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Analysis of Groundwater Flow from Electric Lake Towards the Skyline Mine

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Abstract

This report documents analyses of tritium, noble gases, and chlorofluorocarbons (collectively referred to as environmental tracers) that have been performed on waters collected in the vicinity of Electric Lake and Skyline Mine. These analyses provide insights regarding groundwater flow and the transport of solutes dissolved in this groundwater. They have been used to develop a conceptual hydrologic model that describes interactions between the surface and subsurface hydrologic systems.

The primary conclusion of this report is that substantial quantities of surface water in the vicinity of Electric Lake are being diverted towards subsurface discharge points (mine workings and dewatering wells.) The rapid introduction of surface water is likely to have resulted from fractures that were either created or enlarged as mining activities moved towards Electric Lake in 1999. The basis for this conclusion is that the isotopic and chemical character of subsurface discharge is evolving towards that of surface water with this evolution commencing in approximately 2001. A mathematical model of flow and transport along fracture pathways predicts that the isotopic character of subsurface discharge will continue to evolve for more than 10 years as water in pores surrounding fracture pathways is gradually replaced by surface water. While the model predicts a gradual evolution in the chemical and isotopic character of subsurface discharge, it predicts a rapid (nearly instantaneous) effect on the surface water hydrology. The model is fully consistent with losses on the order of 5000 gal/min of water from Electric Lake as documented by water balance studies.

This report is organized as follows. Evidence that shows the presence of surface water in subsurface is discharge is first presented. The most direct evidence comes from a large number of tritium analyses, and is supported by a smaller number of dissolved gas measurements. These data are then evaluated in the context of a mathematical model that simulates the transport of environmental tracers along fracture pathways. Finally, the data and mathematical modeling are discussed in terms of a conceptual model for the impact of subsurface flow on the surface water hydrology of the site. For reference, an overview of the use of environmental tracers to evaluate groundwater flow is presented in Appendix A.

This report was originally prepared in May, 2004. It has been updated to include tritium data from samples collected through March, 2005.

Evidence for the Presence of Surface Water in Subsurface Discharge

Tritium

Tritium is a radioactive isotope of hydrogen with a half-life and 12.3 years. Tritium in natural waters is derived mostly from nuclear sources (reactors, weapons testing and productions, etc.) and because of its half-life is present at only very low concentrations in subsurface water that is older than about 50 years. Figure 1 shows tritium values as a

function of time for samples collected from wells JC1, JC3, and from underground mine workings. Also shown in Figure 1 are tritium values obtained by the Skyline Mine. Tritium data are located in Table 1. The most prominent feature of Figure 1 is the consistent increase in tritium with time. For example, the tritium value for JC1 was 0.2 TU in September of 2001 and has risen to 3.0 TU in March of 2005. While the only long-term time series is from well JC1, it is clear from Figure 1 that this well is also representative of water in mine workings (which could not be sampled directly after 2002 due to flooding in the mine.) Table 1 also shows tritium values from various surface sources including Electric Lake and Huntington Creek. These values range from 7.7 to 12.6 TU with an average of about 9 TU. The continuous increase in tritium through time with values reaching 3.0 TU (March 2005) can only occur by the rapid and downward movement of surface water to subsurface discharge points.

Tritium/Helium-3

In addition to tritium, samples were collected for analysis of dissolved gases. Dissolved noble gases (especially helium-3) can be combined with tritium to estimate groundwater ages. The utility of groundwater dating using tritium and helium-3 has been well documented in the scientific literature (Poreda et al. 1988; Solomon et al.,1992; Solomon et al. 1993; Cook and Solomon, 1997; Solomon and Cook, 2000.) These samples were analyzed at the University of Utah and the results are shown in Table 2. Also shown are calculated values such as the apparent age of the water (or recharge year) and the amount of terrigenic ^{4}He (He that is derived from radioactive decay in the subsurface.)

Apparent tritiuim/helium-3 ages were 18 and 16 years for samples collected from JC1 and JC3 in 2003. Because this water is a mixture of old and young water (discussed later in more detail) the age calculation is sensitive to the isotopic composition of He produced in the subsurface (terrigenic He) and this value is not well known. As a result, there is significant uncertainty in these ages, probably on the order ± 7 years. In a mixture of young and old water, the tritium/helium-3 age is biased strongly towards the young fraction. Thus, I interpret these ages to represent the mean travel time of tritium moving from the surface towards the well intake. However, there is a broad range of travel times even within the young (tritiated) fraction of water that discharges at the wells. Thus, the apparent ages should not be confused with the shortest travel times in this system but rather is more representative of the mean travel time for the young fraction of water. Furthermore, as shown with the mathematical model later in this report, the travel distance divided by the apparent travel time does NOT provide a measure of fluid velocity in fracture pathways. This is because exchange with pore water that surrounds fracture pathways influences the chemical and isotopic composition of discharging waters.

CFCs

Samples were also analyzed for dissolved chlorofluorocarbons (CFC) that can also be used to estimate the occurrence of surface water in subsurface flow systems (Busenberg and Plummer, 1992, Cook and Solomon, 1997.) Apparent CFC recharge years were

computed and are shown in Table 3. Because CFC ages are determined using absolute concentrations, they are highly affected by dilution of young water with old (CFC-free) water. Thus, the CFC ages shown in Table 3 do NOT represent travel times. They are included in Table 3 to show that the apparent age has been declining through time as more and more young water makes it to the well intakes. The primary value of the CFCs is that they can be used to indicate the fraction of old versus young water that is discharging from the wells (discussed in next section of this report.)

Fraction of Surface Water in Subsurface Discharge

While the environmental tracer data clearly indicate the presence of "young" surface water in subsurface discharge, the data also indicate that older groundwater is also discharging. The analysis below provides estimates of the fraction of young surface water that is discharging from the subsurface.

The tritium value for JC1 was 0.2 TU in September of 2001 and had risen to 2.7 TU in March of 2004. Tritium in surface waters ranges from 7.7 to 12.6 TU with an average of about 9 TU. A simple binary mixing model can be developed to estimate the fraction of young surface water this has discharged in JC1 as a function of time. Because the tritium content of the old fraction is insignificant, the fraction of modern water (MF) can simply be computed as

MF = "Mixture Tritium"/"Modern Tritium".

The results of this calculation are shown in Figure 2. The calculation was made using concentrations of both 9 and 12 TU for "Modern Tritium" and do not account for radioactive decay. The fraction of modern water ranges from near zero in 2001 to 0.30 (30%) in March of 2004. Figure 2 also shows linear regressions of the results for both the 9 and 12 TU values for "Modern Tritium." The linear trends intercept the x axis (date) in May, 2001 (i.e. the date when the "Modern Fraction" is 0.) These trend lines extrapolate to a modern fraction of 1 (100%) in November 2009 and September 2012 for the 9 and 12 TU "Modern Tritium" respectively. As discussed later, I don't expect this trend to remain linear nor do I expect the "Mixture Tritium" to ever reach the "Modern Tritium" value (due to radioactive decay); however, it is clear from these trends alone that years (not months) are required before the modern fraction approaches 1. While the above calculations do not account for radioactive decay (which would make the modern fraction even greater), the mathematical model presented later does show that neglecting decay in the above calculations is not a significant issue at the current point in time, but may be significant in the future. This linear mixing model was applied only to the data between 2001 and 2003 because non-linear behavior is clear in the data beyond 2003.

Another indicator of the fraction of modern water present in JC1 discharge comes from the CFC data. An optimization technique (using the Solver in Microsoft Excel) was used to find the modern fraction that best fits all three of the CFC values measured (CFC-11, CFC-12, and CFC-113.) The results of these calculations are shown in Table 4. The CFC concentration of the old fraction was assumed to be 0. As shown in Table 4, the modern fraction in JC1 changed from 0.02 in March 2003 to 0.44 in August 2003. While

these values are not in perfect agreement with the tritium results, they show the same general pattern of an increasing fraction of modern water with time. The CFC concentration of the old fraction is not well known and may in fact be greater than zero due to gas transport in the vadose zone. CFC concentrations greater than zero for the old fraction would results in a lower modern fraction that is closer to the tritium results. While the CFC results are less reliable than the tritium, they nevertheless show the same trend and both techniques indicate that at the present point in time significant amounts modern surface waters are discharging from the subsurface.

Simulation of Tritium Transport

The environmental tracer data clearly show a gradual increase in the presence of surface water at subsurface discharge points. On the other hand, water balance calculations show that major losses from Electric Lake began in late 1999 and have continued to the present. Furthermore, in April 2003 a dye tracer test was started by injecting 50 pounds of eosine dye mixture and 35 pounds of fluorescein mixture on the bottom of Electric Lake. Small, but above background concentrations of fluorescein were detected in JC1 discharge in June, 2003. The appearance of detectable dye in approximately 65 days suggests a minimum fluid velocity that is on the order of 30 m/day (approximately 8400 feet in 65 days.) A subsequent dye test was initiated in February of 2004 and the dye was detected in JC1 in early 2005 suggesting a velocity on the order of 7.2 m/day. This rapid transport is strong evidence for fluid movement along fractures rather intergranular flow. However, the 65- and 355-day dye travel times and the rapid onset of losses from Electric Lake might appear to be inconsistent with the tritium and CFC binary mixing results (i.e. years to reach a modern fraction that approaches 1.) However, as discussed below, these results are consistent with a model of rapid fluid flow along fractures accompanied with mass exchange (due to molecular diffusion) into the surrounding porous matrix. This model illustrates how a rapid onset of the diversion of surface water accompanied with large fluid velocities along fracture pathways is consistent with a more gradual increase in tritium and other environmental tracers.

Fluid and solute transport in a fractured rock mass are controlled by both advection and molecular diffusion. Fluid velocities along fracture pathways can be very large (tens to thousands of meters per day) and very large quantities of fluid can be conveyed through millimeter-size fractures. When a dissolved tracer is introduced into the fracture flow system, it will be transported rapidly by flowing water (advection), but due to its thermal energy will tend to migrate out of the fracture into the surrounding porous matrix. This process is known as matrix diffusion (Grisak and Pickens, 1980; Tang et al., 1981; Sudicky, 1989) and results in a net tracer movement that can be substantially less than the fluid velocity in the fracture. When fractures exist in rocks that contain minimal intergranular porosity, the effects of matrix diffusion are small. In contrast, when small fractures exist in rocks or sediments with high intergranular porosity, the net transport rate of tracer can be orders of magnitude less than the fluid velocity in the fractures.

An analogy to matrix diffusion is when heat is introduced to one end of an efficient heat exchanger. Even though the fluid velocity inside the heat exchanger may be large, high temperature fluid introduced at one end does not rapidly appear at the downstream end of

the exchanger because of heat loss out of the system. In fact, depending on the efficiency of the exchanger and the heat capacity of the surrounding system, the temperature at the downstream end may never reach that of the inlet and can remain at a significantly lower temperature. If the exchanger is surrounded by an insulator (as in the case when fractures are in crystalline rocks that have minimal matrix porosity), the temperature at the downstream end will rapidly approach that of the inlet.

I have utilized a computer program known as CRAFLUSH, developed by E. A. Sudicky at the University of Waterloo to simulate tritium transport. CRAFLUSH evaluates an analytical solution to differential equations that describe fluid advection in a system of parallel fractures along with molecular diffusion into the surrounding matrix. Figure 3 is a conceptual diagram that illustrates this model. Input data for two separate model runs (el2.dat and el5.dat) are shown below.

Input Data for Model el2.dat

SOURCE CONCENTRATION AT FRACTURE ORIGIN= 10.0000 TU
INITIAL CONCENTRATION IN MATRIX AND FRACTURES= .0000 TU
VELOCITY IN FRACTURE= 25000.000 m/yr
FRACTURE DISPERSIVITY= 1.000 m
FRACTURE APERTURE= 0.8000E-03 m
FRACTURE SPACING= 1.000 m
MATRIX POROSITY= .100
MATRIX TORTUOSITY= .500
DIFF. COEFF. IN WATER= 0.3150E-01 m^2/yr
FRACTURE RETARDATION FACTOR= 1.000
MATRIX RETARDATION FACTOR= 1.000
HALF-LIFE= 0.124E+02 yr

Input Data for Model el5.dat

SOURCE CONCENTRATION AT FRACTURE ORIGIN= 10.0000 TU
INITIAL CONCENTRATION IN MATRIX AND FRACTURES= .0000 TU
VELOCITY IN FRACTURE= 350000.000 m/yr
FRACTURE DISPERSIVITY= 1.000 m
FRACTURE APERTURE= 0.2500E-03 m
FRACTURE SPACING= 1.000 m
MATRIX POROSITY= .200
MATRIX TORTUOSITY= .700
DIFF. COEFF. IN WATER= 0.3150E-01 m^2/yr
FRACTURE RETARDATION FACTOR= 1.000
MATRIX RETARDATION FACTOR= 1.000
HALF-LIFE= 0.124E+02 yr

In model el2.dat the fluid velocity in the fracture was set to 25,000 m/yr, and in model el5.dat the velocity was set to 350,000 m/yr. Other differences in the models are in the fracture aperture (fracture width) and the matrix porosity. Model el2.dat uses a matrix porosity of 10% and a fracture aperture of 0.8 mm, whereas model el5.dat uses a matrix porosity of 20% and a fracture aperture of 0.25 mm. Also, model el2.dat is for a transport distance of 2000 m whereas el5.dat uses a transport distance of 4000 m. These models cover a range of possible values that are reasonable for the system.

The results of these simulations are shown in Figure 4 along with observed tritium values from well JC1. Both of the models provide a good fit with the observed data, although the most recent values (late 2004 to early 2005) fall below the simulated values. This illustrates that the models are not unique (i.e. there are many combinations of parameters such as matrix porosity and fracture aperture that can fit the data equally well); however, these results show that it is possible to transport tritium from the surface without having the tritium concentration rapidly change to that of the input value. Furthermore, the model is consistent with the very rapid transport of small concentrations of dye.

An important result from the CRAFLUSH model is that the tritium concentration in JC1 will continue to increase in the coming years, but not in a linear fashion. Both the simulations shown in Figure 4 (el2.dat and el5.dat) predict that tritium will approach a stable value of about 6 TU. More than 10 years are required in both simulations to reach this steady state value. This value is less than the input value of 10 TU because of radioactive decay. A simulation was performed with input parameters identical to el2.dat except with no radioactive decay. Approximately 25 years were required to reach a concentration near 10 TU at a distance of 2000 m from the source. The difference between the simulation without and with radioactive decay represents the approximate amount of tritiogenic ^{3}He in the water. The ratio of tritiogenic ^{3}He to tritium is used to calculate the tritium/helium-3 age. The simulated age varies with time and is about 1 year after 2 years of transport and increases to about 8 years when the tritium value reaches a steady state. This increase in the apparent age is consistent with observations (see Table 1), but the absolute values of the observed ages are greater than the simulated values. This may be a result of the inherent uncertainty in the observed ages due to uncertainty in the ^{3}He/^{4}He ratio of terrigenic He. Nevertheless, the observed and simulated ages are of the same order of magnitude and both show a general increase with time.

A final important point about the tritium transport model is that **all** subsurface discharge is assumed to come from transport along fracture pathways that are connected to surface water. It is likely that some intergranular flow occurs in the vicinity of dewatering wells and mine discharge that mixes with fracture flow before discharging. A more realistic model of tritium transport might include both fracture and intergranular flow. Indeed, the fact that the most recent tritium data (late 2004 to early 2005) fall below the model may indicate the presence of a component of "old" intergranular flow. However, additional site characterization is needed before such a model could be implemented in a meaningful manner. The CRAFLUSH model is not intended to be a precise representation of subsurface flow conditions at the site. Rather, it demonstrates that it is

physically possible to rapidly transport measured losses from Electric Lake towards subsurface discharge points while having the chemical signal of the discharge gradually approach that of the surface water.

Fluid Flow Rates

The CRAFLUSH model includes fluid flow only in the fractures with intergranular flow being negligible. JC1 has been pumping approximately 4000 gal/min throughout the year 2003 with an additional 3000 to 5000 gal/min from JC3 beginning in July of 2003. Water balance studies have shown that losses from Electric Lake are on the order of 5000 gal/min in 2002 and 2003. To evaluate the viability of a model in which all flow occurs in fractures, I have computed the total fluid flow rate possible for the two fracture apertures used in simulations el2.dat and el5.dat. This was done using the well-known cubic law that relates the total fluid flow to the cube of the fracture aperture as follows:

$$Q = \frac{\rho g W b^3}{12\mu} i$$

where, Q is the fluid flow rate [m^3/s], ρ is the fluid density [kg/m^3], W is the total length of fractures (map view) [m], b is the fracture aperture [m], I is the hydraulic gradient, and μ is the fluid viscosity [kg/m/s]. The water level in Electric Lake is approximately 8500 feet. On 6/19/2002 the water level in an observation well in Burnout Canyon (Well 79-35-1) was 8195 feet (Canyon Fuels Map No. PHC A-4). If this water level is representative of JC1, then the vertical hydraulic gradient is approximately (8500-8195)/700 = 0.44 (where 700 is the depth of the observation well below Electric Lake.) Setting Q to 0.315 m^3/s (5000 gal/min), with ρ = 1000 kg/m^3 and μ = 0.0013 kg/m/s, it is possible to calculate the length of fractures (W) necessary to transmit 5000 gal/min from Electric Lake for the two different values of aperture (0.8 and 0.25 mm) used in the transport simulations. The results show that for an aperture of 0.8 mm a total length of 2226 m is needed. Electric Lake is approximately 200 m wide, and thus 11 fractures that extend the width of the lake that each has an aperture of 0.8 mm are sufficient to transmit 5000 gal/min of water from Electric Lake to subsurface discharge points. For an aperture of 0.25 mm, a total length of about 72,935 m, or 365 fractures that extends across Electric Lake is sufficient to transmit 5000 gal/min.

Although both of the simulations (el2.dat and el5.dat) provide reasonable fits to the observed data, it is important to note that fluid velocity used in simulation el2.dat is significantly less than the velocity that would occur along a fracture with an aperture of 0.8 mm when the hydraulic gradient is 0.44. In contrast, the velocity used in simulation el5.dat is consistent with an aperture of 0.25 mm (as used in the simulation) and a hydraulic gradient of about 0.3 that is similar to the gradient discussed above. Thus, only one of the two simulations presented appears to be consistent with both the time series of tritium in discharge and the observed hydraulic gradient. This suggests that a moderate number of fractures (≈ 350) with apertures that are on the order of 0.25 mm may be responsible for fluid and mass transport in this system.

Conceptual Model

The environmental tracer data presented in this report are consistent with the following conceptual model. Pore waters within the Star Point Sandstone are part of a regional flow system that has a mean residence time on the order of thousands of years. This age is consistent with both the ^{4}He measurements presented in this report, and ^{14}C measurements presented by Mayo and Morris (2000.) It is highly unlikely that these pore waters are connate and hydraulically isolated from the near surface flow system. Instead, it is likely that sluggish (but finite) flow occurs in this system as a result of regional hydraulic gradients and the generally low permeability of this formation. Superimposed on this regional flow system are fast fracture flow paths. A small number of these pathways may have existed prior to mining activities, but both water balance calculations and evolving (changing with time) environmental tracer data indicate that the onset of significant flow is coincident with mining activities in this area.

Tritiated water from the surface began moving towards subsurface discharge points at the onset of losses from Electric Lake. Initially, much of the discharge would have the character of old stored water, but the fraction of old water will continually decrease with time. In this model, the subsurface discharge may include a significant draining of old stored water as well as having a large impact on the surface water system.

Alternative Model

If one considers only the tritium data at a selected point in time, it is possible to explain small values in subsurface discharge resulting from a steady-state mixture of minor amounts of surface water with large amounts of old groundwater. For example, in September 2001 the tritium content of JC1 was 0.2 TU and this represents a modern fraction of only about 2 %. Without the benefit of other data, one might conclude that the majority of subsurface discharge is derived from the Starr Point Sandstone that generally contains tritium-free water. Tritium in discharge is conveyed from the surface and mixes with the old water in the Star Point Sandstone. A characteristic feature of this model is that the majority of discharge is derived from stored water with only a modest input of modern water from the surface. Furthermore, this conceptual model implies that in the future, water will continue to drain from the Starr Point Standstone as it represents a very large volume of water. In other words, this alternative conceptual model represents a steady state mixture between mostly stored water and a small amount of surface water that will continue for a long period of time. However, when one considers (1) the increasing nature of the tritium and other environmental tracer data (2) large losses from Electric late beginning in 1999, and (3) the detection of dye in JC1 discharge, **this alternative conceptual model is not viable**.

Conclusions

The tritium, dissolved gas, and dye tracer results are consistent with a model of rapid fluid flow along fractures with mass exchange via diffusion with the surround porous matrix. These data are consistent with the onset of losses from Electric Lake derived from water balance calculations. The systematic increase in tritium in JC1 and other underground monitoring points is strong evidence for a fracture controlled flow system

that is conveying water from surface sources towards underground workings and dewatering wells. Binary mixing calculations show that water discharging from well JC1 is currently a mixture of approximately 22 to 45 % modern water that is derived from surface sources. A mathematical model of fluid flow and rapid solute transport along fractures indicates that the tritium content of JC1 will continue to increase, but will approach a value that is less than the modern value of surface water due to radioactive decay in the subsurface and possibly the mixing of young surface water with some old water stored in the subsurface. This model also indicates that more than 10 years are required before the tritium value will stabilize. Even though fluid velocities along fractures are large (30 to 1000 m/day), the net rate of solute movement is substantially lower due to matrix diffusion. However, the hydraulic effect on the surface hydrology from fracture flow is essentially instantaneous (i.e. water began draining from the surface system immediately after the formation of a connected system of fractures.)

While the mathematical modeling is not unique in that multiple combinations of input parameter can fit the observed data equally well, the model clearly indicate that it is physically possible to transport large quantities (more than 5000 gal/min) of water along a relatively small number of fractures. However, the simulation that is most consistent with all of the data suggests that a moderate number (≈ 350) of smaller fractures (aperture on the order of 0.25 mm) may be responsible for conveying surface water towards mine workings and dewatering wells.

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Appendix A

Overview of Tritium, Dissolved Gases, and Chlorofluorocarbons as Indicators of Groundwater Flow

Tritium

Tritium (^3H) is a radioactive isotope of hydrogen (12.43 year half-life.) Large amount of ^3H were introduced into the atmosphere as a result of thermonuclear weapons testing in the 1950s and 1960s. Small quantities are also produced naturally in the upper atmosphere mainly through the bombardment of nitrogen by the flux of neutrons in cosmic radiation. Prior to 1950 the ^3H activity of precipitation ranged from about 3 to 6 TU (1 TU represents one molecule of $^3H^1HO$ in 10^{18} molecules of ^1H_2O) in North America. In the mid 1960s, the ^3H activity of precipitation rose to more than 3000 TU in Ottawa, Canada, and to over 8000 TU in Salt Lake City. Although ^3H can also be produced in the subsurface (mostly through spontaneous fission of ^6Li; $^6Li(n,\alpha)^3H$), the activity in water resulting from average crustal rocks should be less than about 0.2 TU (Lehmann et al., 1993).

Because (1) of the spike-like input of into groundwater, and (2) because it is a part of the water molecule, ^3H is one of the most widely used dating methods in hydrology. In North America groundwater that originated as precipitation prior to 1950 should have a present day ^3H activity of less than 0.5 TU. The simplest use of ^3H is to distinguish pre-1950 ("pre-bomb) water from post-1950 water.

If the history of ^3H activity in recharge is well known, it is possible to obtain a more precise estimate of age. However, long-term ^3H records exist for only selected stations (see http://isohis.iaea.org/ for a comprehensive data base) and temporal variations (from season to season and even from storm to storm) make it difficult to define the ^3H input activity precisely at a given site. As a result, it is typically not possible to collect a single water sample and derive a precise age (e.g. ± 5 or 10 years) from a measurement of ^3H only.

Dissolved Gases

Gases dissolved in groundwater can be derived from either exchange with the atmosphere of the vadose zone, or can be generated within the aquifer. Noble gases that are primarily derived from the atmosphere include neon, argon, krypton, and xenon. Gases that are derived mostly from the atmosphere, but can be produced in significant amounts in the subsurface include nitrogen and helium.

For gases that are derived primarily from the atmosphere, the concentration in groundwater depends on the following.

1. The temperature at the water table (recharge temperature.)
2. The salinity at the water table.

3. The atmospheric pressure at the water table (controlled mostly be the elevation.)
4. The degree to which the water table fluctuates up and down trapping air bubbles which then dissolve (excess air.)

Items 1 through 3 result from equilibrium processes and the concentration associated with each of these can be calculated precisely using solubility equations. In contrast, item number 4 (excess air) is commonly observed in groundwater samples, but is difficult to estimate from a theoretical point of view. In practice, the concentration of each dissolved gas is expressed as follows:

$$C_i = Pt\, X_i\, K_i + X_i\, EA \quad (1)$$

where Pt is the total atmospheric pressure (and depends on elevation), X_i is the mole fraction of gas i in the atmosphere (e.g. 0.78 for N_2; 5.24 X 10^{-6} for ^4He), K_i is Henry's coefficient for gas i (and depends on temperature and salinity), and EA is the amount of excess air. If a series of dissolved gases are measured (that have either no or minimal subsurface source), then equation (1) can be written for each gas. This system of equations is then solved simultaneously to obtain estimates of the input parameters (e.g. temperature, atmospheric pressure, etc.) that best fit the observed data. Usually, the salinity of the water at the water table is low (and therefore does not significantly affect the concentration), and the elevation of recharge (and therefore the atmospheric pressure) is known. Under such conditions the only unknowns are the recharge temperature and the amount of excess air. If three or more atmospherically derived gases are measured, the determination of recharge temperature and excess air is relatively unique with a typical uncertainty in recharge temperature being ± 2 °C.

For gases that are derived from the atmosphere but are also produced in the subsurface, the concentration in groundwater depends on items 1 through 4 above, but also depends on the amount produced in the subsurface. The processes that produce gas in the subsurface are specific to each gas and are discussed below.

1. Dissolved nitrogen is mostly derived from the atmosphere, but can be produced in the subsurface as a result of denitrification of nitrates. Thus, values of dissolved nitrogen that are in excess of atmospheric solubility generally indicate that geochemical conditions in the aquifer are causing nitrate (NO_3^-) to be reduced to nitrogen gas (N_2).
2. Dissolved helium-4 is mostly derived from the atmosphere that contains 5.24 ppmv helium-4. However, as uranium and thorium decay to stable daughters, helium-4 is produced. This production occurs mostly within minerals in the subsurface. If these minerals completely retained the helium-4, there would be essentially no source for groundwater. However, most minerals do not retain helium-4 but rather it is released (e.g. due to solid state diffusion) into groundwater that flows past the minerals. As a result, the concentration of helium-4 in groundwater depends on the rate at which it is being released from minerals, and on the amount of time the water is in contact with these minerals (i.e. the travel time.) It is often assumed that the release of helium-4 from

minerals is equal to the production from uranium and thorium decay (i.e. after a steady state is obtained in the mineral.) To the extent that the U and Th concentrations in minerals and the ^4He release rate is spatially constant, ^4He concentrations above atmospheric solubility indicate groundwater travel times. Helium-4 produced in the subsurface is known as terrigenic ^4He and is estimated by subtracting the atmospheric concentration of ^4He from the measured value.

3. Dissolved helium-3 is mostly derived from the atmosphere that contains 7.252 X 10^{-6} ppmv (i.e. 7.252 parts of ^3He for every 10^{12} parts of air). However, when groundwater contains tritium (^3H), ^3He will be produced as a result of ^3H decay. Because the decay of ^3H is a first order rate process, the production of ^3He in the subsurface depends on the travel time. Thus, measurements of both ^3H and ^3He can be used to date groundwater. The amount of ^3He in groundwater that is derived from ^3H decay is known as tritiogenic ^3He and is estimated by subtracting the atmospheric concentration of ^3He from the measured value. Helium-3 can also be produced by neutrons in the subsurface interacting with lithium-6; however, this is typically only significant in waters that are older than a few hundred years. Atmospheric concentrations of ^3H were low prior to 1950, and then increased dramatically as a result of above-ground testing of thermonuclear weapons. As a result, the use of ^3H and ^3He to date groundwater is generally limited to waters younger than 1950. In practice the ratio of ^3He to ^4He (known as R) is typically reported rather than the absolute concentration. Furthermore, this ratio is usually referenced to the ratio of ^3He to ^4He in air (Ra). For example, a reported value for R/Ra of 1.100 means that the ^3He to ^4He ratio of the sample was 1.1 times greater than air. The air ratio (Ra) is 1.384 X 10^{-6}. To compute the absolute concentration of ^3He from the reported value, multiply the R/Ra value by 1.384 X 10^{-6} and then multiply this by the absolute concentration reported for ^4He.

Chlorofluorocarbons

Chlorofluorocarbons (CFCs) are stable volatile organic compounds that were first produced in the 1930s as refrigerants and have since been used for a variety of industrial and domestic purposes. The global distribution and temporal variations of CFCs are relatively well know as a result of extensive atmospheric measurements since 1978 at stations throughout the world.

The concentration of CFCs in recharging groundwater is given by Henry's law:

$$C_{CFC} = K_{CFC,T} P_{CFC}$$

where K is the Henry's law constant for the ith CFC compound at temperature T, and P is the atmospheric partial pressure of the ith CFC compound. By combining the atmospheric CFC growth curves and Henry's law solubilities at a given temperature it is possible to determine the expected concentrations of CFCs in water recharged between approximately 1950 and the present. Thus, measurements of CFCs dissolved in

groundwater can be related to the year in which the water was in equilibrium with the atmosphere providing a measure of groundwater travel times.

Table 1 Results of Tritium Analyses.

Site	Date	Tritium (TU)
10L Sump	7/2/02	1.31
10L Sump	7/16/02	1.16
10L Sump (alternate)	8/1/02	1.19
10L Sump	8/15/02	1.21
10L Sump	8/28/02	1.20
10L Sump (alternate)	9/13/02	1.18
10L Sump	9/23/02	1.46
9L Borehole XC59	4/10/02	0.16
9L Horizontal Borehole	7/2/02	0.17
9L Horizontal Borehole	8/15/02	0.86
9L Horizontal Borehole	8/28/02	0.83
9 Left Horizontal Borehole	9/23/02	0.24
JC-1	26-Sep-01	0.24
JC-1	24-May-02	1.00
JC-1	24-May-02	1.04
JC-1	4-Jun-02	0.96
JC-1	19-Jun-02	1.11
JC-1	28-Jun-02	1.18
JC-1	16-Jul-02	1.09
JC-1	1-Aug-02	1.22
JC-1	13-Sep-02	1.25
JC-1	24-Sep-02	1.50
JC-1	28-Sep-02	1.42
JC-1 argon purged	10-Dec-02	1.62
JC-1 triple rinsed	10-Dec-02	1.69
JC-1 argon purged	11-Dec-02	1.66
JC-1 triple rinsed	11-Dec-02	1.64
JC-1	31-Jan-03	1.80
JC-1	15-Feb-03	2.12
JC-1	10-Mar-03	1.59
JC-1	10-Mar-03	2.50
JC-1	10-Mar-03	1.70
JC-1	26-Mar-03	2.05
JC-1	21-Apr-03	1.94
JC-1	19-May-03	2.17
JC-1	7-Aug-03	2.43
JC-1	3-Sep-03	2.48
JC-1	23-Dec-03	2.57
JC-1	4-Mar-04	2.59

Site	Date	Tritium (TU)
JC-1	15-Apr-04	2.68
JC-1	4-Aug-04	2.72
JC-1	11-Oct-04	1.72
JC-1	28-Dec-04	2.91
JC-1	17-Feb-05	2.80
JC-1	17-Mar-05	2.99
JC-3	7-Aug-03	1.45
JC-3	20-Oct-03	2.23
JC-3	23-Dec-03	1.81
JC-3	4-Mar-04	1.94
JC-3	15-Apr-04	1.70
Upper Electric Lake	26-Aug-01	12.6
E. Lake-1 Mid Lake	24-May-02	7.67
E.Lake-2 North End	24-May-02	8.52
North End Shallow Elect.	11-Jul-02	8.48
North End Deep Elect.	11-Jul-02	8.49
South End Shallow Elect.	11-Jul-02	8.57
South End Deep Elect.	11-Jul-02	8.74
Huntington Creek	7-Aug-03	10.5

Table 2 Results of Dissolved Gas Analyses, Tritium, and Calculated Water Age.

Sample ID	Sample Date	Location	N2 (ccSTP/g)	Ar40 (ccSTP/g)	Ne20 (ccSTP/g)	He4 (ccSTP/g)	[1]R/Ra	Tritium (TU)	Apparent Age (yr)	TerrHe4 (ccSTP/g)
2002 Samples										
EL1-1	23-Sep-02	XC5E	0.0221	5.53E-04	3.00E-07	1.93E-07	0.426	0.0		1.1E-07
EL2-1	24-Sep-02	10 Left	0.0182	4.59E-04	2.37E-07	9.10E-08	0.701	1.6	4.0	2.8E-08
EL2-2	25-Sep-02	10 Left	0.0178	4.48E-04	2.15E-07	8.02E-08	0.717	1.6	6.1	2.4E-08
EL3-1	26-Sep-02	9L	0.0188	5.27E-04	2.55E-07	8.78E-08	0.693	0.3		1.9E-08
EL3-2	27-Sep-02	9L	0.0237	5.54E-04	2.60E-07	1.00E-07	0.699	0.3		3.0E-08
2003 Samples										
JC1-2	26-Mar-03	James Cny	0.0130	3.24E-04	1.62E-07	5.62E-08	0.844	1.8	18.0	1.5E-08
JC3-a	7-Aug-03	James Cny	0.0157	3.64E-04	1.87E-07	6.21E-08	0.838	1.5	15.7	1.3E-08

[1]R is the $^{3}He/^{4}He$ ratio of the sample, Ra is the $^{3}He/^{4}He$ ratio of the air standard (1.384×10^{-6})

Table 3 Results of CFC Analyses and Apparent Recharge Years.

SAMPLE ID and Collection Date	CFC-11 (pmoles/kg)	CFC-12 (pmoles/kg)	CFC-113 (pmoles/kg)	CFC-11 Rech. year	CFC-12 Rech. year	CFC-113 Rech. year
JC1-A mar 26, 2003	0.105	0.124	0.000	1956	1957	1943
JC1-C mar 26, 2003	0.118	0.131	0.000	1956.5	1957.5	1943
JC1-E mar 26, 2003	0.053	0.021	0.000	1953.5	1947.5	1943
JC1-B mar 26, 2003	0.076	0.029	0.000	1954.5	1948.5	1943
JC1-D mar 26, 2003	0.136	0.182	0.000	1957	1959.5	1943
JC1-F mar 26, 2003	0.066	0.031	0.000	1954.5	1949	1943
JC1-A aug 7, 2003	2.235	1.446	0.193	1974	1977.5	1981.5
JC1-B aug 7, 2003	2.263	1.444	0.158	1974	1977.5	1980
JC1-C aug 7, 2003	2.292	1.457	0.179	1974	1977.5	1980.5
JC1-D aug 7, 2003	2.352	1.483	0.190	1974	1977.5	1981
JC1-E aug 7, 2003	2.345	1.494	0.207	1974	1978	1982
JC1-F aug 7, 2003	2.347	1.519	0.204	1974	1978	1982
JC3-A aug 7, 2003	2.401	1.486	0.206	1974.5	1977.5	1982
JC3-B aug 7, 2003	2.444	1.466	0.214	1974.5	1977.5	1982
JC3-C aug 7, 2003	2.443	1.442	0.205	1974.5	1977.5	1982
JC3-D aug 7, 2003	2.362	1.513	0.221	1974.5	1978	1982.5
JC3-E aug 7, 2003	2.390	1.489	0.200	1974.5	1977.5	1981.5
JC3-F aug 7, 2003	2.359	1.513	0.196	1974.5	1978	1981.5

Table 4 CFC Concentrations (average of replicates) and Results of Binary Mixing Calculations.

SAMPLE and Collection Date	CFC-11 (pmoles/kg)	CFC-12 (pmoles/kg)	CFC-113 (pmoles/kg)	Modern Fraction	CFC-11 modern fraction (pmoles/kg)	CFC-12 modern fraction (pmoles/kg)	CFC-113 modern fraction (pmoles/kg)	CFC-11 mixture (pmoles/kg)	CFC-12 mixture (pmoles/kg)	CFC-113 mixture (pmoles/kg)
JC1 Mar 26, 2003	0.092	0.087	0.000	0.021	5.652	2.901	0.552	0.120	0.062	0.012
JC1 Aug 7, 2003	2.305	1.474	0.188	0.439	5.652	2.901	0.552	2.480	1.273	0.242
JC3 Aug 7, 2003	2.400	1.485	0.207	0.452	5.652	2.901	0.552	2.552	1.310	0.249

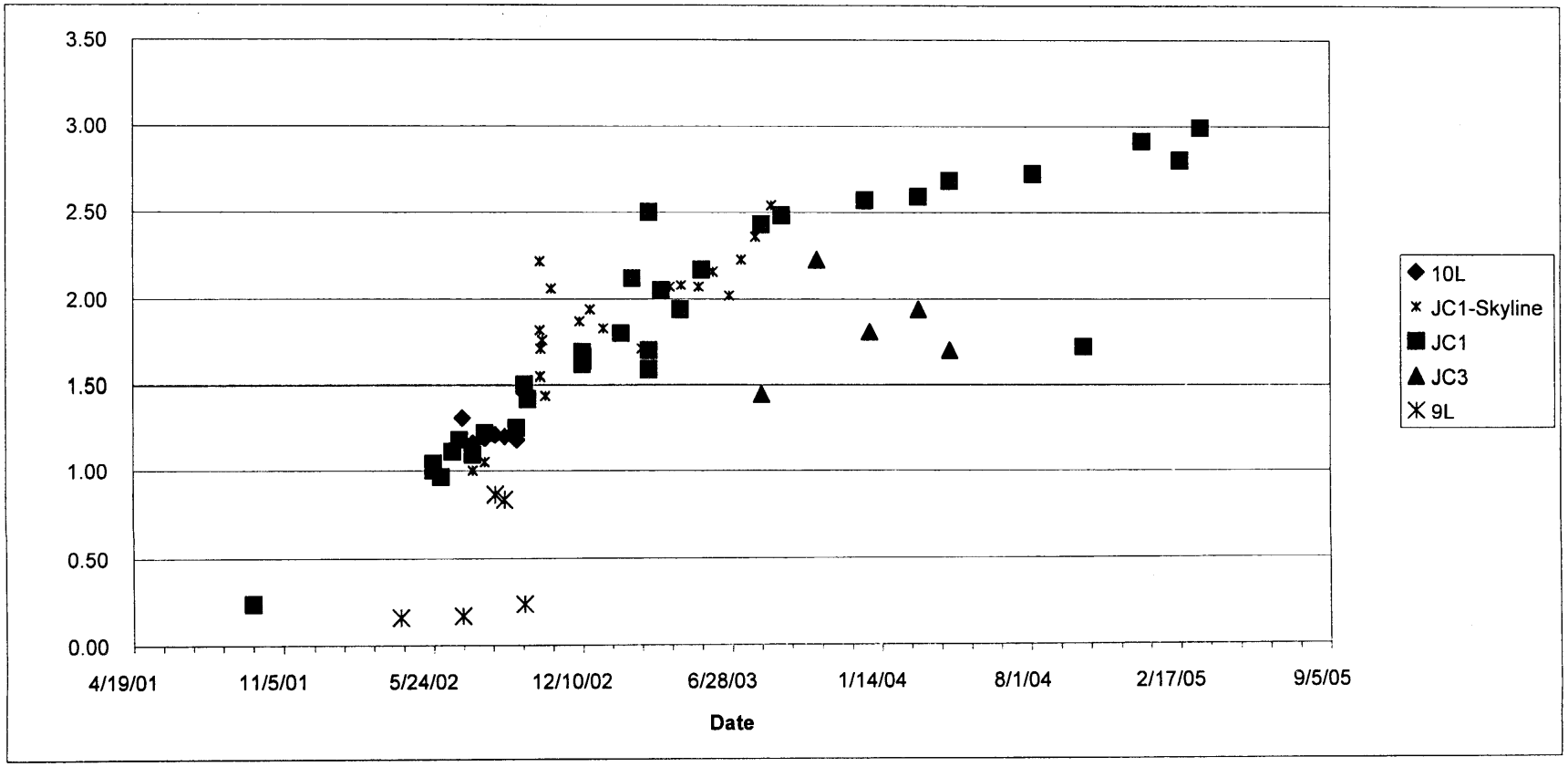

Figure 1 Time series of tritium values from underground mine workings (10L and 9L) and dewater wells (JC1 and JC3) in the vicinity of Electric Lake.

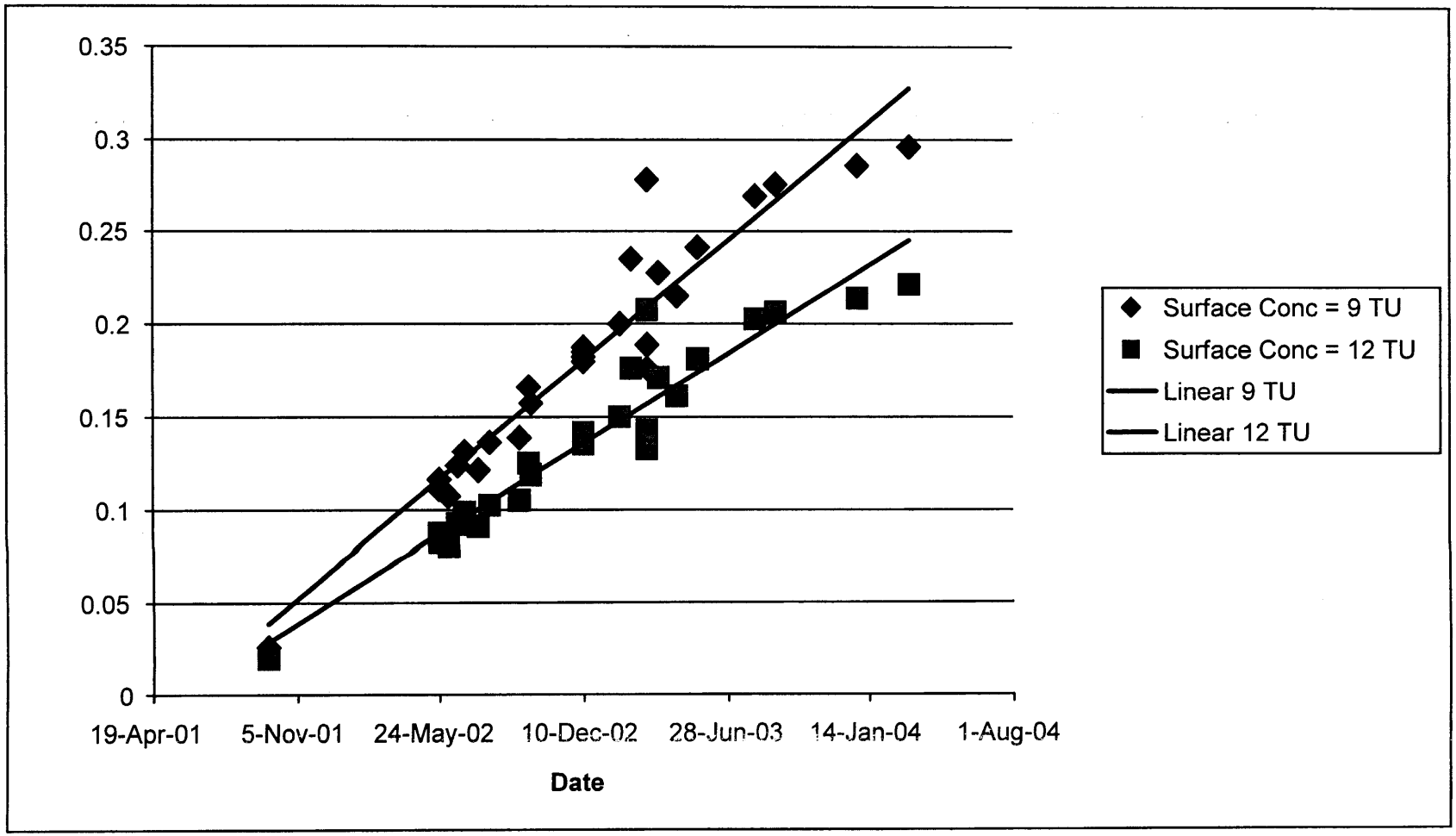

Figure 2 Computed fraction of modern water in discharge of well JC1 using a modern tritium values of 9 and 12 TU. The modern fractions was computed assuming a binary mixture of tritium-free and modern water, and does not account for radioactive decay. The data extrapolate to a modern fraction of zero in mid 2001.

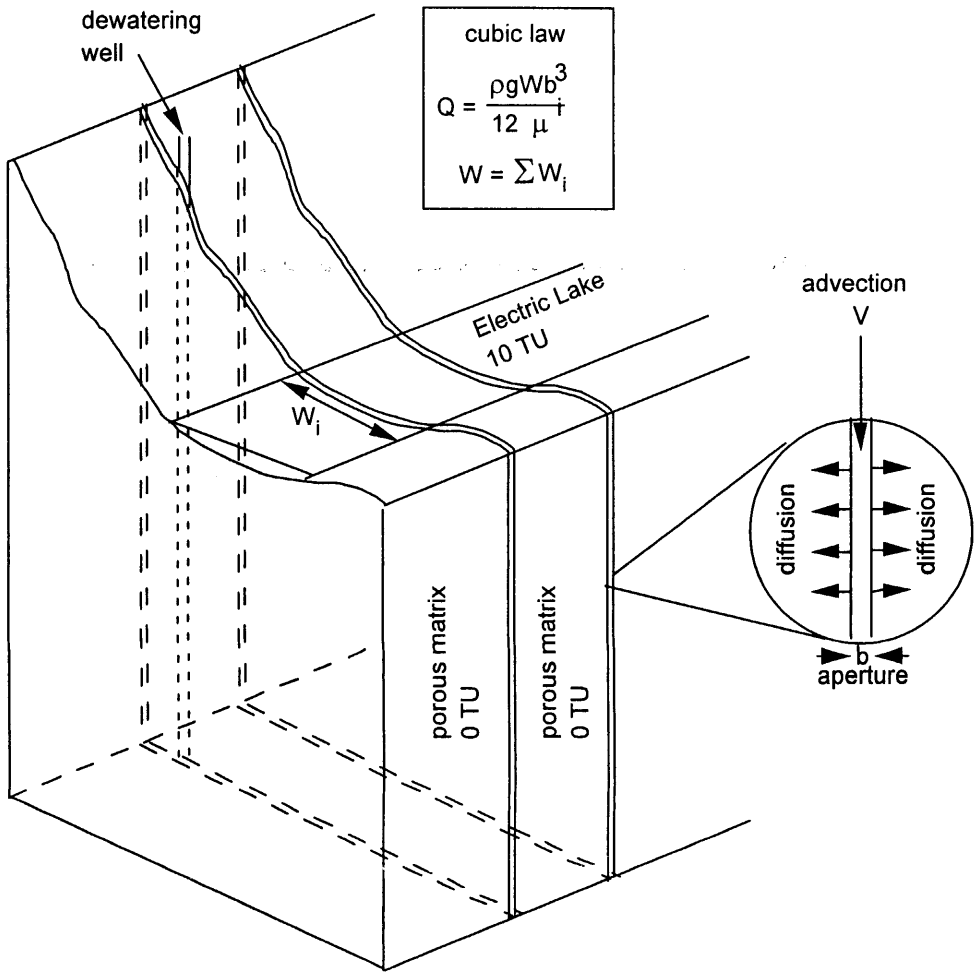

Figure 3 Conceptual diagram of tritium transport model. Fluid movement is rapid along fracture pathways, but dissolved solutes can exchange via diffusion with the surround porous matrix. The net solute transport rate is much less than the fluid velocity.

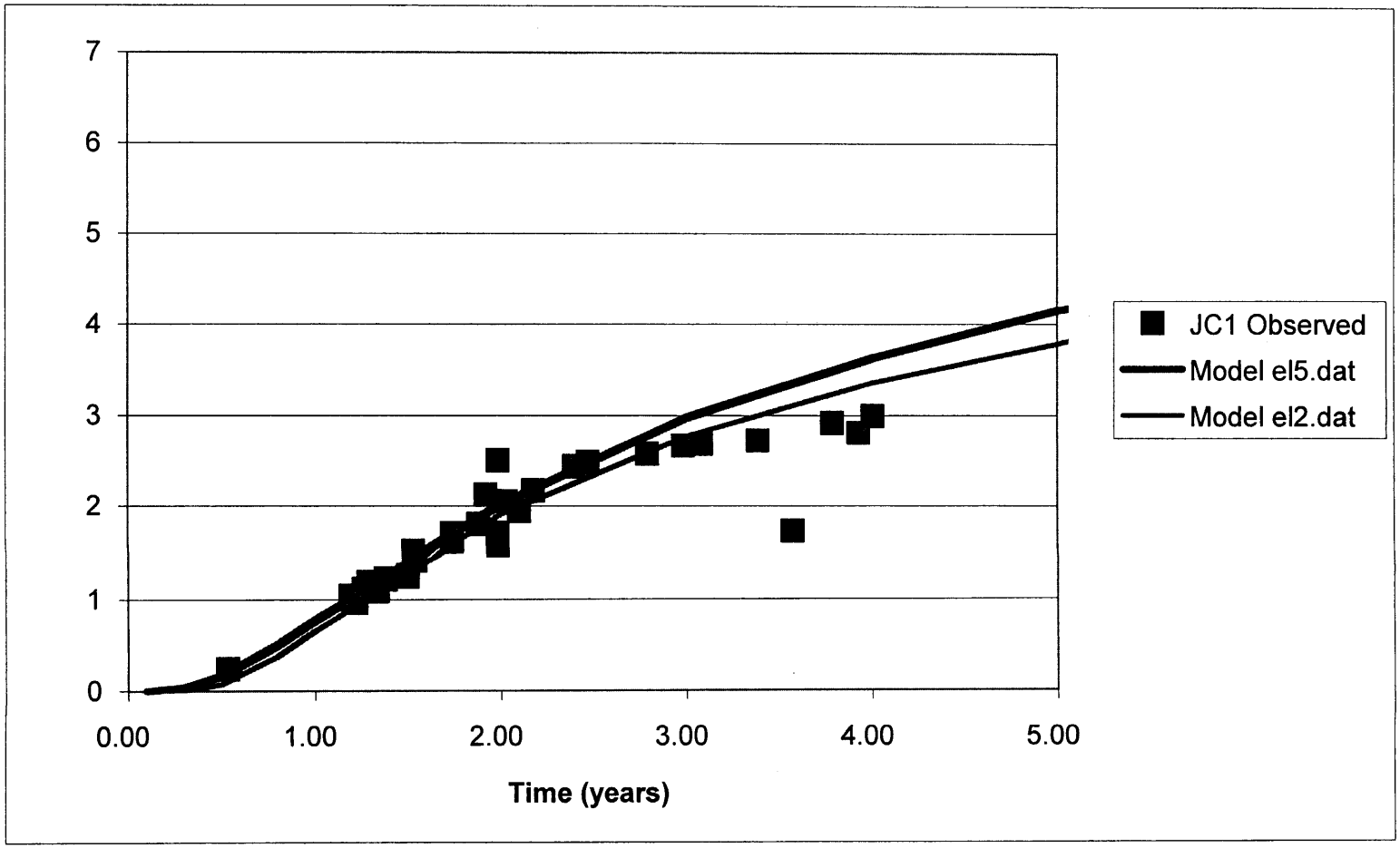

Figure 4 Comparison of observed and modeled tritium values for JC1 using a parallel fracture transport model that accounts for advection in fractures and diffusion into the surround porous matrix. Input values are shown for models el2 and el5 are shown in the text. While the model fits the observed data well, a sensitivity analysis shows that different combinations of input values fit the observed data equally well and thus the model does not uniquely define the physical properties of the system. However, the model

does shown that the observed increase in tritium can occur by flow along fractures that connect surface water (Electric Lake) and the well intake.

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PRELIMINARY DRAFT

SUMMARY OF RESULTS FROM GROUNDWATER TRACING INVESTIGATIONS AT ELECTRIC LAKE, UTAH.

Thomas Aley, RG and PHG
President, Ozark Underground Laboratory, Inc.

June 22, 2005

A client-confidential report prepared for Mr. Blaine Rawson of Holme, Roberts and Owen LLP, 299 S. Main St., Suite 1800, Salt Lake City, Utah 84111-2263

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PRELIMINARY DRAFT

SUMMARY OF RESULTS FROM GROUNDWATER TRACING INVESTIGATIONS AT ELECTRIC LAKE, UTAH.

Introduction

This report provides a preliminary draft summary of results from groundwater tracing investigations at Electric Lake. Various draft and interim documents related to the tracing work and the performance of the tracer dyes in the local geologic environment have previously been prepared. Some of these previous documents are included with the present document as appendixes. The present draft document summarizes previous reports and, where needed, updates or expands upon the previously presented information. While we are confident of the fundamental findings and conclusions, final analytical data verification has not been completed and the data presented must still be viewed as preliminary and subject to revision. We hope that the reader will find this a useful and efficient presentation of interim information on this important investigation.

This report deals with three principal investigations:

- A groundwater tracing study following two April 1, 2003 dye introductions into the bottom of Electric Lake over mapped faults.
- A bench test to assess the magnitude of dye losses onto samples of local bedrock.
- A groundwater tracing study following two February 24, 2004 dye introductions into the bottom of Electric Lake at approximately the same locations used during the April 1, 2003 dye introductions.

Groundwater Tracing Methods

Groundwater tracing with fluorescent tracer dyes is an effective way of determining hydrologic connections in groundwater systems. The tracer dyes are especially useful in groundwater systems where there are preferential flow routes such as fracture zones. Two of the dyes most commonly use in groundwater tracing studies, and those used in these studies, are fluorescein and eosine. Aley (2002) provides substantial information on properties of these dyes and their use in groundwater tracing investigations.

Fluorescein dye (also known as uranine) is Acid Yellow 73; its color index number is 45350. The dye mixture used in the Electric Lake investigations was a powder consisting of approximately 75% dye equivalent and 25% diluent. The powdered dye mixture was mixed with water prior to introduction.

Eosine dye (also known as eosin) is Acid Red 87; its color index number is 45380. The dye mixture used in the Electric Lake investigations was a powder consisting of approximately 75% dye equivalent and 25% diluent. The powdered dye mixture was mixed with water prior to introduction. Throughout this report both fluorescein and eosine dye quantities and dye concentrations are based upon the as-sold weight of the dye mixtures.

Sampling for the presence of fluorescein and eosine dyes is done in two ways. Water samples can be directly analyzed or activated carbon samplers can be utilized. Activated carbon samplers used in this study were fiberglass screen packets that contained 4.25 grams of a laboratory grade of activated coconut shell carbon. The carbon samplers are placed at a sampling station and allowed to remain in place in the water being sampled for a period of time appropriate to the study. The time periods used in this study were commonly about one to two weeks, but shorter or longer periods can be used. The activated carbon adsorbs tracer dyes from the water with which it comes in contact and retains and accumulates the dyes. As a result, because of dye accumulation on activated carbon samplers, the concentration of dye in a carbon sampler is routinely greater than the mean dye concentration in associated water samples.

Water and activated carbon samplers collected in the field were shipped to the Ozark Underground Laboratory (OUL) for analysis. Activated carbon samplers are washed in the laboratory to remove sediment and any plant material that may be present. They are then eluted in a strong base and alcohol solution to desorb the dye from the carbon. The eluting solution is then subjected to analysis in a spectrofluorophotometer operated under a synchronous scan protocol. Water samples are directly analyzed in the same instrument. Appendix A is a copy of the August 22, 2003 OUL dye tracing procedures and criteria document. It provides a detailed discussion of the dye tracing and analysis methods employed during this groundwater tracing investigation.

There is no established EPA or ASTM standard method for dye analysis work associated with groundwater tracing. The methods used by the OUL in this investigation are found in Appendix A. The OUL has a large database from groundwater traces conducted using these protocols. Using this database the OUL has calculated acceptable emission fluorescence wavelengths for fluorescein and eosine in both water and the eluting solution. The acceptable emission wavelength range is based upon the mean emission fluorescence value plus and minus two standard deviations. The OUL has also established detection limits for both dyes in both water and eluting solutions. Acceptable emission fluorescence wavelengths and detection limits are as follows:

Dye	**Matrix**	**Acceptable Emission Wavelength Range (nm)**	**Detection Limit (ppb)**
Fluorescein	Elutant	513.6 to 517.9	0.025
Fluorescein	Water	506.9 to 509.9	0.002
Eosine	Elutant	535.2 to 541.8	0.050
Eosine	Water	532.1 to 540.9	0.015

April 1, 2003 Dye Introductions and Results

Appendix B is an OUL memo dated December 2, 2003 documenting two dye introductions (one with 50 pounds of eosine dye mixture and the other with 35 pounds of fluorescein mixture) made on the floor of Electric Lake on April 1, 2003. At the time of the dye introductions the ice cover was great enough that we were able to walk on top of it. Holes were drilled through the ice and the dye for each location (mixed with water) was introduced through a one-inch diameter pipe to a location approximately six inches above the bottom of the lake. The eosine was introduced at a location overlying the Diagonal Fault, and fluorescein was introduced at a location overlying the Connelsville Fault.

Tracer dyes from the April 1, 2003 dye introductions were detected at a number of sampling stations in Electric Lake, at two sampling stations on Huntington Creek downstream of Electric Lake, and in two wells (JC-1 and JC-3) that penetrate into or near portions of the Skyline Mine located within the Huntington Creek topographic basin. Some fluorescein dye has also been detected at Sampling Station 1 (Eccles Creek 1/4 mile downstream of the Skyline Mine). While it is possible that some of the fluorescein dye detected at Station 1 is derived from our dye introduction, some or all of the detected dye is probably from anti-freeze leakage from equipment used at the mine or anti-freeze fluids leaked from vehicles onto the parking and loading area at the mine or onto the nearby highway.

A substantial amount of dye sampling and analysis work was done within Electric Lake. This work demonstrated and quantified the migration of both of the tracer dyes through essentially all of the lake between the dye introduction points and the dam. Preliminary calculations suggest that about 15 to 20% of the dye introduced on April 1, 2003 discharged through the dam and into Huntington Creek. Other losses of dye due to adsorption, biological degradation, and destruction by sunlight would occur within the lake. Final estimates of the amount of dye that did not enter the groundwater system fault zones have not been made.

Sampling Station 2 was the JC-1 Well. It is completed into a water-saturated fault system intersected by the Skyline Mine. The JC-1 Well intersected the fault system within a horizontal distance of 100 feet from the mine workings. The mine workings adjacent to where JC-1 Well intersects the water-saturated fault system have been flooded since the fault was intersected by the mine workings in August 2001.

Fluorescein dye (and in two cases eosine dye) was detected in three of the five following carbon samplers from the JC-1 Well:

- 5/29 1800 hours to 6/12/03 1115 hours. Fluorescein concentration 0.967 ppb, eosine concentration 0.189 ppb.
- 6/12 1115 hours to 6/18/03 1530 hours. Fluorescein concentration 0.801 ppb. Eosine not detectable.
- 6/18/03 1530 hours to 6/24/03 0745 hours. Well shut down for electrical work; no sample.

- 6/24 0745 hours to 6/30/03 1245 hours. No dyes detected.
- 6/30 1245 hours to 7/7/03 1430 hours. No dyes detected.
- 7/7 1430 hours to 7/14/03 1045 hours. Fluorescein concentration 1.04 ppb, eosine concentration 0.562 ppb.

Prior to the first detection of dye in the JC-1 Well there had been 12 samples in a row (from February 27 to May 29, 2003) in which there was neither fluorescein nor eosine dye. Subsequent to the sampler in place for the period from July 7 to 14, 2003 there were no tracer dyes detected at JC-1 Well through the end of sampling for the April 2003 dye introductions.

The three positive fluorescein peaks at the JC-1 Well are all fully consistent with the presence of this tracer dye. The two eosine dye detections at the JC-1 Well represent fluorescent shoulders on the analytical graph but are fully consistent with the presence of eosine dye in the samples.

The tracer dyes were introduced on April 1, 2003. They were first detected at JC-1 in a carbon sampler in place for the period from May 29 to June 12, 2003. If we use the mid-point of this sampling period as the time of first dye arrival then the time of first dye arrival was 65 days after dye introduction for both of the tracer dyes. The straight-line distance between the dye introduction point and JC-1 was approximately 7,200 feet for the eosine dye and 8,400 feet for the fluorescein dye. Based upon these distances and a first-arrival travel time of 65 days, the mean first dye arrival groundwater velocity was 111 feet per day for the eosine and 129 feet per day for the fluorescein.

Well JC-3 intersects the Skyline Mine workings near where the Skyline Mine intersected the water-saturated fault system. It did not begin pumping water that could be sampled for tracer dye until August 13, 2003. This was after the period in which the tracer dyes were detected at Well JC-1. The first activated carbon sampler from JC-3 (in place for the period from August 13 to August 19, 2003) had a fluorescence peak at 513.4 nm. This is 0.2 nm shorter than the normally acceptable emission wavelength range for fluorescein dye in the eluting solution. The shape of the peak is fully consistent with fluorescein dye, and it is not uncommon for small fluorescein concentrations to display fluorescence peaks a few tenths of a nanometer shorter than the normally acceptable range established for this dye. It is our conclusion that this fluorescence peak does represent fluorescein dye derived from the dye that we introduced into Electric Lake. The fluorescein concentration in this sample was 1.43 ppb.

Bench Test

A bench test was conducted to assess the magnitude of dye losses onto samples of local bedrock. The bench test was designed to determine if it was likely that a significant quantity of dye might have been detained, lost onto, or destroyed by contact with bedrock during the Electric Lake groundwater tracing work. If significant quantities of dye solution were detained or lost, then low or non-detections of dye at sampling points might

be attributable to dye losses rather than a lack of large volume hydrologic connection between Electric Lake and the sampling points.

Appendix B (a December 2, 2003 OUL memo) explains the design of the bench test and provides some early results. Appendix C is an August 12, 2004 draft final report on the bench tests.

PacifiCorp provided samples of different rock types that are present along the anticipated groundwater flow path from Electric Lake to the Skyline Mine. The samples are identified in the following table and the relative distance groundwater travels within each rock type as a percentage of the total distance is estimated. The estimates were provided by PacifiCorp.

Rock types and their relative percentage along the anticipated groundwater flow route from Electric Lake to the Skyline Mine.

Lithology	Percentage
Starpoint Sandstone	50%
Fluvial Sandstone	20%
Interbeds	15%
Mudstone	12%
Carbonaceous Mudstone	2%
Coal	1%

The coal sample was from the Skyline Mine load out facility. Samples of the other five rock types were core samples from PacifiCorp's coal mine located to the south of Electric Lake. This mine has the same rock sequence as that in the area of the Skyline Mine. All samples were crushed in a jaws crusher at a local engineering test laboratory to a diameter of less than 1/2 inch; each sample was passed through the crusher twice.

The following is excerpted from the draft final report on the bench test.

1. The bench test used rock cores or other fresh rock from the six geologic units existing between the floor of Electric Lake and the Skyline Mine. Samples of the six geologic substrates were crushed and submerged in 5 and 50 ppb concentrations of fluorescein and eosine dyes. Samples of the dye solutions on top of the rock substrates were periodically collected over a 63 day period and analyzed to determine dye concentrations.

2. The bench test demonstrated that different rock substrates have different abilities to remove dye from dye solutions that are in contact with the rock. Some of the rock substrates are capable of removing the dye very rapidly; this is demonstrated by samples analyzed one day after the dye solutions were placed in contact with the substrates. For all dye solutions the substrate that provide the most rapid dye loss was the Starpoint sandstone. The mudstone was the second most rapid, but the percentages of dye lost to this substrate were substantially less than those lost to the Starpoint sandstone. The two

substrate types which had the least dye lost from the dye solutions after one day were the fluvial sandstone and the carbonaceous mudstone.

3. The bench test was continued for 63 days. For all dye solutions the substrate that provided the greatest dye loss after 63 days was the carbonaceous mudstone. The Starpoint sandstone had the second greatest dye loss after 63 days. Three of the substrates in contact with the 5 ppb eosine solution had no detectable eosine present at Day 63. The two substrate types that had the least dye lost from the dye solutions after 63 days were the coal and the fluvial sandstone.

4. The Starpoint sandstone represents about 50% of the rock mass that would likely be encountered by water traversing the flow route between Electric Lake and Skyline Mine. Fluvial sandstone represents about 20% of the rock mass, interbeds represent 15%, mudstone represents 12%, carbonaceous mudstone represents 2%, and coal represent 1% of the rock mass likely to be encountered by water following this flow route. Using these percentages we calculated weighted averages of dye losses likely to be encountered by waters moving from Electric Lake to the Skyline Mine.

Based upon the weighted averages, at the end of the 63-day bench test the 50 ppb fluorescein dye solutions contained 3.5 times more dye than did the 50 ppb eosine solutions. The 5 ppb fluorescein solutions contained 4.6 times more dye than did the 5 ppb eosine solutions. The percent of dye lost to substrates after 63 days was greater for 5 ppb dye solutions than for 50 ppb solutions. This applied to both fluorescein and eosine solutions, but the percentage difference was greater for eosine than for fluorescein.

5. The bench test demonstrated that appreciable amounts of tracer dyes are lost onto or destroyed by contact with rock substrates found in the area between Electric Lake and the Skyline Mine. In this hydrogeologic environment fluorescein is a much better groundwater tracing agent than is eosine. Because of the appreciable losses of dyes onto rock substrates, the detection of small amounts of dye during field investigations are adequate to demonstrate a hydrologic connection. Furthermore, the detection of only small dye concentrations does not indicate that only small amounts of water follow the traced flow path.

February 24, 2004 Dye Introductions

Two dye introductions were made at Electric Lake on February 24, 2004. The purpose of these dye introductions was to identify points to which water from these locations flows through the groundwater system and to replicate the trace from the April 1, 2003 dye introductions.

The first of the 2004 dye introductions (Trace 04-01) was made at Way Point 26. This location is on the Diagonal Fault, and is about the same location where 50 pounds of eosine dye mixture was introduced near the floor of the lake on April 1, 2003. For Trace 04-01 75 pounds of fluorescein dye mixture containing approximately 75% dye equivalent and 25% diluent was mixed with approximately 75 gallons of water and

pumped through a plastic pipe to a location 2 feet above the floor of the lake. The dye introduction began at 1217 hours on February 24, 2004 and was completed at 1223 hours.

The second of the 2004 dye introductions (Trace 04-02) was made at Way Point 16. This location is on the Connelsville Fault, and is about the same location where 35 pounds of fluorescein dye mixture was introduced near the floor of the lake on April 1, 2003. For Trace 04-02 125 pounds of fluorescein dye mixture containing approximately 75% dye equivalent and 25% diluent was mixed with approximately 125 gallons of water and pumped through a plastic pipe to a location 2 feet above the floor of the lake. Dye introduction began at 1447 hours on February 24, 2004 and was completed at 1455 hours.

The dye mixing for both of the dye introductions was done on site in barrels using a trolling motor. Dye was shipped to the site in four containers, each of which contained 50 pounds of the dye mixture. The dye in one of the containers was divided approximately in half on-site so that approximately 75 pounds of dye could be introduced at Way Point 26 and approximately 125 pounds could be introduced at Way Point 16. Prior to beginning field work samples of the dye from each container were analyzed at the OUL to verify that the contents were in fact fluorescein dye.

During the dye introductions there was a light breeze with gusts up to 5 or 10 miles per hour. The fluorescein dye mixture was delivered to the site as a powder, and small amounts of the powder were lost into the air when the containers of dye were added to the mixing barrels. The breeze transported this small amount of dye downwind; the maximum visible extent of the drift was about 250 feet. We estimate that the total amount of dye mixture lost to drift was less than one ounce. This dye would be destroyed by sunlight and would in no way interfere with the conduct of the tracer test.

The mixture of dye and water was denser than water alone. As a result, the dye mixture sank to the bottom of the lake and flowed along the low points on the lake bottom. These conditions were deemed suitable for the purposes of these dye traces.

Fluorescein dye derived from the February 2004 dye introductions has been detected at Stations 2, 10, 11, 120, and 121. These detections are described in the following paragraphs.

Station 2. JC-1 Well. Detections of fluorescein dye from activated carbon samplers placed at JC-1 Well are summarized in Table 1. This dye is from the February 2004 dye introductions in Electric Lake.

It is our conclusion that the first dye detection at this station was in an activated carbon sampler in place for the period from December 28, 2004 to January 20, 2005. The emission fluorescence peak in the elutant from this sampler was at 514.8 nm, and the fluorescein dye concentration was 0.885 parts per billion (ppb). While the shape of this peak was less smooth and symmetrical than fluorescence peaks commonly associated with this concentration of fluorescein dye in eluting solutions, the peak wavelength is within the acceptable wavelength range of fluorescein dye in eluting solutions.

Table 1. Fluorescein dye detections in JC-1 Well from dye introduced in Electric Lake on February 24, 2004. All detections are from activated carbon samplers.

Date Placed	Date Recovered	Peak Wavelength (nm)	Fluorescein Concentration (ppb)
12/28/04	1/20/05	514.8	0.885
1/20/05	2/3/05	513.9	1.33
2/3/05	2/17/05	513.8	0.776
2/17/05	3/3/05	513.8	4.92
3/3/05	3/11/05	513.8	1.94
3//11/05	3/17/05	513.6	0.619
3/17/05	3/22/05	513.8	1.31
3/22/05	4/1/05	514.0	0.805
4/1/05	4/7/05	ND	
4/7/05	4/14/05	513.0*	0.591*
4/14/05	4/28/05	513.2*	0.742*
4/28/05	5/12/05	514.6	0.936
5/12/05	5/26/05	514.7	1.06

* Fluorescence peak is shorter than the normally acceptable wavelength range for this dye. The peak is calculated as fluorescein dye.
ND = None Detected

Fluorescein dye was subsequently detected in activated carbon samplers from JC-1 Well for the next seven sampling periods (see Table 1). These samplers covered the period from January 20 to April 1, 2005. Fluorescein dye was not detected in the activated carbon sampler in place at JC-1 Well for the period from April 1 to April 7, 2005. Samplers in place at JC-1 Well for the periods from April 7 to 14 and from April 14 to April 28, 2005 had fluorescence peaks that were probably reflective of fluorescein dye but which had emission fluorescence peaks somewhat shorter than the acceptable emission wavelength range for fluorescein in eluting solutions. However, fluorescein dye was again detected at this sampling station in the following two samplers covering the period from April 28 to May 26, 2005. Subsequent samplers have not yet been analyzed and added to the data file.

The largest dye concentration at JC-1 was in an activated carbon sampler in place for the period from February 17 to March 3, 2005. The fluorescein concentration in this sampler was 4.92 ppb, and the shape of the fluorescence peak was smooth, symmetrical, and fully consistent with fluorescein dye peaks in the eluting solution. The emission fluorescence peak was at 513.8 nm. The next activated carbon sampler from JC-1 Well was in place for the period from March 3 to 11, 2005. It had an emission fluorescence peak at 513.8 nm and a fluorescein concentration of 1.94 ppb. The shape of the fluorescence peak was less smooth than in the previous sample, but still fully consistent with fluorescein dye peaks of this concentration in eluting solutions.

During the period from December 2, 2003 to December 28, 2004 there were 36 carbon samplers analyzed from JC-1 Well. Twenty-six of these had emission fluorescence peaks ranging from 507.8 to 512.6 nm; this range is appreciably shorter than the acceptable emission fluorescence range for fluorescein (which is 513.6 to 517.9 nm). Most of these peaks were also irregular in shape. As a result of the above, it is our conclusion that fluorescein dye was not detected in these samplers.

We made a further assessment of the presence of fluorescence peaks shorter than fluorescein dye in a number of samples from JC-1 Well prior to the detection of fluorescein dye at this station. The mean emission fluorescence wavelength of these 26 samples was 510.9 nm with a standard deviation of 1.3 nm.

During the period when fluorescein dye has been detected in activated carbon samplers from JC-1 Well there have been a total of 13 samples collected and analyzed. Twelve of these had fluorescence peaks, and ten of these peaks were within the acceptable wavelength range of fluorescein dye. The mean emission fluorescence peak in these twelve samplers was 513.9 nm with a standard deviation of 0.6 nm.

Figure 1 is a graph depicting the emission fluorescence peaks of activated carbon sampler elutants from JC-1 Well for all samplers with fluorescence peaks between 507.8 and 514.8 nm. The plotted dates shown on the graph reflect the dates of sampler collection. Note the substantial increase in the peak emission wavelengths associated with the presence of fluorescein dye (the mean value is 513.9 nm) as contrasted with the peak emission wavelengths associated with samplers collected on or before December 29, 2004 (510.9 nm).

Fluorescein dye was introduced at two locations on the floor of Electric Lake on February 24, 2004. This dye was first detected at JC-1 Well in an activated carbon sampler in place for the period from December 28, 2004 to January 20, 2005. If we use the mid-point of this sampling period as the time of first dye arrival (thus January 8, 2005) then the first dye arrival at this well occurred 318 days after dye introductions made in February 2004. The straight-line distance from JC-1 Well to the nearest dye introduction point is 7,200 feet thus yielding a minimum straight-line groundwater velocity of 23 feet per day. The maximum dye concentration arrival at JC-1 Well occurred during the period from February 17 to March 3, 2005. Using the mid-point of this period (February 24, 2005) this represented a minimum straight-line groundwater velocity of 20 feet per day.

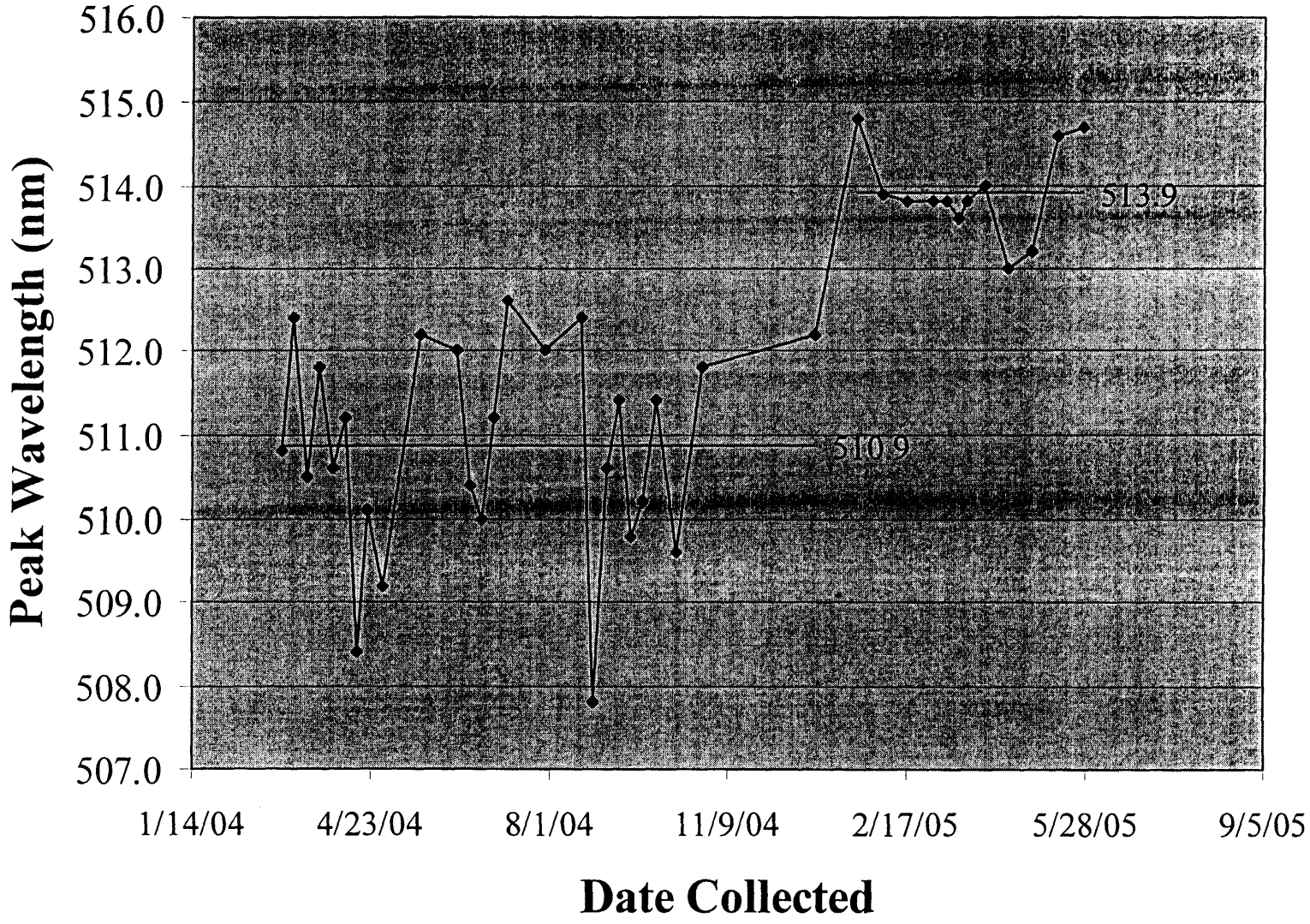
Station 10, Huntington Creek below Dam 1. The first dye detection from the February 2004 dye introduction was probably during the period from March 2 to 11, 2004; the fluorescein concentrations was about 3 times the background concentration. Samplers in place at this station for the period between March 11 and 18, 2004 had 2 orders of magnitude more dye than did background samplers. The peak dye concentration at this station from the present dye trace occurred during the sampling period from March 18 to 25, 2004. Subsequent dye concentrations at this station have generally decreased with time.

Station 11, Huntington Creek below Dam 2. The first dye detection from the February 2004 dye introduction was probably during the period from March 2 to 11, 2004; the fluorescein concentrations was about 2 times the background concentration. Samplers in place at this station for the period between March 11 and 18, 2004 had 2 orders of magnitude more dye than did background samplers. The peak dye concentration at this station from the present dye trace occurred during the sampling period from March 18 to 25, 2004. Subsequent dye concentrations at this station have generally decreased with time.

Stations 120 and 121. Relatively small dye concentrations from the February 2004 dye introduction were detected in activated carbon samplers at Station 120 (Huntington Creek Above Left Fork of Huntington Confluence) and at Station 121 (Huntington Creek at Little Bear Campground). This dye was derived from dye that had flowed past Stations 10 and 11.

Sampling is continuing for this trace and final data analysis is in progress.

Figure 1. Emission fluorescence peaks in activated carbon sampler elutants from JC-1 Well. Horizontal lines represent mean values for the periods shown



Important Information and Findings from the Dye Tracing Investigations.

1. JC-1 Well is completed into a water-saturated fault system intersected by the Skyline Mine. The JC-1 Well intersected the fault system within a horizontal distance of 100 feet of the mine workings. The mine workings adjacent to where the JC-1 Well intersects the water-saturated fault system have been flooded since the fault was intersected by the mine workings in August 2001.

2. Well JC-3 intersects the Skyline Mine workings near where the Skyline Mine intersected the water-saturated fault system. It did not begin pumping water that could be sampled for tracer dye until August 13, 2003. This was after the period in which the tracer dyes were detected at Well JC-1. The first activated carbon sampler from JC-3 had a fluorescence peak at 513.4 nm. This is 0.2 nm shorter than the normally acceptable emission wavelength range for fluorescein dye in the eluting solution. The shape of the peak is fully consistent with fluorescein dye, and it is not uncommon for small fluorescein concentrations to display fluorescence peaks a few tenths of a nanometer shorter than the normally acceptable range established for this dye. It is our conclusion that this fluorescence peak does represent fluorescein dye derived from the dye that we introduced into Electric Lake. The fluorescein concentration in this sample was 1.43 ppb.

3. Thirty-five pounds of fluorescein dye mixture was introduced on the floor of Electric Lake over the Connelsville Fault on April 1, 2003. Fluorescein dye was subsequently detected in JC-1 Well. This dye was detected in three activated carbon samplers from this well. The first dye detection was during the period from May 29 to June 12, 2003. Using the mid-point of this time period as the time of first arrival then the time of first dye arrival was 65 days after dye introduction. The straight-line travel distance from the fluorescein dye introduction point to JC-1 Well is 8,400 feet, and the mean travel rate for the first fluorescein dye arrival is 129 feet per day.

4. Fifty pounds of eosine dye mixture was introduced on the floor of Electric Lake over the Diagonal Fault on April 1, 2003. Eosine dye was subsequently detected in JC-1 Well. This dye was detected in two activated carbon samplers from this well. The first dye detection was during the period from May 29 to June 12, 2003. Using the mid-point of this time period as the time of first arrival then the time of first dye arrival was 65 days after dye introduction. The straight-line travel distance from the fluorescein dye introduction point to JC-1 Well is 7,200 feet, and the mean travel rate for the first eosine dye arrival is 111 feet per day.

5. Well JC-3 (which intersects the Skyline Mine) did not begin pumping water that could be sampled for tracer dye until August 13, 2003. This was after the period in which the tracer dyes were detected at Well JC-1. The first activated carbon sampler from JC-3 (in place for the period from August 13 to August 19, 2003) had a fluorescence peak at 513.4 nm. This is 0.2 nm shorter than the normally acceptable emission wavelength range for fluorescein dye in the eluting solution. The shape of the peak was fully consistent with fluorescein dye, and it is not uncommon for small

fluorescein concentrations to display fluorescence peaks a few tenths of a nanometer shorter than the normally acceptable range established for this dye. It is our conclusion that this fluorescence peak represents fluorescein dye derived from the dye introduced into Electric Lake on April 1, 2003. The fluorescein concentration in this sample was 1.43 ppb.

6. A bench test was conducted to determine if significant quantities of eosine or fluorescein dye might have been detained, lost onto, or destroyed by contact with bedrock during the Electric Lake groundwater tracing work. If significant quantities of dye solution were detained or lost, then low or non-detections of dye at sampling points might be attributable to dye losses rather than a lack of large volume hydrologic connection between Electric Lake and the sampling points.

7. The bench test demonstrated large percentage dye losses from 5 and 50 ppb dye solutions placed in contact with rocks typical of the area. In the test samples 135 grams of crushed rock was covered by 250 ml of dye solution. By weight this is 1.85 times more dyed water than crushed rock. In the bench test much of the dye loss occurred within the first day of contact between the rock and dyed water. However, additional dye loss continues to occur after the first day and, in most cases, throughout the duration of the 63 day study. The discovery of both initial rapid dye losses and continuing dye losses are important. The bench test data demonstrating that the relatively small dye concentrations detected in the Skyline Mine do not indicate that the volume of water moving from the lake into the mine is small.

8. Approximately half of the anticipated groundwater flow route from Electric Lake into the Skyline Mine is through the Starpoint Sandstone. In the bench test this unit removed 89.7% of the fluorescein from a 50 ppb dye solution after one day of contact and 96.0% of the fluorescein after 7 days of contact. The losses were even greater for eosine dye. In the bench test the Starpoint Sandstone removed 96.4% of the eosine from a 50 ppb dye solution after one day of contact and 96.8% after 7 days of contact. Percentage loss rates were even greater for 5 ppb fluorescein and eosine solutions.

9. A second round of dye introductions into the floor of Electric Lake were made on February 24, 2004. Seventy-five pounds of powdered fluorescein dye mixture was mixed with water and introduced on the Diagonal Fault at about the same location where 50 pounds of eosine dye mixture was introduced on April 1, 2003. An additional 125 pounds of powdered fluorescein dye mixture was mixed with water and introduced on the Connelsville Fault at about the same location where 35 pounds of fluorescein dye mixture was introduced on April 1, 2003.

10. Fluorescein dye from the February 24, 2004 dye introduction was first detected at the JC-1 Well in an activated carbon sampler in place for the period from December 28, 2004 to January 20, 2005. The maximum fluorescein dye concentration detected at this station was in an activated carbon sampler in place for the period from February 17 to March 3, 2005. The fluorescein concentration in this sampler was 4.92 ppb, and the shape of the fluorescence peak was smooth, symmetrical, and fully

consistent with fluorescein dye peaks in the eluting solution. The emission fluorescence peak was at 513.8 nm. The next activated carbon sampler from JC-1 Well was in place for the period from March 3 to 11, 2005. It had an emission fluorescence peak at 513.8 nm and a fluorescein concentration of 1.94 ppb. The shape of the fluorescence peak was less smooth than in the previous sample, but still fully consistent with fluorescein dye peaks of this concentration in eluting solutions.

11. Fluorescein dye has been detected in most of the activated carbon samplers in place at JC-1 Well for the period December 28, 2004 to June 26, 2005. If we use the mid-point of the first dye detection sampling period as the time of first dye arrival (thus January 8, 2005) then the first dye arrival at this well occurred 318 days after the dye introductions made on February 2004. The straight-line distance from JC-1 Well to the nearest dye introduction point is 7,200 feet thus yielding a minimum straight-line groundwater velocity of 23 feet per day.

12. Groundwater velocities determined from the dye tracing were more rapid during the first tracing period than during the second. It is our understanding that water level elevations in those portions of the Skyline Mine near JC-1 Well were higher during the second tracing period than during the first, and that pumping rates from the vicinity of JC-1 Well and the adjacent mine (including JC-3 Well) were less during the second tracing period than during the first. These differences could account for the differences in calculated groundwater velocities between the two study periods.

13. The work summarized in this report demonstrates that Electric Lake loses water into the Skyline Mine. The bench test work demonstrates that dye concentrations in water pumped from the mine or areas near the mine cannot be used to estimate the volume of water lost from the lake into the mine.

References

Aley, Thomas. 2002. The Ozark Underground Laboratory's Groundwater Tracing Handbook. Protem, MO. 35p.

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APPENDIX A

OZARK UNDERGROUND LABORATORY PROCEDURES AND CRITERIA

Ozark UNDERGROUND LABORATORY 1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 oul@tri-lakes.net

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

March 21, 2005

Thomas Aley, PHG 179
President
Ozark Underground Laboratory, Inc.

PROCEDURES

Introduction

This document describes standard procedures and criteria currently in use at the Ozark Underground Laboratory 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 up-graded. The Ozark Underground Laboratory maintains a summary of changes in standard procedures and criteria.

Dye Nomenclature

Fluorescein is C.I. Acid yellow 73, Color Index Number 45350. Rhodamine WT is Acid Red 388; there is no assigned Color Index Number for this dye. Eosine (sometimes called eosin) is Acid Red 87, Color Index Number 45380. Sulforhodamine B is C.I. Acid Red 52, Color Index Number 45100. Pyranine is Solvent Green 7 (also called D&C Green 8), Color Index Number 59040.

Description of the Samplers

The charcoal samplers are packets of fiberglass screening partially filled with approximately 4.25 grams of activated coconut charcoal. The charcoal used by the Ozark Underground Laboratory is Barnebey and Sutcliffe coconut shell carbon, 6 to 12 mesh, catalog type AC.

The most commonly used samplers are about 4 inches long by two inches wide. A cigar-shaped sampler is made for use in very small diameter wells (such as 1 inch diameter wells); this is a special order item and should be specifically requested when it is needed. All of the samplers are closed by heat sealing.

Placement of Samplers

Samplers (also called charcoal packets) are placed so as to be exposed to as much water as possible. 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 being flat against it. Two or more separately anchored packets are typically used for sampling springs and streams. 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 placed in sample holders made of PVC pipe fittings. Brass hose fittings are installed 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 consists of 1.5 inch diameter pipe and pipe fittings.

Charcoal packets can also 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. Some sort of weight should be added near the charcoal packet to insure 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 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. 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 narrow 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 stainless steel weight may be added to the top of the disposable bailer. We have had good success with two to three ounce segments of stainless steel pipe which have an outside diameter of 1.315 inches and an inside diameter of 1.049 inches; such pipe weighs about 1.7 pounds per linear foot. The weight of the stainless steel is approximately 497 pounds per cubic foot. The pipe segments can be attached over the anchoring cord at the top of the bailer. All weights should be cleaned prior to use; the cleaning approach should comply with decontamination procedures in use at the project site.

Placement of samplers requires adjustment to field conditions. The above placement comments are intended as guidance, not firm requirements.

Rinsing of Charcoal Packets Prior to Sampling

Charcoal packets routinely contain some fine powder that washes off rapidly when they are placed in water. Since such material could remain in monitoring wells, charcoal packets to be placed in such wells are 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 from 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.

Where convenient, the collected samplers should be briefly rinsed in the water being sampled. This is typically 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 permanent type felt marker pen. 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 are not inserted inside the sample bags.

For most projects the Ozark Underground Laboratory supplies the Whirl-Pak bags. Prior to use, 1% of the new bags are randomly selected. Each bag is soaked in the standard eluting solution and then analyzed for the presence of any of the tracer dyes being used.

Collected samplers are kept in the dark to minimize algal growth on the charcoal prior to analysis work. We prefer (and in some studies require) that samples be placed on "blue ice" or ice upon collection and that they be shipped refrigerated with "blue ice" by overnight express. Do not ship samplers packed in 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.

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 are often collected. They should be collected in either glass or plastic; the Ozark Underground Laboratory routinely uses 50 ml research grade polypropylene copolymer Perfector Scientific vials (Catalog Number 2650) for such water samples. The vials should be placed in the dark and refrigerated immediately after collection. They should be refrigerated until shipment. For most projects the Ozark Underground Laboratory supplies the vials. Prior to use, 1% of the new vials are randomly selected. Each vial is soaked in the standard eluting solution and then analyzed for the presence of any of the tracer dyes being used.

When water or charcoal samplers are collected for shipment to the Ozark Underground Laboratory they should be shipped promptly. We receive good overnight and second day air service from both UPS and Fed Ex; Airborne Service is excessively slow, and the Postal Service does not provide next day service to us.

Each shipment of charcoal samplers or water samples must be accompanied by a sample tracking sheet. These sheets (which bear the title "Samples for Fluorescence Analysis") are provided by the Ozark Underground Laboratory and summarize placement

and collection data. These sheets can be augmented by a client's chain of custody forms or any other relevant documentation. Figure 1 is one of our blank sample forms.

Receipt of Samplers

Samplers shipped to the Ozark Underground Laboratory are refrigerated upon receipt. Prior to cleaning and analysis, samplers are assigned a laboratory identification number. All samples are logged in upon receipt.

It sometimes occurs that there are discrepancies between the chain-of-custody sheets and the actual samples received. When this occurs, a "Discrepancy Sheet" form is completed and sent to the shipper of the sample for resolution. A copy of this form is enclosed as Figure 2. The purpose of the form is to help resolve discrepancies, even when they may be minor.

Cleaning of Samplers

Samplers are cleaned by spraying them with jets of clean water. At the Laboratory we use unchlorinated water for the cleansing to minimize dye deterioration. 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.

After washing, the packets are shaken to remove excess water. Next, the packets are cut open and the charcoal is emptied into a new disposable plastic beaker. The beaker has been pre-labeled with the laboratory identification number. The charcoal is now ready for elution. The emptied fiberglass screen packet is discarded. At stations where two or more charcoal packets are collected, one is selected for analysis and the other is frozen and retained until the end of the study. In some studies the analysis protocol stipulates that a fixed percentage (often 5%) of the samples should be duplicates; in these cases the second charcoal packet is separately analyzed. Note that these are duplicate samples, not replicate samples since each packet is, of necessity, placed in a somewhat different location and is therefore exposed to somewhat different conditions.

Cleaning of Glassware

Most of our work uses disposable plastic containers. A small amount of glassware is occasionally used for preparation of standards. It is dedicated to this use. In the event that any glassware does come in contact with tracer dyes it will be carefully cleaned before re-use. To do this cleaning, containers are rinsed several times in clean water. Glassware that may be contaminated with dyes is washed with detergent, and then again rinsed. Next, the glassware is soaked for one hour or more in a bleach and water solution. Upon removal from this soaking, the glassware is rinsed again and allowed to air dry.

Figure 1. Sample Collection Data Sheet

OZARK UNDERGROUND LABORATORY, INC.

1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 email: oul@tri-lakes.net

SAMPLE COLLECTION DATA SHEET for FLUORESCENCE ANALYSIS

Project:_____ Week No: Samples Collected By:_____

Samples Shipped By:_____ Samples Received By:_____

Date Samples Shipped:___/___/___ Date Samples Received:___/___/___ Time Samples Received:____:____ Return Cooler? Yes No_____

Bill to:_____ Send Results to: _____

Analyze for: Fluorescein Eosine Rhodamine WT Other Ship cooler to: _____

OUL use only		*Please indicate stations where dye was visible in the field* *for field technician use - use black ink only*						*OUL use only*
# CHAR REC'D	LAB NUMBER	STATION NUMBER 1-4 Numbers	STATION NAME	PLACED		COLLECTED		# WATER REC'D
				DATE	TIME	DATE	TIME	

COMMENTS:

This sheet filled out by OUL staff? Yes No Charts for samples on this page proofed by OUL:_____

Page _____ of _____

Figure 2. Discrepancy Sheet

OZARK UNDERGROUND LABORATORY, INC.

DISCREPANCIES BETWEEN CHAIN-OF-CUSTODY SHEETS AND ACTUAL SAMPLES RECEIVED **Page _____ of _____**

Company & Project Name: **Date Rec'd by OUL:** **Wk # _____**

Lab #	Sta #	Station Name	Date Pulled	Problem	Solution

Comments:

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, some water, and a strong basic solution such as aqueous ammonia.

The standard elution solution now used at the Ozark Underground Laboratory is a mixture of 5% aqua ammonia and 95% isopropyl alcohol solution and sufficient potassium hydroxide flakes to saturate the solution. The isopropyl alcohol 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 we use will elute fluorescein, eosine, rhodamine WT, sulforhodamine B, and pyranine dyes. It is also suitable for separating fluorescein peaks from peaks of some naturally present materials found in some 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.

Analysis on the Shimadzu RF-5000U or RF-5301

The Laboratory uses two Shimadzu spectrofluorophotometers. One is a model RF-5000U, and the other is a model RF-5301. Both of these instruments are capable of synchronous scanning. The RF-5301 is the primary instrument used; the RF-5000U is primarily used as a back-up instrument except for tracing studies which were begun using this instrument. The OUL also owns a Shimadzu RF-540 spectrofluorometer which is occasionally used for special purposes.

A sample of the elutant is withdrawn from the sample container using a disposable polyethylene pipette. Approximately 3 ml of the elutant 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 spectral range of the cuvettes is 340 to 800 nm. The pipettes and cuvettes are discarded after one use.

The cuvette is then placed in the RF-5000U or the RF-5301. Both instruments are controlled by a programmable computer. Each instrument is capable of conducting substantial data analysis.

Our instruments are operated and maintained in accordance with the manufacturer's recommendations. On-site installation of the instruments and a training session on the use of spectrofluorophotometers was provided by Delta Instrument Company.

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 "very fast" on the RF-5000U; it is "fast" on the RF-5301. The typical sensitivity setting used on both instruments is "high."

Our typical analysis of an elutant sample where pyranine dye may be present includes a synchronous scanning of excitation and emission spectra with a 35 nm separation between excitation and emission wavelengths. For this dye, the excitation scan is from 360 to 600 nm; the emission scan is from 395 to 635 nm. The emission fluorescence from the scan is plotted on a graph. The typical scan speed setting is "very fast" on the RF-5000U; it is "fast" on the RF-5301. The typical sensitivity setting on both instruments is "high."

Excitation and emission slit width settings vary between the two instruments. The widths vary with the dyes for which we are sampling and for the matrix in which the dyes may be present. Excitation and emission slit width settings are summarized in Table 1.

Table 1. Excitation and emission slit width settings routinely used for dye analysis. Units are nanometers (nm)

Parameter	**RF5000U**	**RF5301**
Excitation slit for Eos, Fl, RWT, and SRB in elutant	5	3
Emission slit for Eos, Fl, RWT, and SRB in elutant	3	1.5
Excitation slit for Eos, Fl, RWT, and SRB in water	5	5
Emission slit for Eos, Fl, RWT, and SRB in water	10	3
Excitation slit for Pyranine in elutant	5	5
Emission slit for Pyranine in elutant	3	3
Excitation slit for Pyranine in pH adjusted water	5	5
Emission slit for Pyranine in pH adjusted water	3	3

Eos = 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; peaks are picked to the nearest 0.1 nm. All samples run on the RF-5000U and RF-5301 are stored on disk and printed on normal typing paper with a laser printer; sample information is printed on the chart.

All samples analyzed are recorded in a bound journal.

Quantification

We calculate the magnitude of fluorescence peaks for fluorescein, eosine, rhodamine WT, sulforhodamine B, and pyranine dyes. Dye quantities are expressed in microgram per liter (parts per billion; ppb). On the RF-5000U and RF-5301 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.

Where there are multiple fluorescence peaks it is sometimes necessary to calculate dye concentrations based upon the height of the fluorescence peak rather that the area. The heights of the peaks are also proportional to dye concentrations.

We run dye concentration standards each day the machine is used. Ten separate 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 pyranine in well water from the Jefferson City-Cotter Formation. A sample of the standard is placed for at least two hours in a high ammonia atmosphere to adjust the pH to a value of 9.5 or greater.
5) 10 ppb fluorescein and 100 ppb rhodamine WT in elutant.
6) 10 ppb eosine in elutant.
7) 100 ppb sulforhodamine B in elutant.
8) 10 ppb pyranine 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 insure 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, sulforhodamine B, and pyranine. The resulting solutions contain 100 mg/l dye (100 parts per million dye). 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 Finnpipette 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. Ozark Underground Laboratory 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 Finnpipette. (see description in Step 2). All other volume measurements are made with Rheinland Kohn Geprufte 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) A solution containing 1 ppm fluorescein dye and 10 ppm rhodamine WT dye.

2) A solution containing 1 ppm eosine.

3) A solution containing 10 ppm sulforhodamine B dye.

4) A solution containing 1 ppm pyranine.

Step 4. A series of eight short-term dye standards are made from solutions in Step 3. These standards were identified earlier in this section. In the experience of the Ozark Underground Laboratory these standards have a useful shelf life in excess of one week. However, in practice, they are kept under refrigeration and new standards are made weekly.

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 dilution is 100 fold. One part of the test sample is combined with 99 parts of water (if the test sample is water) or with 99 parts of the standard elutant (if the test sample is elutant). 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 Finnpipette, 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%

All other volume measurements are made with Rheinland Kohn Geprufte Sicherheit 50 ml. capacity pump dispenser which will pump within plus or minus 1% of the set value.

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.

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 typically includes approximately 1% of materials used.

Reports

Reports are provided in accordance with the needs of the client. At a minimum we provide copies of the analysis graphs and a listing of stations and samples where dye was detected. The reports indicate dye concentrations.

Work at the Ozark Underground Laboratory is directed by Mr. Thomas Aley. Mr. Aley has 40 years of professional experience in hydrology and hydrogeology. He is certified as a Professional Hydrogeologist (Certificate #179) by the American Institute of Hydrology. Mr. Aley has 35 years of professional experience in groundwater tracing with fluorescent tracing agents.

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 five dyes. 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 centrifuged or, if this is not effective, diluted prior to analysis.

Table 2 provides normal emission wavelength ranges and detection limits for the five dyes when analyzed on the OUL's RF-5000U spectrofluorophotometer. Table 3 provides similar data for the OUL's RF-5301. As indicated earlier in Table 1, the analytical protocols used on the two instruments are somewhat different, especially in regard to the widths of excitation and emission slit settings.

Table 2. RF-5000U Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein, eosine, rhodamine WT, sulforhodamine B, and pyranine dyes in water and elutant samples. Detection limits are based upon the as-sold weight of the dye mixtures normally used by the OUL.

Dye and Matrix	Normal Acceptable Emission Wavelength Range (nm)	Detection Limit (ppb)
Eosine in Elutant	533.0 to 539.6	0.035
Eosine in Water	529.6 to 538.4	0.008
Fluorescein in Elutant	510.7 to 515.0	0.010
Fluorescein in Water	505.6 to 510.5	0.0005
Pyranine in Elutant	500.4 to 504.6	0.055
Pyranine in Water*	501.2 to 505.2	0.030
Rhodamine WT in Elutant	561.7 to 568.9	0.275
Rhodamine WT in Water	569.4 to 574.8	0.050
Sulforhodamine B in Elutant	567.5 to 577.5	0.150
Sulforhodamine B in Water	576.2 to 579.7	0.040

* pH adjusted water with pH of 9.5 or greater.

Note: The protocols for the analysis of pyranine dye are substantially different than those for the other dyes. As a result, there is less potential interference between pyranine and fluorescein than might otherwise be indicated by the emission wavelength values shown in the table.

Table 3. RF-5301 Spectrofluorophotometer. Normal emission wavelength ranges and detection limits for fluorescein, eosine, rhodamine WT, sulforhodamine B, and pyranine dyes in water and elutant samples. Detection limits are based upon the as-sold weight of the dye mixtures normally used by the OUL.

Dye and Matrix	Normal Acceptable Emission Wavelength Range (nm)	Detection Limit (ppb)
Eosine in Elutant	538.1 to 543.9	0.050
Eosine in Water	533.4 to 537.9	0.015
Fluorescein in Elutant	514.0 to 518.1	0.025
Fluorescein in Water	508.0 to 511.7	0.002
Pyranine in Elutant	502.1 to 508.1	0.015
Pyranine in Water*	504.1 to 510.1	0.010
Rhodamine WT in Elutant	565.4 to 572.0	0.170
Rhodamine WT in Water	572.7 to 578.0	0.015
Sulforhodamine B in Elutant	572.8 to 579.6	0.080
Sulforhodamine B in Water	580.1 to 583.7	0.008

* pH adjusted water with pH of 9.5 or greater.

Note: The protocols for the analysis of pyranine dye are substantially different than those for the other dyes. As a result, there is less potential interference between pyranine and fluorescein than might otherwise be indicated by the emission wavelength values shown in the table.

Criteria for Determining Positive Dye Recoveries

The following sections identify normal criteria used by the OUL for determining positive dye recoveries. Beginning January 1, 2001, the primary analytical instrument in use at the OUL was the RF-5301; the RF-5000U was the principal backup instrument. Studies which were in progress prior to January 1, 2001 continued to have samples analyzed on the RF-5000U.

Except for pyranine dye, the analytical protocol used for the RF-5301 provides for the use of narrower excitation and/or emission slit settings than the RF-5000U protocol. This enhances our ability to discriminate between dyes and other fluorescent compounds. The protocol which is possible with the RF-5301 (as contrasted with the RF-5000U) also provides for a better balance in the sizes of the fluorescence peaks associated with an equal concentration of all of the dyes.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive <u>Eosine</u> Dye Recoveries <u>in Elutants</u> from Charcoal Samplers.

There is generally little or no detectable fluorescence background in the general range of eosine dye encountered in most groundwater tracing studies. The following four criteria are used to identify fluorescence peaks which are deemed to be eosine dye.

Criterion 1. There must be at least one fluorescence peak at the station in question in the range of 538.1 to 543.9 nm for samples analyzed by the RF-5301. The range must be 533.0 to 539.6 nm for samples analyzed by the RF-5000U.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. For the RF-5301, the eosine detection limit in elutant samples is 0.050 ppb, thus this dye concentration limit equals 0.150 ppb. For the RF-5000U the eosine detection limit in elutant samples is 0.035 ppb, thus this dye concentration limit equals 0.105 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 Ozark Underground Laboratory for Determining Positive <u>Eosine</u> Dye Recoveries <u>in Water</u> Samples.

There is generally little or no detectable fluorescence background in the general range of eosine dye encountered in most groundwater tracing studies. The following three criteria are used to identify fluorescence peaks which are deemed to be eosine dye.

Criterion 1. The associated charcoal samplers for the station should also contain eosine 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 eosine dye from our groundwater tracing work. For samples analyzed on the RF-5301, the fluorescence peak should generally be in the range of 533.4 to 537.9 nm. For samples analyzed on the RF-5000U, the fluorescence peak should generally be in the range of 529.6 to 538.4 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 analyzed on the RF-5301 is 0.015 ppb, thus this dye concentration limit equals 0.045 ppb. For samples analyzed on the 5000U the detection limit is 0.008 ppb, thus this dye concentration limit equals 0.024 ppb.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive <u>Fluorescein</u> Dye Recoveries <u>in Elutants</u> from Charcoal Samplers.

There is often some fluorescence background in the range of fluorescein dye present at some of the stations used in groundwater tracing studies. We routinely conduct background sampling prior to the introduction of any tracer dyes to characterize this background fluorescence and to identify the existence of any tracer dyes which may be present in the area. The fact that a fluorescence peak is identified in our analytical results is <u>not</u> proof that it is fluorescein dye or that it is fluorescein dye from the trace of concern. The following 4 criteria are used to identify fluorescence peaks which are deemed to be fluorescein dye recoveries from our tracing work.

Criterion 1. There must be at least one fluorescence peak at the station in question in the range of 514.0 to 518.1 nm for samples analyzed by the RF-5301. The range must be 510.7 to 515.0 for samples analyzed by the RF-5000U.

Criterion 2. The dye concentration associated with the fluorescence peak must be at least 3 times the detection limit. For the RF-5301, the fluorescein detection limit in elutant samples is 0.025 ppb, thus this dye concentration limit equals 0.075 ppb. For the RF-5000U, the fluorescein detection limit in elutant samples is 0.010 ppb, thus this dye concentration limit equals 0.030 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 Ozark Underground Laboratory for Determining Positive Fluorescein Dye Recoveries in Water Samples.

There is commonly some fluorescence background in the general range of fluorescein dye at some sampling stations used in groundwater tracing studies. The following criteria are used to identify fluorescence peaks which are deemed to be fluorescein dye in water.

Criterion 1. The associated charcoal samplers for the station should also contain fluorescein 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 fluorescein dye from our groundwater tracing work. For samples analyzed on the RF-5301, the fluorescence peak should generally be in the range of 508.0 to 511.7 nm. For samples analyzed on the RF-5000U, the fluorescence peak should generally be in the range of 505.6 to 510.5 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 analyzed on the RF-5301 is 0.002 ppb, thus this dye concentration limit equals 0.006 ppb. For the RF-5000U the detection limit is 0.0005 ppb, thus this dye concentration limit equals 0.0015 ppb.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Rhodamine WT Dye Recoveries in Elutants from Charcoal Samplers.

There is generally little or no detectable fluorescence background in the general range of Rhodamine WT dye encountered in most groundwater tracing studies. The following four criteria are used to identify fluorescence peaks which are deemed to be Rhodamine WT.

Criterion 1. For samples analyzed on the RF-5301, there must be at least one fluorescence peak at the station in question in the range of 565.4 to 572.0 nm. For samples analyzed on the RF-5000U, there must be at least one fluorescence peak at the station in question in the range of 561.7 to 568.9 nm.

Criterion 2. The dye concentration associated with the Rhodamine WT peak must be at least 3 times the detection limit. For the RF-5301, the detection limit in elutant samples is 0.170 ppb, thus this dye concentration limit equals 0.510 ppb. For the RF-5000U, the detection limit in elutant samples is 0.275 ppb, thus this dye concentration limit equals 0.825 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 Ozark Underground Laboratory for Determining Positive Rhodamine WT Dye Recoveries in Water Samples.

The following criteria are used to identify fluorescence peaks which are deemed to be Rhodamine WT dye in water.

Criterion 1. 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. For samples analyzed with the RF-5301, the fluorescence peak should generally be in the range of 572.7 to 578.0 nm. For samples analyzed with the RF-5000U, the fluorescence peak should generally be in the range of 569.4 to 574.8 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 analyzed on the RF-5301 is 0.015 ppb, thus this dye concentration limit is 0.045 ppb. For samples analyzed on the RF-5000U the detection limit is 0.050 ppb, thus this dye concentration limit equals 0.150 ppb.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Sulforhodamine B Dye Recoveries in Elutants from Charcoal Samplers.

There is generally little or no detectable fluorescence background in the general range of sulforhodamine B dye encountered in most groundwater tracing studies. The following four criteria are used to identify fluorescence peaks which are deemed to be sulforhodamine B.

Criterion 1. For samples analyzed on the RF-5000U, there must be at least one fluorescence peak at the station in question in the range of 567.5 to 577.5 nm. The acceptable range for samples analyzed on the RF-5301 is 572.8 to 579.6 nm.

Criterion 2. The dye concentration associated with the sulforhodamine B peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in elutant samples is 0.150 ppb, thus this dye concentration limit equals 0.450 ppb. For the RF-5301, 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 Ozark Underground Laboratory for Determining Positive Sulforhodamine B dye Recoveries in Water Samples.

The following criteria are used to identify fluorescence peaks which are deemed to be sulforhodamine B dye in water.

Criterion 1. The associated charcoal samplers for the station should also contain sulforhodamine B dye in accordance with the criteria listed earlier. 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 sulforhodamine B dye from the tracing work under investigation. For samples analyzed with the RF-5000U, the fluorescence peak should generally be in the range of 576.2 to 579.7 nm. For samples analyzed with the RF-5301, 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. For samples analyzed on the RF-5301 the detection limit in water is 0.008 ppb, thus this dye concentration limit equals 0.024 ppb. For samples analyzed on the RF-5000U the detection limit in water samples is 0.040 ppb, thus this dye concentration limit equals 0.120 ppb.

Normal Criteria Used by the Ozark Underground Laboratory for Determining Positive Pyranine Dye Recoveries in Elutants from Charcoal Samplers.

It must be remembered that the analysis protocol for pyranine dye is different than the protocol for the other four dyes discussed in this document. If the other dyes are present in a sample analyzed for pyranine dye their emission fluorescence peaks (if any) will be appreciably different than the values presented above. Because of this, there is very little analytical interference between fluorescein and pyranine dyes when both are present in a sample.

There is often some detectable fluorescence background encountered in the general range of pyranine dye in groundwater tracing studies. The following four criteria are used to identify fluorescence peaks which are deemed to be pyranine.

Criterion 1. For samples analyzed on the RF-5000U, there must be at least one fluorescence peak at the station in question in the range of 500.4 to 504.6 nm. The acceptable range for samples analyzed on the RF-5301 is 502.1 to 508.1 nm.

Criterion 2. The dye concentration associated with the pyranine dye peak must be at least 3 times the detection limit. For the RF-5000U, the detection limit in elutant samples is 0.055 ppb, thus this dye concentration limit equals 0.165 ppb. For the RF-5301, the detection limit in elutant samples is 0.015 ppb, thus this dye concentration limit equals 0.045 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 pyranine dye. 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 Ozark Underground Laboratory for Determining Positive Pyranine Dye Recoveries in Water Samples.

It must be remembered that the analysis protocol for pyranine dye is different than the protocol for the other four dyes discussed in this document. If the other dyes are present in a sample analyzed for pyranine dye their emission fluorescence peaks (if any) will be appreciably different than the values presented above. Because of this, there is very little analytical interference between fluorescein and pyranine dyes when both are present in a sample.

The fluorescence of pyranine decreases below a pH of about 9.5. Prior to analysis water samples are placed in a high ammonia atmosphere for at least two hours. A pyranine dye in water standard is placed in the same atmosphere as the samples. Prior to analysis samples are tested to insure that their pH is 9.5 or greater. If pyranine dye concentrations in a sample are so great as to require dilution for quantification of the dye concentration the diluting water used is OUL reagent water which has been pH adjusted in a high ammonia atmosphere.

The following criteria are used to identify fluorescence peaks which are deemed to be pyranine dye in water.

Criterion 1. The associated charcoal samplers for the station should also contain pyranine dye in accordance with the criteria listed earlier. 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 pyranine dye from the tracing work under investigation. For samples analyzed with the RF-5000U, the fluorescence peak should generally be in the range of 501.2 to 505.2 nm. For samples analyzed with the RF-5301, the fluorescence peak should generally be in the range of 504.1 to 510.1 nm.

Criterion 3. The dye concentration associated with the fluorescence peak must be at least three times the detection limit. For samples analyzed on the RF-5301 the detection limit in water is 0.010 ppb, thus this dye concentration limit equals 0.030 ppb. For samples analyzed on the RF-5000U the detection limit in water samples is 0.030 ppb, thus this dye concentration limit equals 0.090 ppb.

APPENDIX B

PROGRESS UPDATE ON GROUNDWATER TRACING INVESTIGATIONS RELATED TO ELECTRIC LAKE, UTAH

Ozark UNDERGROUND LABORATORY 1572 Aley Lane Protem, MO 65733 (417) 785-4289 fax (417) 785-4290 oul@tri-lakes.net

CONFIDENTIAL AND PRIVILEGED

Memo to: Mr. Blaine Rawson, Holme, Roberts and Owen LLP, 299 S. Main St., Suite 1800, Salt Lake City, Utah 84111-2263

From: Tom Aley, Ozark Underground Laboratory

Date: December 2, 2003

Subject: Progress update on groundwater tracing investigations related to Electric Lake, Utah.

Tracer Dye Introductions

On April 1, 2003 I introduced 50 pounds of eosine dye mixture and 35 pounds of fluorescein mixture onto the bottom of Electric Lake. Each was a 75% dye equivalent mixture. The eosine was introduced at a location overlying the Diagonal Fault, and fluorescein was introduced at a location overlying the Connelsville Fault.

At the time of the dye introductions the ice cover was great enough that we were able to walk on top of it. Holes were drilled through the ice and the dye for each location (mixed with water) was introduced through a one inch diameter pipe to a location approximately six inches above the bottom of the lake.

The eosine dye introduction was made at Way Point 26 (longitude 39 degrees 37.135 minutes North, latitude 111 degrees 13.552 minutes West). Underwater photography showed that there was some water sinking in the bottom of the lake at this location. The dye mixture was introduced beginning at 1205 hours and was completed at 1300 hours. The bottom of the dye injection pipe was 17.5 feet below the top of the ice and was about 6 inches above the bottom of the lake. After dye introduction colored water could be noted from 17.5 to 15.5 feet below the top of the ice.

The fluorescein dye introduction was made at Way Point 16 (Longitude 39 degrees 37.05 minutes North, latitude 111 degrees 13.437 minutes West). The dye mixture was introduced beginning at 1413 hours and was completed at 1433 hours. The dye was introduced about 6 inches above the bottom of the lake; the bottom of the dye injection pipe was 19.5 feet below the top of the ice.

Various water samples were collected around the dye introduction points to provide data on dye dispersal within the waters of the lake.

On March 31, 2003 I watched an underwater video of the lake bottom in the general vicinity of the planned dye introduction points. The video indicated that there were numerous points where water was sinking into small holes in the floor of the lake. The flow of the water into the lake bed was indicated by small holes in the lake sediments and by sediment particles moving toward these holes.

An important observation from the underwater video relative to the dye tracing study was that water sinking into the floor of the lake did so at a large number of points over a substantial amount of area. As a result, much of the dye introduced at a location near the bottom of the lake near identified leakage points would not enter the groundwater system at the nearby lake leakage point. Subsequent dye detections at various points in the lake and in Huntington Creek downstream of the dam verified that substantial amounts of dye did not enter the groundwater system but instead moved through the lake and into Huntington Creek downstream of the dam.

Detections of Tracer Dyes

Tracer dyes clearly derived from our dye introductions have been detected at a number of sampling stations in Electric Lake, at two sampling stations on Huntington Creek downstream of Electric Lake, and in two wells (JC-1 and JC-3) which penetrate into portions of the Skyline Mine located within the Huntington Creek topographic basin. Some fluorescein dye has also been detected at Sampling Station 1 (Eccles Creek 1/4 mile downstream of the Skyline Mine). While it is likely that some of the fluorescein dye detected at Station 1 is derived from our dye introduction, some or all of the detected dye may have been derived from anti-freeze leakage from equipment used at the mine or anti-freeze fluids leaked onto the parking and loading area at the mine or onto the nearby highway.

A substantial amount of dye sampling and analysis work has been done within Electric Lake. This work has demonstrated and quantified the migration of both of the tracer dyes through essentially all of the lake between the dye introduction points and the dam.

Two sampling stations (Stations 10 and 11) were established on Huntington Creek below the Electric Lake Dam. Station 10 is located about 450 feet downstream of the dam, and Station 11 is located about 3,100 feet downstream of the dam. Both fluorescein and eosine dyes derived from our dye introductions have been routinely detected at these sampling stations in both activated carbon and water samples. Table 1 shows mean dye concentrations in water and charcoal samplers from Stations 10 and 11 for the four month period from April 21 to August 19, 2003; subsequent data exist but have not yet been summarized.

Table 1. Mean dye concentrations in water and charcoal samples for the period from April 21 to August 19, 2003 from Stations 10 and 11. All values are parts per billion (ppb).

Parameter	Station 10	Station 11
Fluorescein in 14 water samples	0.861	0.760
Fluorescein in 13 charcoal samplers	214.5	72.4
Eosine in 14 water samples	1.379	1.518
Eosine in 13 charcoal samplers	155.2	44.0

Charcoal samplers are accumulating samplers; they adsorb and retain a portion of the dye contained in the passing water. In contrast, water samples are collected at particular points in time. The distinction in types of samples explains why the dye concentrations in charcoal samplers are routinely greater than the concentrations in water samples.

The data in Table 1 indicate that most, if not all, of the dyes detected at Stations 10 and 11 have been discharged through the dam on Electric Lake. The data do not indicate any appreciable inflow of dyed water to Huntington Creek in the stream reach between Stations 10 and 11. Mean dye concentrations in activated charcoal samplers were lower in samples from Station 11 than from Station 10. This is consistent with dye losses due to sunlight exposure and other processes as well as some dilution along the stream reach between these two sampling stations. The mean fluorescein concentration in water samples from Station 11 was less than at Station 10, however, the mean eosine concentration at the downstream station (Station 11) was somewhat greater than at Station 10.

Dye concentration data from Stations 10 coupled with water discharge rate data from the dam permit us to estimate the amount of the tracer dyes which have been discharged through the dam and into Huntington Creek. I have made preliminary calculations for dye discharge quantities for the period from April through the middle of July. During this period about 3.5 pounds of fluorescein and about 6.2 pounds of eosine dye mixture discharged through the dam; this represents 10% of the fluorescein introduced and 12.4% of the eosine introduced. Dye concentrations in the discharging water have generally decreased since the middle of July. I have only recently requested and received updated flow rate data from Darcy Guymon; I will use these data to estimate the amount of dye discharged through the dam since the middle of July. The totals will probably be on the order of 15 to 20% of the amount of dye introduced. This is less than I would expect if there were no leakage out of the lake and into the groundwater system; this is an important finding and is consistent with the existence of appreciable leakage out of the lake and into the Skyline Mine.

Unfortunately, neither I nor anyone else with whom I am familiar has a good suite of data on dye detection rates through a lake similar to Electric Lake. As a result, we are in the realm of opinions without a highly relevant data base to support the opinions. If

there were a similar lake (but without leakage to a mine) we could do a similar dye trace to develop data which would either support or refute my opinion. One of the interesting things that we are learning with the bench test to date is that the rate of dye loss in Electric Lake water is very low. Still, sunlight and contact between the dye and the bottom of the lake would undoubtedly result in some dye losses, but I would not anticipate these to exceed about half of the dye introduced over the period of the study.

Station 2 is the JC-1 Well. It is completed into a water-saturated fault system intersected by the Skyline Mine. The JC-1 well intersected the fault system within a horizontal distance of 100 feet from the mine workings. The issue of whether or not the workings at this well are currently flooded is important. If the workings were flooded throughout the period of our sampling then this would greatly diminish the credibility of any argument that perhaps the fluorescein dye detected in samplers from this well was derived from anti-freeze leakage from mine equipment rather than from the dye we introduced. The mine workings adjacent to where well JC-1 intersects the water-saturated fault system have been flooded since the fault was intersected by the mine workings in August 2001.

Fluorescein dye (and in two cases eosine dye) has been detected in three of the five following charcoal samplers from the JC-1 Well:

- 5/29 1800 hours to 6/12/03 1115 hours. Fluorescein concentration 0.967 ppb, eosine concentration 0.189 ppb.
- 6/12 1115 hours to 6/18/03 1530 hours. Fluorescein concentration 0.801 ppb. Eosine not detectable.
- 6/18/03 1530 hours to 6/24/03 0745 hours. Well shut down for electrical work; no sample.
- 6/24 0745 hours to 6/30/03 1245 hours. No dyes detected.
- 6/30 1245 hours to 7/7/03 1430 hours. No dyes detected.
- 7/7 1430 hours to 7/14/03 1045 hours. Fluorescein concentration 1.04 ppb, eosine concentration 0.562 ppb.

Prior to the first detection of dye in the JC-1 well there had been 12 samples in a row (from February 27 to May 29, 2003) in which there was neither fluorescein nor eosine dye. Subsequent to the sampler in place for the period from July 7 to 14, 2003 there has been no tracer dyes detected at JC-1.

The three positive fluorescein peaks are all fully consistent with the presence of this tracer dye. The two eosine dye detections represent fluorescent shoulders on the analytical graph but are fully consistent with the presence of eosine dye in the samples.

The tracer dyes were introduced on April 1, 2003. They were first detected at JC-1 in a charcoal sampler in place for the period from May 29 to June 12, 2003. If we use the mid-point of this sampling period as the time of first dye arrival the time of first dye arrival was 65 days after dye introduction for both of the tracer dyes. The straight-line distance between the dye introduction point and JC-1 was approximately 7,200 feet for

the eosine dye and 8,400 feet for the fluorescein dye. Based upon these distances and a first-arrival travel time of 65 days, the mean first dye arrival groundwater velocity was 111 feet per day for the eosine and 129 feet per day for the fluorescein.

Well JC-3 intersects the Skyline Mine workings near where they intersected the water-saturated fault system. It did not begin pumping water that could be sampled for tracer dye until August 13, 2003. This was after the period in which the tracer dyes were detected at Well JC-1. The first activated carbon sampler from JC-3 had a fluorescence peak at 513.4 nm. This is 0.2 nm shorter than the normally acceptable wavelength range for fluorescein dye in the eluting solution. The shape of the peak is fully consistent with fluorescein dye, and it is not uncommon for small fluorescein concentrations to display fluorescence peaks a few tenths of a nanometer shorter than the normally acceptable range established for this dye. It is my conclusion that this fluorescence peak does represent fluorescein dye derived from the dye which we introduced into Electric Lake. The fluorescein concentration in this sample is 1.43 ppb.

Bench Test of Dye Losses to Local Bedrock

Purpose

A bench test is being conducted to assess the magnitude of dye losses onto samples of local bedrock. The bench test began on November 6, 2003 and is designed to determine if it is likely that a significant quantity of dye might have been detained, lost onto, or destroyed by, contact with bedrock during the Electric Lake Trace. If significant quantities of dye solution are detained or lost, then low or non-detections of dye at sampling points might be attributable to dye losses rather than a lack of large volume hydrologic connection between Electric Lake and the sampling points.

Study Design

Through Rodger Fry we obtained samples of different rock types that are present along the groundwater flow path from Electric Lake to the Skyline Mine. The samples are identified in Table 2 and the relative distance groundwater travels within each rock type as a percentage of the total is estimated. The estimates were provided by Rodger Fry.

Table 2. Rock types and their relative percentage along the groundwater flow route from Electric Lake to the Skyline Mine.

Lithology	Percentage
Starpoint Sandstone	50%
Fluvial Sandstone	20%
Interbeds	15%
Mudstone	12%
Carbonaceous Mudstone	2%
Coal	1%

The coal sample was from the Skyline Mine loadout facility. Samples of the other five rock types were core samples from Pacificorp's coal mine located to the south of Electric Lake which has the same rock sequence as that in the area of the Skyline Mine. All samples were crushed in a jaws crusher at a local engineering test laboratory to a diameter of less than 1/2 inch; each sample was passed through the crusher twice.

The crushed rock samples were divided into "fines" (materials less than 1/4 inch in diameter) and "coarse" (materials from 1/4 to 1/2 inch in diameter). The fines for each rock type were split evenly among four sample jars. Sufficient course material (if necessary) was then added to the jars to bring the total weight of the crushed material to 135 grams. The percent of fines in each of the six rock types were as follows:

- Starpoint Sandstone. 100%
- Fluvial Sandstone. 29.7%
- Interbeds. 100%
- Mudstone. 100%
- Carbonaceous Mudstone. 74.2%
- Coal. 100%

Dye solutions were made in water from Electric Lake; the water was provided by Rodger Fry. The four following dye solutions were made:

- Approximately 50 ppb (parts per billion) fluorescein in lake water.
- Approximately 5 ppb fluorescein in lake water.
- Approximately 50 ppb eosine in lake water
- Approximately 5 ppb eosine in lake water.

Solutions of 5 and 50 ppb dyes were reasonable for the bench study based upon the following calculation. It is my understanding that the estimated leakage rate out of Electric Lake is on the order of 650 acre feet per month. Tracer dyes were detected at JC-1 for approximately 2 months. Thirty-five pounds of fluorescein mixture diluted in 1,300 acre feet of water (650 acre feet for two months) equals a dye concentration of 9.9 ppb. Fifty pounds of eosine mixture diluted in 1,300 acre feet of water equals 14.2 ppb. Five and fifty part per billion dye solutions would bracket these calculated concentrations and

permit us to determine if dye loss percentages were greater at lower dye concentrations than at higher dye concentrations.

For each rock type four sample bottles were partially filled with 135 grams of the crushed rock. Since there were six rock types this resulted in a total of 24 sample bottles. For each rock type 250 ml of one of the four dye solutions was poured into each of the sample bottles. The bottles were then sealed and placed in the dark in a cooler at room temperature (approximately 68 degrees F.). As a control, 250 ml samples of each of the dye solutions were placed in separate sealed bottles in which there were no rock samples; these samples were also placed in the cooler.

Samples were taken from each of the 24 rock sample bottles and 4 control sample bottles one day after the dye solutions were first placed over the rock samples. Each sample was then subjected to fluorescence analysis for the tracer dyes. Additional samples are now being withdrawn and analyzed approximately once per week; this will continue for approximately two months after the start of the bench test. After analysis the 2.5 ml. samples withdrawn for analysis are returned to the sample bottles so as to not alter the ratio of liquid to rock.

For each group of samples analyzed the dye concentration in the liquid above the rock fragments is quantified and compared with the dye concentration in the control samples to calculate a percent of the initial dye concentration remaining. This corrects for any dyes which may be lost to processes not related to the rocks.

Results

Table 3 presents values for the percent of the initial dye concentration which was detectable in the liquid above the rock samples after one day of contact with the dye solution. Table 4 provides similar values for samples analyzed seven days after the contact between the dye solution and the rock began.

Table 3. Dye concentration in samples as a percent of dye concentration in the control sample one day after samples were placed in contact with dye solutions.

Rock Type	Nominal 50 ppb Fluorescein	Nominal 5ppb Fluorescein	Nominal 50 ppb Eosine	Nominal 5 ppb Eosine
Starpoint SS	10.3	3.9	3.6	1.8
Fluvial SS	94.7	90.5	60.6	45.3
Interbeds	96.5	92.3	41.4	20.8
Mudstone	73.4	40.4	21.6	8.3
Carbonaceous Mudstone	77.9	51.9	54.6	68.2
Coal	92.6	43.8	37.0	6.1

Table 4. Dye concentration in samples as a percent of dye concentration in the control sample 7 days after samples were placed in contact with dye solutions.

Rock Type	Nominal 50 ppb Fluorescein	Nominal 5ppb Fluorescein	Nominal 50 ppb Eosine	Nominal 5 ppb Eosine
Starpoint SS	4.0	2.3	3.2	1.8
Fluvial SS	87.1	80.7	49.2	40.4
Interbeds	88.4	85.2	34.9	23.8
Mudstone	55.6	27.4	14.9	24.0
Carbonaceous Mudstone	36.5	19.4	38.3	26.0
Coal	85.5	74.4	32.3	24.0

Several important findings have resulted from the bench test work to date. They are numbered for convenience.

1. The most rapid loss of dyes occurred in the first day after the dye solutions were placed in contact with the rock. This applied to both dyes and to both dye concentrations.

2. The percentage rate of dye loss is greater in the 5 ppb solution than in the 50 ppb solution. This applies to both dyes.

3. Dye concentrations in most samples has continued to decline for at least 20 days after the dye solutions first came in contact with the rock samples.

4. The rock type which provides the greatest dye losses is the Starpoint Sandstone. It is estimated that 50% of the groundwater flow route between the lake and the mine is through this rock type. The rates of dye loss in this rock type are greater for eosine than for fluorescein.

5. Based on the data to date the only rock type where eosine dye is lost more slowly than fluorescein is the carbonaceous mudstone. However, in samples measured 20 days after the start of the bench test the amount of dye lost to the carbonaceous mudstone was less in the 50 ppb fluorescein solution than in the 50 ppb eosine solution.

The bench test is providing very useful information and it is anticipated that it will continue to do so. The extent of dye losses to the various rock substrates is clearly consistent with the low concentration detection of fluorescein at JC-1 and JC-3 and the even smaller concentration of eosine dye detected at JC-1.

Summary of Important Information and Findings

1. 50 pounds of eosine dye mixture and 35 pounds of fluorescein dye mixture were introduced near the floor of Electric Lake at separate dye introduction points. The dye introduction locations were six inches off the bottom of the lake and at locations near points where an underwater video indicated that lake water was sinking into the bed of the lake.

2. The underwater video taken prior to the dye introduction showed that there were numerous points where water was sinking into small holes over a substantial amount of area on the floor of the lake. The flow of the water into the lake bed was indicated by small holes in the lake sediments and by sediment particles moving toward these holes.

3. A result of the numerous small flow rate leakage points over a substantial area was that much of the dye introduced near a single leakage point would not enter the groundwater system at this leakage point. Subsequent dye detections at various points in the lake and in Huntington Creek downstream of the dam verified that substantial amounts of dye did not enter the groundwater system, but instead moved through the lake and into Huntington Creek downstream of the dam.

4. Station 10 is Huntington Creek at a point about 50 feet downstream of the dam on Electric Lake. Dye concentration data from this station coupled with water discharge rate data from the dam permit us to estimate the amount of the tracer dyes which have been discharged through the dam and into Huntington Creek. During the period from April through the middle of July about 3.5 pounds of fluorescein and about 6.2 pounds of eosine dye mixture discharged through the dam; this represents 10% of the fluorescein introduced and 12.4% of the eosine introduced. Dye concentrations in the discharging water have generally decreased since the middle of July. I have only recently requested updated flow rate data from Darcy Guymon; I will use these data to estimate the amount of dye discharged through the dam since the middle of July. The totals will probably be on the order of 15 to 20% of the amount of dye introduced.

5. The amount of dye discharged from Electric Lake to date is less than I would expect if there were no leakage out of the lake and into the groundwater system. This conclusion is consistent with the existence of appreciable leakage out of the lake and into the Skyline Mine.

6. Fluorescein dye introduced onto the floor of Electric Lake was detected in three activated carbon samplers collected from Well JC-1. This well is extracting water from portions of the Skyline Mine located relatively near Electric Lake. The fluorescein concentrations were 0.967, 0.801, and 1.04 ppb.

7. Eosine dye introduced onto the floor of Electric Lake was detected in two activated carbon samplers collected from Well JC-1. Both of these samplers also contained fluorescein dye; both of the fluorescein concentrations were greater than the eosine concentration. The eosine concentrations were 0.189 and 0.562 ppb.

8. Fluorescein dye was detected in one sample from Well JC-3; the concentration was 1.43 ppb.

9. Based upon first dye arrival times at Well JC-1, the mean groundwater travel rates for first dye arrival at Well JC-1 from the eosine and fluorescein dye introduction points was between 111 and 129 feet per day.

10. The relatively low concentrations of fluorescein and eosine dyes detected in water from JC-1 and JC-3 could potentially indicate either 1) that water contributions to the mine from the dye introduction locations is small, or 2) that substantial concentrations of the tracer dyes can be lost from dye solutions in contact with rock units traversed by water moving from the lake into the mine. A bench test was designed and is being conducted to address these two possibilities by assessing dye losses onto rocks typical of the area.

11. The bench test is demonstrating large percentage dye losses from 5 and 50 ppb dye solutions placed in contact with rocks typical of the area. In the test samples 135

grams of crushed rock was covered by 250 ml of dye solution. By weight this is 1.85 times more dyed water than crushed rock.

12. In the bench test much of the dye loss occurred within the first day of contact between the rock and dyed water. However, additional dye loss continues to occur after the first day and for at least 20 days (based upon data to date). The discovery of both initial rapid dye losses and continuing dye losses are important. The bench test data are demonstrating that the relatively small dye concentrations detected in the Skyline Mine do not indicate that the volume of water moving from the lake into the mine is small.

Recommendations

1. The bench test is designed to run for a total period of about two months. It should be continued for at least this period since it is yielding valuable and relevant data.

2. The study plan for the dye trace (see page 4 of the Ozark Underground Laboratory Workplan dated April 15, 2003) stated the following:

Sampling for tracer dyes at long term sampling stations will occur approximately once per week during the course of this study. Slight deviations can be made to avoid holidays, bad weather, or for logistical reasons. The dye quantities selected are appropriate for a groundwater trace where dye detections in the Skyline Mine would first occur within approximately four months of dye introduction (i.e., on or before about August 1, 2003). Weekly sampling will continue until about November 1, 2003. If both of the dyes are detected in waters derived from the Skyline Mine prior to November 1, 2003 the duration of the sampling may be decreased. The decision to terminate sampling will be made after all parties involved in hydrogeologic investigations of Electric Lake have had an opportunity to review data and have input into the decision.

Based upon results to date (including the bench test) I believe it is unlikely that we will have any more detections of tracer dyes in the mine. However, we should expect representatives of the mine to argue in the future that the detected dyes at JC-1 and JC-3 were in only a few samples and that they could have reflected mine activities rather than dye from our dye introductions. If we continue to collect and analyze samples from mine waters and they show no fluorescence peaks characteristic of the tracer dyes we will enhance the credibility of our detections by demonstrating (even more fully than we already have) that the only credible source for the dyes that we detected in the wells is from the dyes that we introduced in Electric Lake.

More sampling of Huntington Creek downstream of the dam will help us more fully quantify the amount of the introduced dye which was discharged through the dam. If sampling persisted until about April 1 (the anniversary of the date when we introduced the dye) we would have a full year of data and these data should minimize potential arguments that appreciable amounts of the tracer dyes are trapped in the lake due to lake stratification.

Based upon the above discussion it is my recommendation that we continue dye monitoring until about April 1.

Thomas Aley, President
Ozark Underground Laboratory, Inc.

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APPENDIX C

DRAFT

FINAL REPORT ON BENCH TEST RELATED TO TRACER DYES USED AT ELECTRIC LAKE, UTAH

August 12, 2004

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DRAFT

FINAL REPORT ON BENCH TEST STUDIES RELATED TO TRACER DYES USED AT ELECTRIC LAKE, UTAH

Thomas Aley, RG and PHG
President, Ozark Underground Laboratory, Inc.

August 12, 2004

A client-confidential report prepared for Mr. Blaine Rawson of Holme, Roberts and Owen LLP, 299 S. Main St., Suite 1800, Salt Lake City, Utah 84111-2263.

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penetrate into portions of the Skyline Mine located within the Huntington Creek topographic basin. Some fluorescein dye has also been detected at Sampling Station 1 (Eccles Creek 1/4 mile downstream of the Skyline Mine). While it is likely that some of the fluorescein dye detected at Station 1 is derived from our dye introduction, some or all of the detected dye may have been derived from anti-freeze leakage from equipment used at the mine or anti-freeze fluids leaked onto the parking and loading area at the mine or onto the nearby highway.

2004 Tracer Studies

The first dye introduction (Trace 04-01) was made through an ice cover at Way Point 26. This location is on the Diagonal Fault, and is the same location where 50 pounds of eosine dye mixture was introduced near the floor of the lake on April 1, 2003. For Trace 04-01 75 pounds of fluorescein dye mixture containing approximately 75% dye equivalent and 25% diluent was mixed with approximately 75 gallons of water and pumped through a plastic pipe to a location 2 feet above the floor of the lake. The dye introduction began at 1217 hours on February 24, 2004 and was completed at 1223 hours.

The second dye introduction (Trace 04-02) was made through an ice cover at Way Point 16. This location is on the Connelsville Fault, and is the same location where 35 pounds of fluorescein dye mixture was introduced near the floor of the lake on April 1, 2003. For Trace 04-02 125 pounds of fluorescein dye mixture containing approximately 75% dye equivalent and 25% diluent was mixed with approximately 125 gallons of water and pumped through a plastic pipe to a location 2 feet above the floor of the lake. Dye introduction began at 1447 hours on February 24, 2004 and was completed at 1455 hours.

BENCH TEST METHODOLOGY

Rock samples were provided to the Ozark Underground Laboratory (OUL) by PacifiCorp. The six types of rock supplied were the Starpoint sandstone, fluvial sandstone, interbeds, mudstone, carbonaceous mudstone, and coal. The coal sample was from the Skyline Mine loadout facility. Samples of the other five rock types were core samples from PacifiCorp's coal mine located to the south of Electric Lake which has the same rock sequence as that in the area of the Skyline Mine.

All samples were crushed in a jaws crusher to a diameter of less than 1/2 inch at a local engineering test laboratory; each sample was passed through the crusher twice. The smallest weight of rock provided was the carbonaceous mudstone. It permitted the use of approximately 135 grams of rock for each of four subsequent tests.

The crushed rock samples were divided into "fines" (materials less than 1/4 inch in diameter) and "coarse" (materials from 1/4 to 1/2 inch in diameter). The fines for each rock type were split evenly among four sample jars. Sufficient course material (if necessary) was then added to the jars to bring the total weight of the crushed material to 135 grams. The percent of fines in each of the six rock types were as follows:

- Starpoint Sandstone. 100%
- Fluvial Sandstone. 29.7%
- Interbeds. 100%
- Mudstone. 100%
- Carbonaceous Mudstone. 74.2%
- Coal. 100%

Pint glass jars were used as the test containers. New jars were purchased for the test. All jars were rinsed with OUL reagent water and dried before use. Two jars were selected at random and a rinsate sample was collected from each and analyzed for the presence of fluorescent compounds. No fluorescent compounds were detected in either sample. Each jar had a printed self-adhesive label affixed that had a station number and a station name that includes the nominal dye concentration and dye type.

Dye solutions were made in water from Electric Lake; the water was provided by Rodger Fry. The Electric Lake water was analyzed for the presence of fluorescent compounds and no fluorescent compounds were detected. The four following dye solutions were made:

- Approximately 50 ppb (parts per billion) fluorescein in lake water.
- Approximately 5 ppb fluorescein in lake water.
- Approximately 50 ppb eosine in lake water
- Approximately 5 ppb eosine in lake water.

Four new amber glass jugs and one piece of lab glassware were used to mix the dye solutions. Rinsate samples were collected from one jug and from the lab glassware. These

samples were analyzed for the presence of fluorescent compounds. No fluorescent compounds were detected in either sample.

Solutions of 5 and 50 ppb dyes were reasonable for the bench study based upon the following calculation. The estimated leakage rate out of Electric Lake is on the order of 650 acre feet per month. Tracer dyes from the 2003 introductions were detected at JC-1 for approximately 2 months. Thirty-five pounds of fluorescein mixture diluted in 1,300 acre feet of water (650 acre feet for two months) equals a dye concentration of 9.9 ppb. Fifty pounds of eosine mixture diluted in 1,300 acre feet of water equals 14.2 ppb. Five and fifty part per billion dye solutions would bracket these calculated concentrations and permit us to determine if dye loss percentages are greater at lower dye concentrations than at higher dye concentrations.

For each rock type four sample bottles were partially filled with 135 grams of the crushed rock. Since there were six rock types this resulted in a total of 24 sample bottles. For each rock type 250 ml of one of the four dye solutions was poured into each of the sample bottles. The bottles were then sealed and placed in the dark in a cooler at room temperature (approximately 68 degrees F.). As a control, 250 ml samples of each of the dye solutions were placed in separate sealed bottles in which there were no rock substrates; these samples were also placed in the cooler.

Samples were taken from each of the 24 rock sample bottles and 4 control sample bottles one day after the dye solutions were first placed over the rock samples. Each sample was then subjected to fluorescence analysis for the tracer dyes. Additional samples were then withdrawn and analyzed approximately once per week for the 63 day duration of the bench test. After analysis the 2.5 ml. samples withdrawn for analysis were returned to the sample bottles so as to not alter the ratio of liquid to rock.

For each group of samples analyzed the dye concentration in the liquid above the rock fragments was quantified and compared with the dye concentration in the control samples to calculate a percent of the initial dye concentration remaining. This corrects for any dyes which may be lost to processes not related to the geologic units being tested.

Approximately 5% of the samples analyzed were replicate samples. The analysis of these samples permits calculation of Relative Percent Difference (RPD) values.

The pH of the dye solutions on top of the various rock types was determined. All pH measurements were near neutral, so pH was not a factor in reducing the fluorescence intensity of any of the samples.

At the end of the study 60 grams of each rock sample was removed and centrifuged at 5000 rpm for 5 minutes. The water was poured off and we weighted out 40 grams of dried rock. The rock sample was put in a glass bottle and covered with 74 ml of un-dyed Electric Lake water. After one day samples of the water were analyzed to determine the concentrations of dye present.

RESULTS

Introduction to Tabular Information

Tables showing analytical results from all samples are enclosed in Appendix A.

Dye concentrations, and their changes through time in the four different dye solutions in contact with the six types of rock substrates, are shown in the following six tables:

- Table 1. Starpoint sandstone and associated dye concentrations.
- Table 2. Fluvial sandstone and associated dye concentrations
- Table 3. Interbeds and associated dye concentrations.
- Table 4. Mudstone and associated dye concentrations.
- Table 5. Carbonaceous mudstone and associated dye concentrations
- Table 6. Coal and associated dye concentrations.

Please note that all initial dye concentrations (50 and 5 ppb solutions) are nominal concentrations. The columns titled "control ppb" shows the measured concentrations of the standards on the dates that they were measured. The only exception to this is that there were no measurements made of the controls on January 8, 2004. The reason is that the laboratory technician neglected to make the measurements and the omission was not detected until the analytical results were reviewed. The measurements made of the controls on January 2, 2004 were used as the results for January 8.

Where there are two lines of data for a particular date this indicates that a duplicate sample was analyzed. Note also that there are entries labeled 1/8/04 - Day 63H. The letter "H" indicates that these are samples where all of the free liquid from the sample was poured into a separate container, mixed, and analyzed as a "homogenized" sample.

Table 1. Starpoint sandstone and associated dye concentrations.

Date & Day	50 ppb Fluorescein Solution			5 ppb Fluorescein Solution		
	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	5.27	51.1	10.3	0.191	4.95	3.9
11/13/03 - Day 7	1.92	48.2	4.0	0.114	4.92	2.3
11/20/03 - Day 14	1.88	50.1	3.8	0.123	4.88	2.5
11/26/03 - Day 20	2.19	50.4	4.3	0.137	4.86	2.8
12/4/03 - Day 28	2.40	49.4	4.9	0.136	4.87	2.8
12/11/03 - Day 35	2.31	51.5	4.5	0.142	4.90	2.9
12/18/03 - Day 42	2.31	50.8	4.5	0.148	4.91	3.0
12/24/03 - Day 48	2.24	48.2	4.6	0.149	5.00	3.0
1/2/04 - Day 57	2.15	51.7	4.2	0.150	5.10	2.9
1/2/04 - Day 57	2.10	51.7	4.1	0.143	5.10	2.8
1/8/04 - Day 63 *	2.24	51.7	4.3	0.163	5.10	3.2
1/8/04 - Day 63 *	2.20	51.7	4.3	--	--	--
1/8/04 - Day 63H *	2.25	51.7	4.4	0.173	5.10	3.4
1/8/04 - Day 63H *	2.21	51.7	4.3	--	--	--

Date & Day	50 ppb Eosine Solution			5 ppb Eosine Solution		
	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	1.99	54.6	3.6	0.097	5.34	1.8
11/13/03 - Day 7	1.74	54.1	3.2	0.095	5.34	1.8
11/20/03 - Day 14	1.25	53.4	2.3	0.049	5.23	0.9
11/26/03 - Day 20	0.886	53.5	1.7	0.049	5.19	0.9
12/4/03 - Day 28	0.885	52.7	1.7	ND	5.24	0
12/11/03 - Day 35	0.781	53.5	1.5	0.032	5.26	0.6
12/18/03 - Day 42	0.668	52.1	1.3	0.032	5.13	0.6
12/24/03 - Day 48	0.602	52.7	1.1	0.044	5.19	0.8
1/2/04 - Day 57	0.533	52.5	1.0	ND	5.10	<0.1
1/2/04 - Day 57	0.517	52.5	1.0	ND	5.10	<0.1
1/8/04 - Day 63 *	0.586	52.5	1.1	ND	5.10	<0.1
1/8/04 - Day 63 *	0.571	52.5	1.1	--	--	--
1/8/04 - Day 63H *	0.508	52.5	1.0	ND	5.10	<0.1
1/8/04 - Day 63H *	0.490	52.5	0.9	--	--	--

ND = None Detected

* = Control values for January 8 were not measured due to an oversight. The values shown are for January 2 when measurements were made.

Table 2. Fluvial sandstone and associated dye concentrations.

	50 ppb Fluorescein Solution			5 ppb Fluorescein Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	48.4	51.1	94.7	4.48	4.95	90.5
11/13/03 - Day 7	42.0	48.2	87.1	3.97	4.92	80.7
11/20/03 - Day 14	38.4	50.1	76.6	3.49	4.88	71.5
11/26/03 - Day 20	35.2	50.4	69.8	3.24	4.86	66.7
12/4/03 - Day 28	32.1	49.4	65.0	3.04	4.87	62.4
12/11/03 - Day 35	32.8	51.5	63.7	2.91	4.90	59.4
12/18/03 - Day 42	29.9	50.8	58.9	2.76	4.91	56.2
12/24/03 - Day 48	29.3	48.2	60.8	2.83	5.00	56.6
1/2/04 - Day 57	30.9	51.7	59.8	2.75	5.10	53.9
1/2/04 - Day 57	30.7	51.7	59.4	2.73	5.10	53.5
1/8/04 - Day 63 *	30.9	51.7	59.8	2.75	5.10	53.9
1/8/04 - Day 63 *	30.7	51.7	59.4	--	--	--
1/8/04 - Day 63H *	31.5	51.7	60.9	2.75	5.10	53.9
1/8/04 - Day 63H *	30.4	51.7	58.8	--	--	--

	50 ppb Eosine Solution			5 ppb Eosine Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	33.1	54.6	60.6	2.42	5.34	45.3
11/13/03 - Day 7	26.6	54.1	49.2	2.16	5.34	40.4
11/20/03 - Day 14	20.0	53.4	37.5	1.86	5.23	35.6
11/26/03 - Day 20	16.7	53.5	31.2	1.30	5.19	25.0
12/4/03 - Day 28	14.0	52.7	26.6	1.16	5.24	22.1
12/11/03 - Day 35	12.8	53.5	23.9	1.04	5.26	19.8
12/18/03 - Day 42	11.5	52.1	22.1	0.872	5.13	17.0
12/24/03 - Day 48	11.2	52.7	21.3	0.880	5.19	17.0
1/2/04 - Day 57	10.3	52.5	19.6	0.763	5.10	15.0
1/2/04 - Day 57	10.3	52.5	19.6	0.787	5.10	15.4
1/8/04 - Day 63 *	9.77	52.5	18.6	0.768	5.10	15.1
1/8/04 - Day 63H *	9.80	52.5	18.7	0.710	5.10	13.9

ND = None Detected

* = Control values for January 8 were not measured due to an oversight. The values shown are for January 2 when measurements were made.

Table 3. Interbeds and associated dye concentrations.

	50 ppb Fluorescein Solution			5 ppb Fluorescein Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	49.3	51.1	96.5	4.57	4.95	92.3
11/13/03 - Day 7	42.6	48.2	88.4	4.19	4.92	85.2
11/20/03 - Day 14	40.5	50.1	80.8	3.66	4.88	75.0
11/26/03 - Day 20	36.7	50.4	72.8	3.34	4.86	68.7
12/4/03 - Day 28	34.1	49.4	69.0	3.07	4.87	63.0
12/11/03 - Day 35	34.5	51.5	67.0	2.91	4.90	59.4
12/18/03 - Day 42	32.4	50.8	63.8	2.73	4.91	55.6
12/24/03 - Day 48	29.9	48.2	62.0	2.68	5.00	53.6
1/2/04 - Day 57	31.0	51.7	60.0	2.54	5.10	49.8
1/2/04 - Day 57	31.1	51.7	60.2	2.54	5.10	49.8
1/8/04 - Day 63 *	29.3	51.7	56.7	2.47	5.10	48.4
1/8/04 - Day 63H *	29.1	51.7	56.3	2.46	5.10	48.2

	50 ppb Eosine Solution			5 ppb Eosine Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	22.6	54.6	41.4	1.50	5.34	28.1
11/13/03 - Day 7	18.9	54.1	34.9	1.27	5.34	23.8
11/20/03 - Day 14	16.3	53.4	30.5	1.09	5.23	20.8
11/26/03 - Day 20	13.8	53.5	25.8	0.922	5.19	17.8
12/4/03 - Day 28	12.1	52.7	23.0	0.757	5.24	14.4
12/11/03 - Day 35	11.0	53.5	20.6	0.714	5.26	13.6
12/18/03 - Day 42	9.44	52.1	18.1	0.630	5.13	12.3
12/24/03 - Day 48	9.03	52.7	17.1	0.563	5.19	10.8
1/2/04 - Day 57	8.26	52.5	15.7	0.519	5.10	10.2
1/2/04 - Day 57	8.15	52.5	15.5	0.511	5.10	10.0
1/8/04 - Day 63 *	7.78	52.5	14.8	0.520	5.10	10.2
1/8/04 - Day 63H *	7.61	52.5	14.5	0.505	5.10	9.9

ND = None Detected

* = Control values for January 8 were not measured due to an oversight. The values shown are for January 2 when measurements were made.

Table 4. Mudstone and associated dye concentrations.

	50 ppb Fluorescein Solution			5 ppb Fluorescein Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	37.5	51.1	73.4	2.00	4.95	40.4
11/13/03 - Day 7	26.8	48.2	55.6	1.35	4.92	27.4
11/20/03 - Day 14	19.8	50.1	39.5	1.30	4.88	26.6
11/26/03 - Day 20	14.8	50.4	29.4	1.09	4.86	22.4
12/4/03 - Day 28	12.2	49.4	24.7	0.893	4.87	18.3
12/11/03 - Day 35	11.0	51.5	21.4	0.752	4.90	15.3
12/18/03 - Day 42	9.15	50.8	18.0	0.615	4.91	12.5
12/24/03 - Day 48	8.17	48.2	17.0	0.589	5.00	11.8
1/2/04 - Day 57	7.04	51.7	13.6	0.520	5.10	10.2
1/2/04 - Day 57	7.01	51.7	13.6	0.519	5.10	10.2
1/8/04 - Day 63 *	6.35	51.7	12.3	0.491	5.10	9.6
1/8/04 - Day 63H *	6.28	51.7	12.1	0.476	5.10	9.3

	50 ppb Eosine Solution			5 ppb Eosine Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	11.8	54.6	21.6	0.443	5.34	8.3
11/13/03 - Day 7	8.05	54.1	14.9	0.367	5.34	6.9
11/20/03 - Day 14	6.64	53.4	12.4	0.266	5.23	5.1
11/26/03 - Day 20	5.39	53.5	10.1	0.162	5.19	3.1
12/4/03 - Day 28	4.08	52.7	7.7	0.144	5.24	2.7
12/11/03 - Day 35	3.35	53.5	6.3	0.123	5.26	2.3
12/18/03 - Day 42	2.60	52.1	5.0	0.095	5.13	1.9
12/24/03 - Day 48	2.31	52.7	4.4	0.091	5.19	1.8
1/2/04 - Day 57	1.90	52.5	3.6	0.066	5.10	1.3
1/2/04 - Day 57	1.90	52.5	3.6	0.044	5.10	0.9
1/8/04 - Day 63 *	1.65	52.5	3.1	ND	5.10	<0.1
1/8/04 - Day 63H *	1.66	52.5	3.2	ND	5.10	<0.1

ND = None Detected

* = Control values for January 8 were not measured due to an oversight. The values shown are for January 2 when measurements were made.

Table 5. Carbonaceous Mudstone and associated dye concentrations.

	50 ppb Fluorescein Solution			5 ppb Fluorescein Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	39.8	51.1	77.9	2.57	4.95	51.9
11/13/03 - Day 7	17.6	48.2	36.5	0.955	4.92	19.4
11/20/03 - Day 14	7.09	50.1	14.2	0.379	4.88	7.8
11/26/03 - Day 20	7.90	50.4	15.7	0.230	4.86	4.7
12/4/03 - Day 28	5.23	49.4	10.6	0.150	4.87	3.1
12/11/03 - Day 35	5.20	51.5	10.1	0.091	4.90	1.9
12/18/03 - Day 42	4.39	50.8	8.6	0.064	4.91	1.3
12/24/03 - Day 48	3.13	48.2	6.5	0.043	5.00	0.9
1/2/04 - Day 57	2.12	51.7	4.1	0.029	5.10	0.6
1/2/04 - Day 57	2.16	51.7	4.2	0.030	5.10	0.6
1/8/04 - Day 63 *	1.75	51.7	3.4	0.017	5.10	0.3
1/8/04 - Day 63H *	1.70	51.7	3.3	0.017	5.10	0.3

	50 ppb Eosine Solution			5 ppb Eosine Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	29.8	54.6	54.6	3.64	5.34	68.2
11/13/03 - Day 7	20.7	54.1	38.3	1.65	5.34	30.9
11/20/03 - Day 14	10.1	53.4	18.9	0.770	5.23	14.7
11/26/03 - Day 20	5.56	53.5	10.4	0.307	5.19	5.9
12/4/03 - Day 28	3.11	52.7	5.9	0.200	5.24	3.8
12/11/03 - Day 35	1.50	53.5	2.8	0.077	5.26	1.5
12/18/03 - Day 42	0.920	52.1	1.8	0.052	5.13	1.0
12/24/03 - Day 48	0.687	52.7	1.3	0.031	5.19	0.6
1/2/04 - Day 57	0.462	52.5	0.9	ND	5.10	<0.1
1/2/04 - Day 57	0.458	52.5	0.9	ND	5.10	<0.1
1/8/04 - Day 63 *	0.283	52.5	0.5	ND	5.10	<0.1
1/8/04 - Day 63H *	0.293	52.5	0.6	ND	5.10	<0.1

ND = None Detected

* = Control values for January 8 were not measured due to an oversight. The values shown are for January 2 when measurements were made.

Table 6. Coal and associated dye concentrations.

	50 ppb Fluorescein Solution			5 ppb Fluorescein Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	47.3	51.1	92.6	2.17	4.95	43.8
11/13/03 - Day 7	41.2	48.2	85.5	3.66	4.92	74.4
11/20/03 - Day 14	40.8	50.1	81.4	3.75	4.88	76.8
11/26/03 - Day 20	38.8	50.4	77.0	2.99	4.86	61.5
12/4/03 - Day 28	38.0	49.4	76.9	3.59	4.87	73.7
12/11/03 - Day 35	37.9	51.5	73.6	3.57	4.90	72.9
12/18/03 - Day 42	38.1	50.8	75.0	3.45	4.91	70.3
12/24/03 - Day 48	35.7	48.2	74.1	3.48	5.00	69.6
1/2/04 - Day 57	37.1	51.7	71.8	3.57	5.10	70.0
1/2/04 - Day 57	37.0	51.7	71.6	3.49	5.10	68.4
1/8/04 - Day 63 *	37.4	51.7	72.3	3.51	5.10	68.8
1/8/04 - Day 63H *	36.5	51.7	70.6	3.37	5.10	66.1

	50 ppb Eosine Solution			5 ppb Eosine Solution		
Date & Day	Sample ppb	Control ppb	% of initial dye remaining	Sample ppb	Control ppb	% of initial dye remaining
11/7/03 - Day 1	20.2	54.6	37.0	0.919	5.34	17.2
11/13/03 - Day 7	17.5	54.1	32.3	1.28	5.34	24.0
11/20/03 - Day 14	14.7	53.4	27.5	0.577	5.23	11.0
11/26/03 - Day 20	14.6	53.5	27.3	0.321	5.19	6.2
12/4/03 - Day 28	12.6	52.7	23.9	0.717	5.24	13.7
12/11/03 - Day 35	12.4	53.5	23.2	0.688	5.26	13.1
12/18/03 - Day 42	11.4	52.1	21.9	0.697	5.13	13.6
12/24/03 - Day 48	11.2	52.7	21.3	1.28	5.19	24.7
1/2/04 - Day 57	11.7	52.5	22.3	0.733	5.10	14.4
1/2/04 - Day 57	12.7	52.5	24.2	0.449	5.10	8.8
1/8/04 - Day 63 *	11.2	52.5	21.3	0.680	5.10	13.3
1/8/04 - Day 63H *	10.2	52.5	19.4	**0.787	5.10	15.4

ND = None Detected

* = Control values for January 8 were not measured due to an oversight. The values shown are for January 2 when measurements were made.

** = Outside normal acceptable wavelength range

Rates of Dye Loss

The amounts of dye remaining in dye solutions after one day of contact with substrates are shown in Table 7. For all dye solutions the substrate which provides the most rapid dye loss (based upon Day 1 values) is the Starpoint sandstone. The mudstone is the second most rapid, but the percentages of dye lost to this substrate are substantially less than those lost to the Starpoint sandstone. The two substrate types which have the least dye lost from the dye solutions after one day are the fluvial sandstone and the carbonaceous mudstone.

Table 7. Percent of dye remaining in dye solutions after one day of contact with rock substrates.

Substrate	50 ppb Fluorescein	5 ppb Fluorescein	50 ppb Eosine	5 ppb Eosine
Starpoint sandstone	10.3	3.9	3.6	1.8
Fluvial sandstone	94.7	90.5	60.6	45.3
Interbeds	96.5	92.3	41.4	28.1
Mudstone	73.4	40.4	21.6	8.3
Carbonaceous mudstone	77.9	51.9	54.6	68.2
Coal	92.6	43.8	37.0	17.2

The bench test was continued for 63 days. The amounts of dye remaining in dye solutions after 63 days of contact with substrates are shown in Table 8. For all dye solutions the substrate which provides the greatest dye loss after 63 days is the carbonaceous mudstone. The Starpoint sandstone has the second greatest dye loss after 63 days. Please note that three of the substrates in contact with the 5 ppb eosine solution had no detectable eosine present at Day 63 (the percent value shown is "ND" for not detected). The two substrate types which had the least dye lost from the dye solutions after 63 days were the coal and the fluvial sandstone.

Table 8. Percent of dye remaining in dye solutions after 63 days of contact with rock substrates.

Substrate	50 ppb Fluorescein	5 ppb Fluorescein	50 ppb Eosine	5 ppb Eosine
Starpoint sandstone	4.3	3.2	1.1	ND
Fluvial sandstone	59.6	53.9	18.6	15.1
Interbeds	56.7	48.4	14.8	10.2
Mudstone	12.3	9.6	3.1	ND
Carbonaceous mudstone	3.4	0.3	0.5	ND
Coal	72.3	68.8	21.3	13.3
Weighted Average	24.9	21.5	7.1	4.7

As discussed in the introduction to this report the Starpoint sandstone represents about 50% of the rock mass which would likely be encountered by water traversing the flow route between Electric Lake and Skyline Mine. Fluvial sandstone represents about 20% of the rock mass, interbeds represent 15%, mudstone represents 12%, carbonaceous mudstone represents 2%, and coal represent 1% of the rock mass likely to be encountered by water following this flow route. The weighted averages shown in Table 8 are based upon the above percentages of rock mass and the percent losses shown in Table 8.

Based upon the weighted averages shown in Table 8, at the end of the 63-day bench test the 50 ppb fluorescein dye solutions contained 3.5 times more dye than did the 50 ppb eosine solutions. The 5 ppb fluorescein solutions contained 4.6 times more dye than did the 5 ppb eosine solutions. The percent of dye lost to substrates after 63 days was greater for 5 ppb dye solutions than for 50 ppb solutions. This applied to both fluorescein and eosine solutions, but the percentage difference was greater for eosine than for fluorescein.

Relative Percent Difference Values

Relative Percent Difference (RPD) values are commonly calculated for analyzed samples. The difference between two analyses of the same sample is divided by the mean of the two samples to calculated the value. The mean RPD value is then calculated from the individual RPD values.

Twenty-six replicate samples of dye solutions were analyzed during the course of the bench test. The mean RPD value was 5.9%. Three of the RPD values equaled or exceeded 8.2%; all of these were eosine samples, and the two pairs of samples with the highest RPD values had dye concentrations of less than 1.00 ppb. If the three high RPD values were to be excluded then the mean RPD for the remaining 23 pairs of samples would have been 1.3%.

Results for Homogenized Samples

The letter "H" in Tables 1 through 6 indicates that these are samples where all of the free liquid from the sample was poured into a separate container, mixed, and analyzed as a "homogenized" sample. These samples were analyzed to determine if there was any appreciable difference between samples routinely collected from the jars and homogenized samples. Such differences could indicate stratification of dyes in the bottles or depletion of dyes in liquids in close proximity to the substrates.

Dye concentrations in homogenized sample were equal to or greater than the concentrations in regular samples in 13 pairs of samples. The samples in homogenized samples were less than those in regular samples in 14 pairs of samples. RPD values were calculated for the 27 pairs of samples. The mean RPD value was 3.5%, and that values ranged from 0 to 15.3%. All five of the sample pairs with RPD values of 7.8% or greater were eosine samples, and four of these had mean concentrations of less than 1.00 ppb.

Comparing the RPD values for homogenized samples with RPD values for the typically collected samples indicates that any difference which may exist between the normally extracted samples and the homogenized samples is minimal and is within the range of our measurement accuracy. From this we conclude that the samples routinely collected and analyzed are reflective of mean dye concentrations in the free liquids throughout the sample bottles.

pH Determinations.

The pH of the dye solutions present on top of the various rock substrates was measured in all 50 ppb fluorescein solutions on Day 63. The values were as follows:

- Starpoint sandstone. 7.0
- Fluvial sandstone. 7.1
- Interbeds. 7.8
- Mudstone. 7.4
- Carbonaceous mudstone. 6.9
- Coal. 7.3

None of these values would result in appreciable decreases in the fluorescence intensity of the tracer dyes

Elution of Substrate Samples

At the end of the study samples of the rock substrates were eluted and the resulting dye concentrations determined. The approach used 4.25 grams of each substrate which was then eluted for one hour in 15 ml of a solution prepared as follows. First, a solution is prepared which consists of 5% aqua ammonia solution and 95% isopropyl alcohol solution. The aqua ammonia solution contains 29% ammonia and 71% reagent water. The isopropyl alcohol solution is 70% isopropyl alcohol and 30% reagent water. Next, pellets of potassium hydroxide are added to the solution until saturation occurs; this is evidenced by the development of a super-saturated solution in the bottom of the container. The supernatant (i.e., the liquid above the super-saturated layer) is then poured off and is used as the eluting solution. This eluting solution is identical with the solution used for eluting activated carbon samplers associated with the Electric Lake dye tracing investigations.

The dye concentrations present in the elutant are shown in the table in Appendix A. We recognized that some of the dye adsorbed onto the rock samples could not be removed by elution, yet we wished to estimate the percent of the initial dye which could be eluted from the substrate. We made this estimate by knowing the total weight of substrate and dye solution which remained after all free water was poured off, the percentage of this weight that was included in our 4.25 grams sample, and the dye concentration present in the eluted sample. This allowed us to proportionally calculate what percent of the initial dye in the associated dye solution was eluted from the

substrate. These values are shown in Table 9. Samples of mudstone, carbonaceous mudstone, and coal contained appreciable suspended material which interfered with the analysis. We centrifuged these samples for 5 minutes at 5,000 rpm; this did not clear the samples. For the more opaque samples we diluted them ten fold to partially overcome the turbidity in the samples. However, for these three rock types the percent of the initial dye eluted from the substrate is possibly under-estimated due to the poor optical characteristics of the samples.

We also measured the amount of free water poured off each substrate sample. This value was multiplied by the dye concentration in the sample at the end of the bench test (Day 63). By comparing this with the initial amount of dye in the sample bottle we were able to calculate the percent of the initial dye which was present in the free water component. These values are also shown in Table 9. Table 9 adds the percent of dye in each substrate to the percent of dye in free water associated with each substrate to produce an estimate of the total percent of initial dye present in each sample at the end of the study. Those percentages range from 0 to 92.7%. As would be expected, the percentages detected are greater for fluorescein than for eosine, and are greater for 50 ppb solutions than for 5 ppb solutions.

Ability of Water to Remove Dye from Substrate Materials

A final bench test used about 60 grams of the substrate samples that had previously been covered by dye solutions for 63 days. The samples were centrifuged at 5000 rpm for 5 minutes and resulting water was poured off. We then used 40 grams of the relatively dry substrate which was placed in a glass bottle and covered with 74 ml of un-dyed Electric Lake water. Forty grams of substrate and 74 ml of water is the same substrate to water ratio as the initial 135 grams of substrate and 250 ml of dye solution. The water was added to the substrates on January 13, 2004. The water was allowed to remain in contact with the rock for one day (until January 14) and then a sample was analyzed for dye concentration. Additional samples were collected on January 20 (after the water had been in contact with the rock for 7 days). The results are shown in Table 10 and in Appendix A.

Table 11 presents mean dye concentrations eluted by Electric Lake water from all substrates. The following observations can be made from the data in Table 11:

- The data show that the amount of dye eluted by the lake water increased with time. The data also show that the mean concentration of eosine eluted from substrates which had been exposed to the 50 ppb eosine solution was only 56% of the concentration of fluorescein eluted from substrates which had been exposed to 50 ppb fluorescein
- In the case of substrates exposed to 5 ppb eosine concentrations they released only about a third as much dye to Electric Lake water as did the substrates exposed to 5 ppb fluorescein concentrations.

- Electric Lake water in contact with substrates which had been exposed to 5 ppb fluorescein solutions eluted about 10% as much dye as was the case with water that had been in contact with substrates exposed to 50 ppb fluorescein solutions. In contrast, Electric Lake water in contact with substrates which had been exposed to 5 ppb eosine solutions eluted about 5.4 % to 5.7% as much dye as was the case with water that had been in contact with substrates exposed to 50 ppb eosine solutions.

Table 9. Percent of original dye concentration detected at end of the bench test.

Substrate	Dye and Concentration		Percent in Free Water	Percent in Substrate	Total % Detected
Starpoint Sandstone	Fl	50 ppb	3.5	34.4	37.9
Starpoint Sandstone	Fl	5 ppb	2.6	15.0	17.6
Starpoint Sandstone	Eos	50 ppb	0.8	32.7	33.5
Starpoint Sandstone	Eos	5 ppb	0	0	0
Fluvial Sandstone	Fl	50 ppb	51.9	14.7	66.6
Fluvial Sandstone	Fl	5 ppb	47.9	13.5	61.4
Fluvial Sandstone	Eos	50 ppb	14.7	53.4	68.1
Fluvial Sandstone	Eos	5 ppb	12.7	80.3	92.7
Interbeds	Fl	50 ppb	51.7	9.5	61.2
Interbeds	Fl	5 ppb	41.8	10.5	62.3
Interbeds	Eos	50 ppb	12.3	39.6	51.9
Interbeds	Eos	5 ppb	8.2	32.2	40.4
Mudstone	Fl	50 ppb	11.2	15.3	26.5
Mudstone	Fl	5 ppb	8.9	0	8.9
Mudstone	Eos	50 ppb	2.7	29.7	32.4
Mudstone	Eos	5 ppb	0	0	0
Carbonaceous Mudstone	Fl	50 ppb	3.1	29.1	32.2
Carbonaceous Mudstone	Fl	5 ppb	0.3	0	0.3
Carbonaceous Mudstone	Eos	50 ppb	0.5	21.6	22.1
Carbonaceous Mudstone	Eos	5 ppb	0	0	0
Coal	Fl	50 ppb	58.5	0	58.5
Coal	Fl	5 ppb	52.5	0	52.5
Coal	Eos	50 ppb	16.8	2.5	19.3
Coal	Eos	5 ppb	9.2	0	9.2

Table 10. Dye concentrations eluted from centrifuged substrates by Electric Lake water.

Substrate	Dye Solution	Jan 14 (1 day) ppb	Jan 20 (7 days) ppb
Starpoint Sandstone	50 ppb Fl	2.54	1.74 and 1.78
Starpoint Sandstone	5 ppb Fl	0.241	0.234
Starpoint Sandstone	50 ppb Eos	0.351	0.414
Starpoint Sandstone	5 ppb Eos	ND	ND
Fluvial Sandstone	50 ppb Fl	5.25	7.78
Fluvial Sandstone	5 ppb Fl	0.470	0.698
Fluvial Sandstone	50 ppb Eos	2.83	3.43
Fluvial Sandstone	5 ppb Eos	ND	0.224
Interbeds	50 ppb Fl	3.64	5.66
Interbeds	5 ppb Fl	0.374	0.549
Interbeds	50 ppb Eos	2.92	3.52
Interbeds	5 ppb Eos	0.409	0.353
Mudstone	50 ppb Fl	2.14	3.72
Mudstone	5 ppb Fl	0.209	0.338
Mudstone	50 ppb Eos	1.60	1.21
Mudstone	5 ppb Eos	ND	ND
Carbonaceous Mudstone	50 ppb Fl	1.74	1.97
Carbonaceous Mudstone	5 ppb Fl	0.147	0.090
Carbonaceous Mudstone	50 ppb Eos	1.51	1.64
Carbonaceous Mudstone	5 ppb Eos	0.107	ND
Coal	50 ppb Fl	2.88	3.68
Coal	5 ppb Fl	0.378	0.503
Coal	50 ppb Eos	2.95	3.57
Coal	5 ppb Eos	0.141 and 0.141	0.212

Fl = fluorescein; Eos = eosine

Table 11. Mean dye concentrations eluted from centrifuged substrates by Electric Lake water. Values shown are means for all substrates. All substrates had been submerged in the dye solutions noted for 63 days.

Previous dye solution	Mean dye concentration after 1 day. ppb	Mean dye concentration after 7 days. ppb
50 ppb fluorescein	3.03	4.10
5 ppb fluorescein	0.303	0.402
50 ppb eosine	2.03	2.30
5 ppb eosine	0.110	0.132

SUMMARY AND CONCLUSIONS

1. The tracer dyes fluorescein and eosine have been used in groundwater tracing studies at Electric Lake, Utah. These tracing studies were designed to help assess travel times involved in the movement of water from the lake into nearby portions of the Skyline Mine.

2. A bench test was conducted to determine if it was likely that a significant quantity of dye might have been detained, lost onto, or destroyed by contact with bedrock during groundwater tracing at Electric Lake.

3. The bench test used rock cores or other fresh rock from the six geologic units existing between the floor of Electric Lake and the Skyline Mine. Samples of the six geologic substrates were crushed and submerged in 5 and 50 ppb concentrations of fluorescein and eosine dyes. Samples of the dye solutions on top of the rock substrates were periodically collected over a 63 day period and analyzed to determine dye concentrations.

4. The bench test demonstrated that different rock substrates have different abilities to remove dye from dye solutions which are in contact with the rock. Some of the rock substrates are capable of removing the dye very rapidly; this is demonstrated by samples analyzed one day after the dye solutions were placed in contact with the substrates. For all dye solutions the substrate which provide the most rapid dye loss was the Starpoint sandstone. The mudstone was the second most rapid, but the percentages of dye lost to this substrate were substantially less than those lost to the Starpoint sandstone. The two substrate types which had the least dye lost from the dye solutions after one day were the fluvial sandstone and the carbonaceous mudstone.

5. The bench test was continued for 63 days. For all dye solutions the substrate which provided the greatest dye loss after 63 days was the carbonaceous mudstone. The Starpoint sandstone has the second greatest dye loss after 63 days. Three of the substrates in contact with the 5 ppb eosine solution had no detectable eosine present at Day 63. The two substrate types which had the least dye lost from the dye solutions after 63 days were the coal and the fluvial sandstone.

6. The Starpoint sandstone represents about 50% of the rock mass which would likely be encountered by water traversing the flow route between Electric Lake and Skyline Mine. Fluvial sandstone represents about 20% of the rock mass, interbeds represent 15%, mudstone represents 12%, carbonaceous mudstone represents 2%, and coal represent 1% of the rock mass likely to be encountered by water following this flow route. Using these percentages we calculated weighted averages of dye losses likely to be encountered by waters moving from Electric Lake to the Skyline Mine.

Based upon the weighted averages, at the end of the 63-day bench test the 50 ppb fluorescein dye solutions contained 3.5 times more dye than did the 50 ppb eosine solutions. The 5 ppb fluorescein solutions contained 4.6 times more dye than did the 5

ppb eosine solutions. The percent of dye lost to substrates after 63 days was greater for 5 ppb dye solutions than for 50 ppb solutions. This applied to both fluorescein and eosine solutions, but the percentage difference was greater for eosine than for fluorescein.

7. The bench test demonstrated that appreciable amounts of tracer dyes are lost onto or destroyed by contact with rock substrates found in the area between Electric Lake and the Skyline Mine. In this hydrogeologic environment fluorescein is a much better groundwater tracing agent than is eosine. Because of the appreciable losses of dyes onto rock substrates, the detection of small amounts of dye during field investigations are adequate to demonstrate a hydrologic connection. Furthermore, the small concentrations do not indicate that only small amounts of water follow the traced flow path.

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ANALYTICAL RESULTS

ELECTRIC LAKE BENCH TEST

Table 1. Analysis results for water samples and eluted rocks 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 Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
M9907	**2**	**Starpoint sandstone - 50ppb fluorescein**	**11/7 1143**	**507.9**	**5.27**	**ND**	
N0017	2	Starpoint sandstone - 50ppb fluorescein	11/13 1414	507.3	1.92	ND	
N0164	2	Starpoint Sandstone - 50ppb fluorescein	11/20 1343	507.6	1.88	ND	
N0313	2	Starpoint Sandstone - 50ppb fluorescein	11/26 1502	507.8	2.19	ND	
N0453	2	Starpoint Sandstone - 50ppb fluorescein	12/4 1541	508.1	2.40	ND	
N0509	2	Starpoint Sandstone - 50ppb fluorescein	12/11 1529	508.2	2.31	ND	
N0585	2	Starpoint Sandstone - 50ppb fluorescein	12/18 1006	508.3	2.31	ND	
N0675	2	Starpoint Sandstone - 50ppb fluorescein	12/24 0947	508.1	2.24	ND	
N0786	2	Starpoint Sandstone - 50ppb fluorescein	1/2 1524	508.2	2.15	ND	
N0786D	2	Starpoint Sandstone - 50ppb fluorescein	1/2 1527	508.3	2.10	ND	
N0885	2	Starpoint Sandstone - 50ppb fluorescein	1/8 1344	508.3	2.24	ND	
N0885D	2	Starpoint Sandstone - 50ppb fluorescein	1/8 1344	508.3	2.20	ND	
N0886	2	Starpoint Sandstone - 50ppb fluorescein, homogenized sample	1/8 1346	508.3	2.25	ND	
N0886D	2	Starpoint Sandstone - 50ppb fluorescein, homogenized sample	1/8 1346	508.3	2.21	ND	
N0935	2	Starpoint Sandstone - 50ppb fluorescein, eluted rocks from dyed samples	1/13 1006	514.9	6.69	ND	
N0935D	2	Starpoint Sandstone - 50ppb fluorescein, eluted rocks from dyed samples	1/13 1006	515.1	6.77	ND	
N0991	2	Starpoint Sandstone - 50ppb fluorescein, dyed rock with undyed water	1/14 1035	508.5	2.54	ND	
N1061	2	Starpoint Sandstone - 50ppb fluorescein, dyed rock with undyed water	1/20 1021	508.4	1.74	ND	
N1061D	2	Starpoint Sandstone - 50ppb fluorescein, dyed rock with undyed water	1/20 1021	508.5	1.78	ND	
M9908	**3**	**Starpoint Sandstone - 5ppb Fluorescein**	**11/7 1145**	**507.6**	**0.191**	**ND**	
N0018	3	Starpoint Sandstone - 5ppb Fluorescein	11/13 1415	507.5	0.114	ND	
N0165	3	Starpoint Sandstone - 5ppb fluorescein	11/20 1345	507.9	0.123	ND	
N0314	3	Starpoint Sandstone - 5ppb fluorescein	11/26 1516	507.9	0.137	ND	
N0454	3	Starpoint Sandstone - 5ppb fluorescein	12/4 1544	508.0	0.136	ND	
N0510	3	Starpoint Sandstone - 5ppb fluorescein	12/11 1537	508.2	0.142	ND	
N0586	3	Starpoint Sandstone - 5ppb fluorescein	12/18 1007	508.1	0.148	ND	
N0676	3	Starpoint Sandstone - 5ppb fluorescein	12/24 0949	508.3	0.149	ND	
N0787	3	Starpoint Sandstone - 5ppb fluorescein	1/2 1529	508.3	0.150	ND	
N0787D	3	Starpoint Sandstone - 5ppb fluorescein	1/2 1530	508.4	0.143	ND	
N0887	3	Starpoint Sandstone - 5ppb fluorescein	1/8 1415	508.3	0.163	ND	
N0888	3	Starpoint Sandstone - 5ppb fluorescein, homogenized sample	1/8 1420	508.1	0.173	ND	
N0936	3	Starpoint Sandstone - 5ppb fluorescein, eluted rocks from dyed samples	1/13 1009	511.8 *	0.277	ND	
N0992	3	Starpoint Sandstone - 5ppb fluorescein, dyed rock with undyed water	1/14 1054	508.4	0.241	ND	
N1062	3	Starpoint Sandstone - 5ppb fluorescein, dyed rock with undyed water	1/20 1026	508.4	0.234	ND	
M9909	**4**	**Starpoint Sandstone - 50ppb Eosine**	**11/7 1151**	**ND**		**534.0**	**1.99**
N0019	4	Starpoint Sandstone - 50ppb Eosine	11/13 1417	ND		534.1	1.74
N0166	4	Starpoint Sandstone - 50ppb eosine	11/20 1348	ND		534.1	1.25

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0315	4	Starpoint Sandstone - 50ppb eosine	11/26 1517	ND		534.1	0.886
N0455	4	Starpoint Sandstone - 50ppb eosine	12/4 1547	ND		533.9	0.885
N0511	4	Starpoint Sandstone - 50ppb eosine	12/11 1539	ND		533.8	0.781
N0587	4	Starpoint Sandstone - 50ppb eosine	12/18 1011	ND		533.9	0.668
N0677	4	Starpoint Sandstone - 50ppb eosine	12/24 0951	ND		534.1	0.602
N0788	4	Starpoint Sandstone - 50ppb eosine	1/2 1531	ND		533.6	0.533
N0788D	4	Starpoint Sandstone - 50ppb eosine	1/2 1533	ND		534.1	0.517
N0889	4	Starpoint Sandstone - 50ppb eosine	1/8 1421	ND		533.9	0.586
N0889D	4	Starpoint Sandstone - 50ppb eosine	1/8 1421	ND		533.9	0.571
N0890	4	Starpoint Sandstone - 50ppb eosine, homogenized sample	1/8 1428	ND		533.6	0.508
N0890D	4	Starpoint Sandstone - 50ppb eosine, homogenized sample	1/8 1428	ND		533.7	0.490
N0937	4	Starpoint Sandstone - 50ppb eosine, eluted rocks from dyed samples	1/13 1021	ND		540.1	6.66
N0937D	4	Starpoint Sandstone - 50ppb eosine, eluted rocks from dyed samples	1/13 1021	ND		540.5	6.68
N0993	4	Starpoint Sandstone - 50ppb eosine, dyed rock with undyed water	1/14 1055	ND		533.2	0.351
N1063	4	Starpoint Sandstone - 50ppb eosine, dyed rock with undyed water	1/20 1030	ND		533.3	0.414
M9910	**5**	**Starpoint Sandstone -5ppb Eosine**	**11/7 1158**	**ND**		**532.8**	**0.097**
N0021	5	Starpoint Sandstone -5ppb Eosine	11/13 1420	ND		533.8	0.095
N0167	5	Starpoint Sandstone - 5ppb eosine	11/20 1349	ND		534.2	0.049
N0316	5	Starpoint Sandstone - 5ppb eosine	11/26 1518	ND		534.4	0.049
N0456	5	Starpoint Sandstone - 5ppb eosine	12/4 1548	ND		ND	
N0512	5	Starpoint Sandstone - 5ppb eosine	12/11 1540	ND		533.6	0.032
N0588	5	Starpoint Sandstone - 5ppb eosine	12/18 1013	ND		533.8	0.032
N0678	5	Starpoint Sandstone - 5ppb eosine	12/24 1002	ND		532.0	0.044
N0789	5	Starpoint Sandstone - 5ppb eosine	1/2 1535	ND		ND	
N0789D	5	Starpoint Sandstone - 5ppb eosine	1/2 1536	ND		ND	
N0891	5	Starpoint Sandstone - 5ppb eosine	1/8 1437	ND		ND	
N0892	5	Starpoint Sandstone - 5ppb eosine, homogenized sample	1/8 1440	ND		ND	
N0938	5	Starpoint Sandstone - 5ppb eosine, eluted rocks from dyed samples	1/13 1024	ND		ND	
N0994	5	Starpoint Sandstone - 5ppb eosine, dyed rock with undyed water	1/14 1057	ND		ND	
N1064	5	Starpoint Sandstone - 5ppb eosine, dyed rock with undyed water	1/20 1033	ND		ND	
M9911	**6**	**Fluvial Sandstone - 50ppb Fluorescein**	**11/7 1203**	**507.7**	**48.4**	**ND**	
N0022	6	Fluvial Sandstone - 50ppb Fluorescein	11/13 1423	507.7	42.0	ND	
N0168	6	Fluvial Sandstone - 50ppb fluorescein	11/20 1350	508.2	38.4	ND	
N0317	6	Fluvial Sandstone - 50ppb fluorescein	11/26 1520	507.8	35.2	ND	
N0457	6	Fluvial Sandstone - 50ppb fluorescein	12/4 1549	507.8	32.1	ND	
N0513	6	Fluvial Sandstone - 50ppb fluorescein	12/11 1542	507.9	32.8	ND	
N0589	6	Fluvial Sandstone - 50ppb fluorescein	12/18 1015	507.8	29.9	ND	
N0679	6	Fluvial Sandstone - 50ppb fluorescein	12/24 1004	507.8	29.3	ND	
N0790	6	Fluvial Sandstone - 50ppb fluorescein	1/2 1538	508.1	30.9	ND	

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0790D	6	Fluvial Sandstone - 50ppb fluorescein	1/2 1544	507.9	30.7	ND	
N0893	6	Fluvial Sandstone - 50ppb fluorescein	1/8 1444	507.7	31.5	ND	
N0894	6	Fluvial Sandstone - 50ppb fluorescein, homogenized sample	1/8 1446	507.7	30.4	ND	
N0939	6	Fluvial Sandstone - 50ppb fluorescein, eluted rocks from dyed samples	1/13 1027	514.7	3.13	ND	
N0995	6	Fluvial Sandstone - 50ppb fluorescein, dyed rock with undyed water	1/14 1059	508.3	5.25	ND	
N1065	6	Fluvial Sandstone - 50ppb fluorescein, dyed rock with undyed water	1/20 1035	508.3	7.78	ND	
M9912	**7**	**Fluvial Sandstone - 5ppb Fluorescein**	**11/7 1312**	**508.3**	**4.48**	**ND**	
N0023	7	Fluvial Sandstone - 5ppb Fluorescein	11/13 1427	508.3	3.97	ND	
N0169	7	Fluvial Sandstone - 5ppb fluorescein	11/20 1409	508.1	3.49	ND	
N0318	7	Fluvial Sandstone - 5ppb fluorescein	11/26 1524	508.1	3.24	ND	
N0458	7	Fluvial Sandstone - 5ppb fluorescein	12/4 1556	508.1	3.04	ND	
N0514	7	Fluvial Sandstone - 5ppb fluorescein	12/11 1548	508.2	2.91	ND	
N0590	7	Fluvial Sandstone - 5ppb fluorescein	12/18 1018	508.2	2.76	ND	
N0681	7	Fluvial Sandstone - 5ppb fluorescein	12/24 1017	508.1	2.83	ND	
N0791	7	Fluvial Sandstone - 5ppb fluorescein	1/2 1547	508.3	2.75	ND	
N0791D	7	Fluvial Sandstone - 5ppb fluorescein	1/2 1548	508.3	2.73	ND	
N0895	7	Fluvial Sandstone - 5ppb fluorescein	1/8 1457	508.1	2.75	ND	
N0896	7	Fluvial Sandstone - 5ppb fluorescein, homogenized sample	1/8 1501	508.1	2.75	ND	
N0941	7	Fluvial Sandstone - 5ppb fluorescein, eluted rocks from dyed samples	1/13 1031	513.0*	0.278	ND	
N0996	7	Fluvial Sandstone - 5ppb fluorescein, dyed rock with undyed water	1/14 1112	508.3	0.470	ND	
N1066	7	Fluvial Sandstone - 5ppb fluorescein, dyed rock with undyed water	1/20 1054	508.3	0.698	ND	
M9913	**8**	**Fluvial Sandstone - 50ppb Eosine**	**11/7 1317**	**ND**		**534.2**	**33.1**
N0024	8	Fluvial Sandstone - 50ppb Eosine	11/13 1428	ND		534.1	26.6
N0170	8	Fluvial Sandstone - 50ppb eosine	11/20 1410	ND		534.0	20.0
N0319	8	Fluvial Sandstone - 50ppb eosine	11/26 1527	ND		533.9	16.7
N0459	8	Fluvial Sandstone - 50ppb eosine	12/4 1557	ND		533.9	14.0
N0515	8	Fluvial Sandstone - 50ppb eosine	12/11 1550	ND		533.9	12.8
N0591	8	Fluvial Sandstone - 50ppb eosine	12/18 1019	ND		534.0	11.5
N0682	8	Fluvial Sandstone - 50ppb eosine	12/24 1018	ND		533.9	11.2
N0792	8	Fluvial Sandstone - 50ppb eosine	1/2 1549	ND		534.0	10.3
N0792D	8	Fluvial Sandstone - 50ppb eosine	1/2 1550	ND		533.9	10.3
N0897	8	Fluvial Sandstone - 50ppb eosine	1/8 1504	ND		533.9	9.77
N0898	8	Fluvial Sandstone - 50ppb eosine, homogenized sample	1/8 1507	ND		533.9	9.80
N0942	8	Fluvial Sandstone - 50ppb eosine, eluted rocks from dyed samples	1/13 1034	ND		540.5	11.5
N0997	8	Fluvial Sandstone - 50ppb eosine, dyed rock with undyed water	1/14 1117	ND		534.0	2.83
N1067	8	Fluvial Sandstone - 50ppb eosine, dyed rock with undyed water	1/20 1057	ND		533.9	3.43
M9914	**9**	**Fluvial Sandstone - 5ppb Eosine**	**11/7 1329**	**ND**		**534.1**	**2.42**
N0025	9	Fluvial Sandstone - 5ppb Eosine	11/13 1430	ND		534.0	2.16
N0171	9	Fluvial Sandstone - 5ppb eosine	11/20 1413	ND		533.9	1.86

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0321	9	Fluvial Sandstone - 5ppb eosine	11/26 1541	ND		533.7	1.30
N0461	9	Fluvial Sandstone - 5ppb eosine	12/4 1600	ND		533.7	1.16
N0516	9	Fluvial Sandstone - 5ppb eosine	12/11 1551	ND		533.8	1.04
N0592	9	Fluvial Sandstone - 5ppb eosine	12/18 1020	ND		533.7	0.872
N0683	9	Fluvial Sandstone - 5ppb eosine	12/24 1020	ND		533.5	0.880
N0793	9	Fluvial Sandstone - 5ppb eosine	1/2 1551	ND		533.6	0.763
N0793D	9	Fluvial Sandstone - 5ppb eosine	1/2 1553	ND		533.8	0.787
N0899	9	Fluvial Sandstone - 5ppb eosine	1/8 1510	ND		533.8	0.768
N0901	9	Fluvial Sandstone - 5ppb eosine, homogenized sample	1/8 1514	ND		533.5	0.710
N0943	9	Fluvial Sandstone - 5ppb eosine, eluted rocks from dyed samples	1/13 1035	ND		540.1	1.84
N0998	9	Fluvial Sandstone - 5ppb eosine, dyed rock with undyed water	1/14 1133	ND		ND	
N1068	9	Fluvial Sandstone - 5ppb eosine, dyed rock with undyed water	1/20 1101	ND		533.0	0.224
M9915	**10**	**Interbeds - 50ppb Fluorescein**	**11/7 1333**	**508.1**	**49.3**	**ND**	
N0026	10	Interbeds - 50ppb Fluorescein	11/13 1431	507.7	42.6	ND	
N0172	10	Interbeds - 50ppb fluorescein	11/20 1416	508.2	40.5	ND	
N0322	10	Interbeds - 50ppb fluorescein	11/26 1543	508.1	36.7	ND	
N0462	10	Interbeds - 50ppb fluorescein	12/4 1602	507.9	34.1	ND	
N0517	10	Interbeds - 50ppb fluorescein	12/11 1553	508.0	34.5	ND	
N0593	10	Interbeds - 50ppb fluorescein	12/18 1023	507.9	32.4	ND	
N0684	10	Interbeds - 50ppb fluorescein	12/24 1021	508.1	29.9	ND	
N0794	10	Interbeds - 50ppb fluorescein	1/2 1555	508.0	31.0	ND	
N0794D	10	Interbeds - 50ppb fluorescein	1/2 1557	508.1	31.1	ND	
N0902	10	Interbeds - 50ppb fluorescein	1/8 1518	508.2	29.3	ND	
N0903	10	Interbeds - 50ppb fluorescein, homogenized sample	1/8 1522	508.2	29.1	ND	
N0944	10	Interbeds - 50ppb fluorescein, eluted rocks from dyed samples	1/13 1042	514.7	2.14	ND	
N0999	10	Interbeds - 50ppb fluorescein, dyed rock with undyed water	1/14 1136	508.3	3.64	ND	
N1069	10	Interbeds - 50ppb fluorescein, dyed rock with undyed water	1/20 1115	508.3	5.66	ND	
M9916	**11**	**Interbeds - 5ppb Fluorescein**	**11/7 1338**	**508.3**	**4.57**	**ND**	
N0027	11	Interbeds - 5ppb Fluorescein	11/13 1436	508.2	4.19	ND	
N0173	11	Interbeds - 5ppb fluorescein	11/20 1419	508.1	3.66	ND	
N0323	11	Interbeds - 5ppb fluorescein	11/26 1546	508.1	3.34	ND	
N0463	11	Interbeds - 5ppb fluorescein	12/4 1605	508.2	3.07	ND	
N0518	11	Interbeds - 5ppb fluorescein	12/11 1556	508.1	2.91	ND	
N0594	11	Interbeds - 5ppb fluorescein	12/18 1028	508.3	2.73	ND	
N0685	11	Interbeds - 5ppb fluorescein	12/24 1026	508.2	2.68	ND	
N0795	11	Interbeds - 5ppb fluorescein	1/2 1601	508.3	2.54	ND	
N0795D	11	Interbeds - 5ppb fluorescein	1/2 1601	508.3	2.54	ND	
N0904	11	Interbeds - 5ppb fluorescein	1/8 1527	508.1	2.47	ND	
N0905	11	Interbeds - 5ppb fluorescein, homogenized sample	1/8 1528	508.2	2.46	ND	

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0945	11	Interbeds - 5ppb fluorescein, eluted rocks from dyed samples	1/13 1052	513.2*	0.210	ND	
N1001	11	Interbeds - 5ppb fluorescein, dyed rock with undyed water	1/14 1142	508.2	0.374	ND	
N1070	11	Interbeds - 5ppb fluorescein, dyed rock with undyed water	1/20 1118	508.3	0.549	ND	
M9917	**12**	**Interbeds - 50ppb Eosine**	**11/7 1340**	**ND**		**534.1**	**22.6**
N0028	12	Interbeds - 50ppb Eosine	11/13 1438	ND		534.0	18.9
N0174	12	Interbeds - 50ppb eosine	11/20 1421	ND		533.9	16.3
N0324	12	Interbeds - 50ppb eosine	11/26 1548	ND		533.8	13.8
N0464	12	Interbeds - 50ppb eosine	12/4 1608	ND		533.8	12.1
N0519	12	Interbeds - 50ppb eosine	12/11 1557	ND		533.9	11.0
N0595	12	Interbeds - 50ppb eosine	12/18 1029	ND		533.9	9.44
N0686	12	Interbeds - 50ppb eosine	12/24 1027	ND		533.9	9.03
N0796	12	Interbeds - 50ppb eosine	1/2 1608	ND		533.9	8.26
N0796D	12	Interbeds - 50ppb eosine	1/2 1610	ND		533.9	8.15
N0906	12	Interbeds - 50ppb eosine	1/8 1531	ND		533.8	7.78
N0907	12	Interbeds - 50ppb eosine, homogenized sample	1/8 1533	ND		533.8	7.61
N0946	12	Interbeds - 50ppb eosine, eluted rocks from dyed samples	1/13 1054	ND		540.3	9.03
N1002	12	Interbeds - 50ppb eosine, dyed rock with undyed water	1/14 1145	ND		533.9	2.92
N1071	12	Interbeds - 50ppb eosine, dyed rock with undyed water	1/20 1121	ND		533.8	3.52
M9918	**13**	**Interbeds - 5ppb Eosine**	**11/7 1341**	**ND**		**533.6**	**1.5**
N0029	13	Interbeds - 5ppb Eosine	11/13 1440	ND		533.8	1.27
N0175	13	Interbeds - 5ppb eosine	11/20 1422	ND		533.6	1.09
N0325	13	Interbeds - 5ppb eosine	11/26 1550	ND		533.5	0.922
N0465	13	Interbeds - 5ppb eosine	12/4 1609	ND		533.5	0.757
N0521	13	Interbeds - 5ppb eosine	12/11 1558	ND		533.3	0.714
N0596	13	Interbeds - 5ppb eosine	12/18 1030	ND		533.7	0.630
N0687	13	Interbeds - 5ppb eosine	12/24 1029	ND		533.3	0.563
N0797	13	Interbeds - 5ppb eosine	1/2 1611	ND		533.7	0.519
N0797D	13	Interbeds - 5ppb eosine	1/2 1613	ND		533.9	0.511
N0908	13	Interbeds - 5ppb eosine	1/8 1535	ND		533.7	0.520
N0909	13	Interbeds - 5ppb eosine, homogenized sample	1/8 1544	ND		533.8	0.505
N0947	13	Interbeds - 5ppb eosine, eluted rocks from dyed samples	1/13 1056	ND		539.3	0.697
N1003	13	Interbeds - 5ppb eosine, dyed rock with undyed water	1/14 1147	ND		532.9	0.409
N1072	13	Interbeds - 5ppb eosine, dyed rock with undyed water	1/20 1123	ND		533.9	0.353
M9919	**14**	**Mudstone - 50ppb Fluorescein**	**11/7 1350**	**508.0**	**37.5**	**ND**	
N0030	14	Mudstone - 50ppb Fluorescein	11/13 1442	507.8	26.8	ND	
N0176	14	Mudstone - 50ppb fluorescein	11/20 1424	508.1	19.8	ND	
N0326	14	Mudstone - 50ppb fluorescein	11/26 1552	508.1	14.8	ND	
N0466	14	Mudstone - 50ppb fluorescein	12/4 1613	508.1	12.2	ND	
N0522	14	Mudstone - 50ppb fluorescein	12/11 1617	508.1	11.0	ND	

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0597	14	Mudstone - 50ppb fluorescein	12/18 1031	508.3	9.15	ND	
N0688	14	Mudstone - 50ppb fluorescein	12/24 1031	508.2	8.17	ND	
N0798	14	Mudstone - 50ppb fluorescein	1/2 1614	508.3	7.04	ND	
N0798D	14	Mudstone - 50ppb fluorescein	1/2 1615	508.3	7.01	ND	
N0910	14	Mudstone - 50ppb fluorescein	1/8 1547	508.3	6.35	ND	
N0911	14	Mudstone - 50ppb fluorescein, homogenized sample	1/8 1549	508.3	6.28	ND	
N0948	14	Mudstone - 50ppb fluorescein, eluted rocks from dyed samples	1/13 1057	515.4	3.46	ND	
N1004	14	Mudstone - 50ppb fluorescein, dyed rock with undyed water	1/14 1150	508.5	2.14	ND	
N1073	14	Mudstone - 50ppb fluorescein, dyed rock with undyed water	1/20 1126	508.5	3.72	ND	
M9921	**15**	**Mudstone - 5ppb Fluorescein**	**11/7 1352**	**508.3**	**2.00**	**ND**	
N0031	15	Mudstone - 5ppb Fluorescein	11/13 1445	508.2	1.35	ND	
N0177	15	Mudstone - 5ppb fluorescein	11/20 1427	508.1	1.30	ND	
N0327	15	Mudstone - 5ppb fluorescein	11/26 1553	508.1	1.09	ND	
N0467	15	Mudstone - 5ppb fluorescein	12/4 1615	508.1	0.893	ND	
N0523	15	Mudstone - 5ppb fluorescein	12/11 1618	508.1	0.752	ND	
N0598	15	Mudstone - 5ppb fluorescein	12/18 1032	508.2	0.615	ND	
N0689	15	Mudstone - 5ppb fluorescein	12/24 1032	508.2	0.589	ND	
N0799	15	Mudstone - 5ppb fluorescein	1/2 1617	508.3	0.520	ND	
N0799D	15	Mudstone - 5ppb fluorescein	1/2 1617	508.3	0.519	ND	
N0912	15	Mudstone - 5ppb fluorescein	1/8 1552	508.2	0.491	ND	
N0913	15	Mudstone - 5ppb fluorescein, homogenized sample	1/8 1554	508.2	0.476	ND	
N0949	15	Mudstone - 5ppb fluorescein, eluted rocks from dyed samples	1/13 1100	ND		ND	
N1005	15	Mudstone - 5ppb fluorescein, dyed rock with undyed water	1/14 1153	508.5	0.209	ND	
N1074	15	Mudstone - 5ppb fluorescein, dyed rock with undyed water	1/20 1128	508.5	0.338	ND	
M9922	**16**	**Mudstone - 50ppb Eosine**	**11/7 1355**	**ND**		**534.0**	**11.8**
N0032	16	Mudstone - 50ppb Eosine	11/13 1455	ND		533.9	8.05
N0178	16	Mudstone - 50ppb eosine	11/20 1429	ND		533.8	6.64
N0328	16	Mudstone - 50ppb eosine	11/26 1555	ND		533.9	5.39
N0468	16	Mudstone - 50ppb eosine	12/4 1617	ND		533.8	4.08
N0524	16	Mudstone - 50ppb eosine	12/11 1619	ND		533.7	3.35
N0599	16	Mudstone - 50ppb eosine	12/18 1034	ND		533.8	2.60
N0690	16	Mudstone - 50ppb eosine	12/24 1033	ND		533.7	2.31
N0801	16	Mudstone - 50ppb eosine	1/2 1620	ND		533.8	1.90
N0801D	16	Mudstone - 50ppb eosine	1/2 1621	ND		533.9	1.90
N0914	16	Mudstone - 50ppb eosine	1/8 1559	ND		533.9	1.65
N0915	16	Mudstone - 50ppb eosine, homogenized sample	1/8 1600	ND		533.7	1.66
N0950	16	Mudstone - 50ppb eosine, eluted rocks from dyed samples	1/13 1102	ND		541.4	6.97
N1006	16	Mudstone - 50ppb eosine, dyed rock with undyed water	1/14 1155	ND		534.2	1.60
N1075	16	Mudstone - 50ppb eosine, dyed rock with undyed water	1/20 1129	ND		533.8	1.21

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
M9923	**17**	**Mudstone - 5ppb Eosine**	**11/7 1358**	**ND**		**534.1**	**0.443**
N0033	17	Mudstone - 5ppb Eosine	11/13 1457	ND		533.5	0.367
N0179	17	Mudstone - 5ppb eosine	11/20 1431	ND		533.3	0.266
N0329	17	Mudstone - 5ppb eosine	11/26 1559	ND		533.8	0.162
N0469	17	Mudstone - 5ppb eosine	12/4 1619	ND		533.2	0.144
N0525	17	Mudstone - 5ppb eosine	12/11 1625	ND		533.6	0.123
N0601	17	Mudstone - 5ppb eosine	12/18 1038	ND		533.2	0.095
N0691	17	Mudstone - 5ppb eosine	12/24 1036	ND		533.2	0.091
N0802	17	Mudstone - 5ppb eosine	1/2 1623	ND		533.4	0.066
N0802D	17	Mudstone - 5ppb eosine	1/2 1624	ND		533.4	0.044
N0916	17	Mudstone - 5ppb eosine	1/8 1601	ND		ND	
N0917	17	Mudstone - 5ppb eosine, homogenized sample	1/8 1604	ND		ND	
N0951	17	Mudstone - 5ppb eosine, eluted rocks from dyed samples	1/13 1104	ND		ND	
N1007	17	Mudstone - 5ppb eosine, dyed rock with undyed water	1/14 1157	ND		ND	
N1076	17	Mudstone - 5ppb eosine, dyed rock with undyed water	1/20 1133	ND		ND	
M9924	**18**	**Carbonaceous Mudstone - 50ppb Fluorescein**	**11/7 1400**	**508.2**	**39.8**	**ND**	
N0034	18	Carbonaceous Mudstone - 50ppb Fluorescein	11/13 1458	508.1	17.6	ND	
N0181	18	Carbonaceous Mudstone - 50ppb fluorescein	11/20 1434	507.8	7.09	ND	
N0330	18	Carbonaceous Mudstone - 50ppb fluorescein	11/26 1602	507.9	7.90	ND	
N0470	18	Carbonaceous Mudstone - 50ppb fluorescein	12/4 1621	507.8	5.23	ND	
N0526	18	Carbonaceous Mudstone - 50ppb fluorescein	12/11 1627	508.0	5.20	ND	
N0602	18	Carbonaceous Mudstone - 50ppb fluorescein	12/18 1042	508.1	4.39	ND	
N0692	18	Carbonaceous Mudstone - 50ppb fluorescein	12/24 1039	508.0	3.13	ND	
N0803	18	Carbonaceous Mudstone - 50ppb fluorescein	1/2 1625	508.0	2.12	ND	
N0803D	18	Carbonaceous Mudstone - 50ppb fluorescein	1/2 1626	508.1	2.16	ND	
N0918	18	Carbonaceous Mudstone - 50ppb fluorescein	1/8 1610	508.0	1.75	ND	
N0919	18	Carbonaceous Mudstone - 50ppb fluorescein, homogenized sample	1/8 1611	508.0	1.70	ND	
N0952	18	Carbonaceous Mudstone - 50ppb fluorescein, eluted rocks from dyed samples	1/13 1106	514.6	6.58	ND	
N1008	18	Carbonaceous Mudstone - 50ppb fluorescein, dyed rock with undyed water	1/14 1201	508.3	1.74	ND	
N1077	18	Carbonaceous Mudstone - 50ppb fluorescein, dyed rock with undyed water	1/20 1137	508.5	1.97	ND	
M9925	**19**	**Carbonaceous Mudstone - 5ppb Fluorescein**	**11/7 1406**	**508.3**	**2.57**	**ND**	
N0035	19	Carbonaceous Mudstone - 5ppb Fluorescein	11/13 1504	507.9	0.955	ND	
N0182	19	Carbonaceous Mudstone - 5ppb fluorescein	11/20 1435	507.5	0.379	ND	
N0331	19	Carbonaceous Mudstone - 5ppb fluorescein	11/26 1604	507.6	0.230	ND	
N0471	19	Carbonaceous Mudstone - 5ppb fluorescein	12/4 1624	507.4	0.150	ND	
N0527	19	Carbonaceous Mudstone - 5ppb fluorescein	12/11 1628	507.4	0.091	ND	
N0603	19	Carbonaceous Mudstone - 5ppb fluorescein	12/18 1045	507.5	0.064	ND	
N0693	19	Carbonaceous Mudstone - 5ppb fluorescein	12/24 1041	507.4	0.043	ND	
N0804	19	Carbonaceous Mudstone - 5ppb fluorescein	1/2 1628	508.3	0.029	ND	

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0804D	19	Carbonaceous Mudstone - 5ppb fluorescein	1/2 1629	508.1	0.030	ND	
N0921	19	Carbonaceous Mudstone - 5ppb fluorescein	1/8 1616	507.8	0.017	ND	
N0922	19	Carbonaceous Mudstone - 5ppb fluorescein, homogenized sample	1/8 1618	507.0	0.017	ND	
N0953	19	Carbonaceous Mudstone - 5ppb fluorescein, eluted rocks from dyed samples	1/13 1109	ND		ND	
N1009	19	Carbonaceous Mudstone - 5ppb fluorescein, dyed rock with undyed water	1/14 1310	508.4	0.147	ND	
N1078	19	Carbonaceous Mudstone - 5ppb fluorescein, dyed rock with undyed water	1/20 1142	508.7	0.090	ND	
M9926	**20**	**Carbonaceous Mudstone - 50ppb Eosine**	**11/7 1408**	**ND**		**534.3**	**29.8**
N0036	20	Carbonaceous Mudstone - 50ppb Eosine	11/13 1506	ND		534.3	20.7
N0183	20	Carbonaceous Mudstone - 50ppb eosine	11/20 1438	ND		534.3	10.1
N0332	20	Carbonaceous Mudstone - 50ppb eosine	11/26 1605	ND		534.5	5.56
N0472	20	Carbonaceous Mudstone - 50ppb eosine	12/4 1631	ND		534.8	3.11
N0528	20	Carbonaceous Mudstone - 50ppb eosine	12/11 1630	ND		535.1	1.50
N0604	20	Carbonaceous Mudstone - 50ppb eosine	12/18 1048	ND		535.1	0.920
N0694	20	Carbonaceous Mudstone - 50ppb eosine	12/24 1043	ND		535.7	0.687
N0805	20	Carbonaceous Mudstone - 50ppb eosine	1/2 1631	ND		536.0	0.462
N0805D	20	Carbonaceous Mudstone - 50ppb eosine	1/2 1632	ND		536.1	0.458
N0923	20	Carbonaceous Mudstone - 50ppb eosine	1/8 1622	ND		536.2	0.283
N0924	20	Carbonaceous Mudstone - 50ppb eosine, homogenized sample	1/8 1624	ND		536.5	0.293
N0954	20	Carbonaceous Mudstone - 50ppb eosine, eluted rocks from dyed samples	1/13 1111	ND		538.4	5.08
N1010	20	Carbonaceous Mudstone - 50ppb eosine, dyed rock with undyed water	1/14 1313	ND		534.1	1.51
N1079	20	Carbonaceous Mudstone - 50ppb eosine, dyed rock with undyed water	1/20 1144	ND		534.3	1.64
M9927	**21**	**Carbonaceous Mudstone - 5ppb Eosine**	**11/7 1410**	**ND**		**534.3**	**3.64**
N0037	21	Carbonaceous Mudstone - 5ppb Eosine	11/13 1508	ND		534.6	1.65
N0184	21	Carbonaceous Mudstone - 5ppb eosine	11/20 1440	ND		534.7	0.770
N0333	21	Carbonaceous Mudstone - 5ppb eosine	11/26 1608	ND		535.3	0.307
N0473	21	Carbonaceous Mudstone - 5ppb eosine	12/4 1632	ND		535.9	0.200
N0529	21	Carbonaceous Mudstone - 5ppb eosine	12/11 1631	ND		534.8	0.077
N0605	21	Carbonaceous Mudstone - 5ppb eosine	12/18 1049	ND		535.6	0.052
N0695	21	Carbonaceous Mudstone - 5ppb eosine	12/24 1101	ND		536.8	0.031
N0806	21	Carbonaceous Mudstone - 5ppb eosine	1/2 1633	ND		ND	
N0806D	21	Carbonaceous Mudstone - 5ppb eosine	1/2 1634	ND		ND	
N0925	21	Carbonaceous Mudstone - 5ppb eosine	1/8 1629	ND		ND	
N0926	21	Carbonaceous Mudstone - 5ppb eosine, homogenized sample	1/8 1630	ND		ND	
N0955	21	Carbonaceous Mudstone - 5ppb eosine, eluted rocks from dyed samples	1/13 1118	ND		ND	
N1011	21	Carbonaceous Mudstone - 5ppb eosine, dyed rock with undyed water	1/14 1317	ND		534.6	0.107
N1081	21	Carbonaceous Mudstone - 5ppb eosine, dyed rock with undyed water	1/20 1150	ND		ND	
M9928	**22**	**Coal - 50ppb Fluorescein**	**11/7 1412**	**508.0**	**47.3**	**ND**	
N0038	22	Coal - 50ppb Fluorescein	11/13 1510	508.1	41.2	ND	
N0185	22	Coal - 50ppb fluorescein	11/20 1443	508.3	40.8	ND	

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0334	22	Coal - 50ppb fluorescein	11/26 1609	508.5	38.8	ND	
N0474	22	Coal - 50ppb fluorescein	12/4 1634	508.2	38.0	ND	
N0530	22	Coal - 50ppb fluorescein	12/11 1633	508.3	37.9	ND	
N0606	22	Coal - 50ppb fluorescein	12/18 1050	507.7	38.1	ND	
N0696	22	Coal - 50ppb fluorescein	12/24 1102	508.3	35.7	ND	
N0807	22	Coal - 50ppb fluorescein	1/2 1635	508.5	37.1	ND	
N0807D	22	Coal - 50ppb fluorescein	1/2 1639	508.4	37.0	ND	
N0927	22	Coal - 50ppb fluorescein	1/8 1635	508.3	37.4	ND	
N0928	22	Coal - 50ppb fluorescein, homogenized sample	1/8 1640	508.3	36.5	ND	
N0956	22	Coal - 50ppb fluorescein, eluted rocks from dyed samples	1/13 1121	ND		ND	
N1012	22	Coal - 50ppb fluorescein, dyed rock with undyed water	1/14 1322	508.3	2.88	ND	
N1082	22	Coal - 50ppb fluorescein, dyed rock with undyed water	1/20 1152	508.3	3.68	ND	
M9929	**23**	**Coal - 5ppb Fluorescein**	**11/7 1417**	**508.5**	**2.17**	**ND**	
N0039	23	Coal - 5ppb Fluorescein	11/13 1515	508.3	3.66	ND	
N0186	23	Coal - 5ppb fluorescein	11/20 1446	508.3	3.75	ND	
N0335	23	Coal - 5ppb fluorescein	11/26 1614	508.0	2.99	ND	
N0475	23	Coal - 5ppb fluorescein	12/4 1640	508.3	3.59	ND	
N0531	23	Coal - 5ppb fluorescein	12/11 1637	508.3	3.57	ND	
N0607	23	Coal - 5ppb fluorescein	12/18 1054	508.3	3.45	ND	
N0697	23	Coal - 5ppb fluorescein	12/24 1106	508.3	3.48	ND	
N0808	23	Coal - 5ppb fluorescein	1/2 1643	508.6	3.57	ND	
N0808D	23	Coal - 5ppb fluorescein	1/2 1645	508.4	3.49	ND	
N0929	23	Coal - 5ppb fluorescein	1/8 1704	508.3	3.51	ND	
N0930	23	Coal - 5ppb fluorescein, homogenized sample	1/8 1707	508.2	3.37	ND	
N0957	23	Coal - 5ppb fluorescein, eluted rocks from dyed samples	1/13 1131	ND		ND	
N1013	23	Coal - 5ppb fluorescein, dyed rock with undyed water	1/14 1327	508.2	0.378	ND	
N1083	23	Coal - 5ppb fluorescein, dyed rock with undyed water	1/20 1154	508.1	0.503	ND	
M9930	**24**	**Coal - 50ppb Eosine**	**11/7 1419**	**ND**		**534.2**	**20.2**
N0041	24	Coal - 50ppb Eosine	11/13 1518	ND		534.0	17.5
N0187	24	Coal - 50ppb eosine	11/20 1448	ND		533.9	14.7
N0336	24	Coal - 50ppb eosine	11/26 1616	ND		533.7	14.6
N0476	24	Coal - 50ppb eosine	12/4 1642	ND		533.9	12.6
N0532	24	Coal - 50ppb eosine	12/11 1639	ND		533.9	12.4
N0608	24	Coal - 50ppb eosine	12/18 1055	ND		534.0	11.4
N0698	24	Coal - 50ppb eosine	12/24 1107	ND		534.0	11.2
N0809	24	Coal - 50ppb eosine	1/2 1647	ND		534.0	11.7
N0809D	24	Coal - 50ppb eosine	1/2 1648	ND		533.9	12.7
N0931	24	Coal - 50ppb eosine	1/8 1710	ND		533.9	11.2
N0932	24	Coal - 50ppb eosine, homogenized sample	1/8 1712	ND		533.8	10.2

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0958	24	Coal - 50ppb eosine, eluted rocks from dyed samples	1/13 1133	ND		541.4	0.535
N1014	24	Coal - 50ppb eosine, dyed rock with undyed water	1/14 1330	ND		534.2	2.95
N1084	24	Coal - 50ppb eosine, dyed rock with undyed water	1/20 1156	ND		534.1	3.57
M9931	**25**	**Coal - 5ppb Eosine**	**11/7 1421**	**ND**		**535.2**	**0.919**
N0042	25	Coal - 5ppb Eosine	11/13 1520	ND		532.8	1.28
N0188	25	Coal - 5ppb eosine	11/20 1450	ND		532.9	0.577
N0337	25	Coal - 5ppb eosine	11/26 1618	ND		534.2	0.321
N0477	25	Coal - 5ppb eosine	12/4 1646	ND		533.1	0.717
N0533	25	Coal - 5ppb eosine	12/11 1640	ND		533.6	0.688
N0609	25	Coal - 5ppb eosine	12/18 1101	ND		533.7	0.697
N0699	25	Coal - 5ppb eosine	12/24 1108	ND		534.8	1.28
N0810	25	Coal - 5ppb eosine	1/2 1650	ND		532.2	0.733
N0810D	25	Coal - 5ppb eosine	1/2 1651	ND		533.0	0.449
N0933	25	Coal - 5ppb eosine	1/8 1719	ND		533.6	0.680
N0934	25	Coal - 5ppb eosine, homogenized sample	1/8 1722	ND		529.4 *	0.787
N0959	25	Coal - 5ppb eosine, eluted rocks from dyed samples	1/13 1137	ND		ND	
N1015	25	Coal - 5ppb eosine, dyed rock with undyed water	1/14 1333	ND		533.2	0.141
N1015D	25	Coal - 5ppb eosine, dyed rock with undyed water	1/14 1333	ND		534.3	0.141
N1085	25	Coal - 5ppb eosine, dyed rock with undyed water	1/20 1158	ND		534.5	0.212
M9932	**26**	**Control - 50ppb Fluorescein**	**11/7 1424**	**508.3**	**51.1**	**ND**	
N0043	26	Control - 50ppb Fluorescein	11/13 1522	507.9	48.2	ND	
N0189	26	Control - 50ppb fluorescein	11/20 1452	508.3	50.1	ND	
N0338	26	Control - 50ppb fluorescein	11/26 1621	508.1	50.4	ND	
N0478	26	Control - 50ppb fluorescein	12/4 1648	508.2	49.4	ND	
N0534	26	Control - 50ppb fluorescein	12/11 1641	507.9	51.5	ND	
N0610	26	Control - 50ppb fluorescein	12/18 1103	507.7	50.8	ND	
N0701	26	Control - 50ppb fluorescein	12/24 1116	508.3	48.2	ND	
N0811	26	Control - 50ppb fluorescein	1/2 1654	508.4	51.6	ND	
N0811D	26	Control - 50ppb fluorescein	1/2 1656	508.5	51.8	ND	
E	26	Control - 50ppb fluorescein	1/8	508.5	51.7	ND	
M9933	**27**	**Control - 5ppb Fluorescein**	**11/7 1428**	**508.3**	**4.95**	**ND**	
N0044	27	Control - 5ppb Fluorescein	11/13 1526	508.3	4.92	ND	
N0190	27	Control - 5ppb fluorescein	11/20 1510	508.3	4.88	ND	
N0339	27	Control - 5ppb fluorescein	11/26 1626	508.3	4.86	ND	
N0479	27	Control - 5ppb fluorescein	12/4 1652	508.2	4.87	ND	
N0535	27	Control - 5ppb fluorescein	12/11 1645	508.3	4.90	ND	
N0611	27	Control - 5ppb fluorescein	12/18 1107	508.3	4.91	ND	
N0702	27	Control - 5ppb fluorescein	12/24 1120	508.3	5.00	ND	
N0812	27	Control - 5ppb fluorescein	1/2 1705	508.3	5.10	ND	

OUL Lab #	Station #	Station Name	Date/Time Recovered 2003/2004	Fluorescein Results		Eosine Results	
				Peak nm	Conc. ppb	Peak nm	Conc. ppb
N0812D	27	Control - 5ppb fluorescein	1/2 1707	508.3	5.10	ND	
E	27	Control - 5ppb fluorescein	1/8	508.3	5.10	ND	
M9934	**28**	**Control - 50ppb Eosine**	**11/7 1430**	**ND**		**534.4**	**54.6**
N0045	28	Control - 50ppb Eosine	11/13 1528	ND		534.4	54.1
N0191	28	Control - 50ppb eosine	11/20 1511	ND		534.3	53.4
N0341	28	Control - 50ppb eosine	11/26 1629	ND		534.3	53.5
N0481	28	Control - 50ppb eosine	12/4 1655	ND		534.3	52.7
N0536	28	Control - 50ppb eosine	12/11 1646	ND		534.3	53.5
N0612	28	Control - 50ppb eosine	12/18 1108	ND		534.4	52.1
N0703	28	Control - 50ppb eosine	12/24 1121	ND		534.3	52.7
N0813	28	Control - 50ppb eosine	1/2 1708	ND		534.5	52.6
N0813D	28	Control - 50ppb eosine	1/2 1710	ND		534.4	52.4
E	28	Control - 50ppb eosine	1/8	ND		534.5	52.5
M9935	**29**	**Control - 5ppb Eosine**	**11/7 1431**	**ND**		**534.5**	**5.34**
N0046	29	Control - 5ppb Eosine	11/13 1530	ND		534.3	5.34
N0192	29	Control - 5ppb eosine	11/20 1512	ND		534.3	5.23
N0342	29	Control - 5ppb eosine	11/26 1631	ND		534.5	5.19
N0482	29	Control - 5ppb eosine	12/4 1656	ND		534.3	5.24
N0537	29	Control - 5ppb eosine	12/11 1647	ND		534.3	5.26
N0613	29	Control - 5ppb eosine	12/18 1109	ND		534.3	5.13
N0704	29	Control - 5ppb eosine	12/24 1122	ND		534.4	5.19
N0814	29	Control - 5ppb eosine	1/2 1712	ND		534.4	5.06
N0814D	29	Control - 5ppb eosine	1/2 1713	ND		534.4	5.14
E	29	Control - 5ppb eosine	1/8	ND		534.4	5.10

Footnotes:

* = a fluorescence peak is present that is out of the normally acceptable wavelength range for this dye

** = this sample is a 1:10 dilution

E = Mean of values from 1/2/04