THE SPATIAL RELATIONSHIP BETWEEN SEPTIC SYSTEM FAILURE AND ENVIRONMENTAL FACTORS IN WASHINGTON TOWNSHIP, MARION COUNTY, INDIANA

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Underground septic systems thrive or fail based on the relationship with their local environment. This paper explores ways environmental variables such as soil type, tree roots, degree of slope, and impervious surfaces affect on-site wastewater treatment systems. It also discusses the effects each of these variables may have on a septic system, and the resulting impact a compromised system may have on the surrounding environment. This research focuses on an approximately 20 square mile area of central Washington Township in Marion County, Indiana. This area of central Indiana contains a large septic system owning population in a sampling of different environments such as wooded areas, hilly areas, and a variety of different soil types.

Daniel P. Johnson, PhD, Chair

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Introduction

This paper explores the relationship between septic systems that have failed in Washington Township, Marion County, Indiana and four of the environmental factors that could have contributed to their failure. A model of the four variables likely to affect the life of a system will determine whether a pattern of septic system failure emerges when these risk factors are present. Knowing which environmental variables associate certain neighborhoods with a high risk of failure is important. The city, county or homeowners' associations, attempting to determine whether it is worth the cost to run sewer lines to a given area, can use the information to make that assessment. Additionally, property owners with a pre-existing septic system will be able to make more informed decisions related to the maintenance of the system.

Identifying spatial patterns associated with the failure of septic systems by comparing related variables such as soil type, slope, impervious surface, and tree root invasion, can provide valuable information to the health department, city utilities, and the owners of private on-site sewage disposal systems. It is common for people to neglect their water treatment system until they're faced with an unignorable problem. Septic systems maintained properly, in favorable environments, have a usable life expectancy of at least twenty years (Vogel, 2005). Conversely, responding to symptoms of an already neglected or damaged system can be expensive (Lawson, Burrows 2009). For example, when a public body of water is contaminated by an unknown source of pollution, the State Department of Health has to spend resources rectifying the problem. If the damage is contained on private property, the owner may not have the knowledge or resources to properly identify and manage the problem. For these reasons, identifying and modeling variables that lead to septic failure, on a neighborhood level, can be useful in mitigating or preventing future septic system failures.

There are approximately 800,000 on-site sewage disposal systems currently in use in Indiana, with county health departments issuing 15,000 permits per year for new installations (http://www.in.gov/isdh/23283.htm). With so many systems in use, proper maintenance of them is important. Failures are expensive, not only financially, but they also contribute to pollution, potentially causing long lasting damage to the environment (US EPA, 2015). Malfunctioning septic systems have a profound impact on local bodies of water (Conn et al 2012). Undigested wastewater from a failed septic system can enter these bodies of water and cause nutrient pollution. Nutrient pollution occurs when an overabundance of nutrients, most commonly nitrogen and phosphorus, enter a body of water and act as fertilizer for algae and other aquatic plant life. A short-term increase in nutrients, such as nitrogen and phosphorus, can have a profound impact on vegetation (He et al, 2013). When this plant life dies, the decay process depletes the oxygen levels in the water, causing hypoxia, or dead zones, where aquatic animals are unable to survive. Extreme algal growth can clog gills of aquatic animals. It can also block sunlight, making the environment less hospitable (US Department of Commerce, 2015).

There are direct effects to humans as well. Aside from the financial effect that environmental damage can have on homeowners and communities, excessive nitrate concentration in drinking water can cause health problems such as methemoglobinemia, or blue baby syndrome, a blood disorder in which an anomalous amount of methemoglobin is produced which prevents blood from releasing oxygen into the body (Wang, 2013). It is because of these health risks that any new construction within a “reasonable distance” of a public sewer must connect to the sewer (in.gov).

Homeowners are often unaware they have a problem with their septic system because the symptoms can be subtle at first. The two biggest problem areas are the septic tank and the drain field. A problem with the tank generally becomes evident when effluent backs up into the house or business. This occurs when an object, or an accumulation of objects, which cannot be processed by the system, ends up in the tank and creates a blockage that prevents water from escaping into the drain field. For this reason, septic tanks must be pumped or flushed occasionally to prevent an excessive buildup of scum and sludge. If a tank goes too long without being flushed, larger than normal amounts of these substances can be forced into the drain field, causing clogging of the perforations in the pipes that accommodate the distribution of wastewater into the ground.

This paper will explore four environmental factors that might negatively affect systems in Washington Township. The (1) first is tree root invasion. Root systems can work their way into the perforated pipes of the drain field and clog or break them (http://fremontcountywy.org/wp-content/uploads/2009/11/WhySepticSystemsFail.pdf). To further judge the sites of the failed systems, this study will explore three more variables that influence septic system longevity – (2) the slope of the ground at the site, (3) the percentage of impervious surface at the site, and (4) the soil type. For the purposes of this research, this study will focus on a large subset of Central Washington Township.

Geographical Context

The study area (Figure 1) is Located in Washington Township. It is one of nine townships that make up the city of Indianapolis, Indiana. At the time of the 2010 census, the population of Washington Township was 132,049 with a population density of 2700 people per square mile. It was first settled in 1819. Since then, the neighborhoods have preserved a large quantity of old growth trees and natural waterways. However, there has also been some change in the environment. There are areas where soils have been mined, creating retention ponds that can affect drainage. Also, expansive shopping centers have been built around large anchor stores, creating large areas of impervious surfaces. These urbanized and processed areas provide contrast to the better-preserved areas and make Washington Township a good area to study soils and the effects of impervious surfaces on septic systems. While parts of the area are serviced by the city sewer system, Washington Township still possesses a relatively large number of neighborhoods that use on-site wastewater treatment systems. Because of the large size of the datasets necessary for this research, I do not use the entirety of Washington Township. The study area for this paper is a subset of central Washington Township that represents a robust sample of the township as a whole.

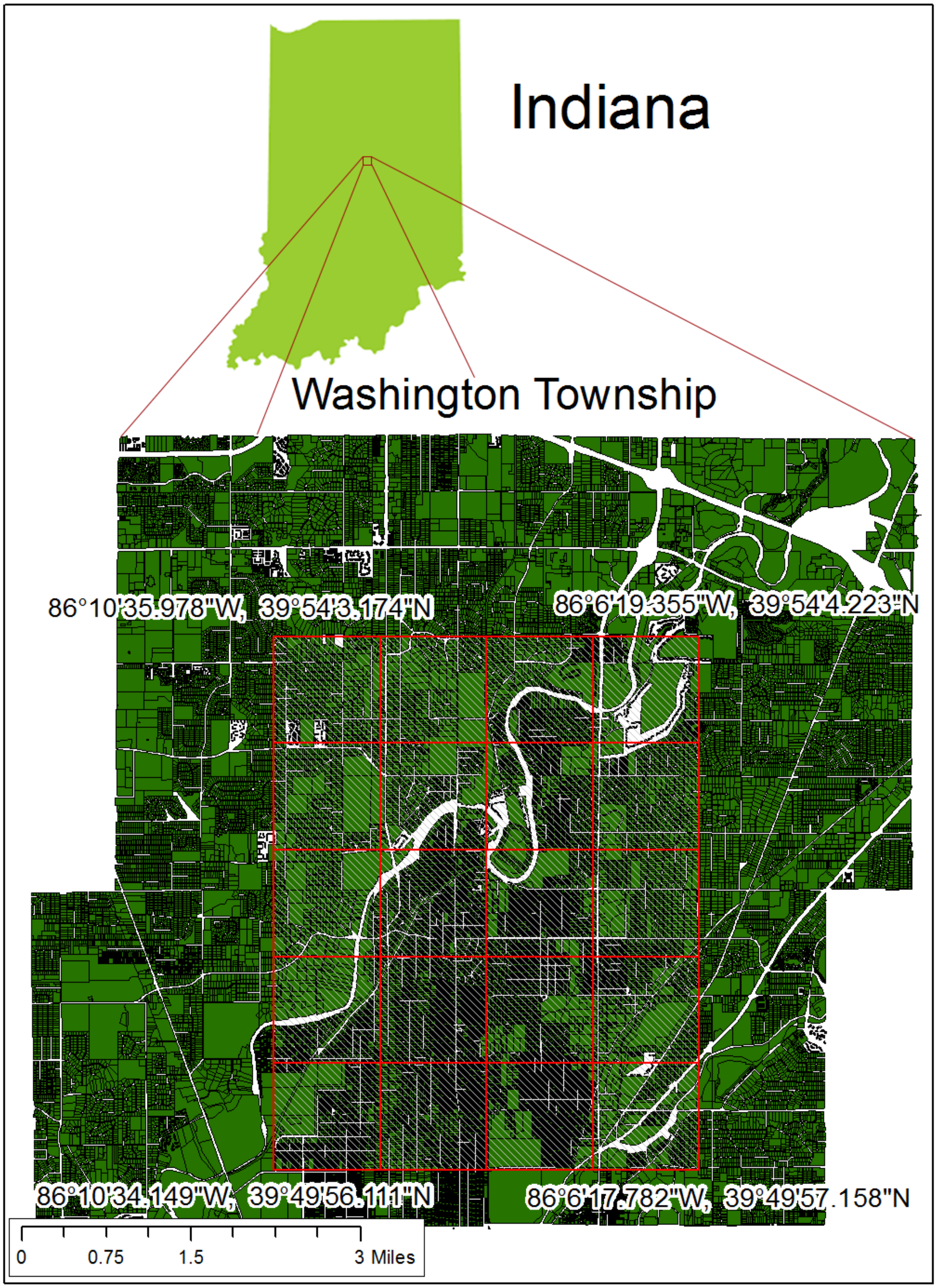

Figure 1. The Study Area Located Within Washington Township, Indiana.

Literature Review

A septic system is a self-contained wastewater treatment system, also known as an on-site sewage disposal system or on-site wastewater treatment system (Figure 2). It consists of four main parts: influent pipe, tank, baffle, and drain field. The water treatment process starts with the influent pipe. It carries waste from its point of origin, in a house or business, to a septic tank. A septic tank is a large watertight vessel buried in the ground that collects waste material flushed from the source. Scum is anything such as oil or grease that floats on top of the water, and sludge is solid waste that sinks to the bottom of the tank. Within the tank is a baffle, a partition with an opening below the water line allowing liquids to pass, but hindering the passage of both scum and sludge into the drain field. The remaining liquid exits the septic tank then enters the drain field, also known as the leach field or distribution field, where it is dispersed into the soil through perforated pipes (Figure 2) (Lawson, Burrows, 2009). Next, it filters through the soil where organic matter, bacteria, ammonia, and viruses process the remaining solids (Vedachalam, Hitzhusen, Mancl, 2013). What remains at the end of this progression is potable water that is safe to return to the environment.

A surprising number of septic systems are placed into unfavorable sites that do not meet the requirements for a successful system. For example, in Ohio, 25% of the residents are serviced by a private on-site sewage disposal system; while an area of only 6.4% of the state has conditions favorable to a septic system (Vedachalam et al, 2012).

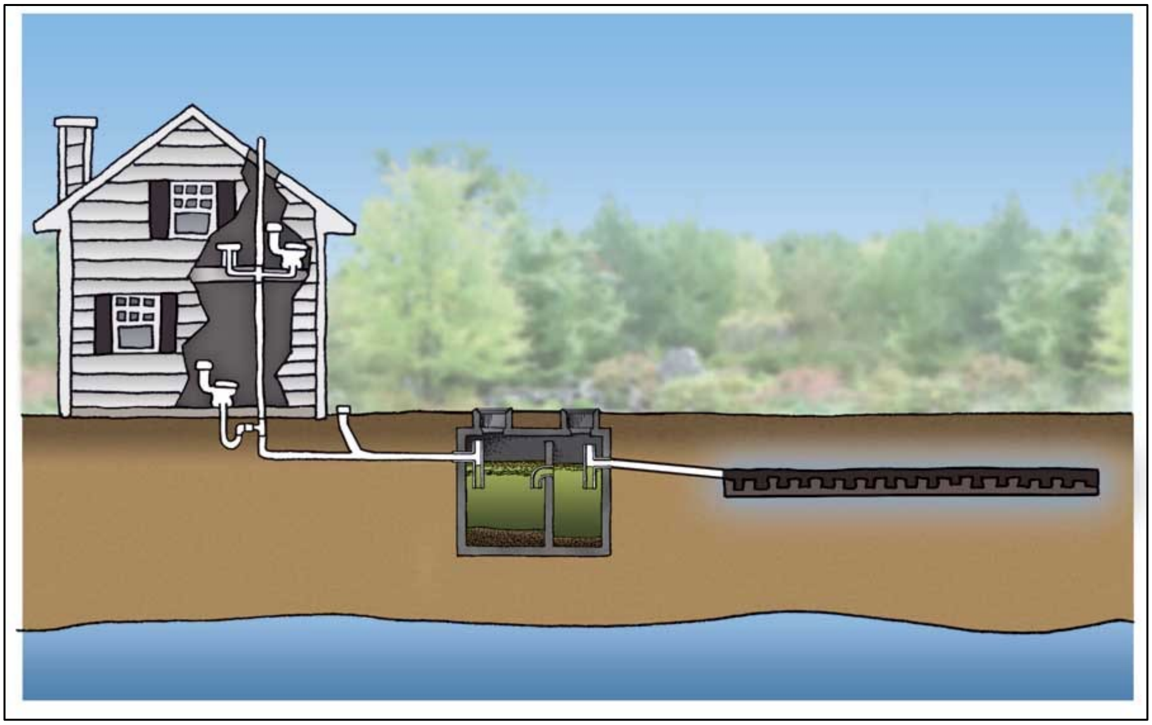

Figure 2. A Typical Septic System. Waste flow starts in the house and travels through an influent pipe to the septic tank where solids separate. The liquid proceeds to the drain field where they are dispersed into the soil.

Soil Types

Soil types provide both advantages and disadvantages for drain field owners to consider. The success of a septic system is related to the hydrological and biogeochemical properties of the soil in which it is installed (Beal et al, 2005). As the water filters through the soil, it encounters microorganisms in the soil, also known as bio-mat (Hui-Hu Yu et al, 2007). Bio-mat completes the purification process by digesting the leftover pollutants that pass through the septic tank.

The main characteristics of soils that affect the viability of a septic drain field are: proximity to a body of water, proximity to an impervious layer, permeability, and capacity. If a drain field is too close to a body of water, the wastewater will percolate into the fresh water body before being thoroughly digested by the bio-mat. If a drain field is too close to an impervious layer of calcareous glacial till, clay, or bedrock, it could get backed up and wastewater could percolate up to the surface instead of down into the water table. It could also traverse laterally, farther than it normally would, and prematurely reach a body of water. Permeability refers to the hydraulic conductivity of wastewater through the soil. If the soil is too coarse, and therefore permeable, wastewater could flow straight into the water table without being properly digested (Figure 3). If the hydraulic conductivity is too low, it will cause a backup. Capacity refers to the ability of a soil to hold water. There must be enough room between the grains of soil for the effluent being flushed to fit in the ground while it's filtering through the bio-mat. Otherwise, untreated wastewater will run-off or cause a backup.

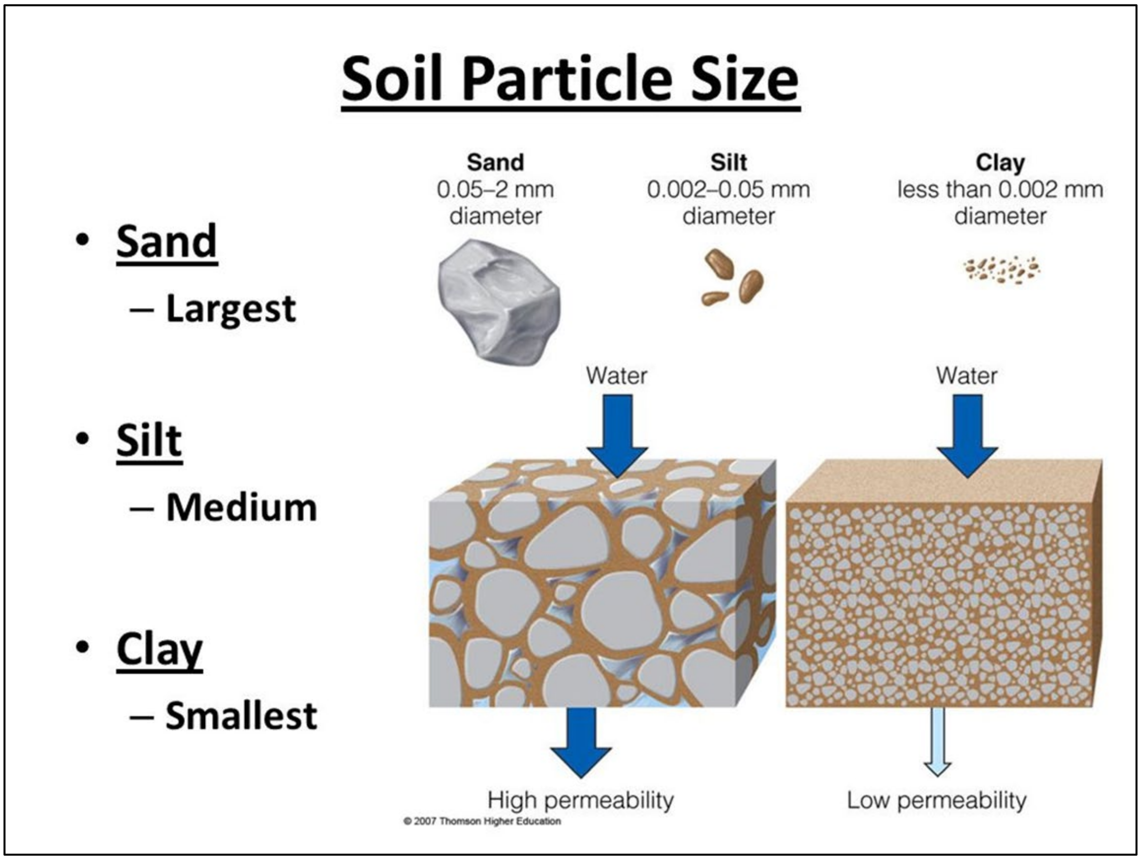

Figure 3. Soil Particle Size. Loose, coarse grained soils have higher capacity and more permeability than denser smaller grained soils such as clay.

A soil absorption system, such as a drain field, is most likely to drain well in a soil type with high hydraulic conductivity and in an area not prone to flooding. An example of a soil type with high hydraulic conductivity is Miami. Miami soils are well drained, but not so coarse that they release unprocessed effluent into the water supply. Miami soils occur on higher ground, so neither flooding nor proximity to an impermeable layer, such as bedrock and glacial till, is likely to cause a problem with septic systems. Fecal coliform bacteria is transported laterally, by not only floodwater on the surface of a saturated drain field, but also by the water table if it rises to the level of the bio-mat (Stewart and Reneau, 1981).

According to these surveys, there are 16 major classifications of soil in Marion County. Some of them are further split into sub-categories of 29 distinct soil types in the study area. The United States Department of Agriculture Soil Conservation Service in cooperation with Purdue University created a soil survey of Marion County, Indiana. The field work for the soil survey was completed between the years 1970-74; and the soil names and descriptions were finalized in 1975. More recently, the Web Soil Survey (WSS) was created and is continuously using information produced by the National Cooperative Soil Survey. It is operated by the USDA Natural Resources Conservation Service (NRCS).

The Miami series consists of deep, moderately well drained soils that provide several feet of space between the surface and an impermeable layer. Miami soils form on the high ground of Indiana's undulating surface, which is advantageous to septic systems because it gives the wastewater plenty of space to percolate through the soil.

The Brookston series is comprised of shallow, poorly drained soils formed by calcareous glacial till. Because it is lower on the landscape, it is closer in proximity to bedrock and glacial till, which hinders drainage, causing problems for septic systems. Unlike Miami soils, Brookston soils form in the low-lying areas, which not only puts them closer to bedrock and glacial till, but also leaves them prone to flooding.

The Crosby soil is slightly better drained because it is not as close to the bedrock. Crosby fits into the topographical profile between Miami and Brookston. Because Crosby is in the middle of Miami and Brookston, it shares the good and bad qualities of both. Percolation is slow, but capacity to hold water is high, which makes Crosby a suitable soil type for wastewater treatment.

The Eel, Fox, and Genesee soils are deposited by water and are loamy, soft, and well drained. They occur on the outwash and floodplains along White River. Their permeability is high and they have a high capacity to hold water. All three have many of the characteristics of a favorable soil that people should look for to bury a septic system. Unfortunately, because of their proximity to bodies of water, high permeability causes a problem. Waste is discharged into the water supply, contributing to pollution. In addition, Eel, Fox, and Genesee soils occur in floodplains which, means they will be compromised more frequently by flooding. Regular flooding lifts unprocessed effluent out of the drain field, to the surface and into the drainage way prematurely.

Because of their capacity to hold water, permeability, and proximity to an impermeable layer, it appears that the Miami soils will be the most favorable for septic system placement.

The cross section illustrated in Figure 4 is a typical soil profile in this study area. Miami, Crosby, and Brookston soils share similar capacity, permeability, and proximity to bodies of water. Where they differ, is their proximity to an impervious layer. Miami is the most favorable for a septic system because it lies on the high ground. This gives wastewater the best opportunity to digest as it filters through the soil. Crosby, although it often occurs on a slope, offers the next best opportunity because it lies on top of a layer of Brookston. The Brookston is an unfavorable soil to bury a septic system in because of its close proximity to an impervious layer. It sits on top of the bedrock or glacial till. In a low lying area, wastewater would have nowhere to go but up, causing pollution to rise to the surface. Eel, Fox, and Genesee have good capacity and permeability, but because they occur on floodplains, they have two problems: they are prone to flooding, and they are too close to a fresh water body.

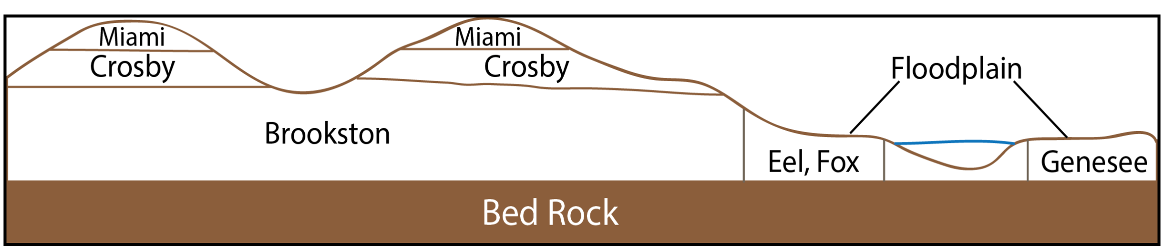

Figure 4. Soil Profile Typical of the Study Area.

The web soil survey addresses whether a certain soil can be expected to host a healthy drain field based on some important characteristics such as conductivity, percolation, capacity, and likelihood of flooding. A Spreadsheet is created using the results of the web soil survey. It identifies each variety of soil as either favorable, neutral, or unfavorable for use as a filtration system for wastewater. Then, the spreadsheet is joined to the soil layer attribute table in ArcMap and a classification is done to create a color coding system to distinguish the favorable from the unfavorable areas (Figure 5).

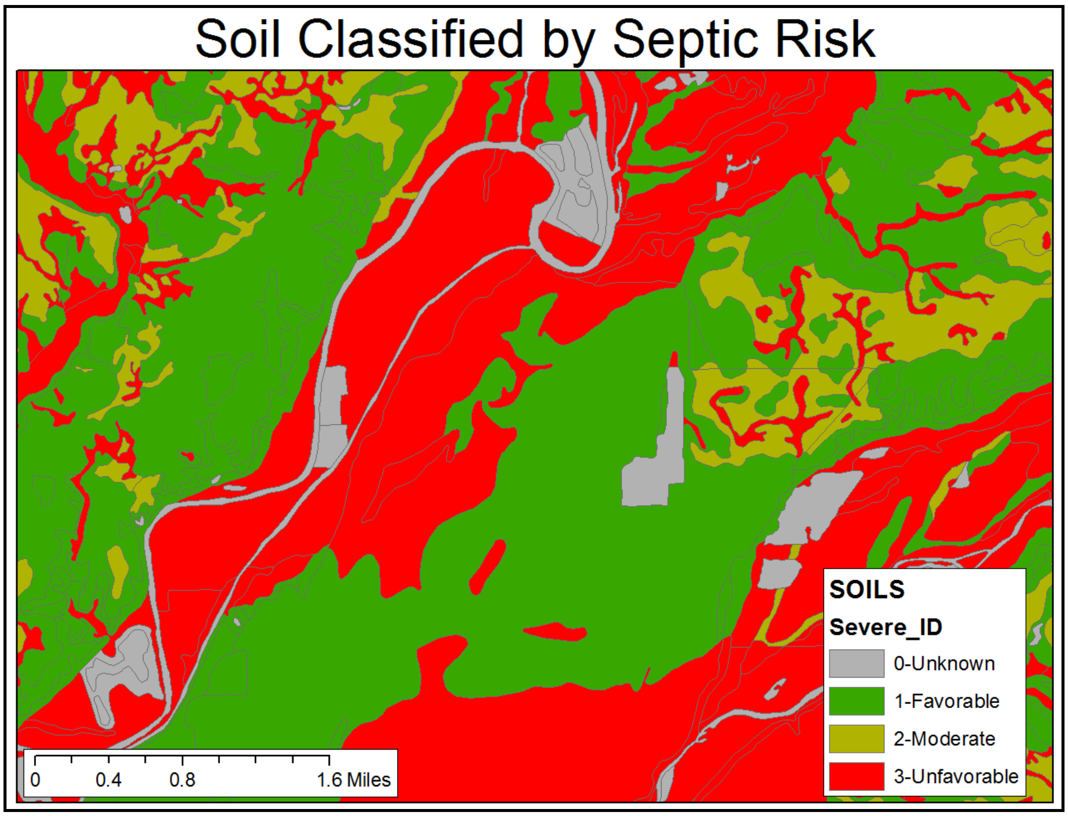

Figure 5. Soil Classified by Septic Risk. Soil types in Central Washington Township, Marion County, Indiana categorized by their expected ability to host a septic system.

Slope

The longevity of an on-site sewage disposal system is also affected by the slope of the surface in the immediate area. Indiana State Department of Health Environmental Public Health Division regulation states that any slope of more than .5% on the property must drain away from the septic drain field. Slope affects the flow of surface and subsurface water (Frankenberger, 1999). Expensive adjustments may have to be made if malfunctions occur because a slope is too steep, if the fingers of the drain field are buried too close to the surface on a sloped site, or if the surface dips to a low point over the drain field, causing ponding. Additional problems may arise if there is an impermeable layer near the surface in conjunction with a slope. Effluent will traverse laterally toward the surface instead of percolating down into the soil. Effluent flowing across the surface or across a shallow impermeable layer may not cause damage to the components of the system themselves, but is a common cause of malfunction in the form of nutrient pollution in nearby water bodies (Robertson 1995). These challenges face anyone installing a drain field on a steep slope, undulating terrain, or in a shallow bed of soil above an impermeable layer (Collick et al, 2006). According to Indiana State Department of Health Environmental Public Health Division Residential On-Site Sewage Systems Rule 410 IAC 6-8.3 section 69(a)(7), a subsurface trench on-site sewage system must be installed on a site with no greater than a 15% slope. A slope of 15%, when converted to degrees, equals approximately 8.5 degrees. There are grades in Washington Township much steeper than this, some of which house septic systems. This rule was effective as of November 19, 2012, so it is likely these systems were installed before the rule was in place. It is possible that septic systems in Washington Township on a slope greater than 15% (8.53 degrees) employ an alternative to the traditional subsurface trench, such as a raised mound or an aerobic treatment septic system.

Tree Root Invasion

Trees are a welcome addition to the landscape for most homeowners. They not only beautify the property, but they stabilize the soil; provide food and shelter for wildlife; and help to purify the air and ease the strain on air conditioning units by providing shade in the summer. Unfortunately, for septic system owners, there can also be negative effects. Tree roots are drawn to a moist nutrient rich environment (Trees, Shrubs, 2000). The perforated pipes that disperse waste water throughout the drain field, as seen in Figure 6, are a common target. Roots can also work their way into the solid distribution pipes leading from the house to the tank, and from the tank to the drain field (http://fremontcountywy.org/wp-content/uploads/2009/11/WhySepticSystemsFail.pdf). Well-sealed polyvinyl chloride (PVC) pipes that are found in modern systems are largely impervious to infiltration by tree roots, because they are far less likely to leak. However, a large number of septic systems currently in the ground, still utilize older concrete, clay, or cast iron pipes. These are more difficult to seal perfectly, and can also decompose, leading to the development of cracks (http://homeguides.sfgate.com/keeping-roots-out-septic-system-71205.html). Moisture leaking from the cracks and imperfect seals invites roots to begin growing into the pipes. Once inside the wet, nutritious environment of the pipe, the roots quickly grow, creating a blockage, or a breakage, and sometimes both.

Figure 6. An Example of a Perforated Pipe Used in a Septic Drain Field.

A septic system with a blockage in it typically exhibits signs that something is wrong. The symptoms of a septic system clogged by a root structure causing a blockage are: slowly draining fixtures such as toilets and sinks, or backups that send wastewater back into the outflow pipe, causing overflowing sinks, toilets, etc. (Vogel, 2005). The most common symptoms of a broken pipe are: patches of vegetation in the yard that are much more lush and healthy than the surrounding area, a spongy waterlogged lawn, or a foul odor (http://homeguides.sfgate.com/symptoms-tree-roots-septic-system-40981.html). A foul odor occurs when undigested wastewater reaches the surface. If it is noticed during times of extreme saturation, such as during a flood or heavy rain storm, it does not necessarily mean there is a serious problem with the drain field. If the smell remains after the excess water recedes from a field that should otherwise be functioning normally, then there is likely an ongoing problem with the drain field. Slowly draining fixtures, such as sinks and drains, are indicative of an obstruction of the pipe between the house and septic tank. Foul odor and soggy, wet ground indicates a distribution pipe shuttling effluent between the tank and drain field has been compromised and is leaking more untreated wastewater into the surrounding environment than the soil can handle. Having an idea of the extent of the root systems of the trees in the area is a good start to predicting whether a septic system is at risk of damage from tree roots. Typically, roots do not spread across a distance greater than the width of the tree's canopy at its maturity. As an example, a tree that has a canopy that stretches 30 feet wide will probably have roots that reach 30 feet laterally, and a 50-foot-wide tree could have roots that spread 50 feet from its trunk, and so on. If part of the treatment system is within this range, it is at risk. Due to the variety of potential complications for both the tree and the landowner, the landowner should consult an arborist to avoid installing the system where tree roots will likely cause a problem.

Light detection and ranging (LiDAR) has proven to be an excellent resource when attempting accurate measurement of tree canopy. When tasked with identifying tree canopy, LiDAR presents distinct advantages over traditional optical remote sensing (Andersen et al, 2006). LiDAR is able to record spatially distributed data, such as the ability to quantify the profile of a tree canopy, very accurately (Gatziolis & Anderson, 2008). A LiDAR system consists of an internal navigational unit, a precision GPS, a laser, and a computer interface that stores the data and communicates between the collection of devices. A stationary GPS station on the ground, aids in the precision of the airborne GPS by operating simultaneously with the airborne GPS in order to differentially correct. Additionally, light pulses can penetrate some surfaces such as leaves and shallow water, and more than one return may be recorded from a single pulse. Using these multiple returns is how this study will determine where the tree canopy is located in Washington Township.

Impervious Surfaces

It is important to consider impervious surfaces when planning a septic site. An impervious surface is a natural or man-made material that keeps water from seeping into the soil. The most common impervious surfaces are paved roads, parking lots, buildings, houses, sidewalks, and exposed rock. If rain water is unable to enter the soil, it is forced to run off which often contributes to localized flooding. If the soil immediately surrounding a drain field floods and becomes completely saturated, the wastewater will not be able to percolate through the soil as it is supposed to. Instead of percolating down through the soil, it may back up or float up to the surface, causing pollution. There is evidence that an area with a large percentage of impervious surface lowers the water table (Arnold, Gibbons, 1996). Instead of runoff collecting in the area of the septic system, causing a flood, excess water may run off of paved and built surfaces and into sewers or rivers, thus moving out of the area without entering the local water table. In many cases, lowering the water table is a negative consequence of increased impermeability. However, with regard to septic systems, it may increase the capacity of the soil and afford the effluent more unsaturated soil to filter through, increasing the chance of purification before returning to the water supply. As the percentage of impervious surface in an area increases, the hydrology in the area changes with it (Roy, Shuster, 2009). (Konrad and Booth, 2005) studied streamflow records from eight urbanized areas around the United States, and five areas where land use is stable. Their goal was to determine whether streamflow patterns were modified by urbanization to the extent that a biological response can be identified, or if climate patterns could account for any changes. They concluded that hydrologic changes of urban environments likely have a significant impact on the ecosystems of local streams.

Nearby septic systems, which are reliant on microbiology to function properly, could be adversely affected as a result of significant hydrological changes in the environment. Figure 7 provides insight into the impervious surfaces affecting systems in Broad Ripple.

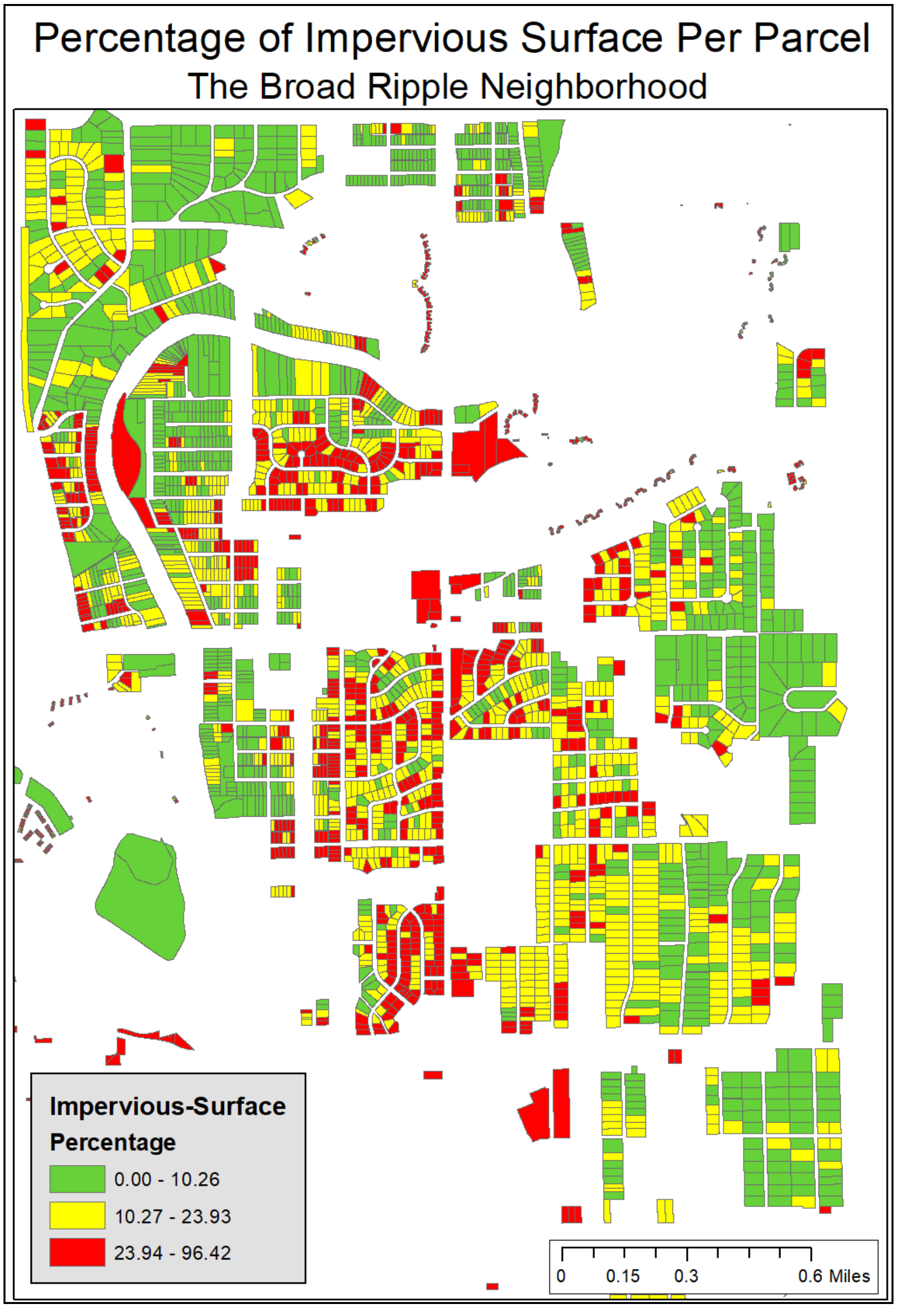

Figure 7. Percentage of Impervious Surface per Parcel - The Broad Ripple Neighborhood. The property parcels in this image are located in Northeastern Washington Township and are categorized by the percentage of surfaces composed of water impervious

materials. The white areas are neighborhoods that were removed from the map because they are serviced by city sewer.

Data and Methods

The septic repair permit point data, the soil data, and the sewer network data were acquired from the Marion County Department of Health (MCDH) and were last updated in 2012. Installing or doing substantial repair to an in-ground, on-site wastewater disposal system requires a permit from the County Health Department. The septic points were derived from geocoded addresses from repair permit applications filed with MCDH by property owners, and cover a span of 24 years between 1988 and 2012. The soil data was acquired by the United States Department of Agriculture Soil Conservation Service in cooperation with Purdue University Agricultural Experiment Station and is maintained by MCDH. Up-to-date soil information can also be found online at websoilsurvey.sc.egov.usda.gov. The sewer network was acquired with the help of MCDH, but the data is maintained by the main public utility in Marion County, Citizens Energy. The LiDAR data used to study tree canopy was found on www.indianamap.org and downloaded from the Indiana Spatial Data Portal. The LiDAR data field was used to outline the study area discussed in the Geographical Context section. The impervious surface data, also found on www.indianamap.org, was produced through a cooperative project conducted by the Multi-Resolution Land Consortium (MRLC).

The classification of soil types was based on them being either most favorable, neutral or least favorable for installing a drain field. The spreadsheet lists soil types by name. In a second field, labeled “SOILS_ID”, the soil types that were unfavorable were labeled 3, neutral soils labeled 2, and favorable soils 1. The SOILS_ID field from the spreadsheet was then joined to the attribute table in ArcMap using the SOILS_ID field to relate the two tables. To bring the county wide data into focus on Washington Township, a shapefile was downloaded of the political boundaries of Marion County townships from indianamap.org. I used it to create a subset of the Marion County soil data specific to the study area. It also became a much smaller and more manageable file. The web soil survey addresses whether a certain soil can be expected to host a healthy drain field based on some important characteristics such as conductivity, percolation, capacity, and likelihood of flooding. Using the recommendations of the web soil survey, a spreadsheet was created identifying each variety as either favorable, neutral, or unfavorable for use as a filtration system for wastewater. The spreadsheet was joined to the soil attribute table, and a classification was done to create a color coding system to distinguish the favorable from the unfavorable areas. There are some industrial areas and large commercial areas where the soil has been either removed or altered too much to fall into any classification. Since these soils are drastically altered by urban processes, the effect on septic systems is unknown; therefore, they are given a value of (0) and are represented visually by the color gray. The less favorable soils (3) are red, and make up 40.2% of the study area. Neutral soil types (2) are yellow, and make-up 4.9% of the study area. The most favorable (1) are green and represent 49.9% of the study area. The remaining 5% of the study area is composed of either water or soils that have been processed by urban development and therefore have an undetermined effect on septic system longevity.

Once the soil types were organized based on their likelihood to host a successful septic system, the Soil Classes layer was merged with a layer of the property parcels in the study area that isn't serviced by city sewer. The result is an illustration of where septic systems in the area are located in relation to the soil classifications. Not surprisingly, it appears that soils were not an immediate concern to city planners at the time the septic systems were installed. The neighborhoods do not appear to follow the pattern of the soils at all. MCDH also provided data illustrating the location of the public sewer lines. In the line file of the sewers, use "select by location" to select all of the parcels within 100 ft., then eliminate them. That is the reason the area in Figure 8 appears to be an isolated cluster of parcels surrounded by unused land. A large percentage of occupants utilize the public sewer. According to the Marion County Department of Health (MCDH) a resident must hook up to the public sewer if there is a line running within 100 ft. of the property line. The health department imposes a 300 ft.

limit on commercial properties instead of 100 ft. Without further research, it is difficult to determine exactly which of the parcels remaining are zoned commercial and which are zoned residential. It is assumed that all parcels in the study area contain a structure with plumbing, but it is possible that a small percentage do not.

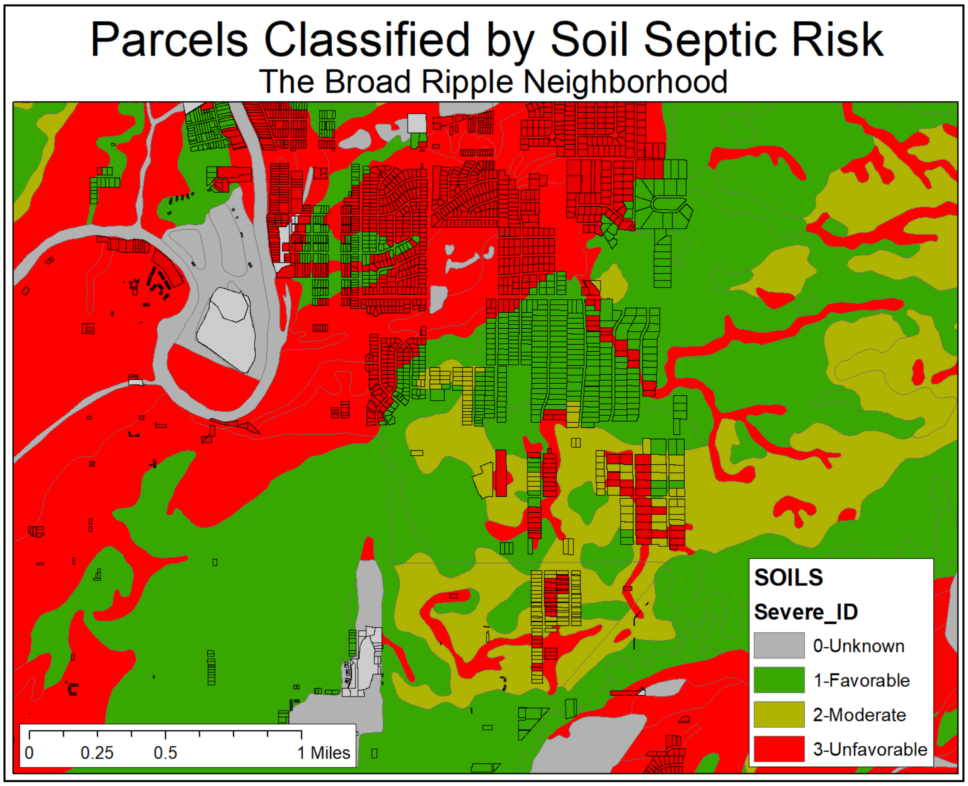

Figure 8. Parcels Classified by Soil Septic Risk – The Broad Ripple Neighborhood. Property parcels (outlined black) categorized by soil type. Parcels are assigned a soil category based on the soil type where their centroid is located.

The base layer used to study slope is a digital elevation model (DEM) of Marion County acquired from the Indiana Spatial Data Portal. Unlike soil data, which consists of classifying areas of the map, the slope requires a slightly different approach. To determine each parcel's slope, stack the parcel layer over the DEM, then calculate the average slope of the pixels contained within each parcel. Because there isn't a good way to determine the exact location of every drain field in this study area, this study uses the average slope of the entire parcel. The goal is to know the gradient of the entire area surrounding the drain field. Then, the parcels are classified based on the average slope and rated favorable, neutral, or unfavorable. A favorable slope is estimated to be less than or equal to 4.5 degrees and, like the favorable soil classification, is given a value of 1; a neutral slope is between 4.51 and 8.5 degrees and has a value of 2; and an unfavorable slope that is greater than 8.51 degrees has a value of 3. Not every property in Washington Township utilizes a septic system to dispose of wastewater. A large percentage of occupants utilize the public sewer. According to the Marion County Department of Health (MCDH) a resident must hook up to the public sewer if there is a line running within 100 ft. of the property line.

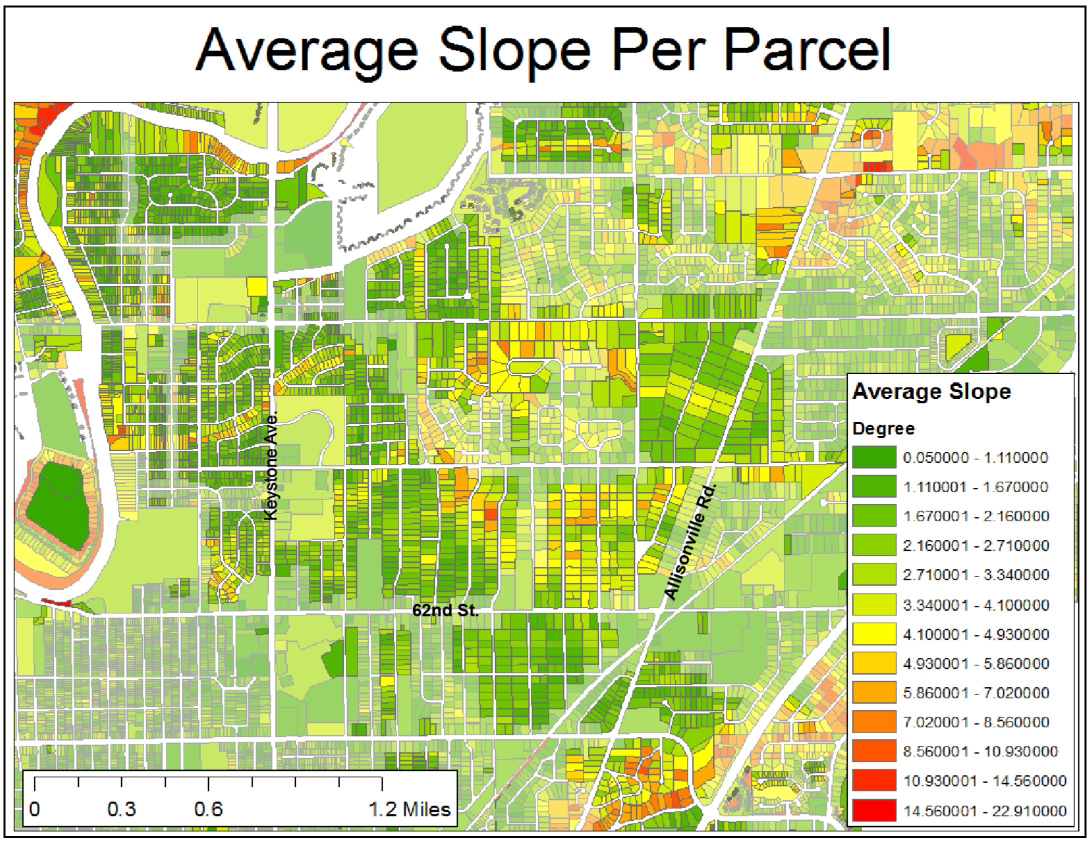

Figure 9. Average Slope per Parcel. This image displays the average degree of slope per parcel in the Broad Ripple neighborhood. Clusters of steep slopes are apparent, especially in parcels near a body of water.

Figure 9 was created using the slope tool in ArcMAP to calculate the slope of each pixel. The pixels in each parcel were averaged to find the average slope per parcel. The results are displayed in degrees, so 0 means flat, 90 means vertical. A 15% slope translates to 8.53 degrees. The faded parcels are on city sewer and therefore not involved in the study, but it is important to leave them in the image to make it easier to visually identify geological features. For instance, some of the faded parcels in the middle of the map are part of a hill, indicated by the ring of yellow/orange parcels surrounding a patch of green.

To quantify the risk of damage done to septic system components by root systems, the ratio of tree canopy cover to exposed ground is calculated for each pixel. Areas with less than or equal to 25% of the ground covered by tree canopy are thought to be at the lowest risk and are assigned a value of 1. Areas between 25.01 – 66% at moderate risk and are assigned a value of 2. Areas greater than 66.01% are at the highest risk and are assigned a value of 3.

The raw LiDAR point data was acquired from the Indiana spatial data portal (http://gis.iu.edu/), though it is also found at www.indianamap.org. Woolpert Inc. originally collected the data in May 2011. LiDAR sensors are flown by airplanes, not by satellites orbiting Earth, so the swath width of LiDAR is 5678 feet which means each block of data covers a relatively small plot of land at high resolution.

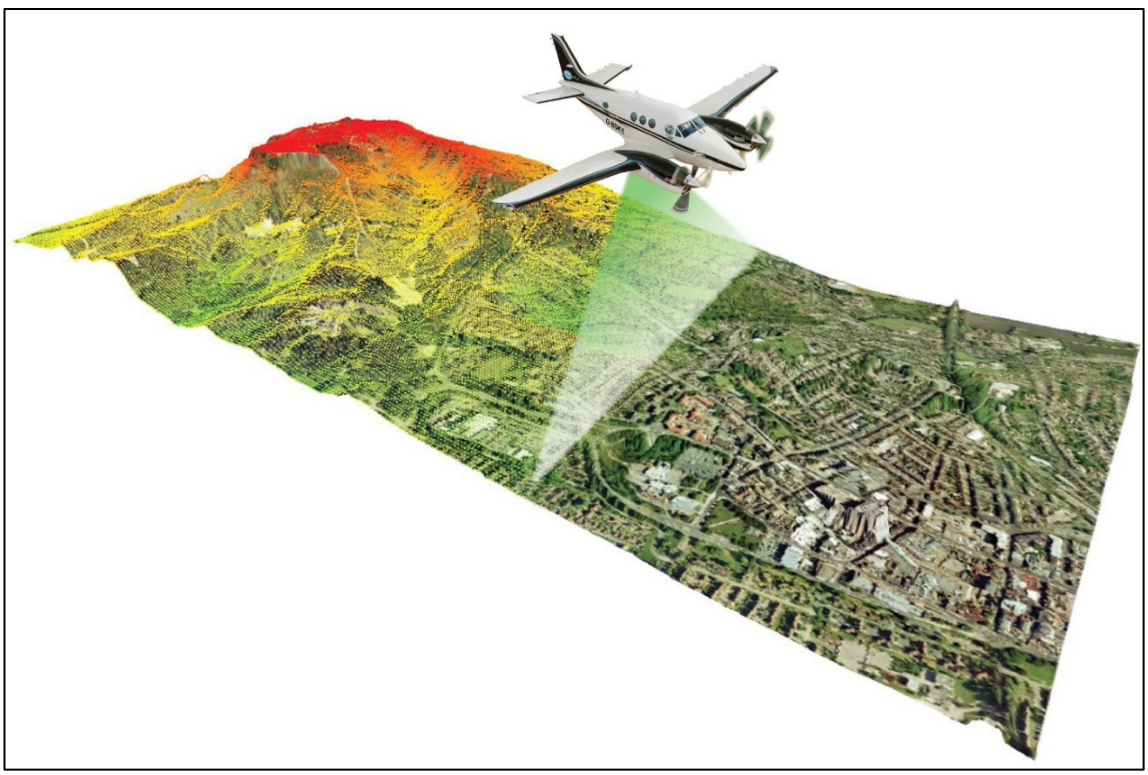

Figure 10: An Illustration of the LiDAR Collection Method.

LiDAR (LAS) data comes in geographically small chunks relative to other remotely sensed data. It has very high resolution, but a narrow swath width, because unlike other sensors that orbit Earth in space, such as Landsat, LiDAR is flown on airplanes much closer to Earth's surface (Figure 10). The data is also very dense, because each laser pulse has multiple returns that come back to the sensor (Figure 11). So the data comes in much smaller chunks, and it is not practical to download the entire footprint of Washington Township. To make sure the sample size was adequate, a large amount of data was gathered and patched it together, creating a mosaic that provides a big enough study area to be representative of the township as a whole. In Figure 12, the study area is in the center of Washington Township and is outlined in red.

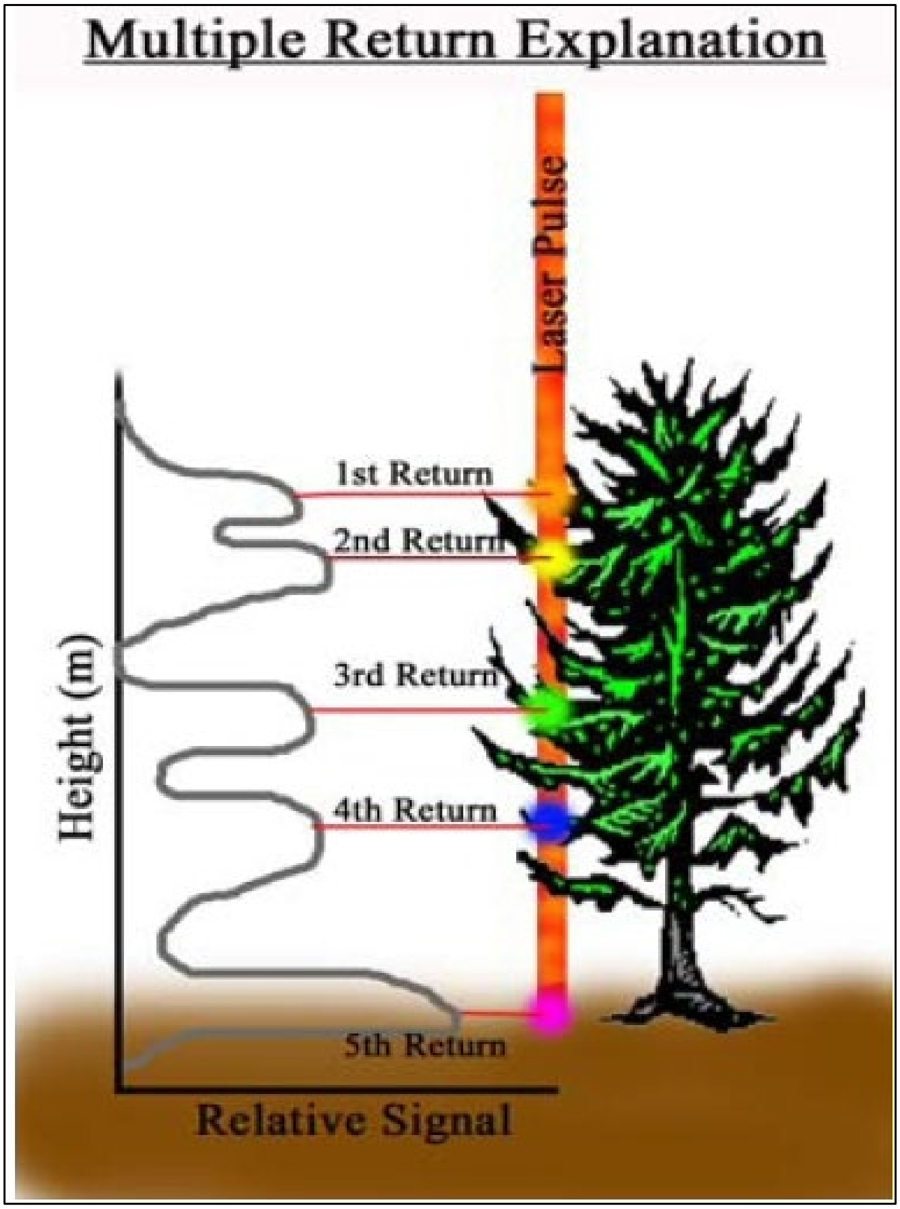

Figure 11. Multiple Return LiDAR Illustration. A full explanation of multiple return LiDAR is available at the following web site: (https://www.e-education.psu.edu/geog481/l8_p3.html).

The primary plan was to locate the tree canopy by doing a spectral analysis to create classifications with Landsat data. It proved to be more difficult and less accurate because there was a much higher incidence of false positives. Classifications using Landsat data are based solely on the wavelength of light reflected back to the satellite.

Based on environmental factors, such as moisture and the time of year the image was recorded. Trees can have a similar spectral signature to some of their surroundings. The 30-meter spatial resolution of Landsat provides an additional challenge when attempting to accurately locate trees. Many trees are obscured when they do not fall comfortably into one pixel. The most common obstacle that causes false positives when using LiDAR, is the edge of rooftops. If a pulse of light catches the edge of a peaked roof the wrong way, the returned signal closely resembles the signature of a tree.

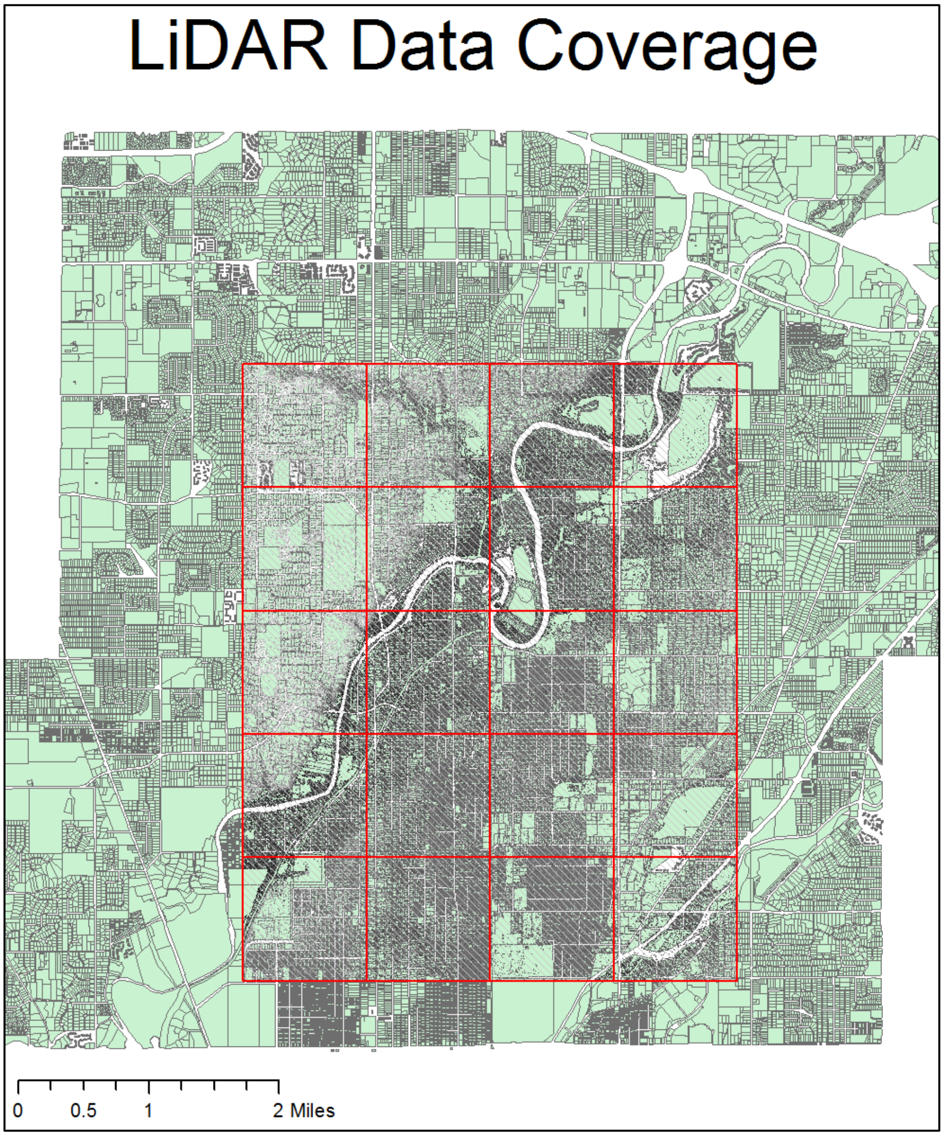

Figure 12. Washington Township Parcels with LiDAR Dataset Overlay. This dataset was created in ArcMap using the Create LAS Dataset tool. The boundaries in this image were adopted as the study area for this research.

The raw LiDAR data is a cloud of points that requires processing before it can be mapped in ArcMap. To calculate the percentage of each parcel covered by tree canopy, turn the LiDAR point cloud into polygons. As seen in Figure 13, the image is cluttered with returns. To identify tree canopy, the returns that came from pulses bouncing off of solid objects, like the ground or buildings, need to be eliminated. The different colors represent different canopy heights. Darker colors and reds indicate the laser received a return from a higher elevation, while lighter colors are lower, flatter objects such as roads.

Figure 13. LiDAR Point Cloud Unfiltered.

After eliminating the returns that are most likely to create noise in the data (Figure 11), what is left is a point cloud that is more clustered. To test this new data set it is layered over a photograph of the same area, in Figure 14. Next, convert the clusters of points into polygons. Using the newly created polygon layer, it is possible to determine how much of each parcel is covered by tree canopy (Ye, 2014).

Figure 14. LiDAR Point Cloud After Filtering. Layered on top of a photograph of the area for visual confirmation of accuracy.

Using the available data, there is not a good way to determine exactly where the components of the septic systems in the study area are buried. For this reason, it is not practical to locate each system and decide whether it is within reach of any nearby root systems. Instead, the risk of root incursion is determined by the percentage of the septic containing parcel covered by tree canopy. Figure 15 is zoomed in on one of the neighborhoods to illustrate the high resolution and accuracy of the LiDAR when locating tree canopies in the area. The grey shapes are trees. Note how parcels often share their trees with neighboring parcels, which is one reason why the decision was made to analyze the canopies instead of the height of individual trees. Much like the canopy, a tree's root system does not follow arbitrary boundaries drawn by humans such as property lines.

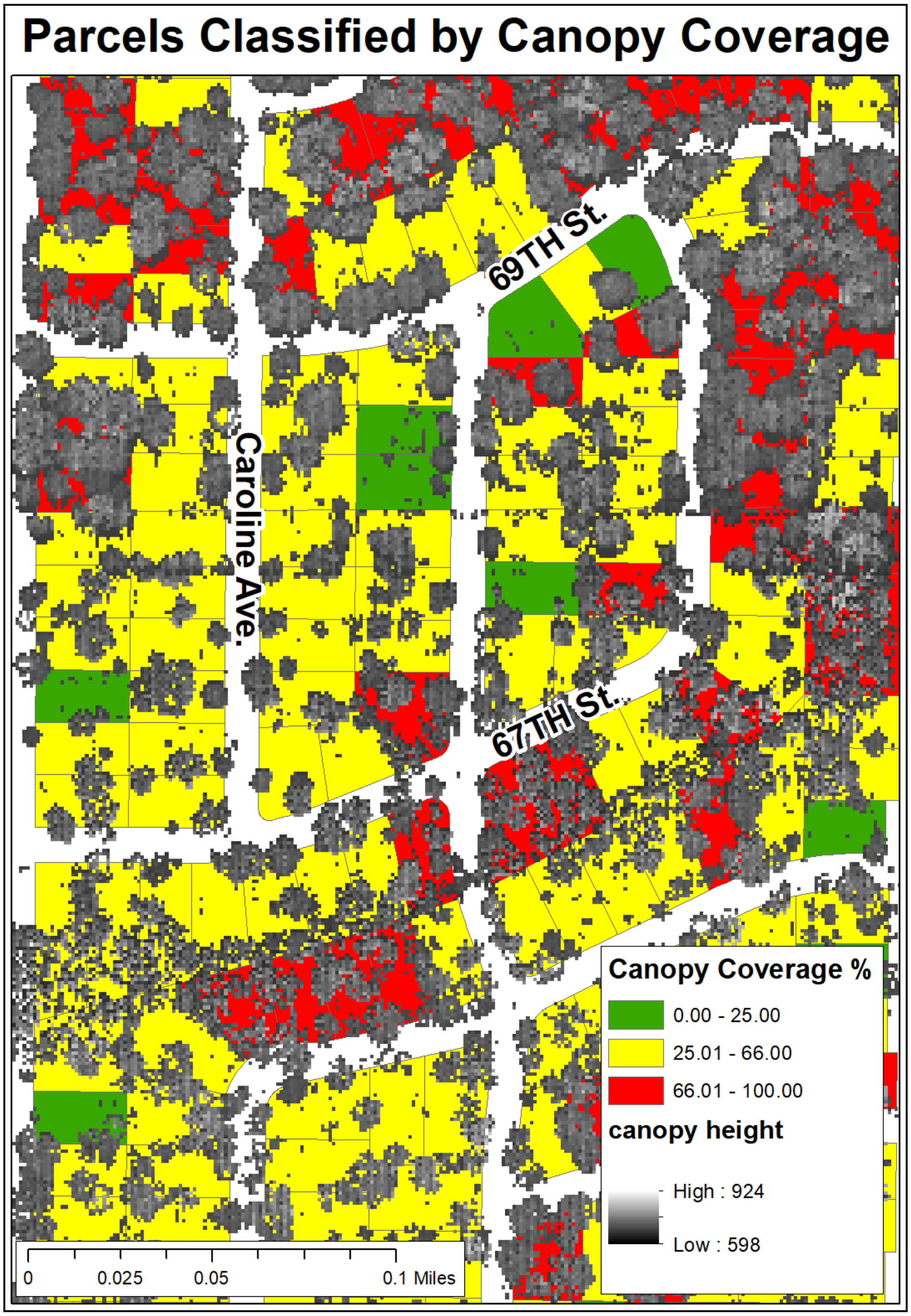

Figure 15. Property Parcels Categorized by Canopy Coverage. This Broad Ripple neighborhood is overlaid with raster imagery of the trees detected by LiDAR. The lighter gray represents taller trees while darker areas represent shorter trees.

To analyze the impervious surface of each parcel in the Washington Township study area, start with a base layer created using LandSAT images. The file was downloaded from www.indianamap.org. For the purpose of impervious surface measurement, LandSAT is a good source since a medium spatial resolution is ideal (Lu et al. 2006). High spatial resolution aerial photographs contain a large amount of data and can lose accuracy due to geometric distortions. LiDAR is a more manageable data set but does not contain the spectral information necessary to identify the surface material and whether water is able to penetrate it. Though more pixels are always better, LandSAT's 30-meter resolution is adequate and the file size is relatively small.

Because impervious surfaces processed last, the necessary parcel data already exists. Instead of making a new property parcel subset and removing the properties known to be serviced by the city sewers; create a copy of the parcel file used in the slope analysis. To determine the percentage of impervious surface per parcel I performed a zonal statistics analysis, similar to what was done with the slope data.

The soil data set is quantified by assigning the soil types that are most favorable for drain field operation to a value of 1, moderately favorable to a value of 2, and least favorable to a value of 3. These assignments are based on their physical characteristics as described by the United States Department of Agriculture Soil Conservation Service. The slope, impervious surface, and tree canopy would need to be categorized in a similar way, but based on the following factors: percentage of tree canopy covering each parcel, the percentage of impervious surface covering each parcel, and the average slope of each parcel. To make that comparison, a new field was created in the slope and tree canopy attribute tables as well as in the impervious surfaces zonal statistics table. To populate the new categorical fields, a script was created in the field calculator using the python parser. The tree canopy ratio code, degree of slope code, and percentage of impervious surface code (in that order) can be found in the appendix of this paper.

The tree canopy classification breaks were made so that each category would have a similar number of values. The most favorable class is parcels with less than or equal to 25% coverage. The moderately favorable class is 25.01% - 66% coverage. The least favorable class is parcels with greater than or equal to 66.01% of coverage.

The classification of the slope data is based on research that recommends septic systems are not installed in an area with greater than a 15% (approximately 8.5 degree) slope, and with the assumption that within the 15% usable slope that steeper slopes will be somewhat less favorable than a flat surface (Collick et al, 2006). Parcels with a slope of less than or equal to 1.78 degrees are most favorable, moderately favorable parcels have a slope of between 1.79 – 2.76 degrees, and unfavorable parcels have a slope greater than or equal to 2.77 degrees.

The classification breaks in the impervious surface data are made using quantile classification of the mean field, created by the "zonal statistics as table" process. The most favorable parcels are less than or equal to 10.26% impervious surfaces, moderately favorable parcels are between 10.26% – 23.93% impervious surfaces, and unfavorable parcels are greater than or equal to 23.93% impervious surfaces.

These categorizations provided the same 1-3 scoring system for the slope, impervious surface, and tree canopy that is already in place with the soil, making all four of them easily relatable. There are clusters of repair permit filings that are visible in certain areas of the map. To determine the cause of the clusters, the next step is to find a pattern in the soil, slope, tree canopy, and impervious surface data sets.

To search for a pattern in the relationship between the individual variables, a series of contingency tables was created to compare them. For the sake of the contingency table calculation, in Microsoft Excel, the numerical 1-3 scores were converted to text values: low (1), medium (2), and high (3). The first table outlines the incidence of failures in each soil category. Since the soil type and its properties are directly involved in the digestive process, the soil will have the greatest influence on the septic system performance. Therefore, the soil data is the foundation for the other tables as well.

Result

	No Repair	Repair	Total
Unknown	222	1	223
Low Risk-Soil	1670	370 **22.2%**	2040
Med Risk-Soil	285	42 **14.7%**	327
High Risk-Soil	2584	402 **15.6%**	2986
Total	4761	815 **17.1%**	5576

Table 1. Repair Permits per Soil Category.

In Table 1, and in the following tables, the row highlighted in gray signifies the highest rate of average repairs per parcel. The expected result of the risk assessment of the soils is not reflected in what the repair permit filings indicate has happened. Contrary to expectations, in this study area, the soil types expected to pose the lowest risk actually have the highest incidence (18%) of septic system repair. The medium and high risk areas both returned a septic failure rate of 13%. Some potential reasons for this discrepancy are discussed later. Of the variables being studied, soil has the greatest impact on septic longevity due to its direct involvement in the purification process. For that reason, the data in Table 1 is the foundation for the rest of the model. The other three variables are added one at a time to the soil table. If the clustering of repair permits change as a result, it is an indication the added variable has had an effect on the well-being of the systems.

	Low %-Canopy			Med %-Canopy			High %-Canopy			
	No Repair	Repair	Count	No Repair	Repair	Count	No Repair	Repair	Count	Total
Unknown	164	--	164	39	1	40	19	--	19	223
Low Risk-Soil	323	37 11.4%	360	830	232 **28%**	1062	517	101 19.5%	618	2040 22.2%
Med Risk-Soil	102	7 6.8%	109	144	32 **22.2%**	176	39	3 7.7%	42	327 14.7%
High Risk-Soil	568	39 6.8%	607	1176	248 **21.1%**	1424	840	115 13.7%	955	2986 15.6%
Total	1157	83 7.1%	1240	2189	513 **23.4%**	2702	1415	219 15.5%	1634	5576

Table 2. Comparison of Repair Permits per Tree Canopy/Soil Category.

Table 2 outlines the comparison of the soil and canopy data sets. It can be broken down into three relationships: High-Canopy/Soil, Medium-Canopy/Soil, and Low-Canopy/Soil. A higher percentage of tree canopy signifies a higher risk of septic system components having been damaged by tree roots as the spread in search of nutrients. The effect of tree roots is evident in the Med-Canopy/Soil comparison. Low-Risk Soil by itself reflects a septic failure rate of 18% with medium and high risk both 13%. However, when you look at the systems in the same soil types as those in the Med-Canopy parcels, they failed at a rate of 22%, 18%, and 17% respectively. Med-Canopy increases the incidence of septic system failure across the board. Meanwhile, the incidence of failure in both the low and high canopy groups dropped significantly.

	Low %-Impervious			Med %-Impervious			High %-Impervious			
	No Repair	Repair	Count	No Repair	Repair	Count	No Repair	Repair	Count	Total
Unknown	39	--	39	22	1	23	161	--	161	223
Low Risk-Soil	534	143 **26.8%**	677	601	153 25.5%	754	535	74 13.8%	609	2040 22.2%
Med Risk-Soil	70	15 **21.4%**	85	104	19 18.3%	123	111	8 7.2%	119	327 14.7%
High Risk-soil	941	117 12.4%	1058	798	161 **20.2%**	959	845	124 14.7%	969	2986 15.6%
Total	1584	275 17.4%	1859	1525	334 **21.9%**	1859	1652	206 **12.5%**	1858	5576

Table 3. Comparison of Repair Permits per Impervious Surface/Soil Category.

Impervious surfaces alter the interaction between septic systems and soils, and change the hydrology in the area. Table 3 illustrates how the systems in parcels with a high percentage of impervious surface fail at a much lower rate than other systems. The systems in Low%-Impervious and Med%-Impervious fail at a higher rate when compared to soil risk table. Protecting septic systems from a large influx of outside water such as a flood or heavy rain has a strong positive influence on the functionality of the system.

As reflected by Table 4, the average slope of the property seems to have the least effect on septic system longevity. The data shows that as long as the slope is at or below 8.5 degrees the failure rate remains consistent with the patterns in the soil table.

	Low %-Slope			Med %-Slope			High %-Slope			
	No Repair	Repair	Count	No Repair	Repair	Count	No Repair	Repair	Count	Total
Unknown	74	--	74	53	--	53	95	1	96	223
Low Risk-Soil	616	139 22.6%	755	568	120 21.1%	688	486	111 **22.8%**	597	2040 22.2%
Med Risk-Soil	102	8 7.8%	110	87	17 **19.5%**	104	96	17 17.7%	113	327 14.7%
High Risk-Soil	822	123 15%	945	858	151 **17.6%**	1009	904	128 14.2%	1032	2986 15.6%
Total	1614	270 16.7%	1884	1566	288 **18.4%**	1854	1581	257 16.3%	1838	5576

Table 4. Comparison of Repair Permits per Degree of Slope/Soil Category.

Conclusion

This research shows there is a relationship between these four environmental variables and septic system failure in Washington Township, Marion County, Indiana.

Out of the four variables being studied, soil is the dominant factor in the longevity of septic systems in Washington Township; however, slope, tree roots, and impervious surfaces did have a measurable effect. The table featuring only soil, reveals a 22.2% chance that systems in low risk soils have required repair, 14.7% in medium risk soils, and 15.6% in high risk soils. In all three of the tables where impervious surface, slope, and tree canopy were added, there is at least one comparison where the added variable significantly changed the result. The high risk soil rows do not reflect much change with the introduction of a 2nd variable, but the medium and low risk soil categories often showed substantial change. This is evidence that soil is the most important factor. It shows if you have a bad soil for a septic drain field, there isn't much that can be done to improve the situation.

While soils are the most important variable to consider when installing septic systems, all of the variables studied have an effect on performance. A large impervious surface has a strong and positive effect on septic systems directly underneath it. If protection from rain water has a strong, positive effect, does the extra run off have a strong negative effect on neighboring septic systems?

The four risk factors were weighted equally in order to create the final model. More research is needed to determine the best way to weigh these risk factors by level of influence on any given septic system. There are undoubtedly more than four potential factors that influence the longevity of an in-ground wastewater treatment system. Other potential points of interest include annual rainfall, number of household occupants, water usage patterns, and concentration of in-ground systems in a given geographical area. Some soils drain very well, but don't have a high water capacity. Soils such as these can be overwhelmed if too many high capacity systems are active in a small area. Even though there may not be anything wrong with the system itself, this will allow under processed effluent to either drain into the water table, nearby bodies of water, or percolate to the surface. It would benefit a future study to add a temporal factor to the model. There were several properties in the study area that filed for more than one repair permit. I did not figure out a way to focus additional attention on those especially problematic locations, but perhaps they could offer additional information about why the environment is that specific area is problematic.

Most of the soils classified as favorable for septic systems in Indianapolis are a sandy glacial deposit. They drain very well, which is why they are deemed a good place for a drain field. However, a densely populated urban area, like Indianapolis, could overwhelm such an environment. It is possible that a quickly draining soil would allow effluent to flow, untreated, into nearby waterways if too much wastewater is forced into it. Deeper analysis can help to better classify the soils specifically on their hydrological traits. For example, six parameters for better classification are: depth to restrictive layer, type of restrictive layer (fragipan, bedrock, or impervious), saturated hydraulic conductivity, saturated moisture content, field capacity, and percent rock fragments (Frankenberger, 1999).

An issue related to slope that is not included in this research is the depth at which a drain field is buried. Sometimes the challenges posed by a steep slope can be overcome by burying the drain field deeper. Conversely, a seemingly harmless slope could turn into a problem. There are issues preventing the drain field from being buried at the optimal depth. Potential obstacles include the depth of the water table and the depth of an impermeable layer such as bedrock in the area. There is a minimum distance that must be left between the drain field pipes and these barriers. The ideal amount of space varies based on the properties of the soil type in question. Further research will need to be done to investigate the depth of bedrock and the water table in Indianapolis on a neighborhood level.

To either remove or neutralize pollutants such as dangerous pathogens, nitrate, phosphorus and other contaminants, some alternative on-site wastewater treatment systems use pumps or gravity to trickle septic tank effluent through sand, organic matter (for example, peat or sawdust), constructed wetlands or other material. Other alternatives evaporate wastewater or disinfect it with chlorine or ozone before discharging it into the soil or surface waters (State Government News, 2001). There are a variety of additives on the market designed to aid in digestion, though they have been demonstrated to enjoy limited success (Predhan et al, 2008). I have not determined whether any of the septic systems in Washington Township employ one of these alternatives to the standard tank and drain field model. Further research may be able to determine if they exist in this area, how many there are, and how their qualities enhance their efficacy in what might otherwise be an unfavorable environment for an on-site wastewater treatment system.

I expected to see an elevated rate of failure in less favorable environments with systems in unfavorable soils surrounded by steep slopes, impervious surfaces, and high tree density. As shown in tables 1-4, the association between soil type, slope, impervious surfaces, tree canopy cover, and septic system longevity is not quite so clear. If the correlation between these variables and septic failure were stronger, the expectation would be to see more failures in high-high and high-med comparisons than in low-low and med-low. A possible reason there isn't a stronger correlation is because of the difficulty in precisely locating every drain field's exact location within the parcel. Instead of the slope of the ground directly above the drain field, the average slope of the entire parcel was used. A more accurate representation of the association between slope and failures could be drawn if someone has the means to determine exactly how far away each drain field is from a given slope.

I suspect the correlation between soil, slope, tree root invasion, impervious surfaces, and septic system failure would be even stronger if all four variables were taken into account at the same time. For example, a worst case scenario would be a property with high risk soil, steep slope, high percentage of tree canopy, and a low percentage of impervious surface. It is likely septic systems in this environment have a high rate of failure. It is also probable septic systems in a property with low risk soil, no slope, no trees, and a high percentage of impervious surface will have a low rate of failure. The best and worst case scenarios would be an interesting topic for future study as the current data set is not amenable to such a large and complicated comparison.

Appendix

Tree Canopy Coverage Classification Code:

```
def reclass(ratio):
  if (ratio <= 25 ) :
    return 1
  elif (ratio >= 25.01 and ratio <= 66) :
    return 2
  elif (ratio >= 66.01) :
    return 3
```

Parcel Slope Classification Code:

```
def reclass(degree):
 if (degree <= 1.78) :
  return 1
 elif (degree >= 1.79 and degree <= 2.76) :
  return 2
 elif (degree >= 2.77) :
  return 3
```

Impervious Surface Classification Code:

```
def reclass(mean):
  if (mean <= 10.262754) :
    return 1
  elif (mean >= 10.262755 and mean <= 23.933205) :
    return 2
  elif (mean >= 23.933206) :
    return 3
```

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Curriculum Vitae

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EDUCATION

MS, GIS, IUPUI, Indianapolis, IN, Spring 2019

BA, Telecommunications, Ball State University, Muncie, IN, Fall 2006

WORK HISTORY

Geography Educators Network of Indiana (GENI) **2012 – 2016**

GIS Student Specialist – Indianapolis, IN

- Co-designed lesson plans and tutorials to fit into Indiana's high school geography curriculum
  - Lesson plans included both GIS and remote sensing principles and focused on natural disasters and land and water management
- Presented GENI tutorials and other material to a group of educators at Indiana GIS Day in 2012 and 2013, as well as at the 2013 Indiana Geographic Information Council Conference
- Raw image/data acquisition and analysis using ArcGIS, ERDAS, and MultiSpec

Indiana State Department of Health **2013 – 2014**

GIS Analyst/Volunteer – Indianapolis, IN

- Organized and formatted property parcel and septic system data for 8 Indiana counties in
  ArcGIS, and Excel for use in a web map application by inspectors and maintenance workers
- Researched and located septic systems that were inaccurately or incompletely reported by counties
  - Creative problem solving required to accurately re-format some counties parcel number submissions using Excel and ArcMap
- Used Arc GIS to Geocode and map the requested septic systems and parcels

Marion County EMA **2010 – 2011**

GIS Analyst/Volunteer – Indianapolis, IN

- Updated the Marion County Critical Infrastructure map and database in ArcCatalog. Verified information of 357 sites currently in the database and researched prospective sites
- Worked with Indiana Department of Homeland Security and local first responders to create a disaster mitigation plan for the 2012 Super Bowl in Indianapolis

Completed Protected Critical Infrastructure Information and FEMA training

WTHR **2007 – Present**

Production Assistant – Indianapolis, IN

- Director and Technical Director of live newscasts in an automated environment
- Train new hires on technical direction, camera, floor direction, audio operation, and teleprompter
- Floor director and camera operator for Emmy award winning news broadcasts
- Audio and graphics operator in a live control room environment

Broadway Digital **2009 – Present**

Studio Manager – Indianapolis, IN

- Manage the day-to-day operation of studio and crew for broadcast of national and international networks such as CNN, FOX, and BBC
- Shot coordinator for TV network clients and high-profile guests such as U.S. Senators and Representatives, professional athletes, and Fortune 500 CEOs

HONORS AND AWARDS

National Geographic society, 2014

Recognized for encouraging the teaching and study of geography.

Geography Educators' Network of Indiana, 2013

Honored as a Friend of Geography.

PROFESSIONAL MEMBERSHIPS

- Indiana Geographic Information Council