Occurrence of Iron in North Carolina Surface Waters

U.S. Environmental Protection Agency Region 4

SUMMARY

North Carolina surface water monitoring data indicates levels of iron that are often higher than the State's water quality criterion of 1.0 milligram/liter (mg/l). The North Carolina Division of Water Quality (NCDWQ) maintains that these elevated iron levels are likely due to natural conditions. The purpose of this paper is to use existing data to evaluate the sources of iron in the surface waters of North Carolina. U.S. Environmental Protection Agency (EPA) Region 4 reviewed available data from NCDWQ and the U.S. Geological Survey (USGS), as well as USGS reports from 1993 and earlier.[1,2]

Iron concentrations in surface waters are associated with natural occurrence and appear to be related to the sediment in streams and the geochemistry of the ecoregions within the state. Percent exceedances of the iron criterion as well as median iron values from the two data sets examined exhibit a general pattern of increasing values from the Blue Ridge through the Piedmont to the Southeastern Plain. Medians of sampling stations of the data sets were plotted and, again, a clear pattern emerges of higher iron values in the Piedmont and Southeastern Plains. The differences in geochemistry, soils and topography represented in the ecoregions are likely responsible for this pattern.

The presence of iron concentrations in storm flow and during low flow conditions indicates that both surface runoff and groundwater inflow contribute to total iron concentrations. Geochemical factors specific to a basin determine which type of transport mechanism - runoff or groundwater - is the major contributor of iron in that basin. The soils in the Blue Ridge indicate that eroded minerals may be an important source of iron in stream water. The less steep slopes and particular soils of the Piedmont ecoregion are likely indicators that iron adsorbed to sediments is the biggest source there. The topography and soil characteristics of the Southeastern Plains and the Middle Atlantic Coastal Plain point to groundwater as the major contributor.

A comparison of levels of iron and turbidity (used as a surrogate for total suspended solids) in these ecoregions supports these assumptions. For example, turbidity is highly associated with total iron concentrations in the Blue Ridge and Piedmont ecoregions and much less so in the Southeastern Plains and Middle Atlantic Coastal Plain ecoregions. These results support the concept that surface runoff may be a significant means of transport of iron to streams in the mountains and piedmont while groundwater is the more significant contributor in the coastal areas.

There does not appear to be a strong association linking anthropogenic sources with elevated iron levels. No obvious visual relationship is apparent when mapped active or invactive mine locations are compared to percent exceedances. The Blue Ridge ecoregion, which has the lowest percent exceedances, has the highest number of active mines. Also, there is not a strong association between urban areas or the locations of the dischargers and the 50% exceedance locations. The largest group of dischargers which

are required to monitor for iron is water treatment plants which are spread across the state.

INTRODUCTION

North Carolina Water Quality Standards

Interest in iron concentrations in the surface waters of North Carolina is generated by concerns about widespread exceedances of the iron criterion as well as the State's position that elevated iron levels are likely due to natural conditions and exceedances should not trigger Clean Water Act Section 303(d) listings. Surface water monitoring results from NCDWQ's network, which are summarized in the state's 17 river Basin Assessment Reports,[3] indicate exceedances of the iron criterion in every basin.

The State's numeric water quality standard for iron is 1.0 mg/l based on total iron. This concentration represents the "maximum permissible level to protect aquatic life applicable to all fresh surface waters."[4] North Carolina's water quality standards address natural conditions, providing that "natural waters may on occasion, or temporarily, have characteristics outside of the normal range established by the standard…. Water quality standards will not be considered violated when values outside the normal range are caused by natural conditions."[5]

Approach

Two sets of data were used to evaluate iron concentrations. Data was provided by the USGS from their reference site studies in North Carolina.[1,2] Also, data was downloaded from the NCDWQ's monitoring network from 1997 to 2007.[6]

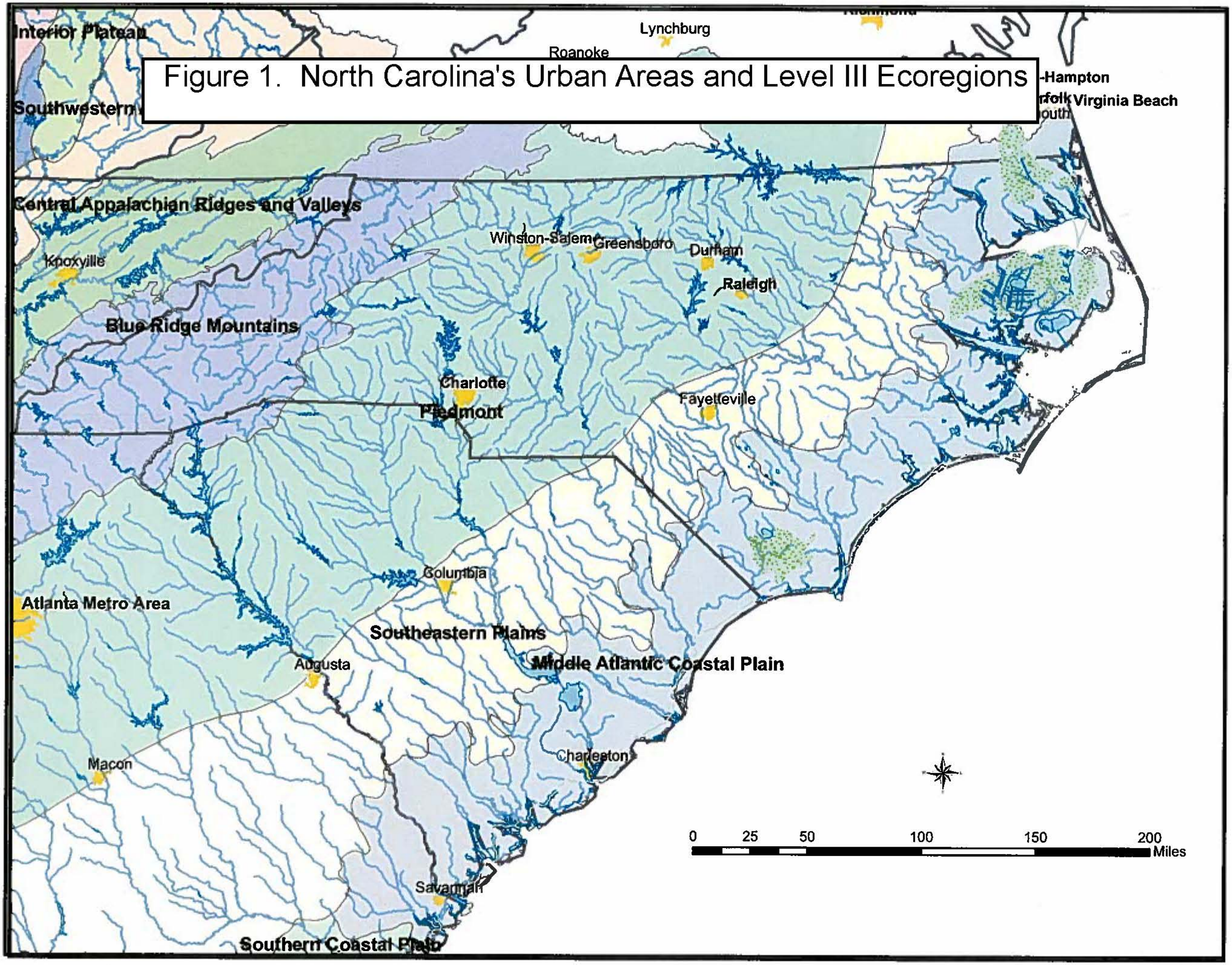
The primary approaches to evaluating data were to use GIS techniques to examine visual relationships and to conduct statistical analyses. The data from NCDWQ's monitoring network was used to calculate the percent of samples at each sampling location that exceeded the iron water quality criterion. In addition, individual sampling station medians were calculated for the NCDWQ and USGS data.

The four Level III ecoregions[7] in North Carolina provided the framework for the evaluations. These ecoregions represent areas with similar ecosystems and similarities in the type, quality and quantity of environmental resources. More detailed descriptions are provided in Appendix A. Figure 1 is a map of North Carolina showing the ecoregions in relation to major urban areas and waterbodies.

Percent Exceedances

The data from NCDWQ's monitoring network was used to identify the percent of samples at each sampling location that exceeded 1.0 mg/l at least one time. GIS techniques were used to calculate and plot the exceedances. Note that exceedance of the 1.0 mg/l criterion is not the same as exceedance of the water quality standard, which is presented as "maximum permissible level." EPA's interpretation of this standard is that

Figure 1. North Carolina's Urban Areas and Level III Ecoregions



Ecoregions: U.S. EPA Western Ecology Division, Not Dated, Ecoregion Maps and GIS Resources, webpage: http://www.epa.gov/wed/pages/ecoregions.htm more than one exceedance of the criterion in a three year period should result in a Section 303(d) listing.[8] For purposes of this paper, the term "exceedances" is used to represent exceedances of the numeric value (1.0 mg/l) of the water quality standard for iron.

The percent exceedances by station are plotted in Figure 2. The categories on the exceedance map exhibit a general pattern of increasing values from the Blue Ridge through the Piedmont to the Southeastern Plain with the Blue Ridge ecoregion having the lowest percent exceedances. The highest level of exceedances is found in the east central part of the state. When percent exceedance was calculated by ecoregion without regard to station location or sampling date, the same pattern is present (Table 1).

Table 1. Percent Exceedance of Iron Concentrations by Level III Ecoregion (>1.0 mg/l, all stations, all dates, NCDWQ data 1997-2007)

Ecoregion	Percent exceedance
Blue Ridge	3
Piedmont	34
Southeastern Plains	42
Middle Atlantic Coastal Plain	21

Of the 421 sampling locations in this data, a total of 369 stations (88 %) exceeded the criterion of 1.0 mg/l at least one time. There is a 34% exceedance rate across the entire State without regard to station location or sampling date. The USGS data produced a similar exceedance rate of 30%. Although the two data sets differ in age and collection purpose, an investigation of the frequency distribution of the two data sets indicates that both are from the same population.

SOURCES OF IRON IN WATERS

Natural sources

Iron is the fourth most abundant by weight of the elements in the earth's crust. Because it is ubiquitous in the earth's crust, iron often reaches higher concentrations in water and sediments than other trace metals. The solubility and availability of iron is dominated by the two valence states of its ions, ferric iron (Fe^{3+}) which is the oxidized state and ferrous iron (Fe^{2+}) which is the reduced state. Although ferrous iron is more soluble, the most common iron ion in surface waters is the ferric state. Microbial reduction of ferric iron to ferrous iron in the oxidation of organic carbon occurs to some degree in most aquifers.[9] The concentration of ferrous iron in groundwater from aquifers is dependent on the geology, climate and hydrology associated with the aquifer.

More than 175 minerals contain iron within their crystalline matrix. Some of the more common iron-containing minerals are magnetite (Fe_3O_4), hematite (Fe_2O_3), goethite (FeOOH). Magnetite is the primary source of iron ore mines in western North Carolina[10].

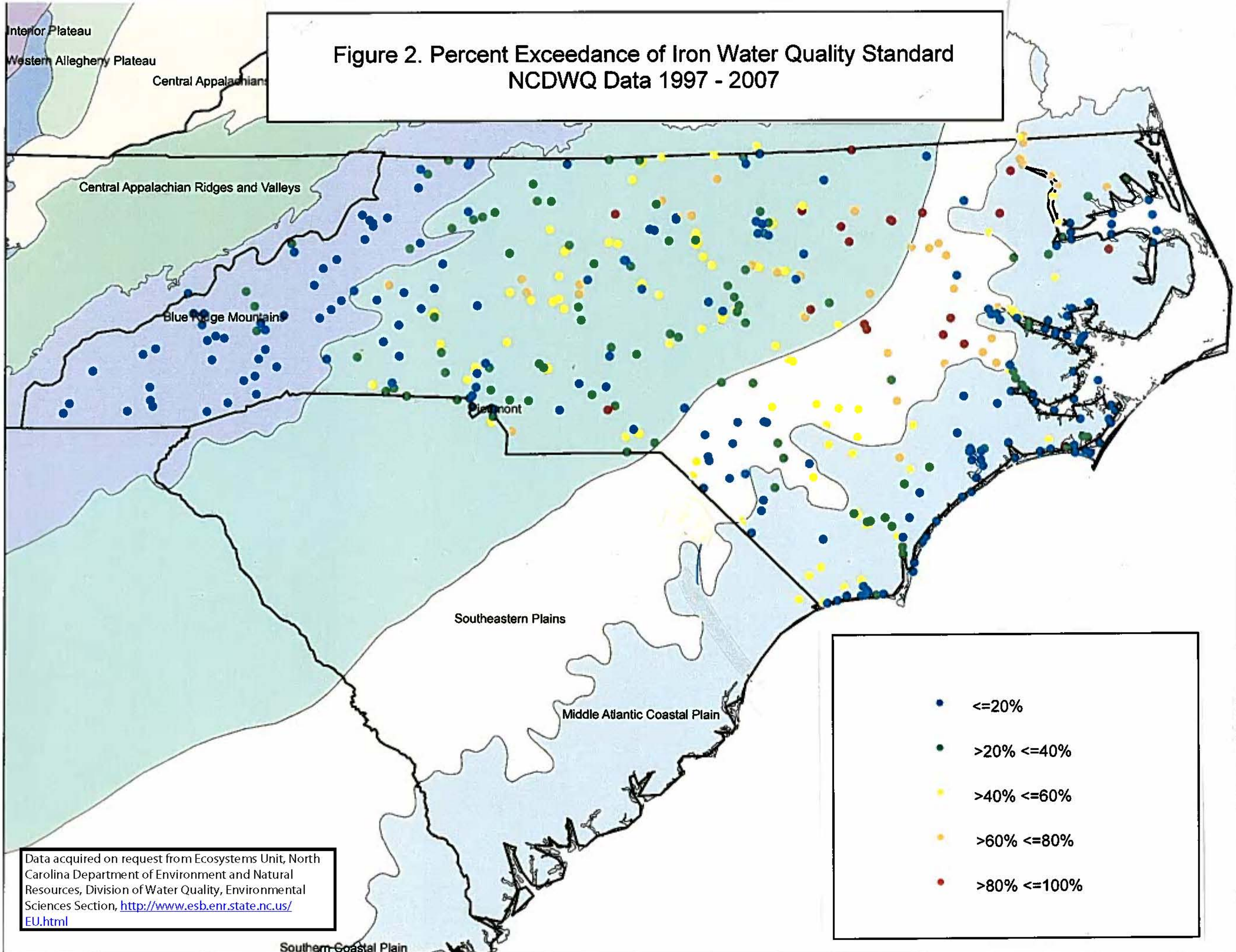


Figure 2. Percent Exceedance of Iron Water Quality Standard
NCDWQ Data 1997 - 2007

Iron ions are released from primary iron-containing minerals in igneous and metamorphic rocks through weathering processes such oxidation and acid dissolution. Once these ions are released from a mineral structure, they may be found in several forms. They can be dissolved in ground and surface water, incorporated into other minerals formed by weathering processes and adsorbed as coatings on soil particles and sediments. Iron ions can also form complexes with organic matter found in soils, bogs and other wet areas as well as be transformed and precipitated by microorganisms[11]. Clay particles in soils can contain iron in their structures and weakly retain iron on exchange sites. The most common form of iron in stream water is that adsorbed to suspended sediments.

Anthropogenic Sources

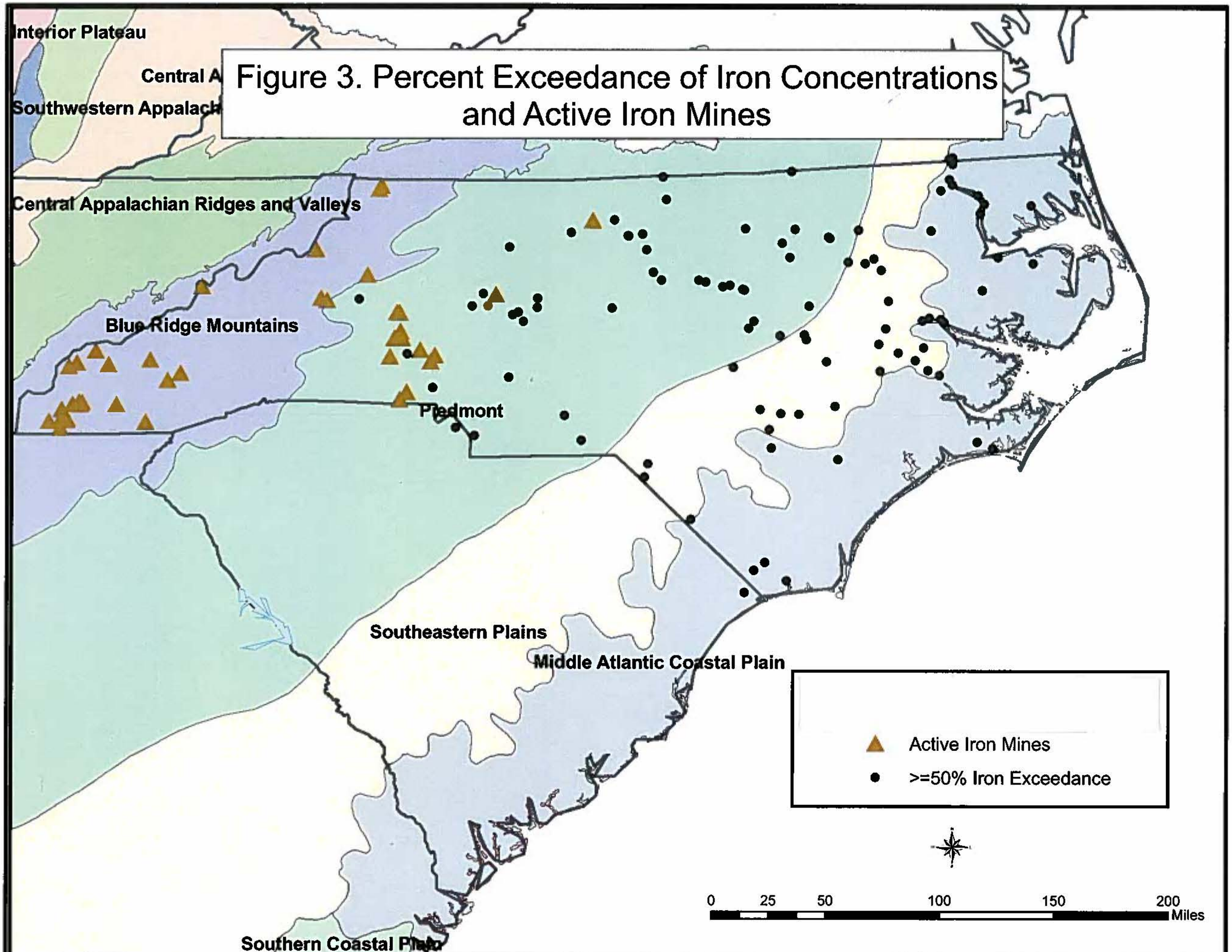
In addition to natural sources of iron, anthropogenic sources of iron can contribute to iron concentrations in surface waters. Possible anthropogenic sources of iron include mining, industrial activities and urban areas.

Mining

Two sources of iron from mining activities were evaluated: active iron mines and possible acid mine drainage from different types of inactive mines. Of the 45 active iron mines including mines that extract iron as one of several commodities[12] in North Carolina, 32 mines are located in the Blue Ridge ecoregion and 13 in the Piedmont. A high percent of exceedances of the numeric iron standard might be expected if active iron mines were contributing to iron concentrations in nearby streams especially in the Blue Ridge where steep slopes can provide opportunities for runoff. However, no obvious visual relationship is apparent when the mine locations are compared to percent exceedances (Figure 3). The Blue Ridge ecoregion, which has the lowest percent exceedances, has the highest number of active mines.

In general, increased iron concentrations have been associated with acid mine drainage from abandoned mines, particularly when pyrite, an iron sulfide mineral, is present. "In the presence of dissolved oxygen, iron in water from mine drainage is precipitated as a hydroxide, $Fe(OH)_3$… ("yellow boy")… Occasionally ferric oxide (Fe_2O_3) is precipitated forming red waters. Both of these precipitates form as gels or flocs that may be detrimental, when suspended in water, to fishes and other aquatic life. They can settle to form flocculant materials that cover stream bottoms thereby destroying bottom-dwelling invertebrates, plants or incubating fish eggs." [13]

To explore the likelihood that inactive mines are contributing to iron concentrations in surface waters, the locations and types of mines were obtained from the USGS Mineral Resources Data System[12]. The data was filtered to retain only past producers of all mine types. The term, past producers, was interpreted to mean that the mines are no longer active. Using GIS techniques, a one-mile buffer radius was placed around all sample locations where iron concentrations exceeded the numeric water quality standard of 1.0 mg/l for more than 50% of the samples taken. Any inactive mine that fell within the buffer was identified by type. The results are shown in Figure 3.



Mine locations: U.S. Geological Survey, 2005, Mineral Resources Data System, Iron mines with identifier equal to "producer" or "occurrence", data available at http://tin.er.usgs.gov/mrds/;
Data acquired on request from Ecosystems Unit, North Carolina Department of Environment and Natural Resources, Division of Water Quality, Environmental Sciences Section, http://www.esb.enr.state.nc.us/EU.html

Overall, there is not a strong association between the locations of the mines and the 50% exceedance locations. Of the 3,223 mines identified as past producers, 19 or 0.6% were within the one-mile radius (Table 2). With the exception of the three gold mines, the types of mines identified are not generally associated with acid mine drainage or pyrite. The past producer gold mines are clustered in one area (Figure 4). The likelihood of iron entering surface water from these mines is dependent on several factors including the geochemistry and topography of the mine sites.

Table 2. Past producer mines within one-mile radius of water sampling locations with greater than 50% exceedance of the numeric iron water quality criterion.[12]

Type of Past Producer	**Number of Mines**
sand and gravel for construction	13
gold	3
clay	1
granite	1
crushed or broken stone	1

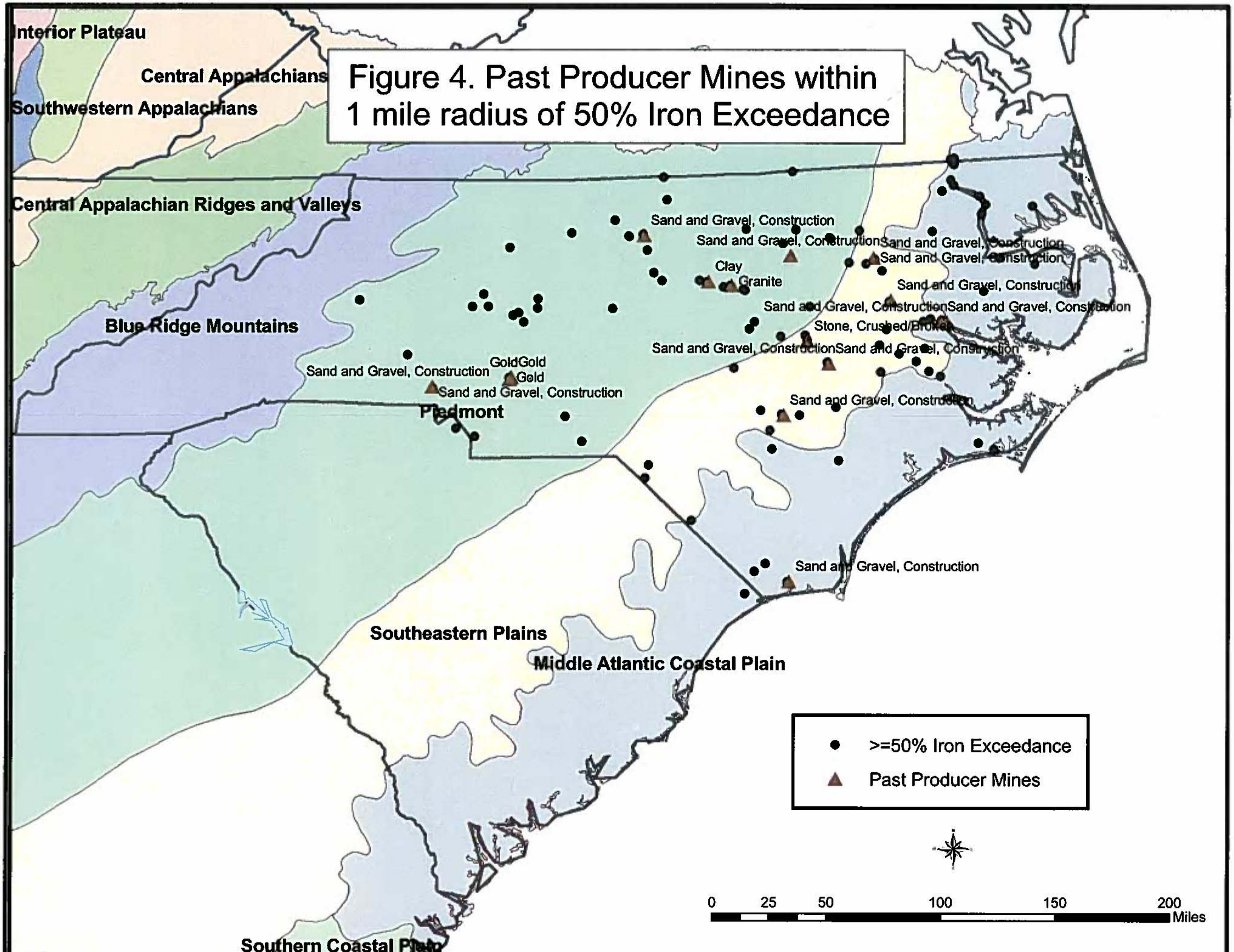
Industrial

The requirement for facilities to monitor for iron concentrations is generally based on the potential for the discharge to violate the water quality standard for iron. To determine the necessity of a limit for iron, NCDWQ performs a reasonable potential analysis on available data. A reasonable potential analysis is a statistical analysis used to calculate maximum predicted effluent concentration. Where there is reasonable potential for a standards violation, a limit is placed on the permit and monthly monitoring is required.

There are 227 regulated facilities in North Carolina which are required to monitor for iron according to the EPA Permit Compliance System[14]. At least 80% or 182 facilities are water supply facilities. Eight percent or 18 facilities are electrical services providers (steam generating power plants). The type of facilities monitoring for iron and the number of each type are given below in Table 3.

Of the facilities required to monitor for iron, only 15 facilities have permit limits on iron. Fourteen of these are steam generating power plants and one is a water treatment plant. Most power plants have permit limits on discharges of metal cleaning wastes and from ash ponds.

The locations of all facilities monitoring for iron was plotted against all monitoring locations where iron concentrations exceeded the numeric water quality standard for more than 50% of the samples taken (Figure 5). Overall, there is not a strong association between the locations of the dischargers and the 50% exceedance locations. The largest group of dischargers is water treatment plants which are spread across the state. The



Mine locations: U.S. Geological Survey, 2005, Mineral Resources Data System, Iron mines with identifier equal to "producer" or "occurrence", data available at http://tin.er.usgs.gov/mrds/;
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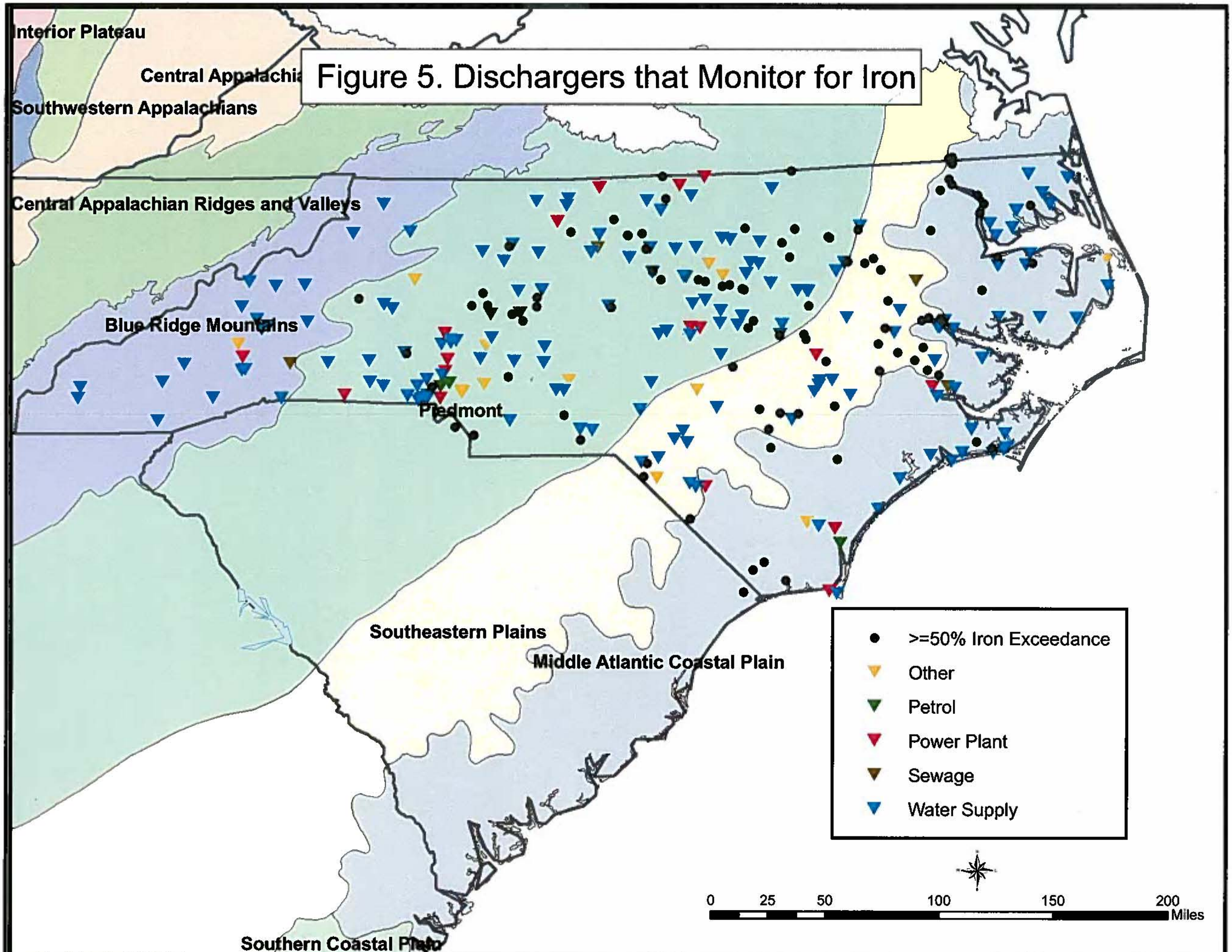


Discharger Information: U.S. EPA Permit Compliance System (PCS), available at http://www.epa.gov/enviro/html/pcs/pcs_overview.html#PCS;
Data acquired on request from Ecosystems Unit, North Carolina Department of Environment and Natural Resources, Division of Water Quality, Environmental Sciences Section, http://www.esb.enr.state.nc.us/EU.html

likelihood of iron entering surface water from these dischargers is dependent on several factors including the levels already existing in their intake and the level of treatment.

Table 3. Types and numbers of facilities monitoring for iron in North Carolina

Type of Discharger (SIC Description) Monitoring for Iron	**Number of Dischargers**
Automobile Parking	1
Broad Woven Fabric Mills	2
Business Services	2
Electrical Services	18
Ferries	1
Finishers Of Textiles	1
Gasoline Service Stations	1
Industrial Organic Chemicals	2
Metal Coating & Allied Service	1
National Security	1
Nonclassifiable Establishments	2
Operators Of Nonresidential Buildings	1
Operators Of Apartment Buildings	1
Petroleum Bulk Stations & Terminals	1
Plastics Materials, Synthetic Resins, and Nonvulcanizable Elastomers	1
Sewerage Systems	6
Transformers	1
Water Supply	182

Urban

Iron exceedances were overlaid on a map of urban areas (Figure 6). There is no obvious visual relationship apparent that would indicate that urban areas contribute disproportionately to statewide elevated iron levels.

IRON CONCENTRATIONS BY ECOREGION

<u>Data Sources</u>
Two sets of data were used to evaluate iron concentrations in North Carolina streams. Data was downloaded from the NCDWQ's monitoring network (1997-2007) and data was provided by the USGS from their reference site studies in North Carolina (1973-1988).

NCDWQ's Environmental Sciences Section monitors the state's aquatic resources through their Ambient Monitoring System (AMS) network.[15] NCDWQ also collects monitoring data through the NPDES Discharge Monitoring Coalition Program, which is located in just a few of the largest basins in the state.[16] Metals monitoring in the NCDWQ network varies from monthly to quarterly.

The USGS conducted several studies to evaluate characteristics of reference waters in North Carolina. The USGS provided the original data from these studies to EPA Region 4 in April 2009. The two primary studies that were reviewed were authored by William

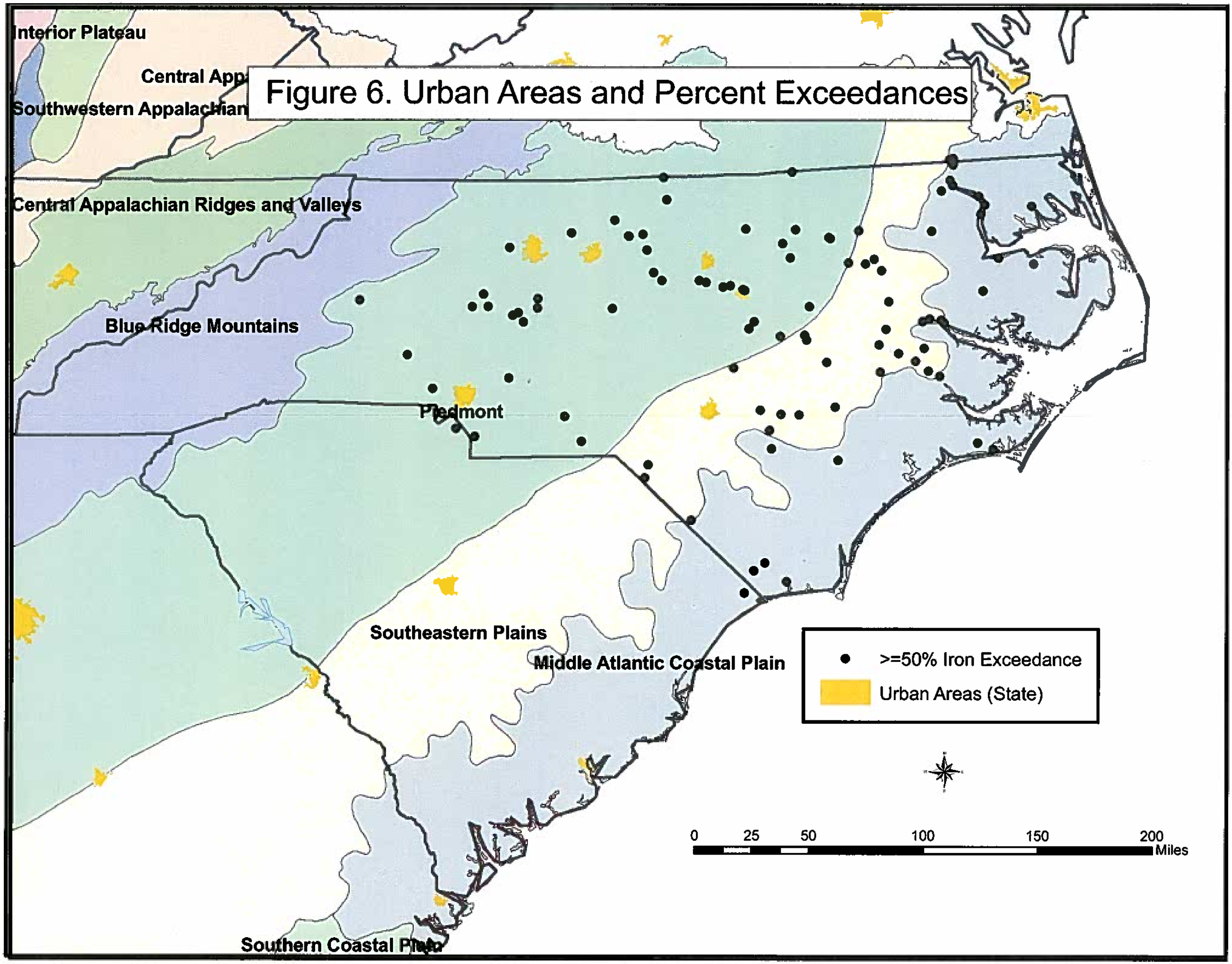


Figure 6. Urban Areas and Percent Exceedances
Interior Plateau
Central App
Southwestern Appalachian
Central Appalachian Ridges and Valleys
Blue Ridge Mountains
Piedmont
Southeastern Plains
Middle Atlantic Coastal Plain
Southern Coastal Plain
>=50% Iron Exceedance
Urban Areas (State)
0
25
50
100
150
200
Miles

S. Caldwell in 1993[1] and C.E. Simmons and R.C. Heath in 1982.[2] The stated purpose of the 1993 report was to describe background conditions for comparison with water quality standards. The study, which built on and supplemented the earlier work of Simmons and Heath, examines the relations between geology, precipitation and surface water chemistry.

Medians

A plot of the medians for sampling station locations in the NCDWQ data set arranged in quintiles (five groups containing equal numbers of observations) clearly shows higher levels of iron in the Piedmont and Southeastern Plains (Figure 7). Medians of all data within a given ecoregion confirm this observation (Table 4).

Table 4. Median Iron Concentration (all stations, all dates) by Level III Ecoregion (NCDWQ 1997-2007)

Level III Ecoregion	**Median Iron, µg/l**
Blue Ridge	300
Piedmont	750
Southeastern Plains	870
Middle Atlantic Coastal Plain	530

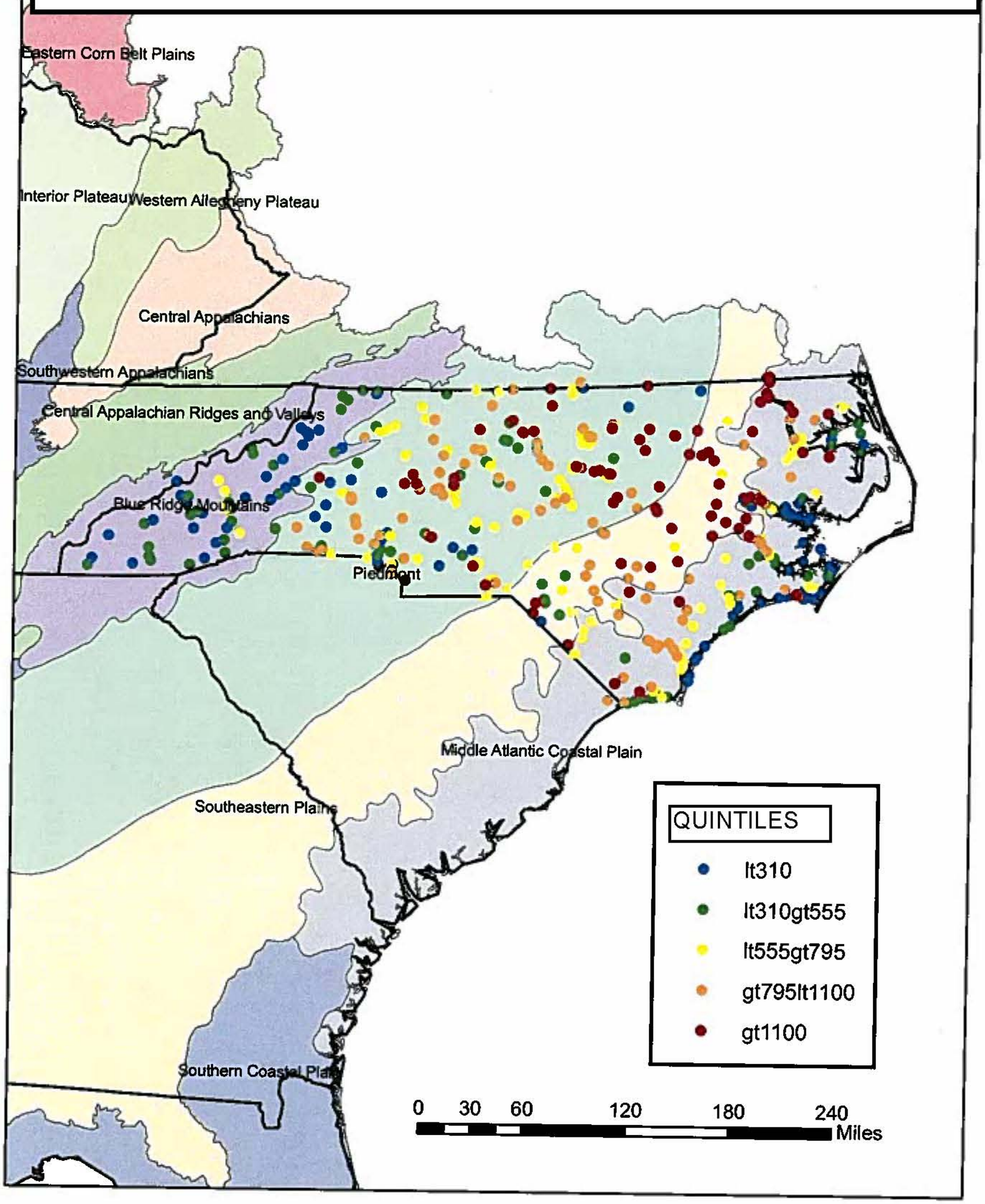
Using the same ranges as in the NCDWQ quintiles map, medians of sampling stations of the USGS data set were plotted (Figure 8). Again, a clear pattern emerges of higher iron values in the Piedmont and Southeastern Plains. The differences in geochemistry, soils and topography represented in the ecoregions are likely responsible for this pattern.

TRANSPORT OF IRON TO NORTH CAROLINA STREAMS

Iron is transported to streams by two major mechanisms, runoff from precipitation events and groundwater inflow. Storm water in the form of rain and melting snow can erode sediments as it flows over soil surfaces. The amount of sediment reaching a stream is controlled by multiple factors including rainfall intensity, surface roughness, availability of sediments and steepness of the slope. Higher velocities of storm water runoff generally increase the likelihood that iron adsorbed to sediments will enter the stream. The sizes of the sediments that can be eroded range from very fine particles, called colloids, through larger sand-sized particles to rocks and stones.

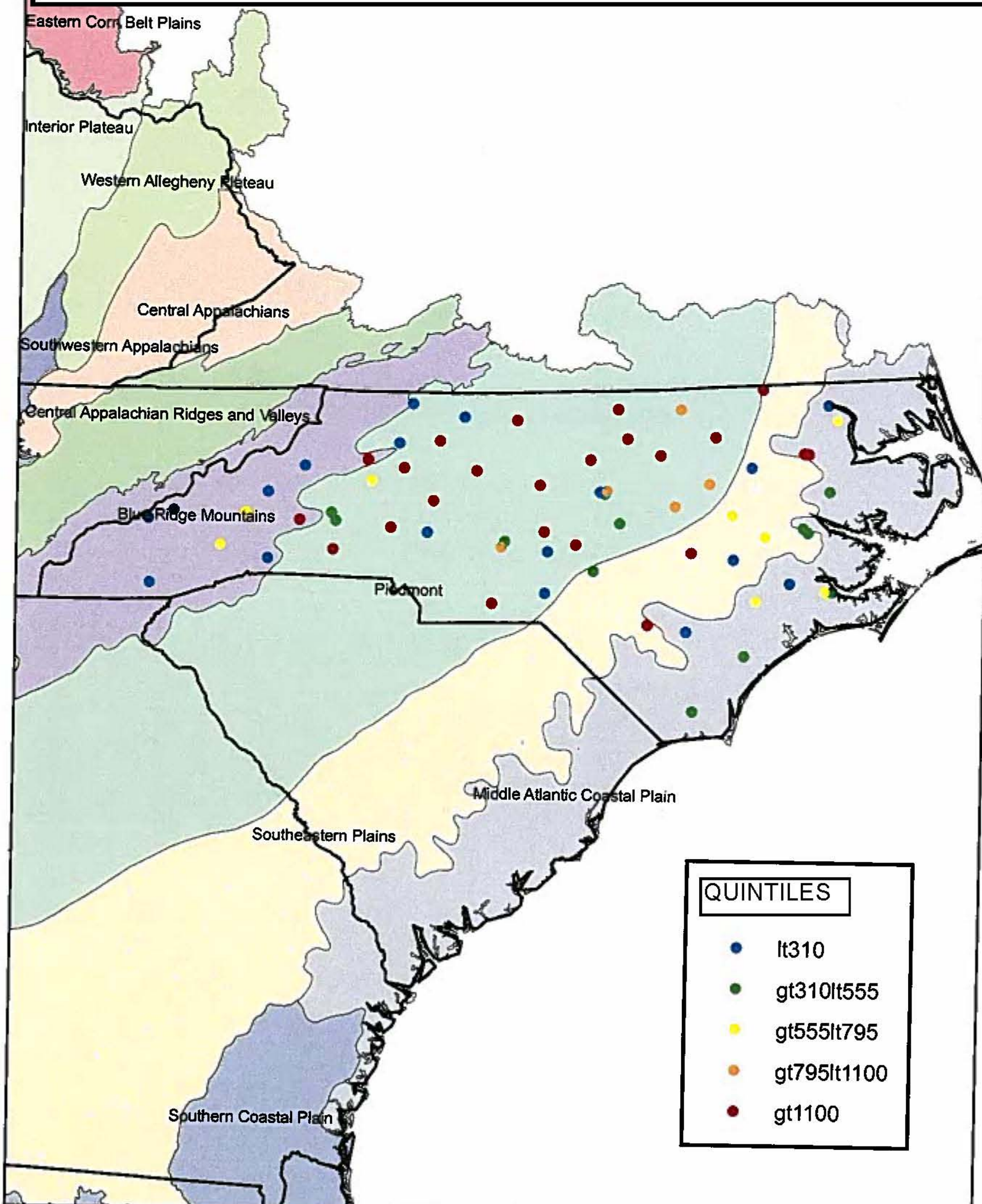
Groundwater inflow or seepage of groundwater into stream channels is usually measured during the baseflow conditions of perennial streams. Baseflow refers to amount of water in the stream during the dry season when rainfall is minimal. Rain water and snow melt that do not run off can infiltrate soils surfaces and percolate downward into groundwater water. The percolation of acid rainfall can dissolve iron adsorbed to clays and other soil particles as well as iron in primary minerals. Groundwater moving through geologic formations beneath the soil can also dissolve iron as well as transport iron adsorbed to colloidal particles.

Figure 7. Medians of NCDWQ Iron Data (1997 - 2007)



Data acquired on request from Ecosystems Unit, North Carolina Department of Environment and Natural Resources, Division of Water Quality, Environmental Sciences Section, http://www.esb.enr.state.nc.us/EU.html

Figure 8. Medians of USGS Iron Data (1973- 1988)



Caldwell, W.S., 1993, Selected water-quality and biological characteristics of streams in some forested basins of North Carolina, 1985-88: U.S. Geological Survey Water-Resources Investigations Report 92-4129, 114 p.

Total iron concentrations in water samples from nine streams in North Carolina during storm flow and low flow (baseflow) conditions were evaluated in the USGS study by Caldwell.[1] These streams drained small forested basins that were selected to represent natural conditions. The large ranges of total iron concentrations in Table 5 are an indication of the complexity of factors that influence the transport of iron to streams. The presence of iron concentrations in storm flow and during low flow conditions indicates that both contribute to total iron concentrations in the nine streams. Factors specific to each basin determine whether storm water runoff or groundwater inflow is the major contributor for that basin.

Table 5. Total iron concentrations under storm flow and low flow conditions for nine streams in forested basins[1].

USGS Study Basin	Level III Ecoregion	Flow Condition	Median Fe, µg/l	Range Fe, µg/l	# of Samples
Beetree Creek	Blue Ridge	Storm flow	890	<10-4400	8
		Low flow	35	<10-1000	27
High Shoals Creek	Blue Ridge	Storm flow	1600	1200-1800	3
		Low flow	580	--	1
North Harper Creek	Blue Ridge	Storm flow	320	110-1700	5
		Low flow	50	<10-490	27
Dutchmans Creek	Piedmont	Storm flow	1300	250-3400	10
		Low flow	400	170-950	31
New Hope River tributary	Piedmont	Storm flow	710	460-3100	9
		Low flow	520	160-1400	17
Suck Creek tributary	Piedmont	Storm flow	480	160-1100	5
		Low flow	250	<10-1200	37
Limestone Creek	Southeastern Plains	Storm flow	250	150-1100	7
		Low flow	640	390-1000	5
Chinkapin Creek tributary	Mid Atlantic Coastal Plain	Storm flow	405	340-780	8
		Low flow	820	390-8900	10
W.P. Brice Creek	Mid Atlantic Coastal Plain	Storm flow	540	240-1100	11
		Low flow	485	240-1000	28

In the basins in the Blue Ridge or Piedmont ecoregions (Table 5), median iron concentrations associated with storm flow were greater than those associated with low flow (baseflow). The steep slopes of the Blue Ride ecoregion and the more rolling slopes of the Piedmont provide the energy to erode particles. The presence of shallow, poorly developed soils in the Blue Ridge may indicate that eroded primary minerals may be an important source of iron in stream water. The less steep slopes and thicker, fine textured soils of the Piedmont ecoregion are likely indicators that iron adsorbed to sediments is an important source of iron. Caldwell[1] concluded that the total iron concentrations appear to be directly related to the suspended sediment concentrations for Beetree Creek, High Shoals Creek, North Harper Creek, Dutchmans Creek and New Hope River tributary.

In two of the three basins in the Southeastern Plains and the Middle Atlantic Coastal Plain (table 5), the median iron concentrations associated with low flow are higher than the medians associated with storm flow conditions. The Southeastern Plains consist of somewhat flat terraces that dip gently toward the east and the Middle Atlantic Coastal Plain is generally made up of flat, often poorly drained land near sea level.[7] These characteristics indicate that the higher iron concentrations during baseflow are likely related to the percolation of storm water through soils to groundwater and the subsequent inflow of groundwater into the stream channel. Groundwater inflow may contain iron dissolved during the percolation of acid rain water and finely, dispersed (colloidal) particles that contain iron.

NCDWQ evaluated iron in groundwater samples from research station wells, private wells and ambient groundwater quality monitoring wells across the state from 2001 to 2007. They found higher iron concentrations in wells in the coastal plain and lower concentrations in wells in the mountain and piedmont areas which had similar iron concentrations. These results support the concept (discussed above) that groundwater may be a significant means of transport of iron to streams in the coastal area. NCDWQ has also found widespread elevated iron concentrations as reported in their Basin Assessment Reports.[3]

To further explore the differences between the ecoregions, the relation between turbidity and iron concentrations was evaluated. Turbidity, which is easily measured in stream water, is an optical property of water based on the amount of light reflected by suspended particles, such as clay, silt, finely divided (colloidal) inorganic and organic matter, soluble colored organic compounds and microscopic organisms. Turbidity can not be used to provide a direct measurement of the amounts or sizes of suspended solids in water[17]. The USGS National Field Manual[18] noted that groundwater turbidity is generally low with values less than 5 Nephelometric Turbidity Units (NTU) although natural turbidity values as large as 19 NTU have been reported for some environmental settings. The low turbidity levels for groundwater indicate that high turbidity levels are more likely related to contributions from stormwater.

The relation between total iron concentrations and turbidity values within a Level III Ecoregion was evaluated with scatter plots and trend lines for the NCDWQ data set. The correlation coefficient, which represents a measure of the association between iron and turbidity, was calculated for all samples within each ecoregion without regard to the sampling location or date (Table 6). A correlation coefficient equal to one represents the strongest positive correlation between the two components whereas a correlation coefficient of zero indicates that there is no correlation between the components.

Table 6. The correlation between total iron concentrations and turbidity for each Ecoregion

Level III Ecoregion	Correlation Coefficient (r value)
Blue Ridge	0.88
Piedmont	0.84
Southeastern Plains	0.49
Middle Atlantic Coastal Plain	0.53

Turbidity is highly associated with total iron concentrations in the Blue Ridge and Piedmont ecoregions and much less so in the Southeastern Plains and Middle Atlantic Coastal Plain ecoregions. The similarity of the Blue Ridge and Piedmont ecoregions reflects the similarity noted in the evaluation of the USGS study above. This further indicates that similar factors control iron concentrations in the Blue Ridge and Piedmont and these factors appear to be different than the control factors for the other two ecoregions.

Scatter plots of the Southeastern Plains and the Middle Atlantic Coastal Plain ecosystems show high iron concentrations associated with low turbidity (Appendix B). These points may represent dissolved iron from groundwater.

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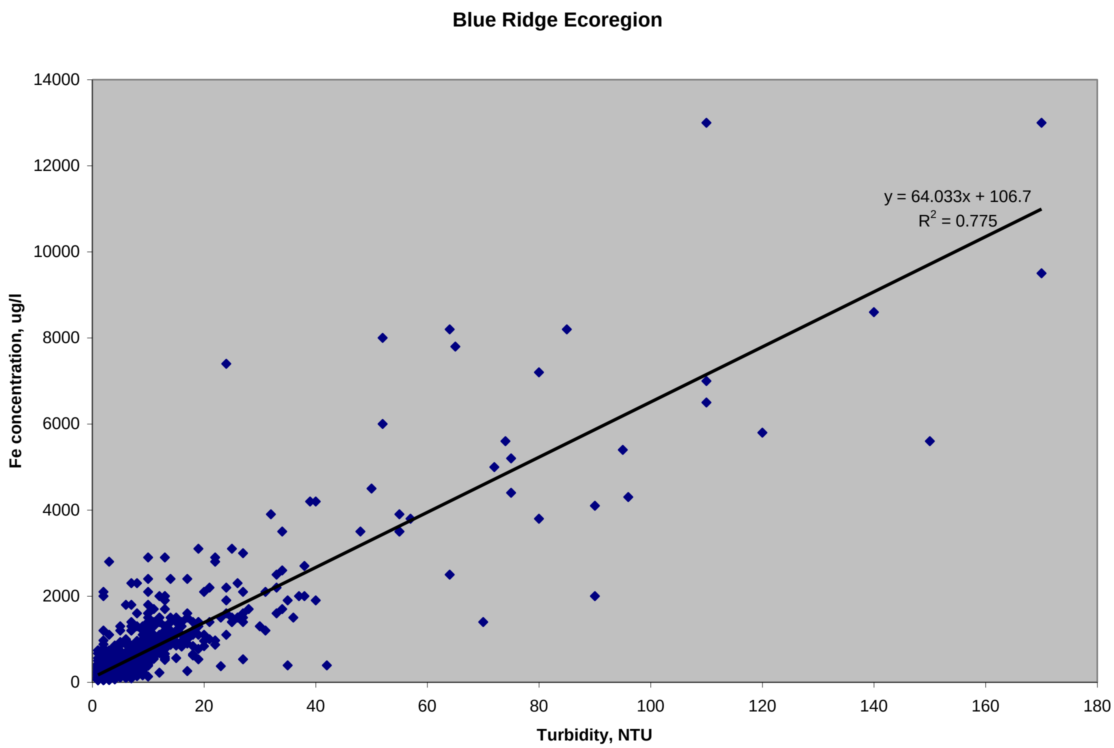
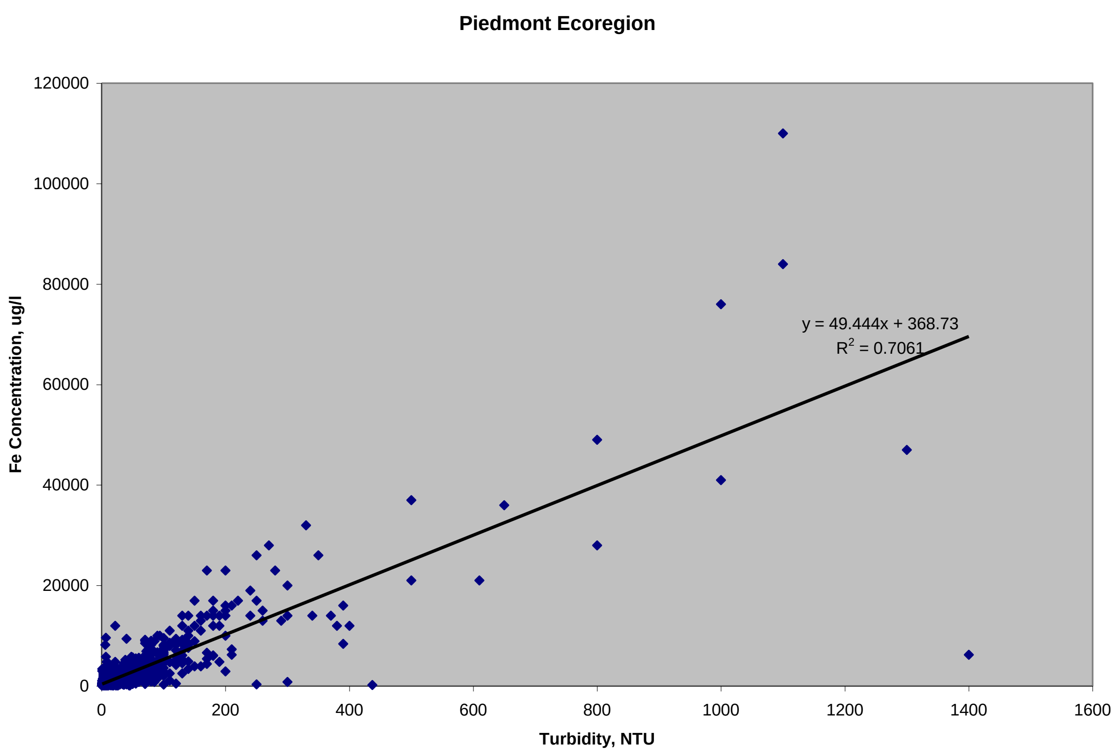
Appendix A. US Level III Ecoregion Descriptions
(http://www.epa.gov/wed/pages/ecoregions/level_iii.htm)

Ecoregion	Description
Blue Ridge	The Blue Ridge extends from southern Pennsylvania to northern Georgia, varying from narrow ridges to hilly plateaus to more massive mountainous areas, with high peaks reaching over 2000 meters. The mostly forested slopes, high-gradient, cool, clear streams, and rugged terrain occur primarily on metamorphic rocks, with minor areas of igneous and sedimentary geology. Annual precipitation of over 200 centimeters can occur in the wettest areas. The southern Blue Ridge is one of the richest centers of biodiversity in the eastern U.S. It is one of the most floristically diverse ecoregions.
Piedmont	The northeast-southwest trending Piedmont ecoregion comprises a transitional area between the mostly mountainous ecoregions of the Appalachians to the northwest and the relatively flat coastal plain to the southeast. It is a complex mosaic of Precambrian and Paleozoic metamorphic and igneous rocks, with moderately dissected irregular plains and some hills. The soils tend to be finer-textured than in Southeastern Plains and Middle Atlantic Coastal Plain ecoregions. Once largely cultivated, much of this region has reverted to successional pine and hardwood woodlands, with an increasing conversion to an urban and suburban land cover.
Southeastern Plains	These irregular plains have a mosaic of cropland, pasture, woodland, and forest. Natural vegetation was predominantly longleaf pine, with smaller areas of oak-hickory-pine and Southern mixed forest. The Cretaceous or Tertiary-age sands, silts, and clays of the region contrast geologically with the older metamorphic and igneous rocks of the Piedmont. Elevations and relief are greater than in the Southern Coastal Plains, but generally less than in much of the Piedmont. Streams in this area are relatively low-gradient and sandy-bottomed.
Middle Atlantic Coastal Plain	The Middle Atlantic Coastal Plain ecoregion consists of low elevation flat plains, with many swamps, marshes, and estuaries. Forest cover in the region, once dominated by longleaf pine in the Carolinas, is now mostly loblolly and some shortleaf pine, with patches of oak, gum, and cypress near major streams. Its low terraces, marshes, dunes, barrier islands, and beaches are underlain by unconsolidated sediments. Poorly drained soils are common, and the region has a mix of coarse and finer textured soils. The Middle Atlantic Coastal Plain is typically lower, flatter, and more poorly drained than the Southeastern Plains. Less cropland occurs in the southern portion of the region.

Appendix B. Scatter plots and trend lines for Level III ecoregions in North Carolina





Appendix B (cont.). Scatter plots and trend lines for Level III ecoregions in North Carolina