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Two New Techniques for Evaluating Connectivity of Septic Fields to Great Lake Watersheds and Embayments

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Two New Techniques for Evaluating Connectivity of Septic Fields to Great Lake Watersheds and Embayments

FINAL REPORT

By

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ABSTRACT

Pictometry Oblique Imagery was successfully used to map septic fields in Oak Orchard watershed. Analysis of the imagery proved to be efficient for finding leach fields, and between 66 to 81% of the septic fields previously mapped by the Genesee Orleans County Department of Health, were identified. The remainder were not identified because of canopy cover, or were either septic systems without leach fields, the septic field postdated the imagery, or were not visible. Consequently under ideal conditions (septic systems with leach fields and no canopy or shadows) the method should be able to identify over 80% of the systems. Imagery taken during the transition from dormant to growing season proved best for identifying leach fields. One example of a plume from a short circuited system was recorded. A total of 1277 septic fields were mapped in the watershed. Spatial distribution was heterogenous, with dense sites of septic fields concentrated along residential road corridors. Approximately 4.2% of the leach fields were located less than 100 feet of a tributary. This is below the minimum separation distance of a leach field to a waterbody that is required by the NYS Department of Health code. The average distance of a leach field to a tributary is 327 meters with 50% of the leach fields occurring within 240 meters of mapped tributaries. Maps of important septic field “hotspots” were developed for watershed stakeholders and include tributaries along Batavia-Elba Townline Rd., Marsh Creek, and tributaries near the intersections of Alleghany and Lockport Rds, Judge Rd and Knowlesville Rd., and Lockport and Albion Rd. Considerable numbers of septic fields occur along Lake Alice in the main stem of the river, however this stretch is probably diluted by water input from the Erie Canal at the Glendale Dam.

In a second set of experiments, a new DNA-based groundwater tracer was introduced to two septic systems to see if it could be used to trace individual septic systems. The tracer was not discovered in one site, however, a breakthrough curve was obtained in the second site 31 days after being introduced into the toilet. This tracer passed through at least 200 meters of groundwater flowpath and 1 km of stream. The results of these experiments suggest that frequent, systematic sampling and careful lab protocols to identify the signal to noise threshold of the procedure are critical to the success of the technique. In summary we suggest that Pictometry Oblique Imagery can be used to map septic fields in a watershed and that the DNA Tracer technique may be successful in some septic systems. Further research needs to be conducted to improve the success of the latter.

INTRODUCTION

Nonpoint source pollution from septic fields have been demonstrated to be an important contributor of nitrogen and phosphorous to groundwater (Yates, 1985, Chen, 1988), shorelines (Duda and Cromartie, 1982, Reay, 2004), streams (Hat et al, 2004, Sagona, 1986), and lakes (Chen, 1988, Hayes etal, 1990). It has also been implicated in bays and water bodies associated with Lake Ontario (Makerewiz, 2000, Landre etal, 2004). Addressing it with watershed policy has been difficult for two reasons: 1) identifying where leach fields are hydrologically connected to water bodies is difficult to do, and 2) determining the magnitude and residence time of septic field pollutant fluxes within watersheds is not possible. Our lack of knowledge in this issue of hydrologic connectivity greatly restricts the kind of management practices and policies we can employ to prevent nonpoint source pollution from septic systems. Furthermore it prevents us from modeling these fluxes in the first place, meaning we do NOT know the true impact of septic fields at the watershed scale. This is not helpful for justifying action in watershed planning. Current modeling of septic field fluxes use a statistical approach based on population or water use (Hayes et al, 1990; Valiela et al, 1998; Dillon and Molot, 1996; Evans, 1979; Brown, et al, 2006). Assumptions are made on the numbers of septic fields that are short circuited or have failed, and no information on their location relative to nearby watershed bodies is accounted for. Yet most field studies of septic systems demonstrate that geology, soil type, water table conditions and distance from the leach field are critical factors in determining nutrient fluxes (Crosby et al, 1972**;** Waltz, 1972**;** Childs et al, 1974**;** Reneau and Petri, 1975**;** Reneau and Petri, 1976; Reneau, 1979; Rea and Upchurch, 1980; Starr and Sawhney, 1980**,** Gerrite et al, 1995**;** Sherlock et al, 2002**;** Collick et al, 2006). This means that estimates of nonpoint source pollution from septic fields are, at best, a guess based on the number of people living with septic fields in the watershed. In this study we ran experiments to test two new approaches towards solving the issue of septic field connectivity at the watershed scale. In our first approach, True Color Oblique Imagery, developed by Pictometry LLC, was used to determine if it has utility for mapping septic leach fields. In our second approach a new DNA based particle tracer (Sharma et al, 2011) was employed to determine if it can be used to track the residence time of septic runoff from individual systems. These approaches will be discussed in detail below.

Approach 1 Remote sensing of Septic Systems using Pictometry LLC oblique imagery

Five previous studies have successfully used near infrared and color photography to identify broken septic fields (Evans, 1979**,** Sagona, 1986; David and Ginsburg, 1995**,** Roper and Blanco, 2005**,** Farrel, 1985). Zhow etal (1985) used color photography to describe the “greenness” of turf, in order to quantify lawn fertilization rates. The reason these studies work is the color of the turf or vegetation is much different where it is exposed to leachate or fertilizer. In the case of a septic field, more water and nutrients are added to the turf which allows it to grow more robustly than surrounding grass. If this imagery was collected in late summer, after a long period of no rainfall, the difference should be dramatic and reflected not only in a change of hue (color) but also in a change in the height and roughness of the turf grass. Pictometry LLC oblique aerial photography may be able to pick up these differences because it captures the imagery in perspective and differences in texture will be enhanced. A physical characteristic of leach fields that is well known to home owners but is not typically considered in remote sensing is the microrelief where the leach field is located. Because the septic tank and the system of pipes were buried in the ground, the soil microrelief is sometimes different than the surrounding area where the ground was not disturbed by burying. In some areas regulations require minimum thicknesses of soil to install leach fields, and where these thicknesses are not met, the ground has to be built up artificially. This raises the ground level above the leach field. Both types of relief may be observable from LIDaR data. Our plan is to use the oblique imagery to see if it can be used to identify leach fields. We will also integrate imagery with LIDaR information to see if that improves identification.

Approach 2: Tracking Flows from Individual Septic Systems using DNA-based Tracers.

Sharma and Walter (2014) have developed an exciting new DNA-based hydrologic tracer that allows the researcher to simultaneously assess hydrologic connectivity between multiple sources (e.g., septic fields) and sampling points (e.g. streams, embayments etc). The tracers consist of short-strands (<500 base-pairs) of DNA surrounded by a polymer mesh of Poly(D,L-lactide-co-glycolide) (PLGA). This system allows us to construct colloidal-sized tracers with identical transport characteristics (size, mass, surface properties, etc.) that can still be uniquely identified from each other by the sequence of base-pairs that make up the encapsulated DNA strands. Using DNA strands of 100 base-pairs, we can theoretically produce 1060 unique sequences or DNA-labels. The DNA labels are "read" using Polymerase Chain Reaction (PCR) and can be quantified using quantitative PCR (qPCR). These biotechnologies are highly sensitive and allow us to detect tracers at very low concentrations; indeed, many orders of magnitude lower than we can measure solute concentrations of conventional groundwater tracers. A paramagnetic core is optional but allows us to use magnetic separation to concentrate or isolate the tracers from water samples if necessary. The primary role of the PLGA is to encapsulate the DNA and protect it from the environment. In the case of this project this means it must be resistant to enzymes and chemical conditions in the septic tank. For proof-of-concept, the tracers have already been successfully demonstrated in bench-top soil-column experiments, plot-scale runoff experiments, and at stream-reach scales (Sharma etal, 2011**)**). Because the tracers are colloidal in size, they preferentially move through macropores in subsurface flows. As disrupted leach fields commonly have soil piping associated with them and/or are associated with emergence and transport of leachate by surface runoff, colloidal tracers will likely reach the stream network faster in the case of clogged or backed-up septic systems. Anomalously fast DNA-tracers, thus indicate broken septic systems. We hypothesize that broken septic field systems that are actively short-circuited will deliver leachate to the stream network much faster than properly working nearby septic systems. Maps of septic field delivery time can then be prepared allowing us to identify problem areas in the watershed.

STUDY AREA

In this research we test the first approach in Oak Orchard watershed, an important contributor of nutrients to the southern shore of Ontario Lake (**Figure 1**). This watershed was chosen because it is undergoing a TMDL for phosphorous and sediment, and watershed stakeholders have raised the question of how important septic field contributions may be to the load from the watershed. This watershed also has available LIDAR data in the southern part so we could evaluate the effectiveness of integrating LIDAR data with the mapping process. The second approach was conducted in two field sites, a one bedroom house located in Rush, NY on the shore of Honeoye Creek, and a house located near an unnamed tributary of 4 mile creek in Webster, NY.

METHODOLOGY

Experiment 1 Can oblique imagery be used to map septic leach fields.

To test approach 1, Oblique Imagery was accessed through Pictometry-Connect (pol.pictometry.com). This provided us with access to Oblique Imagery in the study area for the following years: 2013, 2010, 2008, 2006, 2004, and 2002. Each year of imagery contains four oblique (40 degrees from the nadir) views oriented along the four cardinal directions (N, S, E, W). A top down view is also available in some year's of imagery. Septic fields were identified from the imagery and digitized as points in the POL interface. Septic fields were digitized, township by township, and then downloaded as KML files. The KML files were then converted to shapefiles in ArcGIS and compared to septic fields mapped by the Genesee and Orleans County Department of Health. Statistics on false positives and false negatives were computed on a township by township basis by comparing the Department of Health data to sites evaluated in our analysis. After some early experimentation, the following approach proved to be the most efficient way to map the septic fields in the imagery. The most recent year of imagery was evaluated first and the imagery was viewed along each of the four directions to look for evidence for leach fields. The evidence looked for included: parallel lines where the grass was either darker of lighter than the surrounding grassland, dark areas approximately rectangular in space, or faint rectangles where one or more corners were dark. Care was taken to exclude management features that could be mistaken for leach fields such as old garden areas, and the parallel tracks from lawn mowing. The imagery was evaluated for three more subsequent years if nothing was found in the first year. Based on four weeks of trial and error it was discovered that in most situations if a leach field was not identified by the third year of data analysis, the feature is not present in any of the data.

Experiment 2 Can DNA-based tracers be used to track leachate flow from septic systems.

Prior to conducting the tracer experiment, a meeting was conducted with the Region 8 DEC division of water quality to discuss the use of the new tracer, and to obtain permission to conduct some experiments. Based on the conversation that took place, we obtained additional information on long term degradation rate of the tracer, and developed a factsheet brochure that describes what the tracer is and that it poses no harm to natural water systems. This fact sheet is located in Appendix A and was developed to assuage homeowner concerns that the DNA in the tracer might be harmful to the environment. Once this information was provided, the DEC gave us verbal permission (via email) to conduct the experiments.

Two home sites with septic fields were instrumented for the experiments. A DNA-based tracer was introduced to the toilet and the site was sampled periodically until a breakthrough curve was identified from the data. The two sites and experiments will be described in detail separately.

2187 Rush-Mendon Rd., Rush, New York

This site is a single bedroom home with a small septic field that was installed in 1993 (**Figure 2**). The area near where the septic field is contains a small erosional gully which may be evidence for a breach in the system. The soil also contains a thick clay layer 0.8m below the surface of the ground. This layer is almost pure-clay. The area where the leach field is believed to be located is only 10 meters from the shore of a wetland associated with Honeoye Creek and the surface gradient is high. This site seems to be a worst case scenario for the success of a septic field. The shallow clay layer probably acts as an aquitard in the early spring –and in fact was the top of the water table when the site was instrumented (early Fall). Shallow water table combined with the short distance and high slope, make it likely that some septic leachate will make it into the water body.

As the wetland contained still water, and the location of individual leach lines were not precisely determined, a suite of three shallow wells (wells 1, 2, and 3) were constructed to sample the plume coming from the system (see **Figure 2**). The wells are 1.5 meters deep and are screened from the bottom of the well to 0.3 m above the clay layer. The upper 0.3 meters of each well was sealed with bentonite clay to prevent contamination from surface water from above. The wells were located downgradient from the leach field site and within 3 meters of the wetland surrounding the creek. Two additional wells (wells 4 and 5) were constructed a large distance away from the house to act as a control. A preexisting groundwater well upgradient of the leach field was also sampled as a control (well 6). A well was also constructed downslope of the septic tank (well 7). Lastly, one 3 meter deep well was constructed within the leach field itself to sample leachate (well 8).

On October 21, 2015, 80 mg of T3 DNA tracer were introduced to the toilet of the house. Additionally, 3 liters of concentrated (saturated) sodium bromide solution was also introduced into the toilet. Sampling was conducted at all well and surface water sites the week before to act as a control. All wells and the wetland were sampled periodically over the next three weeks and analyzed for Electroconductivity (EC) and the presence of the DNA Tracer. EC was measured with a YSI EC probe. Well 3 was sampled with an ISCO sampler for part of the experiment. Because of the apparent absence of the DNA tracer, the system was augmented on Oct 29, 2015 by adding 30 gallons of tap water into the toilet. The purpose of this was to make sure the septic talk overflowed into the septic lines. Samples were transported down to the Cornell Soil and Water laboratory for analysis.

60 Schliegl Road, Webster, NY

This site is a three bedroom home located 50 meters from an unnamed tributary of four mile creek (**Figure 3**). The leach field is located in the front yard and was properly built to code and is approximately 250 meters from a small stream. No issues have been reported in the septic system in the past. The yard is sloped up to the road, thus the surface gradient does not augment movement of the plume towards the stream. Movement would be downward into the water table, and then along the prevailing direction of groundwater flow which is Northward. Just downstream of the site is the Kent Park arboretum pond, a man-made pond created by damming the tributary. An ISCO automatic stream sampler was installed in the tributary at the Webster Golf Course approximately 1 km downstream, below the Arboretum pond. On November 7, 2015, 45mg of T3 tracer was introduced into the downstairs toilet of the residence. The ISCO was programmed to sample every 12 hours. The sampler was emptied periodically and the samples transported down to the Cornell Soil and Water Lab for analysis. Although this research project officially ended December 31, 2015, sampling will continue and the samples archived for analysis in the future.

RESULTS

Experiment 1 Can oblique imagery be used to map septic leach fields.

Examples of what septic field look like in the imagery are presented in **Figure 4**. There are generally two patterns of darker grass above septic fields: A rectangular area of darker grass, where the wastewater has spread homogeneously in the surrounding soil (**Figure 4 a**), and sets of parallel dark lines separated by a uniform distance (**Figure 4 b**) The lines of darker grass are located from 5 to 150 feet away from the house. The dimensions vary from 30 to 60 feet for the length of one line, 5 to 6 feet for the width. There can be from 3 to 15 lines, 6 lines being very common. This pattern is the most common in the counties of Orleans and Genesee. These lines are presumably caused by extra nutrient rich water from the leach lines. We have also noticed some darker areas that are not septic fields. These areas seem to be irrigated yards, which can be confused with septic fields when their shape and size are similar. We know that there must be space for the tank and the distribution box between the house and the septic field, which implies that darker areas are usually not directly next to the house. This fact enables us to tell the difference, because owners generally try to irrigate uniformly from their house. The appearance of septic fields does change depending on whether the imagery was taken just before or just after the start of the growing season (**Figure 4 c-d**). In Fall imagery, leaves sometimes accumulate in the microrelief of the leach field. The linear, parallel characteristic of the accumulations (which scale with the dimensions discussed above) help distinguish it from random occurrences of leaves (**Figures 4 e-f**). Generally speaking, large vegetation or shrubbery does not occur in septic fields, this is against code because the roots may sometimes disrupt the piping. Rarely, broken systems can be observed by their plume (**Figure 4 g**). One meter resolution hill shades created from LIDAR data proved useful for locating raised septic fields and occasionally septic tanks and distribution boxes. **Figure 4 h** shows an example of what this looks like.

The mapped data was compared to data from the Genesee and Orleans County Department of Health for quality control. For the past 6 years this agency has been running a program where legacy septic systems are mapped in the field and added to a geospatial database. New systems are automatically added to this database. This geospatial database provided us an opportunity to test the accuracy of our mapping for a sizable subset of the septic fields mapped. In order to do this we selected from their database all systems that had septic tanks and/or a distribution box and outputted the resulting shapefile. **Table 1** presents the percentages of detection for each township. Generally speaking between 66 to 81% (average of 74%) of the septic fields spotted by the Department of Health were identified. Of the sites not identified, between 0 and 11% (average of 7%) were not viewable because canopy cover or shadows obscured the site. Between 0 and 18% (average of 9% in the "other" category) were not identified because the most recent imagery predates the septic field (e.g. new construction), or no leach field was present in the system. This leaves 0 to 19% (average of 11%) that were not found by the methodology. Thus, under ideal conditions of no canopy and septic systems with leach fields, this methodology should be expected to map at least 80% of the systems.

A total of 3207 septic fields were mapped in the two county study area (**Figure 5**) of which 1277 were located within Oak Orchard Watershed (**Figure 6**). **Figure 7** is a probability density function that presents the average number of septic fields as a function of distance to the nearest tributary. Approximately 4.2% of the leach fields were located less than 100 feet of a tributary. This is below the minimum separation distance of a leach field to a waterbody that is required by the NYS Department of Health guidelines. The average distance of a leach field to a tributary is 327 meters with 50% and 90% of the leach fields occurring within 240 and 960 meters of mapped tributaries, respectively. Septic field density was calculated for subbasin catchments previously defined by an earlier study of nonpoint source pollution study in Oak Orchard Watershed (see Richards et al, 2011). Catchments ranged from 0.13 to 13.2 septic fields per square kilometer of watershed area. This analysis was repeated for a 200 meter buffer surrounding each stream to map out hotspots where septic sites are densely concentrated around streams (**Figure 8**). This size buffer assessed approximately 40% of the mapped septic systems and comprises the largest peak of the probability distribution graph. It was chosen because it is small enough to produce some precision in where dense areas of septic fields are clustered close to the stream, yet large enough to assess a sizable portion of the probability distribution function.

Experiment 2 Can DNA-based tracers be used to track leachate flow from septic systems.

At the Rush site, T3 DNA Tracer was introduced on October 21, 2015 at 12:30 PM to the toilet. A saturated solution of sodium bromide was also added to the system so that EC could be used to identify the presence of the tracer. After the solution was mixed with the bathroom water, the EC of the toilet water was 123 mS. Assuming a gallon of water was present in the toilet, this injection should have caused the septic tank water to increase in EC anywhere from 0.25 to 0.12 mS (depending if it is a 500 gallon to 1000 gallon tank). The wells were all sampled the week previous to act as a control and to assess the average EC of the groundwater. Well number 6 which is located upslope of the leach field has an average EC of 0.69 mS. Well number 7, which is located downslope of the septic tank and presumably away from the effects of the leachfield, was 0.67 mS. Natural ambient groundwater EC is therefore interpreted to be 0.68 mS. Prior to the injection of the tracer, the average EC of the wells downslope of the leachfield (Wells 1, 2, 3) were slightly elevated over the EC of the groundwater, 0.73, 0.76 and 0.73 respectively. Multiple measurements taken within the wells vary considerably in EC and Temperature (as much as 0.1 mS and 2 degrees respectively). The highest temperature and EC is always located at the top of the water column. We believe this is because the warmer septic leachate water moves on top of the groundwater. As a consequences field measurements and samples were always taken near the top of the water column. Within 6 hours, well 1 increased in EC from 0.74 to 0.88, but no tracer was found. Well 3 increased from 0.72 to 0.96 26.5 hours later. Well 2 did not change in EC at all, and in fact dropped slightly from its 0.76 pre-tracer level. The delay between well 1 and well 3 is probably because well 3 is located farthest away from the tank and distribution box. We cannot explain the lack of change in well 2, unless perhaps its screened interval was not located in a position to receive leachate (unlikely as its screened interval includes area above the clay layer). Another possibility is that the septic line associated with it was clogged. After this initial increase in EC, well 1 progressively decrease in EC with time until its pre tracer injection level 48 hours later. Well 3 decreased to its pre-injection level after only an hour. We believe this is an artifact of the sampling approach for this well as it was sampled with an ISCO sampler utilizing a rinse procedure. EC in all the samples within the sampler were lower than the pre-tracer experiment average and were fairly close to the average groundwater EC observed in wells 6 and 7. The sampler pumps a considerable amount of water when it samples with a rinse procedure, as a consequence we interpret the lower EC value in the ISCO samples to be caused by dilution from surrounding groundwater that was brought up by the pump. This is supported by the EC measurement of 0.738 taken by the YSI meter on 10/24/2015 (in a manner consistent with how the other wells are measured by hand). EC measurements of samples taken by the ISCO sampler are therefore not comparable to measurements taken by hand using the YSI meter and were excluded from our analysis. After the wells returned to their pre-injection EC, the wells progressively drop in EC to below their pre injection average at the end of the experiment. We interpret this to be due to recharge from several rain events that occurred the week after the tracer was injected as well as the 30 gallons of low EC tap water that was used to augment the system on October 29th.

Based on the EC increase observed in wells 1 and 3 just after the injection, and also that the amount of increase scales with what we might expect from the NaBr solution added to the tank, we believe the tracer may have passed through the system within 24 hours of the injection. The first sample taken was 6 hours after the injection and may have missed the peak of the breakthrough curve. Strangely enough, DNA tracer were not observed in any of the samples. The system was augmented with 30 gallons of water on October 29 in an attempt to flush out the tracer. No tracers were observed. The experiment was discontinued on 11/16/2015, 26 days after the injection. There are two ways to interpret this result. One way is that tracer may not have left the tank during the experiment. The septic tank may not have been full and because of the confirmed lack of water use by the resident of the home (clothes are washed away from the premises), no septic tank water was passed though the distribution box. This is not supported by the increase in EC observed in wells 1 and 3 just after the tracer was injected. The other interpretation is that there were issues with analyzing the DNA tracer in the lab. This seems to be the most likely interpretation and will be explained in detail in the discussion section of this report. We suggest the experiment should be repeated in wells 1 and 3 using a different DNA tracer and a shorter sampling interval.

At the Webster site, T3 DNA tracer was introduced on November 6, 2015 at 1:13PM to the first floor bathroom of the Baldwin Residence. The 45 ml solution contained a total of 7.48E8 individual DNA tracer particles. Based on the shape of the plot of the number of DNA tracers detected (per sample), a break though curve occurred between 12/7/2015 and 12/8/2015 (**Figure 9a**). Tracers numbering 250 per sample or below are considered instrument noise. Thus it took approximately 32 days for the tracer to move from the toilet, though the septic system, to the sampler. This travel path includes the movement through the Aboretum pond, which will have increased the residence time of the streamwater.

DISCUSSION

The mapping provided by this research is a necessary first step towards addressing the question of what role septic field inputs have to stream water quality and watershed scale nutrient fluxes. Most previous work has suggested that they are of lesser importance than other sources of nonpoint source pollution (agricultural runoff, point sources). The exception may be during low flow time periods when streamflow discharge are limited, allowing leachate to become volumetrically significant (Edwards and Withers, 2008; Mackintosh etal., 2011; Withers etal, 2011). To illustrate this, let us consider what the rainfall equivalent will be of septic leachate recharging from a leach field. This can be estimated by dividing the design flows of domestic water use by the area of the leach field. Design flows are estimated based on the number of bedrooms and the age of the bathroom fixtures. Older fixtures tend to be more inefficient in water use, releasing more water into the septic system then newer fixtures. Leach field area minimum size is regulated by a percolation test that is conducted prior to installing the system. If we assume minimum regulated size for the calculation, daily equivalent rainfall rates range from 1 inches to 2.1 inches per day in areas where percolation rates are high (see **Table 2**). To put this in context, 2.0 inches in 24 hours is a 1 year storm event. And this rate continues every day of the year. In the latter part of the growing season, when water tables have dropped, base flows decrease so septic leachate from nearby systems should become a more important source of stream water. Transpiration probably keeps up with rainfall, reducing runoff, which exacerbates the importance of septic leachate as a source of water.

Another way of evaluating how important individual septic fields is their topographic position in the watershed. Glacial watersheds in the northeast tend to be depressional, because of the history of erosion and deposition that occurred in the last period of glaciation. Thus each watershed can be divided into *internally-drained* areas, and *directly-connected* areas. Within *directly-connected* areas, it is possible for water and particulate pollution to move laterally under gravity all the way to the stream network (see Richards and Brenner, 2004). Septic fields occurring in *internally-drained* topography cannot introduce nutrient fluxes to streams by “short circuiting”. Even if leachate does breach to the surface and move laterally, these inputs will simply re-infiltrate into the ground. They cannot flow uphill into the valley that is directly associated with the stream. Nutrients can only travel to the stream network by groundwater flow paths. Broken systems are still a problem in internally drained areas as excessive dissolved nutrients will ultimately make it to streams, but at much longer residence times than systems located in *directly-connected* areas. We employed the PCSA algorithm (Richards et al, 2004) to map all of the internally drained and directly connected areas in the watershed. Septic fields located in these areas were given a different code to distinguish them from leach fields that could produce runoff via fast overland pathways to the stream network. Approximately 14.3% (182 systems total) of all septic leachfields are located in internally drained areas. These can be seen in **Figure 6**.

Soils and mucks with seasonally perched water tables, shallow bedrock, high slope, slow permeability, susceptible to frequent flooding, are a problem for septic systems (Butler and Payne, 1995). Soils containing Fragipans are also problematic (Day et al, 2007), though we have insufficient information to map them in this study. Septic fields in soils with these characteristics were identified using the engineering information included in the County Soil Surveys (Wulforst etal, 1969; Higgins etal, 1969). The criterion included "slow permeability", "D" soil hydrologic group (not available in the Genesee County Soil Survey), shallow (<3 ft) bedrock, "frequent flooding", "perched" or "prolonged" seasonal water table, "high" slope, or contains "Muck". In the Orleans County Soil Survey, the suitability for septic fields is explicitly ranked. If the soil was ranked as "severe", e.g. problematic for septic fields, its attributes were coded in our mapped septic fields. In the Genesee County Survey, a judgement was based on whether the soil was problematic. If any of the above criterion were present in the "suitability for infiltration systems" section of the engineering table, the soil was deemed problematic and coded in each mapped septic field. Approximately 88 % of all of the septic fields mapped in the watershed (1121 total) are impacted by one or more of these issues. By far the most important issues were seasonal perched water tables and slow permeability, effecting 78 and 61% of all of the mapped systems (1001 and 778 systems total). Shallow bedrock is an issue for 5.2% of the mapped septic systems (67 systems total). The other issues (slope, frequent flooding, and muck) were all less than 1%. It should be noted that there are engineering approaches for implementing septic systems successfully in soils that have unsuitable characteristics (such as raised systems), so just because the system is located in a soil that has one or more unsuitable characteristics, doesn't mean it is not working properly.

We can draw some simple inferences on where septic field nutrient inputs may be important in Oak Orchard Watershed, based on our septic field mapping and our knowledge of stream flow spatial variability provided by a SWAT modeling study of the watershed (Richards et al, 2012a, b) and a previous nutrient balance study of the river (Longabucco and Rafferty, 1988). These studies provides information on: 1) discharge changes along the tributary system (provided by the model), 2) locations and discharge values of point sources that contribute significant amounts of water to the stream network, 3) areas of high groundwater influx, and 4) sources of excessive agricultural runoff (the Mucklands). The former three will dilute septic nutrient concentrations, the latter will mask them by other sources of more concentrated nutrients. Most previous studies argue that septic field inputs will be most important during low flow periods, because runoff and baseflow inputs will tend to dilute the effects of septic leachate. Based on this idea, we used the information provided by the Richards et al (2012) study to make the following inferences on how important high density clusters of septic systems shown in Figure 6 are to nutrient concentrations WITHIN nearby stream reaches.

1) Septic systems near the wetlands associated with Iroquois National Wildlife Refuge, and the State Wildlife areas are probably unimportant because groundwater inputs in these areas are excessive in the springtime (see Kappel and Jennings, 2012), and the Mucklands contribute

excessive amounts of nitrogen and phosphorus which will mask septic nutrients (Longabucco and Rafferty, 1988; Richards etal 2011b). The point source of Allen Canning will also mask septic nutrients in this reach.

2) Septic nutrients on the reach of the main river between Glendale dam and Waterport dams will probably be diluted because of water input from the Erie Canal which introduces 225 cfs every day of the canal's navigable season (March through the end of October). This period overlaps the low flow time period of the late summer. The time period when septic leachate might be a problem. Note that there is some dispute over this. Longbucco and Rafferty, 1988 concluded that Erie Canal inputs were not important in diluting waterquality in this reach, and suggested that biological uptake in Lake Alice is responsible for the drop in dissolved Nitrogen. We do not doubt their interpretation that nutrient sequestration is indeed taking place, but based on a water quality study of Erie canal input at Glendale Dam conducted by (Fallot, 2011), which shows the nutrient concentrations in the Erie Canal being lower than Oak Orchard River, and updated information from the Canal Corp on the volume of water being introduced into the river from the canal, we conclude that some dilution HAS to be taking place just from a mass balance perspective. It should be noted that the constant value of 225 cfs for Erie Canal input did an excellent job of calibrating water balance for the river (see Figure 8 of Richards etal, 2012a).

3) Modelled flows in the main reach of the river between Waterport Dam and its outlet into Lake Ontario (Point Breeze), are even greater than the reach discussed above, suggesting that the septic field leachate are also probably diluted along this reach. This is supported with discharge data taken by boat at the end of the river.

4) High density clusters of septic fields in the south are problematic because they are located on first order streams with low flows. These clusters occur from houses built along Batavia Elba-Townline, Oak Orchard Road, and Lewiston Road at the base of the Onondaga escarpment (**Figure 10a-b**). In the late Summer and early Fall, contributions of groundwater to these streams from the Onondaga escarpment are probably minimal because of the large seasonal drop in the water table that takes place in this formation (see Kappel and Miller, 1996; Staubitz and Miller, 1987; Richards et al, 2010). As a consequence some of these streams are ephemeral, so leachate may in fact be the dominant fraction of water in the dry season. Clusters also occur in a first order unnamed tributary of Binningstool Creek (at the intersection of Judge Rd and Knowlesville Rd; **Figure 10c**) and in a first order tributary in South Alabama (**Figure 10d**). This could be important for the phosphorous TMDL of the southern portion of Oak Orchard Creek that is ongoing.

6) High density clusters of septic fields in the north end of the watershed (Marsh Creek and tributaries) are likely important because they are numerous and modelled tributary flows are low (**Figure 11 a-c**). This was confirmed by discharge observations in Beardsley Creek made to calibrate the model. Some of these leach fields are located within the area of the watershed where backwater effects from lake level changes may be influencing flow. At times of high water table, this will reduce the velocity of flow in the channel causing septic leachate to linger

at longer residence times. Many of these leach fields occur from houses along Roosevelt Highway and East Kent Rd.

7) A high density septic field cluster occur in a first order tributary at the intersection of Lockport and Albion Rd. This reach contains no less than 9 leachfields within the 200 meter buffer. The reason for this is Albion road is subparallel to the stream reach and a close distance (145 meters) away from it. Another high density septic field cluster is located along a first order tributary near the intersection of Gainsville Rd. and Bacon Rd. One of these septic systems is located only 17 meters away from the tributary (**Figure 12a**). A high density septic cluster occur on a first order tributary where Main St forks into Oak Orchard Rd and Quaker St. Although only three septic systems are present, one of them is 26 meters from the stream (**Figure 12b**).

Please note that these inferences only consider the importance of septic contribution to nutrient concentration within individual stream reaches. ALL septic field nutrients will ultimately pass through the watershed system and contribute to watershed fluxes, whether they are diluted or not. The only way they can be sequestered from the stream network is through biological uptake (nutrient "spiraling", see Chapter 13 of Allan and Castillo, 2007). Longabucco and Rafferty, (1988) analyzed the nutrient balance for several segments of the main stem of the river and concluded that a significant amount of nutrients (25% of the dissolved phosphorous) was sequestered between Glendale dam and the downstream end of the Waterport Pond.

Are DNA based tracers a viable approach for tracking leachate from individual systems

The experiments demonstrated there are several problems that need to be overcome in order for DNA tracers to be practically used in this application. These are, false positive outliers (individual samples that contain an inordinate number of tracers in samples where we believe should not contain tracers), identification of the threshold between noise and actual presence of tracers, and comparability between analysis runs. These issues are interrelated and could be improved by adopting a more systematic approach of identifying the precise threshold of what number of tracers ("copies") in a sample actually constitutes the presence of the tracer. **Figure 9 b** shows the number of tracers identified for the same samples on two different runs. They are not only different in absolute value, but are also different in the direction of temporal trends. This is a problem, because increasing and decreasing trends in a time series are what we use to identify the location of the breakthrough curve. The samples in Figure were taken early in the experiment when it is unlikely that the tracer made it all the way through the groundwater flow path, and are interpreted to be "noise" from the analysis procedure. Our most successful set of experiment were the analysis runs for the Webster site, where samples taken near the end of the experiment contain numbers of tracers that are almost an order of magnitude greater than the samples shown in Figure. These samples are interpreted to be the first presence of the tracer in the stream and the location of the actual breakthrough curve. When all three runs of the Webster samples are combined, it appears that anything more than 250 tracers constitutes the actual presence of the tracer.

This difficulty of identifying the noise threshold of the procedure may help explain why we did not obtain any useful results from the Rush-Mendon Rd. experiment. From the EC results, it appears the entire breakthrough curve was only sampled with two samples, and the peak was missed completely (our sampling interval was too large). This is not enough samples to identify the noise threshold for the runs. The experiment should be repeated with a shorter sampling interval.

The results from the tracer experiments are therefore mixed. The Rush-Mendon Rd. site, despite being a site where septic fluxes should be large and measurable (< 100 feet distance from the leach field to a water body, high slope, thick clay layer with perched water within 2 feet of the surface), DNA tracers were never observed. But there were increases in EC in two of the wells just after the injection implying that some of the NaBr solution passed through the system. This result underscores the importance of choosing the right sampling interval for conducting the tracer test. Enough samples of the breakthrough curve must be taken in order to identify the signal to noise threshold of the DNA analysis procedure. The Webster site was much more promising, the data shows the start of a break though curve 32 days after the start.

There is another issue associated with tracer experiments on septic systems that should be discussed, though we do not think it is relevant in this set of experiments. This is the importance of water use related to lifestyle on the success of the tracer test. If the people are not using much water in their day to day activities, not much water will leave the tank, and when it does, it could take a long period of time for this to happen. New septic fields require a 1000 gallon minimum size tank, which will require a lot of water use for overflow to take place. This of course, adds an unknown amount of time to the residence time that the tracer takes to go from the leach field to the watershed outlet. An overview of septic tracer tests by Jarrett (2015) discuss how complicated they can be.

OUTREACH

This research generated two products that may be useful to watershed decision makers. A GIS shapefile was created for all septic fields mapped in the watershed. It should be pointed out that this is not every septic fields in the watershed. This shapefile includes the soil type that each leachfield is located in, and whether the soil has any unsuitable characteristics for septic system use (high slope, perched water table, slow permeability, frequent flooding, shallow bedrock or contains muck). The shapefile also includes whether the system is in *directly connected*, or *internally-drained* topography. A rectified JPG map of high-density clusters of septic fields was also prepared. These products were distributed to watershed decision makers; Soil Water Conservation Districts of Genesee County and Orleans County, NYS DEC Region 8, and the Genesee and Orleans County Department of Health. These products may also be obtained for free from the digital commons at the College at Brockport, or by contacting the lead author of this report.

This research project helped Brockport's and Cornell's teaching and research mission in several tangible ways. The study supported the following four graduate students in their post graduate educational experience, Marine David, Nicole Derose, and Michael D. Rodgers at the College at Brockport, and Christine Georgakakis at Cornell University. The Rush Mendon Rd.

project site was also used for two laboratory exercises in our undergraduate and graduate hydrology class. Results from this study were presented to County Department of Health personnel throughout New York State at their April 2014 Minnowbrook conference in the Adirondack Mountains. The results of the study was also presented to a private conference of scientists at Pictometry International.

CONCLUSIONS

We have effectively used Pictometry Oblique Imagery to map septic fields in Oak Orchard watershed. These are not all the septic systems in the watershed, however based on our quality control work, we believe it is the majority of the systems with leach fields. The approach had issues with canopy cover and shading. Mapping of systems without leach fields is not possible. Raised septic fields are identifiable from 1 meter resolution hillshades developed from LIDAR data. Important hotspots of septic inputs into the Oak Orchard stream system, based on stream order, discharge, and septic field density considerations include tributaries along Batavia-Elba Townline Rd., tributaries of Marsh Creek, and tributaries near the intersections of Alleghany and Lockport Rds, Judge Rd and Knowlesville Rd., and Lockport and Albion Rd. Considerable numbers of septic fields occur along Lake Alice in the main stem of the river, however this stretch is probably diluted by water input from the Erie Canal at the Glendale Dam. Of the 1277 septic fields mapped in the watershed, 4.2% of the septic fields are located closer to the stream network than what New York Dept. of Health guidelines suggest minimum separation distance should be. Most of the septic fields (88%) are constructed in soils where at least one or more of the following issues exist (presented in decreasing order of importance): Seasonal or prolonged perched shallow water table, slow permeability, shallow bedrock, slope, contains muck or classified as soil hydrologic group “D”. The jury is still out on the effectiveness of DNA tracers for tracking septic leachate. Our results suggest it will work provided that sufficient samples are taken to assess the threshold count of tracer particles that constitute actual presence of the tracer. Further experiments need to be conducted to develop protocols that identify the threshold of noise in the analysis technique.

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TABLE 1 *Quality control statistics by Township. Others include systems that are not mappable (systems without leach fields) and septic fields that postdate the most recent year of Pictometry Imagery.*

Township	**Yates**	**Carlton**	**Kendall**	**Ridgeway**	**Gaines**
Septic fields mapped	71%	74%	75%	78%	66%
Presence of trees or shadows	10%	8%	11%	11%	10%
Others	6%	6%	4%	5%	15%
Couldn't be spotted	12%	11%	11%	8%	10%

Township	**Alabama**	**Oakfield**	**Elba**	**Byron**	**Bergen**
Septic fields mapped	78%	67%	75%	81%	75%
Presence of trees or shadows	3%	9%	3%	3%	0%
Others	16%	0%	16%	13%	0%
Couldn't be spotted	3%	24%	6%	3%	25%

Township	**Albion**	**Murray**	**Shelby**	**Barre**	**Clarendon**
Septic fields mapped	67%	76%	76%	73%	77%
Presence of trees or shadows	2%	5%	9%	10%	7%
Others	12%	10%	3%	0%	13%
Couldn't be spotted	21%	10%	12%	17%	3%

Township	**Pembroke**	**Batavia**	**Stafford**	**Leroy**	**Tonawanda**
Septic fields mapped	73%	72%	74%	73%	na
Presence of trees or shadows	7%	9%	5%	9%	na
Others	15%	9%	14%	9%	na
Couldn't be spotted	5%	9%	7%	9%	na

TABLE 2 *Rainfall Equivalent Recharge Rates. Assumes proper septic field construction for a 3 bedroom house with newer fixtures. Construction specifications in accordance to Appendix 75-A, Regulations for Septic Field Design. NYSDOH (2010). Note, a 1 year design storm in Western, NY is between 1.8 and 2.1 inches per day. Septic fields not only provide a source of nutrient pollution, but also a hydrologic mechanism to move it to the stream or lake.*

Perc Test (min/in)	Area (sq ft)	Equiv. Rainfall (in/day)
1 to 5	275	1.9
6 to 7	330	1.6
8 to 10	367	1.4
11 to 15	413	1.3
16 to 20	471	1.1
21 to 30	550	1.0
31 to 45	660	0.8
46 to 60	733	0.7

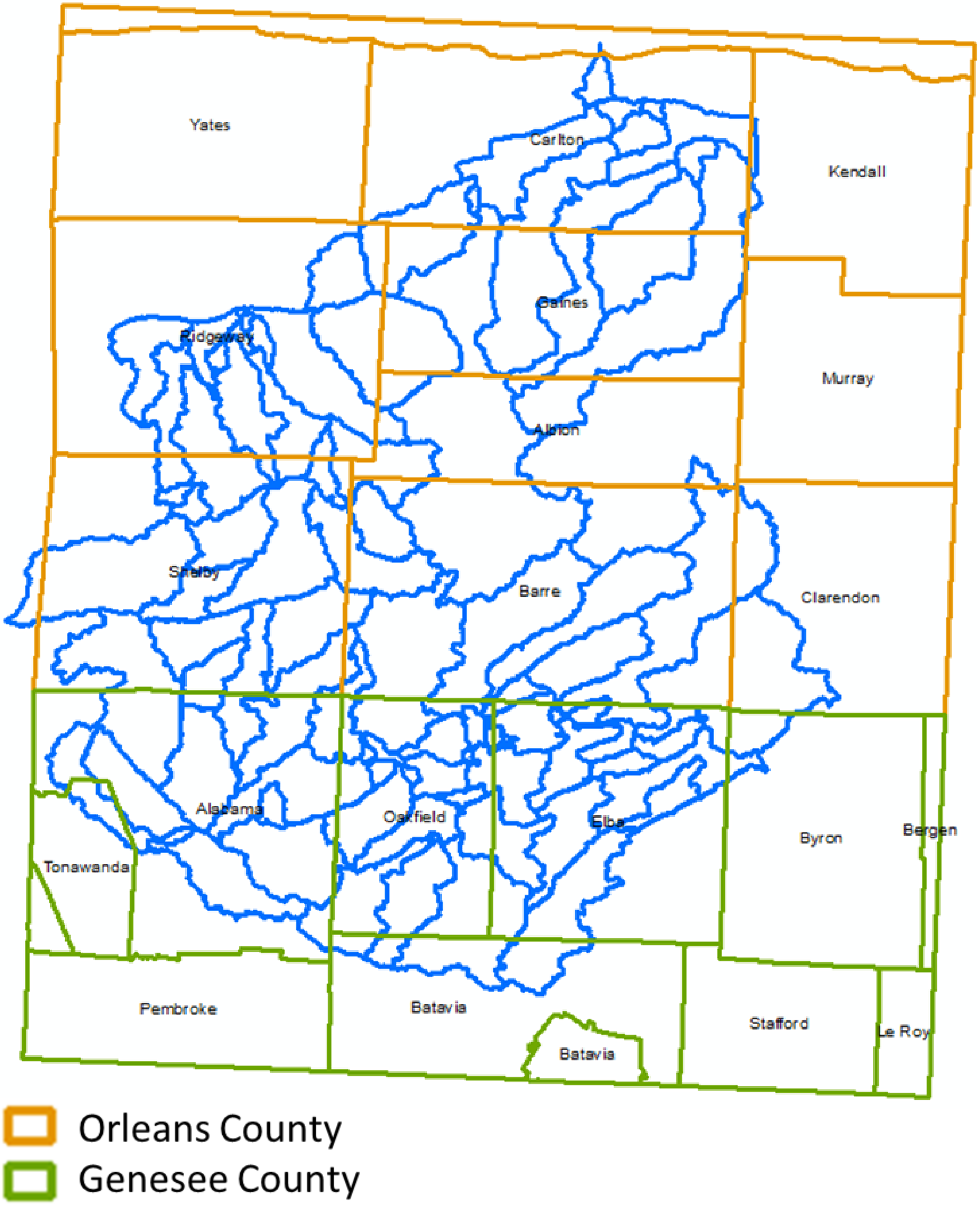


FIGURE 1 Map of study area showing Oak Orchard watershed and the two county region where septic fields were mapped. LIDAR data were available in Genesee County.

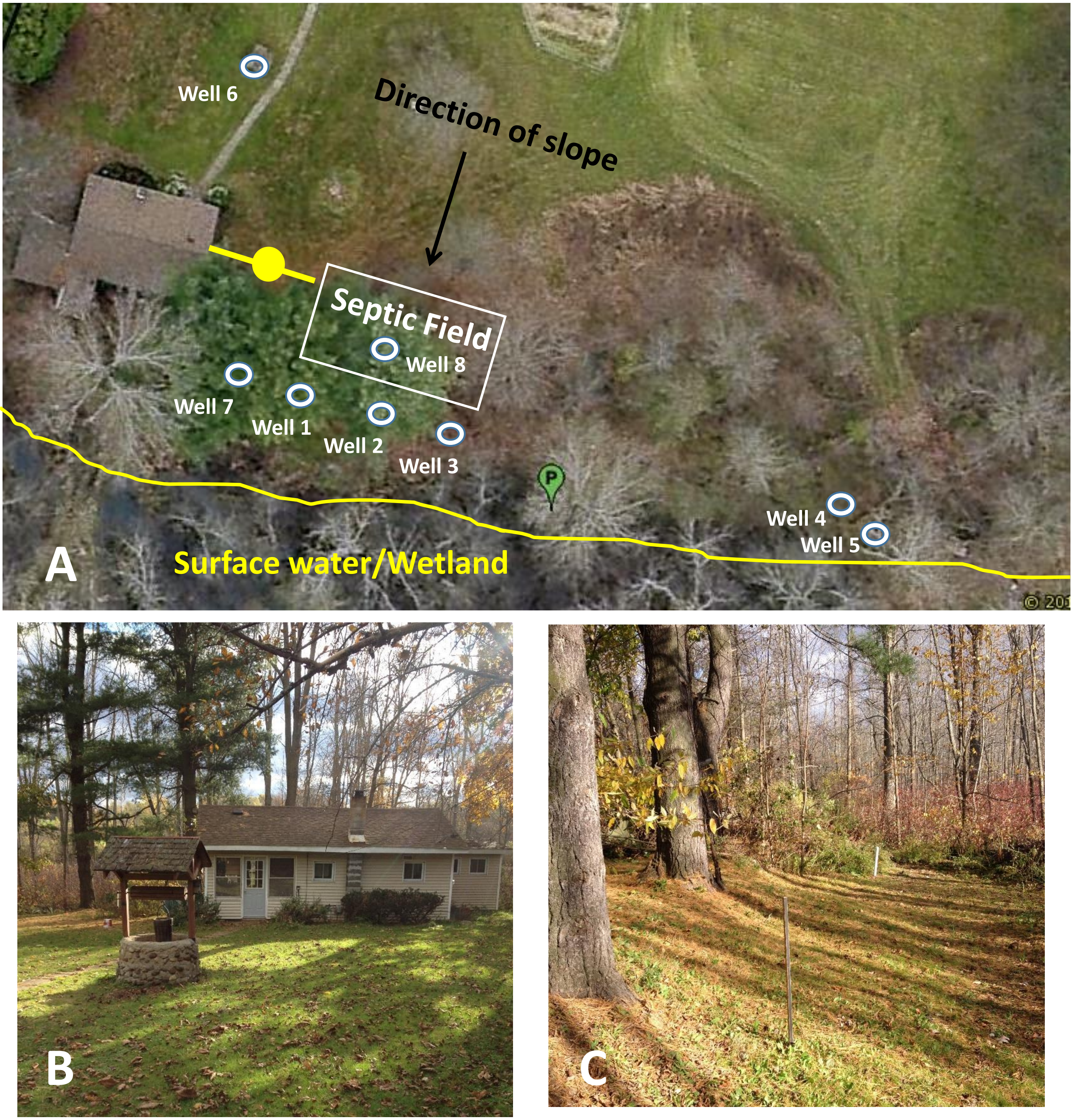
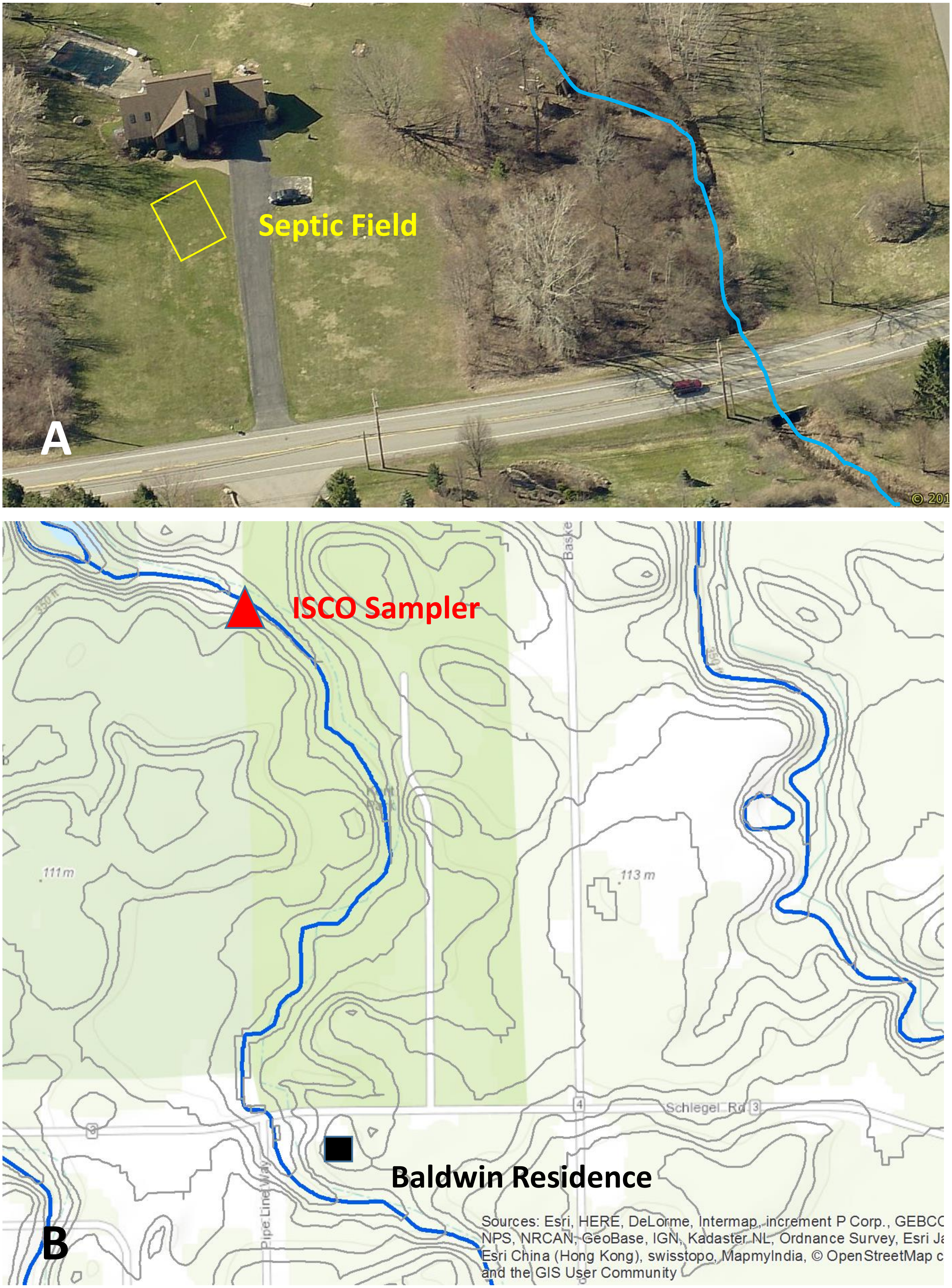


FIGURE 2 Rush DNA Tracer Experiment site. A) Pictometry Image of site showing sampling wells and suspected location of leachfield. The wetland to the south is the large instream wetland associated with Honeoye Creek. B) Photo of one-bedroom house that was the subject of the experiment. The "wishing well" in the foreground is the well 8 that was used to identify EC of groundwater upgradient (and not impacted) by the septic system. This, and wells 4, 5, and 7 were used as controls. C) Photo of high slope just downgradient of the leachfield. High slope, short distance to a standing body of water, thick clay layer within two feet of the surface, and evidence of an eroded gully originating from where the leachfield is, makes this site a prime candidate for the situation where septic leachate will make it to the stream.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Ja Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap c and the GIS User Community

FIGURE 3 Webster DNA Tracer site. Thirty two days after the tracer was flushed down the toilet at the Baldwin Residence (Black square; A), a breakthrough curve was observed at the sampling site located about a kilometer down stream (red marker; B).

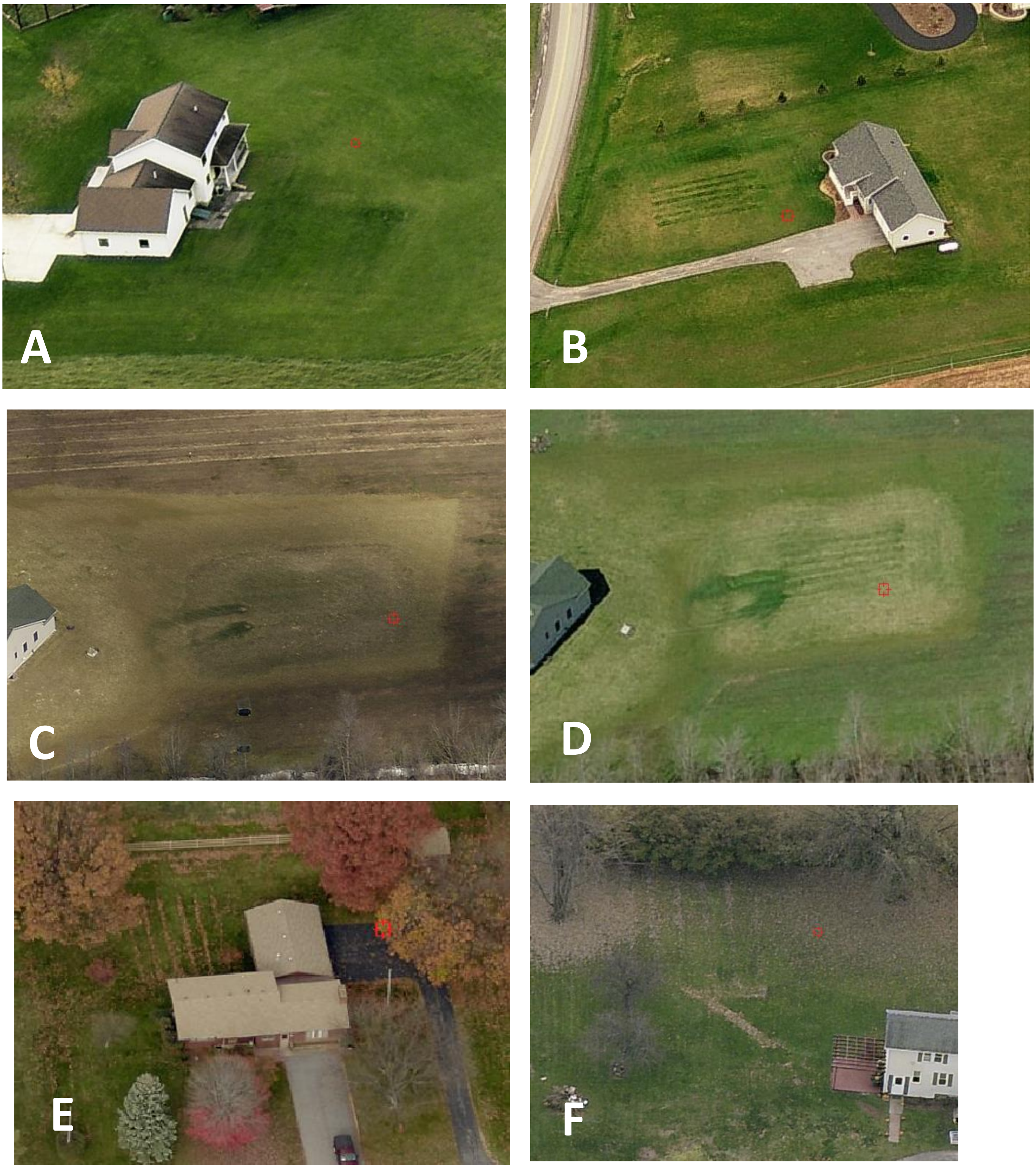


FIGURE 4 Views of septic leachfields in Oblique imagery. A) Example where individual leachlines are darker than surrounding areas. B) Example where the leachfield appears darker than surrounding grass. C) and D) same leachfield taken in March, and April. Note the difference in shading after the growing season kicks in. E) and F) leaves accumulating in microrelief associated with leach field.

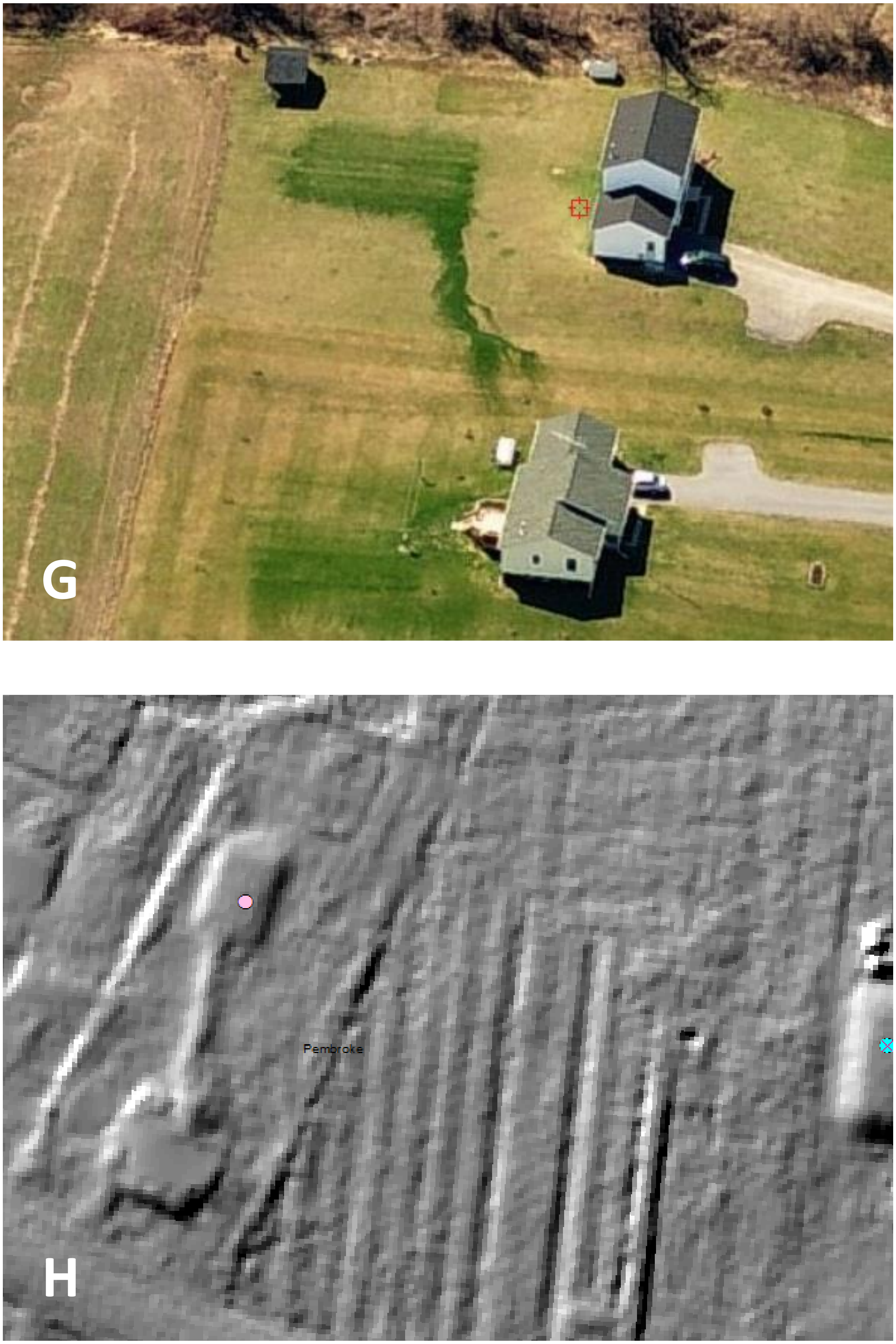


FIGURE 4 (continued) Views of septic leachfields in Oblique imagery. G) Failed Septic system that appears to be short circuiting. H) Hillshade from LIDAR derived topography showing a raised septic system connected to a house.

Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

FIGURE 5 A total of 3207 septic fields were identified and mapped from Pictometry Oblique Imagery.

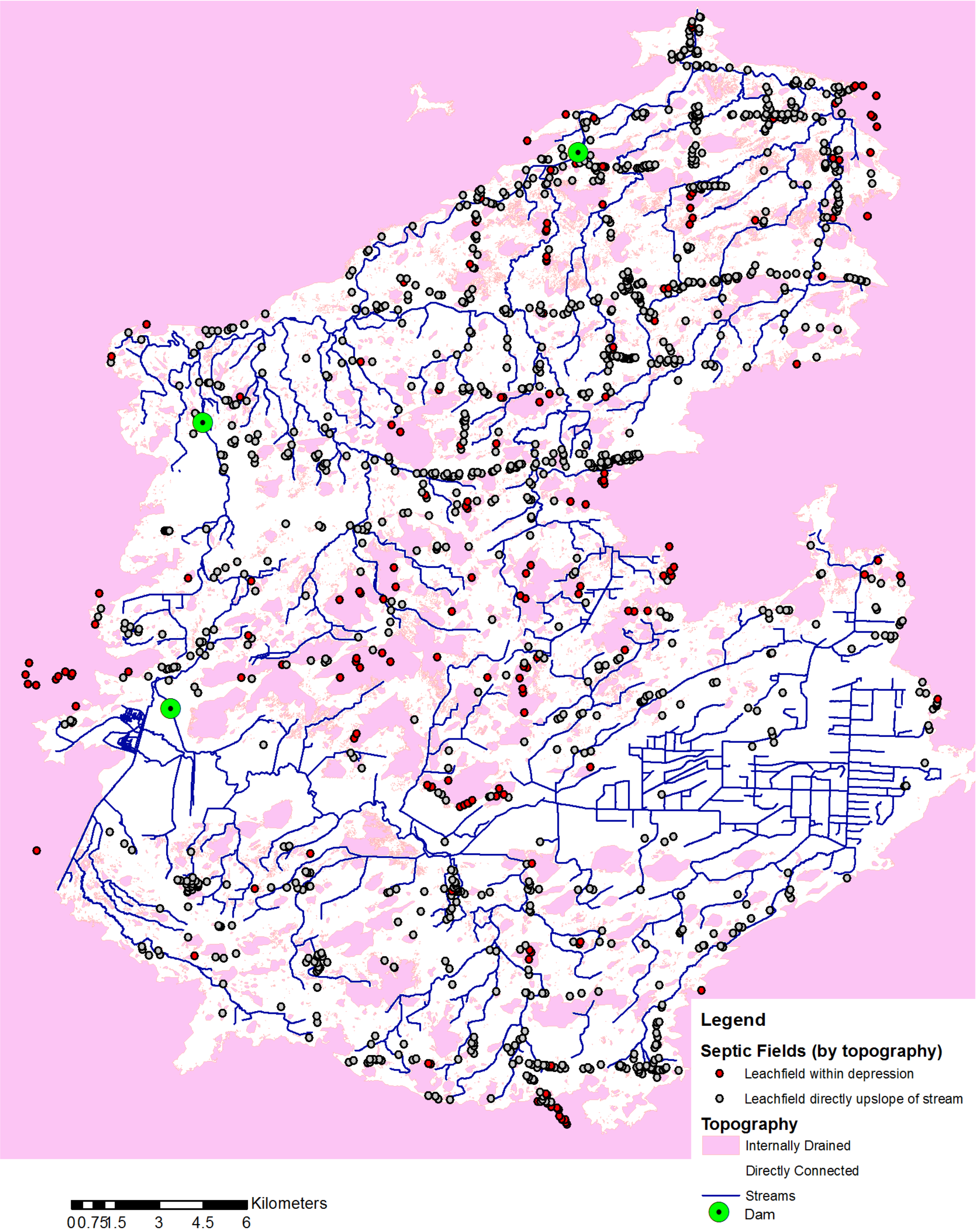


FIGURE 6 A total of 1277 septic fields were mapped in Oak Orchard watershed. 182 of these systems are located in internally-drained areas that are topographically isolated from streams.

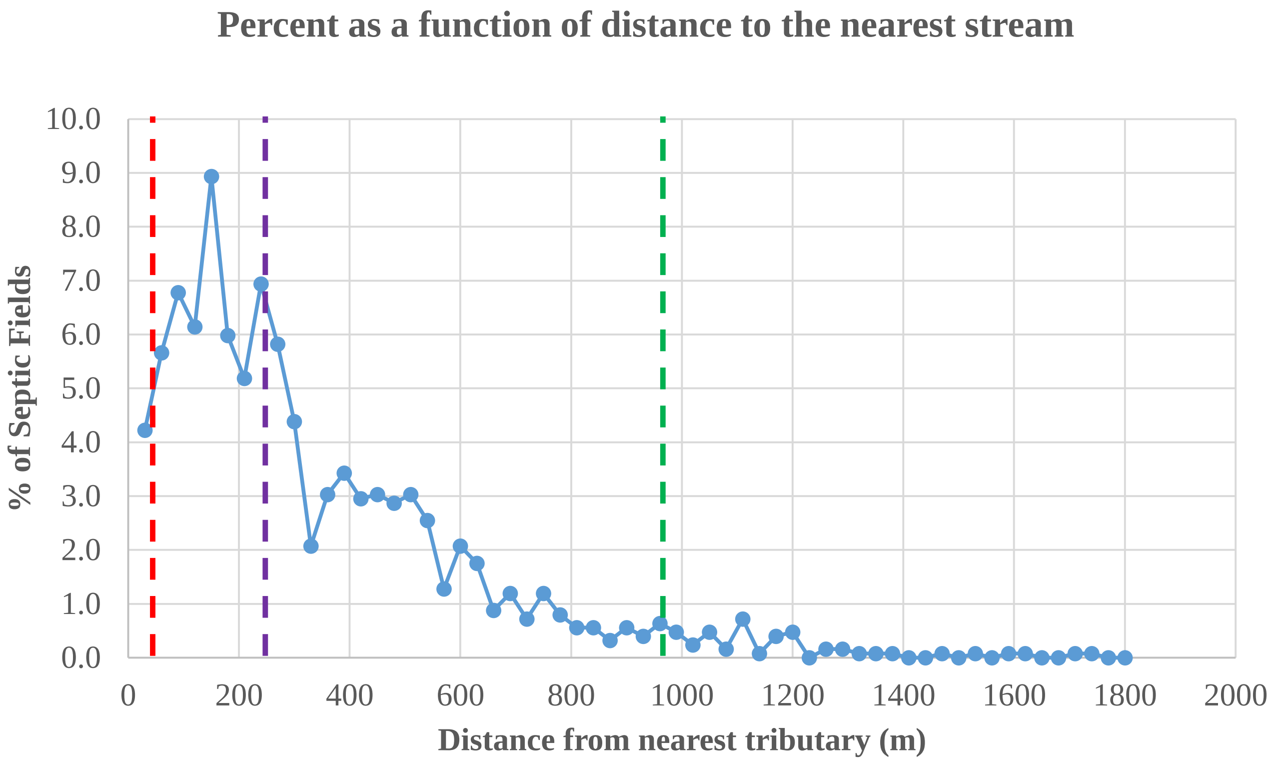


FIGURE 7 Probability density function of the % of total septic fields located within a distance from the nearest stream. 4.2 % of the septic fields were located within 100 ft of the closest stream (red line). This is below the minimum setback distance required by Department of Health guidelines. Fifty and ninety percent of the septic fields were located within 240 and 960 meters of the nearest stream (purple and green lines).

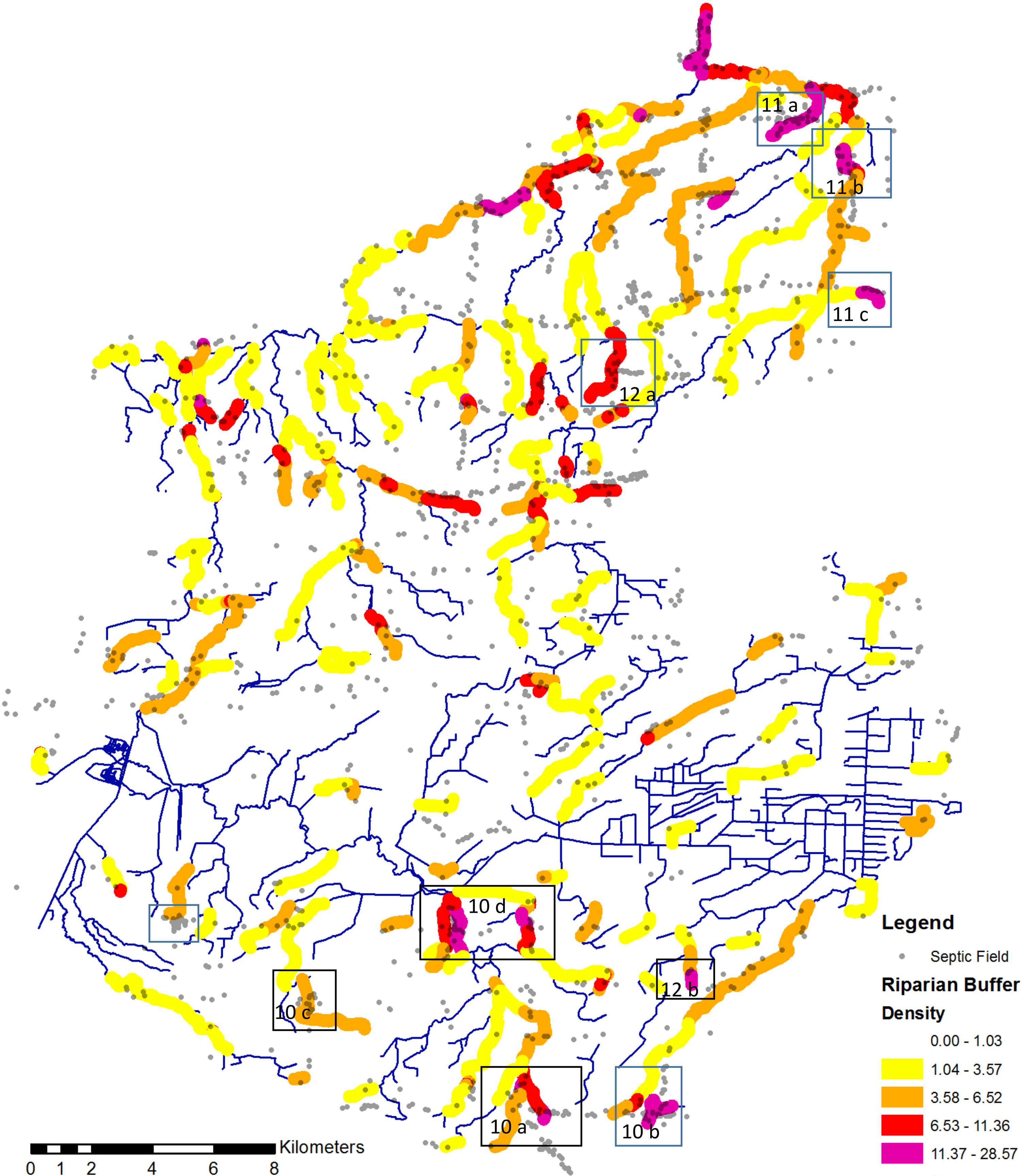


FIGURE 8 Septic field density within the 200 meter riparian corridor. Density expressed as number of septic fields per square kilometer. Higher densities of systems may indicate greater septic inputs during low flow periods. Rectangles are areas of concern, detailed maps of which are presented in Figures 10, 11, 12.

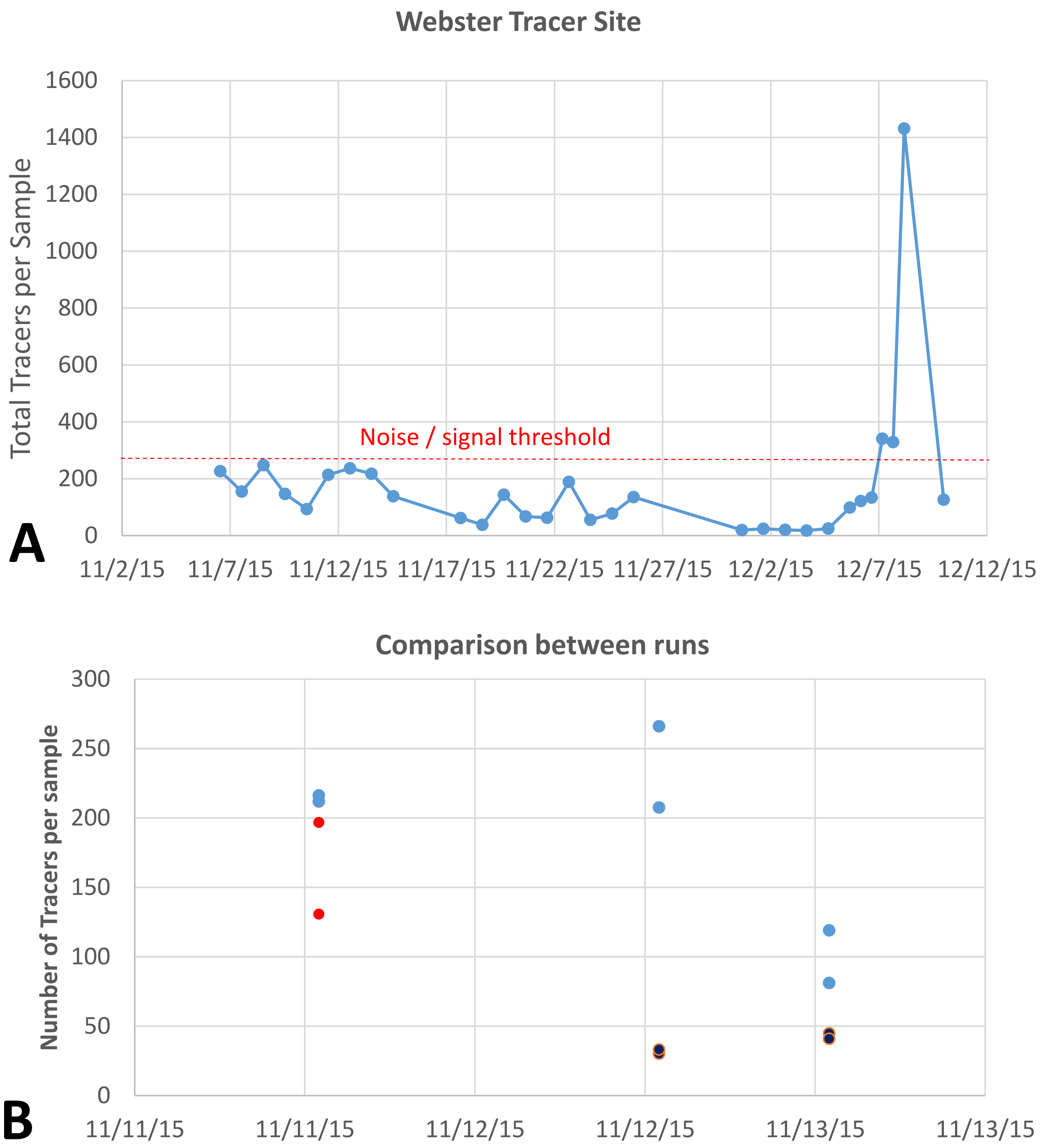


FIGURE 9 A) Total number of tracers determined per sample for the Webster DNA Tracer experiment. Counts above 250 are considered above the noise/signal threshold for the analysis procedure and represent the actual presence of the tracer. Above the 250 count threshold, the method is quantitative. The breakthrough curve arrived on 12/7/2015, 32 days after the tracer was introduced to the site. B) Comparison of runs for the same samples within the noise threshold. These samples were taken sequentially, note that the trends are inconsistent for each run.

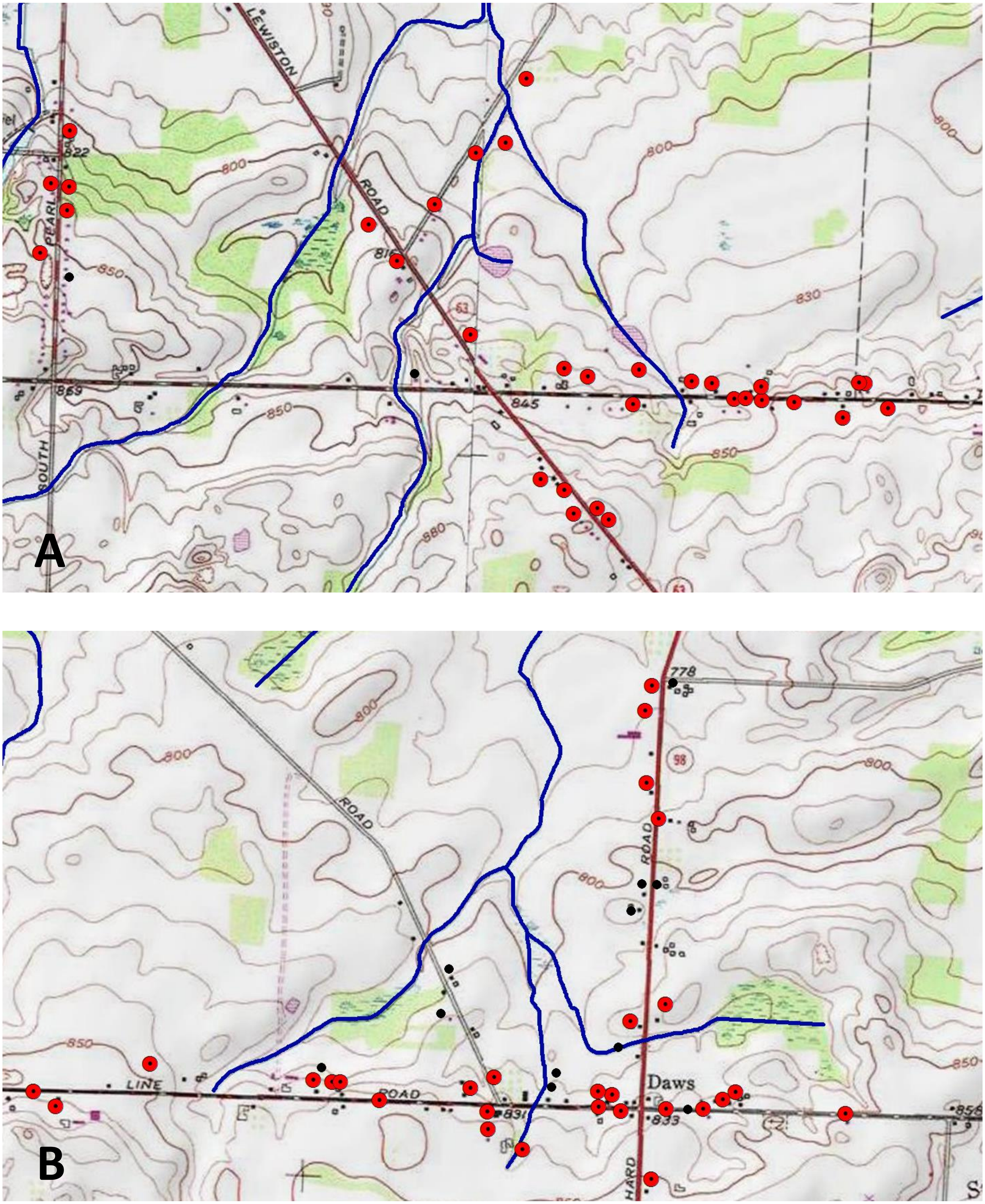


FIGURE 10 First order triburaties at southern end of the watershed with high densities od septic fields. A) In tersection of Oakfield Elba Townline and Lewiston Rds. B) Intersection of Oakfield Elba Townline and Oak Orchard Rd. These occur near the base of the Onondaga Escarpment.

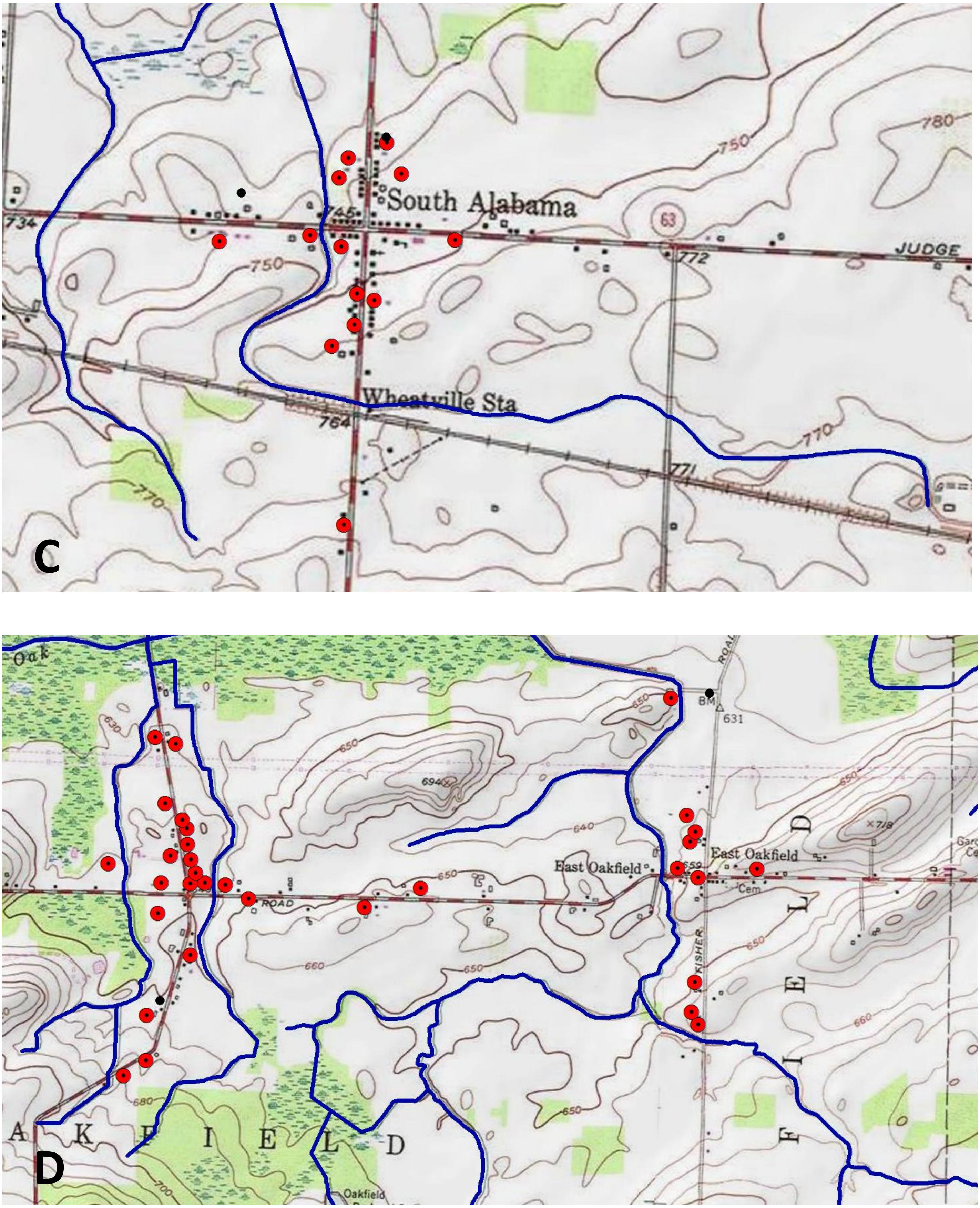


FIGURE 10 continued First order tributaries in southern part of the watershed with high densities od septic fields. c) First order tributary in South Alabama along Judge Rd. D) South Alabama.

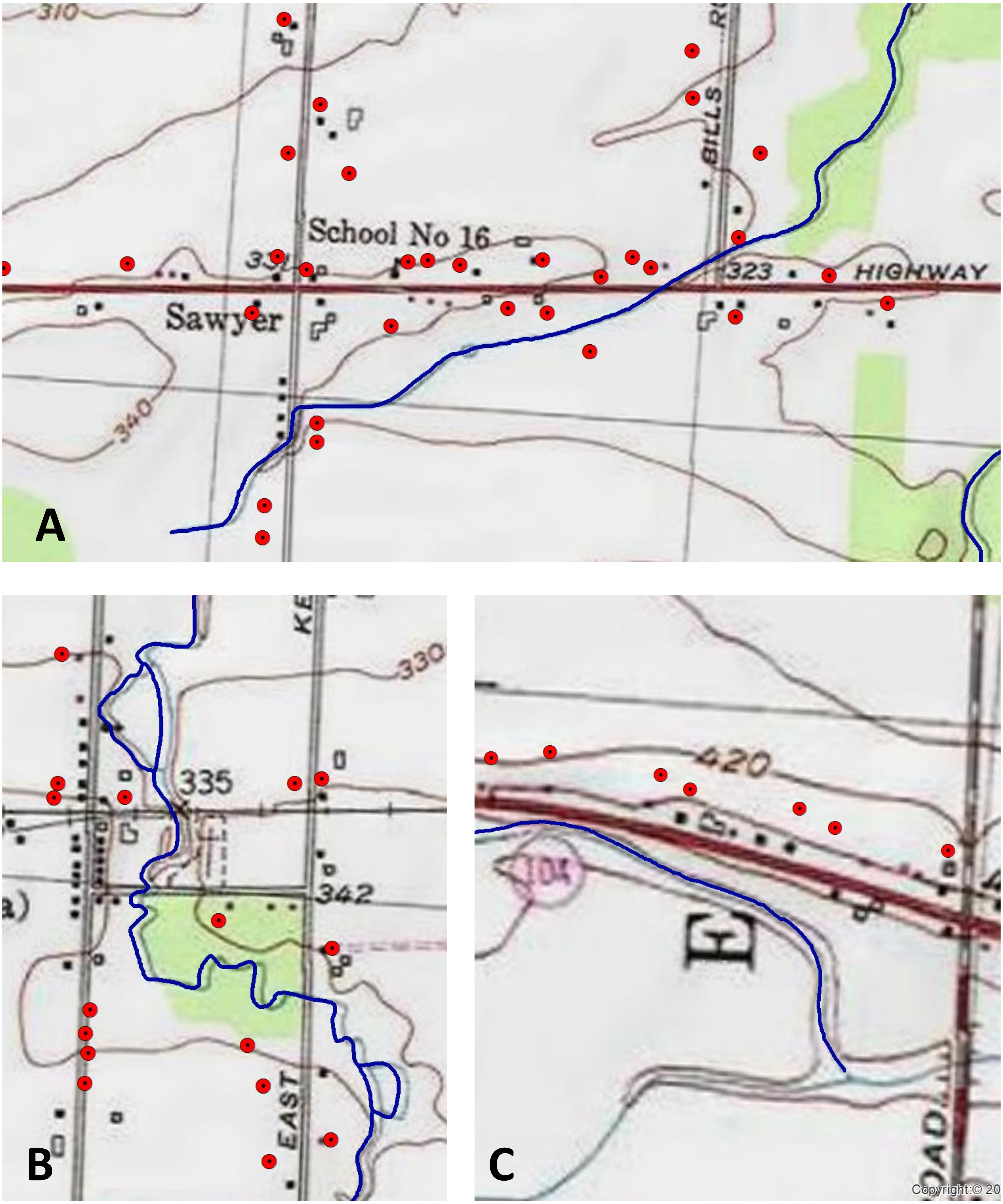


FIGURE 11 Areas of concern associated with Marsh Creek. A) Headwaters of Beardsley Creek with septic fields. Many of these septic fields are associated with Kings Highway. B) Septic fields along East Kent Rd. C) First order tributary near the junction of Route 104 and Transit Rd.

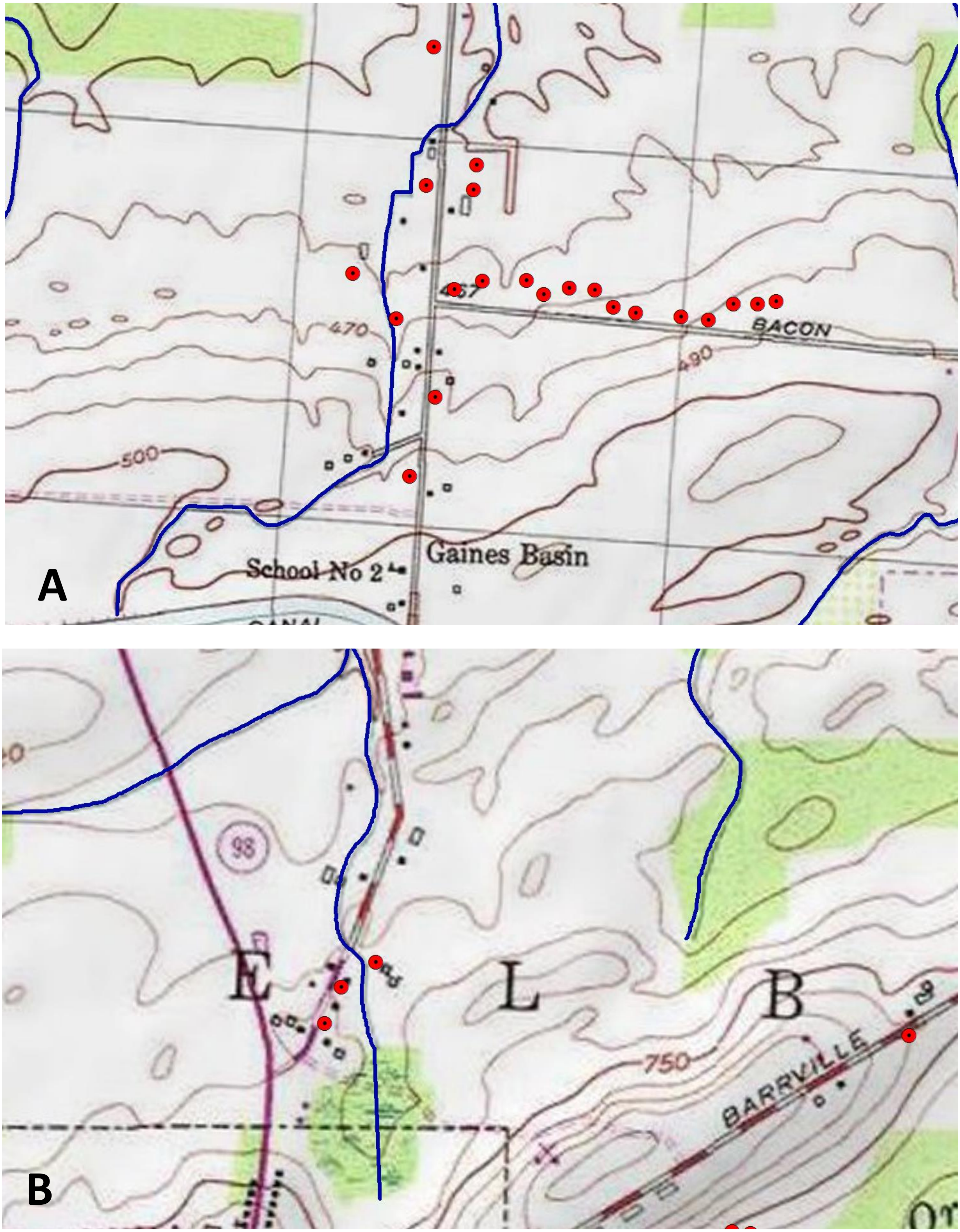


FIGURE 12 Areas of concern . A) First order tributary near the intersection of Gainsville and Bacon Rd.. B) First order tributary near Quaker St.

APPENDIX A

USING DNA TO TRACE WATER FLOW PATHS IN THE ENVIRONMENT

Why?

One of the most significant risks to water quality is "nonpoint" source pollution. This type of pollution is caused by pollutants flowing into stream and lakes with storm runoff or groundwater. It is challenging to determine the source of the pollutants. DNA-based tracers provide a tool for determining which potential pollutant sources are likely contributors to a particular water body.

Algal blooms like this one in Seneca Lake are often the result of excessive phosphorus contamination. Potential sources include fertilizers, animal manure, and septic systems.

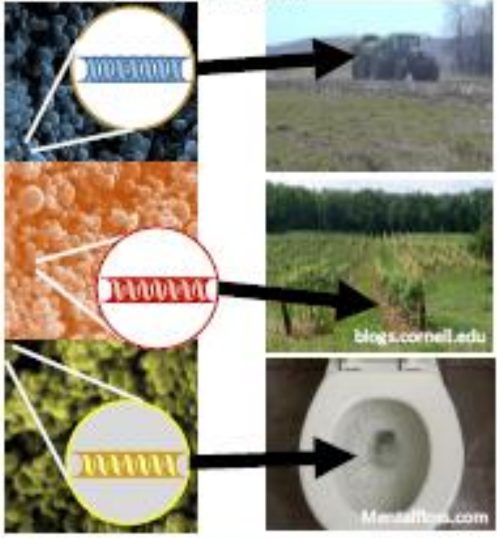
Photo Credit: Finger Lakes Daily News . com

How does it work?

Because of DNA's unique composition, we can fabricate millions of unique DNA strands that are distinguishable from one another. This means we can introduce tracers to multiple potential pollutant sources at the same time. Each batch of DNA tracers has its own unique sequence of several hundred chemical bases, often identified by the letters A, T, C, and G.

Then we regularly sample the stream or lake where there is a pollutant problem. The samples are taken back to the Cornell Soil and Water Lab and analyzed for the different tracers.

Microscope images of the tracers. The DNA is wrapped-up in tiny plastic-like balls to protect it from the environment. The colors here represent different tracers.



An analysis called qPCR allows us to count how many of each kind of tracer is in our sample

Collecting a water sample from Fall Cr.

Is it safe?

There is a curious fear of DNA. Every time we toss an apple core into the weeds or spit or brush dandruff flakes off our head we are putting DNA into the environment. In the case of our tracers, we are using **synthetic DNA**, which has no biological code embedded in it, so it is safer than the DNA in your spit. By contrast, **recombinant DNA** is biologically available … that is what was used in Jurassic Park, but not here.

Also, the protective coating is made out of the same material as biodegradable cups.

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