SPATIAL PATTERNS OF NUTRIENT LOADING IN THE FALL KILL: EVALUATING THE INFLUENCE OF SEPTIC SYSTEMS ON A HUDSON RIVER TRIBUTARY

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

The Fall Kill watershed is a tributary to the Hudson River that spans rural headwaters to urban downstream areas. It is dominated by excessively drained soils and near-surface bedrock creating shallow soils, and it contains numerous distributed septic systems. These characteristics are common throughout the region, and ultimately influence the health of the Hudson River Estuary as a whole. To better understand the high-resolution spatial patterning of any excess nutrient pollution, and how it may be related to factors on the landscape influencing septic system functioning, this study has two components: 1) in-situ electronic measurements of nitrate concentration longitudinally along the stream (50 m resolution) and 2) investigating the relationship between a) land use and land cover, economic data, and septic data from tax parcel datasets and b) N and enterococci concentrations, serving as an easy-to-quantify proxy approach for measuring human-derived septic contaminants along the Fall Kill watershed at a high spatial resolution. Longitudinal in-stream levels of nitrogen have shown high spatial variation in relation to properties with the presence of on-site septic systems. Of 17 observed spikes in nitrogen observed along the Fall Kill, nine of those spikes had strong evidence of possible septic system influence. Dense populations of residential properties with on-site septic systems had the highest levels of enterococci counts, helping indicate a high likelihood of a septic influence to the nitrogen spikes observed there. Unsuitable soils dominate that area, further supporting the hypothesis that on-site septic systems are contributing to contamination of the Fall Kill.

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INTRODUCTION

CyanoHABs (Cyanobacterial Harmful Algal Blooms) are a critical problem the Hudson River watershed faces and present multiple ecological, public health and economic issues (NOAA 2021). Under a warming and more variable climate, the risks of CyanoHABs are growing worldwide. Research shows that upriver Hudson River tributaries are large contributors to nitrogen pollution to the Hudson River. HABs occur in eutrophic, high nutrient water bodies, which has led to necessary investigation into point and nonpoint sources of nutrient loading from Hudson River tributaries (Howarth 2011). Investigating possible sources of nutrient contamination will help with local and regional efforts in the creation of reduction and mitigation strategies of cyanoHABs. Examining nutrient loading from anthropogenic activities, specifically decentralized septic sewers, will further help understand the complexity of the CyanoHABs threat in the Hudson River (Hudson River Sloop Clearwater 2012). This study examines the Fall Kill Watershed, a tributary to the Hudson River.

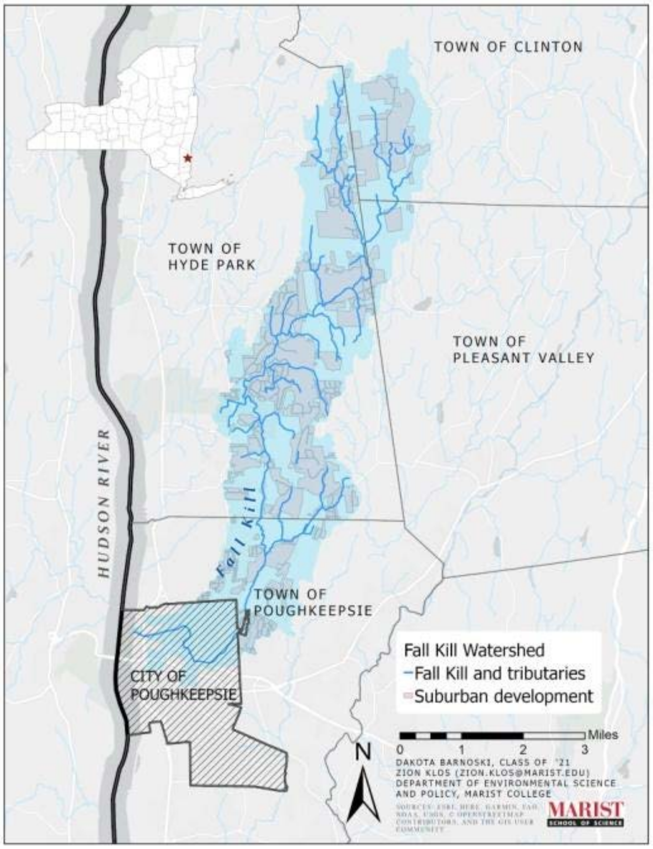


Figure 1. The Fall Kill Watershed in Dutchess County, NY (Barnoski 2020).

Water quality is dependent on multiple factors such as land cover, land use, climate, geology, and soil type (Lintern et al. 2018). This study focuses on water quality in the Fall Kill watershed (Figure 1), located within Dutchess County, NY, originating in northern rural Hyde Park, and traversing downstream through urban Poughkeepsie where it discharges in the Hudson River. Previous research on the health and quality of the Fall Kill and its watershed found high levels of chlorides, nutrients, heavy metals, and the presence of fecal coliform (Bean et al. 2006). Human activity and lack of investigation and remediation led to a continuous degradation of the watershed and stream. Consequently, these conditions led to the Class C stream classification limiting the use of the stream and inclusion on the List of Impaired Waters for New York State

(NYSDEC 2017). Contact with untreated or poorly treated wastewater has serious public health implications as well as ecological issues. Poorly treated wastewater can have lasting effects on the surrounding ecology by contaminating waterways and drinking water sources (Bender 2020).

The chemical and compositional characteristics of the soil influences the amount of nutrients and other anthropogenic constituents that are released into water bodies (Lintern et al. 2018). The soil composition varies greatly throughout the Hudson Valley from sandy loam, silty loam to fine silty clay (Walker and Groffman 2010). Current geospatial data indicate that excessively drained soils are abundant within the Fall Kill watershed (Figure 2). According to *"A Watershed Management Plan for the Fall Kill, Dutchess County, NY"* (Bean et al. 2006), which conducted an extensive soil analysis, 5,543 acres within the watershed contain soils that are excessively to poorly drained, and 5,084 acres are moderately to well-drained. The watershed is dominated by excessively drained and poorly drained soils that are often not suitable for the final treatment of septic tank effluent. The watershed is also dominated by residential properties with decentralized septic systems that rely heavily on soil properties to work efficiently and effectively (Bean et al. 2006; Bender 2020).

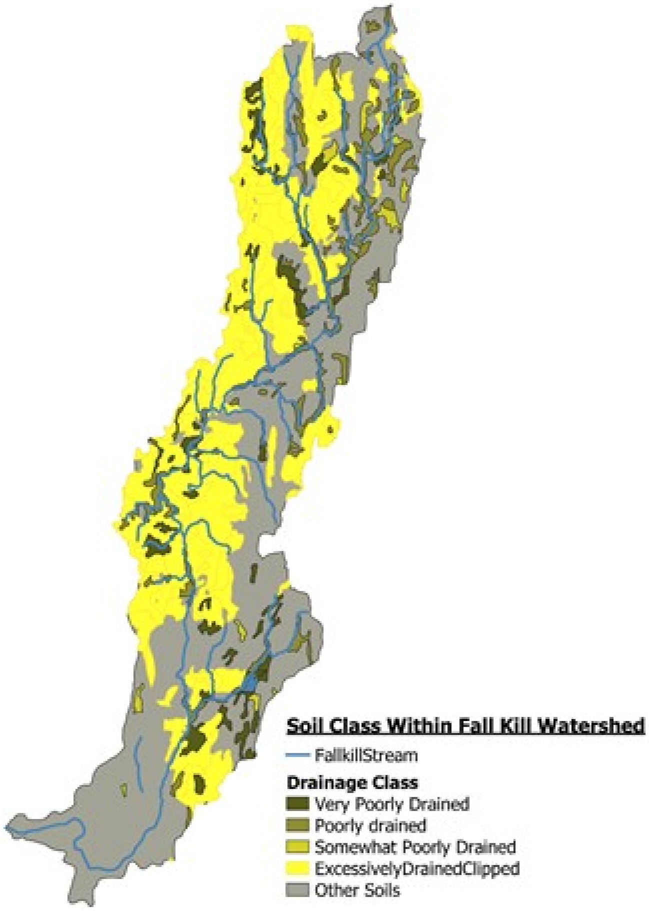


Figure 2. The soil class are projected to illustrate the abundant levels of unsuitable soils for the final treatment of effluent.

Decentralized sewer systems (Septic Systems) are underground waste water treatment structures that treat and filter waste water from onsite buildings (Vogel 2005; Cogger 1987). Septic systems are commonly used in rural areas with one in five American household units having them installed. A yearly increase of installations has led to a focus on treatment design, level of operation and maintenance geological conditions, soil composition and site conditions (US EPA 1980).

Septic systems are comprised of two main components (Figure 3): the septic tank and the absorption field. Waste water collected from kitchens, bathrooms and laundries that comprise of food, human waste, soaps, detergents, chemicals, and bacteria are sent to septic tanks for the first step of onsite wastewater treatment (Vogel 2005). Raw wastewater has enhanced levels of phosphorus and nitrogen from the various components. Raw wastewater flows into a large, watertight container (Septic Tank) buried underground several feet from the household unit. Heavy solids sink to the bottom to be decomposed by bacteria and light solids such as fats float on the top (Vogel 2005). The liquid effluent flows into a distribution box where it is discharged to the absorption field. The absorption field is comprised of several long perforated pipes placed in gravel filled trenches below the ground surface that allow for the final stage of treatment. The perforated pipes slowly allow liquid effluent to percolate downward into the soil where microbes and bacteria treat the remaining contaminants. Properly designed and effective absorption fields eliminate pollutants for acceptable water to be released into the surrounding environment or ground water (Cogger 1987).

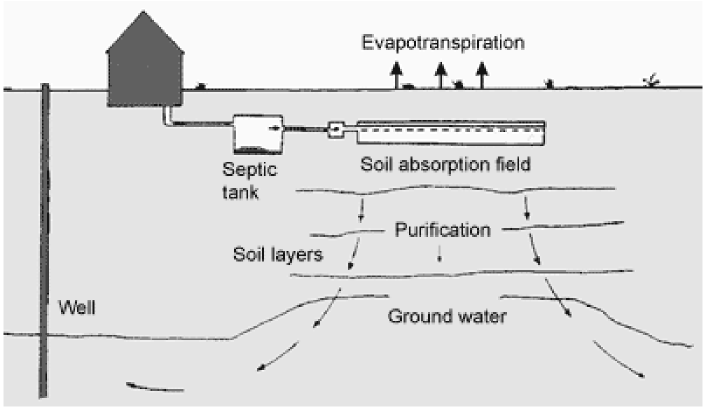


Figure 3: Wastewater Treatment and Disposal in the Soil Courtesy-North Carolina Extension Service. P (Vogel 2005)

The final treatment of effluent is heavily dependent on soil properties and the absorptive capacity to eliminate contaminants (Cogger 1987). The liquid effluent containing heightened concentrations of coliform, nitrates, phosphorus, and pathogens will be eliminated by natural filtering services that soil provides combined with further bacterial action from microbial communities (Holmquist 2012). Soil provides aerobic conditions for specific bacteria that break down the septic tank effluent (Bender 2020). Soil permeability, or the rate at which water moves through soil, is influenced by the percent composition of sand, silt, and clay (Bender 2020). Sand, silt and clay have different surface areas and pore size that lead to different rates of percolation (Walker and Groffman 2010). The texture and structure of the soil determines its absorptive ability. If effluent moves too quickly, pathogens and contaminants are not absorbed and broken down by bacteria effectively. If the soil is too compact, the septic tank effluent cannot percolate through the soil creating a barrier to water flow. Soils with varying sizes of particles such as loams, sandy loams, and loamy silt will provide the best balance between treatment and disposal (Holmquist 2012). The vertical depth of the soil also influences the effectiveness of septic tank effluent as the contaminates require contact time with the soil. Unsaturated soil is necessary to allow percolation downward without hitting water barriers. Distance from flood plains and low groundwater levels are essential to consider as saturated soils are less effective at properly treating and filtering septic tank effluent (Bender 2020). The Fall Kill watershed is dominated by unsuitable soils for the final treatment of effluent, high water tables, and faulty bedrock which lead contamination to water bodies quicker (Bean et al. 2006). Due to numerous variables that contribute to heightened levels of nitrogen and their complex nature, investigation into decentralized septic systems is necessary. Complex interacting variables such as land use, income level, and soil suitability can be represented spatially through Geographic Information Systems (GIS) technology.

The objective of this study was to identify and provide a high resolution spatial map of nitrate levels along the Fall Kill Watershed and understand patterns and relationships between decentralized septic systems and soil suitability. The hypothesis was tested that the locations of decentralized septic systems and areas of poor soil suitability would be spatially correlated with areas of high nitrogen concentration in the Fall Kill. Addressing decentralized septic sewers as a possible source of excess nitrogen will help management agencies, policy makers, and scientists create effective management strategies to mitigate and reduce excess nutrients from Hudson River Tributaries. Through longitudinal in-stream levels of nitrogen, high spatial variation in relation to existing geospatial data will fill knowledge gaps about the high resolution spatial interaction of soils suitability and stream health in this sub-optimal geologic setting to suggest areas of strong septic influence. This study provides suggestive spatial analysis for possible locations of excess nitrate from decentralized septic systems.

METHODS

a. Mapping *In-situ* Data points

Using Google Earth Pro, a pin was dropped every 50 m following the Fall Kill stream beginning at the mouth of the Fall Kill where it discharges into the Hudson River. Using the ‘ruler’ tool, every 50 m was measured out following the main stem of the Fall Kill until East Fishkill Road. The data locations were downloaded as a KML (Keyhole Markup Language File) and exported to google maps for local syncing of data collection points. For further use, the KML was uploaded into QGIS and turned into a shapefile.

b. Data collection

An electronic YSI Professional Plus instrument (pro Plus) portable water quality multiparameter instrument was used to measure in-situ nitrate levels. A 2-point calibration was performed using 1mg/L of nitrate calibration solution as the 1st point and 10 mg/L of nitrate calibration solution as the 2nd point. The nitrate sensor was properly calibrated each time prior to data collection. Following previously mapped out data collection locations, nitrate levels were collected walking upstream to avoid disturbing sediment to ensure accurate YSI readings. The YSI nitrate sensor was fully submerged for 30 seconds before recording parameters. The YSI was kept on during the entire data collection period even when it was out of the water.

Every 150 m water samples were taken using a 250 mL vial provided by Marist College. The vial was filled up and dumped out 3 times before filling up for a final time where it was capped tightly and placed in a cooler with ice packs. The water samples were taken back to the lab, filtered using a filtration cap, placed in an uncontaminated vial, numbered. then placed in the freezer. Once done with collection, the water samples were delivered to the Zarnoch Lab, Department of Natural Sciences at Baruch College CUNY, for further analysis of other forms of nitrogen and phosphorus levels. Analyzed nitrate and phosphorus was graphed and displayed based on each day collected.

Raw nitrate data was normalized within each data collection set. The average and standard deviation was found for each data collection set. Noticing a slight upward trend throughout each data collection set due to the electronic YSI probe, the normalized data was graphed. A line of best fit was added and the slope intercept equation was found. The distance from the trendline for each normalized data point was calculated.

c. GIS Layers

i. Watershed and Stream Data

Using NYS GIS clearinghouse National Hydrography Dataset, the Fall Kill Watershed and Stream was extracted and downloaded as a separate Shapefile for further use.

ii. Soil maps

Spatial Soil Data was obtained from USDA Natural Resource Conservation Service. Using QGIS, “Unsuitable” soils were extracted from the metadata. All Unsuitable soils features were clipped to be included within the Fall Kill Watershed shapefile. This excluded any features outside of the watershed.

iii. Properties with Decentralized Septic Systems

Dutchess County Parcel Data was obtained from the county by request. Properties classified as “Residential” and on a “Private” sewer were extracted and saved as a separate Shapefile. Properties outside the Fall Kill Watershed boundaries were clipped. Residential properties with decentralized septic systems were symbolized as a single fill centroid filled marker.

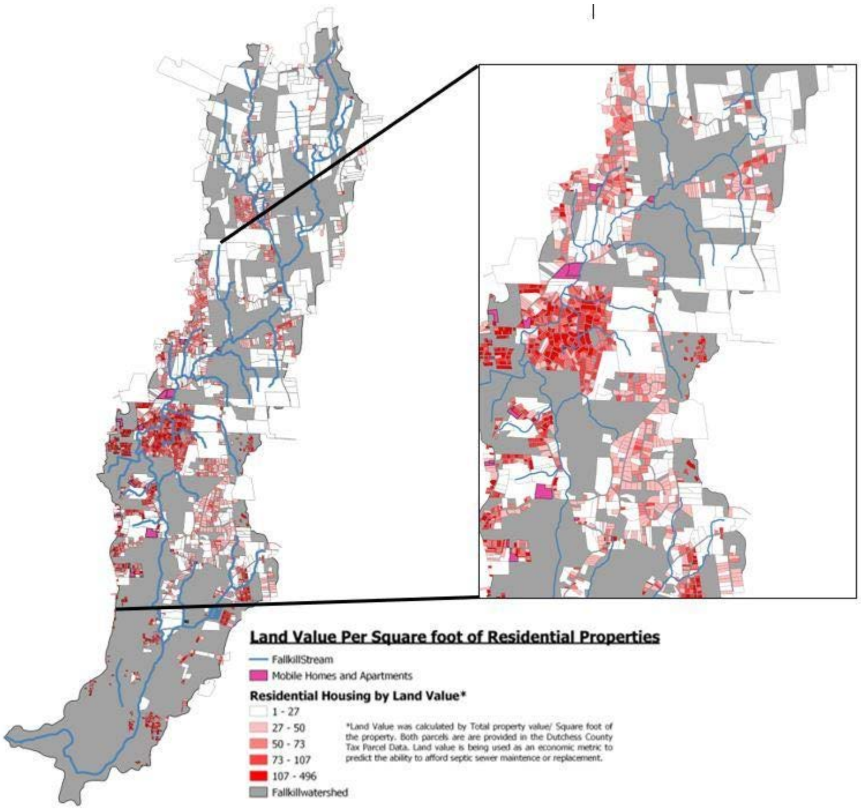
iv. Nitrate Data

Using the existing shapefile of data locations, the file was uploaded into QGIS. A detailed Excel sheet including the normalized nitrate data and the specific data location was saved as a Common Separated Value (CSV) file and joined to the shapefile including the nitrate locations. The normalized nitrate levels were hosted within the attribute table. The nitrate levels were symbolized as graduated and classified as equal count quantile and the color was a gradient of red where the higher levels are represented by darker red and lower levels are represented by light red and white.

d. Economic Metrics

The ability for individual homes to afford septic maintenance is very roughly estimated and predicted by land value. Individual income census data was not used in this study because it does not examine income level by property. Total property value divided by square footage of the land is potentially predictive of the ability to maintain and afford septic sewers by owner, but other economic metrics from the tax parcel data were also evaluated to look for any other predictors. Publicly obtained Dutchess County Tax Parcel Data was able to provide economic metrics at a high resolution leading to a more robust analysis. The Dutchess Tax Parcel Data contains varying data such as land use, location, and year built.

Although maintenance is costly, if septic systems are not regularly maintained, replacing a failing system is very expensive. Dutchess County is participating in a State Septic System Replacement Fund, a program that provides funds to property owners, but does not include routine maintenance (State Septic System Replacement Fund Program 2021). Novel research that includes location of non-point pollution sources on the Fall Kill will help fill knowledge gaps about the interaction of soil suitability, septic maintenance costs, and stream health – ultimately helping to better understand the issue, which can lead to improved economic programs to incentivize and publicly support nutrient remediation via redesign of individual systems. Poorly maintained septic sewers fail for multiple reasons including the lack of maintenance resulting in an increase in discharge and contaminants which influences the treatment efficacy within the septic system. Low income communities often disproportionally experience inadequate sewer services (Heaney et al. 2011). Investigation into correlation between high resolution observations of variation in nutrient input to the stream system with data land value per square foot and septic system (Figure 4) locations is necessary to fill in knowledge gaps regarding possible drivers of poor water quality, and to inform policy that can aid communities most in need of access to adequate wastewater treatment.


Land Value Per Square foot of Residential Properties

*Land Value was calculated by Total property value/ Square foot of the property. Both parcels are are provided in the Dutchess County Tax Parcel Data. Land value is being used as an economic metric to predict the ability to afford septic sewer maintence or replacement.

Figure 4. **Economic Metric reflecting the ability to afford Septic Maintenance and Replacement: Property value divided by the square footage of the land was roughly estimated to represent economic metrics to reflect the ability to maintain or replace on-site septic sewers. The variation of land value per square foot with on-site septic sewers is depicted.**

e. Identifying enterococci testing locations

Sampling locations were determined based on 9 long term standing enterococci monitoring sites on the Fall Kill watershed provided by the Fall Kill Coalition. Clear spikes and prolonged levels of nitrates from *in-situ* measurements were used as an objective criteria for choosing 9 additional enterococci locations and 9 locations that were considered spikes. Spikes in nitrogen were located based on prolonged areas of high nitrate levels. Using 100 mL sterilized plastic bottles, water was collected from each location. Immediately after collection the 100 mL samples were refrigerated until analyzed.

f. Enterococci Analysis

Enterococci levels were measured using the IDEXX enterolert system. The samples were prepared immediately after collection. Enterolert reagent was added to each 100 mL sample and shaken until dissolved. The sample was then added to a labeled Quanti Tray and Sealed. All 18 samples were properly labeled and incubated at 41 degrees ± 0.5 for 24 hours. The samples were individually viewed under a UV light and each blue fluorescent light was counted as positive. Using the Windows- based IDEXX MPN Generator Software, the most probable number was estimated at 95% confidence GIS map. Enterococci levels and locations were downloaded as a CSV file and included in a spatial GIS map.

RESULTS

In-situ nitrogen levels, enterococci counts and residential properties with on-site septic systems were depicted spatially using GIS. Nitrogen spikes were determined by the change in nitrogen levels (mg/L). Aerial images containing locations of on-site septic systems, land use and unsuitable soils were used to understand possible reasons for high levels of nitrogen in the areas labeled in Figures 5-12. Seventeen locations, lettered below, were analyzed based on the nitrogen change. Soil analysis, presence of septic system and enterococci counts were additional factors used to determine if the high level of nitrogen was from septic influence or other contributing source. Out of the seventeen locations, lettered in Figure 5, nine locations had strong indication of septic influence. Economic metrics used to predict the ability to afford septic maintenance or replacement or septic systems are represented in Figure 12.

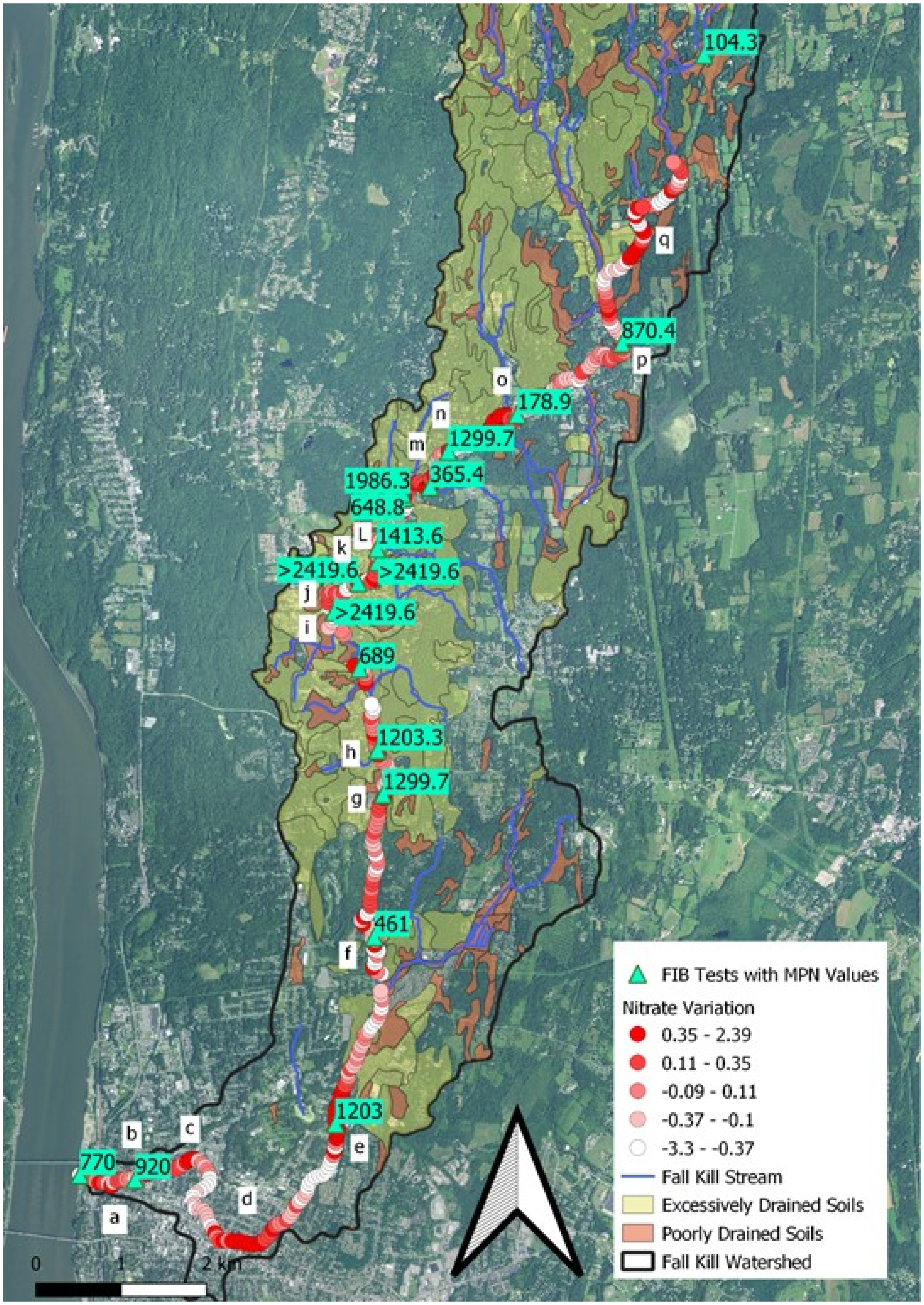


Figure 5. **Full extent of the Fall Kill Watershed located in Dutchess County New York; map depicting soil suitability, nitrate variation, enterococci counts and locations of sustained nitrogen spikes.**

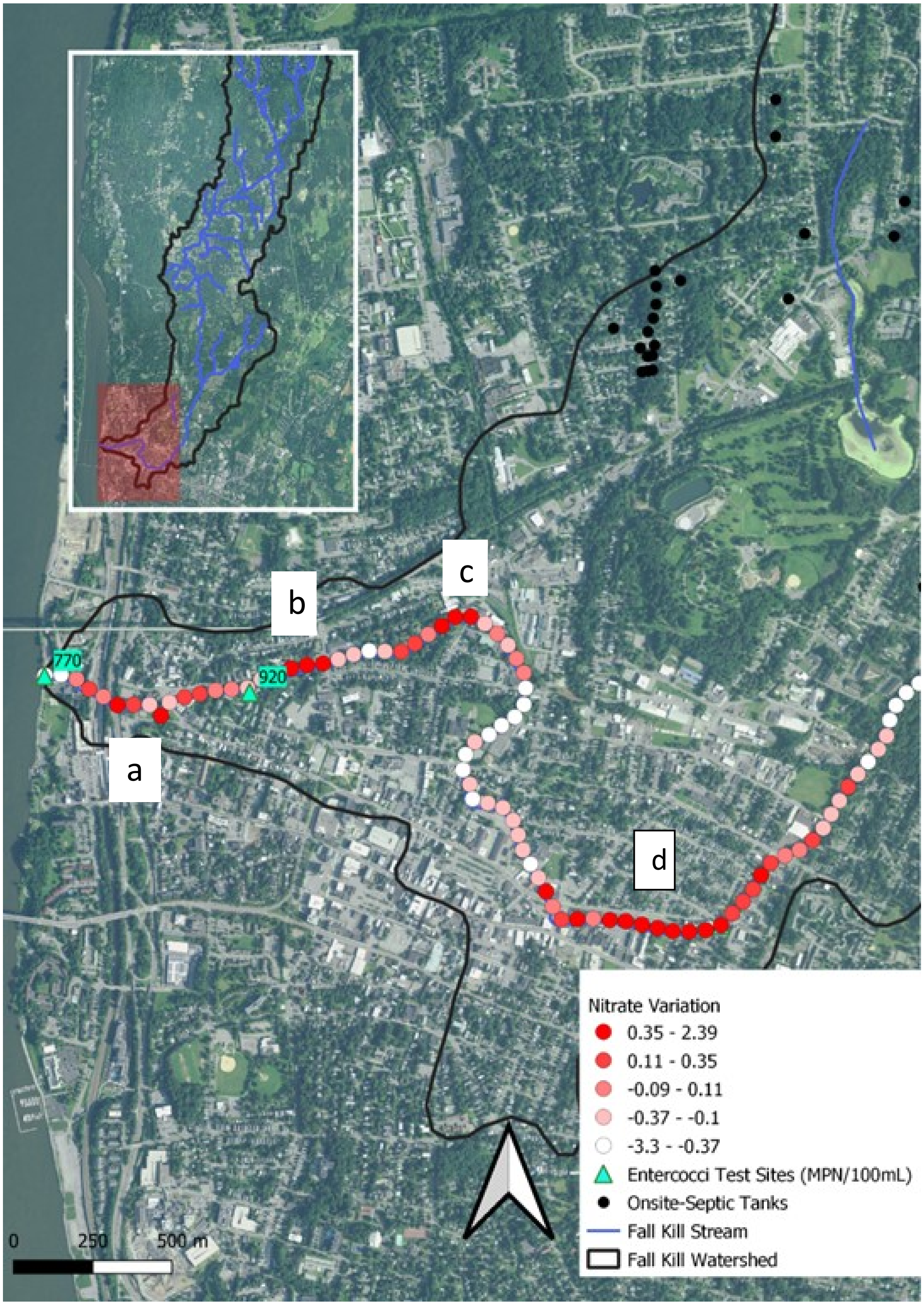


Figure 6. **The Fall Kill stream restricted by high rock walls within the City of Poughkeepsie. Map depicting nitrate variation and enterococci values collected in July 2021.**

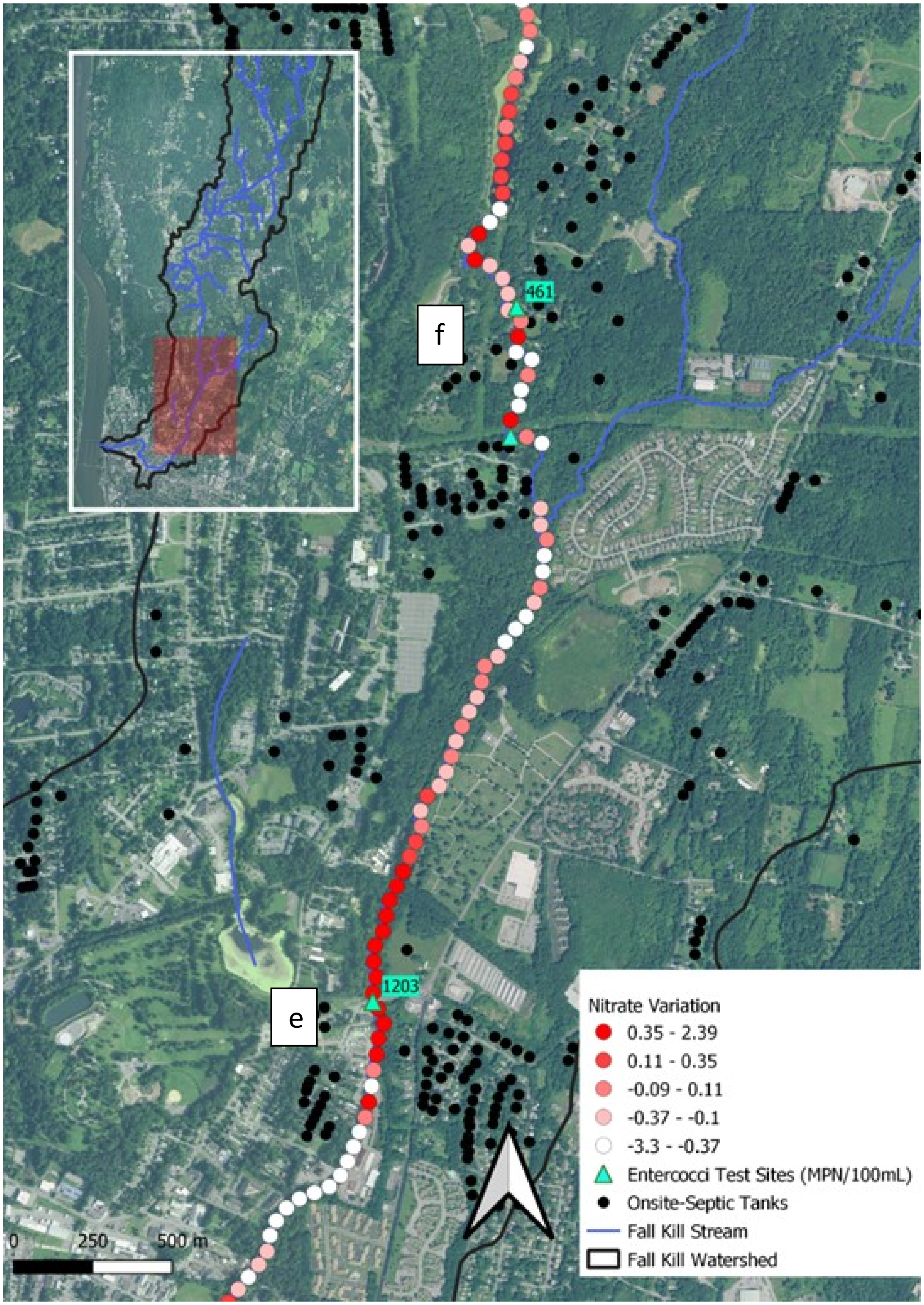


Figure 7. **The Fall Kill stream adjacent to the golf course and downstream from a cemetery depicting nitrate variation, enterococci values and on-site septic systems collected July 2021.**

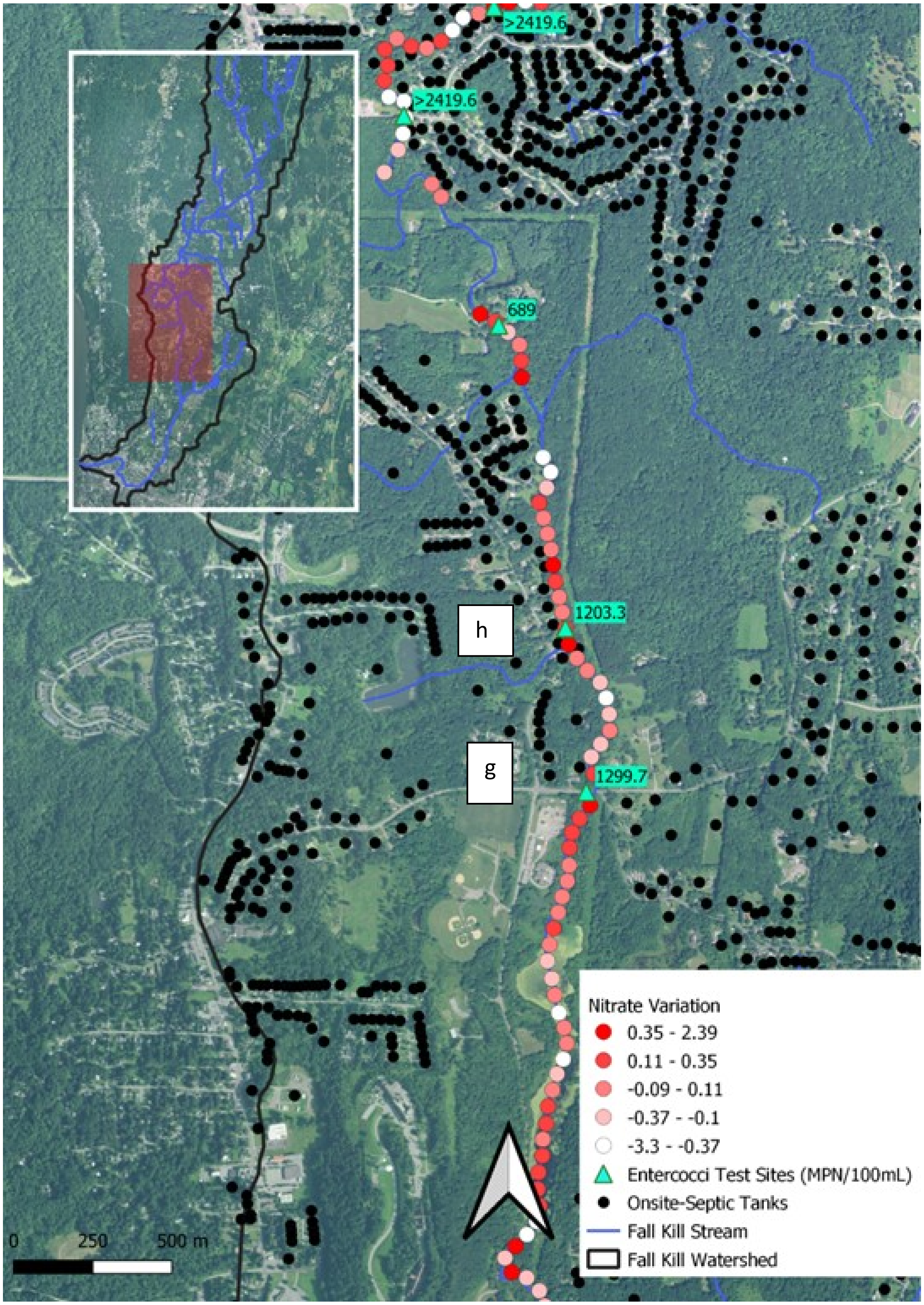


Figure 8. **The Fall Kill stream flowing through Hyde Park depicting nitrate variation, enterococci values and on-site septic systems collected July 2021.**

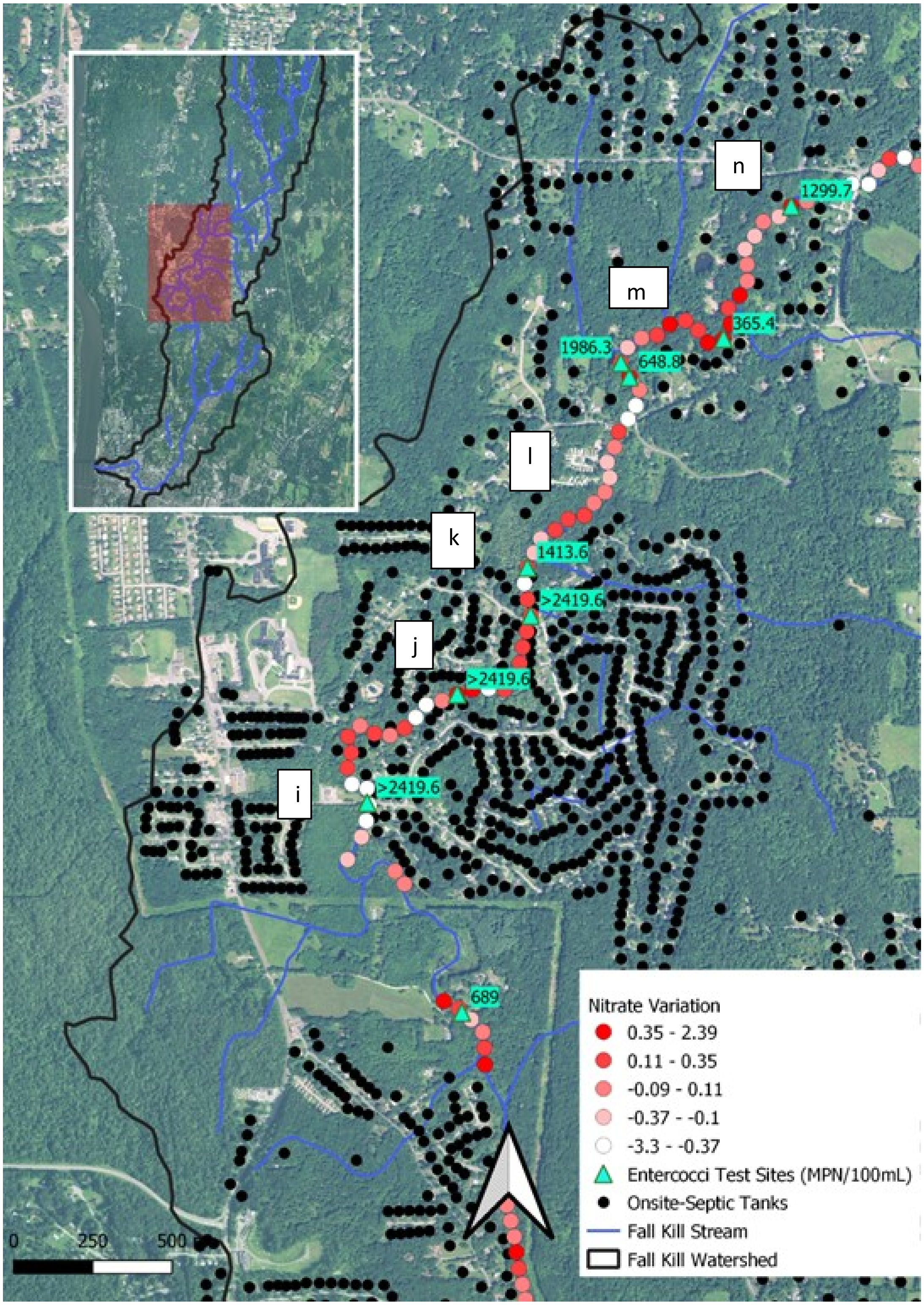


Figure 9. **The Fall Kill stream flowing through highly dense areas of residential properties depicting nitrate variation, enterococci values and on-site septic systems collected July 2021.**

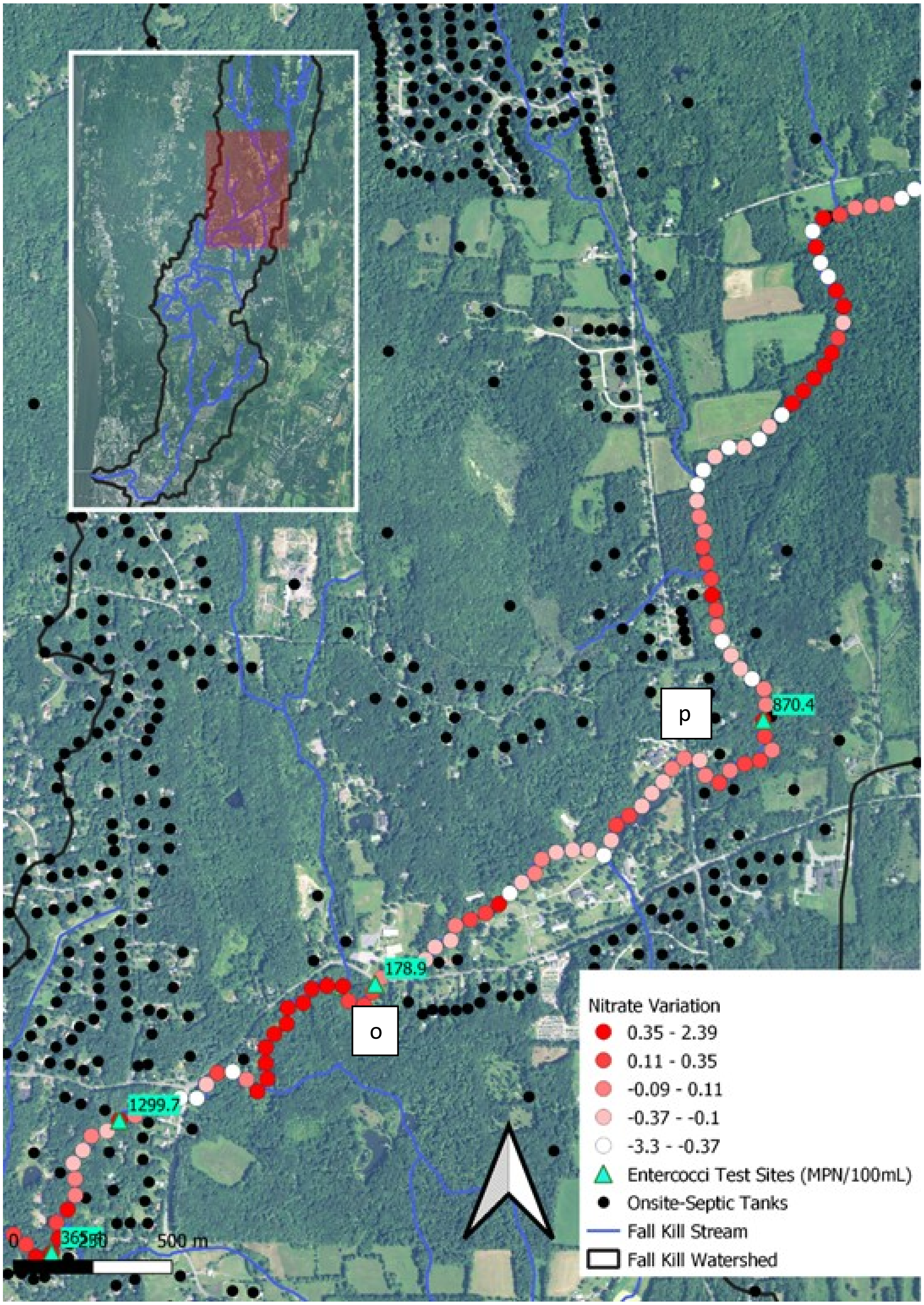


Figure 10. The Fall Kill stream flowing through forested areas with low population of residential properties depicting nitrate variation, enterococci values and on-site septic systems collected July 2021.

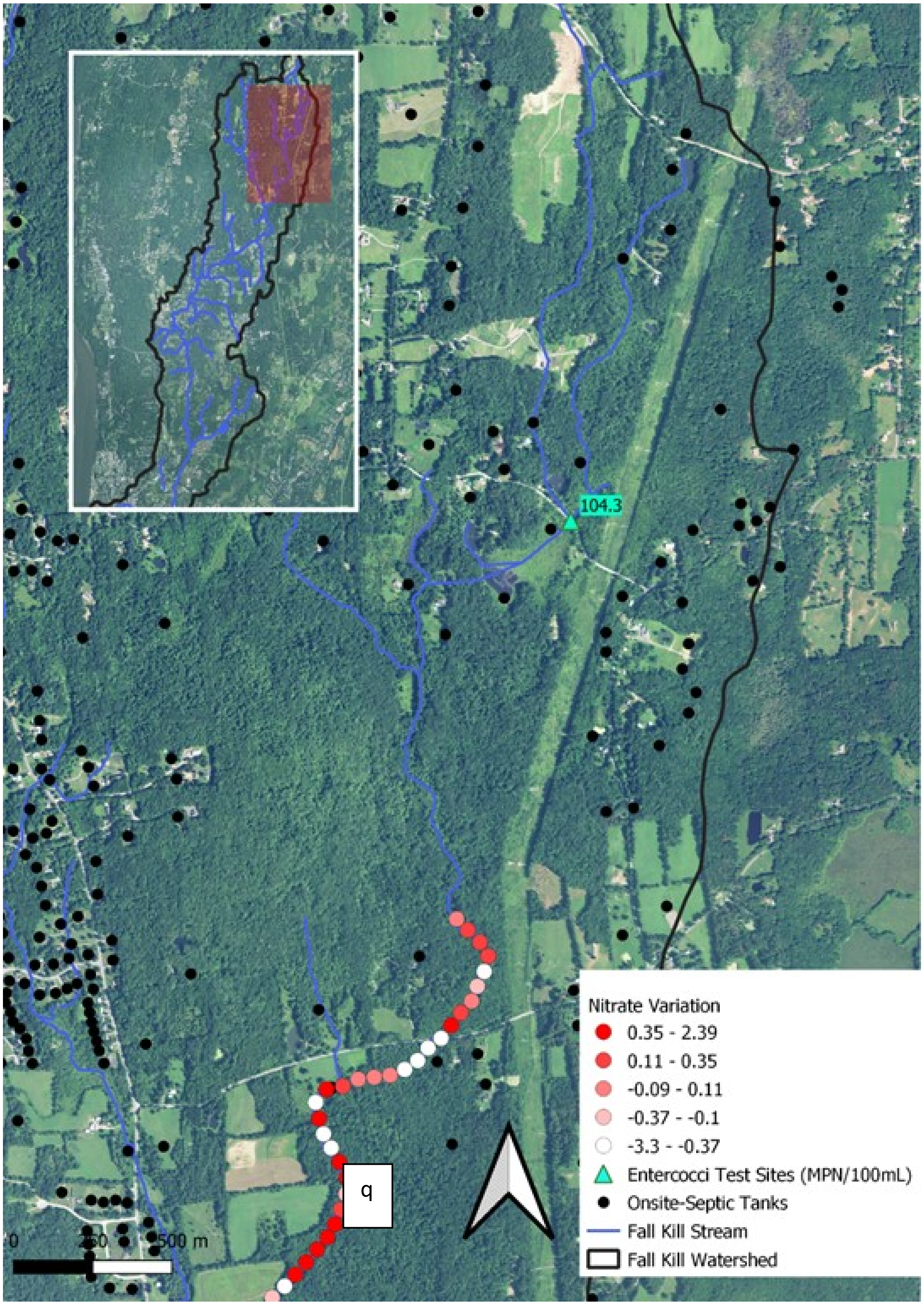
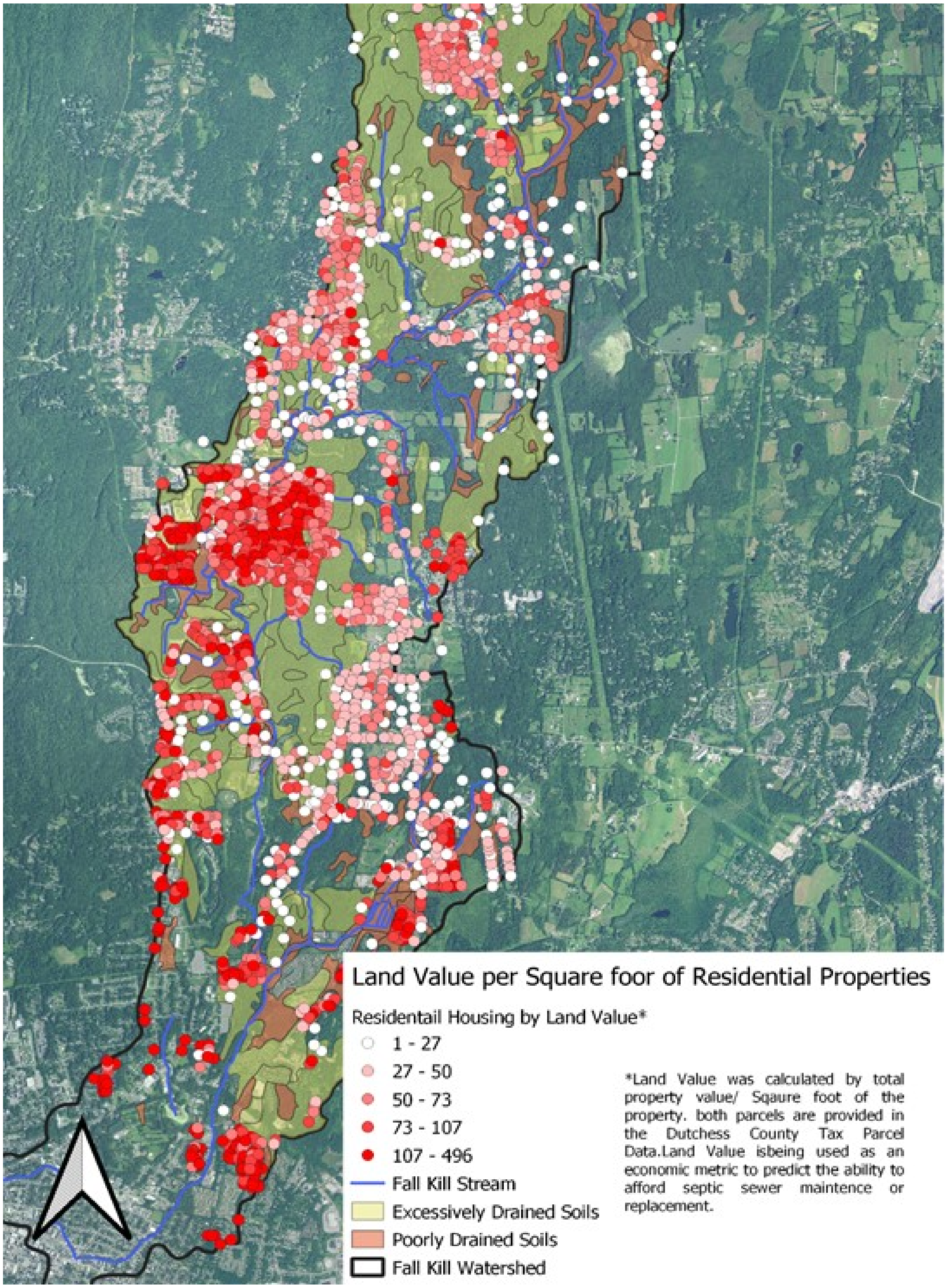


Figure 11. The headwaters of the Fall Kill stream flowing through forested areas with fields depicting nitrate variation, enterococci values and on-site septic systems collected July 2021.



*Land Value was calculated by total property value/ Sqaure foot of the property. both parcels are provided in the Dutchess County Tax Parcel Data.Land Value isbeing used as an economic metric to predict the ability to afford septic sewer maintence or replacement.

Figure 12. **The Fall Kill watershed depicting residential properties with on-site septic systems. Properties are categorized by land value per square foot to predict the ability to afford septic sewer maintenance or replacement.**

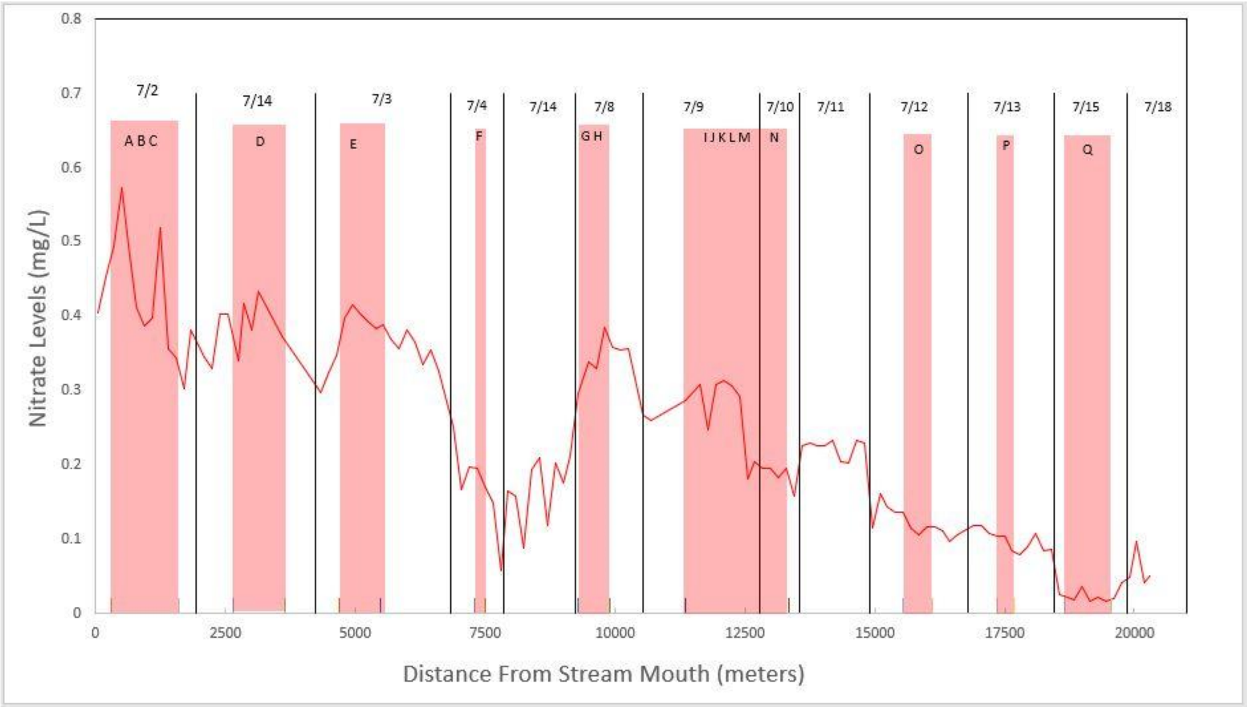


Figure 13. Water samples collected at 150m increments and tested for other forms of N (mg/L). Raw N data displayed within each data collection period. Areas of interest are depicted.

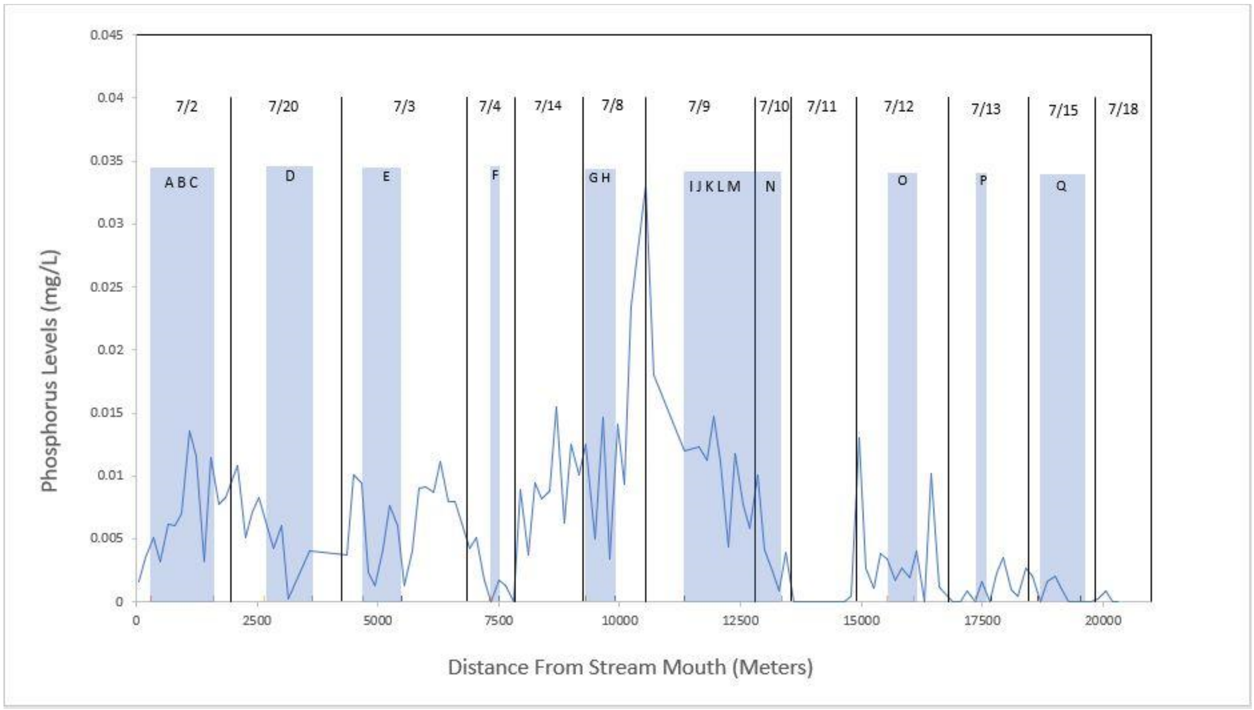


Figure 14. Water samples collected at 150m increments and tested phosphorus (mg/L). Raw P data displayed within each data collection period. Areas of interest are depicted.

DISCUSSION

The Fall Kill watershed is a unique Hudson River tributary spanning rural forested areas into dense residential areas and the City of Poughkeepsie. The watershed contains unique soils (Figure 5), high water tables, and faulted and fractured bedrock in addition to a dense population of residential properties with on-site septic systems. Soil properties, water tables and preferential flow paths through bedrock contribute to the effectiveness of a septic system (Bender 2020). The objective of this study was to understand spatially how Hudson River tributaries contribute excess nitrogen to the Hudson River, fostering an increased potential for CyanoHABS. Previous soil analysis (Walker and Groffman 2010) indicates the soils within the Fall Kill watershed are not well suited for septic systems, leading to a source of nitrogen. Through a GIS analysis, *in-situ* nitrate data was spatially analyzed in relation to on-site septic systems and enterococci counts. The following table (Table 1) provides a detailed analysis of each location containing a spike in nitrogen levels (defined by a sustained rise in nitrogen from lower background levels upstream), and possible reasons for the nitrogen spike (septic systems, fertilizer applications, etc.) deduced based on surrounding land uses. Of seventeen observed spikes in nitrogen observed along the Fall Kill, nine of those spikes had strong evidence of possible septic system influence (Table 1, Figure 9 l-n, Figure 8 g and h, and Figure 10 p). Dense populations of residential properties with on-site septic systems had the highest levels of enterococci counts (> 2419), helping indicate a high likelihood of a septic influence to the nitrogen spikes observed there (Figure 9). Unsuitable soils (Figure 5 and Figure 9) dominate that area supporting the hypothesis that on-site septic systems are contributing to contamination of the Fall Kill stream.

Enterococci and nitrate spikes were found (Figure 8h) within close proximity to properties with on-site septic systems further supporting the hypothesis that septic systems are nitrogen contributors. Water samples collected every 150 m analyzed for P and other forms of N (Figure 13 and Figure 14) indicate high variation in the areas of interest further suggesting strong influence of septic systems. The ability to afford replacement and maintenance of septic systems (Figure 12) had no clear spatial relation with nitrogen spikes and enterococci counts, suggesting the economic metric used may not be a viable proxy for the likelihood of poorly maintained septic systems. Likely geologic and soil controls have a more influential impact on septic effectiveness than the ability to maintain and afford septic systems in the Fall Kill watershed.

Table 1. Locations of nitrogen spikes seen in Figures with possible reasons for nitrogen spikes.

Location of nitrogen spike	Hydrologic setting	Enterococci count	Possible reason for nitrogen spike
Figure 6 a,b,c	City section of the Fall Kill. The stream is contained by high rock walls. The steam flows under bridges and tunnels.	770 and 920	Nitrogen spikes are located after road crossings. Potential leakage from buried street sewers. Low levels of enterococci counts were found (note: old combined sewer systems present, so post rainfall, sewers may be dominated by rainwater).
Figure 6d	City section of the Fall Kill the stream is contained by high rock walls. Pipes lead into the stream.	N/A	Prolonged high levels of nitrogen. Potential leaking from buried street sewers or illegal direct sewers entering the Fall Kill.

Figure 7e	Adjacent from golf course and downstream from cemetery.	1203	Fertilizers from cemetery lawns, and from Morgan Lake which collects fertilizers from golf course lawns.
Figure 7f	Forested area with low population of onsite septic systems.	461	Low levels of enterococci indicate that nitrogen spike may be from lawn fertilizer applications.
Figure 8g, h	Forested area with low population of onsite septic systems.	1299 and 1203	Likely septic influences. High levels of enterococci, and close proximity to on-site septic systems. Septic systems are also located within areas containing unsuitable soils (Figure 5g,h).
Figure 9 I,j,k,l,m,n	Residential Hyde Park.	>2419, >2419, >2419, 1413, 648, 1986, 365, 1299	Strong evidence of septic influences. High levels of enterococci and nitrate variation. Dense population of onsite septic sewers located within areas with unsuitable soils (Figure 5i,j,k,l,m,n).
Figure 10 o	Forested area downstream from Camp Victory Lake.	178.9	Low levels of enterococci counts. Likely lawn fertilizer due to location downstream from Camp Victory Lake.
Figure 10 p	Forested area.	870	Close proximity to on-site septic system. High level of enterococci counts. Likely septic influence.
Figure 11 q	Forested area and close to agricultural fields	N/A	Close proximity to fields, few septics present, suggests high nitrogen is from agricultural fertilizers.

Supporting evidence (Table 1) suggests that septic systems contribute excess nitrogen and human contamination to the Fall Kill. Watershed health is seen as a vehicle to increase community involvement and recreation, as well as boosting economic development (Hudson River Sloop Clearwater 2012; Bean et al. 2006). Better understanding of the causes of ineffective septic sewers will help the communities and organizations within the Hudson River Watershed, such as the Fall Kill Watershed Coalition, and the local Waterfront Revitalization Program Working Group in the City of Poughkeepsie make more informed decisions, and will help to obtain funding for remediation projects that fit the needs of both the stream and community while addressing contributors to Hudson River eutrophication, leading to increased potential for CyanoHABs. This information will inform policy that can aid communities most in need of access to adequate wastewater treatment. Future studies should examine sub-tributaries to the Fall Kill stream to further understand septic influence within more locations in the watershed.

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