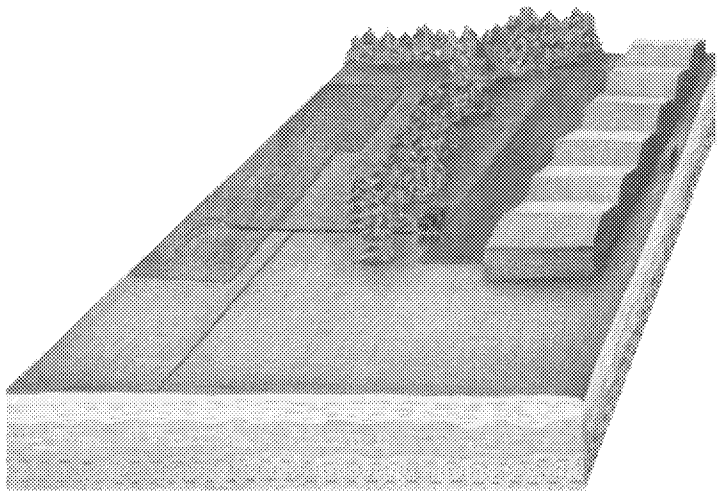
REVIEW AND EVALUATION OF USGS SURFACE WATER QUALITY DATA ASSOCIATED WITH SWINE AND POULTRY CAFOS IN EASTERN NORTH CAROLINA



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for

THE NORTH CAROLINA PORK COUNCIL

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Executive Summary

Geo Solutions was retained by the North Carolina Pork Council to review and evaluate water quality data collected as part of a U.S. Geological Survey (USGS) study. We were tasked with evaluating (1) the reliability of the data and whether it is sufficient to achieve the study's primary objective of characterizing surface water quality associated with swine CAFOs in eastern North Carolina; (2) the deficiencies, if any, in the design and execution of the USGS stream sampling plan; and (3) the data's value, if any, in identifying variables that most closely correlate with nutrient impairment in agricultural watersheds, and thereby serve as the basis for targeted initiatives to improve surface water quality in these watersheds.

In addition to reviewing and evaluating the USGS stream sampling plan and conducting a statistical analysis of the USGS data, we also collected, plotted, and analyzed data for each of the watersheds monitored by the USGS, including the boundaries of the watersheds, the locations of the USGS monitoring stations, the extent of the stream/river network that drains into the monitoring stations, variables known to affect surface water quality (including, but not limited to rainfall, land use and land cover, and soils distributions) as well as swine and poultry population data.

The design and execution of the USGS stream sampling plan is seriously flawed. We found a number of significant deficiencies and limitations in the plan that prevents drawing accurate conclusions from the data. These deficiencies and limitations included too few samples to conduct a valid statistical analysis of the data, significant differences in watershed sizes, soil types, rainfall amounts, and land use and land cover between the background watersheds and the swine and swine/poultry watersheds. The USGS' small data set, the failure to account for the variables

associated with the differences in watersheds, and its failure to collect discharge data and conduct downstream sampling prevented us from using the data to draw any meaningful conclusions about the water quality impacts of swine CAFOs in eastern North Carolina, and led us to conclude that the USGS data are not sufficient to reliably characterize surface water quality associated with swine CAFOs in eastern North Carolina.

Further, there is no correlation between the average and maximum nitrate concentrations in the USGS data compared to the animal population numbers for each individual watershed monitored by the USGS. Accordingly, we concluded that the basic premise that the number of animals in a watershed control water quality is not proven by the USGS data.

The spatial analysis completed as part of our evaluation shows that the differences in stream nitrate concentrations observed by the USGS in the monitored watersheds are related to watershed size, buffer size, land use and soil types in the watershed, and not to the number of animals present. This finding is in line with previous studies, which have indicated that the distribution of land use and soils in the watershed, and especially in the riparian buffers, are the primary factor controlling water quality in receiving streams. Targeted initiatives to improve surface water quality in agricultural watersheds should focus on land use and soil types in river buffers rather than on the number of animals present in the watershed. Implementing cost-effective changes in critical watershed buffer areas can provide for sustainable water quality protection in receiving streams.

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SECTION 1 - INTRODUCTION

The United States Geological Survey (USGS) is in the process of completing a study titled "Characterization of Surface-Water Quality Associated with Swine CAFOs in Eastern North Carolina".

According to USGS, the lack of water quality data associated with swine CAFOs in the coastal plain of North Carolina has made it difficult for the State to assess the effects of swine CAFOs on nutrient concentrations in surface waters. The study's objectives, therefore, are to "characterize stream water-quality conditions in coastal plain watersheds[1] to document whether swine CAFOs have a measurable effect on surface water nutrient concentrations" and to provide a scientific basis for state policy makers and regulators to determine whether and to what extent new regulations are needed to protect and enhance nutrient impaired streams in eastern North Carolina.[2]

Although USGS has not issued its report on the study, it has completed water quality data collection and posted the data on the project website. In light of the study's focus on swine CAFOs, the North Carolina Pork Council engaged Geo Solutions to review and evaluate the USGS data to assess whether the data collected by USGS are sufficient to achieve the study's objectives.

This report presents the results of the following evaluations:

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[1] According to US EPA Watershed Management Units are based on area. In this evaluation most watersheds are less than 10 square miles in area. As such they would normally be classified as Subwatersheds.

[2] More information on the study as well as the water quality data collected by USGS and reviewed and evaluated by Geo Solutions is at the USGS project website at http://nc.water.usgs.gov/projects/cafo/index.html.

1. Design and execution of the USGS Stream Sampling Plan, including the category designations, the sizes and locations of the watersheds, comparisons of rainfalls, geology, and geomorphology between background and CAFO watersheds, and other factors affecting comparisons between background and CAFO watersheds;

2. Numerical analysis of the USGS water quality data including a statistical analysis of the data set, and an examination of the deficiencies and limitations of the study including the small numbers sampling bias, the absence of discharge (flow) data, the absence of paired watersheds or lack of any downstream sampling, and the differences in sizes of the different categories of watersheds.

3. Spatial Analysis to evaluate whether the USGS Data can be used to establish correlations between stream water quality and the numbers of animals in the watersheds, or if the stream water quality data is better correlated to watershed size or changes in the land cover and land use and soil types in the watersheds or in the stream buffer areas of the watersheds.

SECTION 2 - Stream Sampling Plan Evaluation

USGS collected surface water samples from stations in USGS-defined watersheds that were believed to represent swine CAFOs (SW), swine and poultry CAFOs (SP), and "background" watersheds believed to contain no swine or poultry CAFOs (BK). Eighteen stations in each of the three categories (a total of 54 stations) were sampled every other month during a 10-month period June of 2012 to April of 2013), yielding a total of six samples per site and a total of 324 samples for all 54 stations. The samples analyzed by USGS included the following analytes:

Constituent group	Analytes
Field measurements	Specific conductance, pH, temperature, dissolved oxygen
Nutrients	Ammonia + organic nitrogen, ammonia, nitrate + nitrite, total nitrogen, ortho-phosphate, total phosphorus
Major ions	Calcium, chloride, magnesium, potassium, sodium, sulfate

Table I. Partial list of analytes measured by the USGS for all basins.

USGS' analysis also included several light stable isotopes that can be useful in identifying the source and degradation of nitrogen compounds. These include nitrogen and oxygen isotopes of nitrate and hydrogen and oxygen isotopes of water. However, because of extensive natural attenuation of nitrate, the nitrate isotopes in the USGS data are not useful in nitrogen source identification. Since there is no discharge data or adjacent groundwater information, the water isotope data is not useful for determining groundwater inputs into the drainage basins.

It should be noted here that there is a discrepancy between the stream sampling plan outlined on the project website and the sampling actually conducted by USGS. Although the plan calls for one year of monitoring, samples were taken for only 10 months. The website offers no explanation for USGS' deviation from the sampling program outlined in the plan. More important, however, is the fact that too few samples were collected and analyzed to adequately complete of one of the most important tasks outlined in the project scope of work. The project website states that a "statistical analyses will be conducted to examine relations between watershed variables and water-quality conditions at the stream study sites", but as explained later in this report, six samples at each site provides too little data to produce reliable results from a statistical analysis.

Based on the site location information provided by USGS, we were able to identify the drainage boundaries of each of the 54 watersheds that were sampled by USGS (Figure 1, Table 2.). The sites were plotted in ArcMap using the Latitude/Longitude locations provided by USGS. Spatial analysis was completed for the 54 watersheds to define:

- The boundaries and extent of the watersheds above the monitoring stations
- The extent of the stream/river network and stream 100 foot buffer extent that drains into the monitoring stations
- The Land Cover/Land Use in the monitored watersheds
- The hydric soils distributions in the monitored watersheds

The watershed boundaries and monitoring points were transferred to Google Earth and current and historical orthophotographs were examined for important watershed changes since the 1990s. The results are presented as 54 summary figures (typical figure presented as Figure 2) in Appendix A to this report.

The water quality data was downloaded from the USGS project website, and average, maximums, minimums, median and standard variations were computed for each station parameter.

The above information was used to evaluate whether the watersheds were correctly categorized as background, swine, or swine/poultry, and whether there were significant differences in water chemistry between all three categories of watersheds. If there were differences in water chemistry, are these differences related to the presence and numbers of animals in the watershed or to other watershed characteristics.

2.01 Category Designations

The results of this evaluation indicate that eight of the 54 sampled watersheds appear to have been incorrectly categorized as either background, swine, or swine/poultry (Table 2). This further reduces the size of a data set that is already too small to produce reliable results from a statistical analysis.

2.02 Sizes and Locations of Watersheds

2.02.1 Relative Sizes of the Watersheds

The comparative sizes of the USGS-defined watersheds across the study area are summarized in Figures 3 and 4. The background watersheds are typically 21% and 43% larger than the swine/poultry watersheds and swine watersheds, respectively. This significant difference in size means that the background monitoring stations are located further down the watersheds than the swine and swine/poultry monitoring stations. As discussed later in this report, these and other differences related to the relative sizes of the monitored watersheds relate to de-nitrification and natural attenuation of nitrogen in the stream network system, and have serious implications for the proper use and interpretation of the USGS data.

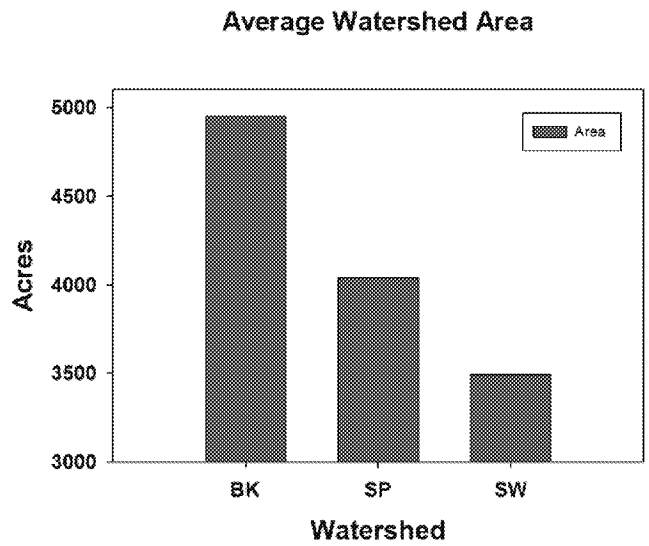

Figure 3. Area of different classifications of watersheds. The average area of background watersheds is 21% larger than SP watersheds and 42% larger than the SW watersheds.

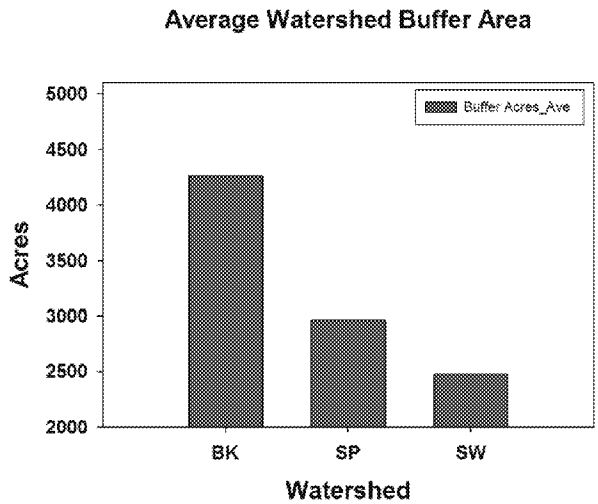

Figure 4. Buffer area of different classifications of watersheds. The average buffer area of background watersheds is 44% larger than SP watersheds and 72% larger than the SW watersheds.

2.02.2 Comparison of Rainfall between Background and CAFO Categories

We collected rainfall precipitation data from the NC State Climate Office ECONET website and from individual farm records (maintained by swine farms, Figure 5). For the purpose of this evaluation, the ECONET rainfall accumulation rates were divided into two categories showing rainfall in the northern portion of the coastal plain (background sample locations) and the southern coastal plain (CAFO sample locations).

The composite graph shows rainfall accumulation rates from six ECONET Stations located in the southern coastal plain (Figure 6). The boxes in the rainfall records show the period of sample collection of the USGS data. A comparison of these data show that the southern swine and swine/poultry sample locations experienced fewer large rainfall events than the background sample locations in the northern coastal plain, which were affected by large rain accumulations resulting from Hurricane Sandy in November 2012, and the Great January rain event of 2013.

Dilution resulting from greater rainfall and higher stream flows in the background watersheds during the sampling period will bias concentration comparisons in favor of the background watersheds.

2.02.3 Comparison of Geology and Geomorphology between Background and CAFO Categories

The North Carolina coastal plain has a varied geology and geomorphology that plays a major role in influencing the surface morphology, storm water runoff, surface water percolation, and eventually ground water recharge and discharge that we measure today. As such, it is important to recognize and account for these differences when establishing the locations and boundaries of watersheds that will be compared as part of a water quality evaluation. Failure to account for differences other than the presence of swine and poultry CAFOs such as geology, geomorphology, and agricultural practices that affect water quality within each watershed will significantly affect the use and interpretation of the data collected by USGS.

Our evaluation disclosed that the locations of the monitored watersheds do reflect significant differences in soils and topography between the background watersheds and the CAFO watersheds. Swine and poultry operations are concentrated in the southern portion of the coastal plain where the soils are generally sandier and are set at a lower elevations than the center of concentration for the background basins, which are located in the northern coastal plain at higher elevations and poorer drainage (Figure 4). As discussed later in this report, these differences have a significant impact on the proper use and interpretation of the USGS data.

2.02.4 Other Factors Affecting Comparisons between Background and CAFO Watersheds

Our evaluation also identified a number of watersheds in the swine and swine/poultry categories that contained free roaming cattle with unobstructed access to streams. Cattle in streams are known to be a significant source of nutrient-related impairments, particularly in small watersheds. Their presence in several of the monitored watersheds was not included in the study design, and will bias the USGS data against the CAFO watersheds.

SECTION 3 - Spatial Analysis of USGS Water Quality Data

We downloaded the surface water geochemical results from the USGS website and entered the information in an EXCEL Spreadsheet for statistical analysis. These data are presented in Appendix B at the end of this report. In addition to the deficiencies identified during our stream sampling network evaluation and discussed in the previous section of this report, we also identified the absence of discharge (flow) data and downstream sampling as deficiencies in the study's design.[3]

3.01 The USGS Data Set is Too Small for a Valid Statistical Analysis

Given the limited number of samples over a 10-month period in the 54 watersheds monitored by USGS, we examined the average nutrient concentrations and the median-percentile variation of nutrient concentrations over the sampling period. The differences between these two statistical approaches confirm that the data set was too small for valid statistical analysis.

[3] We were not able to effectively compare the USGS data to older data collected years ago in connection with earlier water quality studies in many of the same watersheds due to variations in sampling and analytical methods.

Our examination found that the averages of the different nitrogen species indicate that the organic nitrogen concentrations are similar in the different watersheds, and that total nitrogen and the nitrate concentrations are low in the background watersheds and increase in the CAFO watersheds. (Figure 8). When the median values and percentile variations are examined, however, we found that the total nitrogen, nitrate, organic nitrogen and ammonium median values are not significantly different between the watersheds (between 1 and 2 mg/l), but variation is increased for total nitrogen and nitrate in the watersheds with animals (Figures 9 through 12). Finally, when all the data is plotted for each sampling interval, organic nitrogen and ammonium in the swine/poultry watersheds have significantly larger variations compared to the background and swine only watersheds (Figures 13 through 21).

The above exercise shows that different statistical analytical methods result in biased conclusions when, as is the case with the USGS data set, a small number of samples based on an inappropriate sampling interval is compared to the natural variation of the water quality parameter. The small number of samples captured only a random portion of the discharge variation (low flow and storm events) over the 10 month sampling period.

3.02 Absence of Discharge Data

Too little concentration data together with the absence of discharge (flow) data seriously limits one's ability to reliably analyze and interpret the USGS data. Without flow data, no relationship can be established between analyte concentration and impacts on receiving waters.

It is well known that headland streams are important areas of nutrient processing and natural attenuation, and that water chemistry in the upper watershed drainages is strongly influenced by the surrounding catchment. This is especially true in areas of modified catchments such as agricultural and urban areas. Geology, land use and drainage characteristics control the delivery of organic material, nutrients and sediment to these headland streams. The effects of disturbances within the riparian buffer zone around streams are also well studied, but are not as well studied in mid to lower watershed areas as in headland stream areas. It is also well known that discharge

controls sediment and nutrient flux into streams. Nutrient and sediment concentrations and water chemistry can change dramatically during a discharge event as demonstrated, for example, in the case of Rocky Branch, NC (located in south Raleigh, North Carolina) where studies by the NCSU Isotope Lab NC documented significant changes in water and isotope chemistry over a single discharge event (Figures 22 and 23). .

USGS' infrequent sampling interval (Figure 24) does not capture these significant variations in discharge states and creates a random data set of hydrographic conditions. This small number sampling problem calls into question any statistics or interpretations that are based on so few sampling points over a several storm events without corresponding discharge data. Over the course of a discharge year there are many of these similar events that are not sampled.

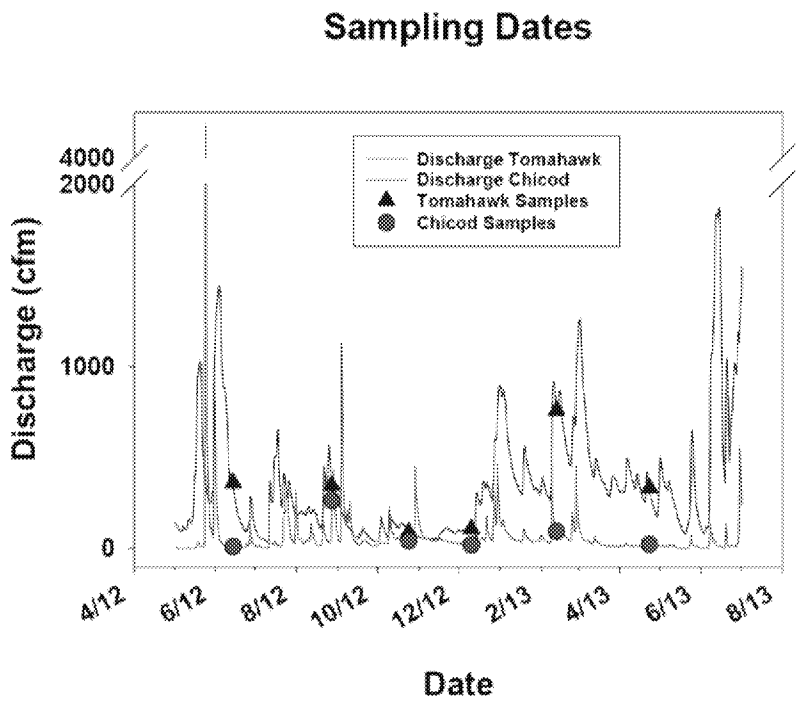

Figure 24. Discharge at Tomahawk on the Black River and Chicod Creek with the sampling dates from SW-03 watershed. The sampling interval does not capture the variation in discharge states, but produces a random data set.

3.03 Absence of Downstream Sampling

A serious problem with the design of the USGS study is the absence of downstream sampling, which makes it impossible to sort out variations in analyte concentrations inherent with single-point sampling used by USGS. Sampling at only one point in the watershed, especially a reduced size headland watershed, does not give an accurate estimate of the discharge flux of sediments, nutrients, or organic matter downstream to the receiving waters. A good example of this is the results of sampling conducted by USGS at the stations designated as SW-13 and SP-13 in the Nahunga watershed of the Goshen Swamp. Figure 25 shows that a single sampling station (SW-13) in the headlands of a drainage system (where the nitrate concentration was measured at 9.4 mg/L) does not accurately measure impacts of land use downstream at station SP-13 where the nitrate concentration was measured at 0.128 mg/L, and where data collected at the Veaches Mill Road bridge further downstream indicates that the wetlands in the Nahunga watershed consume any nutrients that flux into the watershed upstream from the monitoring site (Figure 26).

3.04 Significant Differences in the Sizes of the Watersheds

The Nahunga watershed example above also demonstrates that the size of the watershed has a direct impact upon the organic matter, nutrient, and sediment concentrations. As mentioned previously, the background watersheds are significantly larger than the CAFO watersheds. As in the case of the Nahunga watershed, concentrations decrease downstream and a comparison of watershed water quality of different sizes is invalid. At the outlet of the Nahunaga watershed to the Goshen swamp (Veaches Mill Road) a 16-month conductivity record is consistently low, indicating no nutrient impacts into the receiving waters from SW-13 and SP-13 (Figure 26).

The comparative size of watersheds across the study area is summarized in Figure 3 and 4. Our evaluation found that the background watersheds are typically 21% and 43% larger than the swine/poultry watersheds and the swine watersheds, respectively. (Figures 12a and 12b). When the river buffer areas are compared, the background watersheds are typically 44% and 72%

larger than the swine/poultry watersheds and the swine watersheds, respectively. The background monitoring stations are located further down the watershed than the swine and swine/poultry monitoring stations. This difference in size relates to de-nitrification and consumption of nitrogen in the stream network system. A comparison of the average stream nitrate concentration and the monitored watershed sizes shows that stream nitrate concentrations are reduced in watersheds above 3000-4000 acres (Figure 27).

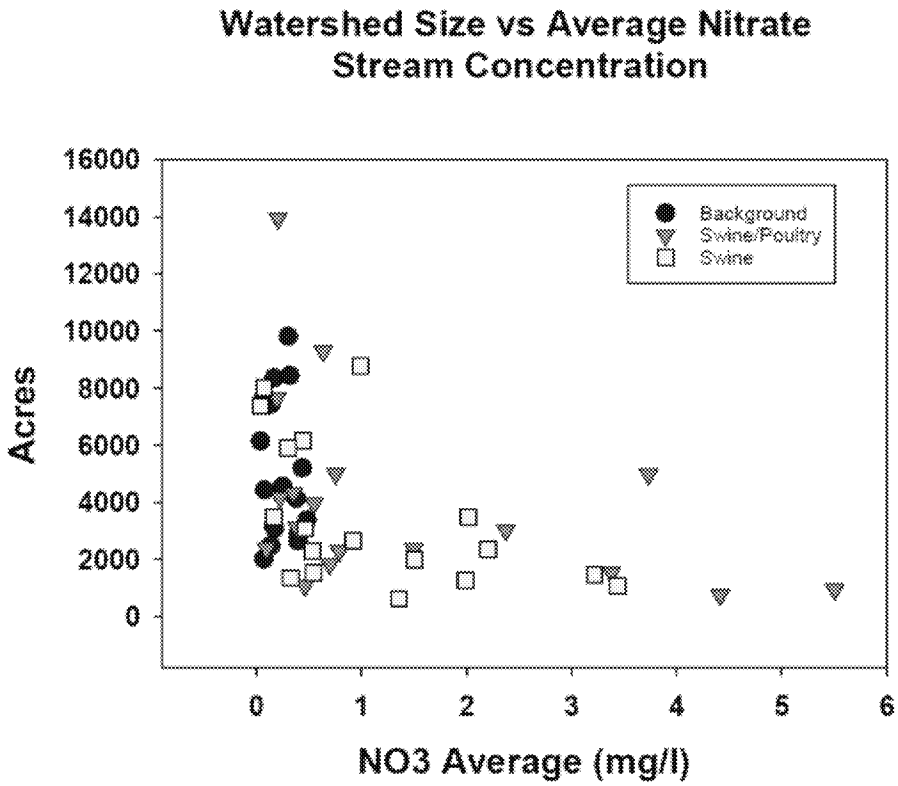

Figure 27. Watershed size versus the average stream nitrate concentration. Watersheds above 2000 acres have reduced nitrate concentrations regardless of the category of land use. The one SP watershed that plots above this trend is SP09, which is a unique channelized drainage system.

Most of the background watersheds are above this threshold, while most of the swine and swine/poultry watersheds are below it. The difference in the sizes of the control background watershed and river buffer areas compared to the swine and swine/poultry watersheds introduces

a significant bias in favor of the background watersheds and against the CAFO watersheds in the water quality data set.

SECTION 4 - Spatial Analysis to Assess whether the USGS Data can be used to Establish Correlations between the Data and Land Cover and Land Use in the Monitored Watersheds

Although deficiencies discussed previously in this report prevent the USGS data from being used to reliably characterize surface water quality associated with swine CAFOs in eastern North Carolina, we undertook an evaluation to assess whether the water quality data can be used to establish a correlation between the data and land cover and land use in the individual watersheds, starting with swine and swine/poultry populations.

4.01 Swine and Swine/Poultry Populations

For this evaluation, we compiled and tabulated the numbers of swine and poultry for each of the 54 watersheds monitored by USGS. The swine data was obtained from the NC DENR permit data set, and the poultry population data was obtained from Dr. Sarah Mason, NC Department of Agriculture, Veterinary Division (Table 3). As we noted previously in this report, we could not identify any poultry CAFOs in SP-2, and no data for poultry populations in SP-15. Also, we could not identify any swine populations in either SP-15 or SW-2. The animal density by watershed is presented for swine and poultry in Figures 28 and 29, respectively.

When the nitrate average concentrations for each individual watershed were compared to the animal population numbers (Figure 30), we could find no correlation in either the swine or swine/poultry watersheds. Also, we could not find a relationship between numbers of animals and nitrate maximum concentrations in any of the monitored watersheds. Therefore, we have concluded that the basic premise that animal populations control water quality is not proven for this data set.

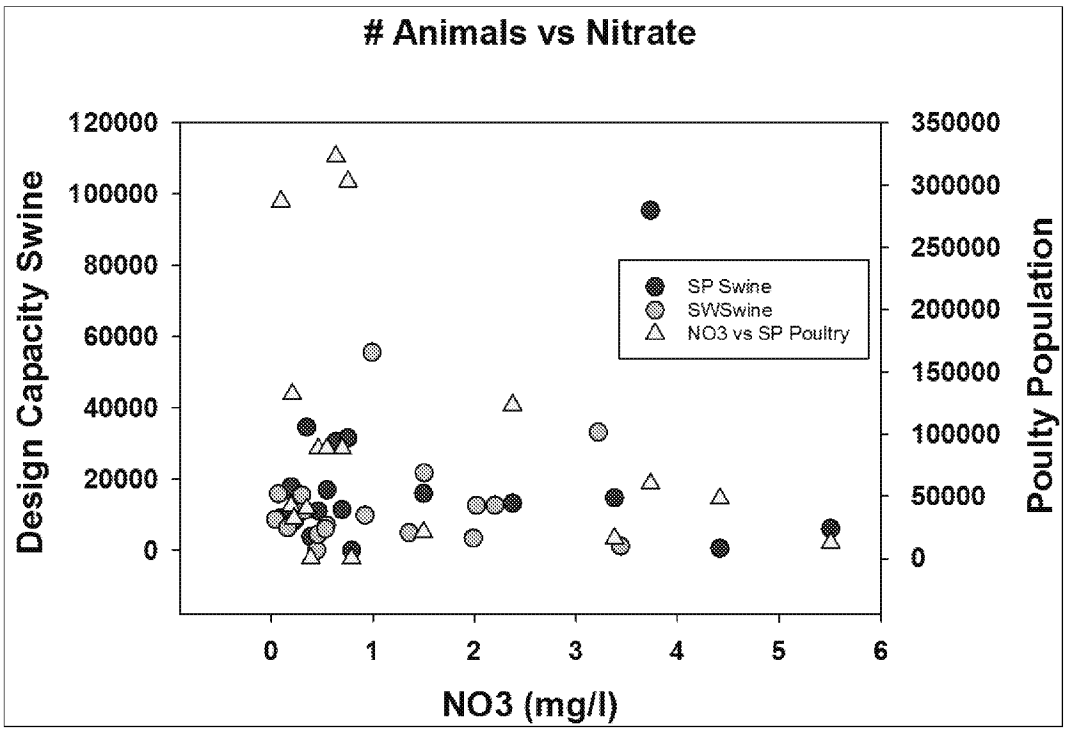

Figure 30. Numbers of animals versus the average nitrate concentration in the USGS monitored watersheds. The red circles are SP swine, the green circles are SW swine, and the yellow triangles are SP poultry.

4.02 Land Cover and Land Uses other than Swine and Swine/Poultry Populations

Since previous studies have indicated that the distribution of land use and soils in the watershed, and in the riparian buffers in particular, control water quality in the receiving streams, we undertook a spatial analysis to assess whether the differences in average nitrate and total nitrogen concentrations and the variation observed in the swine and swine/poultry watersheds is related to watershed size, buffer size and/or land use and soils in the watersheds and river buffers.

4.02.1 Spatial Analysis Procedure and Data Sets

The locations of the USGS monitoring stations were plotted in ArcMap 10.2 with the Latitude/Longitude positions from USGS. The watersheds were constructed from the HUNC data set (CGIA) and modified with the county elevation contour data set (NC ONEMAP) to reflect the drainage basin at the specific point of the monitoring station in that watershed (Figure 21). The two-foot contours were based on 20 foot grid cells generated from LIDAR. Soil distributions were obtained from the NC Soil Survey Geographic (SSURGO) database, and land cover and land use (LCLU) classifications were obtained from the USGS National Land Cover Dataset (NLCD). The National Geospatial Data Asset (NGDA) National Land Cover Database (NLCD) is dated 2011, approximately four months before USGS began collecting data for its study. The hydrography for rivers and major waterways was obtained from NC One Map, and the river buffers were clipped at the 100 foot line with rounded terminus. The soil distributions and LCLU data were then clipped by the watershed boundaries and river buffers (Figure 31 and 32), and the data was then tabulated in EXCEL. Area for soils was determined with the F_area geometry calculation, and area for the LCLU was determined from the pixel counts in the raster data set.

4.02.2 Results of the Analysis – Watershed Impacts

The LCLU categories were combined in the different categories of watersheds to reflect significance to nitrogen transport in the watersheds. Figures 33 and 34 show that the background watersheds have more forests and wetlands, and less cultivated land than the CAFO watersheds, and that the buffers in the background watersheds have more forested land than the buffers in the CAFO watersheds. A comparison of the percent cultivated land in individual watersheds with the nitrate concentrations in the streams, led us to conclude that watersheds with greater than 30% cultivated land export nitrogen into the stream drainage systems (Figure 35). While there are small differences in the land use between the background and CAFO watersheds, there are much larger differences in soil type between the background and CAFO watersheds. The amount of hydric soils is higher in the

background watersheds and in the background watershed buffers (Figure 36 and 37). Watersheds that contain over 60% hydric soils have limited nitrogen export (Figure 38). The difference in watershed size and amount of hydric soils explains why there is little nitrogen export in the background watersheds with increasing amounts of cultivated land. The amount of hydric soils in the total watershed and in the buffers controls nitrogen export into the stream drainage system. The background watersheds have more wetlands and larger areas of river buffers than the other two types of watersheds.

4.02.3 Results of the Analysis – Buffer Impacts

We found one outlier (the SP-09 watershed) in the hydric soil stream nitrate relationship in Figure 30. SP-09 is a channelized agricultural watershed with predominately hydric soils that has buffers that are predominately cultivated land (Figures 39 and 40), which means that the nitrogen is delivered efficiently to the stream drainage system, but has little residence time in the hydric soils to be naturally attenuated. SP-09 contrasts with the Nahunga watershed (discussed previously in this report), which is a natural drainage system which has a high proportion of wetlands and hydric soils in the river buffer zone (Figures 41 and 42). The Nahunga watershed does not export nitrogen because the nutrients are processed in the hydric soil buffer zone and there are no nutrient bypass mechanisms present such as channelized drainages.

These results suggest land use and soil distribution in buffers have a direct effect on stream water quality. The intersection of partially hydric and non-hydric soils with cultivated land in the stream buffer area had a correlation to average stream nitrate concentration (Figure 43).

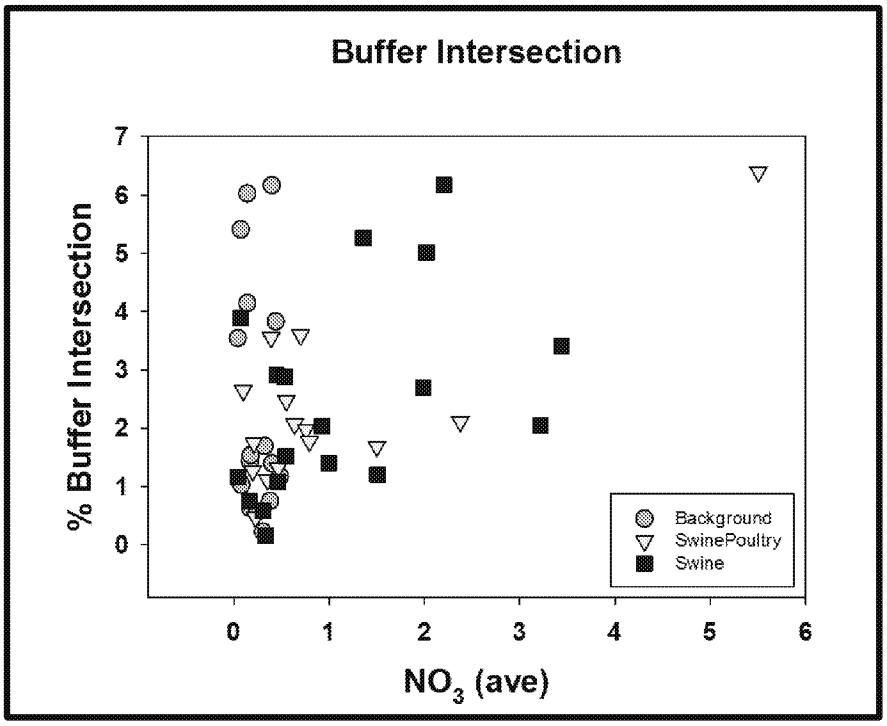

Figure 43. The average stream nitrate concentration versus the % buffer area of the intersection of cultivated/pasture land with non-hydric/partially hydric soils.

Buffers with a higher percentage of the total buffer area that are cultivated and have soils that are not hydric have increased stream nitrate concentrations. This implies that critical areas of watersheds where these conditions exist can be identified and restoration or remediation efforts can be focused on those areas in a cost effective manner to improve water quality in agricultural watershed (Figure 44).

SECTION 5 - FINDINGS, RECOMMENDATIONS AND CONCLUSION

5.01 Findings

1. The limited number of sampling points over the 10-month sampling period does not characterize the water quality chemistry variation over the discharge (stream flow) cycle. Accordingly, any statistical analyses of the USGS data will suffer from small number biases, and not represent the concentration/stage relationships of nutrients and ions, or characterize the level of water quality in the receiving streams. Further, it appears that eight of the 54 monitoring stations have been incorrectly categorized, further reducing the size of an already small data set.
2. The limitations inherent in the small USGS data set is compounded by the absence of stream flow data, which prevents a meaningful analysis of the USGS data because without flow data, it is impossible to establish a relationship between the analyte concentration and quantity of stream flow.
3. The USGS's distribution of watershed types for its monitoring program was not uniform across the North Carolina coastal plain, and so did not take into account the significant role that the coastal plain's varied geology and geomorphology plays in influencing surface morphology, storm water runoff, surface water percolation, and groundwater recharge and discharge. We found significant differences in the basin sizes, soil types, rainfall amounts, and land use and land cover between the background basins and the swine and swine/poultry basins monitored by USGS. These differences and their influence on surface water quality prevent the USGS data from being used to reliably assess the influence of swine and swine CAFOs on water quality.
4. Single-point sampling in the monitored basins and the resulting lack of downstream sampling data prevented us from using the USGS data to reliably assess water quality impacts on the receiving streams. Single-point sampling, particularly in small watersheds such as those represented in the data collected by USGS in the swine and

swine/poultry watersheds, does not give an accurate estimate of the discharge flux of sediments, nutrients, or organic matter downstream of the receiving waters.

5. No correlation was found to exist between the average and maximum nitrate concentrations in the data set compared to animal population numbers for each individual watershed monitored by USGS.
6. The amount of cultivated land in the river buffers controls the amount of nitrogen transported into the receiving waters, and the amount of hydric soils in the total watersheds and in the river buffers controls the natural attenuation of nitrate in the drainages.
7. Watershed size offered the best explanation for the nitrate concentrations in the watersheds monitored by USGS. Watersheds above 4000 acres did not export nitrate regardless of the watershed's classification as "swine" or "swine/poultry" or the animal populations in the watershed.

5.02 Conclusions

1. Deficiencies in the design and execution of the USGS stream sampling plan prevent the data collected by USGS from being used to serve its intended purpose.
2. The USGS data are not sufficient to reliably characterize surface water quality associated with swine CAFOs in eastern North Carolina.
3. Soil and land cover/land use relationships with nutrient concentrations in the receiving waters indicate that not only are the presence of riparian buffers important to facilitating the transport of nutrients into streams, but also the presence of hydric soils in the river buffers controls the natural attenuation of nitrate in the streams draining agricultural areas.

5.03 Recommendation

The creation of riparian buffers, wetlands and hydric soils in the crucial river buffer zone is a well understood and well-studied process. With the type of spatial analysis used in the

evaluation described in this report, critical areas where nutrient bypass mechanisms such as channelized drainages can be identified. These areas can be modified to improve water quality in the receiving waters downstream from agricultural operations. We recognize that different watersheds may require different modifications depending upon the geology, elevation, soil types and drainages. These types of watershed modifications are well known and with the right group of experts, can be successfully applied to the different types of drainage conditions found in eastern North Carolina.

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1 **Partial list of analytes measured by the USGS for all watersheds.**

2 **Tabulation of basin classifications base on USGS selection criteria.**

3 **Animal Populations in the USGS CAFO Watersheds.**

Constituent group	Analytes
Field measurements	Specific conductance, pH, temperature, dissolved oxygen
Nutrients	Ammonia + organic nitrogen, ammonia, nitrate + nitrite, total nitrogen, ortho-phosphate, total phosphorus
Major ions	Calcium, chloride, magnesium, potassium, sodium, sulfate

Table I. Partial list of analytes measured by the USGS for all basins.

CLASSIFICATION OF THREE BASIN TYPES DEFINED BY USGS

SWINE - POULTRY FARM BASINS				SWINE FARM BASINS				BACKGROUND BASINS			
BASIN	NUMBER OF SWINE	NUMBER OF POULTRY	CLASSIFICATION CORRECT?	BASIN	NUMBER OF SWINE	NUMBER OF POULTRY	CLASSIFICATION CORRECT?	BASIN	NUMBER OF SWINE	NUMBER OF POULTRY	CLASSIFICATION CORRECT?
SP-1	7	2	YES	SW-1	2	0	YES	BK-1	0	0	YES
SP-2	3	1	YES	SW-2	1	1	NO	BK-2	0	0	YES
SP-3	7	2	YES	SW-3	1	0	YES	BK-3	0	0	YES
SP-4	4	1	YES	SW-4	1	0	YES	BK-4	2 FORMER	0	NO
SP-5	0	1	NO	SW-5	4	0	YES	BK-5	0	0	YES
SP-6	2	1	YES	SW-6	0	0	NO	BK-6	0	0	YES
SP-7	4	2	YES	SW-7	2	0	YES	BK-7	0	0	YES
SP-8	4	4	YES	SW-8	10	0	YES	BK-8	0	0	YES
SP-9	12	1	YES	SW-9	7	0	YES	BK-9	0	0	YES
SP-10	1	1	YES	SW-10	1	0	YES	BK-10	0	0	YES
SP-11	0	1	YES	SW-11	2	0	YES	BK-11	0	0	YES
SP-12	4	2	YES	SW-12	3	0	YES	BK-12	1	1	NO
SP-13	3	7	YES	SW-13	4	0	YES	BK-13	0	0	YES
SP-14	5	6	YES	SW-14	1	0	YES	BK-14	1 FORMER	0	NO
SP-15	0	1	NO	SW-15	2	0	YES	BK-15	0	0	YES
SP-16	3	0	NO	SW-16	5	0	YES	BK-16	0	0	YES
SP-17	2	2	YES	SW-17	5	0	YES	BK-17	0	0	YES
SP-18	7	2	YES	SW-18	2	0	YES	BK-18	0	0	YES

Geo Solutions reconstructed the drainage basins defined by USGS. Using aerial photographs from Google Earth, Geo Solutions counted the number of Swine, Poultry, or Former farms.

Above is a tabulation of our results. We found 8 of the USGS defined basins that may be miss-classified.

Table 2. Tabulation of basin classifications base on USGS selection criteria. Geo Solutions found 8 potential basin miss-classifications.

Farm SP	Swine	Poultry		Farm SW	Swine
SP1	16560	132000		SW1	12595
SP2	3820	0		SW2	0
SP3	30510	322934		SW3	4400
SP4	11400	88000		SW4	4896
SP5	550	48000		SW5	9760
SP6	11025	88000		SW6	8640
SP7	17832	42000		SW7	11168
SP8	9077	287000		SW8	55596
SP9	95417	60000		SW9	12600
SP10	6080	12500		SW10	1200
SP11	16905	88000		SW11	3400
SP12	14664	16000		SW12	21678
SP13	31500	302714		SW13	33080
SP14	13160	123206		SW14	7040
SP15	0	0		SW15	15840
SP16	15912	20858		SW16	6272
SP17	8200	32000		SW17	15496
SP18	34536	40000		SW18	6000

Table 3. Animal Populations in the USGS CAFO Watersheds

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Figure 39. Buffer LCLU distributions in the SP09 watersheds.
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Figure 41. Buffer LCLU in the Nahunga Creek Watershed.
Figure 42. Buffer soils in the Nahunga Creek Watershed.
Figure 43. The average stream nitrate concentration versus the % buffer area of the intersection of cultivated/pasture land with non-hydric/partially hydric soils
Figure 44. The spatial distribution of the intersection of cultivated/pasture land with non-hydric/partially hydric soils for SW10. This approach defines critical buffer areas that need to be addressed to improve water quality.

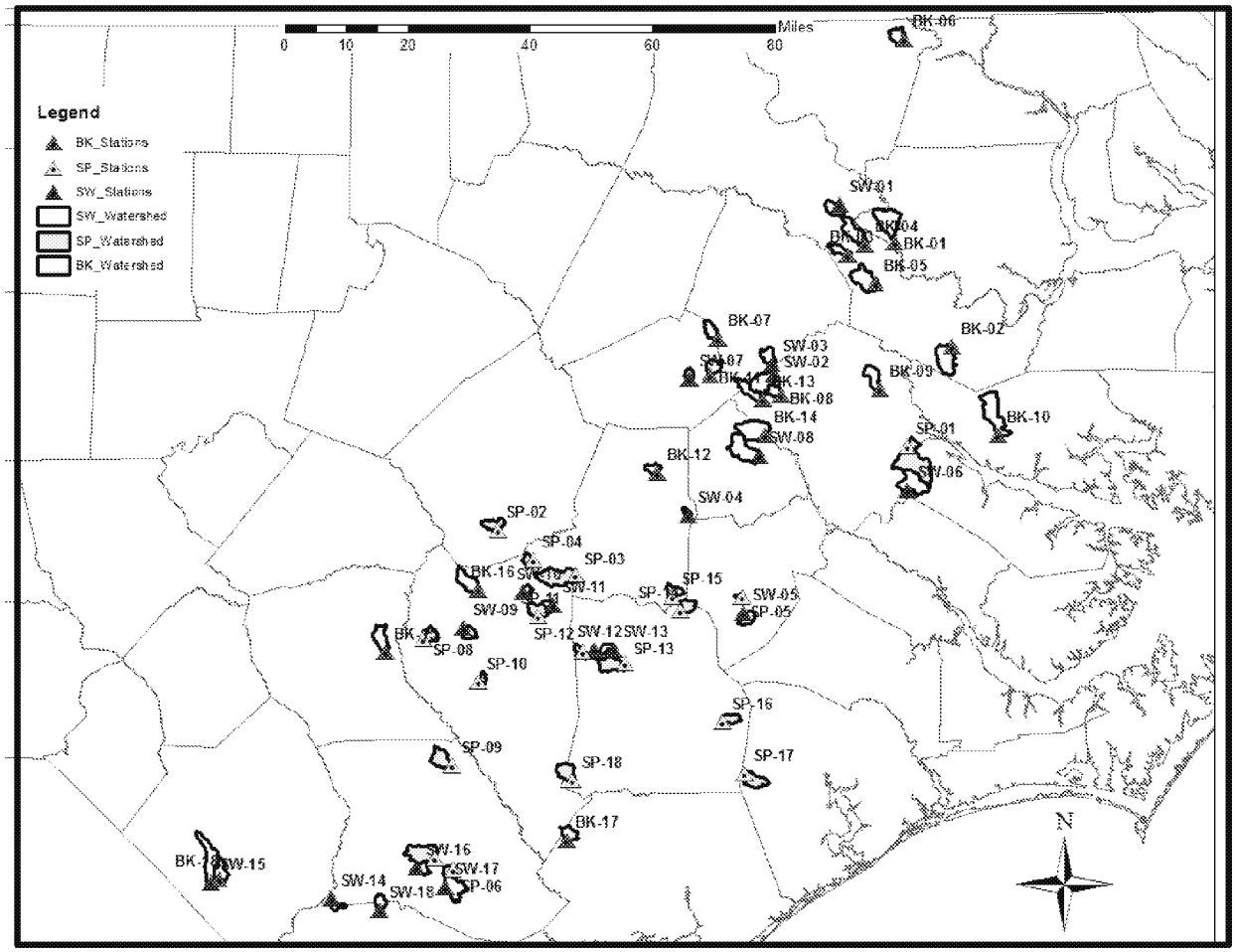

Figure 1. Watershed areas determined for each individual monitored station for the USGS CAFO study.

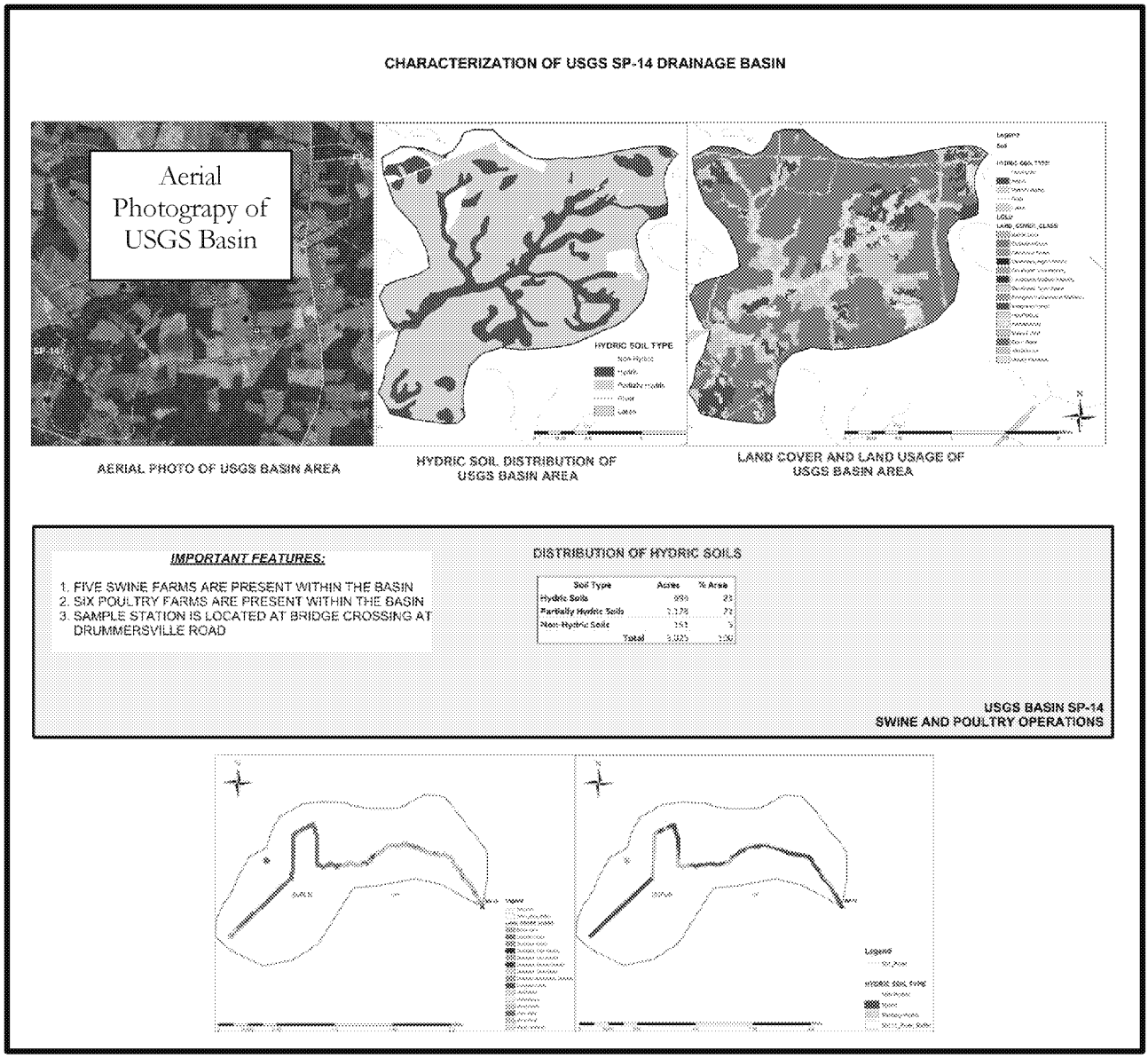

Figure 2. Spatial analysis of the monitored basins include Aerial Photographic analysis, total basin hydric soil distribution, Land Cover Land Use distribution, Basin feature observations, and river buffer LCLU, hydric soil distributions. The analysis for each watershed is compiled in Appendix XX.

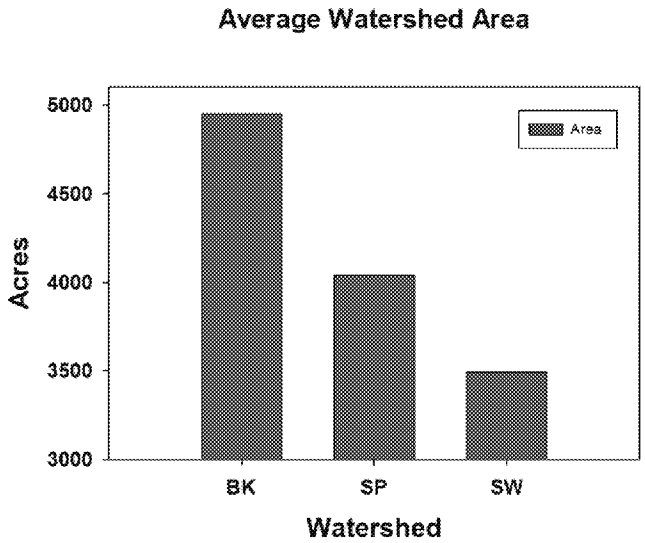

Figure 3. Area of different classifications of watersheds. The average area of background basins is 21% larger than SP watersheds and 42% larger than the SW watershed.

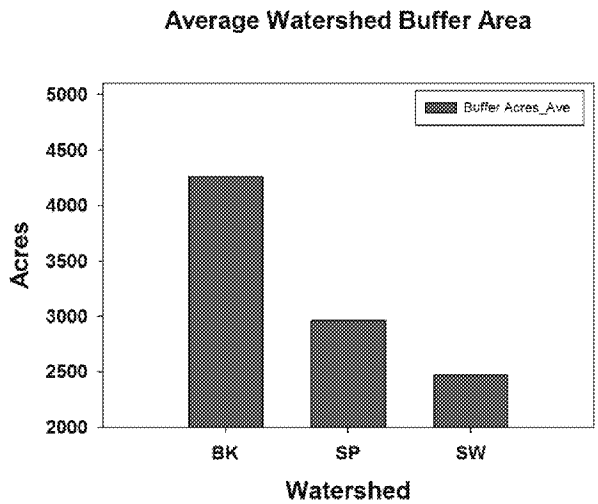

Figure 4. Buffer area of different classifications of watersheds. The average buffer area of background basins is 44% larger than SP watersheds and 72% larger than the SW watershed.

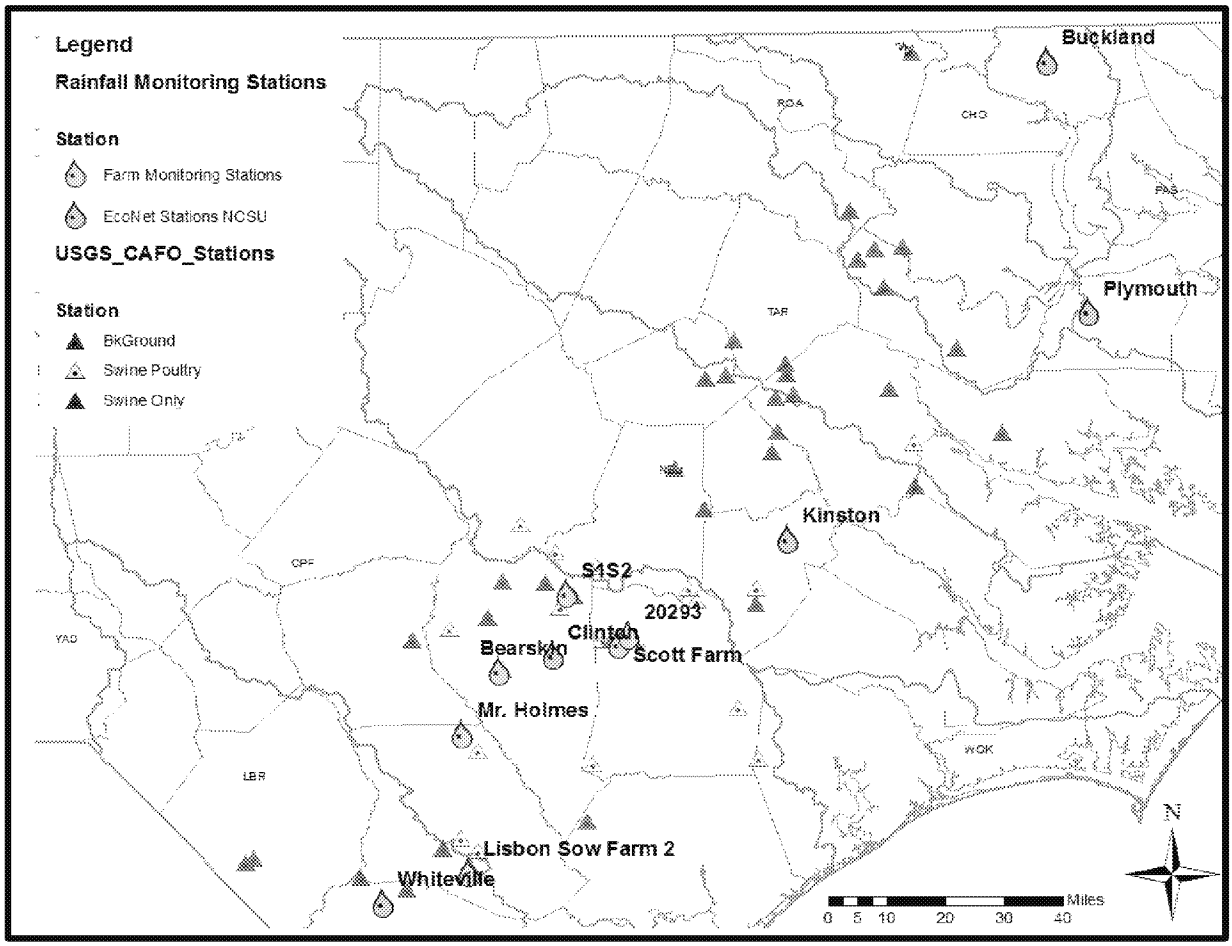

Figure 5. Location of ECONET and Farm Rainfall records. The ECONET Stations cover the entire coastal plain, and the farm records are located in the southern central part of the study areas.

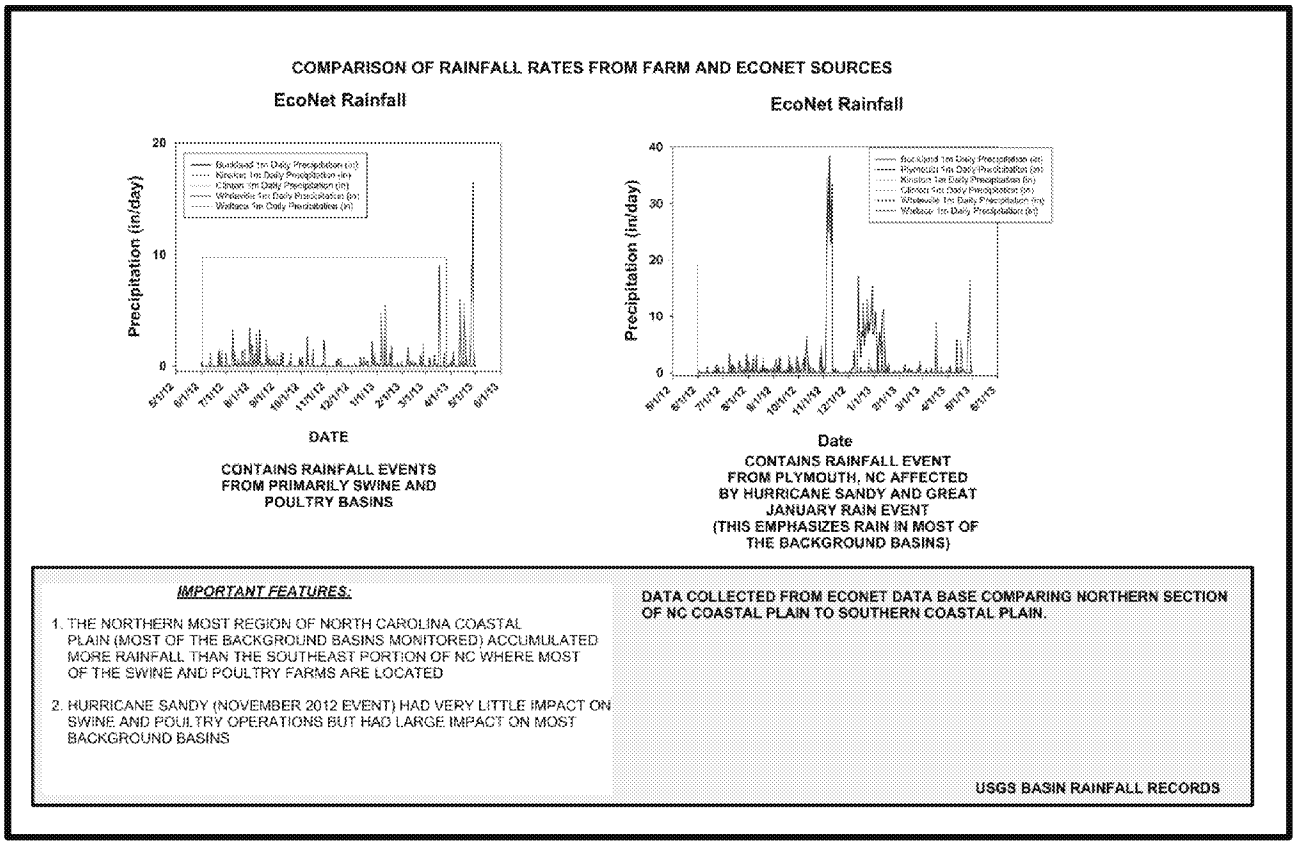

Figure 6. Illustration of rainfall accumulation charts showing ECONET data from the southern (left) and northern (right) coastal plain. Two large rainfall events coincided with the landfall of Hurricane Sandy in November 2012, and the Great Rain event in January 2013.

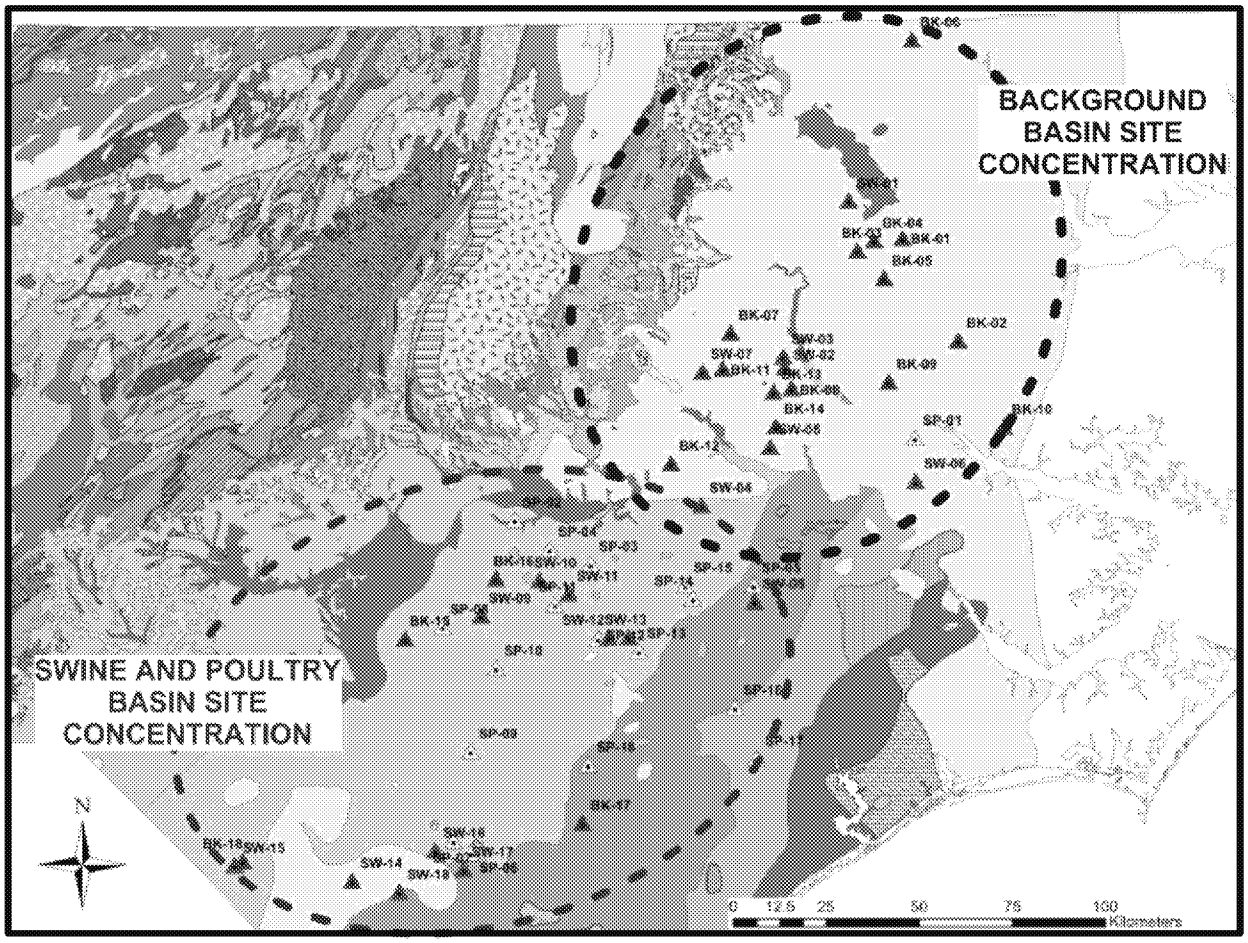

Figure 7. Geologic map of eastern North Carolina illustrating the location of three types of basins identified in the USGS evaluation. Note the differences in the geology and concentration of basin types. The background basins are predominately situated on top of Tertiary sediments dominated by clayey units. The swine and poultry basins are situated in the southern coastal plain on top of Cretaceous units typically covered with sandy surficial units.

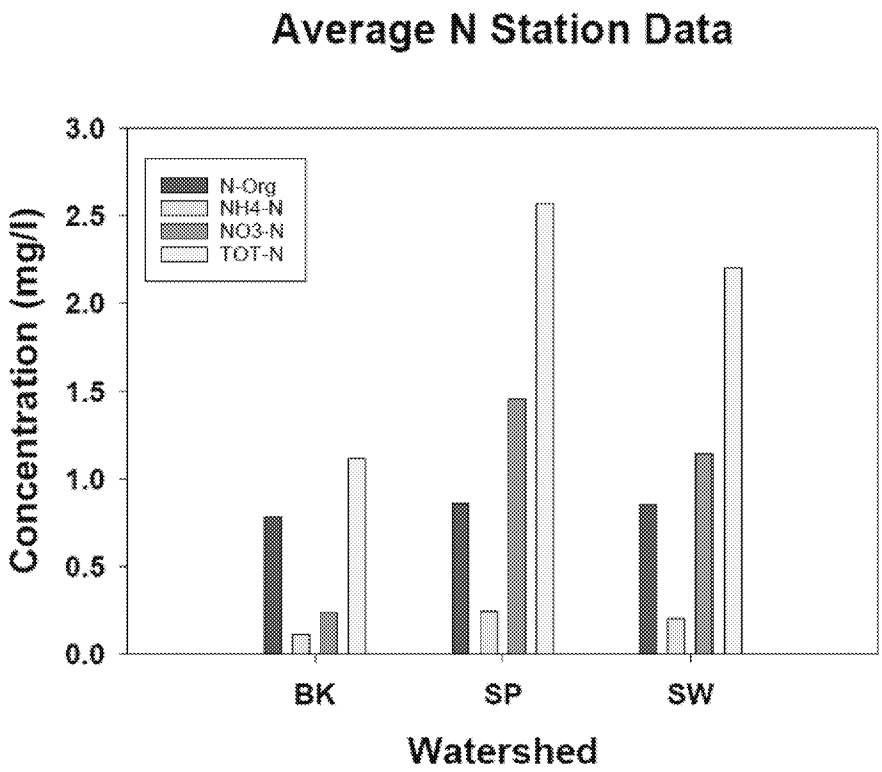

Figure 8. Average concentration of the different nitrogen species in the different types of watersheds. The organic nitrogen averages are similar, but the nitrate and total nitrogen averages are lower in the background watersheds compared to the watersheds with animal populations

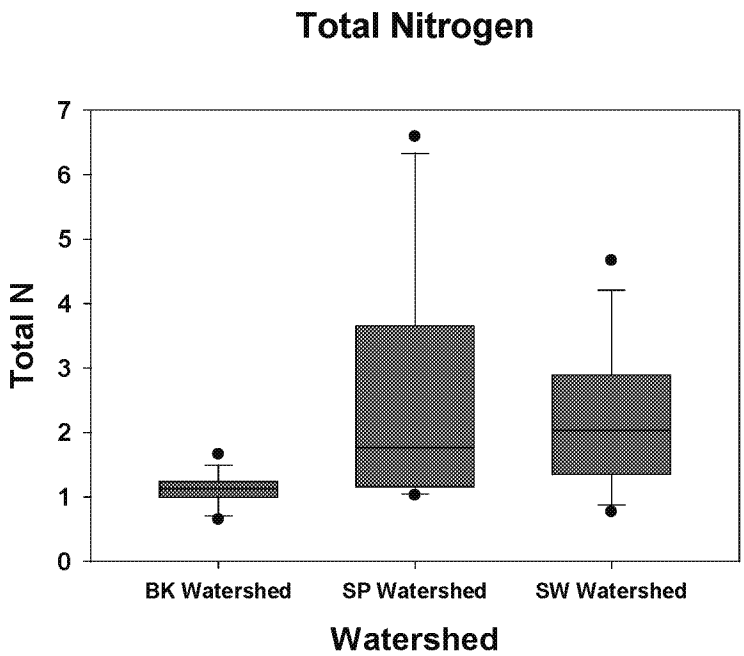

Figure 9. Total nitrogen concentration comparisons between the different watershed classifications. The total Nitrogen in the combined swine and poultry basins.

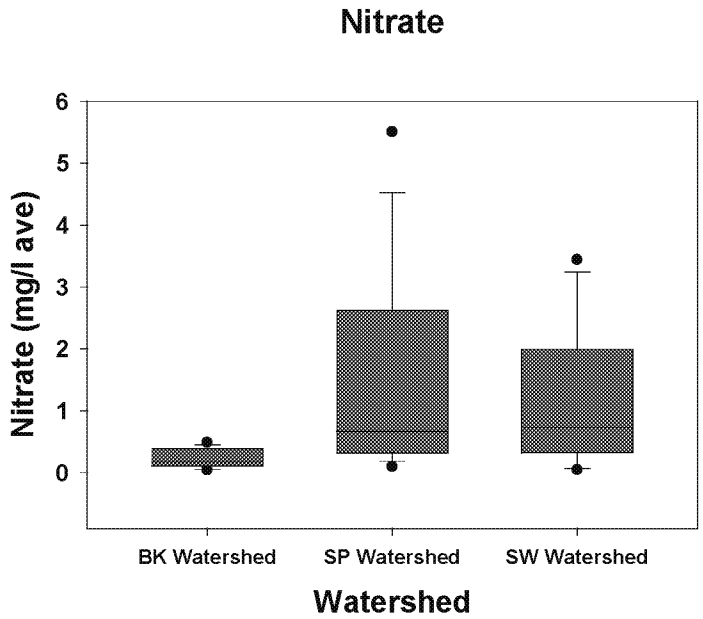

Figure 10. Nitrate concentration comparisons between the different watershed classifications. The nitrate concentration is lowest in the background basins and highest in the combined swine poultry basins.

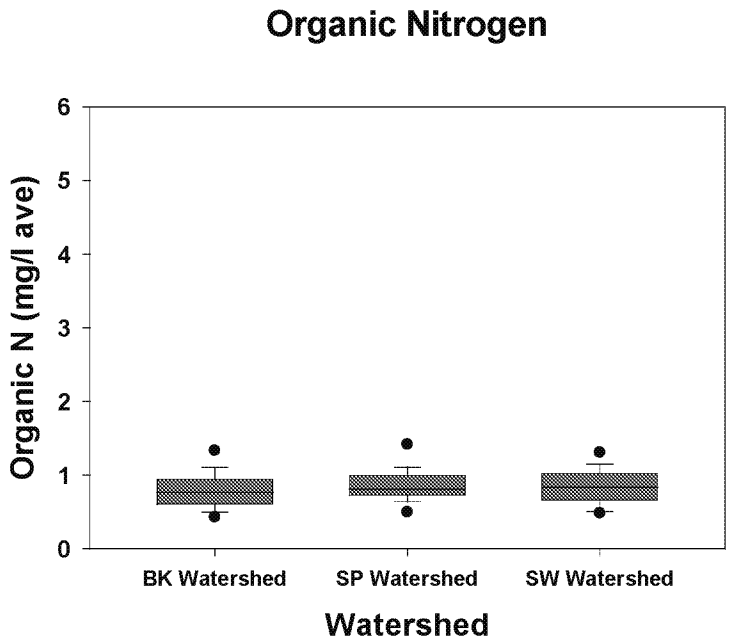

Figure 11. Organic nitrogen concentration comparisons between the different watershed classifications. The average organic nitrogen concentrations are nearly the same across all basin types.

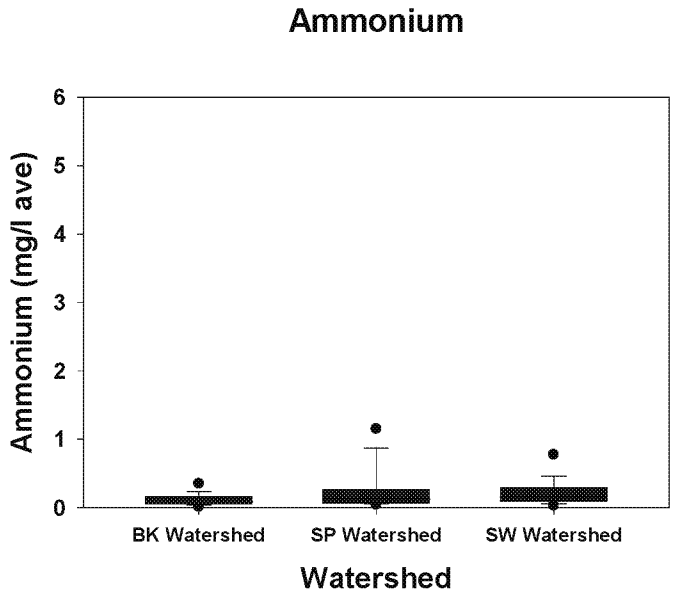

Figure 12. Ammonium concentration comparisons between the different watershed classifications. The ammonium concentrations are nearly the same across all three basin categories.

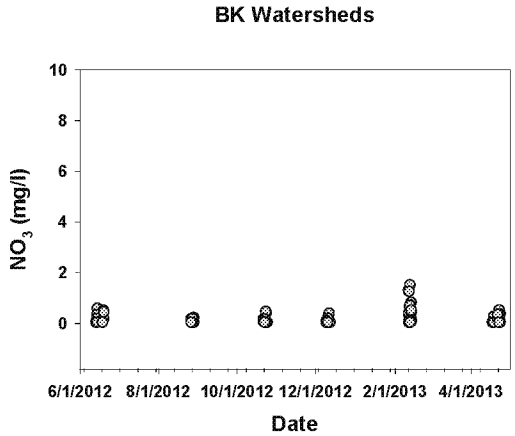

Figure 13. Nitrate concentrations in the BK watersheds. Nitrate concentrations are similar to swine only concentrations.

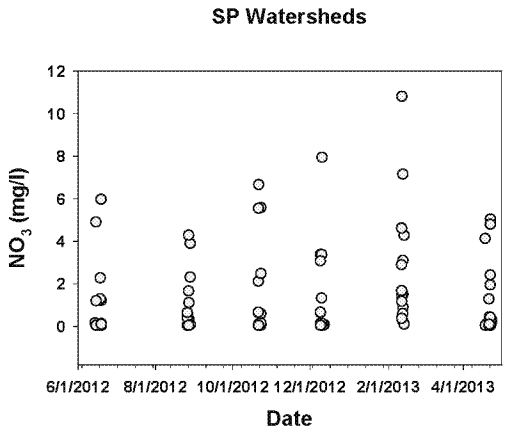

Figure 14. Nitrate concentrations in the SP watersheds. Nitrate concentrations are much higher than swine only and background concentrations.

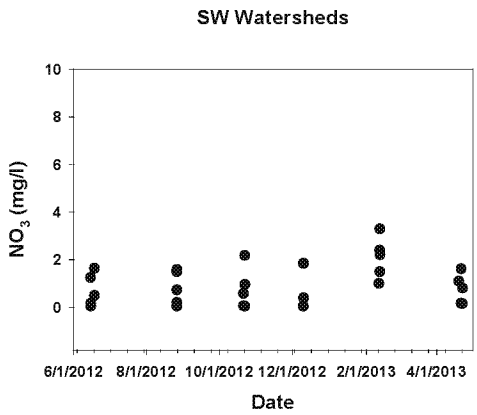

Figure 15. Nitrate concentrations in the SW watersheds. Nitrate concentrations are similar to background concentrations.

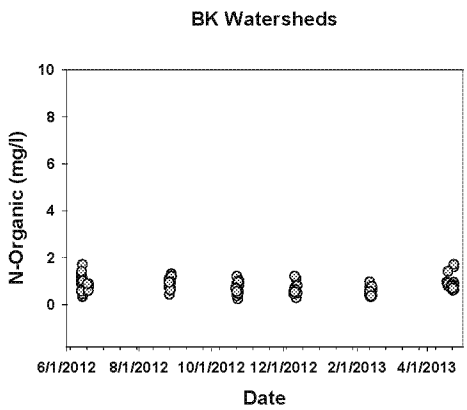

Figure 16. Organic nitrogen concentrations in the background watersheds. These concentrations are similar to concentrations in swine only basins.

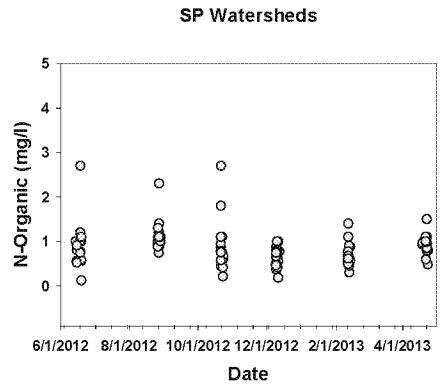

Figure 17. Organic nitrogen concentrations in the SP watersheds. These concentrations are higher than background and swine only basins.

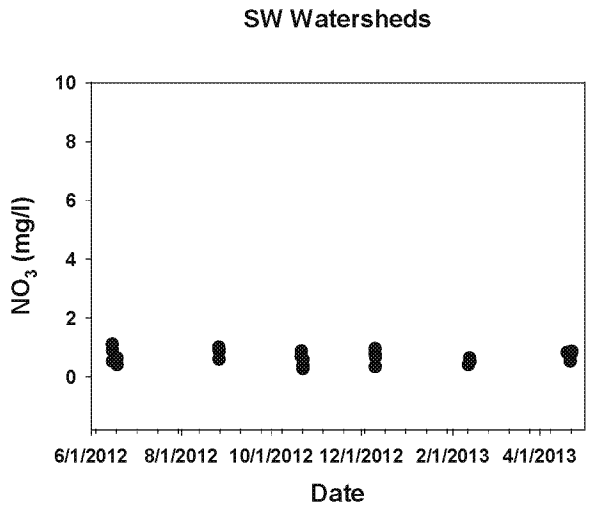

Figure 18. Organic nitrogen concentrations in the SW watersheds.

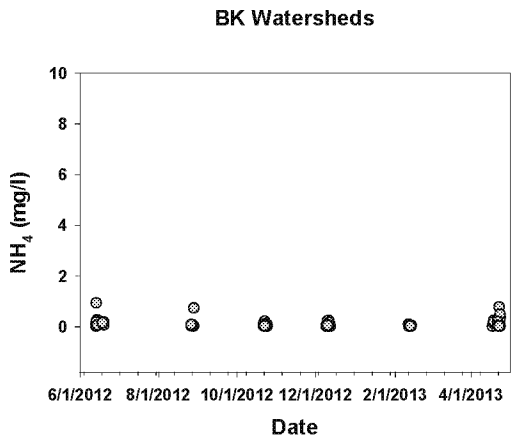

Figure 19. Ammonium concentrations in the SW watersheds.

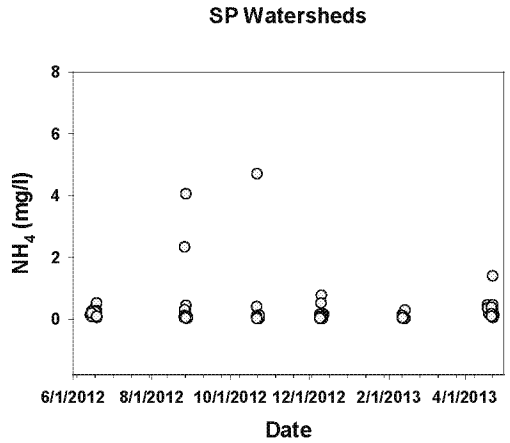

Figure 20. Ammonium concentrations in the SW watersheds.

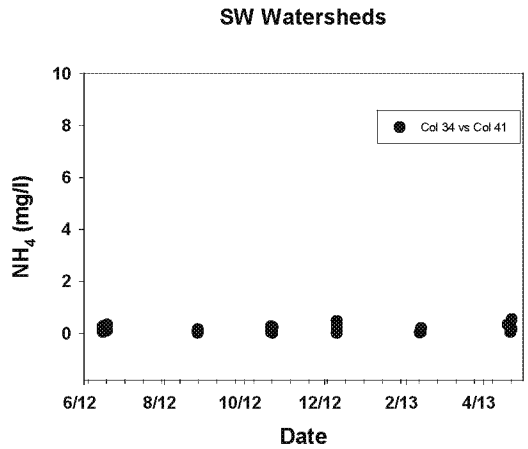

Figure 21. Ammonium concentrations in the SP watersheds.

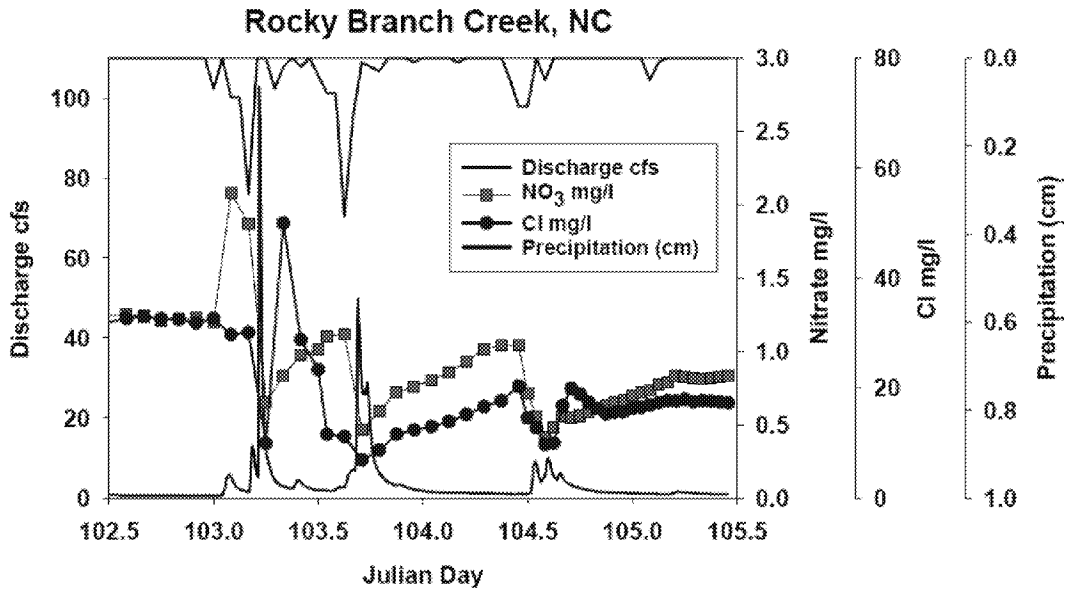

Figure 22. Nitrate and chloride concentrations over a discharge event in Rocky Branch, NC. Sampling over a bimonthly schedule would have been unable to capture this frequent but significant storm event.

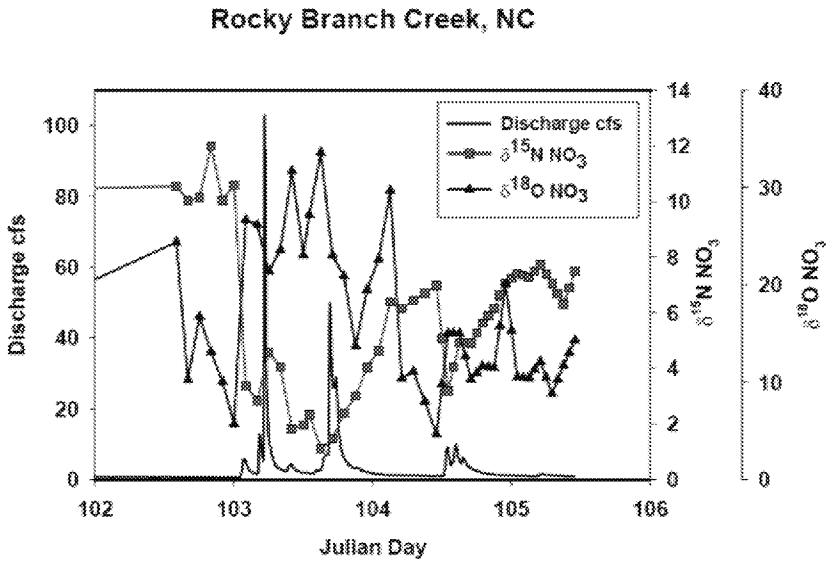

Figure 23. Isotopic composition of nitrate over a discharge event in Rocky Branch, NC

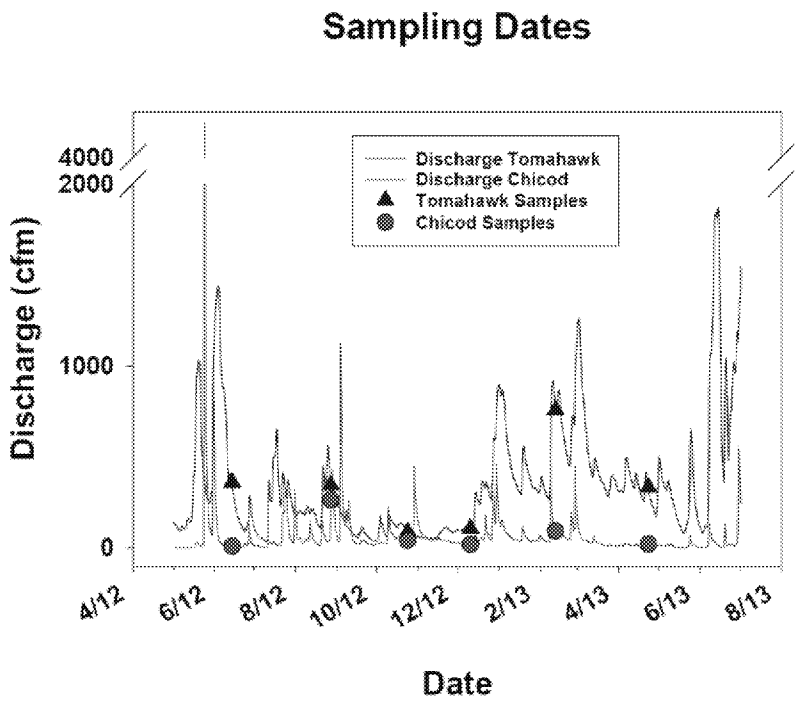

Figure 24. Discharge at Tomahawk on the Black River and Chicod Creek with the sampling dates from SW-03 watershed. The sampling interval does not capture the variation in discharge states, but produces a random data set.

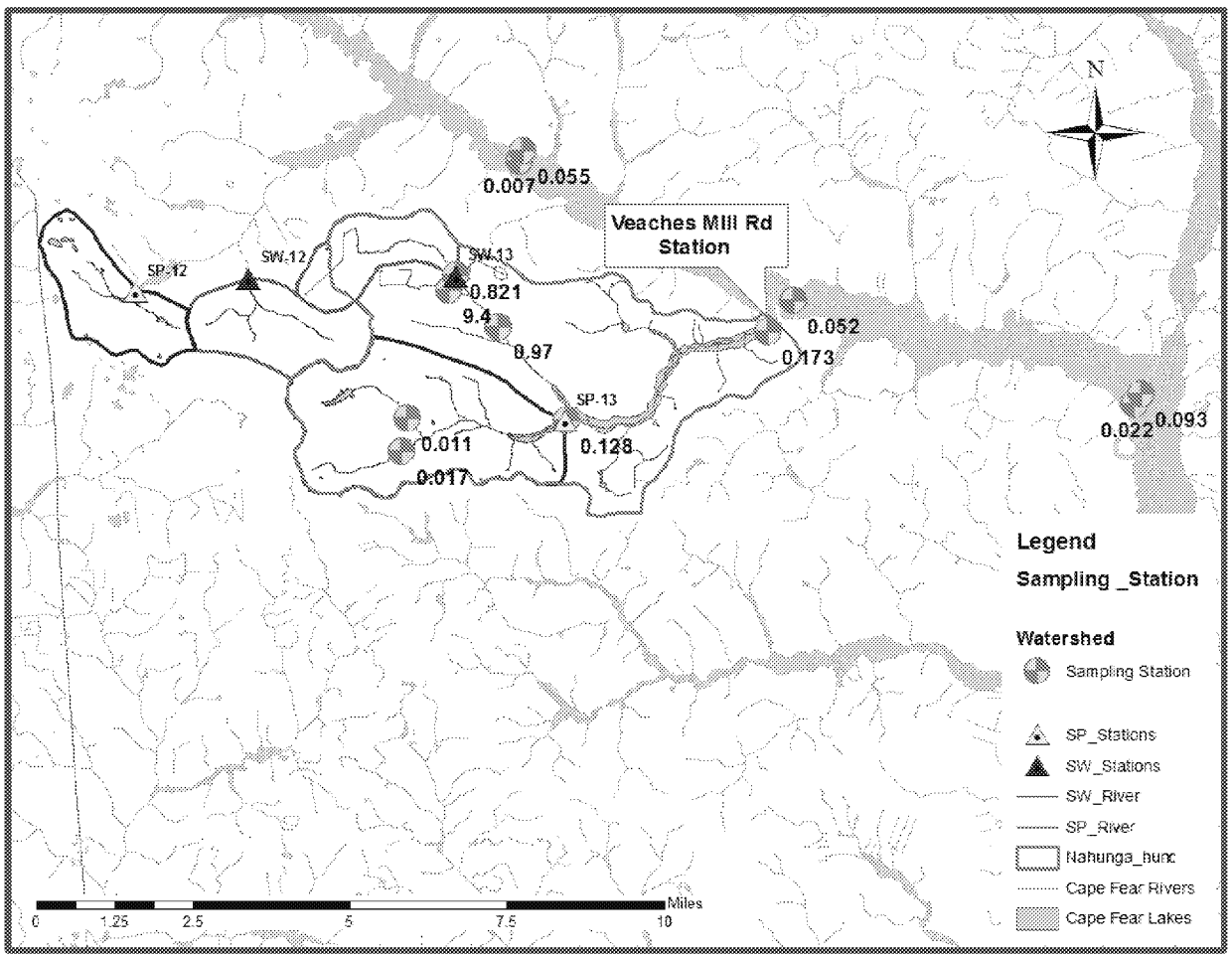

Figure 25. Downstream sampling from SW-13 and SP-13. The stream nitrate concentrations decrease downstream because of the LCLU and soil composition in the stream buffer areas. Downstream sampling is import in the evaluation of impacts upon receiving waters. Notice the Goshen Swamp mainstream nitrate concentrations are extremely low.

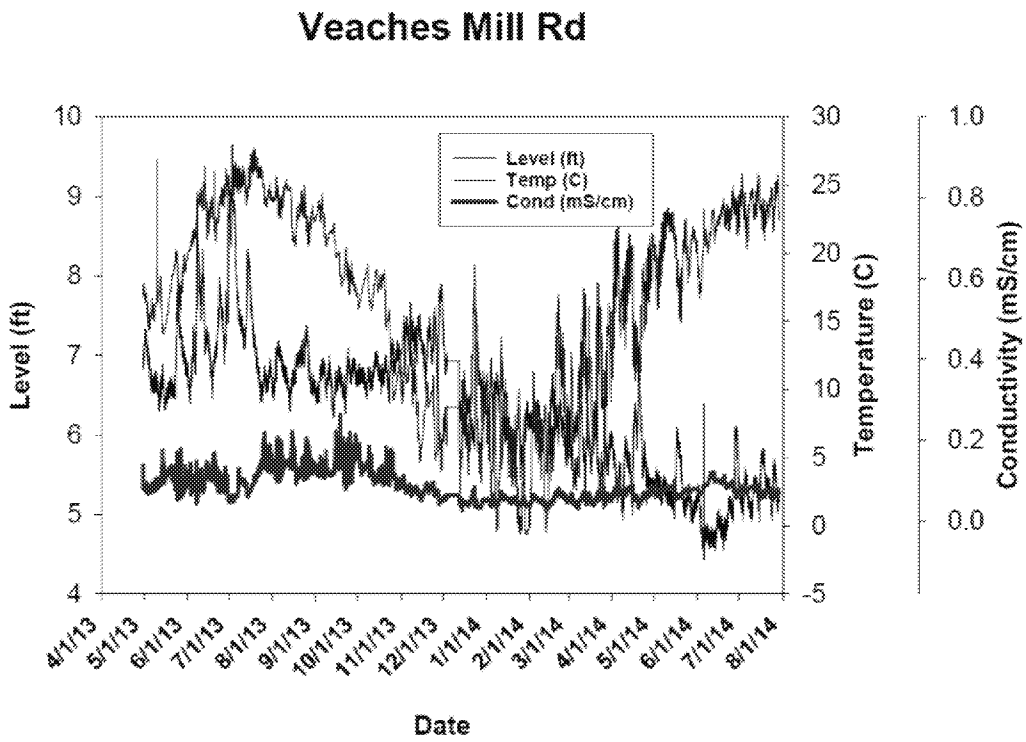

Figure 26. Solinist level logger 15 minute interval record taken at Veaches Mill Road downstream from SW13 and SP13 monitoring sites. Conductivity indicates relatively little change over the 1.3 year period although there are changes in stage and temperature. The relatively high sampling rate and the changes in water levels and temperature re-emphasis the importance of increased sampling frequency.

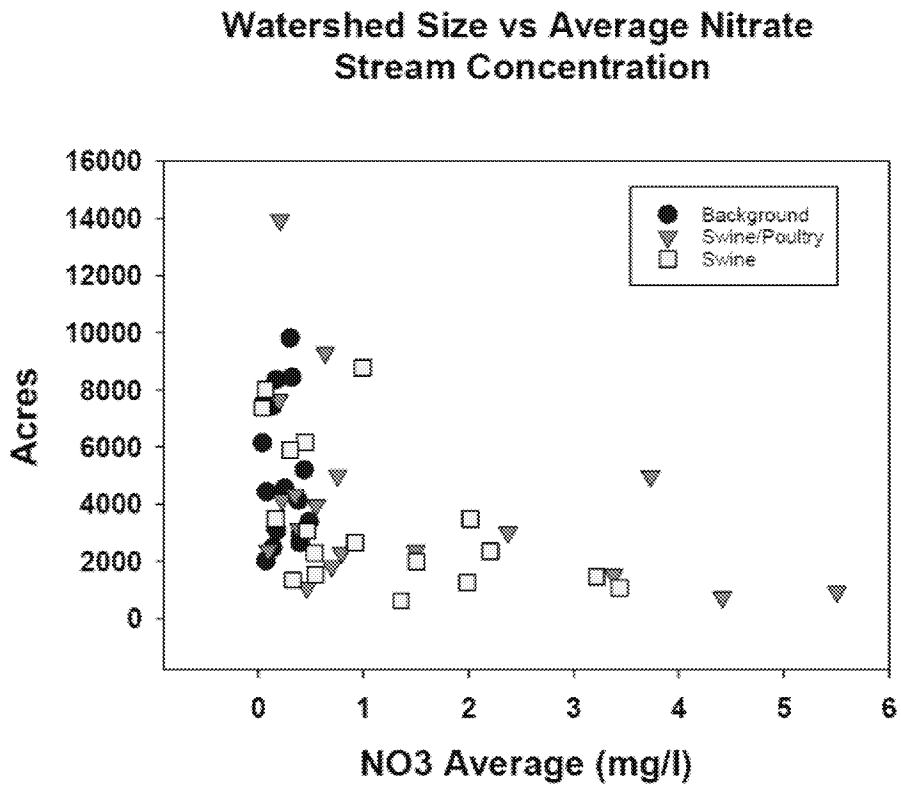

Figure 27. Watershed size versus the average stream nitrate concentration. Watersheds above 2000 acres have reduced nitrate concentrations regardless of the category of land use. The one SP watershed that plots above this trend is SP09, which is a unique channelized drainage system.

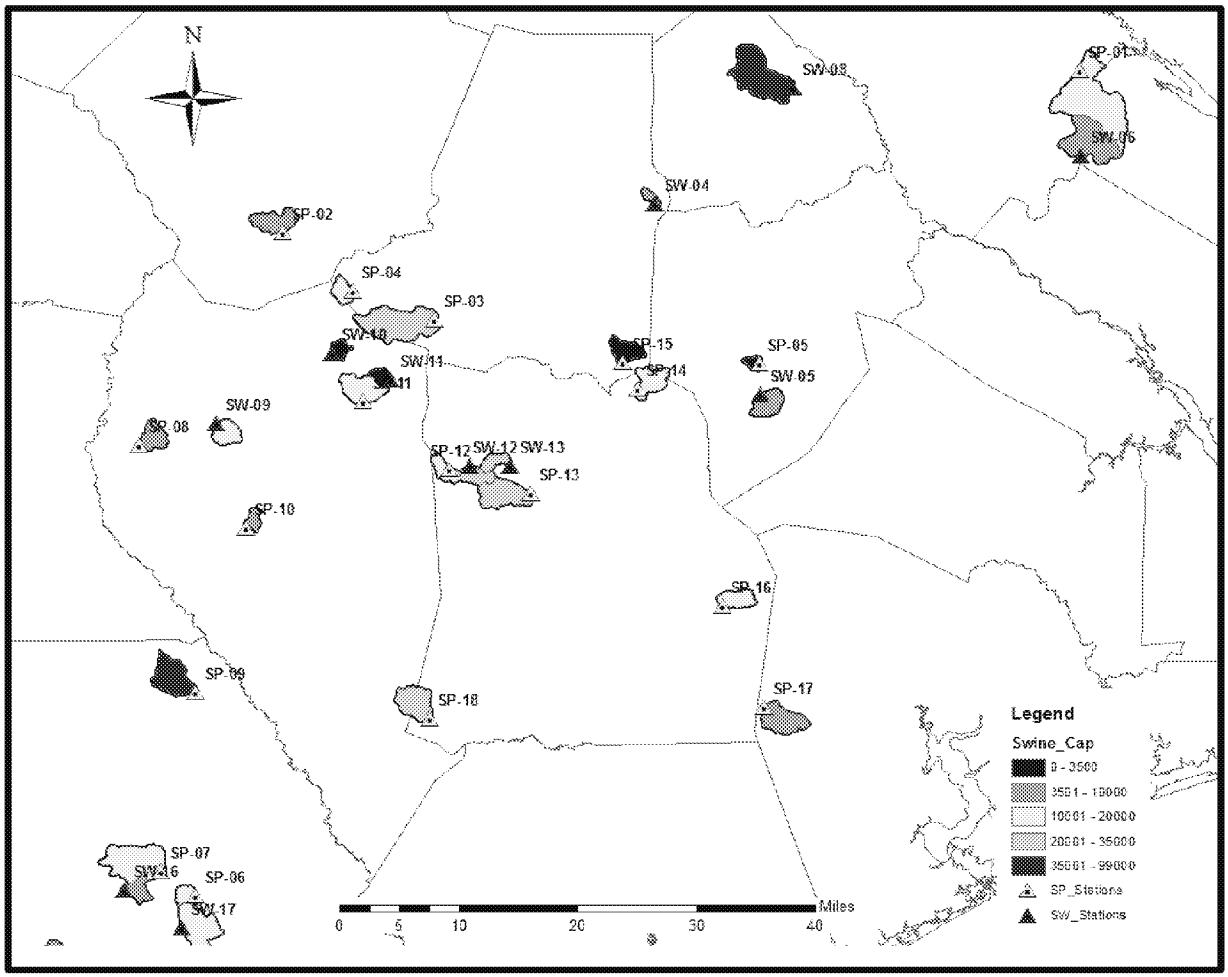

Figure 28. Swine populations in the SW and SP watersheds.

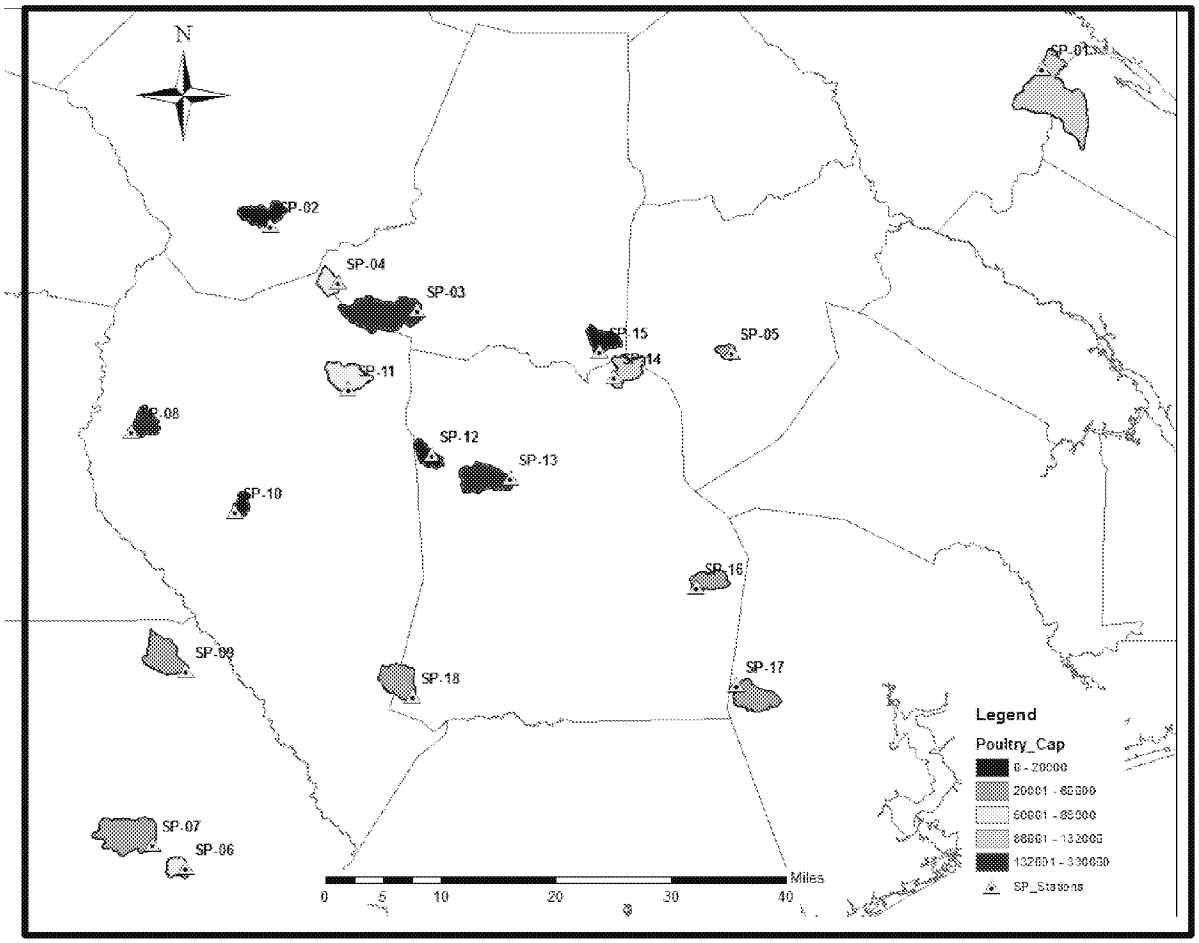

Figure 29. Poultry populations in the SW and SP watersheds.

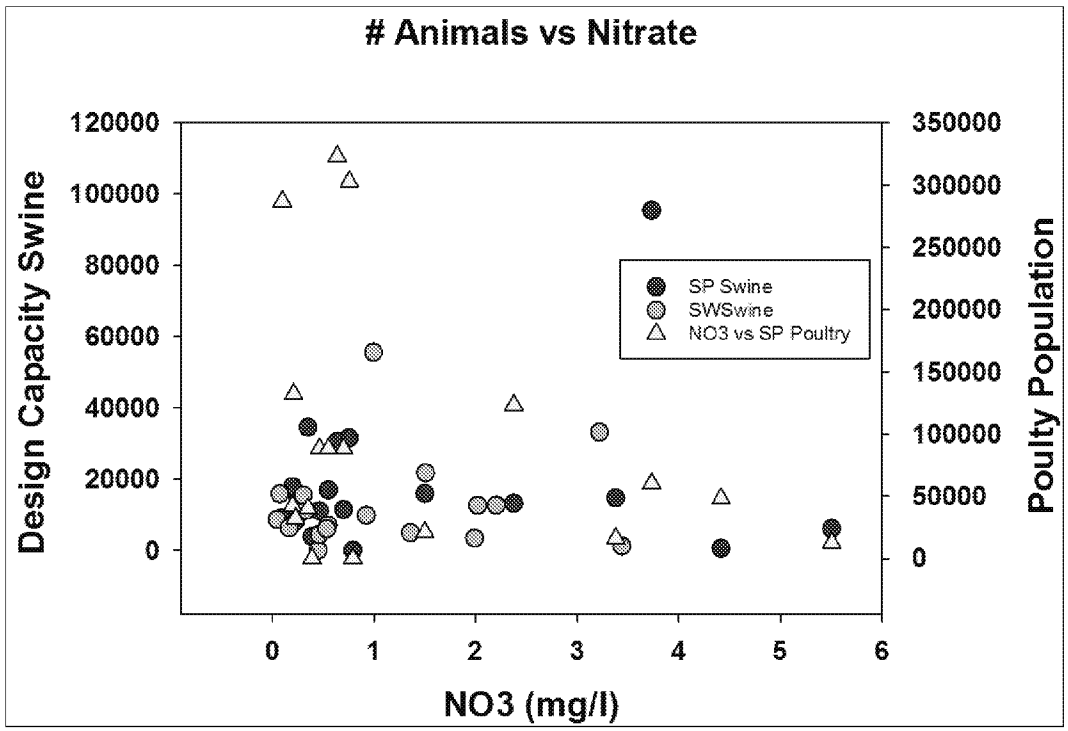

Figure 30. Numbers of animals versus the average nitrate concentration in the USGS monitored watershed. The red circles are SP swine, the green circles are SW swine, and the yellow triangles are SP poultry.

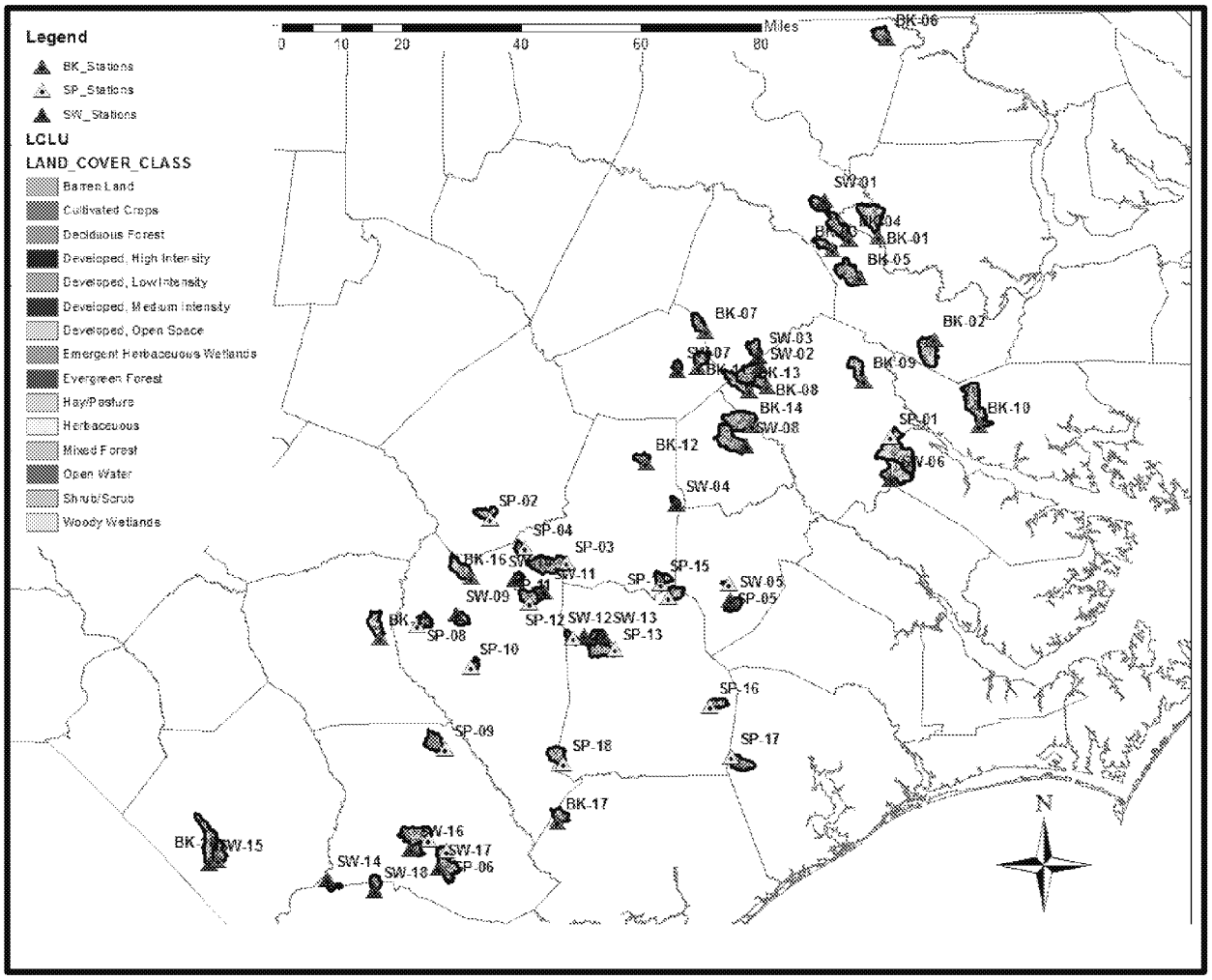

Figure 31. Watershed Land Cover Land Use for each individual monitored watershed.

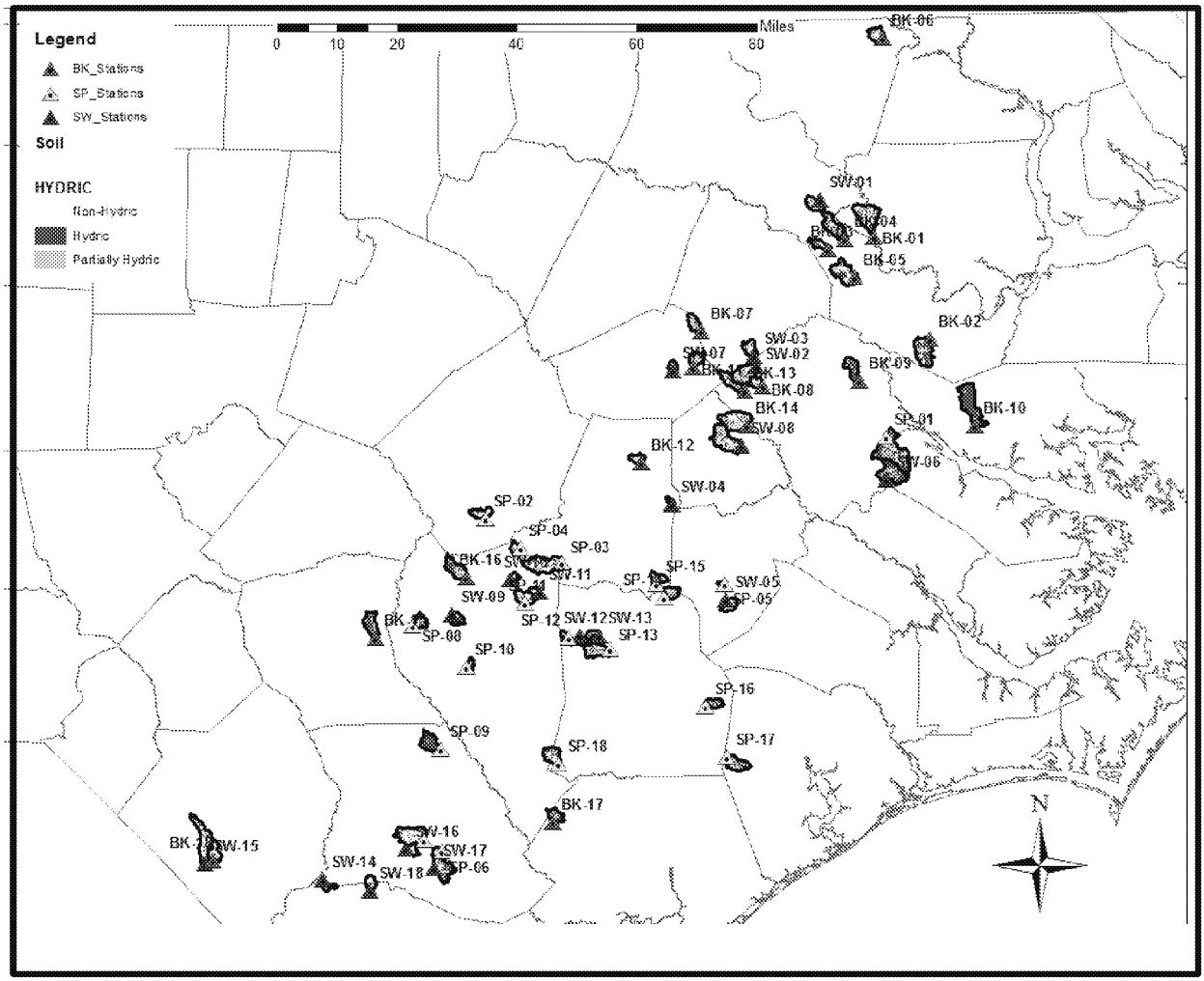

Figure 32. Watershed Hydric Soil distribution for each individual monitored watershed.

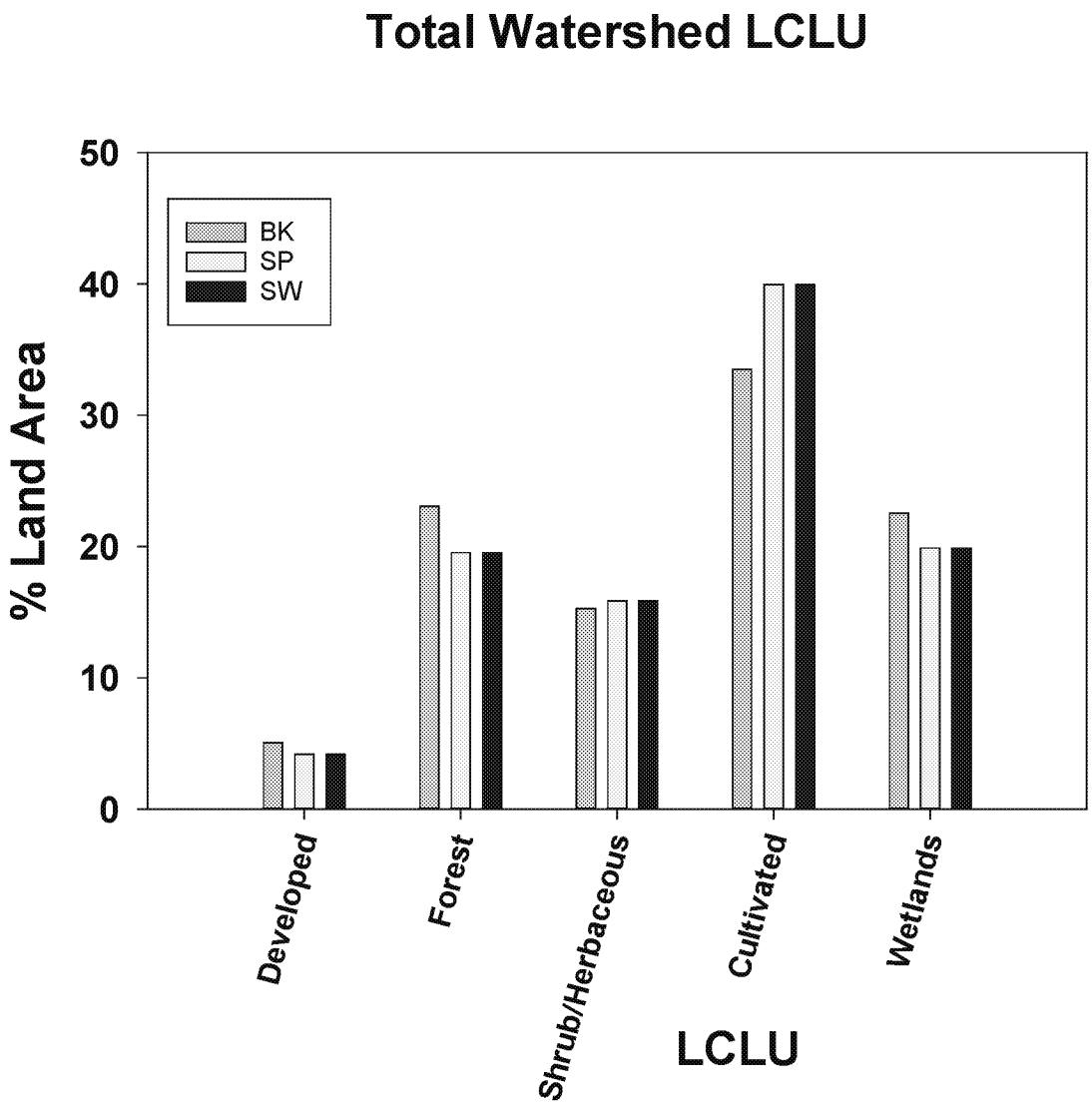

Figure 33. LCLU combined classes for the Total watersheds

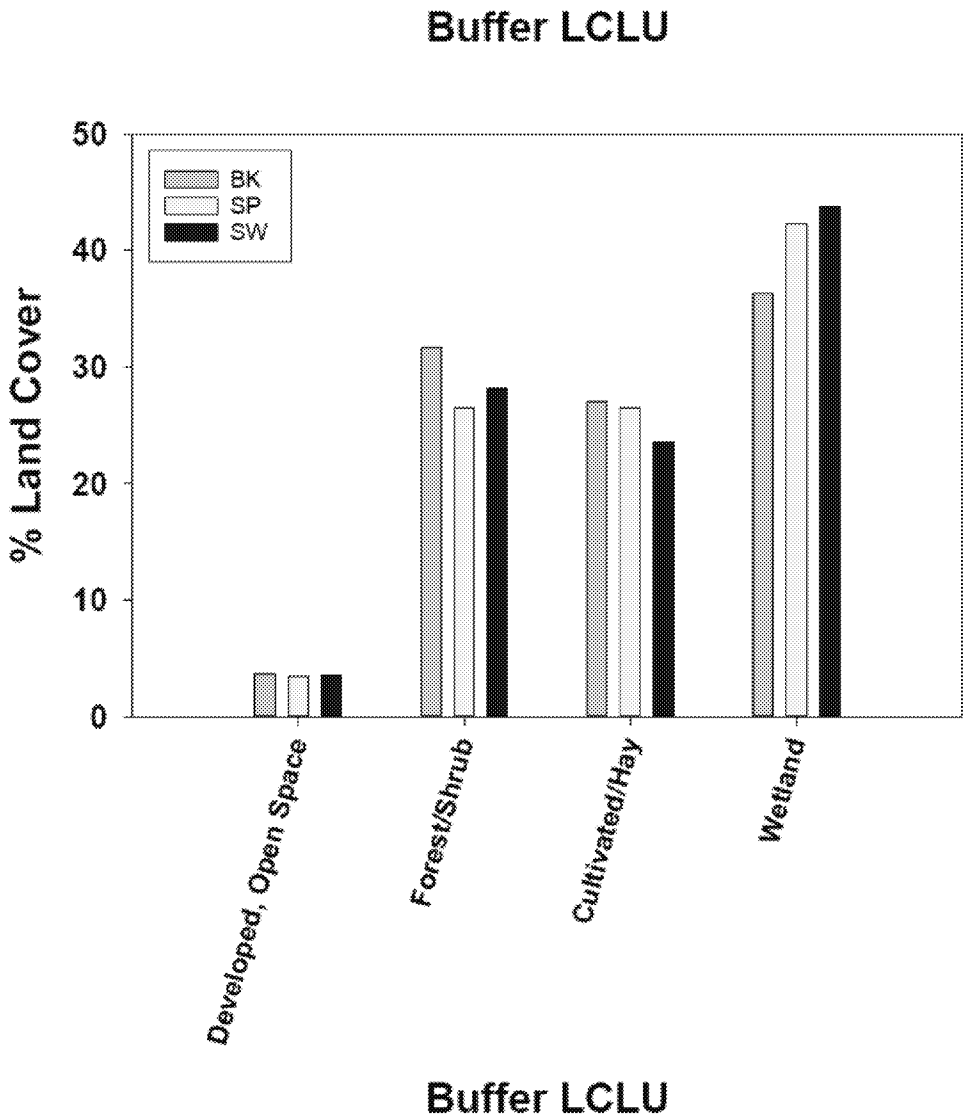

Figure 34. The combined buffer LCLU for the three classes of watersheds.

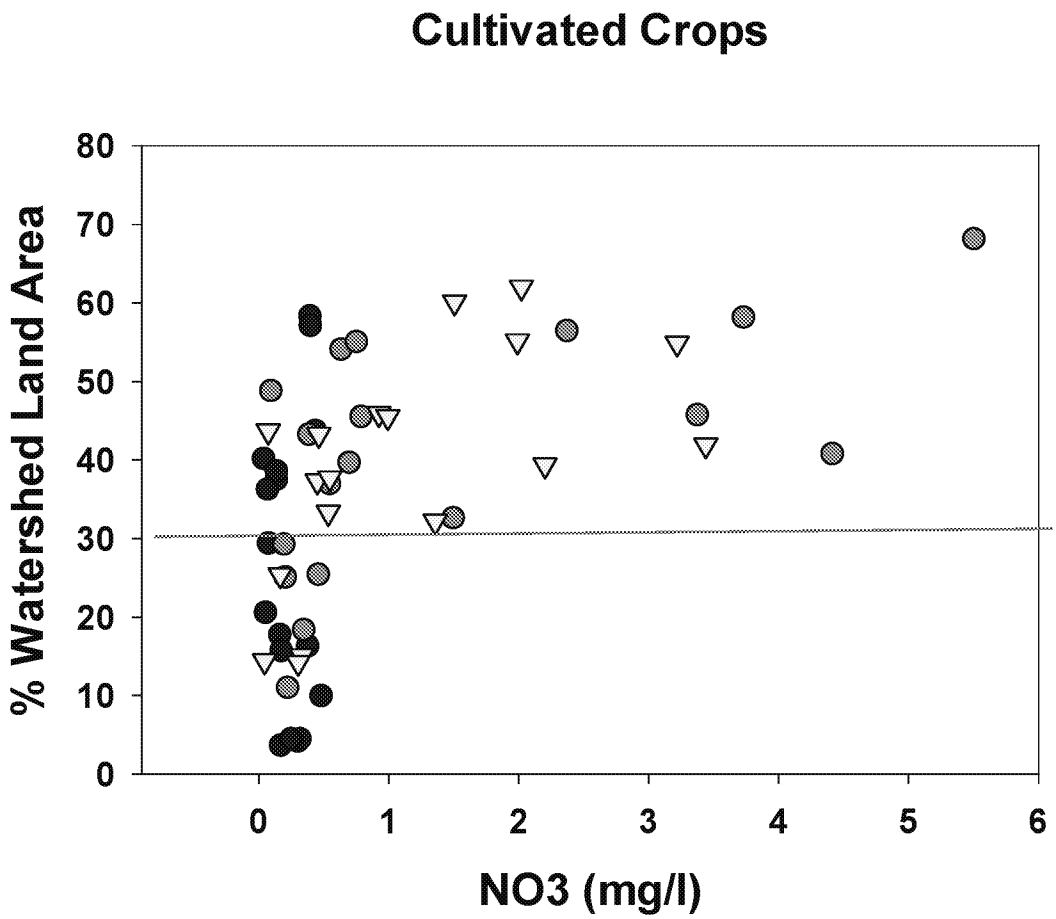

Figure 35. Cultivated crop % versus NO3 concentration in receiving waters for Total watershed. Above 30% cultivated cropland exports nitrate into drainages.

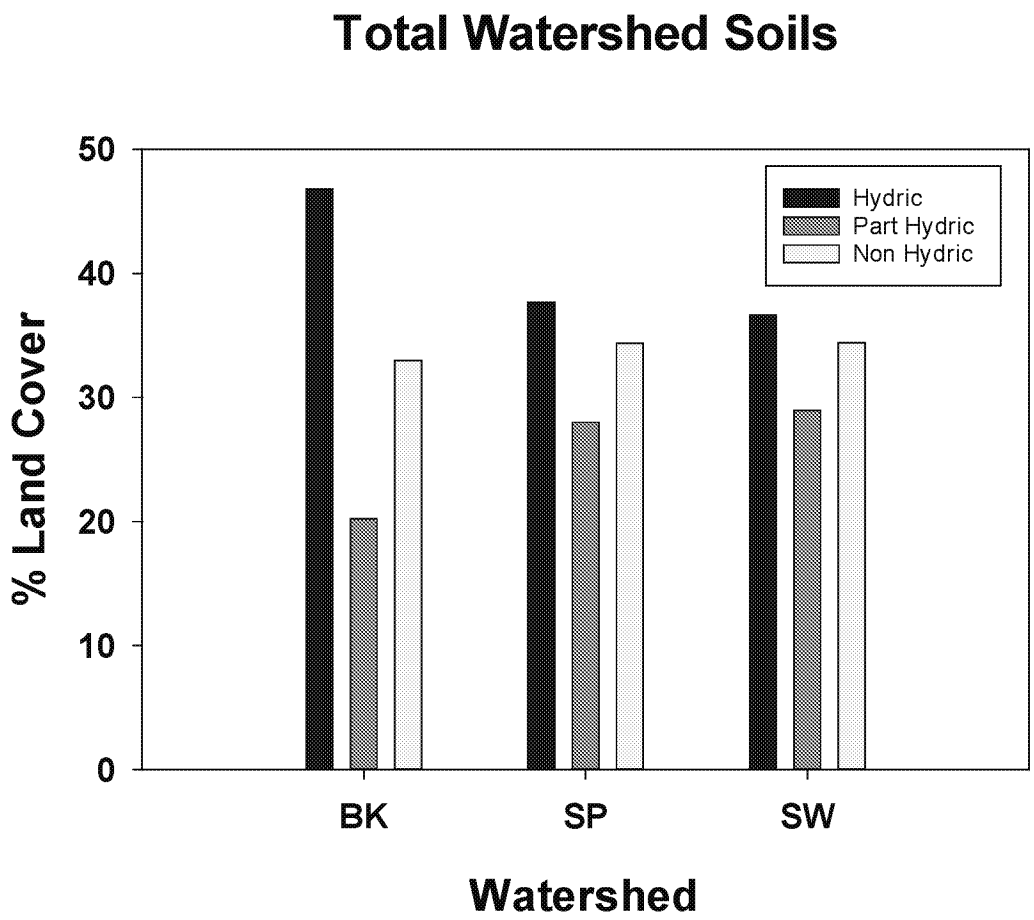

Figure 36. Hydric soil types for the different watersheds, the background sites have a greater proportion of hydric soils than the animal containing watersheds.

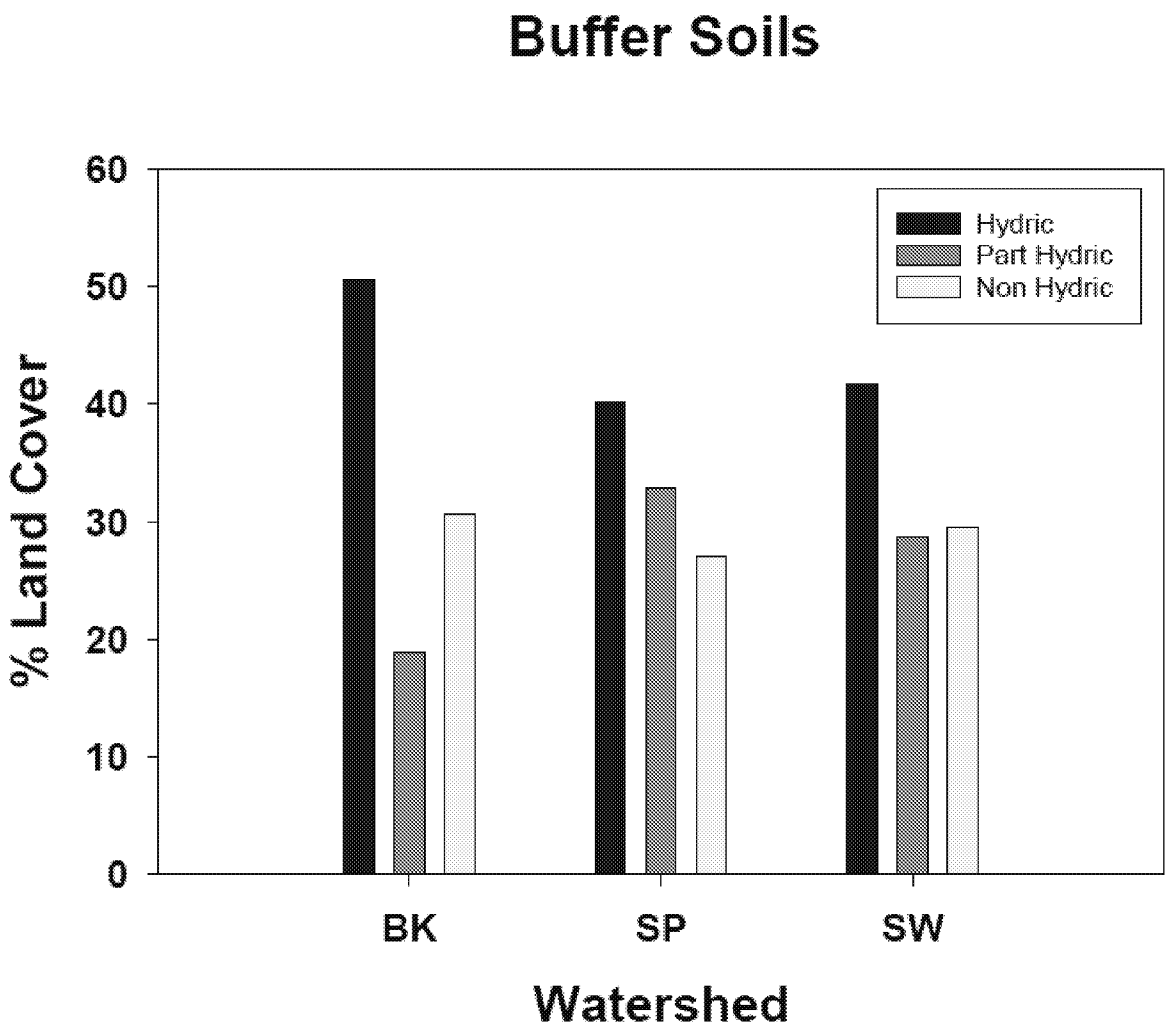

Figure 37. Hydric Soil distribution in watershed buffers.

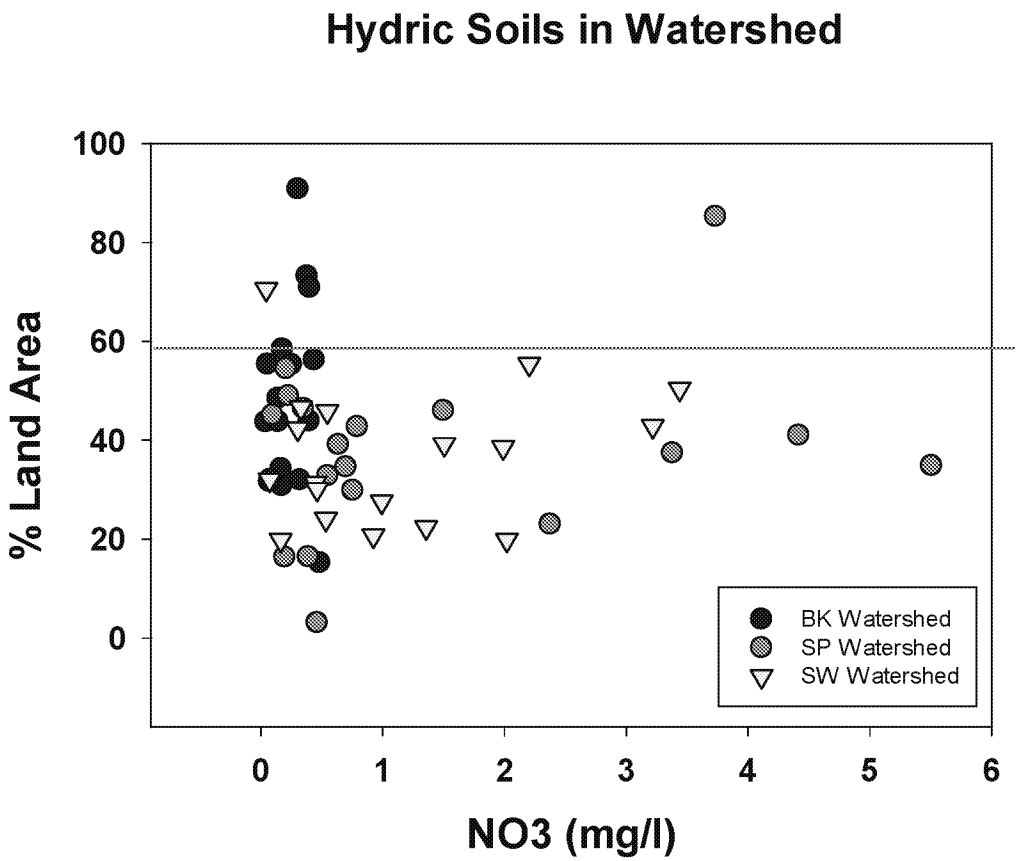

Figure 38. Hydric soil types for Total watersheds versus the average nitrate concentration in the receiving streams. Hydric soil contents above 60% seems to limit nitrogen transport on a watershed scale.

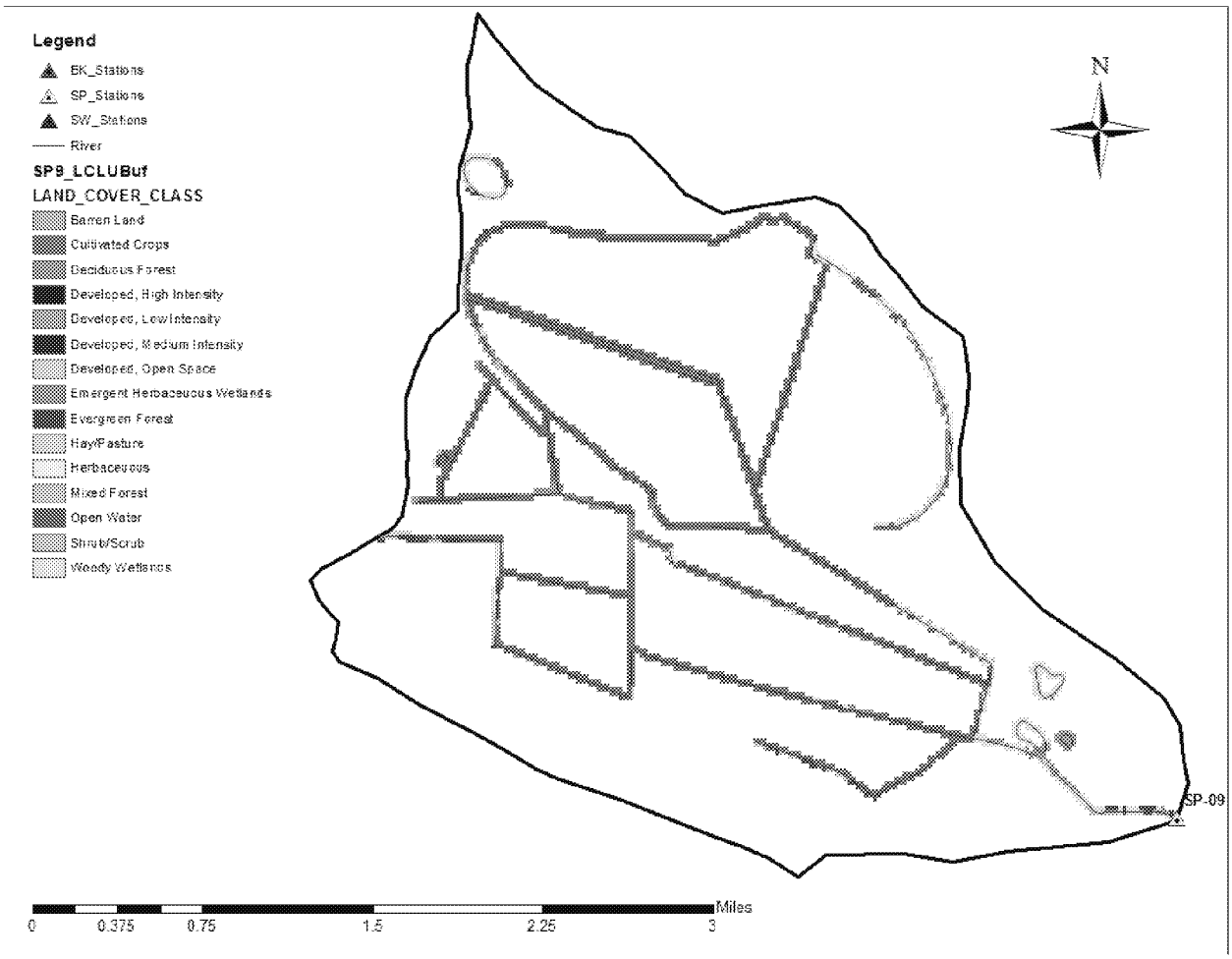

Figure 39. Buffer LCLU distributions in the SP09 watersheds. The drainages are channelized and predominately cultivated crops.

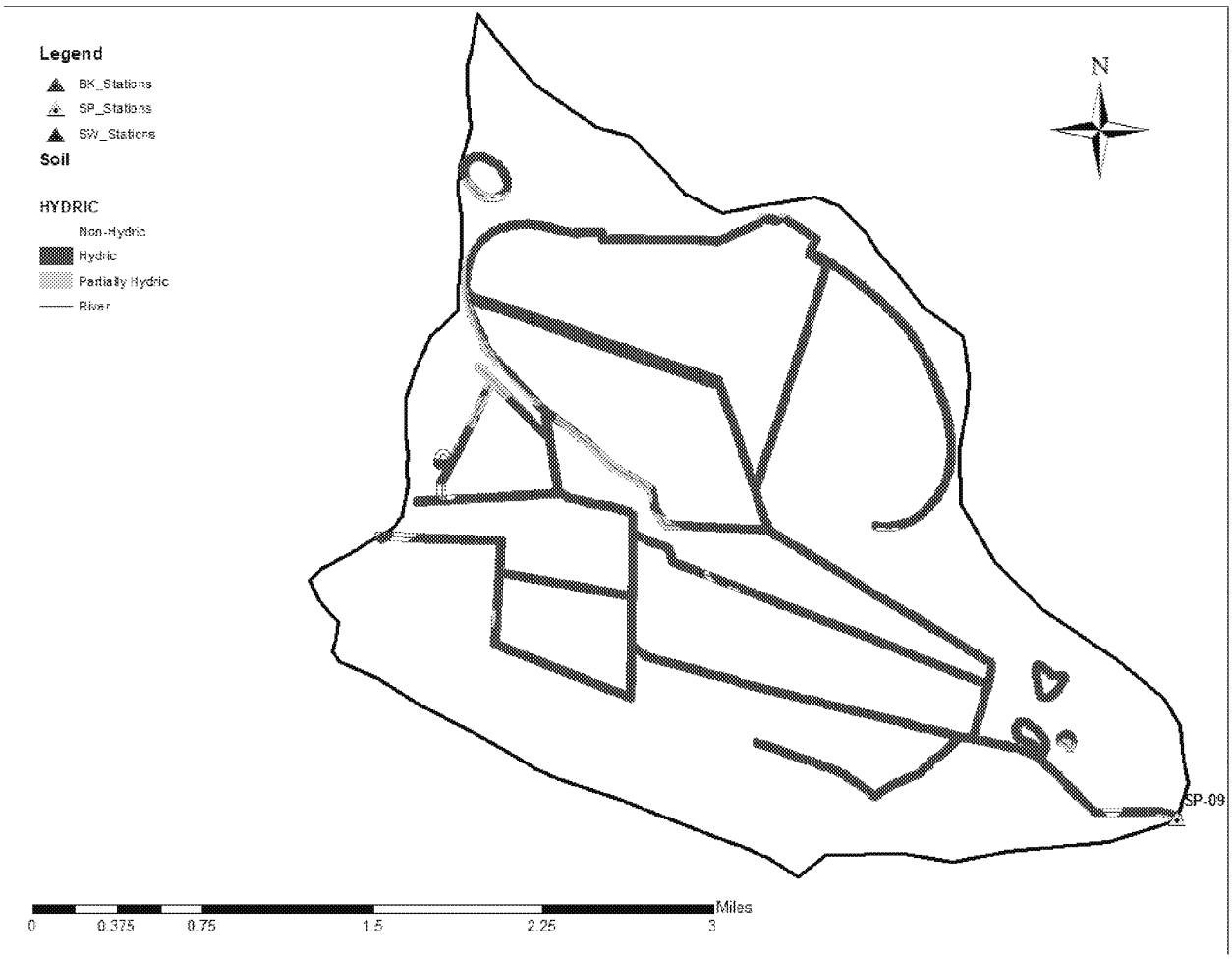

Figure 40. Buffer hydric soil distributions in the SP09 watersheds. The drainages are channelized and predominately hydric soils.

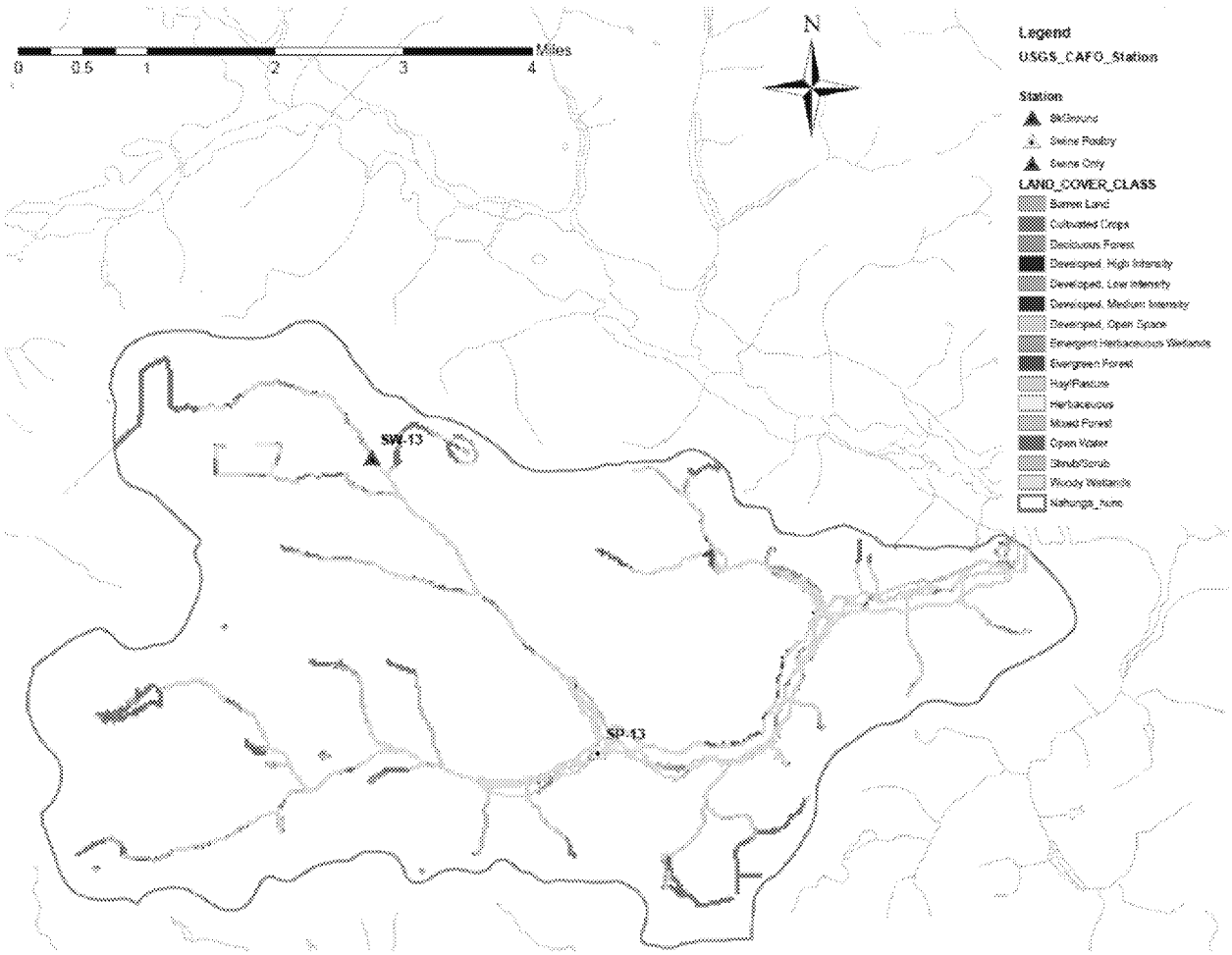

Figure 41. Buffer LCLU in the Nahunga Creek Watershed.

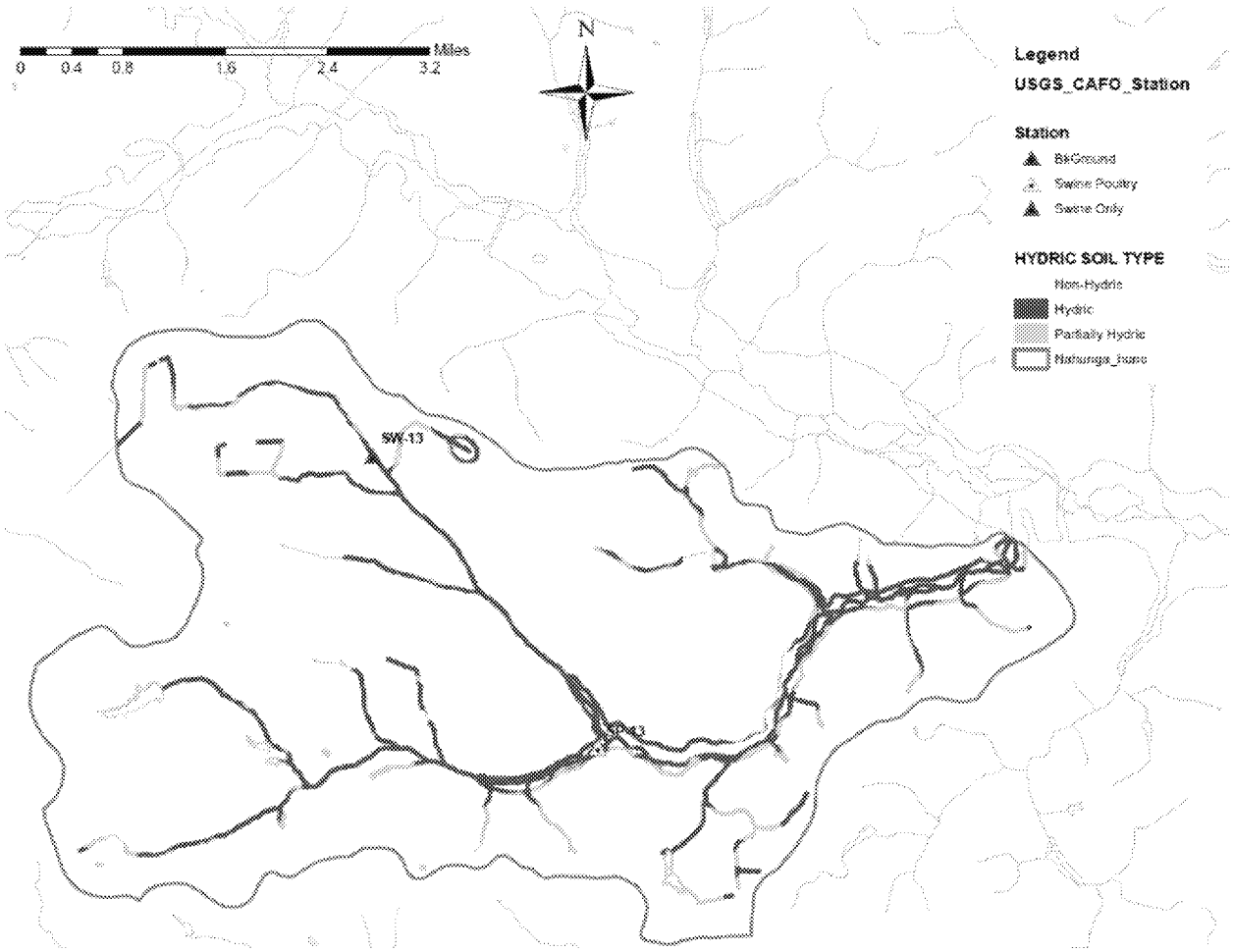

Figure 42. Buffer soils in the Nahunga Creek Watershed. The buffer soils are predominately hydric or partially hydric that naturally attenuate nitrate in the wetlands.

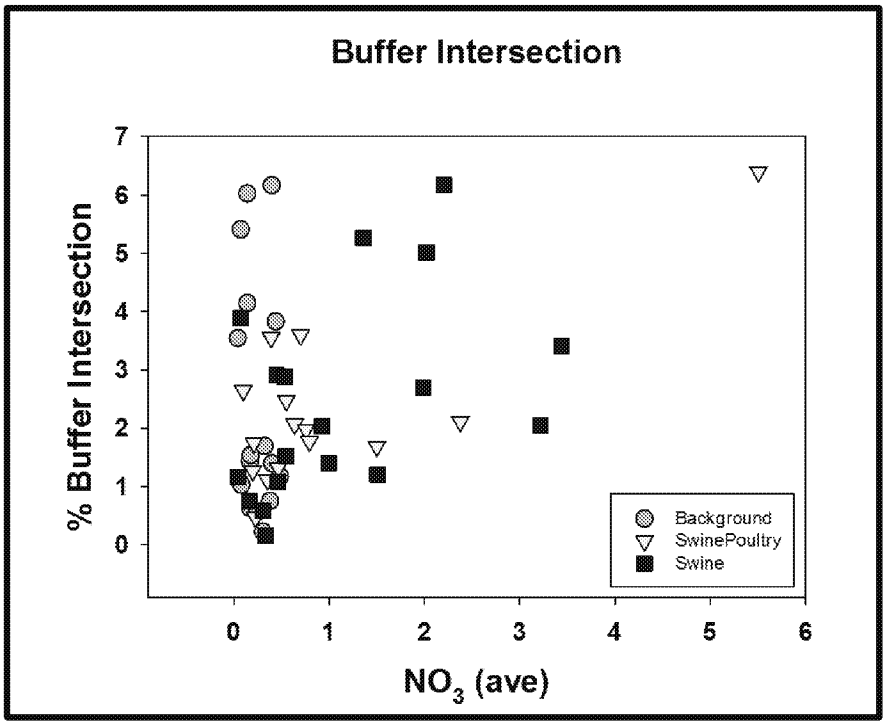

Figure 43. The average stream nitrate concentration versus the % buffer area of the intersection of cultivated/pasture land with non-hydric/partially hydric soils.

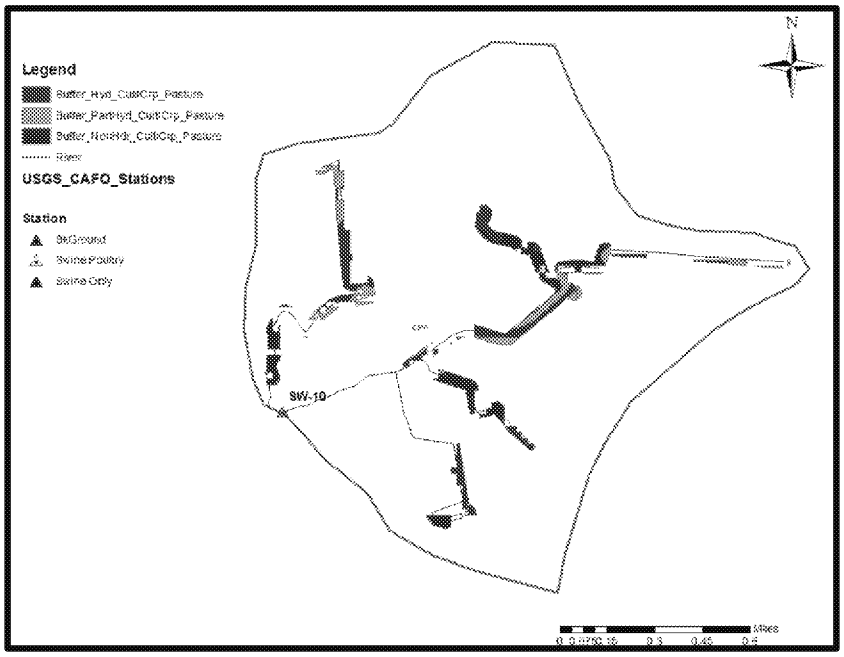

Figure 44. The spatial distribution of the intersection of cultivated/pasture land with non-hydric/partially hydric soils for SW10. This approach defines critical buffer areas that need to be addressed to improve water quality.

APPENDIX A – SUMMARY CHARTS FOR EACH OF THE 54 SAMPLE BASINS (LISTED BY WATERSHED CATEGORY)