Plum Bottom Closed Depression Groundwater Trace Final Report

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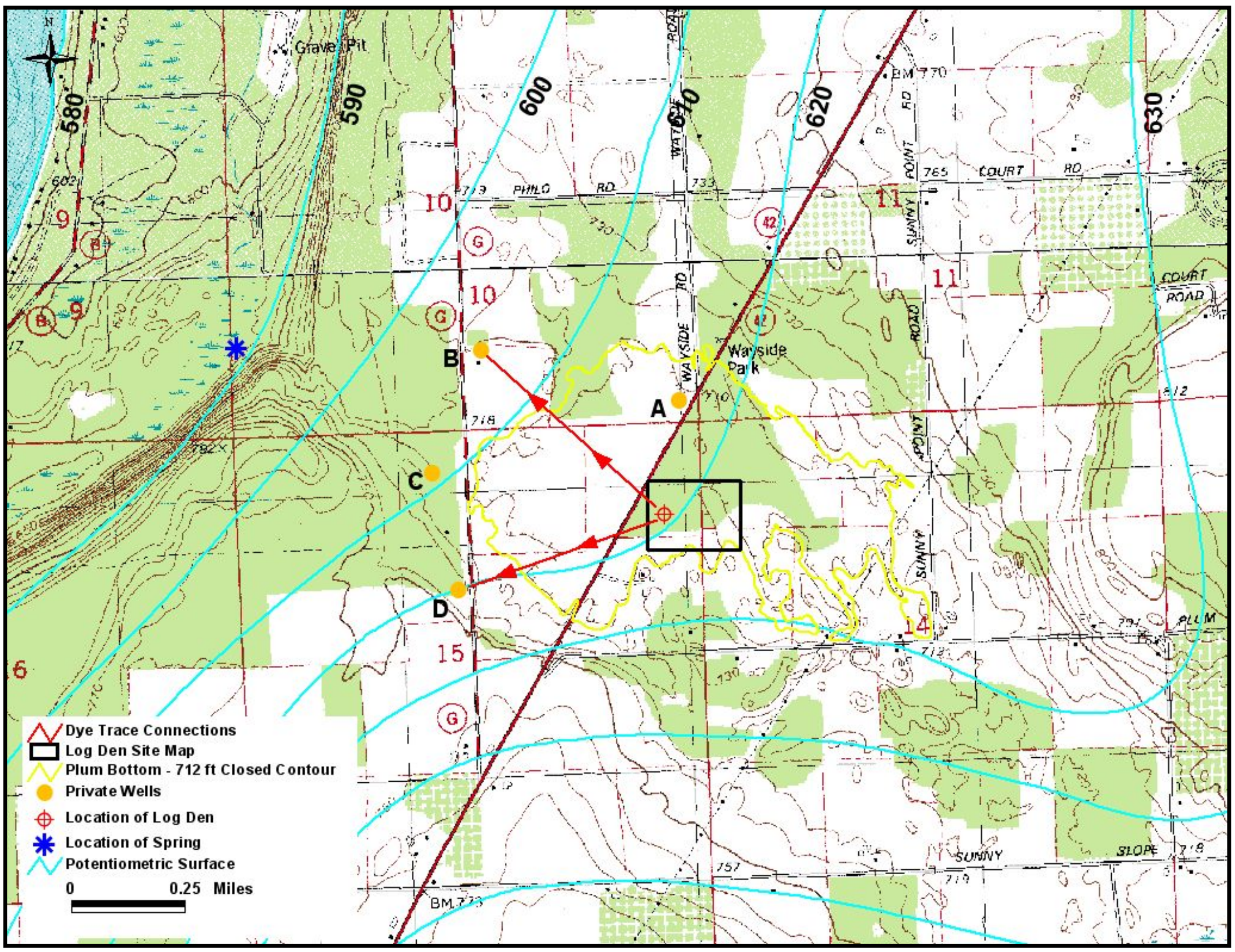

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Purpose

The purpose of this fluorescent dye tracer study was to investigate the connection of surface activities and pollutant sources with the groundwater/drinking water supply in the Plum Bottom closed depression in Door County, Wisconsin. The study was prompted by an outbreak of water-born viral illness shortly after the initial opening of a new restaurant in Plum Bottom. The tracer study looked for fast (months or less) connections between the new, professionally installed, conforming, tested and inspected septic system at the Log Den Restaurant and the Log Den water supply well, four down-gradient private wells and the regional karst groundwater system. The tracer study utilized the Log Den septic system as the tracer introduction points to look for additional evidence of rapid connection to the restaurant's water supply well and potential connections to a regional groundwater flow system. The study was funded through the Door County Soil and Water Conservation District and was conducted in September through December 2007.

Hydrogeologic Setting

The Log Den Restaurant was constructed in closed depression known locally as Plum Bottom. Plum Bottom is a large (~ 230 acre), closed, internally-drained depression crossed by Highway 42 a few miles northeast of Sturgeon Bay, Wisconsin. Plum Bottom is in parts of sections 10, 11, 14 and 15 of Egg Harbor Township (T29N, R26E). The depression shows as a closed 710 foot elevation contour on the Institute and Egg Harbor 7.5' USGS topographic quadrangle maps but is better defined by a closed 712 foot elevation contour on the Door County LIDAR 2 foot contour Digital Terrain Model (DTM) (see cover figure) (EarthData, 2002).

The first encountered bedrock in Plum Bottom is the Silurian Niagaran Series. It is a buff-gray, medium to coarse grained, thin-bedded to massive dolomite. Groundwater movement in the Niagaran is through discontinuous bedding plane joints and nearly vertical joints in the upper part and continuous bedding plane joints in the lower part (Sherrill, 1978). Recharge to the aquifer is from precipitation that enters the dolomite through abundant, near-vertical joints. Groundwater surface mapping indicates that groundwater movement in this area is east toward the Niagaran escarpment and Green Bay (Sherrill, 1978). A dye tracer test under forced gradient conditions at a Niagaran aquifer well pumping 225 GPM demonstrated that groundwater can move rapidly through the joints in the dolomite (Sherrill, 1978). The tracer dye moved 173 ft. horizontally from the injection well to the pumping well in less than two minutes.

The dolomite bedrock of Door County has extensive karst development (Johnson & Stieglitz, 1990). The abundant karst features include sinkholes, dolomite pavements, springs, and caves all occurring on a landscape characterized by very rapid, direct drainage of surface and soil waters into the karst aquifer. These features are ubiquitous in Door County. Sinkholes, caves, and springs all occur in the general vicinity of the Log Den restaurant. Plum Bottom is a karst feature with internal drainage that discharges to the regional groundwater system. The drain field of Log Den's on-site waste disposal system was sited on a small ridge in this feature. Soil boring information from Door County staff stated that there was 8-9 ft. of fine sandy loam till over 2 ft. of loose bedrock. Below the loose bedrock was in-place, fractured dolomite.

The entire Plum Bottom area is in the Holokarst B Karst Drainage Zone (Johnson & Stieglitz, 1990). In this drainage zone "surface runoff is contained within closed drainage basins and is channeled primarily by intermittent streams into alluvial sinkholes". This accurately describes the hydrology and physiography of the Plum Bottom area. They also describe the vulnerability of the holokarst areas: "The holokarst regions have a high potential for infiltration and movements of contaminant throughout the aquifer". Aquifer vulnerability was also assessed by Sherrill in 1978. Plum Bottom is in one the areas of the county with the highest aquifer vulnerability.

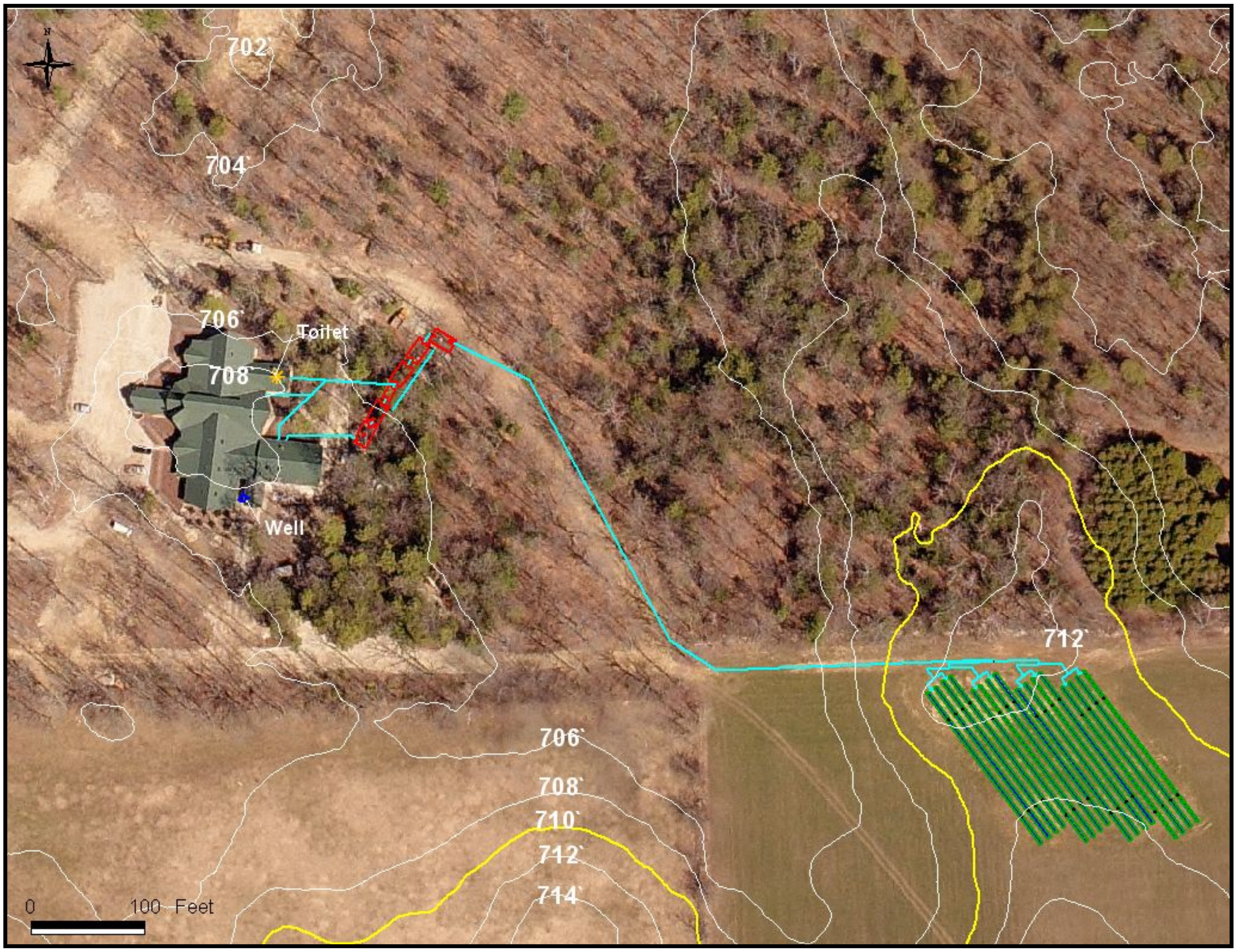

Figure 1. Log Den Restaurant site map. The drain field is show in green. The septic tanks and dosing chamber are shown in red. The sewer lines are shown in aqua.

Figure 1 is an air photo of the Log Den Restaurant with the plumbing features superimposed from the as-built plans. The air photo was taken 20 April 2007 shortly before the Log Den opened for business. The water supply well is indicated.

Methods

An array of monitoring points was established. The raw and treated water from the Log Den water supply well were the primary sampling points. Raw water samples were initially collected daily and the sampling interval was increased as the trace progressed. The effluent in the septic systems was periodically sampled. Four private wells to the west and north of the Log Den, i.e, down the regional groundwater potentiometric gradient, were sampled weekly. The only identified spring in the area was dry throughout the period covered by this report. Sampling began before the dye was introduced and continued until late December 2007.

Two types of samples were collected to monitor the movement of the fluorescent dyes through this system. Charcoal detectors are *integrating* samplers that recorded the passage of dye at anytime during the interval they were in the water but did not yield *quantitative* data on the dye concentration. Direct water samples allowed quantification of dye concentration but only at the time the sample was collected. The direct water samples proved to be most useful on the Log Den Well samples and the effluent samples. The charcoal detectors proved to be most useful on the four private well sampling points.

Water samples were collected in four milliliter borosilicate glass vials with polyethylene closures. Activated carbon detectors, also known as "bugs", were constructed with two grams of 6 to 12 mesh, Type AC coconut charcoal purchased from Barnebey and Sutcliffe Corporation. The activated carbon was enclosed in a 2 by 4 inch section of milk filter sock material sealed at both ends with stainless steel closures. A waterproof plastic tag was attached to each bug with a short loop of copper wire. Sample location, date and time installed and date and time recovered were recorded on each sample tag. Bugs were sealed in individual zip-lock containers for transport. Samples were collected under the direction of Brian Forest, Door County SWCD and transported to the University of Minnesota via US Postal Service Priority Mail for analysis.

Fluorescein and Eosin were purchased as dye concentrates from Chromatech Incorporated. Chromatint Uranine HS Liquid (fluorescein) stock number D11006, lot number 082207C (35% dye by weight) and Chromatint Red 0143 (eosin) stock number D13802, lot number 020706 (33% dye by weight) were repacked into appropriately sized HDPE containers for transport to the dye input site. Two kilograms of fluorescein dye represent 4.77 liters (1.25 gallons) of liquid dye concentrate. Four kilograms of eosin dye is 10.9 liters (2.9 gallons) of liquid dye concentrate. Split samples of each dye were diluted and dye content was confirmed by spectrofluorophotometer analysis.

Eosin was poured into the men's restroom toilet in the northeast corner of Log Den Restaurant at 10:30 AM on 21 September 2007 (Figure 2). Fluorescein was poured into the dosing chamber at the end of the chain of septic tanks at 10:05 AM on 21 September 2007 (Figures 3 and 4). The dosing chamber pumped a dose of dye and effluent toward the drain field immediately after the fluorescein was poured.

All spectra presented are synchronous scans run on a Shimadzu RF-5000 scanning spectrofluorophotometer at the University of Minnesota, Department of Geology & Geophysics Dilute Solutions Laboratory. Direct water samples were run in their 4 ml glass vials. A portion of the carbon samples were removed from the milk filter sock packet and placed into a 16 x 100 mm disposable test tube for elution. The eluent solution is 70% HPLC/ACS grade Isopropyl Alcohol and 30% High Purity De-Ionized Water saturated with 10 g/liter ACS grade Sodium Hydroxide. Ten milliliters of eluent are poured over each sample and allowed one hour to extract any fluorescent dye present on the carbon. The resulting elutant is transferred with a disposable pipette to a 13 x 100 disposable borosilicate test tube for analysis. The resulting spectra are emission referenced with $\Delta\lambda$ of 15 nm, 5 nm bandwidths, a scan rate of 30 nm/sec and 0.02 sec response time. Samples were scanned from 400 nm to 650 nm easily covering the expected peak fluoresence ranges of Eosin and Fluorescein dye. All spectra were fitted using PeakFit™ version 4.0 non-linear curve fitting software (Systat Software Inc., 2004).

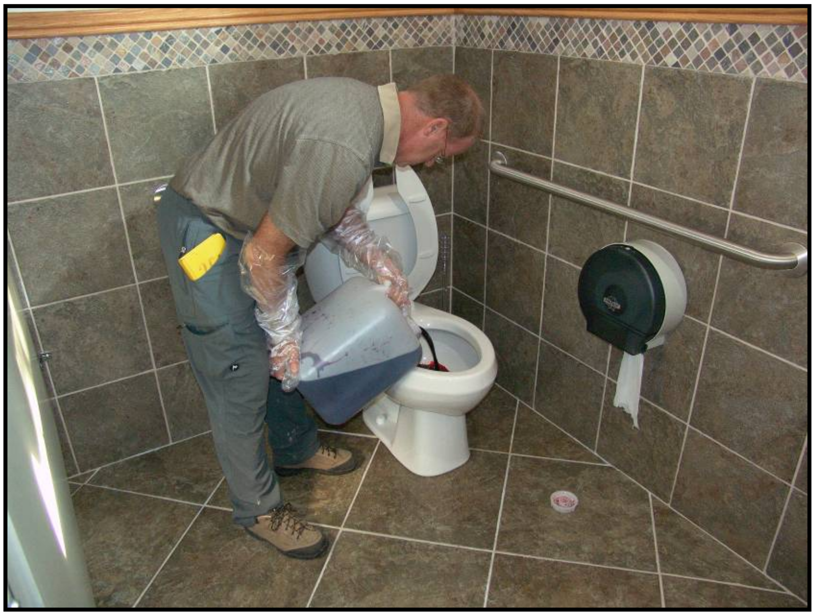

Figure 2. Scott Alexander pouring eosin into a toilet in a rest room in the Log Den Restaurant. Photo by Brian Forest.

Figure 3. Scott Alexander pouring fluorescein into the dosing chamber of the Log Den's waste water treatment system. Photo by Chris Olson.

Results

The results of the spectrofluorophotometric analyses of the raw and treated water from the Log Den water supply well are summarized in Table 1 in the appendix. The results of the analyses of the charcoal detectors are summarized in Table 2 in the appendix.

The eosin dye, which was poured into the toilet in the northeast corner of the Log Den began to break through to the water supply well on 27 September 2007, six days after it was injected.

Eosin rose to a maximum concentration on 25 October 2007 and was still present when the last sample collected on 20 December 2007.

The fluorescein dye, which was poured into the dosing chamber (nominally "down stream" in the sewer system from the eosin input point), began to break through to the water supply well on 6 October 2007 or fifteen days after it was injected. Fluorescein rose to a maximum concentration on 29 October 2007 and was still present when the last sample was collected on 20 December 2007. These data are shown in Figure 4. In addition to the eosin and fluorescein the

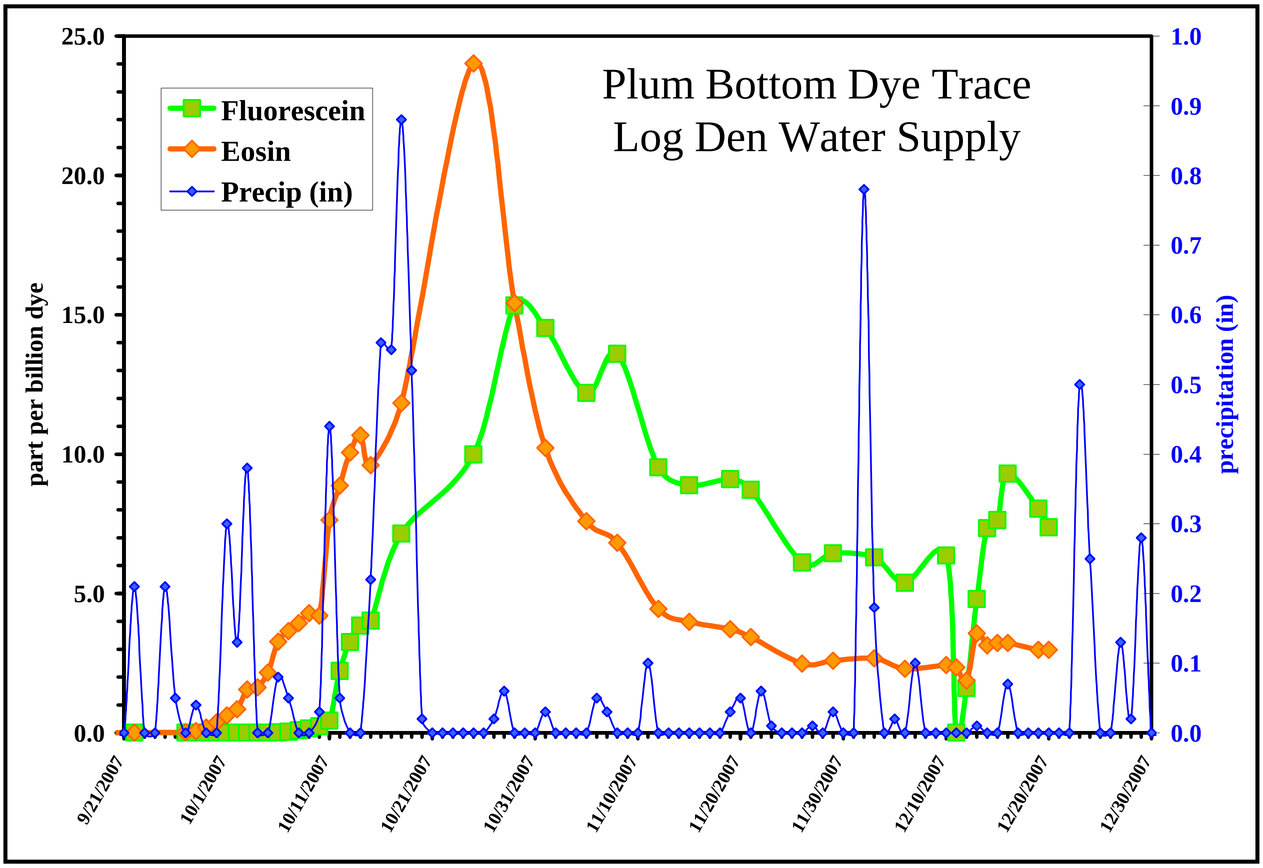

Figure 4. Eosin and fluorescein in the raw water of the Log Den well.

local rainfall data is shown. The concentration of the eosin and to a lesser extent the fluorescein appear to be increase after local rainfalls. The dip in the fluorescein on 10-12 December 2007 and the smaller dip in the eosin data were the dye reaction to a shock chlorination of the well, which was done as part of routine maintenance to control iron bacteria. The effect of the chlorination on the dye was only evident for 2-3 days.

Once dye began to be seen in the raw water samples, parallel samples of the treated water were collected each time a sample of the raw water was collected. None of these samples contained detectable dye. The extensive water treatment system installed in the Log Den's water supply system removed the dye to below our detection limits (0.01 parts per billion).

The charcoal detectors and water samples in the water supplies of the four private wells west and north of the Log Den did not detect any dye during the first two months of testing. One of the four wells dropped out of the testing after 11 October 2007 and a second after 29 November 2007.

In the next to last sampling round, 13 December 2007, fluorescein was detected in well "AW" (Well D in the Cover Figure). In the last sampling round, 20 December 2007, fluorescein and eosin were detected in well "AW" and fluorescein was detected in well "RP" (Well B in the Cover Figure).

Discussion

The rapid movement of both dyes from the on-site waste disposal system to the water supply well indicates that there are multiple, rapid leaks or short-circuits to the regional karst aquifer. Six to fifteen day breakthrough times to the well are much shorter than the retention times necessary for drain fields to remove pathogens from sewage. Drain field theory depends on slow movement through, and long retention times in fine-grained material to attenuate viable pathogens from sewage effluent.

One potential path is at the dosing chamber and septic tanks that were set on gravel over bedrock (Figs 5 and 6). At those sites, any effluent leaking from the system would not pass through soil and there would be very little opportunity for pathogen attenuation. That mechanism can explain the rapid breakthrough of the eosin dye that was introduced into the system from the

Figure 5. The septic tank trench was dug into bedrock and back filled with gravel.

Figure 6. Two of the septic tanks' connecting pipe.

restaurant toilet. A second potential path is similar trenches dug for the building foundations or utilities and then backfilled with permeable materials. Both the septic system trenches and the foundation/utility trenches will collect any effluent from leaks, augment them with rapid infiltration of runoff from roofs and other impermeable surfaces and convey those liquids directly to open joints and bedding planes in the fractured, karsted bedrock aquifer.

The fluorescein (introduced into the system in the dosing chamber) breakthrough in fifteen days could be as a result of a similar path. Alternatively, it could indicate rapid movement from the drain field. The discharge lines in the drain field are not under pressure therefore the effluent flow could be concentrated in the first part of the trenches. This could result in saturated flow, decreasing both the effluent's travel time to the bedrock and the opportunity for pathogen removal. The drain field and the trenches leading to the drain field are also underlain by fractured, highly permeable karst bedrock (Fig 7). This second scenario accommodates the different break through times more easily than does the first scenario. Were a leak in or near the dosing chamber the fluorescein short-circuit, the fluorescein should have arrived at the well in a similar time period as the eosin.

Figure 7. Fractured karst bedrock in a test pit immediately adjacent to the Log Den drain field. Photo by Chris Olson.

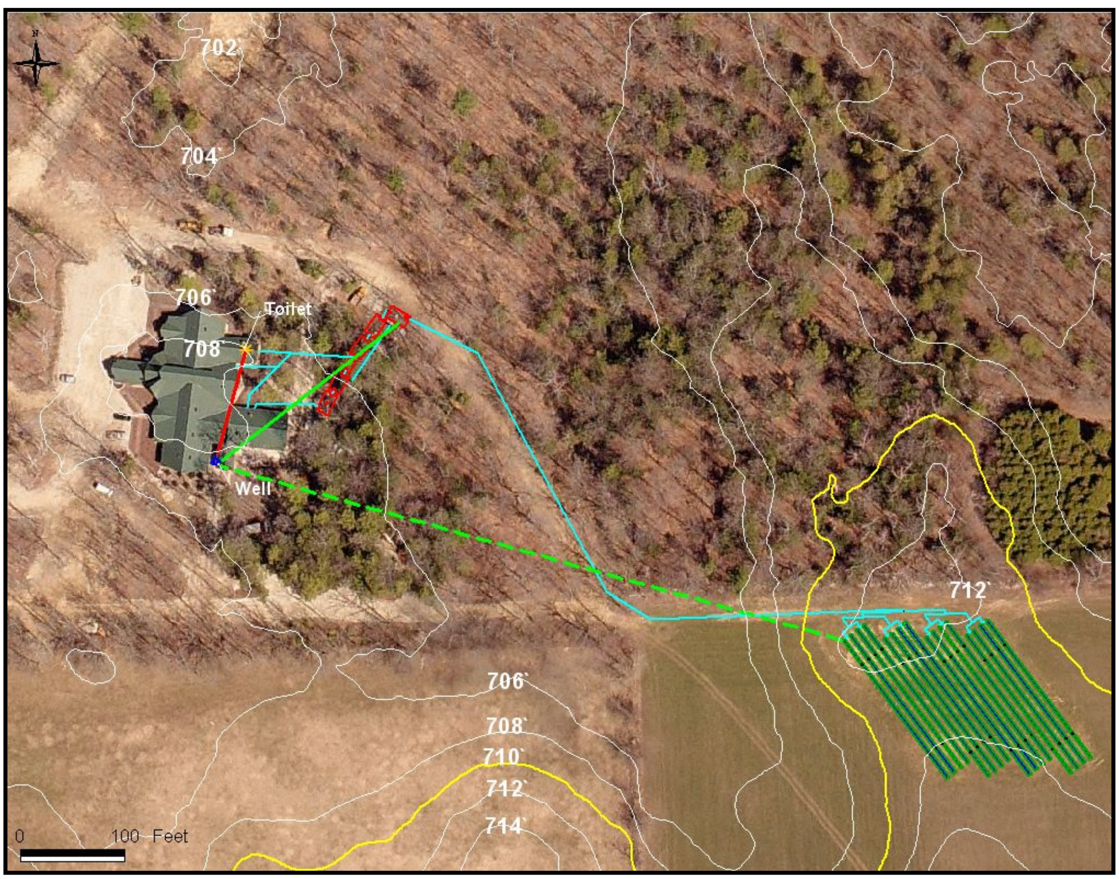

Figure 8. Log Den Restaurant Site Map plan view with diagrammatic dye connections shown.

The dye trace connections at the Log Den can be visualized in either plan (Fig. 8, above) or cross section (Fig. 9, below). In Figure 8 the red line from the "Toilet" to the well signifies a very direct, fast path between materials flushed down the toilet and the water supply well with little if any attenuation. The solid light green line shows a diagrammatic dye connection via a leak from the dosing chamber to the aquifer to the water supply well. The dashed light green line shows a diagrammatic connection between effluent that reaches the drain field and then short circuits to the aquifer and the water supply well.

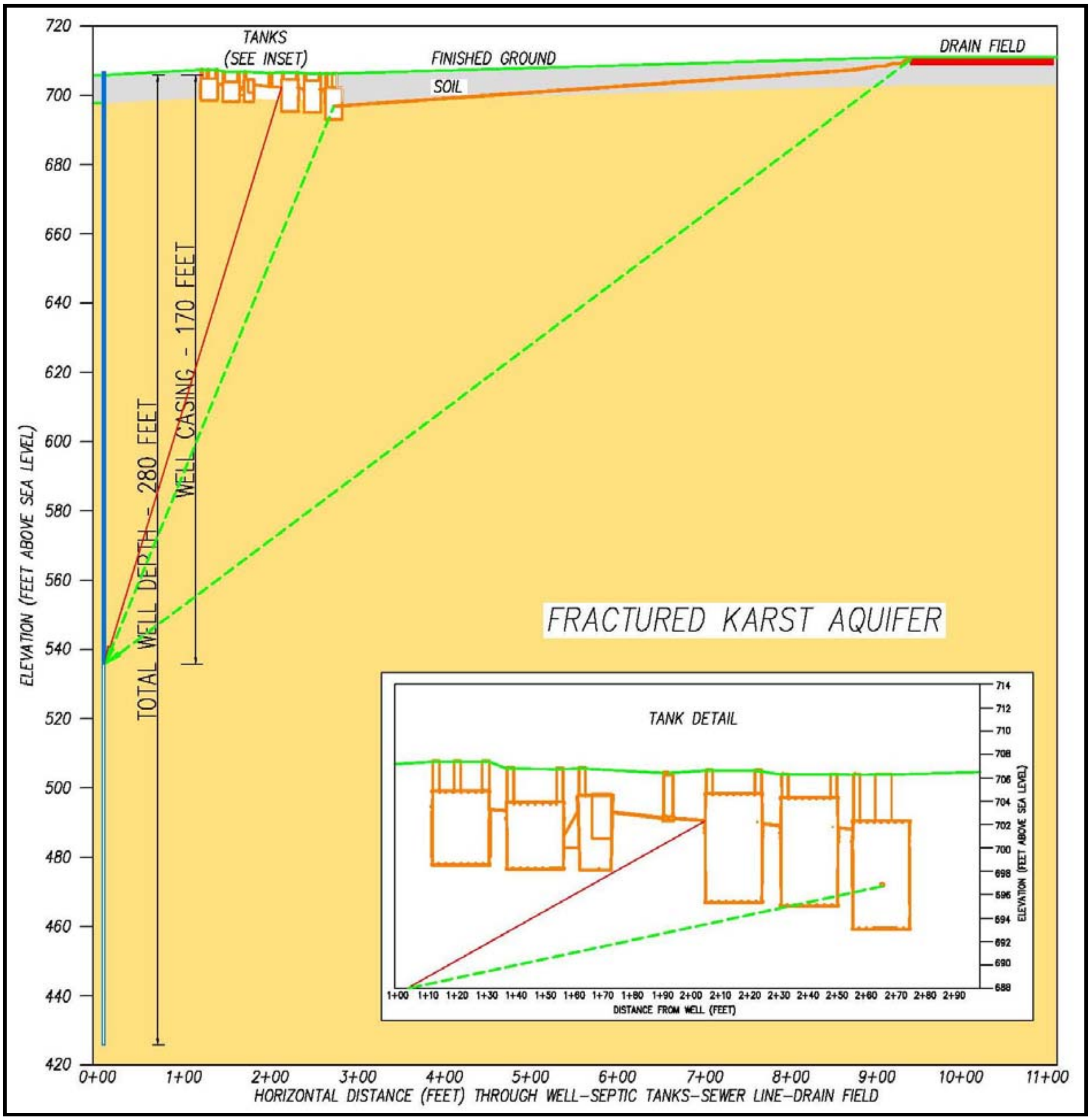

Figure 9. Cross section from Log Den water supply well through the septic tanks and then along the sewer line to the drain field. ~ 5x vertical exaggeration.

Figure 9 shows the same diagrammatic flow paths but in cross section. The eosin from the toilet entered the groundwater very directly and part of it moved downward (in response to pumping) to at least the bottom of the well casing and then was pumped back up the well into the

Log Den. An possible eosin path is show in Figure 9 as the red line reaching the septic tanks through the sewer line, leaking into the installation pit and then into the aquifer. An alternative path could be along a foundation trench to the top of the well, down the outside of the well and then back up the inside.

Figure 9 show as dashed green lines two possible paths for the fluorescein poured into the dosing chamber. One assumes that some sort of leak occurred near the dosing chamber, flowed to the aquifer and through the aquifer to at least the bottom of the well casing. A second possible path assumes the dye reached the drain field, short circuited there and flowed through the aquifer to the well.

We do not know exactly what the pathways to the regional aquifer are but we dye trace results document that those pathways exist and effluent moves through them quickly – in 6 to 15 days. A fraction of the leaked effluent that reaches the regional aquifer was recaptured by the Log Den well.

The rest of leaked effluent moves with the regional groundwater flow through the fractured karst aquifer. Wells B and D (cover Figure) are about half a mile from the Log Den. The breakthroughs of the dyes to wells B and D in about three months is a direct measure of the natural gradient flow velocity in this karst aquifer. That flow velocity is about 2 miles per year under the dry conditions of the fall of 2007.

Viral movement in the subsurface is a complex phenomenon and is affected by a variety of factors. Viruses that do reach the groundwater can survive for periods of months to decades (John and Rose, 2005; Prof. Charles Gerba and Prof. Adria Bodour, private communication 2008) in the cold ground waters of Door County. The natural gradient ground water velocities of several miles per year, which were quantified by the dye detections in wells B and D, can move such viral contaminants many miles in their life times.

The viral outbreak at the Log Den is consistent with the rapid movement of the dye through the dolomite aquifer. Our study indicates that the present site selection, design, and construction criteria for large on-site waste disposal systems in the Holokarst drainage zones of Door County present a risk to the dolomite aquifer.

Recommendations

- A thorough, independent, third-party forensic investigation of the Log Den sewer system should be conducted to determine exactly where and how the failures or short circuiting occurred.
- Information from the forensic investigation and the results of this dye trace should be used to modify the site selection, design, construction and inspection criteria for on-site waste disposal systems. If such modifications prove incapable of preventing pathogens from reaching the regional groundwater system, Door County may need to prohibit further construction of large on-site waste disposal systems in the Holokarst drainage zones.
- Given the long history of water quality problems in Door County, the Log Den illnesses and the results of this dye trace, all groundwater needs to be treated and disinfected

before being used for human consumption particularly for all groundwater used by the general public.

Acknowledgments

We acknowledge a debt of gratitude to the Wayne Lautenbach family and the 240 patrons who got sick. All are victims of a regulatory system that failed to protect them from harm. Their pain and suffering can teach the citizens of Door County a valuable lesson. We thank William Schuster whose vision and persistence made this study happen. Special thanks are due the four private citizens who allowed us to include their water supplies in this study. Brian Forest facilitated this work in many ways including production of the graphics in this presentation. Greg Theide and Chris Olson of the Door County Sanitarian Department provided valuable insights on the on-site waste disposal system and its design and installation. We acknowledge with thanks financial support through a contract with the Door County SWCD.

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Appendix

Table 1. Eosin and Fluorescein dye in the Log Den water supply well.

Date	Time	Eosin Dye Center (nm)	Eosin Dye FWHM (nm)	Eosin Dye Area (nm)	Eosin Dye dye (ppb)	Fluorescein Dye Center (nm)	Fluorescein Dye FWHM (nm)	Fluorescein Dye Area (nm)	Fluorescein Dye dye (ppb)
8/29/2007	09:15				0.01				0.01
9/20/2007	09:30				0.01				0.01
9/22/2007	09:40				0.01				0.01
9/27/2007	10:25	532.4	20.7	6.08	0.02				0.01
9/28/2007	09:25	531.6	20.8	15.8	0.06				0.01
9/29/2007	09:00	531.0	20.9	49.8	0.19				0.01
9/30/2007	08:45	531.2	20.5	96.7	0.37				0.01
10/1/2007	09:45	531.2	20.9	161	0.63				0.01
10/2/2007	08:30	531.4	20.6	217	0.85				0.01
10/3/2007	15:10	531.5	20.5	393	1.55				0.01
10/4/2007	09:30	531.5	20.4	412	1.63				0.01
10/5/2007	08:30	531.4	20.4	546	2.17				0.01
10/6/2007	08:45	531.7	20.4	819	3.27	506.7	21.5	19.2	0.02
10/7/2007	10:20	531.5	20.6	913	3.65	506.4	21.5	37.4	0.04
10/8/2007	10:45	531.1	20.6	983	3.94	505.1	18.8	86.3	0.10
10/9/2007	10:45	531.5	20.5	1070	4.29	505.3	19.9	139	0.16
10/10/2007	10:50	531.4	20.5	1050	4.21	505.7	19.9	200	0.23
10/11/2007	09:50	531.4	20.5	1890	7.64	505.9	19.9	365	0.44
10/12/2007	13:55	531.8	20.6	2190	8.87	507.1	19.9	1670	2.22
10/13/2007	13:50	531.6	20.6	2480	10.06	506.9	19.9	2390	3.25
10/14/2007	12:50	531.5	20.7	2630	10.68	507.0	19.6	2800	3.85
10/15/2007	11:00	531.4	20.7	2370	9.61	506.8	19.9	2920	4.02
10/18/2007	09:35	531.3	20.5	2910	11.83	506.5	19.7	5020	7.15
10/25/2007	09:40	531.5	21.1	5850	24.02	506.9	19.7	6880	9.99
10/29/2007	11:55	531.1	21.7	3780	15.42	506.9	19.8	10300	15.33
11/1/2007	09:35	530.6	22.2	2520	10.22	506.9	19.9	9790	14.53
11/5/2007	14:10	530.4	22.6	1880	7.60	506.9	19.7	8300	12.19
11/8/2007	09:25	530.1	23.1	1690	6.82	506.9	19.8	9200	13.60
11/12/2007	14:00	529.9	23.1	1110	4.45	506.8	19.7	6580	9.53
11/15/2007	09:30	529.4	23.9	995	3.98	506.7	19.7	6160	8.89
11/19/2007	10:45	529.4	23.9	930	3.72	506.8	19.7	6300	9.10
11/21/2007	09:40	529.9	23.3	861	3.44	506.9	19.8	6050	8.72
11/26/2007	10:35	529.6	23.8	626	2.49	506.8	19.7	4330	6.11
11/29/2007	09:40	529.3	24.3	650	2.59	506.8	19.7	4550	6.44
12/3/2007	10:20	528.4	25.3	671	2.67	506.7	19.5	4450	6.29
12/6/2007	09:30	529.6	23.9	579	2.30	506.8	19.7	3840	5.38
12/10/2007	09:00	528.8	25	612	2.43	506.8	19.6	4500	6.37
12/11/2007	09:16	527.5	24.2	590	2.35			10	0.01
12/12/2007	09:10	525.1	27.3	473	1.87	519	23.4	1230	1.61
12/13/2007	08:45	525.1	28.3	893	3.57	506.9	19.9	3450	4.80
12/14/2007	09:00	527.6	26.4	786	3.14	506.8	19.7	5150	7.35
12/15/2007	12:30	528.6	24.9	808	3.23	506.9	19.7	5340	7.64
12/16/2007	12:30	528.7	24.7	807	3.22	506.9	19.7	6430	9.30
12/19/2007	09:45	528.8	25	747	2.98	506.8	19.8	5610	8.05
12/20/2007	09:20	528.8	25	747	2.98	506.8	19.8	5170	7.38

Table 2. Dye input parameters and Charcoal Detector Data.

Input: Dosing Chamber	09/21/07	10:05:00 AM
Fluorescein Dye	Chromatech Uranine HS Liquid	
Chromatint D11006	Lot 082207C	2 kg dye (4.77 L)
Input: Log Den Men's Rm	09/21/07	10:30:00 AM
Eosin Dye	Chromatech Red 0143	
Chromatint D13802	Lot 020706	4 kg dye (10.9 L)
Monitoring Locations	Time(hhmm) and dye detection if present	
	Fluor = Fluorescein Eos = Eosin	

Date	Site Log Den	AW	BW	RP	RW
8/29/2007	Installed	Installed	Installed	Installed	Installed
9/10/2007	0900	1120	1100	1110	1030
9/20/2007	1030	0945	1400	0935	0905
9/24/2007	1110	1030	1055	1040	1020
9/28/2007	0925	0910	0920	0855	0905
10/4/2007	'0930 Fluor	0910	0920	0850	0900
10/11/2007	'0950 Fluor	0915	0925	0900	0905
10/18/2007	No Analysis	0915	0925	0855	Ended
10/25/2007		0920	0930	0910	
11/1/2007		0910	0920	0900	
11/8/2007		0910	0920	0900	
11/15/2007		0910	0920	0905	
11/21/2007		0915	0920	0905	
11/29/2007		0900	0910	0845	
12/6/2007		0945	End	1000	
12/13/2007		'0900 Fluor		0930	
12/20/2007		'0950 Fluor/Eos		'1000 Fluor	