APPENDIX Y
FINAL KARST REPORT (REDACTED)

TECHNICAL REPORT APPENDICES

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Introduction to Appendix F

The purpose of Appendix F is to summarize data on the 41 groundwater traces conducted in the Section 5 area. Dyes for the first group of 28 traces (Trace Numbers 04-01 through 05-28) were introduced in 2004-2005. Dyes for the second group of 13 traces were introduced in 2008-2009.

Each of the dye traces is discussed separately. The discussions include a description of where and how each dye introduction was made and identify the type and quantity of tracer dye used. Where potable water was used with the dye introduction the quantity is identified. A rationale for conducting each of the dye traces is also included.

A total of 205 sampling stations were established and numbered in consecutive order. There was no Station 164. The station numbers where dye derived from a particular trace was detected in one or more activated carbon samplers or in one or more grab samples of water is identified.

The focus of the tracing work was to identify springs that received recharge water from the individual dye introductions. Streams in the area were routinely sampled to ensure that no spring discharge points were missed. As a result of the stream sampling a number of previously undocumented springs were identified.

A figure has been prepared for each trace made during the main investigation showing the dye introduction point and the diagrammatic groundwater flow path followed by the dye to the spring or springs from which the dye discharged. The diagrammatic flow is shown as a straight line; the actual flow route is unknown but is certainly not a straight line. A single figure showing all of the relevant traces used to delineate the recharge area includes the last 13 traces.

Primary sampling reliance in the groundwater tracing study was placed on activated carbon samplers and secondary reliance was on grab samples of water. The activated carbon samplers are continuous samplers that accumulate passing tracer dyes by adsorption rather than filtration. The amount of dye detected when a carbon sampler is analyzed in the laboratory is a function of the concentration of dye in the passing water and the duration of the exposure. The velocity of the passing water has a negligible effect on the amount of dye collected in the activated carbon sampler.

Tables are routinely provided showing a few of the earlier dye detections in activated carbon samplers from the spring sampling stations where dye from the particular trace was detected. All results are reported in Appendix B Other sampling stations that had dye detection associated with a given trace and derived their dye detections from the station or stations shown in the tables are listed in geographic order.

One can sum dye concentrations at a spring to estimate the time at which a particular percent of the total dye detected at the spring discharged from the spring. Estimates of 50% and 90% of total dye discharge are commonly useful. Such estimation requires that the flow rates of the spring be estimated for the period during which dye discharged from the spring. These estimates can be useful in dealing with spills or discharges of materials potentially harmful to groundwater quality that occur at or near the feature traced to the spring.

The estimated number of days after dye introduction that dye from a particular trace was detectable in activated carbon samplers at receiving springs is potentially a very useful value for assessing contamination issues involving contaminants with transport characteristics similar to the tracer dyes. The following assumptions have been used in calculating these values:

- The values use the last date that an activated carbon sampler positive for the dye was in place at the sampling station. This applies even if there are intervening samples where dye was not detected.
- If the last sample collected does not fully meet the criteria for positive dye detection professional judgment is used to determine the last date for dye detection. It is not uncommon for dye

deterioration to result in samples collected near the end of a dye trace not fully meeting positive detection criteria.

- If the last sampler collected from a sampling station was positive for the tracer dye then the number of days shown is prefaced by the symbol for greater than (>).

The discussions of the individual traces include explanatory information as necessary and summarize important findings from the particular traces.

Table F-1
Individual Dye Trace Summary Table

Trace No.	Trace Name	Figure No.	Karst Area	Input Feature No.	Dye Input Date/Time	Input Elevation (feet MSL)	Dye Type	Dye Quantity (lbs)	Water Used (gallons or gpm)	Precipitation/ Conditions	First Detection Station No./Name	Additional Dye Detection Stations No./Name	Time of Travel (1st detection)	Dye Detection Duration	Dye Trace Length (feet)	1st . Detection Station Elevation	Trace Elevation Loss (feet)	Mean Gradient (feet/mile)	Minimim Mean Velocity (feet per day)	Comments
04-01	Trace	F-1	Bloom. Karst	178	6-15-04 @ 0807	810	eosine	1	15,000	Rain after input			<1 day	>216 days	535	790	20	197	5,718	Detected dye at Station 19; dye was later detected at Station 78 once it was established. Velocity derived from Station 54 detection.
04-02	Trace	F-2	Bloom. Karst	91	6-15-04 @ 0938	800	rhodamine WT	2	13,000	Rain after input			8 hours	<33 days	2,616	712	88	178	8,710	Velocity derived from Station 12 detection.
04-03	Trace	F-3	Bloom. Karst	190	6-30-04	852	eosine	2	dry set	dry			1 day	>255 days	1,617	794	58	189	2,097	Veleocity derived from Station 4 detection and runoff-producing rain on 7/4/04.
04-04	Trace	F-4	Bloom. Karst	102	7/26/04 @ 0757	802	eosine	2	0.5 gpm storm runoff, & 2,000	Rain			<1 day	>176 days	2,940	712	90	162	10,462	Velocity derived from Station 68 detection.
04-05	Trace	F-5	Bloom. Karst	174	7-26-04 @ 0848	814	rhodamine WT	1	7,000				11 hours	>176 days	802	774	40	263	1,813	Veleocity derived from Station 16 detection.
04-06	Trace	F-6	Bloom. Karst	ss3	8-30-04 @ 1215	840	rhodamine WT	1	20 gpm from pond				<1 day	<98 days	1,631	781	59	191	9,910	
04-07	Trace	F-7	Bloom. Karst	64	9-10-04 @ 1132	786	fluorescein	.33	6,000				18 days	>210 days	2,155	670	116	284	120	
04-08	Trace	F-8	Bloom. Karst	99	9-10-04 @ 1203	750	rhodamine WT	1	2,000	drought			27 days	>210 days	2,128	667	83	206	78	Velocity derived from Station 67 detection.
04-09	Trace	F-9	Bloom. North Karst	ss5	9-30-04 @ 1838	715	rhodamine WT	2	15 gpm creek flow	drought			6 days	<189 days	5,325	650	65	64	949	Figure 21 does not show Station 4 as a detection point; however, dye was detected there once surface flows had resumed. Velocity based on Station 87 detection.
04-10	Trace	F-10	Bloom. Karst	192	12-1-04 @ 1425	853	eosine	4	1 gpm storm runoff	storm response			2 days	<90 days	2,968	816	37	66	1,475	
04-11	Trace	F-11	Bloom. Karst	ss1	12-7-04 @ 1226	765	eosine	3	10 gpm storm runoff				13 days	>122 days	2,760	674	91	174	214	This was a losing stream dye trace.
													14 days	>122 days	5,971	654	111	98	425	
05-12	Trace	F-12	Bloom. Karst	52	1-5-05 @ 1736	766	sulforhodamine B	3	8 gpm storm runoff				<5 days	<51 days	4,075	674	92	119	833	
05-13	Trace	F-13	Bloom. Karst	446	1-13-05 @ 1522	810	fluorescein	0.5	3 gpm storm runoff				<5 days	>43 days	3,210	711	99	163	660	
05-14	Trace	F14	Bloom. North Karst	272	1-13-05 @ 1540	728	fluorescein	0.67	4 gpm storm runoff				<1 day	>92 days	693	688	40	305	2,371	Velocity base on Station 87 dectection.
05-15	Trace	F-15	Simpson Chapel Karst	433	2-3-05 @ 1710	760	fluorescein	1	4,000				<6 hours	<68 days	1,094	736	24	116	5,276	Velocity base on Station 128 water sample detection.
05-16	Trace	F-16	Simpson Chapel Karst	423	2-4-05 @ 0842	770	rhodamine WT	1	2 gpm				<1 day	>74 days	792	729	41	273	1,483	Figure 28 does not show Station 132 because it is too far west to appear at the figure's scale. Velocity based on Station 132 detection.
05-17	Trace	F-17	Bloom. Karst	67	2-28-05 @ 1137	766	rhodamine WT	0.5	2,000				1 day	>39 days	927	674	92	524	893	
05-18	Trace	F-18	Bloom. Karst	38	2-28-05 @ 1322	765	eosine	0.5	dry set & 2,000				<1 day	>39 days	770	713	52	357	3,073	Dye was introduced as a dry set. Some, but not all, dye seems to have entered the groundwater system during a storm on 3-22-05. The remainder was mobilized by water introduced on 4-5-05.
05-19	Trace	F-19	Simpson Chapel Karst	400	2-28-05	756	eosine	0.5	dry set & 2,000				1 day	>29 days	809	700	56	365	980	Dye was introduced as a dry set. Some, but not all, dye seems to have entered the groundwater system during a storm on 3-22-05. The remainder was mobilized by water introduced on 4-5-05. Figure 31 does not show Station 131 because it is too far west to appear at the figure's scale. Velocity based on Station 131 detection.
05-20	Trace	F-20	Simpson Chapel Karst	ditch failure	3-23-05 @ 1313	758	rhodamine WT	0.5	5 gpm storm runoff				6 days	>28 days	804	730	28	184	132	
05-21	Trace	F-21	Bloom. North	316	4-2-05 @ 1128	707	eosine	0.25	1,800				<20 min.	>18 days	243	683	24	521	13,997	Velocity based on visible dye observation.
													<18 days	>18 days	365	680	27	391	20	

Notes: MSL - Mean Sea Level, lbs - pounds, gpm - gallons per minute, min. - minute, Bloom. - Bloomington, Rd. - Road,

Table F-1 (continued)
Individual Dye Trace Summary Table

Trace No.	Trace Name	Figure No.	Karst Area	Input Feature No.	Dye Input Date/Time	Input Elevation (feet MSL)	Dye Type	Dye Quantity (lbs)	Water Used (gallons or gpm)	Precipitation/ Conditions	First Detection Station No./Name	Additional Dye Detection Stations No./Name	Time of Travel (1st detection)	Dye Detection Duration	Dye Trace Length (feet)	1st . Detection Station Elevation	Trace Elevation Loss (feet)	Mean Gradient (feet/mile)	Minimim Mean Velocity (feet per day)	Comments
05-22	Trace	F-22	Simpson Chapel Karst	ditch failure	4-2-05 @ 1238	781	eosine	0.25	1,000				6 hours	>17 days	689	754	27	207	2,869	Figure 34 does not show Station 128 because it is covered by the title block in the figure; however, Station 34 does appear on Figure 12. Velocity based on Station 128 detection.
05-23	Trace	F-23	Simpson Chapel Karst	405	4-2-05 @ 1258	756	rhodamine WT	0.5	800				<6 hours	>18 days	758	700	56	390	3,087	Figure 35 does not show Station 131 because it is too far west to appear at the figure's scale. Velocity based on Station 131 detection.
05-24	Trace	F-24	Bloom. North Karst	226	4-2-05 @ 1405	790	eosine	1	1,800				1.5 days	>18 days	5,052	650	140	146	3,770	Figure 36 does not show Station 185 because it is too far north to appear at the figure's scale. Velocity based on Station 185 detection.
05-25	Trace	F-25	Bloom. North Karst	318	4-4-05 @ 1635	699	fluorescein	1 oz	1,000				<3 days	>16 days	314	668	31	521	107	The Station 190 detection is somewhat questionable: no background sample, no confirmatory water sample, and the possibility of roadway contamination in the road ditch.
05-26	Trace	F-26	Bloom. North Karst	315	4-4-05 @ 1650	719	sulforhodamine B	0.25	1,000				<10 days	>16 days	687	680	39	300	71	
05-27	Trace	F-27	Simpson Chapel Karst	442	4-4-05 @ 1735	789	rhodamine WT	0.5	1,000				<2 days	>15 days	478	769	20	221	293	
05-28	Trace	F-28	Bloom. North	322	4-4-05 @ 1836	700	rhodamine WT	0.25	1,500				8 min.	>16 days	268	670	30	591	48,240	Velocity based on visible dye observation.
													<10 days	>10 days	1,195	645	55	243	125	
08-01	Trace	F-29	Bloom. Karst	66	11-19-08 @ 1628	778	fluorescein	0.25	2,200				<6 days	>166 days	1,605	670	108	355	297	Velocity based on Station 83 detection.
													<1.5	>166 days	1,306	681	97	392	1,037	Velocity based on Station 12 detection and higher dye concentrations at Treefall Branch.
08-02	Trace	F-30	Bloom. Karst	49	11-19-08 @ 1648	768	rhodamine WT	0.75	4,600				<51 days	<51 days	2,561	665	103	212	50	
08-03	Trace	F-31	Bloom. Karst	103	11-19-08 @ 1722	750	eosine	1	0.25 gpm				3 days	>336 days	5,041	665	85	89	1,688	Velocity based on Station 80 detection.
09-04	Trace	F-32	Bloom. Karst	ss1	2-1-09 @ 1630	736	eosine	1	1.5 gpm				<16 days	>170 days	4,137	667	69	88	262	
													5 days	no data	5,014	654	82	86	1,002	Velocity based on Station 68 detection.
09-05	Trace	F-33	Bloom. Karst	55	2-2-09 @1142	745	fluorescein	0.25	4,200				<1.5 days	<106 days	1,210	696	49	214	1,076	
													8 days	<78 days	7,098	646	99	74	883	
													8 days	<15 days	6,574	644	101	81	817	
09-06	Trace	F-34	Bloom. Karst	154	2-3-09 @1516	738	sulforhodamine B	0.75	dry set				<1 day	<77 days	1,280	688	50	206	9,711	Velocity based on lack of rain until 2/10/09 to mobilize the dye and the detection of dye at Station 67.
09-07	Trace	F-35	Bloom. Karst	ditch	4-27-09 @ 1830	769	eosine	3	4,200				<7 days	no data	1,196	704	65	287	178	
													77-85 days	>177 days	869	720	49	298	10	
													<7 days	>97 days	6,653	646	123	98	996	
													<7 days	<85 days	6,376	637	132	109	954	
09-08	Trace	F-36	Bloom. Karst	109	4-27-09 @ 1935	764	fluorescein	0.5	dry set followed by 4,200 gallons on 4/28/09				<4 days	no data	3,904	674	90	122	1,186	Velocity based on Station 12 detection.
09-09	Trace	F-37	Bloom. Karst	40	4-28-09 @ 1037	765	rhodamine WT	1	4,200				<6 days	<6 days	1,093	696	69	333	181	
													<6 days	<84 days	6,504	646	119	97	1,082	
													<6 days	<21 days	6,195	637	128	109	1,030	
09-10	Trace	F-38	Bloom. Karst	ss1	7-7-09 @ 0616	750	eosine	2.5	4,200				<6 days	<106 days	2,806	674	76	143	475	Velocity based on Station 12 detection.
													<13 days	>14 days	5,300	654	96	96	409	Velocity based on Station 67 detection.
09-11	Trace	F-39	Bloom. Karst	karst window	7-7-09 @ 0835	720	sulforhodamine B	0.25	no noticeable flow				<1.5 days	>106 days	341	704	16	248	301	Velocity based on Station 67 detection.
09-12	Trace	F-40	Bloom. Karst	50	7-7-09 @ 1059	776	fluorescein	1	4,200				<7 days	>106 days	3,764	674	102	143	551	Velocity based on Station 12 detection.
09-13	Trace	F-41	Bloom. Karst	72	7-7-09 @ 1203	736	rhodamine WT	0.5	4,200				<14 days	>14 days	2,771	638	98	187	200	

Notes: MSL - Mean Sea Level, lbs - pounds, gpm - gallons per minute, min. - minute, Bloom. - Bloomington, Rd. - Road,

Trace 04-01: Trace

Potable water was discharged into a sinkhole (GIS insurgence feature No.178) located at approximately at an elevation of approximately 810 feet above mean sea level (msl). The water was from a nearby fire hydrant and flow began at 0807 hours on June 15, 2004. One pound of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced at the bottom of the sinkhole at 0857 hours. Water was discharged continuously until 0907 hours on June 15, 2004. A total of 15,000 gallons of water was used to introduce the dye into the groundwater system. There was a runoff-producing storm later that afternoon.

The dye introduction point was selected because it is within the corridor for I-69 and currently receives runoff from SR37. Eosine dye was selected to reduce the possibility that dye would be visible if it were discharged into

The dye from this trace discharged from (Station 78). However, Station 78 was not established until after the trace was begun. Thus, dye was first detected at Station 19 , which was established below the confluence of its two outlets A and B.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-1. Stations 54 and 13 do not appear on the figure because they are too far south to appear at the figure's scale.

The following table shows groundwater flow route detections of dye in activated carbon samplers from Trace 04-01.

Trace 04-01 Trace Dye Detections at Station 19.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
5/26 to 6/3/04	ND	ND
6/3/ to6/17/04	540.1	986
6/17 to 6/23/04	539.5	75.4*
6/23 to 6/29/04	539.5	55.4
6/29 to 7/8/04	539.4	26.8*
7/8 to 7/18/04	539.2	3.56
7/18 to 7/28/04	538.8	5.80
7/28 to 8/4/04	538.8	5.60
8/4 to 8/13/04	536.2	6.20
8/13 to 8/30/04	536.2	4.80

* Value is the mean of two samples.

When the sampling station was established at dye from Trace 04-01 was still being discharged and demonstrated that the detectable eosine dye from this trace was being discharged from (Station 78) and no dye was being discharged from (Station 79). Dye from this trace continued to be detectable on the activated carbon samplers through the sampling period December 6, 2004 to January 17, 2005, therefore, detectable dye was present for >216 days after dye introduction.

The first dye arrival and the peak dye concentration at (Station 78) were less than one day after dye introduction. This is based on the first detection of dye at (Station 19). The straight-line groundwater flow path distance was approximately 535 feet. The elevation loss is approximately 20 feet. The mean gradient along this flow path is approximately 197 feet per mile.

The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 5,718 feet per day based on the first detection of dye at Station 54.

Dye from this trace was detected at the following sampling stations from upstream to downstream from dye discharged from

Trace 04-01 linked a sinkhole that currently receives runoff from SR37 to , which is also within the Section 5 corridor. No previous traces are known to have been detected at has not been identified as having special significance to the project.

Trace 04-02: Trace

Potable water was discharged into a sinkhole (GIS insurgence feature No.91) located at approximately at an elevation of approximately 800 feet msl. The water was from a nearby fire hydrant and flow was begun at 0938 hours on June 15, 2004. Two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced at the bottom of the sinkhole at 0950 hours. Water was discharged continuously until 1013 hours on June 15, 2004. A total of 13,000 gallons of water was used to introduce the dye into the groundwater system. There was a runoff-producing storm later that afternoon. The dye introduction point was selected because it is within the corridor for I-69 and it had a fire hydrant making for efficient water introduction.

The dye from this trace discharged from (Station 52).

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-2. Station 68 does not appear on the figure because it is too far south to appear at the figure's scale.

The following table shows the groundwater flow route detections of dye in activated carbon samplers from Trace 04-02.

Trace 04-02

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
6/9 to 6/11/04	ND	ND
6/11 to 6/16/04	569.3	458
6/16 to 6/23/04	568.8	366
6/23 to 6/29/04	568.2	265
6/29 to 7/8/04	568.7	102
7/8 to 7/18/04	568.5	56.3

Based on dye detection at the downstream sampling station (Station 12, Unnamed Tributary in Section 25), the first dye arrival at (Station 52) was about eight hours after dye introduction. The straight-line groundwater flow path distance was approximately 2,616 feet. The elevation loss is approximately 88 feet. The mean gradient along this flow path is approximately 178 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 8,710 feet per day. The dye was detectable at Station 52 in activated carbon samplers for approximately 33 days after dye introduction.

Dye from this trace was detected at the following sampling stations from upstream to downstream from dye discharged from

Trace 04-02 hydrologically connected a sinkhole in the Section 5 corridor with a relatively large discharge spring approximately 2,600 feet from the SR37 centerline. It is clear that springs appreciably outside the corridor have the potential to be impacted from activities in the corridor. Also, the trace showed that the tested insurgence feature transfers water across the subwatershed boundary from Jackson Creek to May Creek.

Trace 04-03: Trace

Two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was placed as a dry set in a culvert draining into a sinkhole (GIS insurgence feature No.190) on June 30, 2004 at 1600 hours. The dye introduction point is a sinkhole that has been covered by SR37 but has a culvert directing road runoff into it. The culvert is located at approximately at an elevation of approximately 852 feet msl. Eosine dye was used because of high background concentrations of fluorescein and rhodamine WT dyes at a potential detection point.

The dye almost certainly was not mobilized until a storm event on July 4, 2004, which produced 1.60 inches of rainfall and produced a more than eight-fold increase in discharge from (Appendix G).

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-3. Station 4 does not appear on the figure because it is too far north to appear at the figure's scale.

The following table shows the groundwater flow route detections of dye in activated carbon samplers from Trace 04-03.

Trace 04-03

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
6/24 to 6/30/04	ND	ND
6/30 to 7/9/04	540.2	27,000
7/9 to 7/18/04	539.6	204
7/18 to 7/28/04	540.1	1,910
7/28 to 8/5/04	539.7	548
8/5 to 8/13/04	539.7	548

Note: There are additional eosine detections from Trace 04-03 at this sampling station; the data are found in Appendix B.

Dye from this trace was detected at the following sampling stations from upstream to downstream from dye discharged from

The first dye arrival and the peak dye concentration at (Station 30) occurred about one day after dye introduction. This is based on dye detection at the downstream sampling station, (Station 43). The straight-line groundwater flow path distance is approximately 1,615 feet. The elevation loss is approximately 58 feet. The mean gradient along this flow path is approximately 178 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 2,097 feet per day based on the first detection at the more distant Station 4. Based upon activated carbon samplers the dye was detectable at Station 30 for approximately about 255 days after dye introduction. Dye was still detectable in the last sampler analyzed.

This trace revises the recharge area. Fitch (1994) included the catchment area for this dye introduction point within the recharge area). Trace 04-03 demonstrated that it is not and that road activity within the catchment area for the dye introduction point

would not impact the quantity or quality of water discharged from and its associated springs.

Water discharged from is treated before public exposure since it is contaminated with polychlorinated biphenyls (PCBs). Impervious surfaces, such as roadways, increase the quantity of runoff. If this part of SR37 or the proposed I-69 were in the recharge area it would increase the amount of water flowing to that would need to be treated.

Trace 04-04: Trace

Two pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a road ditch that is failing downwards (GIS insurgence feature No.102). The dye was introduced at 0757 hours on July 26, 2004. Approximately 0.5 gpm of storm runoff was entering the groundwater system at this location at the time of dye introduction. From 0912 to 0922 hours on July 26, 2004, 2,000 gallons of potable water was introduced to enhance the introduction of the dye into the groundwater system.

The dye introduction point is located at approximately at an approximate elevation of 802 feet msl. The purpose of the trace was to help identify which groundwater system is receiving highway runoff from this part of the highway.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-4. Station 68 does not appear on Figure F-4 because it is too far south to appear at the figure's scale.

The following table shows the groundwater flow path detections of dye in activated carbon samplers from Trace 04-04.

Trace 04-04 Dye Detections at Station 52.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
7/8 to 7/18/04	ND	ND
7/18 to 7/27/04	540.2	7,240
7/27 to 8/4/04	540.1	7,130
8/4 to 8/13/04	540.3	1,150
8/13 to 8/31/04	540.1	764
8/31 to 9/9/04	539.9	186

Note: There are additional eosine detections from Trace 04-04 at this sampling station; the data are found in Appendix B.

Dye from this trace was detected at the following sampling stations from upstream to downstream from dye discharged from

The first dye arrival and the peak dye concentration at (Station 52) occurred about one day after dye introduction. The straight-line groundwater flow path distance is approximately 2,940 feet. The elevation loss is approximately 90 feet. The mean gradient along this flow path is approximately 162 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 10,462 feet per day based on the dye detections at Stations 12 and 85. At the dye was detectable from activated carbon samplers for approximately175days after dye introduction. Dye was still detectable in the last sampler analyzed.

Trace 04-04 was the second trace to be detected at and the third (including a pre-Tier 2 trace) to demonstrate water transfer across the subwatershed boundary to
This trace was from a point that currently receives runoff from SR37 through a soil pipe or possibly a reopening sinkhole). However, we have no other evidence of a buried sinkhole at this location. If there was an initial sinkhole it may have been filled during construction of the adjacent lanes of SR37. The reopening point is at the downstream end of the concrete ditch liner. This point could readily transmit

contaminants from the roadway to has not been identified as having special significance for this project.

Trace 04-05: Trace

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a sinkhole at this location (GIS insurgence feature No.174). Water for the trace was from a nearby fire hydrant. Water flow was begun at 0840 hours on July 26, 2004. The dye was introduced at 0848 hours and water flow ceased at 0855 hours on July 26, 2004. A total of 7,000 gallons of water was used to introduce the dye into the groundwater system.

The dye introduction point is located at approximately at an elevation of approximately 814 feet msl. The purpose of the trace was to identify which groundwater system receives runoff from this part of the highway corridor.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-5. Station 13 does not appear on the figure because it is too far south to appear at the figure's scale.

The following table shows the groundwater flow path detections of dye in activated carbon samplers from Trace 04-05.

Trace 04-05 Trace Dye Detections at Station 18.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
7/8 to 7/18/04	ND	ND
7/18 to 7/28/04	567.7	29,200
7/28 to 8/4/04	567.7	25,700
8/4 to 8/13/04	567.9	5,170
8/13 to 8/31/04	569.0	1,300
8/31 to 9/9/04	568.6	309

Note: There are additional rhodamine WT detections from Trace 04-05 at this sampling station; the data are found in Appendix B.

Dye from this trace was detected at the following sampling stations from upstream to downstream from dye discharged from

A nearby quarry occasionally pumps water from an impoundment in immediately upstream of (just upstream of Station 54) and discharges the excess down This was the apparent source of dye detected at Station 53

The first dye arrival at (Station 18) was about 11 hours after dye introduction. This estimate is based on dye detections at the downstream sampling station, at Weimer Road (Station 16). The straight-line groundwater flow path distance was approximately 802 feet. The elevation loss is approximately 40 feet. The mean gradient along this flow path is approximately 263 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 1,813 feet per day based on the dye detection at the downstream Station 16. At the dye was detectable from activated carbon samplers for approximately 174 days after dye introduction. Dye was still detectable in the last sampler analyzed.

Trace 04-05 hydrologically linked a sinkhole in the corridor with a spring in the Section 5 corridor that was undocumented prior to this investigation. is a relatively small spring that discharges into has not been determined to have special significance to the project.

Trace 04-06:

One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into the outflow from a retention pond built in a sinking stream basin (GIS insurgence feature No. ss3). The dye was introduced at 1215 hours on August 30, 2004. There was an estimated 20 gpm flowing out of the pond at the time of dye introduction.

The dye introduction point is located at approximately at an elevation of approximately 840 feet msl. The purpose of the trace was to identify which groundwater system receives runoff from this part of the highway corridor.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-6. Stations 15, 54, 13, and 80 do not appear on Figure F-6 because they are too far south to appear at the figure's scale.

The following table shows the groundwater flow path detections of dye in activated carbon samplers from Trace 04-06.

Trace 04-06

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
8/24 to 8/30/04	ND	ND
8/30 to 9/2/04	567.1	17,900
9/2 to 9/9/04	568.5	240
9/9 to 9/21/04	567.9	102
9/21 to 9/29/04	568.3	50.4
9/29 to 10/5/04	568.6	21.2

Note: There are additional rhodamine WT detections from Trace 04-06 at this sampling station; the data are found in Appendix B.

Rhodamine WT dye from this trace was discharged from (Station 79). No dye was detected at (Station 78). The first dye arrival and the peak dye concentration at (Station 79) were less than one day after dye introduction based on observations of visible concentrations of dye. The flow path from the dye introduction point to the east side of SR37 is almost all through culverts. The straight-line groundwater flow path distance is approximately 1,631 feet. The elevation loss is approximately 59 feet. The mean gradient along this flow path is approximately 191 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 9,910 feet per day. Dye was detectable at for 98 days following the dye introduction.

Dye that discharged from (Station 79) was detected at the following sampling stations from upstream to downstream:

Dye was not detected at Station 19 because this station was not being sampled at the time of this trace. More direct data were being acquired from Stations 78 and 79. Dye certainly passed though the stream reach sampled by Station 19.

Trace 04-06 demonstrated a flow path that had been presumed by local karst experts. This trace hydrologically linked a sinking stream basin that is almost entirely within the highway corridor to a spring that is also in the Section 5 corridor. No previous traces are known to have been detected at has not been determined to have special significance to the project.

The water discharged from often does not thermally equilibrate with the bedrock environment. It felt relatively warm during high flow events during the summer sampling events. This is almost certainly due to its short residence time in the subsurface and the relatively high residence time in the retention pond upstream of the dye introduction point.

Trace 04-07:

On September 10, 2004, potable water was discharged into a sinkhole (GIS insurgence feature No.64) located at approximately at an elevation of approximately 786 feet msl. The actual dye introduction point is outside of the corridor, but the sinkhole captures road runoff from SR37. Two thousand gallons of water was introduced from 1104 to 1110 hours. The water was introduced on the east side of the sinkhole and ponded. Another 2,000 gallons of water was introduced on the west side of the sinkhole from 1130 to 1134 hours. At 1132, approximately one-third pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into the sinkhole. From 1234 to 1238 hours, a third load of 2,000 gallons of water was introduced to flush the dye mixture into the groundwater system. A total of 6,000 gallons of potable water was introduced for this trace.

Dye from this trace discharged from

The two former stations were established when dye from this trace was not detected in the first sampling event after dye introduction. All of these springs are in the same topographic basin. Dye from this trace was detected at the following sampling stations:

Station 85: Upstream of Station 83
Station 86:
Station 12:

The dye introduction point and diagrammatic flow paths of the groundwater trace are shown on Figure F-7.

The following table shows groundwater flow path dye detections in activated carbon samplers from Trace 04-07.

Trace 04-07 Dye Detections

Sampling Period	**Station 52** **Fluorescein Dye Concentration (ppb)**	**Station 84** **Fluorescein Dye Concentration (ppb)**	**Station 83** **Fluorescein Dye Concentration (ppb)**
8/31 to 9/9/04	ND	NS	NS
9/9 to 9/21/04	7.48	NS	NS
9/21 to 9/28/04	8.24	NS	NS
9/28 to 10/5/04	10.9	319	10.2
10/5 to 10/12/04	3.74	156	26.6
10/12 to 10/25/04	ND	192	48.9
10/25 to 11/8/04	2,080*	56.0	13.7
11/8 to 11/17/04	2.87	47.9	12.3
11/17 to 12/6/04	ND	32.7	11.9
12/6 to 12/20/04		21.1	9.62
12/6 to 12/21/04	ND		

* Value is the mean of two samples.
Note: There are additional fluorescein detections from Trace 04-07 at these sampling stations; the data are found in Appendix B.

is not truly a spring; it is sampling a stream below a gaining stream reach. There are two springs at its headwaters (Stations 49 and 50), but neither spring received detectable dye from this

trace. The dye concentrations measured at (Station 83) were consistently lower than those measured at , which is a similar distance from the dye introduction point and has more flow. These data suggest that may be recharged partly by losses in the spring branch above the Treefall Branch sampling station. It is not uncommon in karst areas for the same short stretch of stream to have both gains and losses in flow.

(Station 52) had a dye detection that was an order of magnitude higher than any detections at . The peak concentration arrived almost two months after the dye introduction; however, the period of detection was much shorter at than at . This suggests that there is considerable complexity in the groundwater system in this area that has not been resolved by this investigation. The complexity should be viewed as an example of karst hydrology in the region and not as a deficiency in the investigation. The complexity in the groundwater system should have no effect on road design, construction, operation, or maintenance.

The first dye arrival at (Station 52) was about 2 days after dye introduction. The straight-line groundwater flow path distance was approximately 1,911 feet. The elevation loss is approximately 74 feet. The mean gradient along this flow path is approximately 204 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 783 feet per day based on dye detections at Stations 85 and 12. Dye was detectable for 68 days at . The peak dye concentration was during the October 25 to November 8, 2004 sampling period when the weather had been very dry. On October 12, 2004, a series of storms started moving through the area and through November 2, 2004 a total of approximately 5.8 inches of rain had fallen (including almost 2.5 inches on October 18, 2004). It is these series of storms that presumably provided the unusual pattern of dye detections at

The first dye arrival at (Station 84) was from three to eleven days after dye introduction, depending on the source of dye detected at Station 85. The straight-line groundwater flow path distance was approximately 1,604 feet. The elevation loss is approximately 105 feet. The mean gradient along this flow path is approximately 346 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 147 feet per day. Dye was detectable in for about 199 days after dye introduction when sampling was halted.

The first dye arrival at (Station 83) was from two to eighteen days after dye introduction, depending on the source of dye at Station 12. The straight-line groundwater flow path distance was approximately 2,155 feet. The elevation loss is approximately 116 feet. The mean gradient along this flow path is approximately 284 feet per mile. Dye was discharged from Spring for about 199 days after dye introduction when sampling was halted.

Since the flow path to is a shorter, steeper pathway than the path to , but had lower concentrations of dye, it is probable that the pathway has formed in the recent geologic past and does not yet have sufficient size to accommodate all the available water. Excess flows (essentially overflow) appear to discharge at , while base flow is discharged at . Over time, should capture most or all of the flow, unless its water, in turn, is being pirated to .

None of these springs have been demonstrated to have special importance to this project. Neither were documented before this investigation.

Trace 04-08:

On September 10, 2004 a dye introduction was made into a sinkhole (GIS insurgence feature No.99) located at approximately at an elevation of approximately 750 feet msl. Two thousand gallons of potable water was introduced from 1202 to 1209 hours. One pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into the sinkhole at 1203 hours. There was no ponding of water in the sinkhole.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-8. The following table shows the groundwater flow path detections of dye in activated carbon samplers from Trace 04-08.

Trace 04-08 Dye Detections at Station 74.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
8/31 to 9/21/04	ND	ND
9/21 to 10/25/04	567.4	139
10/25 to 11/8/04	569.1	44.5
11/8 to 11/17/04	568.6	17.6
11/17 to 12/6/04	569.7	25.1
12/6 to 12/21/04	568.8	35.0

Note: There are additional rhodamine WT detections from Trace 04-08 at this sampling station; the data are found in Appendix B.

Dye from this trace was also detected at the (Station 67), downstream from .

The first dye arrival at (Station 74) was about 27 days after dye introduction, almost certainly due to the drought conditions under which the trace was conducted. The straight-line groundwater flow path distance was approximately 2,128 feet. The elevation loss is approximately 83 feet. The mean gradient along this flow path is approximately 206 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 76 feet per day based on the dye detection at the downstream Station 67. Dye was detectable at for >210 days after dye introduction; sampling halted at this time. has not been demonstrated to have special significance for this project. was not documented before this investigation.

Trace 04-09: Trace

On September 30, 2004 at 1838 hours, two pounds of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into (GIS insurgence feature No.ss5)located at approximately at an elevation of approximately 715 feet msl. Flow in at the time and place of dye introduction was estimated at 15 gpm. The trace was started under drought conditions to determine whether or not was losing some or all of its flow around . The topographic basin includes an appreciable portion of the Section 5 corridor and receives runoff from .

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-9.

The following table shows the groundwater flow path detections of dye in activated carbon samplers from Trace 04-09.

Trace 04-09 Trace Dye Detections at Station 89.

Sampling Period	Station 87 Rhodamine WT Dye Concentration (ppb)	Station 89 Rhodamine WT Dye Concentration (ppb)
9/29 to 10/6/04	20,500	NS
10/6 to 10/14/04	1,210	520
10/14 to 10/27/04	341	134
10/27 to 11/8/04	37.5	7.74
11/8 to 11/17/04	17.8	6.94

Note: There are additional rhodamine WT detections from Trace 04-09 at this sampling station; the data are found in Appendix B.

The dye was detected at (Station 89) and in higher concentrations at (Station 87). Dye was detectable at Station 89 for 209 days after dye introduction. No dye was detected at (Station 4) until flow had resumed in the October 14 through October 27, 2004 sampling period. This trace demonstrated that , under the drought conditions tested, loses all of its flow into the groundwater system. That water then resurges at (Station 89) and other points in between Station 89 and Station 87. Figure F-9 does not show Station 4 as a detection point, although dye was detected there. However, the dye was not detected at Station 4 until surface flows had resumed. The detections at Station 4 were about two weeks after the detections in the downstream Station 87.

The first dye arrival at (Station 87) was less than six days after dye introduction. The travel time demonstrated is almost certainly slower under the drought conditions tested than under normal flow conditions. The straight-line groundwater flow path distance was approximately 5,325 feet. The elevation loss is approximately 65 feet. The mean gradient along this flow path is approximately 64 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 949 feet per day. After introduction, dye was detectable for 180 days at .

Trace 04-09 is an important trace because it demonstrates that the tested reach of sinks under very low flow conditions and almost certainly loses water under base and higher flow conditions. The sinking/losing reach receives runoff from and is located downstream of

, which is a Superfund site. Neither nor the gaining reaches downstream of it were documented as groundwater discharge points before this investigation.

Trace 04-10: **Trace**

On December 1, 2004 at 1425 hours, four pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole (GIS insurgence feature No.192) west of the The dye introduction point is located at approximately at an elevation of approximately 853 feet msl. Eosine dye was used because of high background concentrations of fluorescein and rhodamine WT dyes at the nearby

Spring. There was approximately one gpm of storm runoff entering the groundwater system at the time of dye introduction.

The majority of the dye was detected at (Station 31). Smaller concentrations were detected at (Stations 25 and 26, respectively). The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-10. The following tables show the groundwater flow path detections of dye in activated carbon samplers from Trace 04-10.

Trace 04-10 Trace Dye Detections at Station 31.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
11/8 to 11/17/04	ND	ND
11/17 to 12/3/04	541.5	1,150
12/3 to 12/7/04	541.0*	139*
12/7 to 12/21/04	541.8	4,140
12/21 to 1/11/05	541.6	415

* Values are the mean of two samples.

Note: There are additional eosine detections from Trace 04-10 at this sampling station; the data are found in Appendix B.

Trace 04-10 Trace Dye Detections at Station 25.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
11/17 to 12/3/04	ND	
12/3 to 12/21/04	541.5*	22.7*
12/21/04 to 1/11/05	541.5	36.3
1/11 to 1/18/05	541.0	10.9
1/18 to 2/24/05	541.3	3.53
2/24 to 3/16/05	ND	

* Values are the mean of two samples.

Trace 04-10

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
11/17 to 12/3/04	539.0*	1.42
12/3 to 12/21/04	541.5	6.37
12/21/04 to 1/11/05	541.4	41.1
1/11 to 1/18/05	541.3	11.6
1/18 to 2/24/05	540.4*	0.772

* A fluorescence peak is present that does not meet all criteria for a positive dye result but has been calculated as though it were dye for background purposes.

Dye from this trace was detected at the following sampling station downstream of Spring and the associated

The first dye arrival at (Station 31) was about two days after dye introduction, during a recession from storm response. However, the peak dye concentration appears to have arrived on December 7, 2004 and appears to have been in response to a second storm on December 7, 2004. The straight-line groundwater flow path distance was approximately 2,968 feet. The elevation loss is approximately 37 feet. The mean gradient along this flow path is approximately 66 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 1,475 feet per day. After introduction, dye from this trace was detectable for >105 days at . Dye was detectable for 85 days after dye introduction at Station 25 and at Station 26

receives some recharge water from the which is a Superfund site contaminated with PCBs. is very important to the design of I-69 since its contaminated discharge is treated before continuing downstream. Additional impervious surfaces, such as I-69 if it were built in the recharge area, could increase the amount of water requiring treatment. Trace 04-10 confirmed that the sinkhole in which the dye introduction was made lies within the recharge area of The trace also demonstrated interbasin transfer for water from the topographic basin to the

Trace 04-11:

On December 7, 2004 at 1226 hours, three pounds of eosine dye mixture containing approximately 75% dye and 25% diluent was introduced into a road ditch to determine whether or not the road ditch recharges the groundwater system (GIS insurgence feature No. ss1). The dye introduction point is located at approximately at an elevation of approximately 765 feet msl.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-11.

The following tables show detections of dye in activated carbon samplers from Trace 04-11 at

Trace 04-11 Trace Dye Detections at Station 48.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)
11/17 to 12/6/04	ND	ND
12/6 to 12/20/04	541.2	9.82
12/20/04 to 1/5/05	541.2	89.6
1/5 to 1/10/05	541.6	12.6
1/10 to 1/18/05	541.3	12.6

Note: There are additional eosine detections from Trace 04-11 at this sampling station; the data are found in Appendix B.

Dye from this trace was detected at the following sampling stations:

Eosine dye was detected at (Station 48) and at (Station 73).This trace demonstrates that the road ditch or the creek of which it is the headwaters, contributes water to two groundwater systems. The two groundwater systems are those of . The appreciably lower concentrations of dye at compared with the concentrations at suggest that the losses from the channel are occurring in separate reaches of the stream channel.

Trace 04-11 is important for four reasons:

1) The dye introduction point recharges

2) The trace demonstrates that

3) The trace demonstrates that the stream branch is a losing stream.

4) The trace demonstrates complexity in the distribution of recharge in the study area.

The first dye arrival and the peak concentration of dye at (Station 48) were about 13 days after dye introduction. The straight-line flow path distance was approximately 2,760 feet. The elevation loss is approximately 91 feet. The mean gradient along this flow path is approximately 174 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 214 feet per day. After introduction, dye from this trace was detectable for >132 days at when sampling was halted.

The first dye arrival and the peak concentration of dye at (Station 73) were less than 14 days after dye introduction. The straight-line flow path distance was approximately 5,971 feet. The elevation loss is approximately 111 feet. The mean gradient along this flow path is approximately 98 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 425 feet per day. After introduction, dye from this trace was detectable for 106 days at . The decreasing concentrations of dye from Station 76 to Station 75 to Station 90 to Station 73 suggest that is recharged by channel losses downstream from Station 90. The channel was generally dry near station 73 while there was flowing water near Station 74. was not documented before this investigation and has not been determined to have any special significance.

Trace 05-12:

On January 5, 2005 at 1736 hours, three pounds of sulforhodamine B dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole (GIS insurgence feature No.52) located at approximately at an elevation of approximately 766 feet msl. Approximately eight gpm of storm water runoff was entering the groundwater system at the time of dye introduction. The purpose of this dye introduction was to identify the groundwater system that might be impacted by road construction and use in this part of the highway corridor.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-12. The following table shows the groundwater flow path detections of dye in activated carbon samplers from Trace 05-12.

Trace 05-12 Trace Dye Detections at Station 48.

Sampling Period	Peak Emission Wavelength (nm)	Sulforhodamine B Dye Concentration (ppb)
12/20/04 to 1/5/05	ND	ND
1/5 to 1/10/05	579.5	662
1/10 to 1/18/05	578.8	14.1
1/18 to 2/11/05	578.0	12.5

Note: There are additional eosine detections from Trace 04-11 at this sampling station; the data are found in Appendix B.

The first dye arrival and the peak concentration of dye at (Station 48) were less than five days after dye introduction. The straight-line flow path distance was approximately 4,075 feet. The elevation loss is approximately 92 feet. The mean gradient along this flow path is approximately 119 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 833 feet per day. After introduction, dye from this trace was detectable for 51 days at

This trace demonstrates that recharge area crosses the entire SR37 corridor and at least one-half mile of the corridor axis is within the recharge area. is a biologically significant cave.

Trace 05-12 also demonstrates groundwater flow a karst flowpath crossing under SR37. This flow also crosses the subwatershed boundary and transfers water from the topographic basin to the basin.

Trace 05-13:

On January 13, 2005 at 1522 hours, one-half pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole (GIS insurgence feature No.446) that had formed in a ditch along SR37 just north of . The dye introduction location is located at approximately at an elevation of approximately 810 feet msl. The purpose of the trace was to identify which groundwater system receives runoff from this part of the highway corridor.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-13.

The following table shows the groundwater flow path detections of dye from Trace 05-13.

Trace 05-13 Trace Dye Detections at Station 16.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
10/26/04 to 1/10/05	514.8**	1,57*
1/10 to 1/18/05	516.0	43.4
1/18 to 2/1/05	515.9	16.5
2/1 to 2/9/05	514.0 **	1.00
2/9 to 2/25/05	514.6 **	1.19

* mean of two values ** A fluorescence peak is present which does not meet all the criteria for a positive dye result, but is has been calculated as though it were dye for background purposes.

The first dye arrival and the peak concentration of dye at (Station 16) were less than five days after dye introduction. The straight-line flow path distance was approximately 3,210 feet. The elevation loss is approximately 99 feet. The mean gradient along this flow path is approximately 163 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 660 feet per day. After introduction, dye from this trace was detectable for 43 days at (Station 16).

Fluorescein dye from was discharged between and Station 16. No dye from this trace was discharged from (Station 2) or the culvert adjacent to it (Station 1). Similarly, no dye was discharged from (Station 18). The dye may have been discharged from (Station 122), but the sampling station was not established early enough in the trace to be definitive. Additionally, the samplers at Station 63 had been removed and this station was unavailable to narrow the location of the spring from which Trace 05-13 was discharged. However, this trace demonstrates a karst flowpath beneath the SR37 alignment. There are no known groundwater systems associated with this stream reach known to have any special project significance.

Trace 05-14:

On January 13, 2005 at 1540 hours, two-thirds of a pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole (GIS insurgence feature No.272) that had formed in the median of SR37 just south of . The dye introduction is located at approximately at an elevation of approximately 728 feet msl. The purpose of the trace was to identify which groundwater system receives runoff from this part of the highway corridor.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-14.

The following table shows the groundwater flow route detections of dye in activated carbon samplers from Trace 05-14.

Trace 05-14 Trace Dye Detections at Station 88.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
1/5 to 1/10/05	512.6*	1.05
1/10 to 1/14/05	516.7	536
1/14 to 1/21/05	516.8	397
1/21 to 2/11/05	515.7	52.1
2/11 to 3/16/05	515.7	66.3

* A fluorescence peak is present which does not meet all the criteria for a positive dye result, but it has been calculated as though it were dye for background purposes.
Note: There are additional fluorescein detections from Trace 05-14 at this sampling station; the data are found in Appendix B.

Dye from this trace was detected at the following sampling stations (listed from upstream to downstream)

Based on the detection at Station 87, the first dye arrival at (Station 88) was less than one day after dye introduction. The straight-line flow path distance was approximately 693 feet. The elevation loss is approximately 40 feet. The mean gradient along this flow path is approximately 305 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 2,371 feet per day. After introduction, dye from this trace was detectable for about92 days at when sampling was halted.

Fluorescein dye from At lower concentrations, it was also detected at the station in the stream channel upstream of When the sampling station at was established there was no flow in the channel uphill from the spring. This indicates that there is an overflow or intermittent spring above . The trace also demonstrates which groundwater system could be impacted from the section of road tested by this trace. has not been demonstrated to have any special significance to this project. Neither nor the overflow or intermittent spring upstream of it were documented before this investigation. Both the dye introduction point and are in the Section 5 corridor.

Trace 05-15: **e**

One pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced into a sinkhole (GIS insurgence feature No.433) located at approximately at an elevation of approximately 760 feet msl. The trace was started using potable water hauled to the sinkhole on February 3, 2005. The first load of water was discharged into the sinkhole from 1707 hours to 1718 hours. At 1710 hours, one pound of fluorescein dye mixture containing approximately 75% dye and 25% diluent was introduced. A second load of water was discharged from 1748 hours to 1757 hours. A total of 4,000 gallons of hauled water was used for this trace. The purpose of the trace was to identify which groundwater system receives runoff from this part of the highway corridor.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-15.

The following table shows the groundwater flow route detections in activated carbon samplers of dye from Trace 05-15.

Trace 05-15 Trace Dye Detections at Station 137.

Sampling Period	Peak Emission Wavelength (nm)	Fluorescein Dye Concentration (ppb)
2/4 to 2/10/05	516.5	169,000
2/10 to 3/17/05	517.1	2,710
3/17 to 3/24/05	517.2	499
3/24 to 4/5/05	516.5	235
4/5 to 4/12/05	515.9	238
4/12 to 4/20/05	ND	ND

Dye from this trace was detected at the following sampling stations downstream of

Fluorescein dye was visually observed discharging from Station 137 early on the morning of February 4, 2005. Colored water extended for about one mile downstream of This resulted in calls by local residents to the Monroe County Health Department and the Washington Township Water District. Both of these organizations were aware of our dye-tracing program and were able to address the callers' concerns. However the spring had not been discovered and samplers placed until the reports of dye discharge were made. Therefore no background fluorescence values are available. Despite the lack of background data, this was an unambiguous detection.

OUL has found that in most karst settings, one pound of dye is the minimum quantity to be used to ensure a credible dye detection. In some settings, we learn that the systems are more open and smaller quantities could be used to produce credible results. Trace 05-15 was the first trace known to us conducted in the The quantity of dye chosen was based on our experience in the Bloomington Karst and other karst studies. However based on our experience with this trace, appreciably smaller quantities of dye were used in subsequent Simpson Chapel Karst traces.

Appendix B shows detections of fluorescence in the range of fluorescein at (Station 109) and Doug (Station 108) near the date of the dye introduction for Trace 05-15. However, the detection at precedes the dye introduction and is consistent with regional background values. Considering the very high concentrations of dye detected at , it is highly unlikely that the small values at are anything but background fluorescence.

Based on the visual observation of dye in near Station 126, the first dye arrival at (Station 137) was less than six hours after dye introduction. The straight-line flow path distance was approximately 1,094 feet. The elevation loss is approximately 24 feet. The mean gradient along this flow path is approximately 116 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 5,276 feet per day. After introduction, dye from this trace was detectable for 68 days at . It is noteworthy that none of the adjacent springs had detectable fluorescein resulting from this trace. was undocumented before this investigation.

Trace 05-15 hydrologically linked a sinkhole in the Section 5 corridor with a previously undocumented spring that is also in the corridor. The linked sinkhole's boundaries extend beyond the subwatershed boundary, so this trace demonstrates some interbasin transfer from to the has not been demonstrated to have special significance for this project. Trace 05-15 demonstrated the presence of a karst flowpath that crosses under SR37.

Trace 05-16:

On February 4, 2005 at 0842 hours, one pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into a karst window (GIS insurgence feature No.423) located at approximately at an elevation of approximately 770 feet msl. Approximately two gpm were flowing through the karst window at the time of dye introduction. The purpose of the trace was to identify which groundwater system receives runoff from this part of the highway corridor.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-16.

The following table shows the groundwater flow route detections of dye in activated carbon samplers from Trace 05-16.

Trace 05-16. Trace Dye Detections at Station 94.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
1/19 to 2/4/05	ND	ND
2/4 to 2/9/05	568.6	417,000
2/9 to 2/25/05	568.9	4,940
2/25 to 3/22/05	570.0	1,400
3/22 to 4/5/05	569.1	316
4/5 to 4/13/05	569.4	323

Note: There is an additional fluorescein detection from Trace 05-16 at this sampling station; the data are found in Appendix B.

Dye from Trace 05-16 was also detected at the downstream sampling station, (Station 132). The figure does not show Station 132 because it is too far west to appear at the figure's scale.

Based on the detection at (Station 132), the first dye arrival at (Station 94) was about 13 hours after dye introduction. The straight-line flow path distance was approximately 792 feet. The elevation loss is approximately 41 feet. The mean gradient along this flow path is approximately 273 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 1,483 feet per day based on the (Station 132) detection. After introduction, dye from this trace was detectable for about74 days at when sampling was halted. It is noteworthy that none of the adjacent springs had detectable rhodamine WT resulting from this trace. was undocumented before this investigation and is not known to have any special project significance.

The sinkhole linked by this trace has boundaries that extend across the subwatershed boundaries. The trace demonstrates interbasin transfer from the

Trace 05-17:

On February 28, 2005, the was begun using potable water hauled to the introduction point. Water was discharged from 1135 hours until 1145 hours. A total of 2,000 gallons of water was introduced at the dye introduction point. One-half pound of rhodamine WT dye mixture containing approximately 20% dye and 80% diluent was introduced into the sinkhole (GIS insurgence feature No.67) at 1137 hours. The location of the dye introduction point is approximately at an elevation of approximately 766 feet msl. The purpose of this trace was two-fold: to help characterize the patterns of corridor runoff through the subsurface and to evaluate the hydrologic relationship of this insurgence feature with the groundwater system. While the dye introduction point is located outside the corridor, its watershed extends to SR37.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-17.

The following table shows the groundwater flow route detection of dye in activated carbon samplers from Trace 05-17.

Trace 05-17 Trace Dye Detections at Station 48.

Sampling Period	Peak Emission Wavelength (nm)	Rhodamine WT Dye Concentration (ppb)
2/11 to 2/25/05	ND	ND
2/25 to 3/1/05	569.6	799
3/1 to 3/16/05	570.0	412
3/16 to 3/23/05	570.0	13.5

Note: There are additional rhodamine WT detections from Trace 05-17 at this sampling station; the data are found in Appendix B.

The first dye arrival and the peak dye concentration at (Station 48) were approximately one day after dye introduction. The straight-line flow path distance was approximately 927 feet. The elevation loss is approximately 92 feet. The mean gradient along this flow path is approximately 524 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 893 feet per day. After introduction, dye from this trace was detectable for about39 days at when sampling was halted.

This trace demonstrated that the recharge area extends farther north than shown by previous traces. Surface runoff from portions of SR37 tributary to the dye introduction point for Trace 05-17 contribute to the flow of the biologically significant .

Trace 05-18:

On February 28, 2005 at 1322 hours, one-half pound of eosine dye mixture containing approximately 75% dye and 25% diluent was placed in a sinkhole (GIS insurgence feature No.38) as a dry set. The dry set was designed to allow the dye to be transported into the groundwater system during a runoff-producing storm. The dye introduction location is approximately
at an elevation of approximately 765 feet msl. The purpose of the trace was to characterize groundwater flow patterns in this portion of the corridor.

On April 5, 2005, 2,000 gallons of potable water was pumped into the sinkhole to ensure that the dye entered the groundwater system. The water was introduced from 0920 to 0940 hours.

The dye introduction point and diagrammatic flow path of the groundwater trace are shown on Figure F-18. The following tables show the groundwater flow route detections of dye from Trace 05-18 at Station 76

Trace 05-18 Trace Dye Detections at Station 76.

Sampling Period	Peak Emission Wavelength (nm)	Eosine Dye Concentration (ppb)	Source of Dye (Trace Number)
1/17 to 2/25/05	541.0	27.4	04-11
2/25 to 3/16/05	540.1	10.7	04-11
3/16 to 3/23/05	540.7	57.9	05-18
3/23 to 3/31/05	540.9	101	05-18
3/31 to 4/8/05	540.8	225	05-18

The increase in dye concentration is not as dramatic as it would have been if all the dye had been mobilized in a single event. However, there is more than an order of magnitude increase in dye concentration between the pre-trace concentrations and the dye concentrations in the last sampling period. Some, but not all, of the dye seems to have entered the groundwater system during a storm on March 22, 2005. The remainder was mobilized by water introduced on April 5, 2005. The velocity of the dye front was calculated based on the interpretation that some of the dye was mobilized on March 22, 2005.

Dye from this trace was detected at the following sampling stations downstream of Station 76

Based on the detection at the downstream Station 90, the first dye arrival and the peak dye concentration at (Station 76) were about six hours after the March 22, 2005 storm event. The straight-line flow path distance was approximately 770 feet. The elevation loss is approximately 41 feet. The mean gradient along this flow path is approximately 357 feet per mile. The minimum mean groundwater flow velocity along this flow path under these flow conditions was approximately 3,073 feet per day, based on the detection at Station 90. After introduction, dye from this trace was detectable for >39 days at when sampling was halted. This previously undocumented spring has not been demonstrated to have special significance for this project. Dye discharged from the spring at Station 76 was probably the source for the dye detected at Station 75, which samples both surface water in the channel as well as groundwater discharge.