phase 1 study.

Figure 12. Location of Phase 2 dye introduction trenches T-101, T-102, and T-103.



### 3.3 Objectives of the Phase 2 Dye Tracing Study

The study plan for this investigation was prepared by the OUL and dated August 17, 2020 (Aley, 2020). Identified objectives for the study were:

- To develop a general understanding of groundwater movement downgradient of the proposed location of the 2022 LAD's Lower Diffuser configuration by conducting a groundwater tracing study, located entirely east of Hangover Creek.
- To determine, with the introduction of a total of about 15,000 gallons of water and dye into trenches in the 2022 Lower Diffuser configuration, if there is a hydrologic connection with Hangover Creek and/or Glacier Creek.
- If there is, to determine the approximate travel time for first dye arrival at creek sampling points, and to determine the approximate travel time for peak concentrations to arrive at creek sampling points.
- To determine into which stream segments this water discharges (assuming it does).
- To determine which cell of the 2022 Lower Diffuser configuration is reporting to surface water (assuming it does)
- To quantify the concentration of introduced dye(s) in Glacier Creek (assuming it reports to surface water).



### 3.4 Phase 2 Methods

#### 3.4.1 Construction of Trenches for Dye and Water Introductions

Three additional dye and water introduction trenches were constructed in the proposed LAD expansion area east of Hangover Creek. All three trenches followed the same methodology used in the Phase 1 tracer study as described in Section 2.4.1. The Phase 2 tracer study trenches were generally located along the 590-meter contour line (see Figure 12). Each trench was 10 to 11 feet deep (on the uphill side), and approximately 30 feet long at the bottom and 45 inches wide at the bottom (Table 6). The study plan (Aley, 2020) specified that each trench would be about 30 feet long, about three feet wide, and at least 8 feet deep. This requirement was met.

**Table 6. Phase 2 Dye Trace trench dimensions.**

Trench	Depth (ft)	Length (ft)	Width (in)
Trench T-101	10	30	45
Trench T-102	10	30	45
Trench T-103	11	29	45

Dimensions of bottom of trench

Trench T-101 was the nearest of the three pits to Hangover Creek and Infiltration Test Pit 35 (ITP-35). Tundra (2021) created a horizontal geologic log of the trench that described the northeastern 7 feet of the trench as: gray, moderately sorted and imbricated, sub-angular to moderately rounded; 5% boulders, 25% cobbles, 35% gravel, 30% sand, and 5% silt and clay material. The southwestern 23 feet was described by Tundra (2021) as gray, poorly sorted, weakly imbricated, sub-angular to moderately rounded; 20% boulders, 20% cobbles, 20% gravel, 20% sand, and 20% silt and clay material. Trench T-101 was used for eosine dye introduction.

Trench T-102 was located southeast of Trench T-101 and was between the 590 m and 600 m contour lines. The horizontal geologic log by Tundra (2021) described the trench materials as gray, moderately poorly sorted, moderately imbricated, sub-angular; 10% boulders, 25% cobbles, 30% gravel, 30% sand, 5% silt and clay (<clay). This trench was used for a fluorescein dye introduction.

Trench T-103 was located approximately 120 feet east of Trench T-102 and at a similar elevation. Tundra (2021) described the trench materials as gray, moderately imbricated and sorted, sub-angular to sub-rounded, 10% boulder (to 2 meters), 25% cobbles, 30% gravel, 30% sand, 5% silt and clay (<clay). Trench T-103 was used for a fluorescein dye introduction.

Coordinates and ground surface elevations at the centers of each trench are shown in Table 7

**Table 7. Locational information on Phase 2 dye introduction trenches. Coordinates and ground surface elevations are the center of each dye introduction trench. Coordinates are NAD 83, UTM Zone 8N. Measurements from Tundra (2020).**

Trench	Easting	Northing	Elevation (meters)	Elevation (feet)
Trench T-101	422,201	6,583,896	589	1,932.4
Trench T-102	422,238	6,583,884	597	1,958.7
Trench T-103	422,275	6,583,885	597	1,958.7

### 3.4.2 Tracer Dyes and Quantities Used

The dyes used for the Phase 2 tracer study were mixtures of fluorescein and eosine. They were identical mixtures to those used in the Phase 1 tracing work and their characteristics were described earlier in this report. Since likely groundwater travel distances were greater than for the Phase 1 tracer study dye quantities used in each trench for the Phase 2 tracing were three times greater than the quantities used in the Phase 1 study.

Eighteen pounds of eosine dye mixture was introduced into Trench T-101. Nine pounds of fluorescein dye mixture was introduced into Trench T-102 and another 9 pounds was introduced into Trench T-103 (Figure 13). Both dyes were mixtures containing approximately 75% dye equivalent and the remainder a diluent used as a standardizing agent and to assist in the mixing of dye with water. The diluent in both dye mixtures was sodium sulfate, commonly known as Glauber's Salt. All dye concentrations shown in this report are based on the as-sold mixtures of the dyes.

Figure 13. Fluorescein dye introduction into Trench T-102.



The dye mixtures are powders that are mixed with water prior to introduction for groundwater tracing. The dyes were shipped from the OUL to Haines in four Nalgene® carboys; two carboys contained eosine and two contained fluorescein. Each carboy was packed inside a separate cooler. Water was added to each carboy and mixed with the dye at an off-site location (the Big Nugget camp). After dyes were introduced into the trenches, the carboys and their shipping coolers were returned to the OUL.

### **3.4.3 Introduction of Tracer Dyes and Water**

All three trenches for Phase 2 tracer study were excavated in mid-August, 2020 and dye and water were introduced on August 23<sup>rd</sup> and 24<sup>th</sup>, 2020 (Tundra, 2021). The first set of activated carbon samplers for detecting tracer dyes was placed on August 23<sup>rd</sup> prior to any introduction of dye and water into trenches. All test water was pumped out of Waterfall Creek and transported through a system of hoses to the trenches. Water and dye introductions proceeded from Trench T-101 to Trench T-102 and then to Trench T-103.

### **3.4.4 Sampling for Tracer Dyes**

Sampling for the dyes in both of the tracer studies was conducted using activated carbon samplers and grab samples of water. Detailed specifics on the sampling methods and analysis methods, including QA/QC considerations, are outlined in Appendix A, the OUL's Procedures and Criteria document. The OUL trained personnel who would do the sampling in proper sampling methods.

Each carbon sampler contains 4.25 grams of activated charcoal. Manufacturer's data indicates that the carbon in each sampler has a surface area in excess of one acre. Fluorescein and eosine dyes are readily adsorbed onto activated carbon when the sampler is anchored in the flow of a stream, spring, or monitoring well. Carbon samplers are continuous samplers for the presence of tracer dyes including fluorescein and eosine and accumulate dye from the passing water. For streams and springs, the dye concentration recovered from carbon samplers during laboratory analysis is routinely at least two orders of magnitude greater than the mean concentration in the passing water for carbon samplers in place for periods of about a week (Aley, 2017).

Two independently anchored carbon samplers were placed at each stream sampling point during this tracing study.

Carbon samplers were periodically collected and new samplers placed at all sampling locations. Each time carbon samplers were collected a grab sample of water was also collected from the sampling station. Sampling protocols are specified in Appendix A. Sampling stations used for this study are identified in Table 8 and shown in Figure 14.

### **3.4.5 Study Schedule**

The study schedule was designed to provide guidance and was to be used approximately as outlined. It was intended that the actual schedule could be modified for logistical reasons, weather, or other appropriate reasons. Table 9 shows the planned study schedule as well as the schedule actually followed.

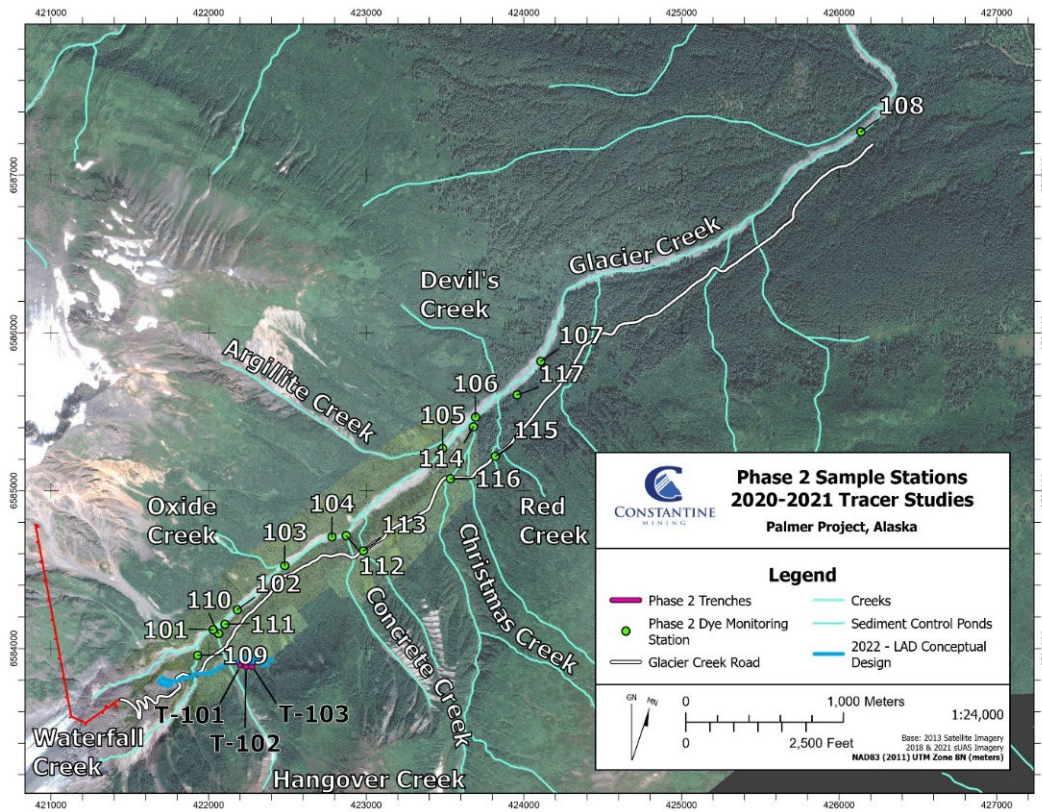
### 3.4.6 Dye Analysis Methods

All collected samples were shipped to the Ozark Underground Laboratory at 1572 Aley Lane, Protem, Missouri 65733 for analysis. The dye analysis used a Shimadzu RF-5301 spectrofluorophotometer operated under a synchronous scan protocol. The protocol is specified in the OUL's Procedures and Criteria document attached as Appendix A.

**Table 8. Locations of dye sampling stations for Phase 2 Dye tracer study.**

Station Number	Station Name	Station Location
101	GC U/S of Hangover	Glacier Creek upstream of Hangover Creek (Station 6 of Phase 1 Study)
102	GC D/S Hangover	Glacier Creek downstream of Hangover Creek (Station 8 of Phase 1 Study)
103	GC near Oxide	Glacier Creek (near Oxide Creek)
104	GC U/S Concrete	Glacier Creek upstream of Concrete Creek #2 (Station 9 of Phase 1 Study)
105	GC U/S Xmas	Glacier Creek upstream of Christmas Creek
106	GC D/S Xmas	Glacier Creek downstream of Christmas Creek
107	GC D/S Red	Glacier Creek downstream of Red Creek
108	GC @ Old Bridge	Glacier Creek at old bridge
109	Waterfall U/S GC	Waterfall Creek upstream of Glacier Creek.
110	Hangover U/S GC	Hangover Creek upstream of Glacier Creek
111	Seep D/S Hangover /GC Conf.	Seep downstream of Hangover/Glacier Creek confluence
112	Concrete #2 U/S GC	Concrete Creek #2 upstream of Glacier Creek
113	Concrete#1 Access Rd	Concrete Creek #1 at access road
114	Xmas U/S GC	Christmas Creek upstream of Glacier Creek
115	Xmas East Branch @ Rd	Red Creek at access road
116	Xmas West Branch @ Rd	Christmas Creek, western branch at access road (main bridge)
117	Red U/S GC	Red Creek upstream of Glacier Creek

Figure 14. Locations of Phase 2 dye sampling stations.



**Table 9. Phase 2 study schedule. Modifications and actual dates of accomplishment are shown in italics. Day numbers 0 through 130 are 2020; Day 350 is August 8<sup>th</sup>, 2021.**

Day Number	Activity
	Place carbon samplers at all sampling locations prior to introducing any dye. Stations 105, 106, 107, 113, 114, 115, 116, 117 installed 8/17/2020; Stations 102, 103, 104, 108, 109, 110, 111, 112 installed 8/19/2020; Station 101 installed 8/20/2020 prior to any dye introduction.
0 – 1	Introduce dye and water into all three trenches. Dye and water introduction at trench T-101 was completed on 8/23/2020. Dye and water introduction at trenches T-102 and T-103 was completed on 8/24/2020. Fresh carbon samplers were placed at all stations prior to dye introduction.
4	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 8/27/2020.</i>
8	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 8/31/2020.</i>
15	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 9/7/2020.</i>
22	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 9/14/2020.</i>
29	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 9/21/2020.</i>
39	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 10/1/2020.</i>
44	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 10/6/2020.</i>
53	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 10/15/2020.</i>
64 – 65	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 10/26/2020 and 10/27/2020.</i>
78 – 79	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 11/9/2020 and 11/10/2020.</i>
92 – 93	Collect used carbon samplers and grab samples of water from all sampling locations. Place new carbon samplers at all stations. <i>All work conducted on 11/23/2020 and 11/24/2020.</i>
116 – 118	Collect used carbon samplers and grab samples of water from stations 103 – 108, 112, 114, 116, and 117. Place new carbon samplers at all stations. <i>All work conducted between 12/17/2020 and 12/19/2020.</i>
134 – 135	Collect used carbon samplers and grab samples of water from stations 103 – 108, 112, 114, 116, and 117. Place new carbon samplers at all stations. <i>All work conducted on 1/4/2021 and 1/5/2021.</i>
349 – 350	Collect used carbon samplers and grab samples of water from stations 101, 103, 104, 106, 107, 108, 109, 110, 112, 114 – 117. Place new carbon samplers at all stations. <i>All work conducted on 8/7/2021 and 8/8/2021.</i>



One of the two carbon samplers from each sampling location was analyzed for each round of sampling. Extra carbon samplers were stored in the event they might be needed. Duplicates were analyzed for at least 5% of total samples.

If dye was detected in a carbon sampler from a station, then the second carbon sampler was analyzed and the water samples from that station for the beginning and end of the period that the carbon sampler was in place would also be analyzed. To maximize fluorescence intensity all water samples are pH adjusted to a pH of greater than 9.5 prior to analysis. This approach is specified in Appendix A and does not change the volume of the sample. The Shimadzu RF-5301 analysis determines the emission peaks and concentrations of dye present in the samples.

The OUL has established normal acceptable emission fluorescence wavelength ranges for each of the dyes described in this document. These values are derived from actual groundwater tracing studies conducted by the OUL. The range equals mean values plus and minus two standard deviations.

The detection limits are based upon concentrations of dye necessary to produce emission fluorescence peaks where the signal to noise ratio is 3. The detection limits are realistic for most field studies since they are based upon results from actual field samples rather than being based upon values from spiked samples in a matrix of reagent water or the elutants from unused activated carbon samplers. In some cases, detection limits may be smaller than reported if the water being sampled has very little fluorescent material in it. In some cases, detection limits may be greater than reported; this most commonly occurs if the sample is turbid due to suspended material or a coloring agent such as tannic compounds. Turbid samples are typically allowed to settle, centrifuged, or, if these steps are not effective, diluted prior to analysis.

The normal emission wavelength ranges and detection limits for eosine and fluorescein when analyzed on the OUL's RF-5301 were shown earlier in Table 5. They apply to both the Phase 1 and Phase 2 tracer studies. In addition, criteria for determining positive fluorescein and eosine dye detections were the same for both Phase 1 and Phase 2 studies; they were shown earlier in the description of methods for the Phase 1 tracer study.

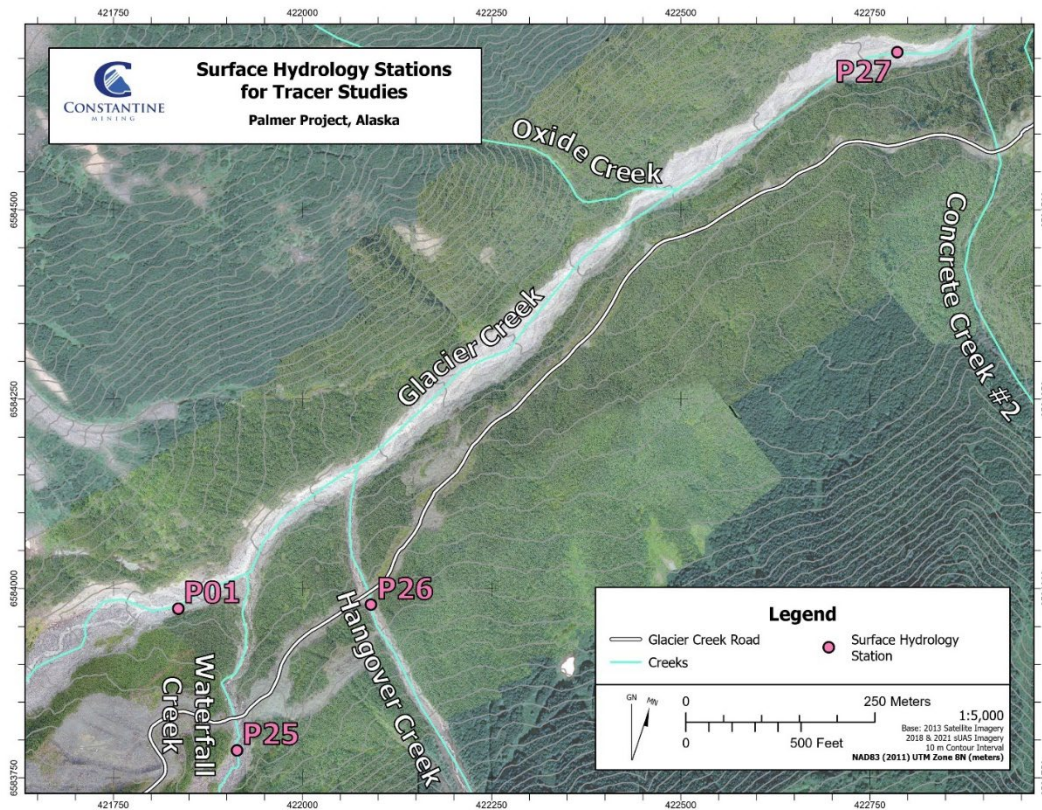
### **3.4.7 Flow Rate Measurements in Glacier Creek**

Streamflow rates were measured when accessible at stations along Glacier Creek and in selected tributaries as a part of Constantine's long-term, quarterly Surface Water Quality Monitoring Program. Again, measurement of various hydrologic parameters during dye tracing studies provides important data on hydrologic conditions for which the results are representative. If hydrological conditions change significantly from those under which the test was conducted, the results may no longer be representative.



Stations for which streamflow measurements were taken during the Phase 2 tracer study included P01, P25, P26, and P27 (Figure 15). Both P01 and P27 are stations on Glacier Creek and P25 and P26 are tributary stations (i.e., Waterfall Creek and Hangover Creek, respectively).

Figure 15. Map showing streamflow measurement stations along Glacier Creek and tributaries.



### 3.4.8 Precipitation Measurements

Hourly precipitation during the study period was measured at a site in Glacier Creek Valley (near the Glacier Creek Laydown). The resulting data are included in Appendix C.

## 4. Results

### 4.1 Infiltration Rates in the Tracer Study Areas

Infiltration testing was conducted in both the Phase 1 and Phase 2 tracer study areas. Constantine Mining (2019, page 8) provided the following information on infiltration rates in the Phase 1 tracer study area. The data are based on detailed testing of two test pits.

“Based on preliminary infiltration rates observed during testing, only Hangover Creek test pits were selected for detailed analysis. The measured infiltration rate for Hangover Area soils during infiltration testing was  $3.2 \times 10^{-4}$  m/s (45 in/hr) at a water depth of 2.7 m (8.9 ft). The results were consistent at both test pits.”

The three trenches constructed for the Phase 1 introduction of water and tracer dyes provided a larger scale test of infiltration rates. Five thousand gallons of water was added to each of the three dye introduction trenches and the time required for all introduced water to disappear from the trenches was recorded. The surface area at the bottom of each trench was approximately 112.5 square feet and the trench bottoms were level. 5,000 gallons of water = 668 cubic feet = 71.28 inches of water depth over surface area of 112.5 square feet. The mean depth of water in the trenches during the tracer study was assumed to equal the maximum estimated depth of water divided by 2. Infiltration rates observed in the three trenches for the Phase 1 study were as follows:

- Trench T-1. All water infiltrated within 3.42 hours. The mean infiltration rate was 20.8 inches/ hour with a mean head of 1.2 feet.
- Trench T-2. All water infiltrated within 1.70 hours. The mean infiltration rate was 41.9 inches/ hour with a mean head of 0.58 feet.
- Trench T-3. All water infiltrated within 1.38 hours. The mean infiltration rate was 51.7 inches/ hour with a mean head of 0.5 feet.

The mean infiltration rate for the three trenches in the Phase 1 Tracer Area was 38.1 inches per hour with a mean head of 0.76 feet. This rate with a mean head of 0.76 feet would undoubtedly have yielded a rate of at least 45 inches per hour with a head of 8 feet. The rates we measured varied by a factor of 2.5 between the highest and lowest rates of infiltration in the trenches. This suggests reasonably consistent infiltration rates in the portions of the Phase 1 Study Area tested.

Infiltration testing was conducted at six test pits in the Phase 2 tracer study area (Tundra Consulting, 2020). Tundra (2020) provided the following description of the infiltration rates in this area:

“The  $K_s$  value resulting from tests in the two areas [Phase 1 and Phase 2 Study Areas] have similar median values, but the testing in 2020 indicates that the  $K_s$  of the area east of

Hangover Creek [Phase 2 area] is much more variable. The median  $K_s$  value of the area tested in 2020 is 3.8 m/day ( $4.4 \times 10^{-5}$  m/s; 6 in/hr). If the furthest east portion of the study area is excluded from the LAD footprint, the median  $K_s$  for the LAD would be approximately 7.4 m/day ( $8.6 \times 10^{-5}$  m/s; 12 in/hr) based on the results of this study.”

In addition to infiltration measurements, twelve new boreholes were installed throughout the Phase 2 Dye tracer study area from which representative hydraulic conductivity estimates were measured within both the unsaturated and saturated zone of the aquifer (See KCB Consulting Ltd., 2022, Table 2.10 and Table 2.11). Incorporating hydraulic conductivity measurements from both the saturated and unsaturated zones provide valuable insights into hydraulic properties controlling fate and transport as the discharge system relies on the entire aquifer. The mean representative hydraulic conductivities for all stratigraphic units described in the Phase 2 Dye tracer study area were all very similar with values in the range of  $1 \times 10^{-4}$  m/s (8.64 m/day).

#### 4.2 Groundwater Gradients in Tracer Study Area

There is a steep gradient in the aquifer beneath the dye introduction trenches on the hillside slope in the Phase 1 tracer study area. The gradient is toward Glacier Creek and is roughly similar to the slope of the overlying topography. This relationship is shown by surface and water table elevations in Monitoring Wells-01 and -02 shortly after their construction. The distance between the two wells is about 525 feet. The values (converted to feet) in Table 10 are from Teller (2018).

**Table 10. Monitoring well and groundwater elevation data.**

Feature	MW-01	MW-02	Difference
Surface Elevation	1,891.4 ft.	1,749.5 ft.	141.9 ft.
Static Water Level	1,844.3 ft.	1,698.1 ft.	146.2 ft.
Depth to Water	47.1 ft.	51.4 ft.	

Using the above values, the mean groundwater gradient between these two wells was 28%. This estimate agrees well with the most recent groundwater contour map (See KCB Consultants Ltd., 2020), resulting in a groundwater gradient of about 0.25 within the same portion of the Discharge Aquifer. The hydraulic gradient throughout the Phase 2 Study Area was about 0.22, based on the most recent water level measurements reported by KCB Consultants Ltd. (2022), with flow oriented down-valley towards the northeast.

### 4.3 Dye Tracing Results

Appendix B provides all dye analysis results.

#### 4.3.1 Phase 1 Results

Eosine dye, from Trench T-3, Cell 1, was detected in the activated carbon samplers in place at Station 9 (Glacier Creek mid-point) during the following sampling periods:

- December 10, 2019 to February 10, 2020. Eosine concentration in sampler elutant was 0.572 ppb in one sampler and 0.188 ppb in the second sampler.
- February 10, 2020 to February 22, 2020 -no dye detected.
- February 22, 2020 to March 18, 2020 -no dye detected.
- March 18 to April 20, 2020. Eosine concentration was 0.649 ppb in one sampler. Eosine was not detected in the second sampler.
- April 20 to May 12, 2020. Eosine concentration was 0.134 ppb in one sampler and 0.159 ppb in the second sampler. The peak emission wavelength in the second sampler was at 538.2 nm, which is 1.1 nm shorter than the normally acceptable wavelength range for eosine dye in carbon sampler elutants. In the opinion of the OUL both the samplers for this sampling period were positive for eosine dye.

Sampling for the Phase 1 tracer study was initially planned to last for 28 days after dye introduction (Aley, 2019B). In the opinion of the OUL this study duration was adequate to determine if dye from any of the trenches would quickly move through the groundwater system and discharge into Waterfall Creek and/or Hangover Creek. Near the end of the planned study period no dye had been detected in either Waterfall Creek or Hangover Creek. It should be noted that there was a carbon sampler from Station 4 (Hangover Creek at Access Road) which had a small fluorescence peak in the emission wavelength range of fluorescein dye. However, it did not meet all the criteria for a positive dye result (see Section 2.4.6 for criterion). There was no fluorescence peak in the range of fluorescein dye in the duplicate sampler. There were no similar peaks in any subsequent samples from this location. It is the conclusion of the OUL that no fluorescein dye was detected at Station 4.

At the end of the 28-day planned sampling period weather conditions and the risk of avalanches was such that it was feasible to extend the sampling period. As a result, Constantine and the OUL extended the sampling period to 42 days after dye introduction. No dye from any of the three dye introductions was detected at any sampling stations during the 42 days of sampling after dye introduction. At the end of the 42-day sampling period it was possible to continue sampling at some stations and whenever possible such sampling was completed. All sampling for the Phase 1 tracer study ended after 275 days.

During the Phase 1 tracer study activated carbon samplers were continuously in place at Stations 1, 2, and 9 for the entire 275-day duration of the study, which was from October 28, 2019, to July 30, 2020. Activated carbon samplers were continuously in place for the period

from October 28 to December 10, 2019 at Stations 4 and 7. Samplers were continuously in place at Station 3 for the period from October 28 to December 10, 2019 except for the period from November 19 to December 3, 2019. Sampling ended at Stations 3, 4, and 7 on December 10, 2020. At Station 6 there were no samplers recovered for the period from December 10, 2019 to June 12, 2020. At Station 8 samplers were continuously in place for the entire 275-day duration of the study except for the period from May 28 to June 12, 2020.

Sample testing was periodically interrupted in both studies due to avalanche risk or when sample sites became inaccessible or were buried in snow.

Figure 16 shows the activated carbon samplers collected at Station 9 on Glacier Creek on February 10, 2020. The samplers were anchored in the wire bait cages shown in the photo. The bait cages were in turn anchored in the stream. All stream sampling stations were sampled in similar fashion. Note the strong flow of Glacier Creek in the photo. Discharge of groundwater at temperatures of several degrees Celsius help prevent or at least minimize winter freezing of Glacier Creek within the study area. The OUL finds no data that suggest that freezing temperatures slowed the movement of tracer dyes from the dye introduction trenches to sampling points.

The detection limit for eosine dye in carbon sampler elutants is 0.050 ppb. A grab sample of water was collected at Station 9 on February 10, 2020 at 11:10 hours; no dye was detected in this water sample but this is consistent with the fact that carbon samplers accumulate dye and routinely yield substantially larger dye concentrations than water samples.

Figure 16. Carbon samplers recovered at Station 9 on February 10, 2020.



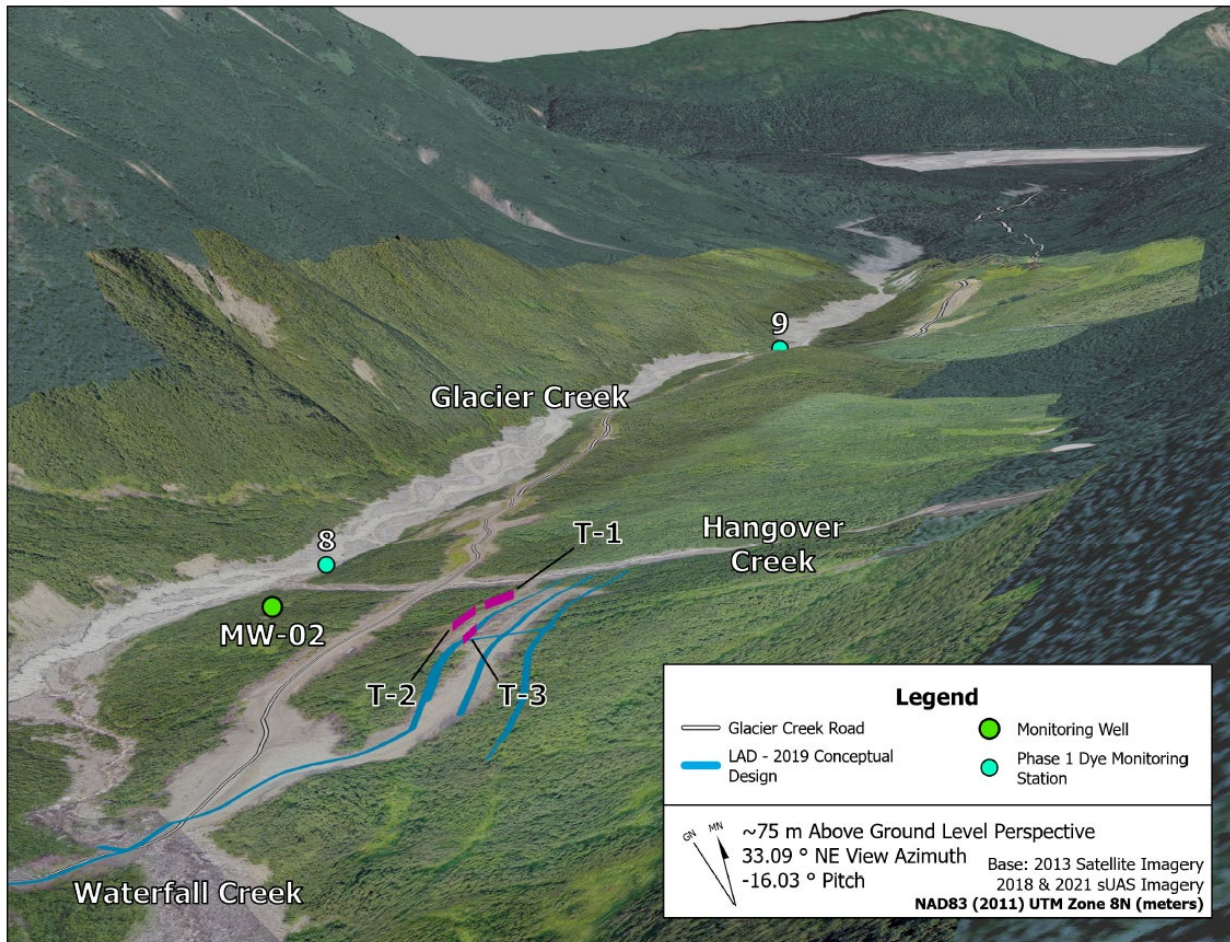
Eosine was detected at Station 9 during three sampling periods. There were no detections of eosine dye at Station 8, which is the first sampling station upstream of Station 9. There were also no detections of eosine dye at any other stations upstream of Station 9. It is the conclusion of the OUL that the only discharge point for eosine dye from the Trench T-3 dye introduction was at one or more points between Stations 8 and 9 (Figure 17). The straight-line distance from the dye introduction point to Station 8 is 935 feet. The straight-line distance from the dye introduction point to Station 9 is 3,900 feet. The flow route taken by the eosine to Station 9 from Trench T-3 is unknown and would be affected by the heterogeneity in the overburden formations.

No eosine was detected at Station 9 after May 12, 2020, in the four subsequent sampling events ending on July 7, 2020. No fluorescein was detected at any test site during the study. Station 9 was also sampled as a part of the Phase 2 tracer study (Station 104). No tracer dyes were detected at any sampling stations during Phase 2 sampling from August 19, 2020 to August 7, 2021.



No eosine or fluorescein was detected in monitor well MW-02 immediately downgradient from the test trenches or from the Hangover Creek testing stations. No dye was detected in any water samples.

Figure 17. Oblique view of the Phase 1 and Phase 2 test Study Areas.



#### **4.3.2 Phase 2 Results**

No dye from any of the three dye introductions was detected at any of the 17 sampling stations throughout the duration of the Phase 2 study. Phase 2 of the tracer study began August 23, 2020 and continued until August 8, 2021, 350 days. This result indicates that either sampling was not conducted for a long enough duration to detect dye breakthrough at the surface water sampling points or dye introduced at the three trenches did not reach Glacier Creek in detectable concentrations. Based on the results of the Phase 1 study and experience in similar settings, a 350-day sampling period was sufficiently long to detect a measurable hydraulic connection, if present, under the testing conditions present throughout the study periods. Given the sampling period duration, the results indicate that the dye introduced at the three trenches did not reach the Glacier Creek in detectable concentrations. This is supported by the groundwater velocities estimated for Eosine in the Phase 1 Study.



#### 4.4 Flow Rate Measurements in Glacier Creek

Flow rates were measured at Stations 8 and 9 on Glacier Creek during the Phase 1 tracer study period when accessible (Figure 11). Station 8 is the upstream station and is located on Glacier Creek downstream of the mouth of Hangover Creek at a point on the stream where flows from upstream points on Glacier Creek and Hangover Creek should be well mixed. Station 9 is the downstream station and is located on Glacier Creek at a point about 2,840 feet downstream of Station 8. Station 9 is at Constantine's Surface Water Quality Monitoring Site P27. There are no tributaries discharging to Glacier Creek from the south side of the creek in the stream segment between Stations 8 and 9, however Oxide Creek is a small tributary on the north side of Glacier Creek between Stations 8 and 9.

Flow rates were measured at Stations P01, P25, P26, and P27 during the Phase 2 tracer study period, when accessible (Figure 15). Station P01 is upstream of both Waterfall Creek and Hangover Creek on Glacier Creek. Station P25 is located near the headwaters of Waterfall Creek. Station P26 is located on Hangover Creek along the same elevation contour as the 2022 LAD. Station P27 is the downstream station and is located on Glacier Creek at a point about 2,840 feet downstream of Station 8. Station P27 is equivalent to Station 9, described above.

The results from the streamflow gaging during Phase 1 and Phase 2 of the study are shown in Table 11 and 12, respectively. Field records for the measurements were reviewed and in the opinion of the OUL the accuracy of the measurements is good.

Table 11 shows that flow rate measurements made on the same dates in late fall / early winter are always greater at Station 9 than at Station 8 and that the mean measured difference is 2.54 cfs. Allowing for an estimated mean flow from Oxide Creek of approximately 0.5 cfs, this suggests a groundwater discharge into Glacier Creek between Stations 8 and 9 under late fall / early winter conditions of about 2 cfs. If we assume groundwater discharges to Glacier Creek from both sides of the creek are equal that suggest a mean winter groundwater discharge of about 1 cfs (448.8 gpm) from the aquifer that would likely include the area of the Phase 2 tracer study. This estimate of groundwater contribution to Glacier Creek may decrease when the water table elevation is at its lowest in early spring season, prior to snowmelt. Measurements of streamflow have not been collected during this period to verify baseflow contribution to Glacier Creek. A more comprehensive dataset on groundwater surface water interactions is currently being developed by Constantine Mining LLC.

Flow rate measurements collected during Phase 2 Study also show that Glacier Creek is a net gaining stream during summer and fall months. Using the streamflow measurements from September 24<sup>th</sup>, 2020, when all of the stations were measured on the same dates, streamflow in Glacier Creek increased between Station P01 and Station P27 by 10.58 cfs, accounting for contributions from Waterfall Creek and Hangover Creek. Allowing for an estimated mean flow from Oxide Creek of approximately 0.5 cfs, this suggests groundwater discharge into Glacier

Creek between Stations P01 and P27 of about 10 cfs during summer and fall months. Again, a more comprehensive dataset on groundwater surface water interactions is currently being developed by Constantine Mining LLC.

**Table 11. Flow rate measurements on Glacier Creek at Stations 8 and 9 for Phase 1 of Dye tracer study (see Figure 9 for station locations). 1 cubic foot/second (cfs) = 448.8 gallons per minute = 1,700 liters/minute.**

Date	Station 8 (cfs)	Station 9 (P27) (cfs)	Difference (cfs)
10/30/2019	12.42	12.76	0.34
10/31/2019	12.99	14.89	1.90
11/2/2019	13.42	18.44	5.02
11/5/2019	12.73	15.12	2.39
11/8/2019	12.57	15.12	2.55
11/12/2019	9.27	11.42	2.15
11/15/2019	15.57	16.84	1.27
11/19/2019	10.66	14.36	3.70
11/26/2019	12.76	16.28	3.52
12/3/2019	9.95	12.14	2.19
12/10/2019	9.84	12.72	2.88
<b>Mean</b>	12.02	14.55	2.54

**Table 12. Flow rate measurements on Glacier Creek and tributaries during the Phase 2 of Dye tracer study. 1 cubic foot/second (cfs) = 448.8 gallons per minute = 1,700 liters/minute.**

Station	Date	Discharge (cfs)
P01	9/24/2020	52.00
P27		71.66
P26		6.00
P25		3.08
P25	11/22/2020	1.11
P01	11/23/2020	9.89
P27		11.84
P25	6/20/2021	23.66

---

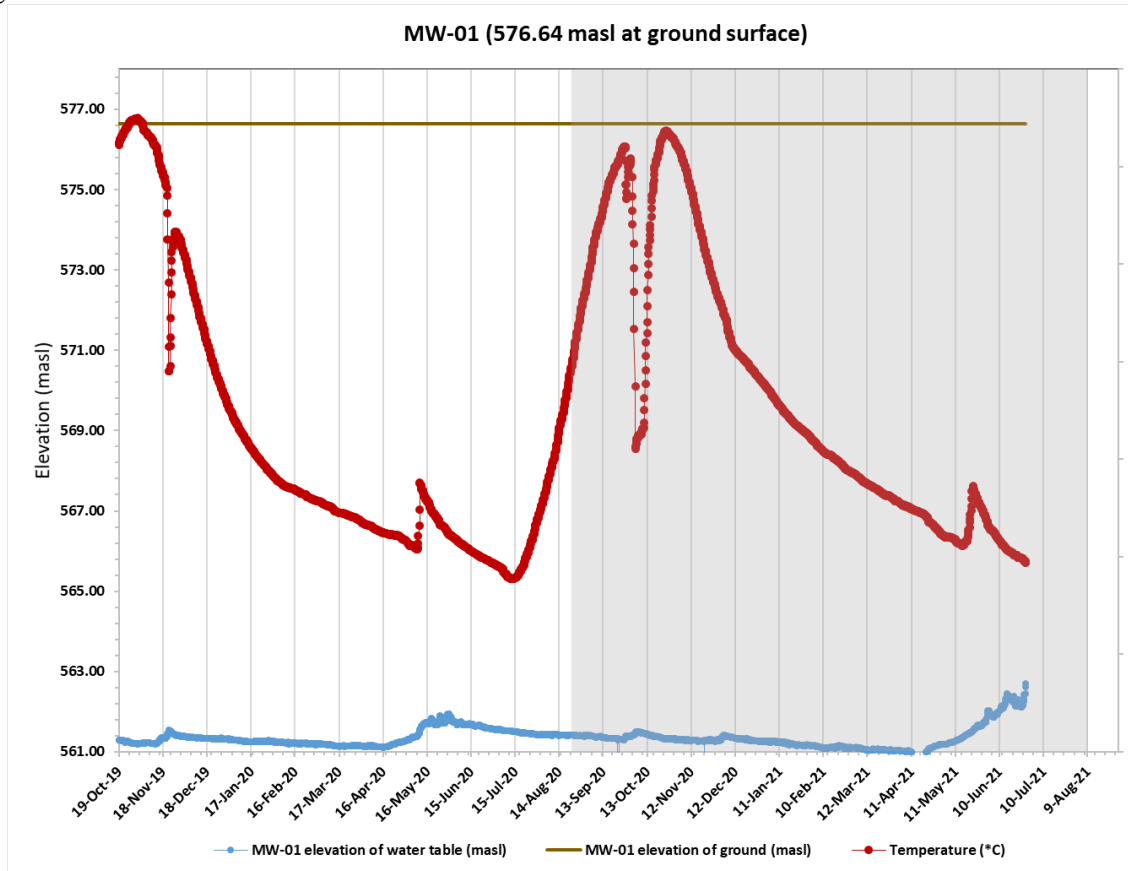
#### **4.5 Water Level and Temperature Measurements in Monitoring Wells**

All three of the monitoring wells (MW-01, MW-02, and MW-03) are equipped with instrumentation that records the elevation of the water table and groundwater temperature four times per day. Figure 18 is a graph of pressure transducer and temperature records from MW-01 from October, 2019 until June, 2021. Figure 19 is a similar graph for MW-02, and Figure 20 is a similar graph for MW-03. All values are metric since this is the way they were recorded. The surface elevation at MW-01 is 576.64 meters (approximately 1,891.4 feet); surface elevation at MW-02 is 533.38 meters (approximately 1,749.5 feet); surface elevation at MW-03 is 547.44 meters (approximately 1,795.6 feet). Based on these data groundwater temperatures are always above freezing.

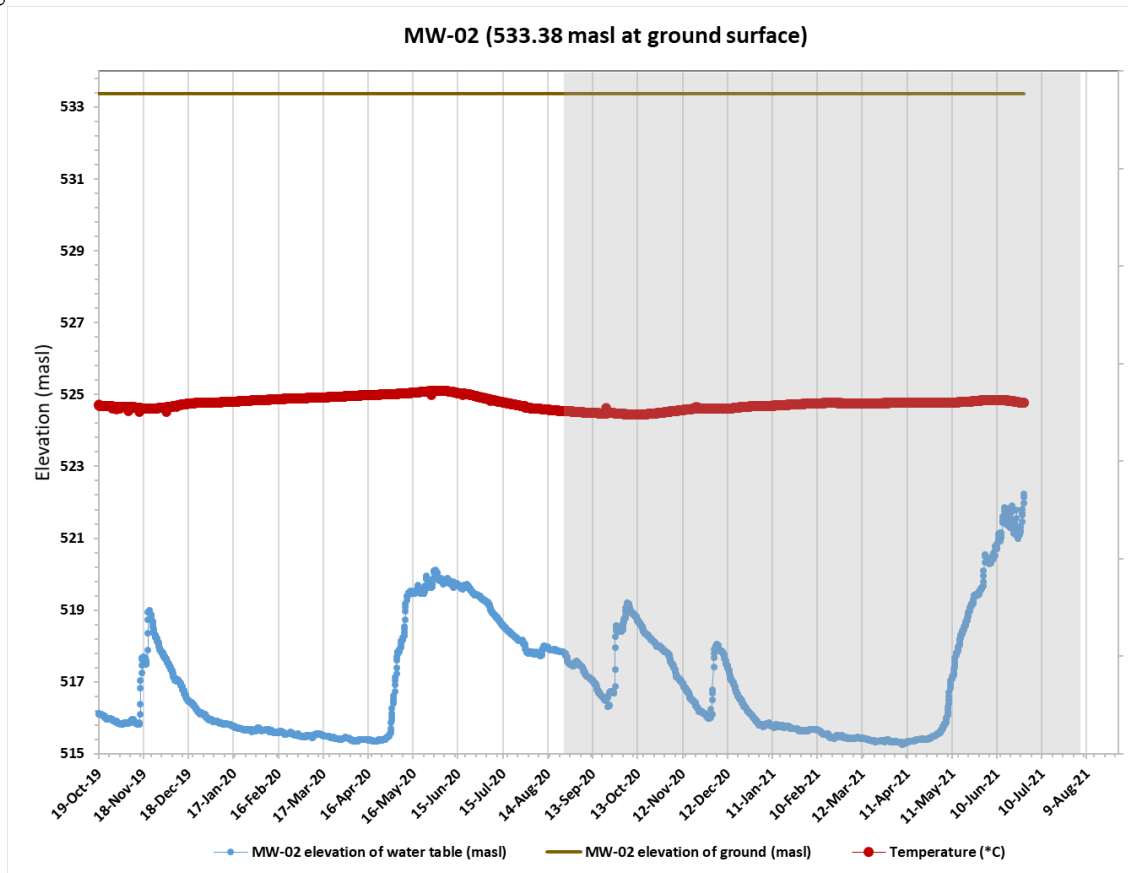
Monitoring Wells 1 and 2 are located at points that are especially relevant to the Phase 1 tracer study area. Water level records from Phase I show that water elevations varied by 0.84 m (2.8 feet) in MW-01, 4.79 m (15.7 feet) in MW-02, and 2.45 meters (8.0 feet) in MW-03. Water well records from Phase II show that water elevations varied by 6.29 m (20.6 feet) in MW-01, 6.96 meters (22.8 feet) in MW-02, and 2.93 meters (9.6 feet) in MW-03. Increases in water table elevations are in response to snow melt and precipitation events. Eosine dye was first detected in activated carbon samplers in place at Station 9 in Glacier Creek for the period from December 10, 2019 to February 10, 2020; this was a period of low water levels in Monitoring Wells 1 and 2.

For both Phase 1 and Phase 2, the lowest temperatures are in July due to snowmelt and the highest temperatures recorded are in September to December.

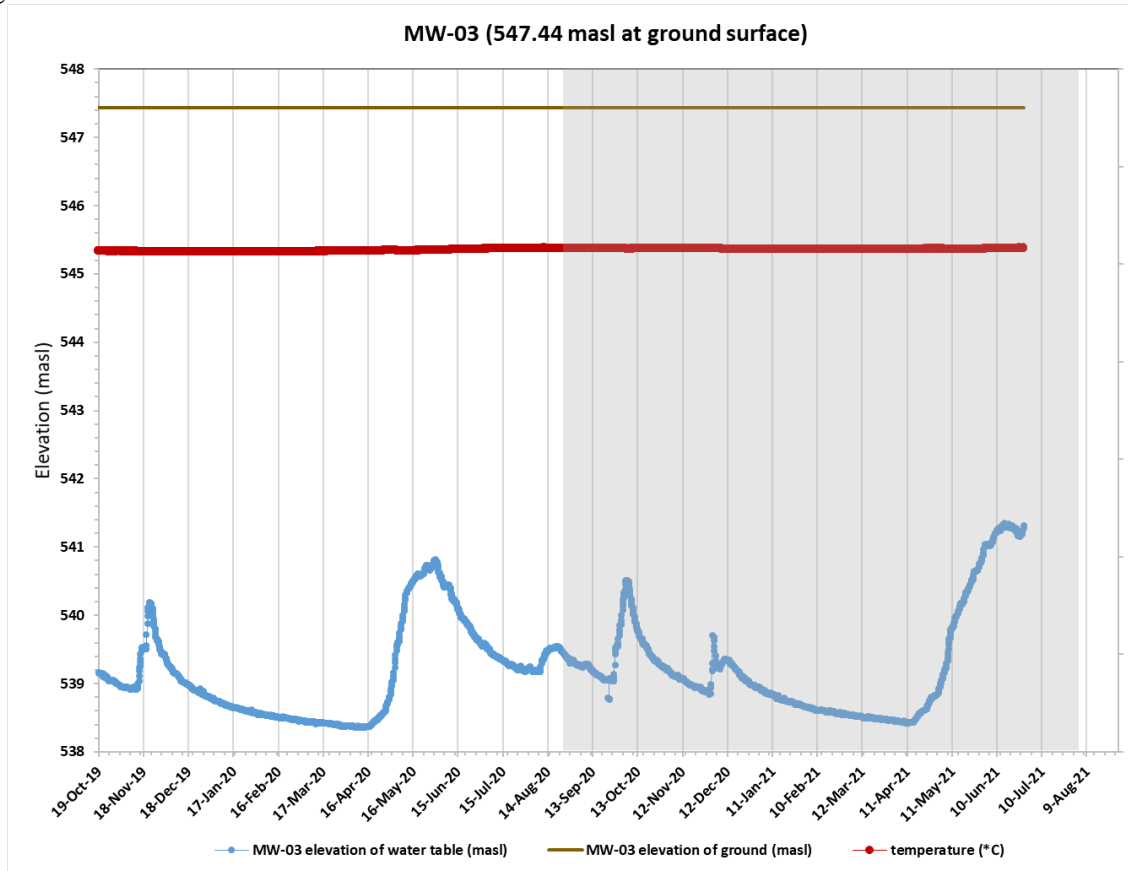
**Figure 18.** Water levels and water temperatures in MW-01. The Phase 1 tracer study period is shown with a white background and the Phase 2 study period is highlighted with a gray background.



**Figure 19.** Water levels and water temperatures in MW-02. The Phase 1 tracer study period is shown with a white background and the Phase 2 study period is highlighted with a gray background.



**Figure 20.** Water levels and water temperatures in MW-03. The Phase 1 study period is shown with a white background and the Phase 2 study period is highlighted with a gray background.



## **5. Summary and Findings**

Constantine Mining has a permit to develop an underground exploration ramp to support underground drilling in the Glacier Creek Valley at the Palmer Site. Constantine plans to dispose of water encountered in construction of this exploration ramp and the underground drilling by treating it prior to a land application disposal (LAD) system located on the overburden slope southwest of Glacier Creek. The Ozark Underground Laboratory (OUL) was retained to conduct groundwater tracing studies to assist in characterizing the hydrology of two potential areas for the Lower Diffuser system with particular emphasis on groundwater movement from the Lower Diffuser areas toward streams in the area. The work was conducted in two phases, and are summarized in separate sections, below.

### **5.1 Phase 1 Tracer Study**

The purpose of the Phase 1 tracer study was to investigate the area of the proposed 2019 Lower Diffuser system. Phase 1 work was conducted from October 29, 2019 to July 30, 2020.

Tracer test results indicate that during approximately 9 months of sampling for tracer dyes most of the introduced dye remained in the aquifer. Low concentrations of eosine dye, originating from trench T-3, were detected at Station 9 in Glacier Creek. No eosine was detected in the concurrent water sample tested at the same site. Detection of eosine at low concentrations in carbon samplers and below detection limit in water samples is consistent with dye concentrations in surface waters at concentrations below the detection limit in water. The positive dye detections in the carbon samplers are explained by the accumulative nature of carbon samplers. Again, carbon samplers typically magnify the dye concentration present in the water by a factor of at least 100. No dye from trenches T-1 or T-2 was detected for the duration of the study.

The Phase 1 tracer study included dye and flush water introductions into three trenches excavated in unconsolidated material in the planned Lower Diffuser area between Waterfall Creek and Hangover Creek. All trenches in the Phase 1 tracing area were southwest of Hangover Creek and the mid-point of the trenches was approximately 620 feet from the channel of Glacier Creek.

For the Phase 1 tracer study three pounds of fluorescein dye mixture was introduced into trench T-1 and another three pounds of fluorescein was introduced into trench T-2. Six pounds of eosine dye mixture was introduced into trench T-3. Trench T-3 is the trench nearest the channel of Waterfall Creek. Five thousand gallons of flush water was added to each trench. The detection limits of fluorescein in water and elutant are 0.002 ppb and 0.025 ppb, respectively. The detection limits of eosine in water and elutant are 0.015 ppb and 0.050 ppb, respectively. All dye and water introductions were made on October 29, 2019.



Sampling for tracer dyes placed primary sampling reliance on activated carbon samplers and secondary reliance on grab samples of water. Activated carbon samplers adsorb and retain tracer dyes including both eosine and fluorescein. As a result, the carbon samplers function as continuous and accumulating samplers. When dyes are eluted from the carbon samplers in the laboratory the dye concentrations in the eluting solutions are commonly at least two orders of magnitude larger than mean dye concentrations in the flowing water being sampled if the samplers have been in place for at least 7 days.

The activated carbon in each of the carbon samplers contains over an acre of surface area (Aley, 2017), and in high quality water can continue to adsorb and accumulate both of the tracer dyes used in these studies for periods of at least two months and probably substantially longer. Both fluorescein and eosine are strongly adsorbed on the activated carbon and do not appear to experience appreciable desorption when left in place in sampling locations for long periods of time.

Eosine dye from Trench T-3 in Phase 1 was detected in the carbon samplers in place at Station 9 for the period from December 10, 2019, to February 10, 2020. Activated carbon samplers concurrently collected and analyzed from Station 8 (the first sampling point upstream of Station 9) did not contain any eosine dye. In addition, eosine was subsequently detected in samplers in place at Station 9 for the periods March 18 to April 20, and April 20 to May 12, 2020, but not detected for the interval February 10, 2020, to March 18, 2020. No eosine was detected during these periods at Station 8 or at any other stations upstream of Station 9. As a result, it is clear that eosine dye from the Trench T-3 introduction discharged to Glacier Creek at one or more unidentified points between Stations 8 and 9. Fluorescein dye from trenches T-1 and T-2 were not detected in any carbon sampler station. In Phase 1, no dyes were detected in any other activated carbon samplers and no dye was detected in any water samples collected during the study period.

The primary findings of the Phase 1 Study are as follows:

- Eosine dye introduced in trench T-3 was detected at Station 9.
- Eosine dye was not detected at any other sampling station. Therefore, the dye entered Glacier Creek at a point, or points, between Stations 8 and 9.
- The straight-line distance between trench T-3 and Station 8 is 935 feet.
- The straight-line distance between trench T-3 and Station 9 is 3,900 feet.
- The first detection of eosine dye at Station 9 occurred during the sampling period from December 10, 2019 to February 10, 2020 (days 42 to 104, after Phase 1 dye introduction). The carbon samplers for these sampling periods were deployed for a period of 62 days. Eosine concentration in sampler elutant was 0.572 ppb in one sampler and 0.188 ppb in the second sampler.
- No eosine dye was detected at Station 9 during sampling periods from February 10, 2020 to February 22, 2020 (days 104 to 116, after dye introduction) and February 22, 2020 to

March 18, 2020 (days 116 to 141, after Phase 1 dye introduction). The carbon samplers for this sampling period were deployed for a period of 12 days and 25 days, respectively.

- Eosine dye was detected at Station 9 during the sampling period from March 18 to April 20, 2020 (days 141 to 174, after Phase 1 dye introduction). The carbon samplers for this sampling period were deployed for a period of 33 days. Eosine concentration was 0.649 ppb in one sampler. Eosine was not detected in the second sampler.
- Eosine dye was detected at Station 9 during the sampling period from April 20 to May 12, 2020 (days 174 to 196, after Phase 1 dye introduction). The carbon samplers for this sampling period were deployed for a period of 22 days. Eosine concentration was 0.134 ppb in one sampler and 0.159 ppb in the second sampler. The peak emission wavelength in the second sampler was at 538.2 nm, which is 1.1 nm shorter than the normally acceptable wavelength range for eosine dye in carbon sampler elutants. In the opinion of the OUL both the samplers for this sampling period were positive for eosine dye.
- Sampling at Station 9 for the Phase 1 tracer study terminated on July 7, 2020 (252 days after Phase 1 dye introduction). Sampling at Stations 6 and 8 for the Phase 1 tracer study terminated on July 30, 2020.
- Station 9 continued to be used as a sampling station throughout the Phase 2 tracer study when sampling ceased on August 7, 2021. The only gap in sampling was a 43-day period from July 7, 2020 to August 19, 2020.
- No eosine was detected at Station 9 after May 12, 2020 (day 196 after Phase 1 dye introduction) through August 7, 2021 (day 648 after Phase 1 dye introduction)

## 5.2 Phase 2 Tracer Study

The purpose of the Phase 2 tracer study was to investigate the area of the newly proposed 2022 Lower Diffuser system. Phase 2 work was conducted from August 23, 2020 to August 8, 2021.

No dyes from the Phase 2 tracer study were detected at any sampling stations.

The Phase 2 tracer study included dye and flush water introductions into three trenches excavated in unconsolidated material in an area northeast of Hangover Creek, the location of the newly proposed LAD Diffuser configuration. The mid-point of these trenches is approximately 1,300 feet from the channel of Glacier Creek if the distance is measured perpendicular to the topographic contour lines.

For the Phase 2 tracer study 9 pounds of fluorescein dye mixture was introduced into trench T-102 and another 9 pounds of fluorescein dye mixture was introduced into trench T-103. Eighteen pounds of eosine dye mixture was introduced into trench T-101. Five thousand gallons of flush water was added to each trench. Because potential groundwater travel distances were greater for the Phase 2 tracer study than for the Phase 1 Study the amount of dye introduced into each trench for the Phase 2 tracer study was 3 times greater than the amount used for the Phase 1

tracer study. Dye and water introductions were made into trench T-101 on August 23, 2020 and into trenches T-102 and T-103 on August 24, 2020.

Sampling for the Phase 2 tracer study continued at all sampling stations until November 24, 2020 (93 days after dye introductions). After that date some stations were still accessible and were sampled periodically until August 7 and 8, 2020 (349 and 350 days after the dye introductions).

### **5.3 General Discussion**

Two Dye Tracer Studies were completed. Phase 1 was conducted from October 29, 2019 to July 30, 2020 and focused on the area of the 2019 LAD configurations, west of Hangover Creek and East of Waterfall Creek (Figure 4). The Phase 1 dye introductions were completed on October 29, 2019. Phase 2 was conducted from August 23, 2020 to August 8, 2021 and focused on the area of the 2022 LAD configurations, east of Hangover Creek (Figure 12). The Phase 2 dye introductions were completed on August 24, 2020. Note, these are two separate but adjacent areas. Due to the results of Phase 1, the amount of dye introduced in the Phase 2 Study was increased by a factor of three to accommodate for longer travel distances expected. Sampling for the presence of tracer dyes was conducted for 275 days after dye introduction in the Phase 1 Study and 350 days after dye introduction in the Phase 2 Study. Phase 2 did not detect either dye type during the testing period. This would also mean that any residual dye from the Phase 1 testing was also not detected even though the same and additional carbon sampler sites were tested during Phase 2.

The results of the Phase 2 Study have shown that the Phase 2 Diffuser Aquifer did not report any test dye to surface waters from either Phase 1 and Phase 2 dye introductions.

Phase 1 Study detected small concentrations of eosine from Trench T-3 in carbon samplers during three sampling periods at Station 9, before becoming non-detected at the end of the study period. Water samples taken concurrently did not detect either dye.

The unconsolidated material that forms the high gradient Discharge Aquifer into which the LAD system would discharge is heterogeneous. Infiltration tests of 10 test pits showed saturated hydraulic conductivity estimates that varied nearly three orders of magnitude; they varied from 0.034 meters per day to 15 meters per day. A three order of magnitude variation was also observed in the more extensive hydraulic conductivity testing performed in the Hydrologic Site Investigation (KCB Consultants Ltd., 2022). The important point to be taken from this is the high variability in the rates at which water can move through the materials that comprise the aquifer.

Glacial moraine and related materials including subsequent rock fall, landslides and debris flows are an important part of the depositional history of the Discharge Aquifer that includes the

LAD system. The surface streams are high gradient streams with broad cross sections and highly permeable channel materials. Debris flows have undoubtedly filled former stream channels but left localized and more permeable groundwater flow routes in the paleochannels. These provide preferential groundwater flow routes associated with the flow paths followed by eosine dye as it moved from trench T-3 to Glacier Creek or elsewhere.

Eleven sets of flow rate measurements were made at two sampling stations (Stations 8 and 9) on Glacier Creek between October 30 and December 10, 2019. The mean difference between flow rates at the two stations on Glacier Creek was 2.54 cfs with the higher rates increasing from upstream to downstream. This increase reflects surface water additions to Glacier Creek from Oxide Creek (located on the north side of Glacier Creek) and groundwater discharges. The flow rate of Oxide Creek during late autumn is minor, so groundwater discharge to this segment of Glacier Creek during the streamflow monitoring period in late autumn is estimated at 2.0 cfs.

The groundwater contribution to surface waters was increased during Phase 2 streamflow measurements conducted on September 24<sup>th</sup>, 2020, compared to those measured during Phase 1. The streamflow measurements at Station P27 during the September 24<sup>th</sup>, 2020 sampling were approximately 6 times greater than the streamflow measurements collected during the Phase 1 study. In addition, Streamflow measurements during Phase 2 showed an increase in streamflow of 10 cfs between Stations P01 and P27, accounting for other surface water contributions.

Calculations on groundwater interactions with Glacier Creek are important for determining the impacts of discharged waste water on water table rise and groundwater discharge to Glacier Creek. The dataset presented in this report does not provide sufficient detail to permit reasonable estimates of groundwater contributions to Glacier Creek. A more comprehensive dataset for determination of groundwater flux to Glacier Creek is currently being developed by Constantine Mining LLC. This more comprehensive dataset should be used for estimates of groundwater flux to Glacier Creek and will be important in the determination of the impacts of discharged waste water on water table rise and groundwater discharge to Glacier Creek.

## **6. Conclusions**

**Conclusion 1.** No dyes were detected in Glacier Creek or any tributaries from the Phase 2 tracer study.

**Conclusion 2.** Eosine dye was detected in the Phase 1 tracer study, from trench T-3 to sampling Station 9 on Glacier Creek. Dye entered Glacier Creek at an undetermined point or points between Stations 8 and 9.

**Conclusion 3.** Explanations for not detecting dyes from five of the six dye introductions includes the fact that there is substantial heterogeneity within the Discharge Aquifer. The aquifer is comprised heterogeneous alluvium deposits which have been further impacted by landslides and debris flows. This influences travel times and pathways.

**Conclusion 4.** The location of the proposed 2022 Lower Diffuser is an improvement over the 2019 location as the dye tracing indicates that it does not impact Glacier Creek and its tributaries in the time interval tested. The 2022 location also provides for a longer total length of lateral diffusion piping along contours for better dispersal and attenuation of the treated water.

## 7. References

- Aley, Thomas. 2017. Improving the detection of fluorescent tracer dyes in groundwater investigations. *Remediation; The Journal of Environmental Cleanup Costs, Technology, and Techniques*. Vol. 27, pp. 39-46.
- Aley, Thomas. 2019A. The Ozark Underground Laboratory's groundwater tracing handbook. Available for download from [www.ozarkundergroundlab.com](http://www.ozarkundergroundlab.com). 41p.
- Aley, Thomas. 2019B. Study plan for a dye tracing study of a land application disposal (LAD) system, Palmer project, Alaska. Ozark Underground Laboratory report for Constantine Mining. 12p. + appendix.
- Aley, Thomas. 2020. Study plan for a second dye tracing study of a land application disposal (LAD) system site, Palmer project, Alaska. Ozark Underground Laboratory report for Constantine Mining. 12p. + appendix.
- BGC Engineering. 2018. Final design report for sediment ponds, temporary rock storage pad, LAD, and diffuser system. Report to Constantine North Inc. Palmer Exploration Project. December 11, 2018. 21p. + appendixes.
- Constantine Mining. 2019. Application for waste management permit for the Palmer Phase II Exploration Project, Haines, Alaska Upland Mining Lease No. 9100759. Prepared for Alaska Dept. of Environmental Conservation, March 2019.
- Driscoll, Fletcher G. 1986. *Groundwater and wells*, second edition. Johnson Division, p. 67.
- Fetter, C.W. Jr. 1980. *Applied hydrogeology*. Merrill Publishing Co., p. 64.
- Field, Malcolm S.; Ronald G. Wilhelm; James F. Quinlan; and Thomas J. Aley. 1995. An assessment of the potential adverse properties of fluorescent tracer dyes used in groundwater tracing. *Environmental Monitoring and Assessment*, Vol. 38. Kluwer Academic Publishers, Pp. 75-96.
- Gugins, Caitlin and Cliff Candy. 2015. Constantine Metal Resources Ltd. report on seismic refraction and multi-spectral analysis of surface waves (MASW) investigation Palmer Project, Haines, Alaska. Frontier Geosciences Inc. 7p. + appendix materials.
- KCB Consultants Ltd. 2022. Constantine Mining LLC. Palmer LAD Redesign: Hydrogeological Site Investigation Summary. March 3, 2022. 25p. + 4 appendixes.

Logic Geophysics & Analytics LLC. 2021. Seismic surveys in support of the Palmer Project near Haines, Alaska. Prepared for Constantine Mining LLC. October 14, 2021. 47p.

Tundra Consulting LLC. 2018. Memo of November 20, 2018 from Steve Teller to Darwin Green and Ian Dunlop. Subject: monitoring well installation report 2018. 3p. + well logs.

Tundra Consulting LLC. 2020. Infiltration testing – 2020 Palmer Project. Prepared for Constantine Mining, Haines, Alaska. 13p. + 2 appendixes.

Tundra Consulting LLC. 2021. Memo of February 8, 2021 from Steve Teller to Allegra Cairns. Subject: Phase 2 tracer testing field report - Draft. 7p. + infiltration pit logs.

S:\tom\constantine-DRAFT FINAL.doc





**Appendix A: Ozark Underground Laboratory Procedures and Criteria**

**PROCEDURES AND CRITERIA  
ANALYSIS OF FLUORESCENT DYES  
IN WATER AND CHARCOAL SAMPLERS:  
  
FLUORESCEIN, EOSINE, RHODAMINE WT,  
AND SULFORHODAMINE B DYES**

Revision Dates:

**March 3, 2015**

Pages A-14 to A-18 corrected to match Table 4 on **December 27, 2018**

**Thomas Aley, PHG, PG**

President

and

**Shiloh L. Beeman, PG**

Sr. Hydrogeologist

**Ozark Underground Laboratory, Inc.**

1572 Aley Lane

Protom, Missouri 65733

417-785-4289

[contact@ozarkundergroundlab.com](mailto:contact@ozarkundergroundlab.com)

---

## INTRODUCTION

This document describes standard procedures and criteria currently in use at the Ozark Underground Laboratory (OUL) as of the date shown on the title page. Some samples may be subjected to different procedures and criteria because of unique conditions; such non-standard procedures and criteria are identified in reports for those samples. Standard procedures and criteria change as knowledge and experience increases and as equipment is improved or upgraded. The OUL maintains a summary of changes in standard procedures and criteria.

## TRACER DYES AND SAMPLE TYPES

### Dye Nomenclature

Dye manufacturers and retailers use a myriad of names for the dyes. This causes confusion among dye users and report readers. The primary dyes used at the OUL and described in this document are included in Table 1 below.

**Table 1.** Primary OUL Dye Nomenclature.

OUL Common Name	Color Index Number	Color Index Name	Other Names
Fluorescein	45350	Acid Yellow 73	uranine, uranine C, sodium fluorescein, fluorescein LT and fluorescent yellow/green
Eosine	45380	Acid Red 87	eosin, eosine OJ, and D&C Red 22
Rhodamine WT	None assigned	Acid Red 388	fluorescent red (but not the same as rhodamine B)
Sulforhodamine B	45100	Acid Red 52	pontacyl brilliant pink B, lissamine red 4B, and fluoro brilliant pink

The OUL routinely provides dye for tracing projects. Dyes purchased for groundwater tracing are always mixtures that contain both dye and an associated diluent. Diluents enable the manufacturer to standardize the dye mixture so that there are minimal differences among batches. Additionally, diluents are often designed to make it easier to dissolve the dye mixture in water, or to produce a product which meets a particular market need (groundwater tracing is only a tiny fraction of the dye market). The percent of dye in “as-sold” dye mixtures often varies dramatically among manufacturers and retailers, and retailers are sometimes incorrect about the percent of dye in their products. The OUL subjects all of its dyes to strict quality control (QC) testing. Table 2 summarizes the as-sold dye mixtures used by the OUL.

**Table 2.** As-Sold Dye Mixtures at the OUL.

<b>OUL Common Name</b>	<b>Form</b>	<b>Dye Equivalent</b>
Fluorescein	Powder	75% dye equivalent, 25% diluent
Eosine	Powder	75% dye equivalent, 25% diluent
Rhodamine WT	Liquid	20% dye equivalent, 80% diluent
Sulforhodamine B	Powder	75% dye equivalent, 25% diluent

Analytical results are based on the as-sold weights of the dyes provided by the OUL. The use of dyes from other sources is discouraged due to the wide variability of dye equivalents within the market. However, if alternate source dyes are used, a sample should be provided to the OUL for quality control and to determine if a correction factor is necessary for the analytical results.

### **Types of Samples**

Typical samples that are collected for fluorescent tracer dye analysis include charcoal samplers (also called activated carbon or charcoal packets) and water samples.

The charcoal samplers are packets of fiberglass screening partially filled with 4.25 grams of activated coconut charcoal. The charcoal used by the OUL is Calgon 207C coconut shell carbon, 6 to 12 mesh, or equivalent. The most commonly used charcoal samplers are about 4 inches long by 2 inches wide. A cigar-shaped sampler is made for use in very small diameter wells (such as 1-inch diameter piezometers); this is a special order item and should be specifically requested in advance when needed. All of the samplers are closed by heat sealing.

In specialized projects, soil samples have been collected from soil cores and analyzed for fluorescent tracer dyes. Project-specific procedures have been developed for projects such as these. For additional information, please contact the OUL.

### **FIELD PROCEDURES**

Field procedures included in this section are intended as guidance, and not firm requirements. Placement of samplers and other field procedures require adjustment to field conditions. Personnel at the OUL are available to provide additional assistance for implementation of field procedures specific to specialized field conditions.

## Placement of Samplers

Charcoal samplers are placed so as to be exposed to as much water as possible. Water should flow through the packet. In springs and streams they are typically attached to a rock or other anchor in a riffle area. Attachment of the packets often uses plastic tie wires. In swifter water galvanized wire (such as electric fence wire) is often used. Other types of anchoring wire can be used. Electrical wire with plastic insulation is also good. Packets are attached so that they extend outward from the anchor rather than laying flat against it. Two or more separately anchored packets are typically used for sampling springs and streams. The placement of multiple packets is recommended in order to minimize the chance of loss during the sampling period. The use of fewer packets is discouraged except when the spring or stream is so small that there is not appropriate space for placing multiple packets.

When pumping wells are being sampled, the samplers are typically placed in sample holders made of plastic pipe fittings. Brass hose fittings can be at the end of the sample holders so that the sample holders can be installed on outside hose bibs and water which has run through the samplers can be directed to waste through a connected garden hose. The samplers can be unscrewed in the middle so that charcoal packets can be changed. The middle portions of the samplers consist of 1.5 inch diameter pipe and pipe fitting.

Charcoal packets can be lowered into monitoring wells for sampling purposes. In general, if the well is screened, samplers should be placed approximately in the middle of the screened interval. Due to the typically lower volume of water that flows through a well, only one charcoal sampler should be used per well. However, multiple packets can be placed in a single well at depths to test different depth horizons when desirable. A weight should be added near the charcoal packet to ensure that it will not float. The weight should be of such a nature that it will not affect water quality. One common approach is to anchor the packets with a white or uncolored plastic cable tie to the top of a dedicated weighted disposable bailer. We typically run nylon cord from the top of the well to the charcoal packet and its weight. ***Do not use colored cord*** since some of them are colored with fluorescent dyes. Nylon fishing line should not be used since it can be readily cut by a sharp projection in the well.

In some cases, especially with small diameter wells and appreciable well depths, the weighted disposable bailers sink very slowly or may even fail to sink because of friction and floating of the anchoring cord. In such cases a weight may be added to the top of the disposable bailer. Stainless steel weights are ideal, but are not needed in all cases. All weights should be cleaned prior to use; the cleaning approach should comply with decontamination procedures in use at the project site.

## Optional Preparation of Charcoal Samplers

Charcoal packets routinely contain some fine powder that washes off rapidly when they are placed in water. While not usually necessary, the following optional preparation step is suggested if the fine charcoal powder is problematic.

Charcoal packets can be triple rinsed with distilled, demineralized, or reagent water known to be free of tracer dyes. This rinsing is typically done by soaking. With this approach, approximately 25 packets are placed in one gallon of water and soaked for at least 10 minutes. The packets are then removed from the water and excess water is shaken off the packets. The packets are then placed in a second gallon of water and again soaked for at least 10 minutes. After this soaking they are removed from the water and excess water is shaken off the packets. The packets are then placed in a third gallon of water and the procedure is again repeated. Rinsed packets are placed in plastic bags and are placed at sampling stations within three days. Packets can also be rinsed in jets of water for about one minute; this requires more water and is typically difficult to do in the field with water known to be free of tracer dyes.

### **Collection and Replacement of Samplers**

Samplers are routinely collected and replaced at each of the sampling stations. The frequency of sampler collection and replacement is determined by the nature of the study. Collections at one week intervals are common, but shorter or longer collection frequencies are acceptable and sometimes more appropriate. Shorter sampling frequencies are often used in the early phases of a study to better characterize time of travel. As an illustration, we often collect and change charcoal packets 1, 2, 4, and 7 days after dye injection. Subsequent sampling is then weekly.

The sampling interval in wells at hazardous wastes sites should generally be no longer than about a week. Contaminants in the water can sometimes use up sorption sites on the charcoal that would otherwise adsorb the dye. This is especially important if the dye might pass in a relatively short duration pulse.

Where convenient, the collected samplers should be briefly rinsed in the water being sampled to remove dirt and accumulated organic material. This is not necessary with well samples. The packets are shaken to remove excess water. Next, the packet (or packets) are placed in a plastic bag (Whirl-Pak® bags are ideal). The bag is labeled on the outside with a black permanent type felt marker pen, such as a Sharpie®. *Use only pens that have black ink*; colored inks may contain fluorescent dyes. The notations include station name or number and the date and time of collection. Labels must not be inserted inside the sample bags.

Collected samplers are kept in the dark to minimize algal growth on the charcoal prior to analysis work. New charcoal samplers are routinely placed when used charcoal packets are collected. The last set of samplers placed at a stream or spring is commonly not collected.

### **Water Samples**



Water samples are often collected. They should be collected in either glass or plastic; the OUL routinely uses 50 milliliter (mL) research-grade polypropylene copolymer Perfector Scientific vials (Catalog Number 2650) for such water samples. No more than 30 mL of water is required for analysis. The sides of the vials should be labeled with the project name, sample ID, sample date and time with a black permanent felt tip pen. **Do not label the lid only.** The vials should be placed in the dark and refrigerated immediately after collection, and maintained under refrigeration until shipment. The OUL supplies vials for the collection of water samples.

### Sample Shipment

When water or charcoal samplers are collected for shipment to the OUL they should be shipped promptly. We prefer (and in some studies require) that samples be refrigerated with frozen re-usable ice packs upon collection and that they be shipped refrigerated with frozen ice packs by overnight express. **Do not ship samplers packed in wet ice** since this can create a potential for cross contamination when the ice melts. Our experience indicates that it is not essential for samplers to be maintained under refrigeration; yet maintaining them under refrigeration clearly minimizes some potential problems. A product known as "green ice" should not be used for maintaining the samples in a refrigerated condition since this product contains a dye which could contaminate samples if the "green ice" container were to break or leak.

We receive good overnight and second day air service from both UPS and FedEx. The U.S. Postal Service does not typically provide next day service to us. DHL does not provide overnight service to us. FedEx is recommended for international shipments. The OUL does not receive Saturday delivery.

Each shipment of charcoal samplers or water samples **must be accompanied by a sample custody document.** The OUL provides a sheet (which bears the title "Samples for Fluorescence Analysis") that can be used if desired. These sheets can be augmented by a client's chain-of-custody forms or any other relevant documentation. OUL's custody document works well for charcoal samplers because it allows for both the placement date and time as well as the collection date and time. Many other standard chain-of-custody documents do not allow for these types of samples. Attachment 1 includes a copy of OUL's Sample Collection Data Sheet.

Please write legibly on the custody documents and **use black ink.** Check the accuracy of the sample sheet against the samples prior to shipment to identify and correct errors that may delay the analysis of your samples following receipt at the laboratory.

### Supplies Provided by the OUL

The OUL provides supplies for the collection of fluorescent tracer dyes. Supplies provided upon request are charcoal packets, Whirl-Pak® bags (to contain the charcoal packets after collection for shipment to the laboratory), and water vials. These supplies are subjected to strict QA/QC procedures to ensure the materials are free of any potential tracer dye contaminants. The charge for these materials is included in the cost of sample analysis. Upon request, coolers and re-freezable ice packs are also provided for return shipment of samples.

The OUL also has tracer dyes available for purchase. These dyes are subject to strict QA/QC testing. All analytical work is based upon the OUL as-sold weight of the dyes.

## LABORATORY PROCEDURES

The following procedures are followed upon receipt of samples at the laboratory.

### Receipt of Samples

Samplers shipped to the OUL are logged in and refrigerated upon receipt. Prior to cleaning and analysis, samplers are assigned a laboratory identification number.

It sometimes occurs that there are discrepancies between the sample collection data sheet and the actual samples received. When this occurs, a "Discrepancy Sheet" form is completed and sent to the shipper of the sample for resolution. The purpose of the form is to help resolve discrepancies, even when they may be minor. Many discrepancies arise from illegible custody documents. *Please write legibly* on the custody documents and *use black ink*. Check the accuracy of the sample sheet against the samples prior to shipment to identify and correct errors that may delay the analysis of your samples following receipt at the laboratory.

### Cleaning of Charcoal Samplers

Samplers are cleaned by spraying them with jets of clean water from a laboratory well in a carbonate aquifer. OUL uses non-chlorinated water for the cleansing to minimize dye deterioration. We do not wash samplers in public water supplies. Effective cleansing cannot generally be accomplished simply by washing in a conventional laboratory sink even if the sink is equipped with a spray unit.

The duration of packet washing depends upon the condition of the sampler. Very clean samplers may require less than a minute of washing; dirtier samplers may require several minutes of washing.

### Elution of the Charcoal

There are various eluting solutions that can be used for the recovery of tracer dyes. The solutions typically include an alcohol, water, and a strong basic solution such as aqueous ammonia and /or potassium hydroxide.

The standard elution solution used at the OUL is a mixture of 5% aqua ammonia and 95% isopropyl alcohol solution and sufficient potassium hydroxide pellets to saturate the solution. The isopropyl alcohol solution is 70% alcohol and 30% water. The aqua ammonia solution is 29% ammonia. The potassium hydroxide is added until a super-saturated layer is visible in the bottom of the container. This super-saturated layer is not used for elution. Preparation of eluting solutions uses dedicated glassware which is never used in contact with dyes or dye solutions.

The eluting solution will elute fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes. It is also suitable for separating fluorescein peaks from peaks of some naturally present materials found in samplers.

Fifteen mL of the eluting solution is poured over the washed charcoal in a disposable sample beaker. The sample beaker is capped. The sample is allowed to stand for 60 minutes. After this time, the liquid is carefully poured off the charcoal into a new disposable beaker which has been appropriately labeled with the laboratory identification number. A few grains of charcoal may inadvertently pass into the second beaker; no attempt is made to remove these from the second sample beaker. After the pouring, a small amount of the elutant will remain in the initial sample beaker. After the transfer of the elutant to the second sample beaker, the contents of the first sample beaker (the eluted charcoal) are discarded. Samples are kept refrigerated until analyzed.

### **pH Adjustment of Water Samples**

The fluorescence intensity of several of the commonly used fluorescent tracer dyes is pH dependent. The pH of samples analyzed for fluorescein, eosine, and pyranine dyes are adjust to a target pH of greater than 9.5 in order to obtain maximum fluorescence intensities.

Adjustment of pH is achieved by placing samples in a high ammonia atmosphere for at least two hours in order to increase the pH of the sample. Reagent water standards are placed in the same atmosphere as the samples. If dye concentrations in a sample are off-scale and require dilution for quantification of the dye concentration, the diluting water used is OUL reagent water that has been pH adjusted in a high ammonia atmosphere. Samples that are only analyzed for rhodamine WT or sulforhodamine B are not required to be pH adjusted.

### **Analysis on the Shimadzu RF-5301**

The OUL uses a Shimadzu spectrofluorophotometer model RF-5301. This instrument is capable of synchronous scanning. The OUL also owns a Shimadzu RF-540 spectrofluorometers that is occasionally used for special purposes.

A sample of the elutant or water is withdrawn from the sample container using a disposable polyethylene pipette. Approximately 3 mL of the sample is then placed in disposable rectangular polystyrene cuvette. The cuvette has a maximum capacity of 3.5 mL. The cuvette is designed

for fluorometric analysis; all four sides and the bottom are clear. The acceptable spectral range of these cuvettes is 340 to 800 nm. The pipettes and cuvettes are discarded after one use.

The cuvette is then placed in the RF-5301. This instrument is controlled by a programmable computer and operated by proprietary software developed for dye tracing applications.

Our instruments are operated and maintained in accordance with the manufacturer's recommendations. On-site installation of our first instrument and a training session on its use was provided by the instrument supplier. Repairs are made by a Shimadzu-authorized repairman.

Our typical analysis of an elutant sample where fluorescein, eosine, rhodamine WT, or sulforhodamine B dyes may be present includes synchronous scanning of excitation and emission spectra with a 17 nm separation between excitation and emission wavelengths. For these dyes, the excitation scan is from 443 to 613 nm; the emission scan is from 460 to 630 nm. The emission fluorescence from the scan is plotted on a graph. The typical scan speed setting is "fast" on the RF-5301. The typical sensitivity setting used is "high."

**Table 3.** Excitation and emission slit width settings routinely used for dye analysis.

<b>Parameter</b>	<b>Excitation Slit (nm)</b>	<b>Emission Slit (nm)</b>
ES, FL, RWT, and SRB in elutant	3	1.5
ES, FL, RWT, and SRB in water	5	3

Note: ES = Eosine. FL = Fluorescein. RWT = Rhodamine WT. SRB = Sulforhodamine B.

The instrument produces a plot of the synchronous scan for each sample; the plot shows emission fluorescence only. The synchronous scans are subjected to computer peak picks using proprietary software; peaks are picked to the nearest 0.1 nm. Instrument operators have the ability to manually adjust peaks as necessary based upon computer-picked peaks and experience. All samples run on the RF-5301 are stored electronically with sample information. All samples analyzed are recorded in a bound journal.

### Quantification

We calculate the magnitude of fluorescence peaks for fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes in both elutant and water samples. Dye quantities are expressed in microgram per liter (parts per billion; ppb). The dye concentrations are calculated by separating fluorescence peaks due to dyes from background fluorescence on the charts, and then calculating the area within the fluorescence peak. This area is proportional to areas obtained from standard solutions.

We run dye concentration standards each day the RF-5301 is used. Six standards are used; the standard or standards appropriate for the analysis work being conducted are selected. All standards are based upon the as-sold weights of the dyes. The standards are as follows:

- 1) 10 ppb fluorescein and 100 ppb rhodamine WT in well water from the Jefferson City-Cotter Formation
- 2) 10 ppb eosine in well water from the Jefferson City-Cotter Formation
- 3) 100 ppb sulforhodamine B in well water from the Jefferson City-Cotter Formation.
- 4) 10 ppb fluorescein and 100 ppb rhodamine WT in elutant.
- 5) 10 ppb eosine in elutant.
- 6) 100 ppb sulforhodamine B in elutant.

### **Preparation of Standards**

Dye standards are prepared as follows:

Step 1. A small sample of the as-sold dye is placed in a pre-weighed sample vial and the vial is again weighed to determine the weight of the dye. We attempt to use a sample weighing between 1 and 5 grams. This sample is then diluted with well water to make a 1% dye solution by weight (based upon the as-sold weight of the dye). The resulting dye solution is allowed to sit for at least four hours to ensure that all dye is fully dissolved.

Step 2. One part of each dye solution from Step 1 is placed in a mixing container with 99 parts of well water. Separate mixtures are made for fluorescein, rhodamine WT, eosine, and sulforhodamine B. The resulting solutions contain 100 mg/L dye (100 parts per million dye mixture). The typical prepared volume of this mixture is appropriate for the sample bottles being used; we commonly prepare about 50 mL of the Step 2 solutions. The dye solution from Step 1 that is used in making the Step 2 solution is withdrawn with a digital Finnpiptette which is capable of measuring volumes between 0.200 and 1.000 mL at intervals of 0.005 mL. The calibration certificate with this instrument indicates that the accuracy (in percent) is as follows:

At 0.200 mL, 0.90%

At 0.300 mL, 0.28%

At 1.000 mL, 0.30%

The Step 2 solution is called the long term standard. OUL experience indicates that Step 2 solutions, if kept refrigerated, will not deteriorate appreciably over periods of less than a year. Furthermore, these Step 2 solutions may last substantially longer than one year.

Step 3. A series of intermediate-term dye solutions are made. Approximately 45 mL of each intermediate-term dye solution is made. All volume measurements of less than 5 mL are made with a digital Finnpiptette. (see description in Step 2). All other volume measurements are made with Rheinland Kohn Geprüfte Sicherheit 50 mL capacity pump dispenser which will

pump within plus or minus 1% of the set value. The following solutions are made; all concentrations are based on the as-sold weight of the dyes:

- 1) 1 ppm fluorescein dye and 10 ppm rhodamine WT dye.
- 2) 1 ppm eosine.
- 3) 10 ppm sulforhodamine B dye.

Step 4. A series of six short-term dye standards are made from solutions in Step 3. These standards were identified earlier in this section. In the experience of the OUL these standards have a useful shelf life in excess of one week. However, in practice, Step 4 elutant standards are made weekly, and Step 4 water standards are made daily.

### **Dilution of Samples**

Samples with peaks that have arbitrary fluorescence unit values of 500 or more are diluted a hundred fold to ensure accurate quantification.

Some water samples have high turbidity or color which interferes with accurate detection and measurement of dye concentrations. It is often possible to dilute these samples and then measure the dye concentration in the diluted sample.

The typical dilutions are either 10 fold (1:10) or 100 fold (1:100). A 1:10 dilution involves combining one part of the test sample with 9 parts of water (if the sample is water) or elutant (if the sample is elutant). A 1:100 dilution involves combining one part of the test sample is combined with 99 parts of water or elutant, based upon the sample media. Typically, 0.300 mL of the test solution is combined with 29.700 mL of water (or elutant as appropriate) to yield a new test solution.

All volume measurements of less than 5 mL are made with a digital Finnpiptette. All other volume measurements are made with Rheinland Kohn Geprüfte Sicherheit 50 mL capacity pump dispenser which will pump within plus or minus 1% of the set value.

The water used for dilution is from a carbonate aquifer. All dilution water is pH adjusted to greater than pH 9.5 by holding it in open containers in a high ammonia concentration chamber. This adjustment takes a minimum of two hours.

### **Quality Control**

Laboratory blanks are run for every sample where the last two digits of the laboratory numbers are 00, 20, 40, 60, or 80. A charcoal packet is placed in a pumping well sampler and at least 25 gallons of unchlorinated water is passed through the sampler at a rate of about 2.5 gallons per minute. The sampler is then subjected to the same analytical protocol as all other samplers.



System functioning tests of the analytical instruments are conducted in accordance with the manufacturer's recommendations. Spiked samples are also analyzed when appropriate for quality control purposes.

All materials used in sampling and analysis work are routinely analyzed for the presence of any compounds that might create fluorescence peaks in or near the acceptable wavelength ranges for any of the tracer dyes. This testing includes approximately 1% of materials used.

Project specific QA/QC samples may include sample replicates and sample duplicates. A replicate sample is when a single sample is analyzed twice. A sample duplicate is where two samples are collected in a single location and both are analyzed. Sample replicates and duplicates are run for QA/QC purposes upon request of the client. These results are reported in the Certificate of Analysis.

## Reports

Sample analysis results are typically reported in a Certificate of Analysis. However, specialized reports are provided in accordance with the needs of the client. Certificates of Analysis typically provide a listing of station number, sample ID, and dye concentrations if detected. Standard data format includes deliverables in MS Excel and Adobe Acrobat (.pdf) format. Hard copy of the data package, and copies of the analytical charts are available upon request.

Work at the OUL is directed by Mr. Thomas Aley. Mr. Aley has 45 years of professional experience in hydrology and hydrogeology. He is certified as a Professional Hydrogeologist (Certificate #179) by the American Institute of Hydrology and licenced as a Professional Geologist in Missouri, Arkansas, Kentucky, and Alabama. Additional details regarding laboratory qualifications are available upon request.

## Waste Disposal

All laboratory wastes are disposed of according to applicable state and federal regulations. Waste elutant and water samples are collected in 15 gallon poly drums and disposed with a certified waste disposal facility as non-hazardous waste.

In special cases, wastes for a particular project may be segregated and returned to the client upon completion of the project. These projects may have samples that contain contaminants that the client must account for all materials generated and disposed. These situations are managed on a case-by-case basis.

## CRITERIA FOR DETERMINATION OF POSITIVE DYE RECOVERIES

### Normal Emission Ranges and Detection Limits

The OUL has established normal emission fluorescence wavelength ranges for each of the four dyes described in this document. The normal acceptable range equals mean values plus and minus two standard deviations. These values are derived from actual groundwater tracing studies conducted by the OUL.

The detection limits are based upon concentrations of dye necessary to produce emission fluorescence peaks where the signal to noise ratio is 3. The detection limits are realistic for most field studies since they are based upon results from actual field samples rather than being based upon values from spiked samples in a matrix of reagent water or the elutants from unused activated carbon samplers. In some cases detection limits may be smaller than reported if the water being sampled has very little fluorescent material in it. In some cases detection limits may be greater than reported; this most commonly occurs if the sample is turbid due to suspended material or a coloring agent such as tannic compounds. Turbid samples are typically allowed to settle, centrifuged, or, if these steps are not effective, diluted prior to analysis.

Table 4 provides normal emission wavelength ranges and detection limits for the four dyes when analyzed on the OUL's RF-5301 for samples analyzed as of March 3, 2015.

**Table 4.** RF-5301 Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein, eosine, rhodamine WT, and sulforhodamine B dyes in water and elutant samples.

Fluorescent Dye	Normal Acceptable Emission Wavelength Range (nm)		Detection Limit (ppb)	
	Elutant	Water	Elutant	Water
Eosine	539.3 to 545.1	532.5 to 537.0	0.050	0.015
Fluorescein	514.1 to 519.2	505.9 to 509.7	0.025	0.002
Rhodamine WT	564.6 to 571.2	571.9 to 577.2	0.170	0.015
Sulforhodamine B	575.2 to 582.0	580.1 to 583.7	0.080	0.008

Note: Detection limits are based upon the as-sold weight of the dye mixtures normally used by the OUL.

Fluorescein and eosine detection limits in water are based on samples pH adjusted to greater than 9.5.

It is important to note that the normal acceptable emission wavelength ranges are subject to change based on instrument maintenance, a change in instrumentation, or slight changes in dye formulation. Significant changes in normal acceptable emission wavelength ranges will be updated in this document as they occur.

### **Fluorescence Background**

Due to the nature of fluorescence analysis, it is important to identify and characterize any potential background fluorescence at dye introduction and monitoring locations prior to the introduction of any tracer dyes.

There is generally little or no detectable fluorescence background in or near the general range of eosine, rhodamine WT, and sulforhodamine B dyes encountered in most groundwater tracing studies. There is often some fluorescence background in or near the range of fluorescein dye present at some of the stations used in groundwater tracing studies.

### **Criteria for Determining Dye Recoveries**

The following sections identify normal criteria used by the OUL for determining dye recoveries. The primary instrument in use is a Shimadzu RF-5301.

## EOSINE

### Normal Criteria Used by the OUL for Determining Eosine Dye Recoveries in Elutants from Charcoal Samplers

**Criterion 1.** There must be at least one fluorescence peak in the range of 539.3 to 545.1 nm in the sample.

**Criterion 2.** The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. The eosine detection limit in elutant samples is 0.050 ppb, thus this dye concentration limit equals 0.150 ppb.

**Criterion 3.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

**Criterion 4.** The shape of the fluorescence peak must be typical of eosine. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of eosine. In addition, there must be no other factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work.

### Normal Criteria Used by the OUL for Determining Eosine Dye Recoveries in Water Samples

**Criterion 1.** In most cases, the associated charcoal samplers for the station should also contain eosine dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

**Criterion 2.** There must be no factors which suggest that the fluorescence peak may not be eosine dye from our groundwater tracing work. The fluorescence peak should generally be in the range of 532.5 to 537.0 nm.

**Criterion 3.** The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our eosine detection limit in water samples is 0.015 ppb, thus this dye concentration limit equals 0.045 ppb.

**Criterion 4.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

## FLUORESCCEIN

### **Normal Criteria Used by the OUL for Determining Fluorescein Dye Recoveries in Elutants from Charcoal Samplers**

**Criterion 1.** There must be at least one fluorescence peak in the range of 514.1 to 519.2 nm in the sample.

**Criterion 2.** The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. The fluorescein detection limit in elutant samples is 0.025 ppb, thus this dye concentration limit equals 0.075 ppb.

**Criterion 3.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

**Criterion 4.** The shape of the fluorescence peak must be typical of fluorescein. Much background fluorescence yields low, broad, and asymmetrical fluorescence peaks rather than the more narrow and symmetrical fluorescence peaks typical of fluorescein. In addition, there must be no other factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work.

### **Normal Criteria Used by the OUL for Determining Fluorescein Dye Recoveries in Water Samples**

**Criterion 1.** In most cases, the associated charcoal samplers for the station should also contain fluorescein dye in accordance with the criteria listed above. This criterion may be waived if no charcoal sampler exists.

**Criterion 2.** There must be no factors which suggest that the fluorescence peak may not be fluorescein dye from our groundwater tracing work. The fluorescence peak should generally be in the range of 505.9 to 509.7 nm.

**Criterion 3.** The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our fluorescein detection limit in water samples is 0.002 ppb, thus this dye concentration limit equals 0.006 ppb.

**Criterion 4.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

## RHODAMINE WT

### **Normal Criteria Used by the OUL for Determining Rhodamine WT Dye Recoveries in Elutants from Charcoal Samplers**

**Criterion 1.** There must be at least one fluorescence peak in the sample in the range of 564.6 to 571.2 nm.

**Criterion 2.** The dye concentration associated with the rhodamine WT peak must be at least 3 times the detection limit. The detection limit in elutant samples is 0.170 ppb, thus this dye concentration limit equals 0.510 ppb.

**Criterion 3.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

**Criterion 4.** The shape of the fluorescence peak must be typical of rhodamine WT. In addition, there must be no other factors which suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

### **Normal Criteria Used by the OUL for Determining Rhodamine WT Dye Recoveries in Water Samples**

**Criterion 1.** In most cases, the associated charcoal samplers for the station should also contain rhodamine WT dye in accordance with the criteria listed above. These criteria may be waived if no charcoal sampler exists.

**Criterion 2.** There must be no factors which suggest that the fluorescence peak may not be rhodamine WT dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 571.9 to 577.2 nm.

**Criterion 3.** The dye concentration associated with the fluorescence peak must be at least three times the detection limit. Our rhodamine WT detection limit in water samples is 0.015 ppb, thus this dye concentration limit is 0.045 ppb.

**Criterion 4.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

## SULFORHODAMINE B

### **Normal Criteria Used by the OUL for Determining Sulforhodamine B Dye Recoveries in Elutants from Charcoal Samplers**

**Criterion 1.** There must be at least one fluorescence peak in the sample in the range of 575.2 to 582.0 nm.

**Criterion 2.** The dye concentration associated with the sulforhodamine B peak must be at least 3 times the detection limit. The detection limit in elutant samples is 0.080 ppb, thus this dye concentration limit equals 0.240 ppb.

**Criterion 3.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.

**Criterion 4.** The shape of the fluorescence peak must be typical of sulforhodamine B. In addition, there must be no other factors which suggest that the fluorescence peak may not be dye from the groundwater tracing work under investigation.

### **Normal Criteria Used by the OUL for Determining Sulforhodamine B dye Recoveries in Water Samples**

**Criterion 1.** In most cases, the associated charcoal samplers for the station should also contain sulforhodamine B dye in accordance with the criteria listed earlier. This criterion may be waived if no charcoal sampler exists.

**Criterion 2.** There must be no factors which suggest that the fluorescence peak may not be sulforhodamine B dye from the tracing work under investigation. The fluorescence peak should generally be in the range of 580.1 to 583.7 nm.

**Criterion 3.** The dye concentration associated with the fluorescence peak must be at least three times the detection limit. The detection limit in water is 0.008 ppb, thus this dye concentration limit equals 0.024 ppb.

**Criterion 4.** The dye concentration must be at least 10 times greater than any other concentration reflective of background at the sampling station in question.



### Standard Footnotes

Sometimes not all the criteria are met for a straight forward determination of tracer dye in a sample. For these reasons, the emission graph is scrutinized carefully by the analytical technician and again during the QA/QC process. Sometimes the emission graphs require interpretation as to whether or not a fluorescence peak represents the tracer dye or not. Background samples from each of the sampling stations aid in the interpretation of the emission fluorescence graphs. When the results do not meet all the criteria for a positive dye detection, often the fluorescence peak is quantified and flagged with a footnote to the result as not meeting all the criteria for a positive dye detection. Standard footnotes are as follows:

Single asterisk (\*): A fluorescence peak is present that does not meet all the criteria for a positive dye recovery. However, it has been calculated as though it were the tracer dye.

Double asterisk (\*\*): A fluorescence peak is present that does not meet all the criteria for this dye. However, it has been calculated as a positive dye recovery.

Other footnotes specific to the fluorescence signature are sometimes also used. These footnotes are often developed for a specific project.

The quantification of fluorescence peaks that do not meet all the criteria for a positive dye detection can be important for interpretation of the dataset as a whole.

S:\tom\procedures-and-criteria2015.doc

**ATTACHMENT 1**  
**Sample Collection Data Sheet**





## **Appendix B: Dye Tracing Results**

### **List of Tables**

<b>Table 1B.</b> Results for Phase 1 charcoal samplers analyzed for the presence of fluorescein and eosine dyes. Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).....	1
<b>Table 2B.</b> Results for Phase 1 water samples analyzed for the presence of fluorescein and eosine dyes....	8
<b>Table 3B.</b> Results for Phase 2 charcoal samplers analyzed for the presence of fluorescein and eosine dyes. ....	8
<b>Table 4B.</b> Results for Phase 2 water samples analyzed for the presence of fluorescein and eosine dyes..	17



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

**Table 1B.** Results for Phase 1 charcoal samplers analyzed for the presence of fluorescein and eosine dyes. Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
<b>D9186</b>	<b>1</b>	<b>MW-02</b>	<b>10/28/19 1100</b>	<b>10/30/19 1230</b>	<b>ND</b>		<b>ND</b>	
D9195	1	MW-02	10/30/19 1230	10/31/19 1050	ND		ND	
D9205	1	MW-02	10/31/19 1050	11/2/19 1150	ND		ND	
D9349	1	MW-02	11/2/19 1150	11/5/19 1115	ND		ND	
D9358	1	MW-02	11/5/19 1115	11/8/19 1010	ND		ND	
D9494	1	MW-02	11/8/19 1010	11/12/19 1130	ND		ND	
D9504	1	MW-02	11/12/19 1130	11/15/19 1040	ND		ND	
D9710	1	MW-02	11/15/19 1040	11/19/19 1145	ND		ND	
D9719	1	MW-02	11/19/19 1145	11/26/19 1200	ND		ND	
E0064	1	MW-02	11/26/19 1200	12/3/19 1035	ND		ND	
E0072	1	MW-02	12/3/19 1035	12/10/19 0955	ND		ND	
E4875	1	MW-02	12/3/19 1035	5/28/20 1030	ND		ND	
E5702	1	MW-02	5/28/20 1030	6/12/20 1230	ND		ND	
E5814	1	MW-02	6/12/20 1230	6/18/20 1130	ND		ND	
E5913	1	MW-02	6/18/20 1130	7/7/20 1015	ND		ND	
E6572	1	MW-02	7/7/20 1015	7/30/20 1400	ND		ND	
<b>D9187</b>	<b>2</b>	<b>Waterfall Creek at Access Rd.</b>	<b>10/28/19 1000</b>	<b>10/30/19 1137</b>	<b>ND</b>		<b>ND</b>	
D9196	2	Waterfall Creek at Access Rd.	10/30/19 1137	10/31/19 1015	ND		ND	
D9196D	2	Waterfall Creek at Access Rd.	10/30/19 1137	10/31/19 1015	ND		ND	
D9206	2	Waterfall Creek at Access Rd.	10/31/19 1015	11/2/19 1110	ND		ND	
D9350	2	Waterfall Creek at Access Rd.	11/2/19 1110	11/5/19 1020	ND		ND	
D9359	2	Waterfall Creek at Access Rd.	11/5/19 1020	11/8/19 0920	ND		ND	
D9495	2	Waterfall Creek at Access Rd.	11/8/19 0920	11/12/19 1045	ND		ND	
D9505	2	Waterfall Creek at Access Rd.	11/12/19 1045	11/15/19 0945	ND		ND	
D9711	2	Waterfall Creek at Access Rd.	11/15/19 0945	11/19/19 1055	ND		ND	
D9711D	2	Waterfall Creek at Access Rd.	11/15/19 0945	11/19/19 1055	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D9721	2	Waterfall Creek at Access Rd.	11/19/19 1055	11/26/19 1105	ND		ND	
E0065	2	Waterfall Creek at Access Rd.	11/26/19 1105	12/3/19 0945	ND		ND	
E0073	2	Waterfall Creek at Access Rd.	12/3/19 0945	12/10/19 0900	ND		ND	
E2814	2	Waterfall Creek at Access Rd.	12/10/19 0900	3/17/20 1115	ND		ND	
E4879	2	Waterfall Creek at Access Rd.	3/17/20 1115	5/29/20 1030	ND		ND	
E5703	2	Waterfall Creek at Access Rd.	5/29/20 1030	6/12/20 1400	ND		ND	
E5815	2	Waterfall Creek at Access Rd.	6/12/20 1400	6/19/20 1400	ND		ND	
E5914	2	Waterfall Creek at Access Rd.	6/19/20 1400	7/7/20 0930	ND		ND	
E6573	2	Waterfall Creek at Access Rd.	7/7/20 0930	7/30/20 1315	ND		ND	
<b>D9188</b>	<b>3</b>	<b>Waterfall Creek upstream of Glacier Creek</b>	<b>10/28/19 1015</b>	<b>10/30/19 1202</b>	<b>ND</b>		<b>ND</b>	
D9197	3	Waterfall Creek upstream of Glacier Creek	10/30/19 1202	10/31/19 1025	ND		ND	
D9207	3	Waterfall Creek upstream of Glacier Creek	10/31/19 1025	11/2/19 1125	ND		ND	
D9351	3	Waterfall Creek upstream of Glacier Creek	11/2/19 1125	11/5/19 1045	ND		ND	
D9361	3	Waterfall Creek upstream of Glacier Creek	11/5/19 1045	11/8/19 0935	ND		ND	
D9496	3	Waterfall Creek upstream of Glacier Creek	11/8/19 0935	11/12/19 1105	ND		ND	
D9506	3	Waterfall Creek upstream of Glacier Creek	11/12/19 1105	11/15/19 1000	ND		ND	
D9712	3	Waterfall Creek upstream of Glacier Creek	11/15/19 1000	11/19/19 1110	ND		ND	
	3	Waterfall Creek upstream of Glacier Creek	11/19/19 1110	11/26/19 1130	wso			
	3	Waterfall Creek upstream of Glacier Creek	11/26/19 1130	12/3/19 1005	wso			
E0074	3	Waterfall Creek upstream of Glacier Creek	12/3/19 1005	12/10/19 0920	ND		ND	
E6574	3	Waterfall Creek upstream of Glacier Creek	12/3/19 1005	7/29/20 1630	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
<b>D9189</b>	<b>4</b>	<b>Hangover Creek at Access Road</b>	<b>10/28/19 1040</b>	<b>10/30/19 1256</b>	<b>ND</b>		<b>ND</b>	
D9198	4	Hangover Creek at Access Road	10/30/19 1256	10/31/19 1100	ND		ND	
D9208	4	Hangover Creek at Access Road	10/31/19 1100	11/2/19 1205	ND		ND	
D9352	4	Hangover Creek at Access Road	11/2/19 1205	11/5/19 1135	ND		ND	
D9362	4	Hangover Creek at Access Road	11/5/19 1135	11/8/19 1035	ND		ND	
D9497	4	Hangover Creek at Access Road	11/8/19 1035	11/12/19 1145	ND		ND	
D9497D	4	Hangover Creek at Access Road	11/8/19 1035	11/12/19 1145	ND		ND	
D9507	4	Hangover Creek at Access Road	11/12/19 1145	11/15/19 1030	ND		ND	
D9713	4	Hangover Creek at Access Road	11/15/19 1030	11/19/19 1135	517.8 *	0.181	ND	
D9713D	4	Hangover Creek at Access Road	11/15/19 1030	11/19/19 1135	ND		ND	
D9722	4	Hangover Creek at Access Road	11/19/19 1135	11/26/19 1215	ND		ND	
D9722D	4	Hangover Creek at Access Road	11/19/19 1135	11/26/19 1215	ND		ND	
E0066	4	Hangover Creek at Access Road	11/26/19 1215	12/3/19 1050	ND		ND	
E0075	4	Hangover Creek at Access Road	12/3/19 1050	12/10/19 1010	ND		ND	
E6575	4	Hangover Creek at Access Road	7/22/20 1300	7/30/20 1415	ND		ND	
<b>D9190</b>	<b>5</b>	<b>Hangover Creek upstream of Glacier Creek</b>	<b>10/28/19 1120</b>	<b>10/30/19 1320</b>	<b>ND</b>		<b>ND</b>	
D9199	5	Hangover Creek upstream of Glacier Creek	10/30/19 1320	10/31/19 1125	ND		ND	
D9209	5	Hangover Creek upstream of Glacier Creek	10/31/19 1125	11/2/19 1225	ND		ND	
D9353	5	Hangover Creek upstream of Glacier Creek	11/2/19 1225	11/5/19 1150	ND		ND	
D9363	5	Hangover Creek upstream of Glacier Creek	11/5/19 1150	11/8/19 1050	ND		ND	
D9498	5	Hangover Creek upstream of Glacier Creek	11/8/19 1050	11/12/19 1200	ND		ND	
D9508	5	Hangover Creek upstream of Glacier Creek	11/12/19 1200	11/15/19 1105	ND		ND	
D9714	5	Hangover Creek upstream of Glacier Creek	11/15/19 1105	11/19/19 1205	ND		ND	





**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D9723	5	Hangover Creek upstream of Glacier Creek	11/19/19 1205	11/26/19 1230	ND		ND	
E0067	5	Hangover Creek upstream of Glacier Creek	11/26/19 1230	12/3/19 1120	ND		ND	
E0076	5	Hangover Creek upstream of Glacier Creek	12/3/19 1120	12/10/19 1025	ND		ND	
E5816	5	Hangover Creek upstream of Glacier Creek	12/10/19 1025	6/19/20 1215	ND		ND	
E5915	5	Hangover Creek upstream of Glacier Creek	6/19/20 1215	7/7/20 1045	ND		ND	
E6576	5	Hangover Creek upstream of Glacier Creek	7/7/20 1045	7/30/20 1430	ND		ND	
<b>D9191</b>	<b>6</b>	<b>Glacier Creek upstream of Hangover Creek</b>	<b>10/28/19 1130</b>	<b>10/30/19 1328</b>	<b>ND</b>		<b>ND</b>	
D9201	6	Glacier Creek upstream of Hangover Creek	10/30/19 1328	10/31/19 1132	ND		ND	
D9210	6	Glacier Creek upstream of Hangover Creek	10/31/19 1132	11/2/19 1235	ND		ND	
D9210D	6	Glacier Creek upstream of Hangover Creek	10/31/19 1132	11/2/19 1235	ND		ND	
D9354	6	Glacier Creek upstream of Hangover Creek	11/2/19 1235	11/5/19 1200	ND		ND	
D9364	6	Glacier Creek upstream of Hangover Creek	11/5/19 1200	11/8/19 1100	ND		ND	
D9364D	6	Glacier Creek upstream of Hangover Creek	11/5/19 1200	11/8/19 1100	ND		ND	
D9499	6	Glacier Creek upstream of Hangover Creek	11/8/19 1100	11/12/19 1210	ND		ND	
D9509	6	Glacier Creek upstream of Hangover Creek	11/12/19 1210	11/15/19 1110	ND		ND	
D9715	6	Glacier Creek upstream of Hangover Creek	11/15/19 1110	11/19/19 1210	ND		ND	
D9724	6	Glacier Creek upstream of Hangover Creek	11/19/19 1210	11/26/19 1240	ND		ND	
E0068	6	Glacier Creek upstream of Hangover Creek	11/26/19 1240	12/3/19 1130	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E0077	6	Glacier Creek upstream of Hangover Creek	12/3/19 1130	12/10/19 1030	ND		ND	
E5817	6	Glacier Creek upstream of Hangover Creek	6/12/20 1130	6/19/20 1145	ND		ND	
E5916	6	Glacier Creek upstream of Hangover Creek	6/19/20 1145	7/7/20 1100	ND		ND	
E6577	6	Glacier Creek upstream of Hangover Creek	7/7/20 1100	7/30/20 1445	ND		ND	
<b>D9192</b>	<b>7</b>	<b>Glacier Creek 110 feet downstream of Waterfall Creek</b>	<b>10/28/19 1020</b>	<b>10/30/19 1210</b>	<b>ND</b>		<b>ND</b>	
D9202	7	Glacier Creek 110 feet downstream of Waterfall Creek	10/30/19 1210	10/31/19 1035	ND		ND	
D9211	7	Glacier Creek 110 feet downstream of Waterfall Creek	10/31/19 1035	11/2/19 1135	ND		ND	
D9355	7	Glacier Creek 110 feet downstream of Waterfall Creek	11/2/19 1135	11/5/19 1050	ND		ND	
D9365	7	Glacier Creek 110 feet downstream of Waterfall Creek	11/5/19 1050	11/8/19 0945	ND		ND	
D9501	7	Glacier Creek 110 feet downstream of Waterfall Creek	11/8/19 0945	11/12/19 1110	ND		ND	
D9510	7	Glacier Creek 110 feet downstream of Waterfall Creek	11/12/19 1110	11/15/19 1010	ND		ND	
D9716	7	Glacier Creek 110 feet downstream of Waterfall Creek	11/15/19 1010	11/19/19 1115	ND		ND	
D9725	7	Glacier Creek 110 feet downstream of Waterfall Creek	11/19/19 1115	11/26/19 1140	ND		ND	
E0069	7	Glacier Creek 110 feet downstream of Waterfall Creek	11/26/19 1140	12/3/19 1010	ND		ND	
E0069D	7	Glacier Creek 110 feet downstream of Waterfall Creek	11/26/19 1140	12/3/19 1010	ND		ND	
E0078	7	Glacier Creek 110 feet downstream of Waterfall Creek	12/3/19 1010	12/10/19 0930	ND		ND	
<b>D9193</b>	<b>8</b>	<b>Glacier Creek 100 feet downstream of Hangover Creek</b>	<b>10/28/19 1140</b>	<b>10/30/19 1336</b>	<b>ND</b>		<b>ND</b>	
D9203	8	Glacier Creek 100 feet downstream of Hangover Creek	10/30/19 1336	10/31/19 1140	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D9212	8	Glacier Creek 100 feet downstream of Hangover Creek	10/31/19 1140	11/2/19 1250	ND		ND	
D9356	8	Glacier Creek 100 feet downstream of Hangover Creek	11/2/19 1250	11/5/19 1210	ND		ND	
D9366	8	Glacier Creek 100 feet downstream of Hangover Creek	11/5/19 1210	11/8/19 1110	ND		ND	
D9502	8	Glacier Creek 100 feet downstream of Hangover Creek	11/8/19 1110	11/12/19 1220	ND		ND	
D9511	8	Glacier Creek 100 feet downstream of Hangover Creek	11/12/19 1220	11/15/19 1120	ND		ND	
D9717	8	Glacier Creek 100 feet downstream of Hangover Creek	11/15/19 1120	11/19/19 1215	ND		ND	
D9726	8	Glacier Creek 100 feet downstream of Hangover Creek	11/19/19 1215	11/26/19 1245	ND		ND	
E0070	8	Glacier Creek 100 feet downstream of Hangover Creek	11/26/19 1245	12/3/19 1140	ND		ND	
E0079	8	Glacier Creek 100 feet downstream of Hangover Creek	12/3/19 1140	12/10/19 1035	ND		ND	
E4355	8	Glacier Creek 100 feet downstream of Hangover Creek	12/10/19 1035	5/12/20 1345	ND		ND	
E4355D	8	Glacier Creek 100 feet downstream of Hangover Creek	12/10/19 1035	5/12/20 1345	ND		ND	
E4878	8	Glacier Creek 100 feet downstream of Hangover Creek	5/21/20 1230	5/28/20 1230	ND		ND	
	8	Glacier Creek 100 feet downstream of Hangover Creek	5/28/20 1230	6/12/20 1200	No samples received			
E5818	8	Glacier Creek 100 feet downstream of Hangover Creek	6/12/20 1200	6/19/20 1130	ND		ND	
E5917	8	Glacier Creek 100 feet downstream of Hangover Creek	6/19/20 1130	7/7/20 1115	ND		ND	
E6578	8	Glacier Creek 100 feet downstream of Hangover Creek	7/7/20 1115	7/30/20 1440	ND		ND	
<b>D9194</b>	<b>9</b>	<b>Glacier Creek mid point</b>	<b>10/29/19 0900</b>	<b>10/30/19 1506</b>	<b>ND</b>		<b>ND</b>	
D9204	9	Glacier Creek mid point	10/30/19 1506	10/31/19 1250	ND		ND	
D9213	9	Glacier Creek mid point	10/31/19 1250	11/2/19 1410	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
D9357	9	Glacier Creek mid point	11/2/19 1410	11/5/19 1330	ND		ND	
D9367	9	Glacier Creek mid point	11/5/19 1330	11/8/19 1215	ND		ND	
D9503	9	Glacier Creek mid point	11/8/19 1215	11/12/19 1350	ND		ND	
D9512	9	Glacier Creek mid point	11/12/19 1350	11/15/19 1215	ND		ND	
D9718	9	Glacier Creek mid point	11/15/19 1215	11/19/19 1315	ND		ND	
D9727	9	Glacier Creek mid point	11/19/19 1315	11/26/19 1345	ND		ND	
E0071	9	Glacier Creek mid point	11/26/19 1345	12/3/19 1340	ND		ND	
E0081	9	Glacier Creek mid point	12/3/19 1340	12/10/19 1140	ND		ND	
E1584	9	Glacier Creek mid point	12/10/19 1140	2/10/20 1115	ND		542.8	0.574
E1584D	9	Glacier Creek mid point	12/10/19 1140	2/10/20 1115	ND		544.4	0.188
E1990	9	Glacier Creek mid point	2/10/20 1115	2/22/20 1130	ND		ND	
E1990D	9	Glacier Creek mid point	2/10/20 1115	2/22/20 1130	ND		ND	
E2813	9	Glacier Creek mid point	2/22/20 1130	3/18/20 1330	ND		ND	
E2813D	9	Glacier Creek mid point	2/22/20 1130	3/18/20 1330	ND		ND	
E3852	9	Glacier Creek mid point	3/18/20 1330	4/20/20 1030	ND		ND	
E3852D	9	Glacier Creek mid point	3/18/20 1330	4/20/20 1030	ND		543.6	0.649
E4354	9	Glacier Creek mid point	4/20/20 1030	5/12/20 1045	ND		538.2 **	0.159
E4354D	9	Glacier Creek mid point	4/20/20 1030	5/12/20 1045	ND		544.0	0.134
E4877	9	Glacier Creek mid point	5/12/20 1345	5/28/20 1500	ND		ND	
E4877D	9	Glacier Creek mid point	5/12/20 1345	5/28/20 1500	ND		ND	
E5704	9	Glacier Creek mid point	5/28/20 1500	6/12/20 1430	ND		ND	
E5819	9	Glacier Creek mid point	6/12/20 1430	6/19/20 1030	ND		ND	
E5918	9	Glacier Creek mid point	6/19/20 1030	7/7/20 1145	ND		ND	

**Footnotes:** ND = No dye detected

\* = A fluorescence peak is present that does not meet all the criteria for a positive dye result. However, it has been calculated as though it was the tracer dye.

\*\* = A fluorescence peak is present that does not meet all the criteria for this dye. However, it has been calculated as a positive dye result.

wso = A water sample only was collected during this sampling period.

**Table 2B.** Results for Phase 1 water samples analyzed for the presence of fluorescein and eosine dyes. Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Collected	Fluorescein		Eosine	
				Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E5961	2	Waterfall upper	7/7/20 0930	ND		ND	
D9873	3	Waterfall Creek upstream of Glacier Creek	11/26/19 1130	ND		ND	
D9873R	3	Waterfall Creek upstream of Glacier Creek	11/26/19 1130	ND		ND	
E0097	3	Waterfall Creek upstream of Glacier Creek	12/3/19 1005	ND		ND	
D9872	4	Hangover Creek at Access Road	11/19/19 1135	ND		ND	
E1589	9	Glacier Creek mid point	2/10/20 1115	ND		ND	
E3950	9	Glacier Creek mid point	4/20/20 1030	ND		ND	

**Footnotes:** ND = No dye detected

**Table 3B.** Results for Phase 2 charcoal samplers analyzed for the presence of fluorescein and eosine dyes. Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E7085	101	GC U/S of Hangover	8/22/20 1545	8/23/20 1000	ND		ND	
E7103	101	GC U/S Hangover	8/23/20 1000	8/27/20 1230	ND		ND	
E7121	101	GC U/S Hangover	8/27/20 1230	8/31/20 1335	ND		ND	
E7410	101	GC U/S of Hangover	8/31/20 1335	9/7/20 1340	ND		ND	
E7456	101	GC U/S of Hangover	9/7/20 1340	9/14/20 1420	ND		ND	
E7586	101	GC U/S of Hangover	9/14/20 1420	9/21/20 1435	ND		ND	
E7851	101	GC U/S of Hangover	9/21/20 1435	10/1/20 1315	ND		ND	
	101	GC U/S of Hangover	10/1/20 1315	10/6/20 1225	wso			
E8301	101	GC U/S of Hangover	10/6/20 1225	10/15/20 1420	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E8553	101	GC U/S of Hangover	10/15/20 1420	10/26/20 1550	ND		ND	
E8912	101	GC U/S Hangover	10/26/20 1550	11/10/20 1205	ND		ND	
E9095	101	GC U/S of Hangover	11/10/20 1205	11/24/20 1245	ND		ND	
	101	GC U/S of Hangover	11/24/20 1245	8/7/21 1545	wso			
<b>E7086</b>	<b>102</b>	<b>GC D/S Hangover</b>	<b>8/19/20 1305</b>	<b>8/22/20 1500</b>	<b>ND</b>		<b>ND</b>	
E7104	102	GC D/S Hangover	8/22/20 1500	8/27/20 1200	ND		ND	
E7122	102	GC D/S Hangover	8/27/20 1200	8/31/20 1310	ND		ND	
E7411	102	GC D/S Hangover	8/31/20 1310	9/7/20 1315	ND		ND	
E7457	102	GC D/S Hangover	9/7/20 1315	9/14/20 1355	ND		ND	
E7587	102	GC D/S Hangover	9/14/20 1355	9/21/20 1415	ND		ND	
E7852	102	GC D/S Hangover	9/21/20 1415	10/1/20 1240	ND		ND	
E7996	102	GC D/S Hangover	10/1/20 1240	10/6/20 1200	ND		ND	
E8302	102	GC D/S Hangover	10/6/20 1200	10/15/20 1350	ND		ND	
E8554	102	GC D/S Hangover	10/15/20 1350	10/26/20 1515	ND		ND	
E8554D	102	GC D/S Hangover	10/15/20 1350	10/26/20 1515	ND		ND	
E8913	102	GC D/S Hangover	10/26/20 1515	11/10/20 1130	ND		ND	
E9096	102	GC D/S Hangover	11/10/20 1130	11/24/20 1200	ND		ND	
<b>E7087</b>	<b>103</b>	<b>GC near Oxide</b>	<b>8/19/20 1230</b>	<b>8/22/20 1440</b>	<b>ND</b>		<b>ND</b>	
E7105	103	GC near Oxide	8/22/20 1440	8/27/20 1150	ND		ND	
E7105D	103	GC near Oxide	8/22/20 1440	8/27/20 1150	ND		ND	
E7123	103	GC near Oxide	8/27/20 1150	8/31/20 1300	ND		ND	
E7412	103	GC near Oxide	8/31/20 1300	9/7/20 1305	ND		ND	
E7458	103	GC near Oxide	9/7/20 1305	9/14/20 1335	ND		ND	
E7588	103	GC near Oxide	9/14/20 1335	9/21/20 1405	ND		ND	
E7853	103	GC near Oxide	9/21/20 1405	10/1/20 1225	ND		ND	
E7997	103	GC near Oxide	10/1/20 1225	10/6/20 1150	ND		ND	
E8303	103	GC near Oxide	10/6/20 1150	10/15/20 1340	ND		ND	
E8555	103	GC near Oxide	10/15/20 1340	10/26/20 1500	ND		ND	
E8914	103	GC near Oxide	10/26/20 1500	11/10/20 1046	ND		ND	
E9097	103	GC near Oxide	11/10/20 1046	11/24/20 1125	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E9636	103	GC near Oxide	11/24/20 1125	12/18/20 1035	ND		ND	
E9985	103	GC near Oxide	12/18/20 1035	1/4/21 1130	ND		ND	
	103	GC near Oxide	1/4/21 1130	8/7/21 1435	wso			
<b>E7088</b>	<b>104</b>	<b>GC U/S Concrete</b>	<b>8/19/20 1210</b>	<b>8/22/20 1420</b>	<b>ND</b>		<b>ND</b>	
E7106	104	GC U/S Concrete	8/22/20 1420	8/27/20 1140	ND		ND	
E7124	104	GC U/S Concrete	8/27/20 1140	8/31/20 1250	ND		ND	
E7413	104	GC U/S Concrete	8/31/20 1250	9/7/20 1300	ND		ND	
E7459	104	GC U/S Concrete	9/7/20 1300	9/14/20 1325	ND		ND	
E7459D	104	GC U/S Concrete	9/7/20 1300	9/14/20 1325	ND		ND	
E7589	104	GC U/S Concrete	9/14/20 1325	9/21/20 1355	ND		ND	
E7854	104	GC U/S Concrete	9/21/20 1355	10/1/20 1215	ND		ND	
E7998	104	GC U/S Concrete	10/1/20 1215	10/6/20 1140	ND		ND	
E8304	104	GC U/S Concrete	10/6/20 1140	10/15/20 1330	ND		ND	
E8556	104	GC U/S Concrete	10/15/20 1330	10/26/20 1435	ND		ND	
E8915	104	GC U/S Concrete	10/26/20 1435	11/9/20 1430	ND		ND	
E9098	104	GC U/S Concrete	11/9/20 1430	11/24/20 1100	ND		ND	
E9637	104	GC U/S Concrete	11/24/20 1100	12/18/20 1050	ND		ND	
E9986	104	GC U/S Concrete	12/18/20 1050	1/4/21 1140	ND		ND	
	104	GC U/S Concrete		8/7/21 1350	wso			
<b>E7089</b>	<b>105</b>	<b>GC U/S Xmas Creek</b>	<b>8/17/20 1645</b>	<b>8/21/20 1145</b>	<b>ND</b>		<b>ND</b>	
E7107	105	GC U/S Xmas Creek	8/21/20 1145	8/27/20 1025	ND		ND	
E7125	105	GC U/S Xmas Creek	8/27/20 1025	8/31/20 1130	ND		ND	
E7414	105	GC U/S Xmas Creek	8/31/20 1130	9/7/20 1200	ND		ND	
E7461	105	GC U/S Xmas Creek	9/7/20 1200	9/14/20 1220	ND		ND	
E7590	105	GC U/S Xmas Creek	9/14/20 1220	9/21/20 1215	ND		ND	
E7855	105	GC U/S Xmas Creek	9/21/20 1215	10/1/20 1040	ND		ND	
E7999	105	GC U/S Xmas Creek	10/1/20 1040	10/6/20 1030	ND		ND	
E8305	105	GC U/S Xmas Creek	10/6/20 1030	10/15/20 1210	ND		ND	
E8557	105	GC U/S Xmas Creek	10/15/20 1210	10/26/20 1215	ND		ND	
E8916	105	GC U/S Xmas Creek	10/26/20 1215	11/9/20 1245	ND		ND	
E8916D	105	GC U/S Xmas Creek	10/26/20 1215	11/9/20 1245	ND		ND	





**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E9099	105	GC U/S Xmas Creek	11/9/20 1245	11/23/20 1225	ND		ND	
E9638	105	GC U/S Xmas Creek	11/23/20 1225	12/18/20 1230	ND		ND	
E9987	105	GC U/S Xmas Creek	12/18/20 1230	1/5/21 1330	ND		ND	
<b>E7090</b>	<b>106</b>	<b>GC D/S Xmas CRK</b>	<b>8/17/20 1610</b>	<b>8/21/20 1120</b>	<b>ND</b>		<b>ND</b>	
E7108	106	GC D/S Xmas CRK	8/21/20 1120	8/27/20 1015	ND		ND	
E7126	106	GC D/S Xmas CRK	8/27/20 1015	8/31/20 1110	ND		ND	
E7126D	106	GC D/S Xmas CRK	8/27/20 1015	8/31/20 1110	ND		ND	
E7415	106	GC D/S Xmas CRK	8/31/20 1110	9/7/20 1145	ND		ND	
E7462	106	GC D/S Xmas CRK	9/7/20 1145	9/14/20 1200	ND		ND	
E7591	106	GC D/S Xmas CRK	9/14/20 1200	9/21/20 1155	ND		ND	
E7856	106	GC D/S Xmas CRK	9/21/20 1155	10/1/20 1105	ND		ND	
E8001	106	GC D/S Xmas CRK	10/1/20 1105	10/6/20 1015	ND		ND	
E8306	106	GC D/S Xmas CRK	10/6/20 1015	10/15/20 1200	ND		ND	
E8558	106	GC D/S Xmas CRK	10/15/20 1200	10/26/20 1145	ND		ND	
E8917	106	GC D/S Xmas CRK	10/26/20 1145	11/9/20 1215	ND		ND	
E9101	106	GC D/S Xmas CRK	11/9/20 1215	11/23/20 1150	ND		ND	
E9639	106	GC D/S Xmas CRK	11/23/20 1150	12/19/20 1200	ND		ND	
E9988	106	GC D/S Xmas CRK	12/19/20 1200	1/5/21 1230	ND		ND	
F3751	106	GC D/S Xmas CRK	1/5/21 1230	8/7/21 1110	ND		ND	
F3751D	106	GC D/S Xmas CRK	1/5/21 1230	8/7/21 1110	ND		ND	
<b>E7091</b>	<b>107</b>	<b>GC D/S Red Crk</b>	<b>8/17/20 1520</b>	<b>8/21/20 1100</b>	<b>ND</b>		<b>ND</b>	
E7109	107	GC D/S Red Crk	8/21/20 1100	8/27/20 0945	ND		ND	
E7127	107	GC D/S Red Crk	8/27/20 0945	8/31/20 1040	ND		ND	
E7416	107	GC D/S Red Crk	8/31/20 1040	9/7/20 1125	ND		ND	
E7463	107	GC D/S Red Crk	9/7/20 1125	9/14/20 1135	ND		ND	
E7592	107	GC D/S Red Crk	9/14/20 1135	9/21/20 1140	ND		ND	
E7857	107	GC D/S Red Crk	9/21/20 1140	10/1/20 1010	ND		ND	
E8002	107	GC D/S Red Crk	10/1/20 1010	10/6/20 0955	ND		ND	
E8307	107	GC D/S Red Crk	10/6/20 0955	10/15/20 1140	ND		ND	
E8559	107	GC D/S Red Crk	10/15/20 1140	10/26/20 1115	ND		ND	
E8918	107	GC D/S Red Crk	10/26/20 1115	11/9/20 1138	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E9102	107	GC D/S Red Crk	11/9/20 1138	11/23/20 1107	ND		ND	
E9641	107	GC D/S Red Crk	11/23/20 1107	12/19/20 1100	ND		ND	
E9989	107	GC D/S Red Crk	12/19/20 1100	1/5/21 1140	ND		ND	
F3752	107	GC D/S Red Crk	1/5/21 1140	8/8/21 0900	ND		ND	
<b>E7092</b>	<b>108</b>	<b>GC @ Old Bridge</b>	<b>8/19/20 1500</b>	<b>8/21/20 1015</b>	<b>ND</b>		<b>ND</b>	
E7110	108	GC @ Old Bridge	8/21/20 1015	8/27/20 0900	ND		ND	
E7128	108	GC @ Old Bridge	8/27/20 0900	8/31/20 0945	ND		ND	
E7417	108	GC @ Old Bridge	8/31/20 0945	9/7/20 1050	ND		ND	
E7464	108	GC @ Old Bridge	9/7/20 1050	9/14/20 1100	ND		ND	
E7593	108	GC @ Old Bridge	9/14/20 1100	9/21/20 1110	ND		ND	
E7858	108	GC @ Old Bridge	9/21/20 1110	10/1/20 0930	ND		ND	
E8003	108	GC @ Old Bridge	10/1/20 0930	10/6/20 0915	ND		ND	
E8003D	108	GC @ Old Bridge	10/1/20 0930	10/6/20 0915	ND		ND	
E8308	108	GC @ Old Bridge	10/6/20 0915	10/15/20 1105	ND		ND	
E8561	108	GC @ Old Bridge	10/15/20 1105	10/26/20 0955	ND		ND	
E8919	108	GC @ Old Bridge	10/26/20 0955	11/9/20 1030	ND		ND	
E9103	108	GC @ Old Bridge	11/9/20 1030	11/23/20 1025	ND		ND	
E9642	108	GC @ Old Bridge	11/23/20 1025	12/17/20 1335	ND		ND	
E9990	108	GC @ Old Bridge	12/17/20 1335	1/4/21 1030	ND		ND	
	108	GC @ Old Bridge	1/4/21 1030	8/7/21 1020	wso			
<b>E7093</b>	<b>109</b>	<b>Tributaries Waterfall Cr. U/S GC</b>	<b>8/19/20 1350</b>	<b>8/22/20 1600</b>	<b>ND</b>		<b>ND</b>	
E7111	109	Tributaries Waterfall Cr. U/S GC	8/22/20 1600	8/27/20 1245	ND		ND	
E7129	109	Tributaries Waterfall Cr. U/S GC	8/27/20 1245	8/31/20 1345	ND		ND	
E7418	109	Tributaries Waterfall Cr. U/S GC	8/31/20 1345	9/7/20 1350	ND		ND	
E7465	109	Tributaries Waterfall Cr. U/S GC	9/7/20 1350	9/14/20 1430	ND		ND	
E7594	109	Tributaries Waterfall Cr. U/S GC	9/14/20 1430	9/21/20 1450	ND		ND	
E7859	109	Tributaries Waterfall Cr. U/S GC	9/21/20 1450	10/1/20 1325	ND		ND	
E8004	109	Tributaries Waterfall Cr. U/S GC	10/1/20 1325	10/6/20 1230	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E8309	109	Tributaries Waterfall Cr. U/S GC	10/6/20 1230	10/15/20 1430	ND		ND	
E8562	109	Tributaries Waterfall Cr. U/S GC	10/15/20 1430	10/26/20 1630	ND		ND	
E8921	109	Tributaries Waterfall Cr. U/S GC	10/26/20 1630	11/10/20 1235	ND		ND	
E9104	109	Tributaries Waterfall Cr. U/S GC	11/10/20 1235	11/24/20 1310	ND		ND	
F3753	109	Tributaries Waterfall Cr. U/S GC	11/23/20 1330	8/7/21 1530	ND		ND	
F3753D	109	Tributaries Waterfall Cr. U/S GC	11/23/20 1330	8/7/21 1530	ND		ND	
<b>E7094</b>	<b>110</b>	<b>Hangover U/S GC</b>	<b>8/19/20 1330</b>	<b>8/22/20 1525</b>	<b>ND</b>		<b>ND</b>	
E7112	110	Hangover U/S GC	8/22/20 1525	8/27/20 1225	ND		ND	
E7130	110	Hangover U/S GC	8/27/20 1225	8/31/20 1330	ND		ND	
E7419	110	Hangover U/S GC	8/31/20 1330	9/7/20 1335	ND		ND	
E7466	110	Hangover U/S GC	9/7/20 1335	9/14/20 1415	ND		ND	
E7595	110	Hangover U/S GC	9/14/20 1415	9/21/20 1430	ND		ND	
E7861	110	Hangover U/S GC	9/21/20 1430	10/1/20 1310	ND		ND	
E8005	110	Hangover U/S GC	10/1/20 1310	10/6/20 1220	ND		ND	
E8310	110	Hangover U/S GC	10/6/20 1220	10/15/20 1415	ND		ND	
E8563	110	Hangover U/S GC	10/15/20 1415	10/26/20 1540	ND		ND	
E8922	110	Hangover U/S GC	10/26/20 1540	11/10/20 1155	ND		ND	
E9105	110	Hangover U/S GC	11/10/20 1155	11/24/20 1235	ND		ND	
	110	Hangover U/S GC	11/24/20 1235	8/7/21 1600	wso			
<b>E7095</b>	<b>111</b>	<b>Seep D/S Hangover /GC Conf.</b>	<b>8/19/20 1320</b>	<b>8/22/20 1515</b>	<b>ND</b>		<b>ND</b>	
E7113	111	Seep D/S Hangover /GC Conf.	8/22/20 1515	8/27/20 1215	ND		ND	
E7131	111	Seep D/S Hangover /GC Conf.	8/27/20 1225	8/31/20 1320	ND		ND	
E7421	111	Seep D/S Hangover /GC Conf.	8/31/20 1320	9/7/20 1330	ND		ND	
E7467	111	Seep D/S Hangover /GC Conf.	9/7/20 1330	9/14/20 1405	ND		ND	
E7596	111	Seep D/S Hangover /GC Conf.	9/14/20 1405	9/21/20 1425	ND		ND	
E7496D	111	Seep D/S Hangover /GC Conf.	9/14/20 1405	9/21/20 1425	ND		ND	
E7862	111	Seep D/S Hangover /GC Conf.	9/21/20 1425	10/1/20 1300	ND		ND	
E8006	111	Seep D/S Hangover /GC Conf.	10/1/20 1300	10/6/20 1215	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E8311	111	Seep D/S Hangover /GC Conf.	10/6/20 1215	10/15/20 1405	ND		ND	
E8564	111	Seep D/S Hangover /GC Conf.	10/15/20 1405	10/26/20 1530	ND		ND	
E8923	111	Seep D/S Hangover /GC Conf.	10/26/20 1530	11/10/20 1145	ND		ND	
E9106	111	Seep D/S Hangover /GC Conf.	11/10/20 1145	11/24/20 1220	ND		ND	
<b>E7096</b>	<b>112</b>	<b>Concrete Crk #2 U/S GC</b>	<b>8/19/20 1155</b>	<b>8/22/20 1415</b>	<b>ND</b>		<b>ND</b>	
E7114	112	Concrete Crk #2 U/S GC	8/22/20 1415	8/27/20 1130	ND		ND	
E7132	112	Concrete Crk #2 U/S GC	8/27/20 1130	8/31/20 1245	ND		ND	
E7422	112	Concrete Crk #2 U/S GC	8/31/20 1245	9/7/20 1240	ND		ND	
E7468	112	Concrete Crk #2 U/S GC	9/7/20 1240	9/14/20 1320	ND		ND	
E7597	112	Concrete Crk #2 U/S GC	9/14/20 1320	9/21/20 1350	ND		ND	
E7863	112	Concrete Crk #2 U/S GC	9/21/20 1350	10/1/20 1205	ND		ND	
E8007	112	Concrete Crk #2 U/S GC	10/1/20 1205	10/6/20 1130	ND		ND	
E8312	112	Concrete Crk #2 U/S GC	10/6/20 1130	10/15/20 1320	ND		ND	
	112	Concrete Crk #2 U/S GC	10/15/20 1320	10/27/20 1245	wso			
E8924	112	Concrete Crk #2 U/S GC	10/27/20 1245	11/9/20 1415	ND		ND	
E9107	112	Concrete Crk #2 U/S GC	11/9/20 1415	11/24/20 1045	ND		ND	
E9643	112	Concrete Crk #2 U/S GC	11/24/20 1045	12/18/20 1105	ND		ND	
E9991	112	Concrete Crk #2 U/S GC	12/18/20 1105	1/4/21 1150	ND		ND	
	112	Concrete Crk #2 U/S GC	1/4/21 1150	8/7/21 1330	wso			
<b>E7097</b>	<b>113</b>	<b>Concrete Crk #1 Access Rd</b>	<b>8/17/20 1720</b>	<b>8/21/20 1230</b>	<b>ND</b>		<b>ND</b>	
E7115	113	Concrete #1 Access Rd	8/21/20 1230	8/27/20 1115	ND		ND	
E7133	113	Concrete #1 Access Rd	8/27/20 1115	8/31/20 1210	ND		ND	
E7423	113	Concrete #1 Access Rd	8/31/20 1210	9/7/20 1230	ND		ND	
E7469	113	Concrete #1 Access Rd	9/7/20 1230	9/14/20 1305	ND		ND	
E7598	113	Concrete #1 Access Rd	9/14/20 1305	9/21/20 1340	ND		ND	
E7864	113	Concrete #1 Access Rd	9/21/20 1340	10/1/20 1140	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E8008	113	Concrete #1 Access Rd	10/1/20 1140	10/6/20 1100	ND		ND	
E8313	113	Concrete #1 Access Rd	10/6/20 1100	10/15/20 1250	ND		ND	
E8565	113	Concrete #1 Access Rd	10/15/20 1250	10/26/20 1325	ND		ND	
E8925	113	Concrete #1 Access Rd	10/26/20 1325	11/9/20 1355	ND		ND	
E9108	113	Concrete #1 Access Rd	11/9/20 1355	11/23/20 1340	ND		ND	
<b>E7098</b>	<b>114</b>	<b>Xmas Crk U/S GC</b>	<b>8/17/20 1620</b>	<b>8/21/20 1130</b>	<b>ND</b>		<b>ND</b>	
E7116	114	Xmas Crk U/S GC	8/21/20 1130	8/27/20 1020	ND		ND	
E7134	114	Xmas Crk U/S GC	8/27/20 1020	8/31/20 1115	ND		ND	
E7424	114	Xmas Crk U/S GC	8/31/20 1115	9/7/20 1145	ND		ND	
E7470	114	Xmas Crk U/S GC	9/7/20 1145	9/14/20 1210	ND		ND	
E7599	114	Xmas Crk U/S GC	9/14/20 1210	9/21/20 1210	ND		ND	
E7865	114	Xmas Crk U/S GC	9/21/20 1210	10/1/20 1035	ND		ND	
E8009	114	Xmas Crk U/S GC	10/1/20 1035	10/6/20 1025	ND		ND	
E8314	114	Xmas Crk U/S GC	10/6/20 1025	10/15/20 1205	ND		ND	
E8566	114	Xmas Crk U/S GC	10/15/20 1205	10/26/20 1205	ND		ND	
E8926	114	Xmas Crk U/S GC	10/26/20 1205	11/9/20 1230	ND		ND	
E9109	114	Xmas Crk U/S GC	11/9/20 1230	11/23/20 1200	ND		ND	
E9644	114	Xmas Crk U/S GC	11/23/20 1200	12/19/20 1220	ND		ND	
E9992	114	Xmas Crk U/S GC	12/19/20 1220	1/5/21 1245	ND		ND	
F3754	114	Xmas Crk U/S GC	1/5/21 1245	8/7/21 1120	ND		ND	
F3754D	114	Xmas Crk U/S GC	1/5/21 1245	8/7/21 1120	ND		ND	
<b>E7099</b>	<b>115</b>	<b>Xmas Crk East Branch @ Rd</b>	<b>8/17/20 1720</b>	<b>8/21/20 1200</b>	<b>ND</b>		<b>ND</b>	
E7117	115	Xmas Crk East Branch @ Rd	8/21/20 1200	8/27/20 1100	ND		ND	
E7135	115	Xmas Crk East Branch @ Rd	8/27/20 1100	8/31/20 1150	ND		ND	
E7425	115	Xmas Crk East Branch @ Rd	8/31/20 1150	9/7/20 1215	ND		ND	
E7471	115	Xmas Crk East Branch @ Rd	9/7/20 1215	9/14/20 1240	ND		ND	
E7601	115	Xmas Crk East Branch @ Rd	9/14/20 1240	9/21/20 1235	ND		ND	
E7866	115	Xmas Crk East Branch @ Rd	9/21/20 1235	10/1/20 1118	ND		ND	
E8010	115	Xmas Crk East Branch @ Rd	10/1/20 1118	10/6/20 1045	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E8315	115	Xmas Crk East Branch @ Rd	10/6/20 1045	10/15/20 1230	ND		ND	
E8567	115	Xmas Crk East Branch @ Rd	10/15/20 1230	10/26/20 1230	ND		ND	
E8927	115	Xmas Crk East Branch @ Rd	10/26/20 1230	11/9/20 1305	ND		ND	
E9110	115	Xmas Crk East Branch @ Rd	11/9/20 1305	11/23/20 1311	ND		ND	
F3755	115	Xmas Crk East Branch @ Rd	11/23/20 1311	8/7/21 1200	ND		ND	
F3755D	115	Xmas Crk East Branch @ Rd	11/23/20 1311	8/7/21 1200	ND		ND	
<b>E7101</b>	<b>116</b>	<b>Xmas Crk West Branch @ Rd</b>	<b>8/17/20 1725</b>	<b>8/21/20 1215</b>	<b>ND</b>		<b>ND</b>	
E7118	116	Xmas Crk West Branch @ Rd	8/21/20 1215	8/27/20 1105	ND		ND	
E7136	116	Xmas Crk West Branch @ Rd	8/27/20 1105	8/31/20 1200	ND		ND	
E7426	116	Xmas Crk West Branch @ Rd	8/31/20 1200	9/7/20 1225	ND		ND	
E7472	116	Xmas Crk West Branch @ Rd	9/7/20 1225	9/14/20 1300	ND		ND	
E7602	116	Xmas Crk West Branch @ Rd	9/14/20 1300	9/21/20 1245	ND		ND	
E7867	116	Xmas Crk West Branch @ Rd	9/21/20 1245	10/1/20 1125	ND		ND	
E7867D	116	Xmas Crk West Branch @ Rd	9/21/20 1245	10/1/20 1125	ND		ND	
E8011	116	Xmas Crk West Branch @ Rd	10/1/20 1125	10/6/20 1055	ND		ND	
E8316	116	Xmas Crk West Branch @ Rd	10/6/20 1055	10/15/20 1240	ND		ND	
E8568	116	Xmas Crk West Branch @ Rd	10/15/20 1240	10/26/20 1315	ND		ND	
E8928	116	Xmas Crk West Branch @ Rd	10/26/20 1315	11/9/20 1340	ND		ND	
E9111	116	Xmas Crk West Branch @ Rd	11/9/20 1340	11/23/20 1320	ND		ND	
E9645	116	Xmas Crk West Branch @ Rd	11/23/20 1320	12/17/20 1220	ND		ND	
E9993	116	Xmas Crk West Branch @ Rd	12/17/20 1220	1/4/21 1300	ND		ND	
F3756	116	Xmas Crk West Branch @ Rd	1/4/21 1300	8/7/21 1215	ND		ND	
F3756D	116	Xmas Crk West Branch @ Rd	1/4/21 1300	8/7/21 1215	ND		ND	
F3756T	116	Xmas Crk West Branch @ Rd	1/4/21 1300	8/7/21 1215	ND		ND	
<b>E7102</b>	<b>117</b>	<b>Red Crk U/S GC</b>	<b>8/17/20 1535</b>	<b>8/21/20 1115</b>	<b>ND</b>		<b>ND</b>	
E7119	117	Red Crk U/S GC	8/21/20 1115	8/27/20 1000	ND		ND	
E7137	117	Red Crk U/S GC	8/27/20 1000	8/31/20 1050	ND		ND	



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

OUL Number	Station Number	Station Name	Date/Time Placed	Date/Time Collected	Fluorescein		Eosine	
					Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
E7427	117	Red Crk U/S GC	8/31/20 1050	9/7/20 1130	ND		ND	
E7473	117	Red Crk U/S GC	9/7/20 1130	9/14/20 1145	ND		ND	
E7603	117	Red Crk U/S GC	9/14/20 1145	9/21/20 1145	ND		ND	
E7603D	117	Red Crk U/S GC	9/14/20 1145	9/21/20 1145	ND		ND	
E7868	117	Red Crk U/S GC	9/21/20 1145	10/1/20 1015	ND		ND	
E8012	117	Red Crk U/S GC	10/1/20 1015	10/6/20 1005	ND		ND	
E8317	117	Red Crk U/S GC	10/6/20 1005	10/15/20 1150	ND		ND	
E8569	117	Red Crk U/S GC	10/15/20 1150	10/26/20 1125	ND		ND	
E8929	117	Red Crk U/S GC	10/26/20 1125	11/9/20 1155	ND		ND	
E9112	117	Red Crk U/S GC	11/9/20 1155	11/23/20 1130	ND		ND	
E9646	117	Red Crk U/S GC	11/23/20 1130	12/19/20 1120	ND		ND	
E9994	117	Red Crk U/S GC	12/19/20 1120	1/5/21 1200	ND		ND	
F3757	117	Red Crk U/S GC	1/5/21 1200	8/8/21 0920	ND		ND	
F3757D	117	Red Crk U/S GC	1/5/21 1200	8/8/21 0920	ND		ND	

Footnotes: ND = No dye detected      NT = No time given      wso = Water sample only

**Table 4B.** Results for Phase 2 water samples analyzed for the presence of fluorescein and eosine dyes. Peak wavelengths are reported in nanometers (nm); dye concentrations are reported in parts per billion (ppb).

OUL Number	Station Number	Station Name	Date/Time Collected	Fluorescein		Eosine	
				Peak (nm)	Conc. (ppb)	Peak (nm)	Conc. (ppb)
<b>E8121</b>	<b>101</b>	<b>GC U/S Hangover</b>	<b>10/6/20 1225</b>	ND		ND	
F3772	101	GC U/S Hangover	8/7/21 1545	ND		ND	
<b>F3773</b>	<b>103</b>	<b>GC near Oxide</b>	<b>8/7/21 1435</b>	ND		ND	
<b>F3774</b>	<b>104</b>	<b>GC U/S Concrete</b>	<b>8/7/21 1350</b>	ND		ND	
<b>F3775</b>	<b>107</b>	<b>GC D/S Red Crk</b>	<b>8/8/21 0900</b>	ND		ND	
<b>F3776</b>	<b>108</b>	<b>GC @ Old Bridge</b>	<b>8/7/21 1020</b>	ND		ND	
<b>F3777</b>	<b>109</b>	<b>Tributaries Waterfall Cr. U/S GC</b>	<b>8/7/21 1530</b>	ND		ND	
<b>F3778</b>	<b>110</b>	<b>Hangover U/S GC</b>	<b>8/7/21 1600</b>	ND		ND	
<b>E8667</b>	<b>112</b>	<b>Concrete Crk #2 U/S GC</b>	<b>10/27/20 1245</b>	ND		ND	
F3779	112	Concrete Crk #2 U/S GC	8/7/21 1330	ND		ND	





**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

---

F3781	114	Xmas Crk U/S GC	8/7/21 1120	ND		ND	
-------	-----	-----------------	-------------	----	--	----	--

**Footnotes:** ND = No dye detected



**Appendix C: Phase 1 and Phase 2 Precipitation Data**



Table 1C shows precipitation during the period from October 28, 2019 through February 10, 2020. This was the period that included the first detection of eosine dye at Station 9. There was a total of 14.50 inches of precipitation during this 104-day monitoring period. Table 2C shows precipitation during the Phase 2 tracer study period from August 23, 2020 through June 22, 2021. There was a total of 35.35 inches of precipitation during this period.

**Table 1C. Precipitation during the Phase 1 study period. Data from Glacier Creek precipitation station in units of inches.**

Day	Oct. 2019	Nov. 2019	Dec. 2019	Jan. 2020	Feb. 2020
1		0.00	0.34	0.34	0.06
2		0.00	0.31	0.13	0.00
3		0.00	0.00	0.06	0.00
4		0.58	0.01	0.02	0.02
5		0.09	0.00	0.00	0.13
6		0.09	0.00	0.03	0.00
7		0.05	0.00	0.05	0.00
8		0.03	0.05	0.00	0.00
9		0.00	0.00	0.00	0.00
10		0.00	0.01	0.00	0.08
11		0.00	0.20	0.00	
12		0.04	0.34	0.01	
13		0.08	0.01	0.00	
14		0.09	0.00	0.00	
15		0.09	0.00	0.00	
16		0.40	0.06	0.00	
17		0.04	0.82	0.00	
18		0.00	0.31	0.00	
19		0.01	0.05	0.26	
20		1.58	0.00	0.17	
21		0.32	0.00	0.06	
22		0.59	0.05	0.07	
23		0.13	0.04	0.46	
24		0.09	0.02	0.22	
25		0.01	0.51	0.64	
26		0.01	0.21	0.96	
27		0.00	0.45	0.32	
28	0.00	0.00	0.23	0.34	
29	0.04	0.02	0.05	1.19	
30	0.00	0.02	0.00	0.10	
31	0.00		0.34	0.31	
Total	0.04	4.36	4.41	5.74	0.29

**Study Period Total: 14.84 inches**



**Dye Tracing Studies  
Land Application Disposal System  
Constantine Mining**

**Table 2C.** Precipitation during the Phase 2 study period. Data from Glacier Creek precipitation station in units of inches.

Day	Aug. 2020	Sept. 2020	Oct. 2020	Nov. 2020	Dec. 2020	Jan. 2021	Feb. 2021	March 2021	April 2021	May 2021	June 2021
1		0.02	0.00	0.52	2.41	0.00	0.00	0.17	0.10	0.02	0.03
2		0.13	0.81	0.38	2.99	0.00	0.00	0.50	0.01	0.03	0.11
3		0.07	0.12	0.13	0.30	0.00	0.00	0.04	0.00	0.00	0.14
4		0.00	0.00	0.35	0.65	0.07	0.00	0.22	0.01	0.06	0.02
5		0.00	0.01	0.00	0.73	1.02	0.00	0.03	0.03	0.00	0.13
6		0.00	0.03	0.00	0.45	0.35	0.00	0.15	0.00	0.08	0.50
7		0.00	0.00	0.00	0.25	0.15	0.00	0.00	0.00	0.00	0.00
8		0.02	0.05	0.05	0.09	0.54	0.00	0.00	0.17	0.01	0.00
9		0.00	0.13	0.04	0.01	0.29	0.00	0.00	0.28	0.00	0.00
10		0.00	0.07	0.00	0.00	0.98	0.00	0.00	0.00	0.00	0.00
11		0.00	0.01	0.06	0.00	0.37	0.00	0.15	0.00	0.00	0.00
12		0.00	0.00	0.11	0.00	0.33	0.00	0.01	0.09	0.00	0.00
13		0.00	0.00	0.04	0.00	0.06	0.00	0.00	0.02	0.01	0.00
14		0.00	0.00	0.04	0.00	0.11	0.00	0.00	0.06	0.04	0.00
15		0.00	0.00	0.02	0.00	0.72	0.00	0.02	0.01	0.10	0.11
16		0.00	0.20	0.00	0.00	0.25	0.00	0.13	0.05	0.00	0.00
17		0.00	0.00	0.00	0.00	0.37	0.00	0.68	0.04	0.00	0.00
18		0.00	0.00	0.00	0.00	0.30	0.25	0.15	0.00	0.00	0.00
19		0.00	0.00	0.00	0.01	0.57	0.36	0.00	0.00	0.00	0.00
20		0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.08
21		0.20	0.00	0.28	0.00	0.00	0.20	0.13	0.01	0.18	0.00
22		0.18	0.00	0.68	0.01	0.01	0.11	0.00	0.00	0.00	0.00
23	0.00	0.33	0.00	0.53	0.25	0.13	0.01	0.17	0.00	0.00	
24	0.02	0.02	0.00	0.23	0.00	0.05	0.11	0.05	0.00	0.28	
25	0.00	0.12	0.00	0.08	0.00	0.01	0.28	0.00	0.00	0.03	
26	0.00	0.19	0.00	0.18	0.19	0.00	0.00	0.00	0.00	0.15	
27	0.06	1.44	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	
28	0.24	0.17	0.00	1.10	0.04	0.00	0.59	0.00	0.00	0.00	
29	0.00	0.00	0.00	1.32	0.06	0.00		0.00	0.00	0.00	
30	0.17	0.09	0.14	0.00	0.00	0.00		0.00	0.01	0.00	
31	0.20		0.39		0.00	0.00		0.43		0.30	
<b>Total</b>	<b>0.69</b>	<b>2.98</b>	<b>1.96</b>	<b>6.14</b>	<b>8.44</b>	<b>6.68</b>	<b>2.03</b>	<b>3.13</b>	<b>0.89</b>	<b>1.29</b>	<b>1.12</b>

**Study Period Total: 35.35 inches**