Using Geographic Information Systems And Large Historical Data Bases To Protect Public Health And The Environment

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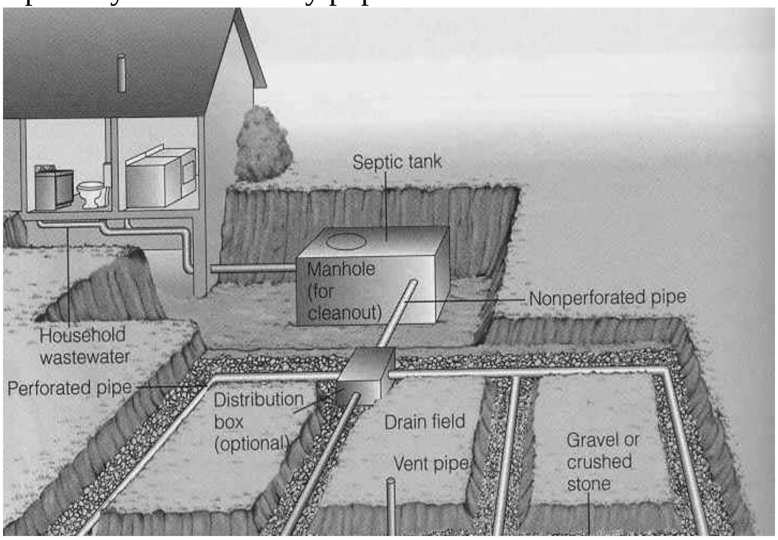
Abstract

The Lowcountry of South Carolina, USA experienced rapid growth and development as tourism and recreation replaced rural agriculture and silviculture land uses in the 1960's. At that time no water and wastewater infrastructure existed. Septic systems and shallow drinking water wells were installed to service private homes. The pace of development increased dramatically in the 1970's with the conversion of Hilton Head Island (Island) into a world class beach, tennis and golf resort destination. This new high-density development included water and wastewater infrastructure; however, a few older, more rural sections of the Island still retain septic systems. Hilton Head Public Service District (PSD), the local water/wastewater utility, is planning to provide service to these remaining properties over the next few years by extending both water and sewer to affected residents. This study utilized Geographic Information Systems (GIS) and large digitized databases such as soil survey and wetland inventory data to map the distribution of soils and wetlands on Hilton Head Island that were identified as unsuitable for effective operation of septic systems. A hazard ranking scheme was developed and a hazard assessment conducted to determine which properties on the Island faced the greatest risk of septic system failure. The PSD would use the results of this study to prioritize which properties would be targeted for sewer and water line extension and connection to the affected residents. This way potential health risks and impacts to surface water quality by failing septic systems could be avoided in a cost-effective and expeditious manner.

Keywords: Public Health, Environment, Septic System, GIS

Introduction

After World War II there was a significant shift in the demographics of the population of the United States. The “GI Bill”, that provided returning veterans free college tuition and low-interest loans to purchase property and re-enter civilian life, fueled rapid economic growth as many more individuals were able to afford their own homes. Most of this growth in the real estate market occurred in the single-family home sector, largely in the suburban areas around major cities. This suburban land was previously low-density farmland, field and forest land (Dunham-Jones & Williamson, 2008). At that time there were very few areas outside of cities that were served by public sewer systems so most of the new homes in these suburban and rural areas had to rely on on-site sanitary disposal systems such as septic systems to treat and dispose of sanitary wastewater. Previously in rural areas cesspools and pit privies (outhouses) were the common on-site disposal technologies predominantly in use. While these systems functioned moderately well in low-density rural areas, high-density suburban development required a more effective on-site treatment. Septic systems presented a simple, cost effective and expedient technical solution. When properly sited, installed, operated and maintained these decentralized wastewater treatment systems can protect public health and preserve water quality, especially in less densely populated areas.



From Texas A&M University

Figure 1. Generalized diagram of a typical residential septic system.

Traditional septic systems (Figure 1) consist of a septic tank (~1,000 gal.) and a subsurface leach, or drain field (sometimes called a tile field) to treat gravity fed wastewater generated from toilets, sinks, bathing and laundering. The septic tank separates the solid components of the wastewater stream from the liquids. The solids and potential pathogenic microorganisms and chemical contaminants are partial broken down by a combination of aerobic (in the presence of oxygen) and anaerobic (without oxygen) processes utilized by microorganisms that are naturally present in the wastewater stream. The solids (sludge) collects in the bottom of the tank, while the scum floats on the surface of the liquid. (USEPA, EPA/625/R-00/008, February 2002) Baffles in the tank are intended to prevent sludge and floatables from reaching the lateral drain pipes and clogging the drain field. Clogging of the drain field is one to the primary ways septic systems fail. Unfortunately, when septic systems fail to properly function, biological contaminants such as viruses, pathogenic bacteria, fungi and protozoans can reach the groundwater. These contaminants can have negative impacts on public health, potentially far from the site of the failure. Additionally, local surface water quality can be significantly degraded from the release of nutrient-rich and bacteria-laden wastewater.

Septic System Failure

Septic tanks and drain fields have been the sources of groundwater and surface water pollution (Craun, 1979, 1984; Fetter, 1994; Katz et al., 2009). Many infectious disease outbreaks and water-borne diseases have been traced back to one or more failed septic systems (Bicki, 1989; DeBorde et al., 1998; Fong et al., 2007). Improper siting and poor design are two of the primary causes of septic system failure. When siting and designing a septic system the location and depth of the drain field (relative to the groundwater table) are the most critical steps in assuring reduction of contaminants and dispersal of septic wastewater. Key components of proper design and siting of drain fields are the permeability of the local soils and the frequency and duration of inundation of subsurface soils by groundwater ("drainage class"). Low permeability of certain soil types slows the vertical and horizontal movement of liquid wastewater. Low soil permeability will cause septic drain fields to function poorly or fail, often resulting in wastewater backing up and being present at or near the ground surface presenting a public health issue (as photo documented in Figure 2).

Figure 2. Failing septic system on north end of Hilton Head Island with Intracoastal Waterway in background.

The maintenance of an appropriate vertical distance between the bottom of the drain pipe and the surface of the groundwater table (unsaturated zone) is critical to effective and efficient decontamination of wastewater in the area of the drain field. This unsaturated zone is where wastewater is decontaminated and treated through physical, chemical, and biological processes. In this zone, aerobic microorganisms in the soil break down contaminants and effectively remove pathogenic microorganism from the wastewater as it moves vertically through the zone. Once the wastewater reaches the groundwater table (saturated zone) anaerobic conditions exist and decontamination processes become very slow because of the absence of sufficient concentrations of oxygen. After potential contaminants reach the saturated zone they can migrate horizontally relatively quickly along natural groundwater migration routes (typically down topographic gradients). This horizontal movement of groundwater can result in contaminants migrating away from the site/property from which they were released, potentially contaminating neighboring properties or surface water down-gradient.

The frequency and duration of inundation of subsurface soils by groundwater varies by location, topographic elevation (above sea level), soil type, and season. (Schoeneberger, 2002) Often soils that have low permeability also have poor drainage which makes them poor candidates for septic system siting. Additionally, low lying areas should also be avoided because they have very short vertical distances between the ground surface and the top of the groundwater table. Seasonal difference in the groundwater table elevation, due to lack of evapotranspiration by trees during winter months, results in groundwater being at or near the ground surface for a significant portion of the year. These areas with seasonally high water tables should be avoided when installing septic systems.

Improper maintenance of septic systems is one of the primary causes of septic system failure. It is critical to prevent solids and floatables from reaching the drain field. When solids, fats, oils and biological waxes reach the drain field the pore spaces between the soil particles could become clogged, reducing the natural filtration and contaminant degradation that occurs within the drain field. Clogging this interstitial space between soil particles reduces permeability and, in extreme circumstances, artificially raises the water table limiting the thickness of the unsaturated zone (Figure 3). The result is lack of decontamination and more rapid horizontal migration of contaminants off site. Under-sink garbage disposals, paper products, cooking oils and feminine hygiene products should not be discharged into septic systems as these materials often cause blockage and failure of the system.

Local Conditions That Affect Septic System Performance

Hilton Head Island is located in the Sea Island Coastal Region of the Atlantic Coastal Plain and includes geological deposits which formed and were reworked by fluctuations in sea levels during the Pleistocene epoch. Fine sands, muds, silts and clays make up the majority of the soil types found on Hilton Head Island. The Island is characterized by a "corrugated" dune ridge and slough landscape where narrow, old sand dune ridges are separated by low-lying sloughs, some with forested wetlands.

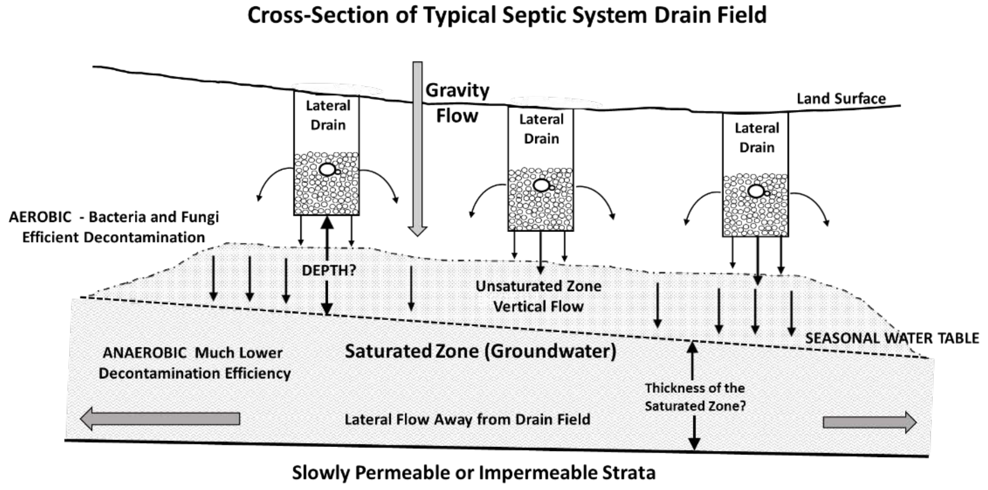


Figure 3. Addition of sanitary wastewater to the drain field artificially raises the groundwater table further restricting the depth of the unsaturated decontamination zone

One of the practical consequences of this geologic landscape is that upland (dune ridge) habitat – which might be suitable for traditional septic system designs – is quite limited and typically bordered by broad, low-lying sloughs and wetlands. Soil types found in these sloughs include Hydric (wetland) soils (Table 1) that present significant challenges in the proper operation of a septic system (Stuck, 1980). Hydric Soils are defined as a soil that formed under conditions of saturation, flooding or ponding long enough during the local growing season to develop anaerobic conditions near the ground surface (59 Fed. Reg. 35680, 7/13/94). If the zone of decontamination underlying septic system drain fields is not greater than 12 inches there is a strong likelihood that the septic system will fail to function effectively. If the water table is at or near the ground surface, septic system wastewater will directly impact the public and potentially run off into adjacent surface waters (Vogel and Rupp, 1999; Ward and Trumble, 2003). Clearly septic systems installed over hydric soils cannot function as intended. Complicating this problem is the fact that sanitary wastewater distributed throughout the drain field can artificially raise the local groundwater table, further reducing the amount of time wastewater is retained within the unsaturated zone (Figure 3). Additionally, locally heavy precipitation can raise the local groundwater table very quickly leading to rapid failure of the drain field as well as enhancing runoff into surface water. High rainfall has been shown to reduce this filtration process by saturating the soil allowing contamination of groundwater and surface water (Hagedorn, 1984).

Hydric Soils of Beaufort County, SC	
Soil Type	*Depth of water table from surface*
Argent	0.0’ – 1.0’
Baratari	0.0’ – 1.0’
Bladen	0.0’ – 1.0’
Bohicket	+3.0’ – 0.0
Cape Fear	+0.5’ – 1.5’
Capers	+1.0’ – 1.0’
Deloss	0.0’ – 1.0’
Fripp	0.0’ – 1.0’
Handsboro	+3.0’ – 0.5
Hobonny	+1.0’ – 0.0
Levy	+2.0’ – +1.0’
Okeetee	0.5’ – 1.0’
Osier	0.0’ – 1.0’
Pinckney	0.0’ – 1.0’
Polawana	0.0’ – 0.5’
Rosedhu	0.0’ – 1.0’
Santee	0.0’ – 1.0’
Sewee	1.0’ – 2.0’
Tomotley	0.0’ – 1.0’
Wahee	0.0’ – 1.0'
Williman	0.0’ – 1.0’
Yemassee	0.0’ – 1.5’
Yonges	0.0 ‘– 1.0’

Table 1. Depth to water table from ground surface (in feet) for Hydric Soils found in Beaufort County. Positive values indicate water table is above the ground surface

Some sandy soils (Wando) found on high, old dune ridges (i.e. Brahms Point on Hilton Head Island) have high permeability but relatively deep water tables. These areas are excessively drained and septic wastewater moves so rapidly in the vertical direction that it is not retained in the decontamination zone long enough to effectively decontaminate and de-nutrify the wastewater. Inorganic nutrients like nitrogen, phosphorous and chloride can move quickly through the unsaturated zone without being attenuated. Locally, groundwater migrating through these soils typically discharges to tidal surface water; therefore, the potential does exist for septic systems in excessively drained soils such as Wando soils to impact water quality.

Conditions on Hilton Head Island are not ideal for the use of on-site disposal systems such as septic systems. Historically a succession of high and low sea level stands during the Pleistocene epoch have reworked the local soils in such a way that very fine sands, silts and clays dominate the soil types found on the Island (Zeigler, 1959). Many of these soil types exhibit low permeability and therefore drain very slowly. A high percentage of soils on Hilton Head Island are Hydric Soils. As identified in the Soil Survey of Beaufort and Jasper Counties, SC (Stuck, 1980), the surficial water table is at, or near the ground surface for a significant portion of the time (Table 1). Clearly, septic systems located in the areas where these soils are present are much more likely to fail even under normal operating conditions.

Documented Local Impacts of Septic System Failure

The PSD is a special purpose district created by the South Carolina General Assembly in 1969 to provide water and sewer services to Hilton Head Island. Residents of the Island relied on private wells and on-site wastewater disposal systems (mostly septic tanks) for their drinking water and wastewater disposal needs until 1957. At that time, a local development firm called the Hilton Head Water Company introduced a community waterworks system, installing water lines and drilling wells throughout the Island. As the community expanded and development progressed, however, Hilton Head Island citizens became increasingly aware of the need for enhanced services, a need especially apparent in fire protection.

In 1995 the Hilton Head Public Service District (PSD) was formed from the consolidation of several smaller utilities. Today, the PSD serves more than 18,000 customers in the north- and mid-island areas of Hilton Head Island.

The PSD presently operates the sanitary sewer system in a section of the Island where sewer access has yet to be provided to all properties. Residents in the areas report many examples of not being able to take showers or wash clothes after periods of rainfall due to malfunctioning septic systems. Even worse situations include homeowners who have suffered property damage to floors, walls, and furniture as a result of failing septic systems sending household wastewater back into the home.

Recently (24 April, 2015) the local newspaper, *The Island Packet* reported that (http://www.islandpacket.com/2015/04/24/3715642/unpaved-roads-aside-residents.html) many residents on the Island experience foul odors and pools of household wastewater on the ground in their neighborhood as a result of malfunctioning septic systems. Residents fashion makeshift barricades around the failed systems using PVC pipe and tarps, or place pieces of plywood over them. “But when it rains, the makeshift solutions don't work, and the sludge comes pouring out. A few months ago, a little boy tripped and fell into a sewage pile," the newspaper story reports.

Unfortunately, many properties on the Island that lack access to the sanitary sewer system are owned by low-income residents who cannot afford the cost of sewer connection. A partnership among the PSD, the Town of Hilton Head Island, and Project SAFE (Sewer Access for Everyone) – a charitable fund of the Hilton Head-based Community Foundation of the Lowcountry – is working to provide sewer access and connection assistance for low-income homeowners.

Veronica Miller, a Hilton Head Island schoolteacher and president of a Native Islander neighborhood association, had to use blankets and quilts to clean up the interior of her home after her septic system backed up in spring of 2015. This had been a regular occurrence for Miller. In the summer of 2015, her home was connected to the PSD's sanitary sewer system thanks to a grant from Project SAFE.

The solution to this problem is obvious: extend sanitary sewer connections to all residents and businesses on Hilton Head Island. The PSD has developed a Master Sewer Plan that details the sewer projects necessary to provide access throughout its service area. The utility is planning to fund $1 million for regional sewer pump stations needed under the plan. The Town of Hilton Head Island is planning to fund $3.5 million for the sewer lines called for by the plan, and Project SAFE is embarking upon a $3 million capital campaign to fund low-income homeowners' connection costs.

One of the critical considerations in this planning process is assuring that residents in areas that are most prone to septic system failure are offered sewer connection access as soon as practical. To this end, a hazard analysis was conducted to identify which areas of the PSD service area were at the greatest risk of exposure to the harmful impacts on public health and the environment caused by septic system failure.

Hazard Analysis

We were able to conduct a hazard analysis of soil types located within the PSD service area on Hilton Head Island using pre-existing data sets (Table 2) available from the Town of Hilton Head Island, the Federal Emergency Management Agency (FEMA), U.S. Fish and Wildlife Service (USFWS) and the Natural Resources Conservation Service (NRCS).

LIDAR Base Elevation Data – Beaufort County GIS
USDA-NRCS Soil Survey Maps
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627
FEMA Flood Zone Maps: Searchable
http://www.hiltonheadislandsc.gov/publicsafety/flood/floodzonesearch.cfm
USFWS National Wetland Inventory (NWI) Maps
http://www.fws.gov/wetlands/Data/Metadata.html

Table 2. Digital mapping data bases used in the development of the hazard analysis of soil types

The first step in the hazard analysis was to make a list of project-appropriate assumptions that would guide the implementation of the analysis. These assumptions were based upon general data regarding the factors that would most affect septic system performance. These included soil permeability and expected drainage patterns in relation to land position/elevation differences. The first and most logical assumption is that we would consider only areas on Hilton Head Island within the PSD service area. Secondly, areas that were tidally inundated or wetlands that were permanently or seasonally inundated were excluded from the analysis because no septic systems were found there.

The next assumption in the hazard analysis considers the effect of soil permeability on septic system performance. Based upon the NRCS Soil Survey for Beaufort and Jasper Counties (Stuck, 1980), soils that have slow permeability are not suitable for the effective operation of septic systems. Also, soils that have rapid permeability are poorly suited for septic system operation. The permeability scoring system developed for this hazard analysis (Table 3) considered soils with permeability scores of 2 or lower to be poorly suited for effective septic system operation.

Soil Permeability	Soil Permeability Score
Very Slow Permeability	1
Slow Permeability	2
Moderately Slow Permeability	3
Moderate Permeability	4
Moderately Rapid Permeability	3
Rapid Permeability	2

Table 3. Permeability scoring system developed for the hazard analysis

In addition to soil permeability the hazard analysis considered the effect of drainage class on septic system performance. Based upon the NRCS Soil Survey, soils that have poor drainage or are excessively drained are not suitable for the effective operation of septic systems. The Drainage Class scoring system developed for this hazard analysis (Table 4) considered soils with Drainage Class scores of 2 or lower to be poorly suited for effective septic system operation.

Soil Drainage Class	Soil Drainage Score
Very Poorly Drained	1
Poorly Drained	2
Somewhat Poorly Drained	3
Moderate Well Drained	4
Well Drained	3
Excessively Drained	2

Table 4. Drainage Class scoring system developed for the hazard analysis

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The goal of the hazard analysis was to develop a risk-based hazard ranking system that could then be used to consider how much risk to public health and the environment could be mitigated as a result of the sewer line extension planning process. Therefore, the final step in the hazard analysis process is the computation of a final soil type "Risk Score" and assignment of a "Hazard Class" to each type of soil found within the PSD service area. The primary assumption that was made in the calculation of the Risk Score was that the combined effect of soil permeability and soil drainage characteristics would more accurately inform the users of this hazard analysis as to the risk of septic system failure in these soil classes. Consequently, the Risk Score was calculated by simply adding the soil permeability score and the soil drainage class score together (Table 5).

In assigning the Hazard Class, three different Hazard Classes were established:

- **HH** = **High Hazard** (Risk Score of 3 and lower, or 5 and lower if either the soil permeability score or drainage class score was 1)
- **MHH** = **Moderately High Hazard** (Risk Score 4 or 5 except when either the soil permeability score or drainage class score was 1)
- **LMH** = **Low - Moderate Hazard** (Risk Score 6 or higher)

The High Hazard Class designation should indicate to the users of this Hazard Analysis that properties found within these soil class zones have an extremely high probability of septic system failure and are not suited for effective septic system operation. The Moderately High Hazard Class designation should indicate that properties found within these soil class zones have a moderate to high probability of septic system failure, especially in winter months or during significant precipitation events. These soil types are poorly suited for effective septic system operation. The Low - Moderate Hazard Class designation should indicate that properties found within these soil class zones have a low to moderate probability of septic system failure. They are more prone to failure during winter months or during exceptional precipitation events. These soil types are moderately well suited for effective septic system operation especially when water tables are greater than three feet below the surface.

Hazard Class	Soil Map Units in PSD Service Area
High Hazard	Bohicket, Capers, Cape Fear, Hobcaw, Handsboro, Hobonny, Levy, Pinckney, Lynn Haven, Santee
Moderately High Hazard	Argent, Leon, Osier, Ogeechee, Bladen. Yonges
Low - Moderate Hazard	Leon. Pinckney, Williman

Table 5. Hazard Class designation for each soil type found within the PSD service area on Hilton Head Island.

GIS Mapping and Sewer Line Extension Planning

Once the hazard ranking of each soil type found within the PSD service area was completed the mapping of each hazard class could proceed. Utilizing the substantial Geographic Information Systems (GIS) capabilities of the PSD, soil types of the same Hazard Class were grouped and mapped as four “Hazard Class Units” (High, Moderately High, Moderate, and Low) on a base map that included tax parcel data layer and NWI wetland data. This new Soil Hazard Class Map was combined with the PSD Master Sewer Plan map (Figure 4) resulting in project-site, parcel-specific information about the current risk to public health and the environment at each of the PSD’s Sewer Master Plan project sites.

This combination of environmental and public health risk data and project planning tools like GIS will provide the end users with critical risk-based information that was previously unavailable. Certainly environmental and public health protection aren’t the only factors to be considered on large capital projects like the PSD Master Sewer Plan, but they should be given equal weight in the planning and decision making process. This effort demonstrated that locating, analyzing and mapping environmental and public health data is relatively inexpensive and not very labor intensive when compared with engineering and contractor support required on capital projects. It provided useful information that can aid in future planning and project scheduling.

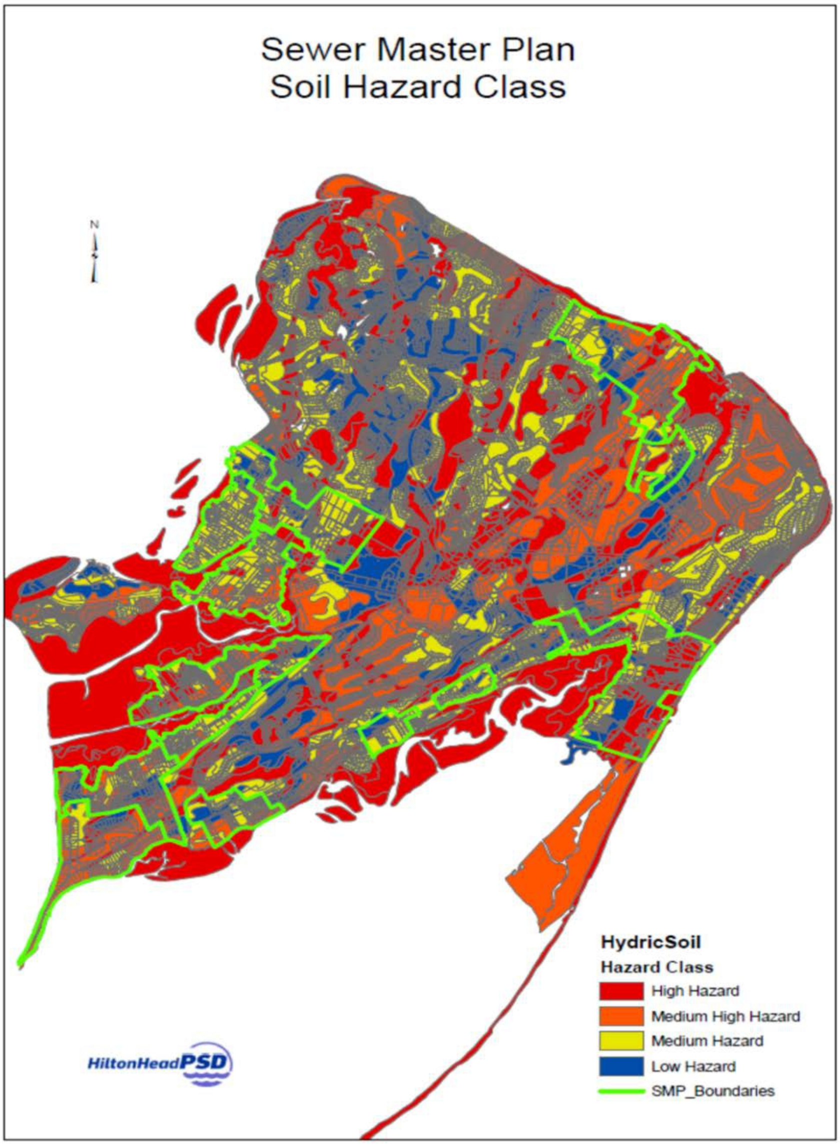

Figure 4. Soil Hazard Class Map combined with the
PSD Master Sewer Plan map

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