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

STUDY PLAN FOR A DYE TRACING STUDY IN THE POLE CANYON LIMESTONE, GREAT BASIN NATIONAL PARK, NEVADA

August 11, 2009

Tom Aley, PHG & PG
President, Ozark Underground Laboratory, Inc

A study plan prepared for the National Park Service under Purchase Order P2380093521, WASO-WRD, Fort Collins, Colorado 80525

Introduction

Groundwater tracing using fluorescent tracer dyes is a well-established methodology for identifying and delineating areas that contribute water to important springs, and for determining and characterizing subsurface flow paths in karst and fractured rock regions. Tracing work is routinely and extensively used in the major karst regions and karst aquifers of the United States. Dye tracing methods are explained in detail in a 24-page chapter in a recently published textbook on hydrogeology field methods (Aley 2008), and substantial information on characteristics of the dyes is found in Aley (2002), which is available on-line. About 90% of all groundwater tracing in the United States uses fluorescent tracer dyes.

Most of America's karst lands are east of the Rocky Mountains and people living further west are often unfamiliar with dye tracing work. As a result, they sometimes ask if the dyes are environmentally safe. Yes they are and they have been studied extensively (Field et al., 1995) and found to be safe when used in professionally directed groundwater studies such as outlined in this study plan. They have been used in a number of studies to trace water to public drinking water supply wells, and at least one state (Alabama) routinely requires that such tracing work be done for new public water supply wells in karst areas.

People also sometimes ask if the use of tracer dyes requires formal environmental assessments. The answer is no, even when federal agencies fund the work. In fact, in karst areas dye tracing of groundwater is a common tool used in basic studies for the preparation of environmental impact statements. The following are some examples of dye tracing work conducted by the Ozark Underground Laboratory (OUL) to develop data for federal environmental impact statements.

1. Tracing to delineate springs that could be impacted by the proposed Northwest Arkansas Regional Airport and connecting highways, Rogers, Arkansas. Some of the springs of concern provide habitat for the Ozark Cavefish (*Amblyopsis rosae*), a federally listed threatened species and the Benton Cave Crayfish (*Cambarus aculabrum*), a federally listed endangered species.
2. Tracing to delineate springs that could be impacted by a major airport expansion and connecting new highways at the Springfield-Branson National Airport, Springfield, Missouri. Again, one of the associated springs provides habitat for the Ozark Cavefish.
3. An extensive tracing program involving 31 separate dye introductions designed to identify all springs that could be impacted by approximately 20 miles of highway corridor for Interstate 69 in and around Bloomington, Indiana. A number of the traces discharged from multiple springs. Aquatic species of state concern occurred at some of the sampling stations.
4. A tracing program to identify springs that might be impacted by construction of about 25 miles of new corridor for U.S. Highway 71 in northwest Arkansas. Most of the work focused on Cave Springs which provides habitat for the largest known population of Ozark Cavefish and for a large summer colony of federally endangered Gray Bats,

(*Myotis grisescens*). The tracing work resulted in re-alignment of part of the highway corridor.

5. Corridor H tracing, West Virginia where multiple dye traces were conducted from a proposed interstate highway corridor. Tracing was focused on a municipal well, a warm spring at a resort, and trout waters. The total corridor length was over 100 miles.
6. Five tracing projects at numerous sites on the Tongass National Forest in southeastern Alaska to assess potential impacts of timber harvest and road construction on springs with major emphasis on identifying potential impacts on salmon streams.

We have also done a substantial amount of groundwater tracing work for the National Park Service. This has included extensive tracing projects on the Ozark National Scenic Riverways, MO; Wilson Creek National Battlefield, MO; George Washington Caver National Monument, MO; Buffalo National River, AR; and Great Smoky Mountains National Park, TN. We have done smaller projects for Timpanogos Cave National Monument, UT and Oregon Caves National Monument, OR. In addition to our work, very extensive groundwater tracing over a number of years has been conducted at Mammoth Cave National Park, KY and some tracing work has been done at Jewel Cave National Monument, SD.

The OUL has also done extensive groundwater tracing work for the U.S. Forest Service, U.S. Bureau of Land Management, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, U.S. Navy, U.S. Air Force, and for a number of state agencies. None of this work has ever required conducting an environmental impact assessment prior to doing the tracing work. In fact, much of our tracing work has involved sensitive issues in areas with substantial human populations and often has involved federally listed threatened and endangered aquatic species.

Given the importance of cave and karst resources at Great Basin National Park (GBNP) it is somewhat surprising that a modern groundwater tracing has not been previously conducted at this park. People studying caves in the Baker Creek topographic basin made some simple tracing efforts a few decades ago, but modern analytical methods were not available at that time and the work that was done was narrowly focused.

This study plan:

- Outlines the purposes and objectives of the planned groundwater tracing study.
- Provides a rationale (that includes case histories) demonstrating why the groundwater tracing work is essential.
- Specifies how the work will be conducted.

Purposes, Objectives, and Study Overview

Concerns over water rights applications by the Southern Nevada Water Authority (SNWA) have prompted and necessitated detailed hydrogeologic work in and around GBNP.

This work is designed to better understand and quantify interactions between surface water and groundwater in Snake Valley and adjacent lands including GBNP.

The Baker Creek and Lehman Creek area has the most extensive cave development of any area in Nevada. The caves contain abundant evidence that they are part of a large and old system of caves that was primarily formed by ascending waters derived from deep sources. Such caves are called hypogenic caves. In contrast, caves formed by shallower waters rather recently derived from the surface are called epigenic caves and are typically of more recent origin. The areal extent of hypogenic caves is routinely about five times larger than is the case for epigenic caves, and cavern porosity in hypogenic aquifers is typically about an order of magnitude greater than for epigenic aquifers (Klimchouk 2007). Complex groundwater flow routes undoubtedly exist in the area given the hypogenic nature of the caves and the karst aquifer in the region. Characterizing these flow systems requires a well-designed and conducted groundwater tracing study such as outlined in this study plan.

The dye tracing work is planned for a period when there is no water discharging from the resurgence below Model Cave. Under these conditions, the tracing work as designed will answer the following five questions:

1. Does water that sinks in the channel of **Baker Creek** contribute to the flow Rowland Spring, Rose Thorn Spring, Kious Spring, or any other springs feeding Lehman or Baker Creeks? Which springs, if any, are involved?
2. Does water in the main stream in the **Baker Creek Caves Complex** contribute to the flow Rowland Spring, Rose Thorn Spring, Kious Spring, or any other springs feeding Lehman or Baker Creeks? Which springs, if any, are involved?
3. Does water that sinks in the channel of **Pole Canyon** upstream of Baker Creek contribute to the flow Rowland Spring, Rose Thorn Spring, Kious Spring, or any other springs feeding Lehman or Baker Creeks? Which springs, if any, are involved.
4. Lange (1958) concluded that waters that flow through caves in the Baker Creek basin and waters that sink in Pole Canyon and Baker Creek recharge regional groundwater supplies. This is an appreciable volume of water. The proposed tracing program will yield data to either support or refute this important possibility.
5. To the extent that in-cave sampling can be conducted, the tracing work will determine if Baker Creek, the main Baker Creek Cave stream, or Pole Canyon contribute water to Model Cave.

We considered the possibility of conducting the dye tracing during higher flow conditions when water would be discharging from the resurgence below Model Cave. This flow is known to discharge from Model Cave, and it enters Baker Creek at an elevation higher than the springs to be sampled for tracer dyes. As a result, any dye discharging from the Model Cave resurgence would enter Baker Creek where it could again sink into the groundwater system and possibly discharge from one or more of the springs that are to be sampled. We believe that supporting or refuting Lange's conclusion that a substantial volume of water in the vicinity of the Baker Creek Caves Complex and Model Cave enters the regional groundwater system is of major importance and that the data should be as unambiguous as possible. As a result, we recommend that the tracing work be done when water is not discharging from the resurgence below Model Cave.

Nettle Spring has intermittent flow and discharges from the base of a springhead about 3800 feet east of the entrance to Model Cave. Water flows only during relatively high flow conditions and cannot be effectively sampled except under these conditions. Based upon channel appearance the peak discharge rate of this spring is about 0.5 cfs. If dye introductions are made under conditions where there is no flow from the resurgence below Model Cave it is possible (but not certain) that some residual dye from the tracing work might be detectable on activated carbon samplers in place at this spring during the early portion of the snow-melt runoff period.

Three different tracer dyes will be used and they will be introduced as “slugs” at three separate points. The analytical protocol that will be used for dye sampling can separate and quantify each of the three dyes.

Sampling for tracer dyes will be conducted at a comprehensive network of 22 sampling stations. Several of these are upstream “control” stations on Lehman Creek, Baker Creek, and Pole Canyon. Sampling will place primary reliance on activated carbon samplers and secondary reliance upon grab samples of water. A few stations will be sampled at frequent intervals during the first week of the study and then at lesser frequencies as the study progresses.

OUL staff will introduce the tracer dyes, although NPS assistance with the dye introduction within the Baker Creek Caves Complex may be needed. OUL staff will also be on-site for approximately one week after dye introduction to conduct the intensive sampling for tracer dyes and to train NPS staff in dye sampling methods. The frequency of sampling after the first week will be greatly decreased. After OUL staff leaves the Park activated carbon samplers will need to be periodically collected by NPS staff. NPS personnel will do any in-cave sampling in the Baker Creek Cave System or Model Cave. We anticipate that almost all sampling will end 12 weeks after dye introduction, but the end of sampling will need to be based upon sampling results.

All schedules can be changed slightly to adjust for weather conditions, holidays, and logistical considerations. If snow makes some stations inaccessible changing the samplers can be suspended until more favorable conditions exist as long as samplers are eventually collected from all sampling stations.

Rationale for Groundwater Tracing Work

The current impetus for conducting the proposed groundwater tracing work is water rights applications by SNWA. A National Park Service response to the applications has been to develop basic hydrologic data for GBNA (see for example Elliott et al. 2006). This work is complicated by the karst aquifer, and is especially complicated in areas where surface streams lose part of their flow to the groundwater system and where springs with appreciable flow volumes exist. In calculating water budgets knowing whether or not the losing streams contribute flow to some or all of the springs, and knowing which springs are related to which losing streams, is needed to credibly calculate total water yield. This is especially important in view of Lange's (1958) conclusion that there is a substantial volume of water that is being lost from the Baker Creek basin into the deep karst groundwater system. The groundwater tracing program will provide critical data for developing science-based water budget data.

Large groundwater extractions that lower groundwater levels in karst aquifers are notorious for pirating water out of surface streams, diminishing or causing the ceasing of flow in springs, drastically lowering groundwater elevations in wells, and causing the catastrophic formation of sinkholes. Impacted areas around a groundwater extraction point can encompass a number of square miles and the shape and location of impacted areas is difficult to accurately delineate in advance. Furthermore, the severity and extent of the problems commonly increases with time and with increases (and sometimes fluctuations) in pumping rates. The following quote from the abstract in Newton (1984) states the issue clearly.

"Numerous sinkholes resulting from the declines in the water table due to ground-water withdrawals in carbonate terranes have occurred in the eastern United States and elsewhere. In Alabama alone, it is estimated that more than 4,000 of these sinkholes, areas of subsidence, or related features have formed since 1900. Almost all occur where cavities develop in residual or other unconsolidated deposits overlying openings in carbonate rocks. The downward migration of the deposits into underlying openings in the bedrock and the formation and collapse of resulting cavities are caused or accelerate by a decline in the water table that results in (1) loss of buoyant support, (2) increase in the velocity of movement of water, (3) water-level fluctuations at the base of unconsolidated deposits, and (4) induced recharge."

The following case history is illustrative of the problems that can occur. While the case history is for a quarry, a quarry pumping groundwater can be visualized as a well with very large lateral dimensions.

A limestone quarry was developed at Opelika, Alabama. Mean annual precipitation in the area is about 58 inches per year with groundwater recharge commonly estimated at 20% of precipitation. Groundwater extraction to permit deep quarrying began in the summer of 1999. A large perennial spring called Spring Villa was located 6,800 feet from the quarry in a different topographic basin and supplied water to a swimming pool in an Opelika city park. Prior to quarry activity the mean flow of the spring was 3.74 cfs (2.42 mgd). The spring ceased flowing in late spring 2000 and flow has never returned. By late 2002 Little Uchee Creek, a perennial stream adjacent to Spring Villa, ceased flowing and numerous large sinkholes began forming catastrophically in and around the stream channel. Mean quarry pumping rates increased with time and reached about 8 million gallons per day by 2006. This represents about 9,000 acre feet of water per year.

Groundwater elevations at the quarry declined by about 115 feet from pre-quarry to 2006 condition. At Spring Villa the water table decline during this period was about 60 feet. Prior to quarry operations there were few if any sinkholes in the region, but new sinkholes now continue to form due to the loss of buoyant support for overlying alluvium and residuum. An inventory in January 2006 identified 185 new sinkholes and 344 piping holes in an area of 2.03 square miles around the quarry. One of the larger sinkholes was 50 feet by 20 feet by 12 feet deep. The entire area was not inventoried; the calculated Zone of Influence for the quarry at current pumping rates is 17.4 square miles. Sinkholes have formed catastrophically under a county highway and a bridge, beneath vehicles, beneath one of a pair of poles for an electric transmission line, under a propane transmission line, and beneath ponds.

Geologic mapping conducted for the quarry showed that the limestone at the quarry was separated from the limestone at Spring Villa by quartzite and schist units. However, dye tracing from the point where flow in Little Uchee Creek terminated in a sinkhole showed that this water reappeared in the quarry pumping.

The case history demonstrates that pumping large volumes of water that result in groundwater level declines in karst aquifers can seriously impact springs, surface streams, and various human land uses over large areas. This is the case even in a region with many times the annual precipitation and annual groundwater recharge of GBNP. When karst aquifers are involved groundwater studies, including groundwater tracing, should be conducted prior to major groundwater extraction projects that may be difficult or impossible to terminate if or when they create problems.

Conduct of the Study

This section of the study plan outlines how the study will be conducted. It identifies (1) dye introductions points, (2) background sampling, (3) dye types and quantities, (4) sampling approach, (5) sampling stations, sampling frequency, and study duration, (6) analytical methods, and (7) reports.

Dye Introduction Points.

We plan to make three separate dye introductions. Trace 1 will be on Baker Creek about 500 feet upstream of the upstream end of the lower campground on Baker Creek. The dye introduction point will be close to the trail that connects the two campgrounds, and will be at an elevation of about 7,300 feet. The rationale for this introduction is to determine the points at which water sinking in Baker Creek reappears on the surface. This dye introduction point is designed to be immediately upstream of the point where Baker Creek first flows onto the Pole Canyon Limestone.

Groundwater recharge into karst aquifers is often divided into discrete and diffuse recharge. Discrete recharge is concentrated in localized areas and diffuse recharge is more dispersed. The stream entrance to Ice Cave and the entrance to Dynamite Cave are two examples of discrete recharge zones associated with overflow channels of Baker Creek and more examples undoubtedly exist. The dye from Trace 1 will enter the karst groundwater system through both discrete and diffuse recharge from the channel of Baker Creek.

The dye introduction point for Trace 2 will be in the Baker Creek Cave system at a point as far upgradient in the system as possible under the conditions existing when the dye is placed. If water were flowing into Ice Cave we would introduce the dye where flow from Baker Creek cascades into Ice Cave. If, as we recommend, dye introductions are made under lower flow conditions then a point further downstream in the system where there is flow of at least 5 gallons per minute will be selected. The rationale for this introduction is to determine if (or where) water flowing through this cave stream discharges to the surface.

The dye introduction point for Trace 3 will be into the flow of Pole Canyon a short distance upstream of the point where this stream flows onto the Pole Canyon Limestone. This point is located at an elevation of about 7,200 feet and is about 3,700 feet straight-line distance upstream of the mouth of this stream. This dye introduction will be made at a time when surface flow in Pole Canyon does not reach Baker Creek. A passage in Model Cave passes beneath Pole Canyon near the stream segment where surface flow commonly disappears into the groundwater system. This losing stream segment is downstream of the planned dye introduction point. The rationale for this introduction is to determine if (or where) waters entering the groundwater system from the losing stream segment discharge to the surface.

Background Sampling.

On July 16 and 17, 2009 the OUL conducted background sampling of waters in the area for fluorescent tracer dyes and compounds that might interfere with the use of the planned dyes. The sampling used grab samples of water. The sampling and analytical protocols were in accordance with the OUL’s Procedures and Criteria document included as Appendix A to this study plan. No dyes and no fluorescent compounds that might cause interference with the tracer dyes were detected. Sampling locations for the July 2009 background sampling were as follows:

- Baker Creek near planned dye introduction point for Trace 1.
- A spring discharging from quartzite near the planned dye introduction point for Trace 1.
- Baker Creek at the Pole Canyon Trail crossing.
- Discharge waters from Model Cave.
- Pole Canyon along the Pole Canyon Trail and downstream of the planned dye introduction point for Trace 3
- Rowland Spring
- Kious Spring

Prior to the introduction of dyes for the tracing work additional samples will be collected to characterize fluorescence background conditions. Control stations to demonstrate the absence of extraneous fluorescent compounds will be established and maintained during the duration of the tracing study. These control stations will be located:

- On Lehman Creek where the road up Wheeler Peak is near the creek at an elevation of about 7,400 feet (thus higher than any of the dye introduction points).
- On Baker Creek upstream of the dye introduction point for Trace 1.
- On Pole Canyon upstream of the dye introduction point for Trace 3.

Dye Types and Quantities

Five pounds of fluorescein dye mixture will be used for Trace 1, the Baker Creek Trace. Fluorescein is also known as Acid Yellow 73 and its Color Index Number is 45350. This dye is also known as uranine. The powdered dye mixture to be used contains 75% dye equivalent and 25% diluent (corn starch) as a standardizing agent and to aid in dissolving the mixture in water. This dye has a green color and decomposes fairly rapidly in sunlight and, as a result, will not persist long in surface waters in the sunlight.

Six pounds of rhodamine WT dye mixture will be used for Trace 2, the Baker Creek Caves Trace. Rhodamine WT is also known as Acid Red 388; it has no assigned Color Index Number. The letters “WT” in the name stand for Water Tracing since this dye was developed for this purpose. This dye should not be confused with Rhodamine B, a totally different dye inappropriate for groundwater tracing. Rhodamine WT is a liquid dye mixture containing 20% dye equivalent and 80% diluent (water) as a standardizing agent and to aid in dissolving the mixture into receiving waters. This dye has a red color.

Six pounds of eosine dye mixture will be used for Trace 3, the Pole Canyon Trace. Eosine is also known as Acid Red 87 and its Color Index Number is 45380. This dye is also known as D&C Red 22. The powdered dye mixture to be used contains 75% dye equivalent and 25% diluent (corn starch) as a standardizing agent and to aid in dissolving the mixture in water. This dye has a pink or green color depending upon concentration and decomposes fairly rapidly in sunlight and, as a result, will not persist long in surface waters in the sunlight.

Sampling Approach

Sampling for tracer dyes at most stations will place primary reliance on activated carbon samplers and secondary reliance on grab samples of water. The types of samples are explained in the OUL’s Procedures and Criteria document in Appendix A, and all sampling will be consistent with this document.

Activated carbon is coconut charcoal that is capable of adsorbing and retaining all of the tracer dyes. The activated carbon is similar to the charcoal filters found in some cigarettes and in home water treatment systems. Activated carbon samplers function as continuous and accumulating samplers for any dyes present during the period that the samplers are in place. Given the clean waters present in the study area the samplers will work effectively for the sampling intervals planned in the study plan even if some intervals need to be lengthened due to adverse weather conditions or logistical considerations.

Grab samples of water are reflective of conditions existing at a sampling station at the time the sample was “grabbed”. Each grab sample will contain about 30 ml of water.

As a general rule all activated carbon samplers are collected and replaced each time a sampling station is visited and a grab sample of water is also collected. During the early phases of the study periodic water samples may be collected at more frequent intervals from a few sampling stations without collecting the activated carbon. However, activated carbon samples will be collected at least once per day.

Water samples are routinely analyzed only if dye is detected in the associated activated carbon samplers. Exceptions are made if carbon samplers are lost or if it is believed that the quality of the study will be enhanced by the analysis of additional water samples.

Sampling Stations, Sampling Frequency, and Study Duration

Table 1 identifies 22 sampling stations and the planned sampling frequency. The five categories of sampling frequency identified in the table are explained at the bottom of the table. Figure 1 is a map showing sampling stations and dye introduction points.

Table 1 Sampling stations and anticipated frequency of sampling.

Station Number and Name	Comments	Sampling Frequency
1. Baker Cr. u/s of dye intro. point Trace 1.	Control Station	3)
2. Baker Creek at rd. xing u/s of Ice Cave	To determine duration of dye pulse from Trace 1	1) End 3 weeks after dye intro
3. Pole Canyon u/s of dye intro point Trace 3	Control Station	3)
4. Pole Canyon about 100 ft. d/s of end of surface flow	To verify the end of surface flow during study	3)
5. Pole Canyon about 50 ft. u/s of mouth	To verify no flow during study and no dye from Trace 1.	2)

Table 1 (continued). Sampling stations and anticipated frequency of sampling.

Station Number and Name	Comments	Sampling Frequency
6. Baker Cr. about 50 ft. u/s mouth of Pole Can.	Sample for all traces	2)
7. Baker Creek @ Pole Canyon Trail	Sample for all traces, determine duration of dye pulse from Trace 1.	1)
8. Model Cave discharge	Should not flow if traces conducted under low to moderate flow conditions.	3) and 4)
9. Nettle Spring.	Should not flow if traces conducted under low to moderate flow conditions	3) and 4)
10. Rose Thorn Spring	Critical station for all three traces	1)
11. Baker Creek u/s Thorn Spring Branch		2)
12. Baker Cr. diversion 100 ft. u/s Lehman Creek	Furthest d/s station on Baker Cr.	2)
13. Lehman Cr. 100 ft. u/s Baker Cr. diversion	Furthest d/s station on Lehman Cr.	2)
14. Lehman Cr. @ rd. xing at elev. about 6205 ft.		2)
15. Lehman Cr. @ rd. xing at elev. about 6420 ft.		2)
16. Rowland Spring	Critical station for all three traces	1)
17. Lehman Cr. @ Hwy 488	Sample for all three traces	3)
18. Lehman Cr. @ about elev. 7,400 ft.	Control station	3)
19. Kious Spring	Critical for all traces	1)
20. Lehman Cave Pool at end of tour trail	No dye expected, but a verification station	3)
21. Inside Model Cave	All sampling by NPS	5)
22. Other station(s) in Baker Cr. Cave Sys.	All sampling by NPS	5)

Abbreviations:

u/s = upstream
d/s = downstream
xing = crossing
rd = road
intro= introduction

Sampling Frequencies:

1) Intense Sampling. At least once per day for first week after dye introduction. More frequently if feasible. Sample 10 and 14 days after dye introduction, then weekly for the remainder of the study.*
2) Routine Sampling. Once a week after dye introduction for the first six weeks then on weeks 8, 10, and 12 after dye introduction.
3) Control Sampling. Collect 1, 4, and 8, and 12 weeks after dye introduction.
4) Snow-Melt Sampling. Collect about 1 and 2 weeks after flow starts in the spring.
5) As Feasible. Sampling at these stations would be desirable but is dependent upon logistical considerations and the availability of NPS personnel.

*Snow and ice could limit access to Rose Thorn Spring and especially Kious Spring. To the extent reasonable the schedule will be maintained with these stations being sampled at least once every 2 weeks.

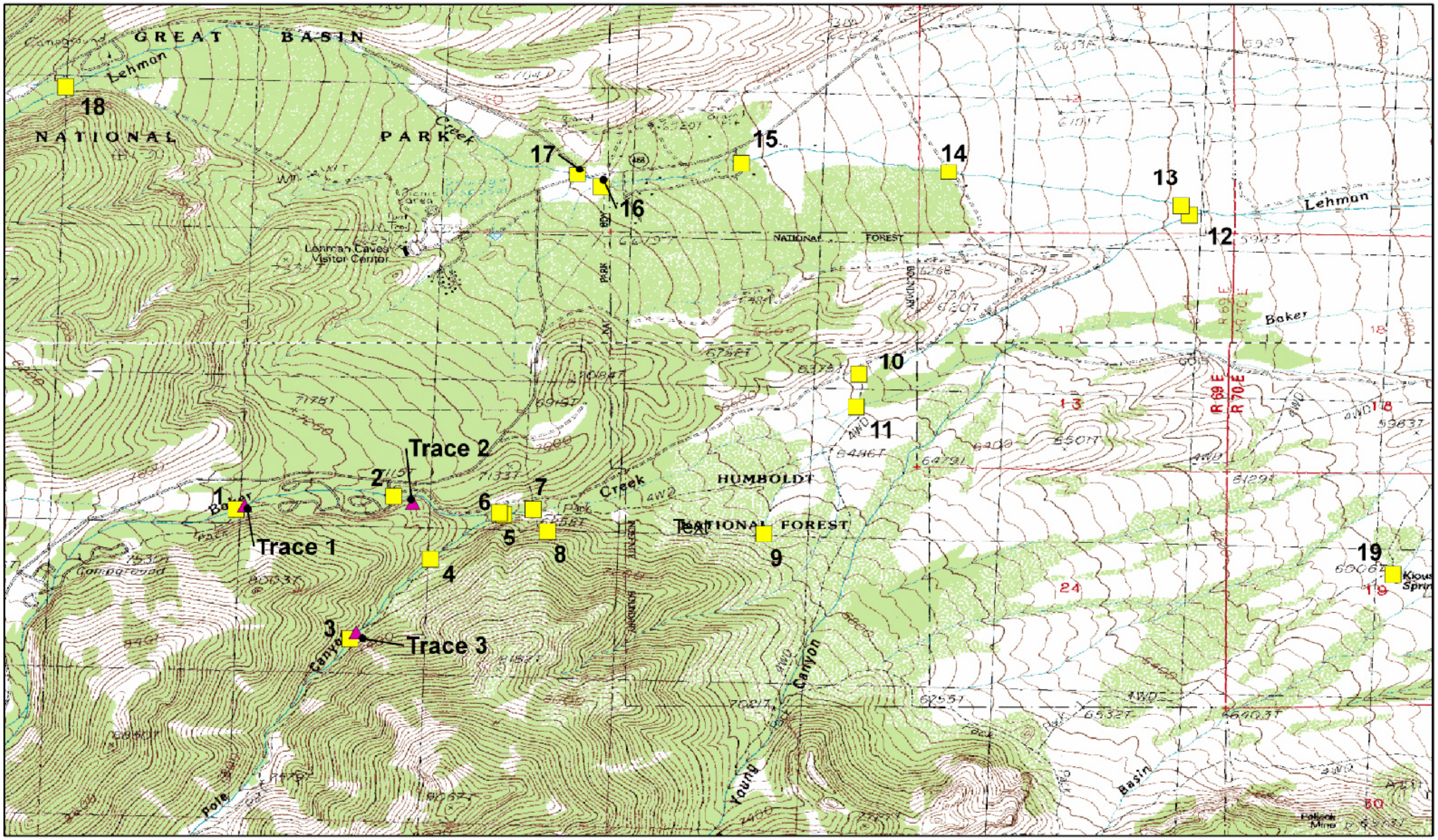

Figure 1. Sampling Stations and Dye Introduction Points

The introduction location for Trace 2 is approximate. The locations of Stations 20 through 22 are in caves and are not shown.

Intense sampling is planned for 5 sampling stations. At one of these (Station 2, Baker Creek at road crossing upstream of Ice Cave) sampling can be terminated 3 weeks after dye is introduced. The other four stations are designed to detect and quantify dye rapidly reaching springs in the area. If the tracing work can be started in late summer or early fall all of these stations are easy to reach and most or all of them could be sampled twice per day during the first week by OUL staff. The intense sampling stations are:

- Station 2. Baker Creek at road crossing upstream of Ice Cave.
- Station 7. Baker Creek at Pole Canyon Trail. This station may detect dye from Traces 2 and 3.
- Station 10. Rose Thorn Spring. A critical sampling station that could receive dye from all three traces.
- Station 16. Rowland Spring. A critical sampling station that could receive dye from all three traces.
- Station 19. Kious Spring. A possible, but not likely, detection site for dye from one or more of the traces.

Rowland Spring is located east of Lehman Caves and near the GBNP boundary at an elevation of about 6580 feet in the Lehman Creek topographic basin. This perennial spring discharges from alluvium that is underlain by the Pole Canyon Limestone.

One important objective of the planned groundwater tracing study is to determine if any waters from Baker Creek, Pole Canyon, or some of the Baker Creek caves contribute water to Rowland Spring (Station 16). If they do, the time of travel is important. Very rapid groundwater movement toward Rowland Spring is possible and the study is designed to sample this spring frequently during the week after dye introductions are made.

Elliott et al. (2006) includes daily flow rate data for Rowland Spring and Baker Creek at the Narrows for water years 2003 and 2004. Table 2 presents selected data from these two stations. Among other things Table 2 shows that minimum monthly flow rates of both the spring and Baker Creek occurred during February of each of the two years. Maximum monthly flow rates occurred in May and June of the two years on Baker Creek and in July for Rowland Spring. This suggests that a lag time of a month or so may be involved between peak snow-melt runoff entering the karst groundwater system and the time at which it discharges from Rowland Spring. The total annual flow of Rowland Spring in Water Year 2003 was 38% of the flow in Baker Creek at the Narrows, and in Water Year 2004 it was 45%.

Given the data provided in the Elliott et al. (2006) report the planned duration for the tracing study is 12 weeks after dye introduction. Results obtained during the study may result in a somewhat earlier or later termination of the sampling work.

Table 2. Comparison of Flow Rate Data from Rowland Spring and Baker Creek at the Narrows for Water Years 2003 and 2004. Data from Elliott et al. (2006).

Parameter	Rowland Spr. WY 2003	Rowland Spr. WY 2004	Baker Cr. at Narrows WY 2003	Baker Cr. at Narrows WY 2004
Total Annual Flow (A.ft)	1,699	1,606	4,496	3,555
Maximum Daily cfs	3.7	3.5	116	25
Minimum Daily cfs	1.3	0.75	0.94	0.95
Peak Monthly Flow	July	July	June	May
Peak Monthly Flow (A.ft.)	213	202	1850	1,000
Minimum Monthly Flow	Feb.	Feb.	Feb.	Feb.
Min. Monthly Flow (A.ft.)	82	55	56	59

A second objective of the planned study is to determine if Baker Creek, Pole Canyon Creek, or the Baker Creek Caves contribute water to Rose Thorn Spring (Station 10). This spring is located in the Baker Creek Valley at an elevation of about 6500 feet and is along the gravel road on the north side of the valley. The specific conductance of this spring was 142 micromhos/cm on July 16, 2009 at 0957 hours. In contrast, the specific conductance of Rowland Spring on July 17, 2009 at 1325 hours was 113 micromhos/cm. As a generalization, the higher the specific conductance value the longer the water has been in contact with the limestone bedrock. During the same period the specific conductance in Baker Creek at the Pole Canyon trail crossing was 27 micromhos/cm. Given these values, it is reasonable to expect that any dye from the planned dye introductions might not appear at Rose Thorn Spring for as much as two months after dye introduction.

A third objective of the planned study is to determine if any of the tracer dyes discharge at any intermediate points on Baker Creek downstream of the planned dye introduction point or at any points on Lehman Creek downstream of the point where the stream is crossed by Nevada Highway 488. Several sampling stations were established to permit these assessments.

Stations 8 and 9 (Model Cave Discharge and Nettle Spring) only flow during periods of substantial snow-melt runoff. If the tracing work is conducted in the fall as planned these springs will not flow until late spring to early summer. However, the springs can be sampled in the event that some dye from one or more of these traces discharges during the snowmelt runoff period.

There are three control stations designed to show that no dye or fluorescent compounds that could interfere with dye tracing have flowed into the study area during the study period. These are sampling stations 1, 3, and 18. In addition, there are two sampling stations (stations 4 and 5) designed to verify that no dyed water from Trace 3 flows down the channel of Pole Canyon to reach these stations. Station 17 is at an elevation lower than the dye introduction points but is not viewed as a location likely to receive any dye. Station 20 in Lehman Caves might receive dye if the pool in the cave is sometimes the upper surface of the water table and not simply a perched pool. This seems unlikely, but the sampling station will address this possibility with minimal effort. It is worth remembering that vertical water level fluctuations in Model Cave can be in excess of 240 feet.

As indicated earlier in this study plan, schedules for collecting samples and placing new samplers can be modified as necessary to accommodate weather conditions, holidays, and logistical considerations.

Analytical Methods

Dye analysis will be conducted in accordance with the OUL's Procedures and Criteria document included with this study plan as Appendix A.

Reports

We will prepare a final report on the tracing work once the work has been completed. Progress report can be provided if they are requested.

References

Aley, Thomas. 2002. The Ozark Underground Laboratory's groundwater tracing handbook. Protem, MO. 35p. Available in hard copy or on line from www.ozarkundergroundlab.com.

Aley, Thomas. 2008. Chapter 15: Tracer tests—dye. IN: Weight, Willis D. Hydrogeology field manual. McGraw-Hill Publishers. Pp. 675-698.

Elliott, Peggy E.; David A. Beck; and David E. Prudic. 2006. Characterization of surface-water resources in the Great Basin National Park area and their susceptibility to ground-water withdrawals in adjacent valleys, White Pine County, Nevada. U.S. Geological Survey, Scientific Investigations Report 2006-5099. 157p.

Field, Malcolm S.; Ronald G. Wilhelm; James F. Quinlan; and Thomas J. Aley. 1995. An assessment of the potential adverse properties of fluorescent tracer dyes used for groundwater tracing. Environmental Monitoring and Assessment, Vol. 38. Kluwer Academic Publishers, Pp. 75-96.

Klimchouk, Alexander. 2007. Hypogene speleogenesis: hydrogeological and morphogenetic perspective. National Cave and Karst Research Institute, Carlsbad, NM. Special Paper No. 1. 106p.

Lange, Arthur L. 1958. Stream piracy and cave development along Baker Creek, Nevada. Western Speleological Institute, Bull. No. 1. Santa Barbara, CA. 20p. + plates.

Newton, J.G. 1984. Sinkholes resulting from ground-water withdrawals in carbonate terranes—an overview. Geol. Soc. of Amer., Review in Engineering Geology, Vol. VI. Pp. 195-202.

S:\tom\gbnpdyestudy1.doc