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Characterizing the groundwater quality of the Upper Pearl River watershed in Central Eastern Mississippi

By

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Characterizing the groundwater quality of the Upper Pearl River watershed in Central Eastern Mississippi

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The Upper Pearl River and its watershed is the main source of water flowing into the Ross Barnett Reservoir, the City of Jackson's major drinking water supply. Groundwater characterization of the watershed was achieved by analyzing viable groundwater wells and a groundwater spring best representing the land use and land cover extraction map created. Incorporated surface geology demarcated specific stratum, helping describe the different hydrogeochemical interactions observed. Analysis indicated that chloride and nitrate exceeded the Maximum Contamination Levels (MCLs) possibly contributing to eutrophication in the reservoir. Several of the metal and trace elements analyzed were below the MCLs, with the exceptions of manganese, aluminum, and iron. No pharmaceuticals, pesticides, or industrial residues exists in Carthage and Philadelphia's groundwater, the largest cities in the region. Conclusively, the watershed's groundwater contains high concentrations of anions along with metal concentrations associated with the ferruginous sandy-clay surface geology moving closer to the reservoir.

*Keywords: Mississippi’s Groundwater, Pearl River, Pharmaceuticals in Groundwater, Ross Barnett Reservoir Water Quality, Upper Pearl River Watershed.

DEDICATION

This paper is dedicated to the great State of Mississippi, its peoples, and to the city officials involved in helping me collect groundwater samples.

ACKNOWLEDGEMENTS

The author wishes to acknowledge and give a special thanks to Dr. Varun Paul- academic advisor, Dr. Padmanava Dash, and Dr. Darrel Schmitz, whose financial contributions in providing field & laboratory testing equipment helped make the study possible.

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And finally, the author would like to express a great appreciation to the wonderful Geosciences Faculty and Staff at Mississippi State University; of which whose constant

support, extensive resources, and continual enthusiasm in bettering their great State, helped achieve the results of this project.

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CHAPTER I

INTRODUCTION

Since the late 1970's, the Jackson metropolitan area, Mississippi's capital, has seen significant population growth and urban sprawl (MDEQ, 2007; Census Bureau, 2000; Oakley, 1984; Lang, 1972). Jackson is the State's center for legislation, economic commerce, finances, manufacturing, and distribution, as well as a medical hub for the State with many colleges throughout the city. Jackson is also widely known for its cultural Blues music and recreational venues (MDEQ, 2007; Lang, 1972). The city receives its drinking water from the Ross Barnett Reservoir (RBR) surface waters. This reservoir is in turn fed by the Upper Pearl River (UPR), a fluvial system with its own watershed occupying an area of 7,588km^2 (Parajuli *et al.*, 2011). In the past 30 years, the RBR and Upper Pearl River Watershed (UPRW) have been reported to contain sediments, anions like phosphates, nitrates, and chloride, trace elements and heavy metals, specifically arsenic, iron, aluminum, and manganese, as well as cyanobacterial toxins and total coliforms in high concentrations (Dash *et. al*, 2015; Parajuli *et al.,* 2010 and 2011; MDEQ, 2009 and 2007; Oakley, 1984). Arsenic is on the EPA's primary Maximum Contamination Level (MCL) drinking water standards since it is a carcinogen, trace amounts causing cancer within the human body. Iron, aluminum, and manganese are secondary MCLs drinking water standards, only affecting the water's taste, color, or odor, or causing skin and/or tooth discoloration in humans. It is most worthy to note that the Pearl River Basin- Upper, Middle, and Lower portions of the River's basin- has the greatest opportunity for groundwater development compared to any other area of similar size within the contiguous United States (Lang, 1972).

The RBR is not only Jackson's source of drinking water, but also one of Jackson's (and surrounding areas) primary sources of recreation (Parajuli, 2012; MDEQ, 2007). There are parks, boating marinas, and designated fishing and recreational areas throughout the reservoir. In Mississippi, hunting and fishing for food is common; many of the local people keep and eat the fish they catch in the reservoir (MDEQ, 2007).

Since contaminants, trace elements and heavy metals, toxins, and pharmaceuticals tend to bioconcentrate in fish tissues and prograde through the food-web, the people of Jackson are most at risk when it comes to water pollution (Escher *et al.*, 2011; Schriks *et al.*, 2010; MDEQ, 2007; Santos *et al.*, 2007; Hernando *et al.,* 2006). When animals drink polluted waters, the toxins bioconcentrate within the animal's body and travel throughout the food-web eventually reaching the end user (MDEQ, 2007). Humans, often being the final link in the food-web, will ingest the highest bioconcentrations of these pollutants that were initially extracted from the drinking water source. Not only do pollutants affect humans, but they directly and indirectly affect wildlife behavior and reproductive habits (Hernando *et al.*, 2006). With so many people, livestock, and wild game in our State directly and indirectly utilizing the UPRW and reservoir's water, the water quality of this body is of the utmost importance.

Another part of this study focused on testing for pharmaceuticals in the groundwater of the two largest and most densely populated cities within the UPRW, Carthage and Philadelphia (Census Bureau, 2000). Pharmaceuticals in surface and groundwater is an evolving contaminant issue. Most pharmaceuticals dissolve readily in water and do not evaporate, making their way into the soils, waste waters, reclamation waters, and irrigation waters (Cunningham, 2008; Nikolaou *et al*., 2007). Findings at conventional waste-water plants clearly indicate that current water treatment procedures and technologies do not adequately remove pharmaceuticals and their metabolites and by-products (Joss *et al*., 2008; Benotti and Brownawell, 2007; Debska *et al*., 2004). Even though some pharmaceuticals do in-fact degrade upon administration or consumption, most become persistent within the environment remaining unchanged. These undegraded pharmaceuticals have shown to be an immense source of chemical pollution in surface and groundwaters, including tap and even bottled waters (Joss *et al., 2008*). Continual exposure to these mixtures of waste pharmaceutical compounds and metabolites may imbalance the human body's immune system's antibodies and enhance a resistance to old and newly developed antibiotics that can save millions of lives. This is a potentially huge posing threat to human health and society. Particularly noteworthy, 2017-2018 Winter Season in the United States (except Hawaii) reported record flu deaths and wide-spread at over-capacity hospitals dedicated to treating the deadly new H3N2 Flu virus, a subtype of the fatal influenza-A virus (CDC, 2018; CBS Interactive Inc., 2018). Further proof that non-filtration of pharmaceuticals in drinking water could be affecting new designer vaccinations' effectiveness. For instance, the Flu vaccine was less than 20% effective against the new, fatally evasive H3N2 Flu strain for people who were already inoculated with the vaccine (CBS Interactive Inc., 2018).

This study was aimed to characterize the groundwater of the UPRW by selecting and analyzing 49 pumping wells and a groundwater spring that best represented the land use and land cover of the study area. A State-wide surface geology, aquifer outcrop, and stratigraphic map were used to determine the water-bearing rock units, non-water-bearing rock units, and approximate well depths needed to reach the groundwater at each specific site within the study area. The UPRW was delineated by: HUC 10 data files, state digital elevation models, and first, second, third, and fourth order tributaries as classified using the Strahler Stream Order Approach.

Groundwater quality data collected was combined with a current regional land use and land cover classification scheme created for a comparative analysis of possible point-source and non-point source pollution sites. Surface geology, hydrogeochemical analyses, and groundwater movement comparisons were compiled to characterize the groundwater of the UPRW to see, if by baseflow, contaminants were infiltrating into the RBR.

CHAPTER II

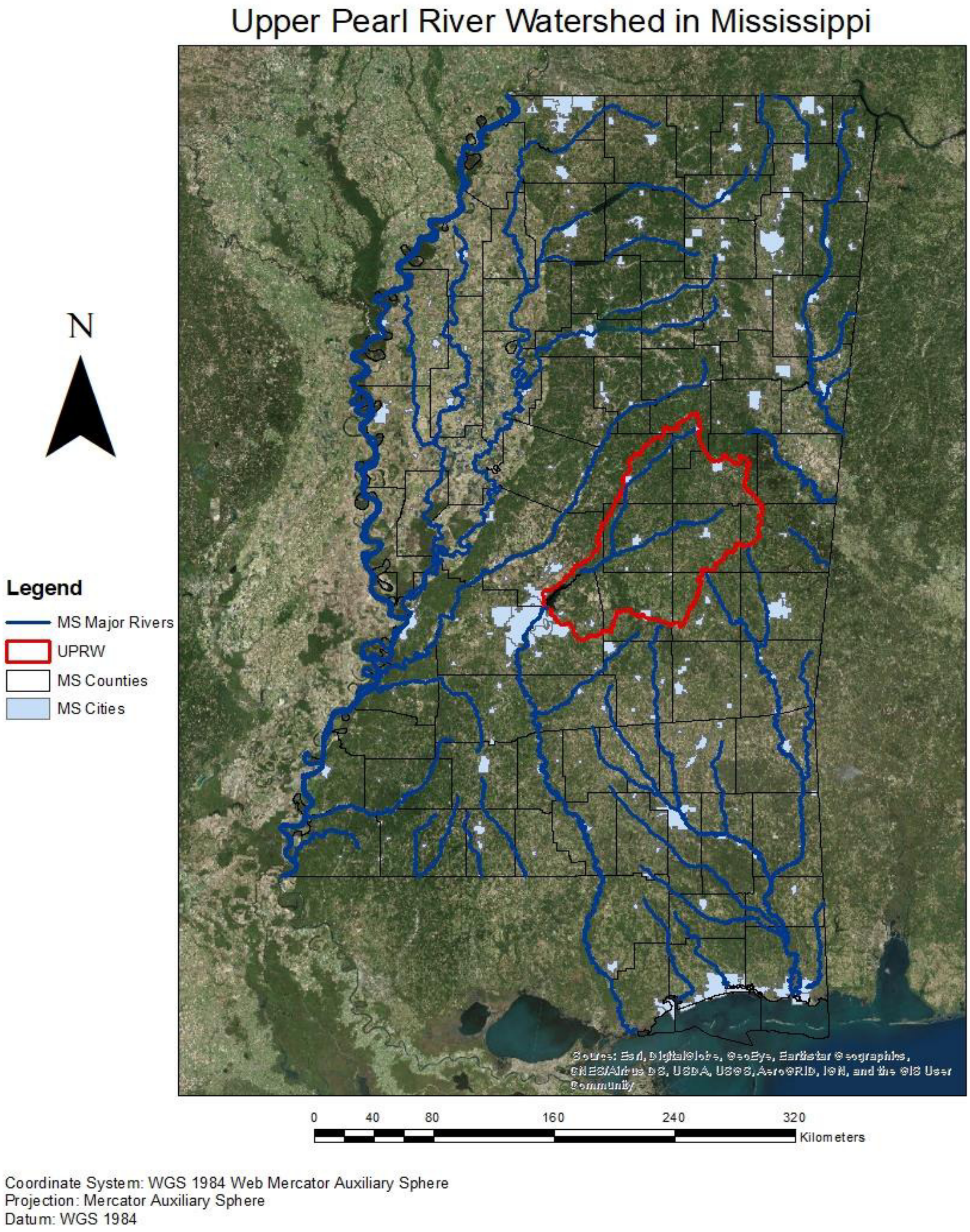
STUDY AREA

The UPRW covers 7,588km^2 and encompasses 10 counties in east-central Mississippi: Choctaw, Attala, Winston, Leake, Neshoba, Kemper, Madison, Rankin, Scott, and Newton (Parajuli, 2010 and 2012). Approximately 72% of the watershed is covered by woodlands, with 20% being covered in grassland. Only 8% of the total land used in the UPRW is urban. The forest industry is the main economy throughout the watershed (Khanal *et. al*, 2013). A fine-sandy to silt loam textured soil covers a vast majority of the area. Average elevation in the watershed is approximately 133 meters, with a minimum elevation of 78 meters and a maximum elevation of 221 meters.

The Pearl River headwaters begin in the Nanih Waiya Indian mounds area in southern Winston County and in Choctaw Counties in Mississippi (Parajuli, 2011; MDEQ, 2007). The UPRW supplies the waters of the Pearl River which feed into the RBR, Jackson's main surface drinking water supply (Parajuli, 2012). Groundwater supplies the UPRW with a majority of its household drinking water (MDEQ, 2007). Groundwater aquifers in the watershed are naturally protected from pollutants by thick layers of clay and according to the Mississippi Department of Health, water quality tests indicate groundwater supplies were excellent. The rolling hills in the upper portion of the UPRW allow shallow streams to flow freely. At the most southwestern part of Leake

County, about a third of the way down the UPRW, the Pearl River widens behind the man-made cemented dam at Ridgeland to form the RBR.

The RBR is one of the largest surface water bodies in the state at approximately 33,000 acres (MDEQ, 2007). This reservoir is fed by the UPR which drains the waters that encompass the UPRW (Fig. 2.1). Waters of the Pearl River build up and spread out behind the dam at Ridgeland to form the RBR (MDEQ, 2007).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2.1 The above map illustrates the complex river systems in Mississippi. Notice that the Upper Pearl River watershed is highlighted in red, segregating the surrounding rivers. The Ross Barnett Reservoir is at the southwestern most portion of the watershed and is indicated by a red arrow; southwest of the reservoir, the city of Jackson and metro area are highlighted in light blue.

CHAPTER III

BACKGROUND

3.1 General Geologic Setting of the Upper Pearl River Watershed

The State of Mississippi lies in the Coastal Plains of the Mississippi embayment, except for an extremely small area in the northeast corner (Dockery and Thompson, 2016; Cushing *et al*., 1964; Crider and Johnson, 1906). This embayment was periodically submerged by a portion of the sea in which several thousand meters of sediments were deposited over millions of years (Dockery and Thompson, 2016; Cushing *et al.*, 1964). These sand deposits now form the vast water-bearing units and horizons, or aquifers, located in the region.

A gentle southwest slope prevails throughout the state from the highest hills (approximately 700ft) in the northeast region of Mississippi to sea level at the Gulf of Mexico (Crider and Johnson, 1906). Larger rivers such as the Pearl River on the east and the Mississippi River on the west, have cut valleys down to almost base-level. The rivers and smaller streams in many cases flow at right angles to the strike; ergo, cutting across different strata of several formations, and thereby dramatically changing the geochemistry.

While Mississippi's geology is overall simple, recent deposits of alluvium, and the Quaternary orange sand have made detailed stratigraphy hard to interpret (Dockery and Thompson, 2016; Cushing *et al.,* 1964; Crider and Johnson, 1906). Within the

UPRW, a slow southward slope of less than 0.6 meters per kilometer (2 feet per mile) prevails from the city of Louisville to the Jackson prairies. The UPRW consist of the following geologic Systems (from oldest to youngest) (Fig. 3.1 and Fig. 3.2): Tertiary Systems are Paleocene series = Wilcox Group; Eocene series = Claiborne Group and Jackson Group; Oligocene series = Vicksburg Group; Miocene Series. The following paragraphs briefly discuss general characteristics of the series sampled.

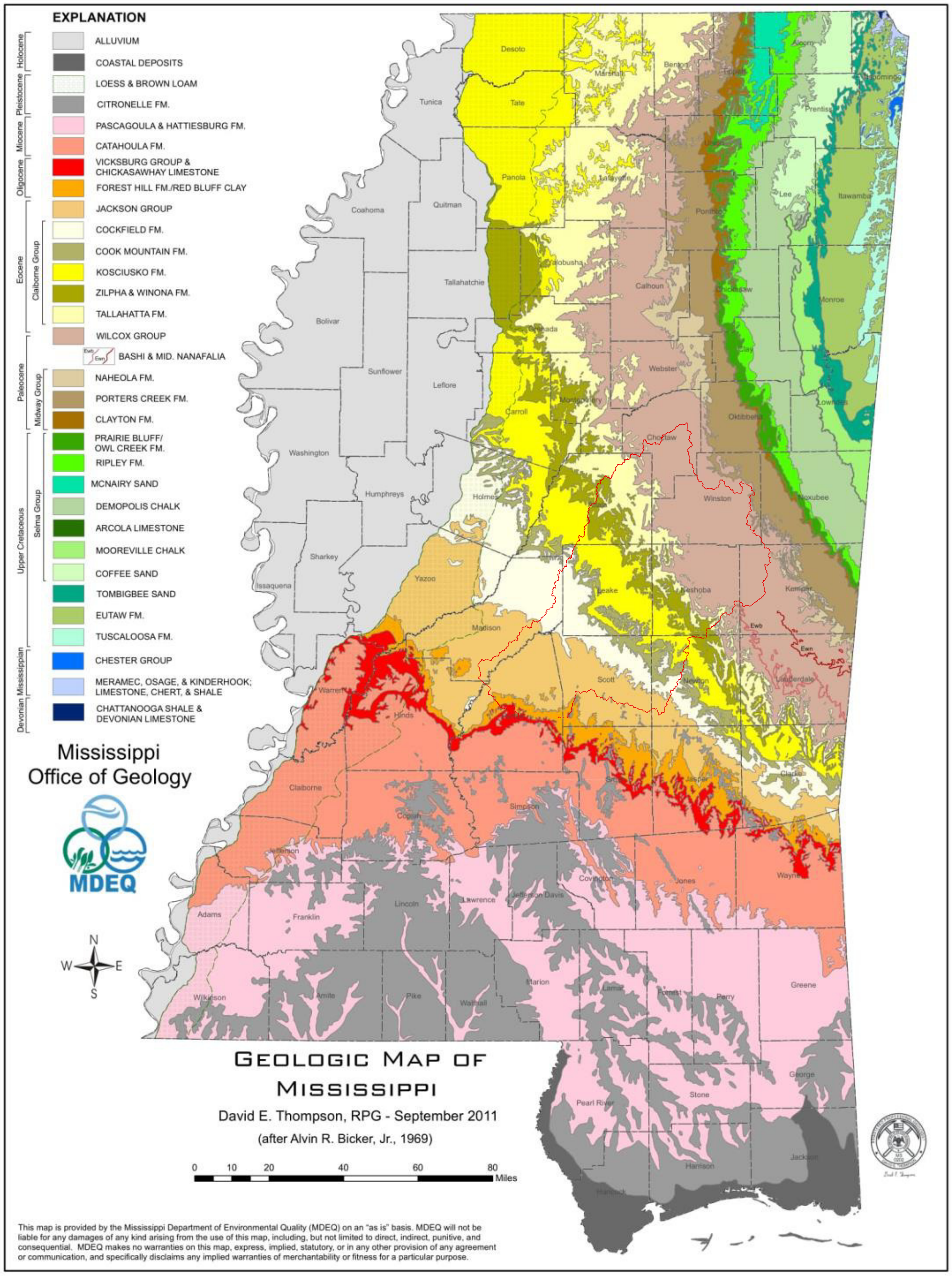


Figure 3.1 Surface geology map of Mississippi created by the Mississippi Office of Geology, MDEQ. The Upper Pearl River watershed is highlighted in red.

(Thompson, 2011)

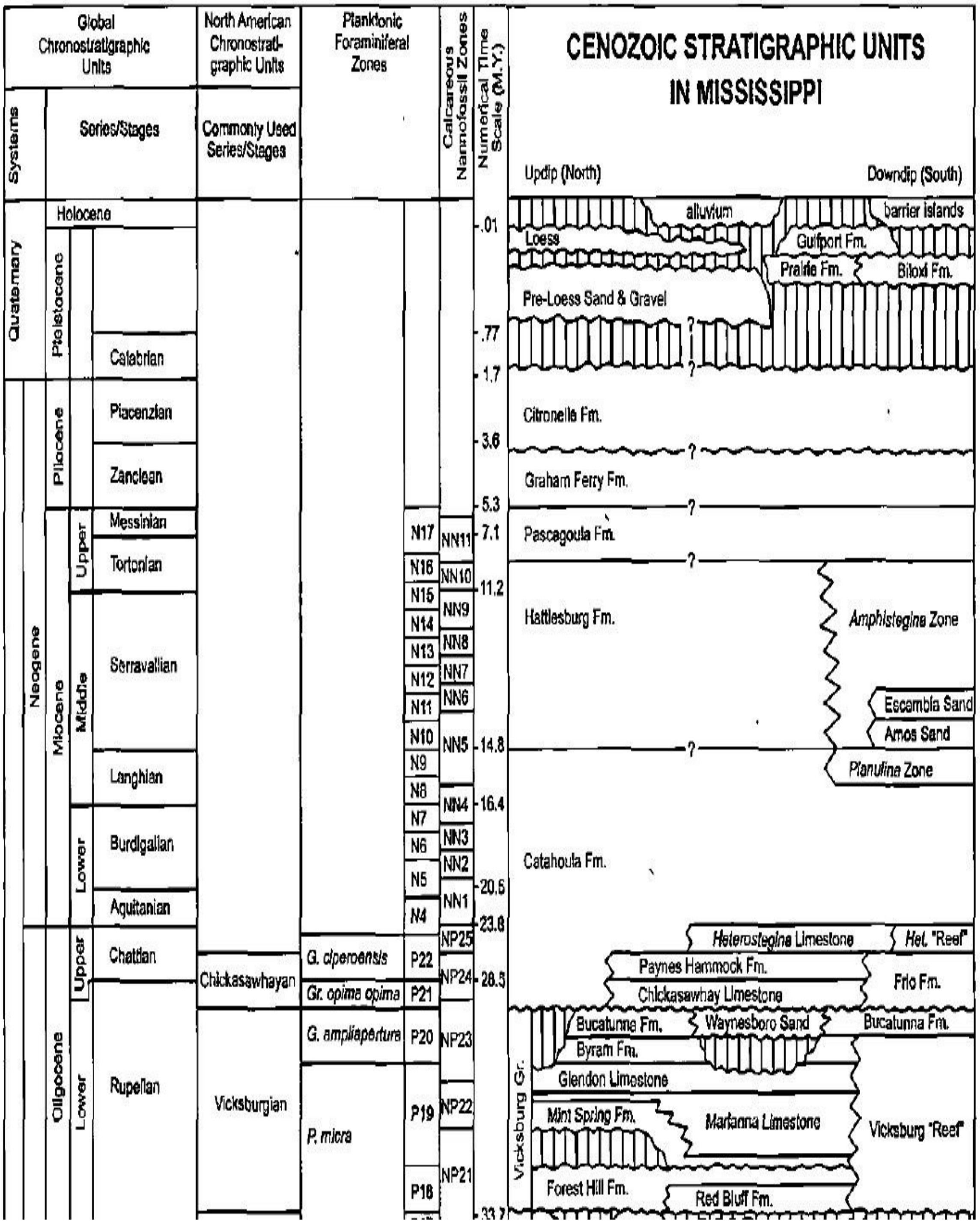


Figure 3.2 Stratigraphy column of Mississippi showing the Tertiary System to the most recent formations in the State as described by Dockery and Thompson in 2016. The International Stratigraphic Commission has formally excluded the Tertiary System from the geologic timescale as of 2004.

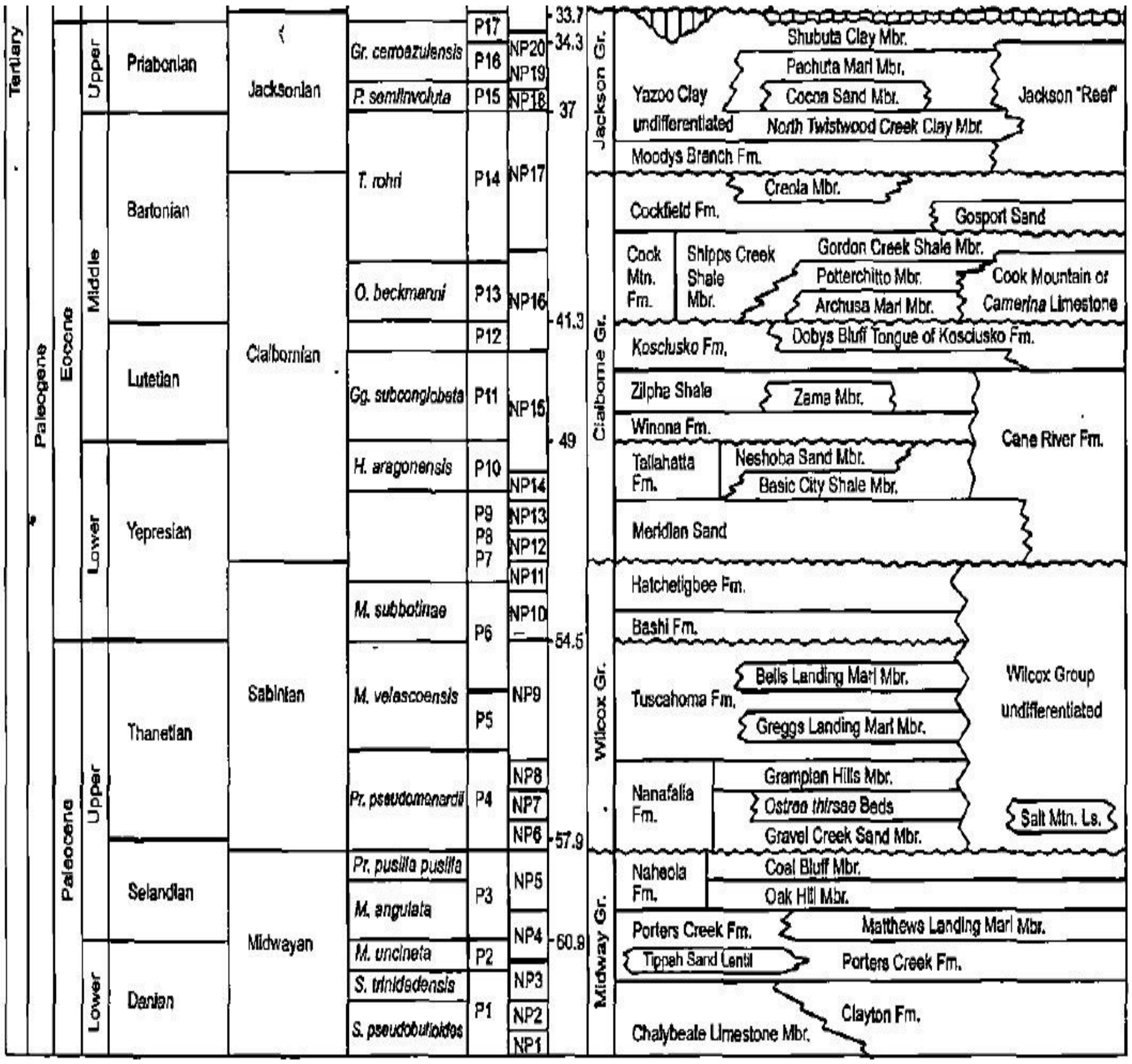


Figure 3.2 (continued)

3.1.2 Tertiary System

The Mississippi embayment Tertiary System within the UPRW comprises of the Paleocene, Eocene, Oligocene, and Miocene series from oldest to youngest respectively. The maximum thickness measured is approximately 2135 meters (7,000 feet) (Dockery and Thompson, 2016; Cushing *e. al.*, 1964). Tertiary sediments are largely unconsolidated consisting of sand, clays, and shale. The Tertiary overlies the Cretaceous with an unconformity.

3.1.2.1 Paleocene Series

The Paleocene Series lies above the upper Cretaceous Series and below the Eocene Series. The Paleocene is comprised of approximately 305 meters (1,000 feet) of dark clay sediments (Cushing *et al.*, 1964). The Wilcox Group makes up the full Paleocene series throughout the UPRW.

3.1.2.1.1 Wilcox Group

The Wilcox Group (often referred to as Formation) occupies a vast area of the northern portion of the UPRW. Thickness of the Wilcox Group ranges from 230 - 295 (750-963 feet). It includes a complex mass of fluvial Midway sands and clays, and lignites and marls (Dockery and Thompson, 2016). The clays are very dark and exists as shales. In the eastern half, loosely bedded sands dominate. The western half of the formation is a series of irregularly cross-bedded sands and sandy clays. This formation, along with its equivalents in the lower Wilcox) form an excellent water-bearing formation because of numerous interbedded sands with clays. For instance, there are beds of clay in the upper division of the Wilcox to sufficiently compact and confine the water below the clay to form artesian basins. Within the Wilcox Group is the Nahafalia Formation.

The Nahafalia Formation is in the basal Wilcox Group with a maximum thickness of approximately 70 meters (230 feet) (Dockery and Thompson, 2016; Cushing *et al.,* 1964; Smith, 1866). The Nahafalia is composed of sand, marl, and clays. Small amounts of kaolinitic and bauxitic materials are spread throughout the formation with local deposits occurring in the lower part of the Nahafalia or Wilcox.

3.1.2.2 Eocene Series

The Eocene Series underlies a substantial area of the central and southern UPRW and is thickest at the southeastern portion (Dockery and Thompson, 2016; Cushing *et al*., 1964). It is comprised of the Claiborne, and Jackson Groups in descending order. This series best represents the stratum in central and southern portions of the watershed where groundwater wells were dug and constructed.

3.1.2.2.1 Claiborne Group

Composed of cyclical depositional sequences of marine and non-marine sands, sand, clay, shale, and limestone the Claiborne Group is above the Wilcox (Dockery and Thompson, 2016; Conrad, 1848). The Claiborne Group's maximum thickness is approximately 750 meters (2,460 feet) in its southern part of the UPRW. The Claiborne Group is undifferentiated in the northern region (Gasport Sand and Lisbon Formation), however, in its southern region, the Claiborne can be further subdivided based on marine bed formations. Within the UPRW, in descending order, the Claiborne Group is comprised of the following units: Meridian Sand, Tallahatta Formation and Neshoba Sand, Winona Sand Formation, Zilpha Clay Formation, Kosciusko Formation, Sparta Sand Formation, Cook Mountain Formation, Gosport Sand and Lisbon Formation, and Cockfield Formation.

The Meridian Sand is the lower sand Member of the Tallahatta and is dominated by cross-bedded, medium- to coarse-grained sand with a clay clast conglomerate in the lower 5 – 6 meters (15 – 20 feet) (Dockery and Thompson, 2016). It was determined that the depositional environment of the Meridian Sand wear near-shore marine depositions where wave action allowed for considerable sorting of the sands.

The Tallahatta Formation is glauconitic claystone and clay with intermixed sand and sandstone lenses. The basal portion is highly cross-bedded. Its average thickness of 27 meters (90 feet) is in eastern Mississippi (Dall, 1898). This Formation forms a very important water horizon in the central portion of the state. The porous texture of its materials makes it well suited for absorbing large amounts of rainfall and the water-tight clay at the base of the overlying formation confine the water within the Tallahatta. The Meridian Sand Member is a productive aquifer of the Tallahatta Formation, averaging approximately 30 meters (100 feet thick) (Lowe, 1933). Included at the top of the Tallahatta Formation and below the Winona Formation lies the Neshoba Sand Member composed of nonglauconitic sands and claystone (Dockery and Thompson, 2016). Neshoba Sand, consists of glauconitic coarse-grained micaceous sandstone, siliceous and aluminous clay stones, and white siliceous sandstone that is almost quartzite (Dockery and Thompson, 2016; Crider and Johnson, 1906).

The Winona, or locally known Winona Formation, sits atop the Tallahatta Formation with a maximum thickness of 15 meters (50 feet) (Lowe, 1919). The formation is an extremely glauconitic fossiliferous sand and clay (Dockery and Thompson, 2016). The Winona Sand Formation is an important aquifer in the UPRW.

Above the Winona Formation, is the Zilpha Clay Formation, aptly named as it serves as a confining layer between the Wilcox and Claiborne aquifers. The clay has a thickness of a meter to 23 meters (a few feet to 75 feet) (Thomas, 1942). The formation thickens substantially to the southwest. The Zilpha Formation is composed of a dark-gray carbonaceous clay. It is mainly marine in origin, usually glauconitic, with few fossils (Dockery and Thompson, 2016). The Zama Member of the Zilpha Formation in Attala County, consists of silt-free clay, glauconitic clay, and concretional siderite at the base of the Zilpha Formation in Attala County (Dockery and Thompson, 2016).

The Kosciusko Formation overlies the Zilpha Formation and is split into an upper carbonaceous, nonfossiliferous shale and lower cross-bedded coarse to very fine-grained quartz sands portion (Dockery and Thompson, 2016; Merrill *et al.*, 1985). The upper portions, reaching a maximum thickness of 27 meters (88 feet), are defined by thin to medium bedded, tabular cross-beds. The upper Kosciusko is truncated by thin beds of shale composed of clayey silt. The lower Kosciusko's thickness ranges from 17 to 49 meters (56 to 160 feet) and is defined by very coarse to medium grained, well-sorted quartz sand, with increasing amounts of glauconite as the contact with the Zilpha Formation is introduced. The formation is not a high-yielding, water-bearing unit.

With an average thickness of 91 meters (300 feet) in outcrops, the Sparta Sand, or Sparta Sands Formation lies above the Kosciusko Formation (originally defined by Vaughan, 1895; updated by Dockery and Thompson, 2016). In the southeastern part of the UPRW, the formation thins to less than 30 meters (100 feet). The Sparta Sand Formation is primarily composed of fluvial sands containing smaller amounts of sandy clay or shale. Outcropping beds in the UPRW show lower portions of the formation with orthoquartzite appears on the ledges. In the upper portions of the outcropping formation, sand and light-gray clays are interfingered. Various organic materials like lignite are common throughout the Sparta Sand Formation. This is one of the most productive water-bearing units (aquifers) in the UPRW.

Lying above the Sparta Sand Member is the Cook Mountain Formation which is approximately 30 meters (100 feet) thick at outcrops, with a maximum subsurface thickness of 61 meters (200 feet) (Dockery and Thompson, 2016; Kennedy, 1892). The lower part of the formation is mainly marine beds consisting of glauconitic sands, calcareous fossiliferous sandy marl or limestone (Thomas, 1942). Locally glauconitic sandy carbonaceous clay or shale occupy the upper portion of the Cook Mountain formation. This formation is not a source of water.

The upper-most, newest unit in the Claiborne Group is the Cockfield Formation (Vaughan, 1895). The formation's outcrop has an average thickness of approximately 76.2 meters (250 feet) with a maximum subsurface thickness of about 200 meters (650 feet) (Dockery and Thompson, 2016). The Cockfield's lenticular arrangement consists of fine to medium quartz sand, carbonaceous clay, and lignite clay (Dockery and Thompson, 2016). In the lower portion of the unit, sand is prevalent. In the subsurface of the Cockfield formation, lignite is widespread.

3.1.2.2.2 Jackson Group

The Jackson Group disconformably overlies Claiborne sediments; it starts the point of a large marine transgression (Dockery and Thompson, 2016). It consists of gray calcareous and lignitic clays and sands (Conrad, 1848). Within the lower or middle Jackson Group, there is not a continuous water horizon and usually absent of potable water. Groundwater wells in this region acquire their waters from the from the Sparta and Cockfield Aquifers. This formation has regularly stratified marls, clays, and siliceous sands indicative of a low energy environment of deposition. The uppermost member of the Jackson formation consists of very porous white to grey sands. The sands are to some extent cemented with iron oxide, making them more resistant to erosion. The sands are exposed through erosion over large areas in Mississippi and absorb vast amounts of water; the water table nearly reaching the surface in some areas. The uppermost sandy portion of the Jackson Group is the only horizon within the group that bears water. Within the Jackson Group is the Moodys Branch Formation and the newer Yazoo Clay.

The oldest formation within the Jackson Group is the Moodys Branch Formation at approximately 6 to 9 meters (20 to 30 feet) thick (Dockery and Thompson, 2016; defined by Meyer, 1885; described by Lowe, 1915). This highly fossiliferous glauconitic sandy marl overlies the uppermost beds of the Claiborne Group, the Cockfield Formation, unconformably.

Overlying the Moodys Branch Formation is the Yazoo (Clay) Formation (Dockery and Thompson, 2016; Lowe, 1915). The dark-gray to blue calcareous, fossiliferous clay has a thickness ranging from 122 to 152 meters (400 to 500 feet) where the entirety of the formation is present (Stover *et al.,* 1988). Yazoo Clay is an expansive clay relatively absent of impurities like sand, silt, and organic material, having the capacity of absorbing large quantities of water during long-term precipitation events and periods of flooding (Dockery and Thompson, 2016; Stover *et al.,* 1988). When Yazoo Clay is exposed to water, it will expand/swell, then again shrink upon drying or desiccation. This is called the “shrink/swell rate”; Yazoo Clay having approximately a 200% shrink/swell rate. In the UPRW, the formation covers portions of Newton, Scott, Rankin, and Madison Counties. The formation is conformably underlain by the Moodys

Branch Formation and restricted above by the overlying Forest Hill Sand formation which marks the contact boundary between the Eocene and Oligocene (Stover *et al.,* 1986; Murray, 1947).

3.1.2.3 Oligocene and Miocene Series

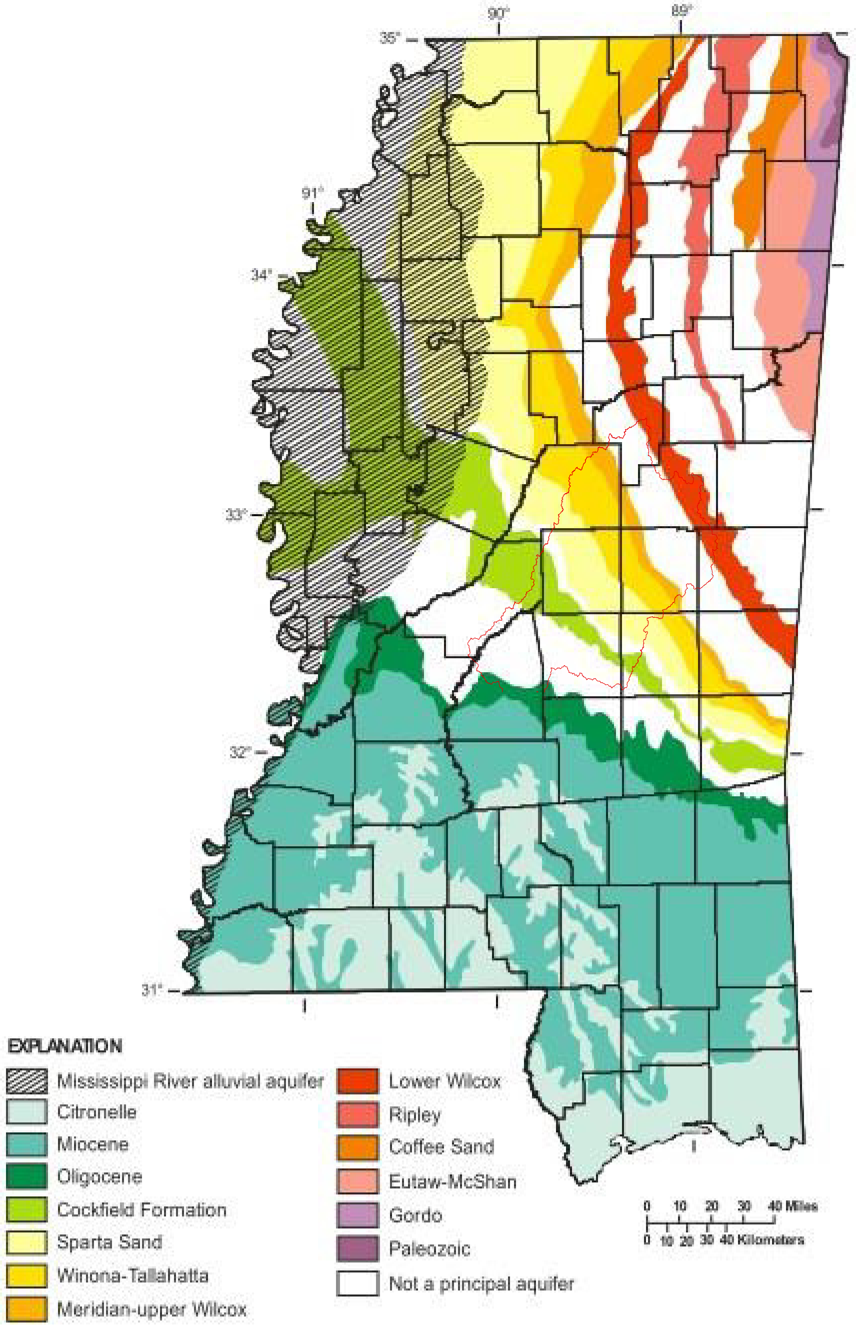
Within the southern-most portions of the UPRW are Oligocene and Miocene Series which comprise the Forest Hill Sand, Vicksburg Group, and Miocene's Catahoula Formation (Dockery and Thompson, 2016; Cushing *et al.*, 1964). The Vicksburg Group and Catahoula Formation were not sampled in this investigation and therefore will not be discussed.

At the basal portion of the Oligocene Series is the Forest Hill Sand Formation (Dockery and Thompson, 2016; Cooke, 1918). The Forest Hill Sand contains lignitic, or organic-rich sands and clays below the Vicksburg Group. This formation outcrops in the far south-central part of the UPRW. The average thickness is approximately 61 meters (200 feet), with the formation thickening more in the subsurface.

3.2 Upper Pearl River Watershed Groundwater Horizons (Aquifers)

There are two main groundwater horizons in the UPRW, the Wilcox and Claiborne Horizons (Dockery and Thompson, 2016; Gandl, 1982; Crider and Johnson, 1906). The Wilcox, being the oldest group, horizon sits directly below the Claiborne group's horizon. Within the Wilcox horizon is the Lower Wilcox Aquifer and Meridian-upper Wilcox Aquifer. The Claiborne horizon contains the Winona/Tallahatta Aquifer, Sparta Aquifer System, and Cockfield Aquifer; all of which contain significant amounts of groundwater currently being pumped. Within the Claiborne's horizon, the

Winona/Tallahatta provides artesian water that covers an extensive portion of the state. Each horizon contains a catchment area, upper confining stratum, dip of the water-bearing strata, and area of available artesian water. All the UPRW's aquifers exhibit heterogeneous, anisotropic conditions throughout; the aquifers' hydraulic properties vary spatially, and the hydraulic conductance differs with direction.



Note: The Coker aquifer is included in this summary but is not listed here because it does not crop out in Mississippi

Figure 3.3 Location of outcrop areas from principal aquifers in Mississippi. Notably, in between several aquifers of the UPRW (highlighted in red), are areas of white indicating no aquifer is used in this area or there is no principle aquifer. Revised in 2005 by USGS, Jackson, MS.

(modified from Wasson, 1986)

The Wilcox Formation outcrop covers approximately 8,000mi^2 (Crider and Johnson, 1906). For the UPRW, the counties included in the Wilcox Formation are Choctaw, Winston, and Kemper. The entire Wilcox, lower, middle, and upper, is a prolific water-bearing formation that supplies much of the northern UPRW (Fig. 3.3). The aquifer's catchment area consists of porous sands and sandy clays outcropping in the eastern half which is confined by the Porters Creek formation and clays (Gandl, 1982). These clays form the upper confining stratum of the Wilcox horizon. Tallahatta sands cover a large part of the catchment area enabling uninhibited absorption of large amounts of rainfall.

There is a westward dip in the northern section of the Wilcox horizon of approximately five meters to the kilometer (17 feet to the mile) (Crider and Johnson, 1906). The dip is greater to the south than it is westward. The westward dip allows artesian water to stay near the surface, whereas, the southern dip quickly carries the water horizon beyond obtainability (Gandl, 1982). Choctaw, Kemper, Winston, and Newton Counties get most of their water from the Wilcox horizon.

3.2.2 Claiborne Horizon (Aquifer)

The confining layer of the Tallahatta Formation's Basic City Shale Member separates the middle Claiborne's units above the Wilcox horizon, and prevents inter-aquifer flow division between the Wilcox and Claiborne water horizons (Gandl, 1982; Crider and Johnson, 1906). In the UPRW, the catchment area of the Claiborne includes Attala, Leake, southwestern Neshoba and Newton Counties (Fig. 3.3). The Claiborne horizon outcrop's strata consists of beds of micaceous sands, sandy clays, and coarse-grained micaceous sandstone. Within the lower Claiborne lies the Winona/Tallahatta

Aquifer which contains glauconite, iron ore, and lignite and is capable of holding large volumes of water while saturated (Gandl, 1982).

The Tallahatta Formation covers much of the surface of the Claiborne horizon except in places along streams and hillsides where erosion has taken affect (Gandl, 1982; Crider and Johnson, 1906). These eroded areas of Tallahatta sands have exposed the porous sands and sandstone of the underlying formations. Meteoric water and streams passing over the inclined edges of these porous strata are directly absorbed into the Claiborne horizon. The coarse-grained sands allow water to sink quickly and many streams only flow a short time after a heavy rainfall. This is most evident along the upper courses of streams where the stream beds have not been silted up with impermeable clay layers. Water absorption into the Claiborne horizon is highest in the summer season.

Crider and Johnson (1906) noted the Tallahatta Formation is up to 61 meters (200 feet) thick in some places, siting unconformably on older formations. In places where the Tallahatta passes over older formations, it becomes one of the primary sources of shallow-well water within the UPRW and the State of Mississippi (Gandl, 1982). The catchment area is formed from the surface between these two blue-green clay layers. Artesian waters can reach a height of 6 meters (20 feet) above surface level due to the elevation change in and throughout the catchment area. Along the coast, the recent clay deposits, 11 to 30 meters (35 to 100 feet) thick, lie unconformably on the Claiborne horizon forming the upper confining unit stratum (Crider and Johnson, 1906). The water-bearing-strata dips southward approximately five to six meters to the kilometer (15 to 20 feet to the mile).

The Sparta and Cockfield Formations lie below the Tallahatta Formation, from youngest to oldest respectively; both can hold large volumes of water and currently supply rural water associations within the southern-most portion of the studied UPRW.

The Sparta Aquifer System is utilized for industrial, municipal, and domestic purposes, with the deepest wells being 427 meters (1,400 feet) (Gandl, 1982). Water in this aquifer is a soft-bicarbonate type, which is acidic at the outcrop area in the northern part of the state, but alkaline somewhere else. The Sparta Aquifer is high in iron in the UPRW. The Cockfield Aquifer is a hard calcium-bicarbonate type near the outcrop and changes to a sodium-bicarbonate type downdip with high iron concentrations found in shallow wells (Gandl, 1982).

Within the Claiborne Aquifer, there is a series of “soapstone” and pipe-clay beds as a part of the basal Lisbon Formation which form the upper confining stratum (Crider and Johnson, 1906). The UPRW within the Claiborne horizon has a dip of the water-bearing sands of 8 meters to the kilometer (25 feet to the mile). Available artesian water in the UPRW’s Claiborne horizon is in the southern RBR area where water is mineral-rich and too warm for human consumption without treatment. Notably, dowing wells are located within Newton County.

3.3 Sources of Groundwater Within the Upper Pearl River Watershed

The depositional cycles of sands and clays within the Coastal Plains of Mississippi allow for groundwater to be derived to two different primary sources. They are, ocean waters, which were retained in the deposits since the accumulation of sediment layers beneath the sea, and meteoric fresh water, which is found in all the shallow and a large portion of the deep wells (Crider and Johnson, 1906). Naturally, sodium concentrations are high in the groundwater. The UPRW's average rainfall is approximately 137 – 147 centimeters (54 – 58 inches) annually (Fig. 3.4); however, year-to-year rainfall fluctuations are so drastic in the state that an annual precipitation map is of little value (Parajuli, 2010; Crider and Johnson, 1906).

Overall factors aiding in groundwater source-flow throughout the UPRW region are: precipitation events (atmospheric pressure), retention of the original oceanic waters within the strata, permeability and porosity of outcrops and soils in which the precipitation and overland flow overlies, pressure due to a confining unit, hydraulic gradient (gravity) of the shallow southwestward downdip throughout the State towards the Gulf of Mexico, and characteristics of the groundwater itself.

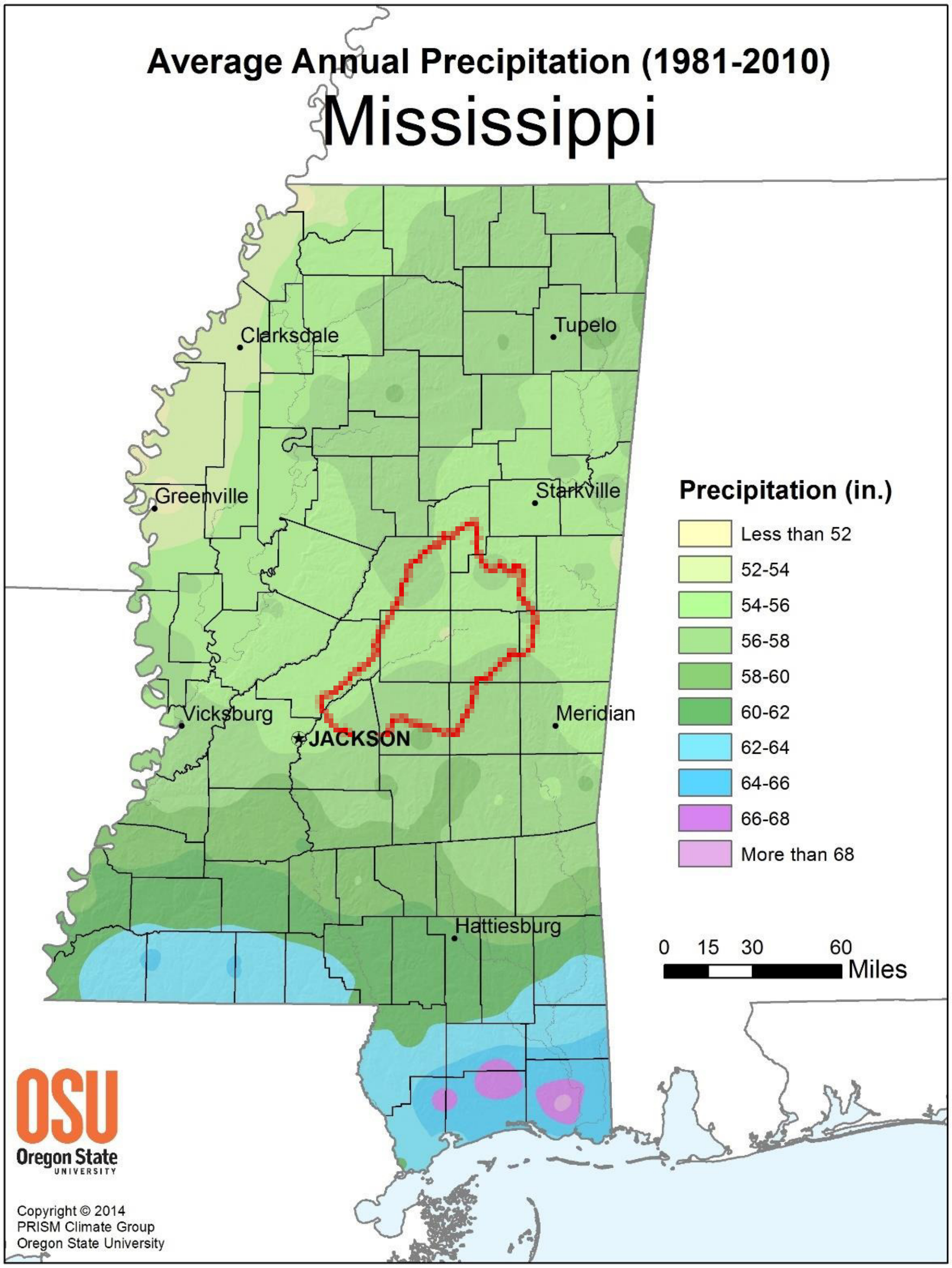


Figure 3.4 Average annual precipitation of Mississippi from 1981-2010 compiled by Oregon State University. The UPRW, highlighted in red, gets an average annual precipitation of 137 – 147 centimeters (54 to 58 inches).

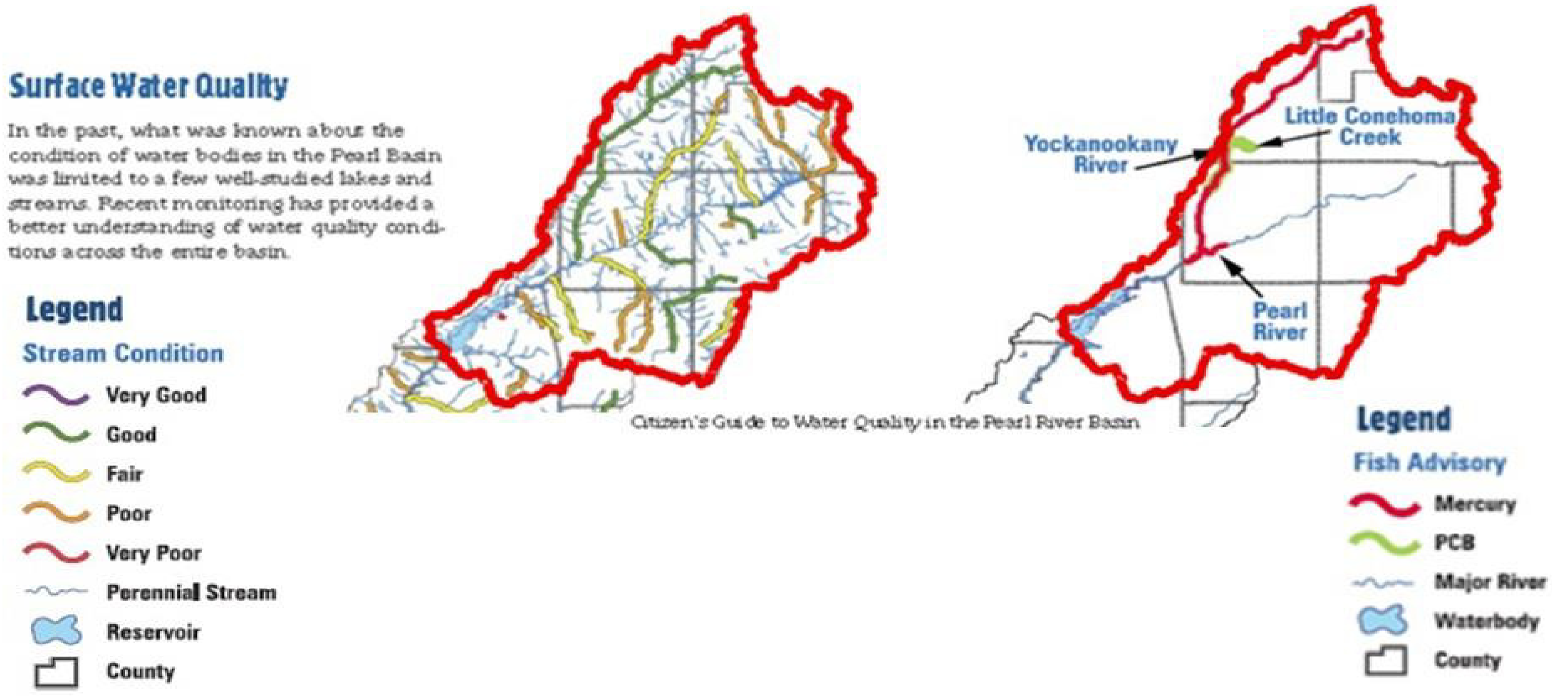
3.4 Water Quality of the Upper Pearl River Watershed and the Pearl River

There have been many State authorized and Federally funded studies of the UPRW with regards to water quality, soil, and overall watershed quality. Studies, past and present, have found that the main pollutants of the UPRW are sedimentation, biological impairments, and fecal coliform (Dash *et al.*, 2015; Parajuli, 2012 and 2010; MDEQ 2009 and 2007; Oakley, 1984). Nonpoint-source pollutants are generated from surface runoffs and overland flows from agricultural and urban development sites carrying sediment, organic matter, and anions through the watershed. Agricultural pollution in the UPRW originates from livestock grazing, chicken litter application, failing septic systems, and wildlife. Impressively, within the UPRW, Scott County is the leading poultry-producing county in the State and the fourth largest in the United States (MDEQ, 2009). Cattle and livestock comprise for approximately 24% of the land use in this watershed. As a major nonpoint-source polluter within the watershed, nutrients, especially phosphates and nitrates (Dash *et al.,* 2015) from agriculture and poultry farms, cause eutrophication of waters leading to harmful algal blooms (HABs). HABs rapid increase in algae populations blocks sunlight, depletes available oxygen in the ecosystem, and can produce and release toxins detrimental to human health and the environments which they inhibit (Dash *et. al*, 2015; MDEQ, 2009).

Previous studies conducted in the UPRW using the Soil and Water Assessment Tool (SWAT) aimed at modeling the effects of long-term potential future climate change on average mean monthly stream flow (Parajuli, 2010). The study concluded that long-term average monthly sensitivity due to climate change effects were greatest with changes in precipitation accompanied with changes in carbon dioxide concentrations and temperatures. The long-term model simulation scenarios as compared with base scenarios estimated an average monthly stream flow decreasing from 67 to 54% and average monthly flow increasing from 67 to 79%. Conclusively, as determined by the SWAT model, hydrology of the UPRW is extremely sensitive to potential climate change, the biggest impact in the area would be increasing streamflow generated from the watershed itself due to over-saturation.

Further field level studies conducted in the UPRW aimed at assessing biomass and feedstock yields of bio-energy crops on water quality (Parajuli, 2012). Again, using the SWAT simulated model, results showed that a corn crop scenario in the watershed had the greatest annual average sediment yield and a Miscanthus grass scenario had the least sediment yield. The model also illustrated that increased corn and soybean crop production would reduce annual average evapotranspiration within the UPRW. However, an increase in grasslands throughout the watershed would increase annual average evapotranspiration and reduce water and sediment yields. The SWAT model simulated results further indicated that Miscanthus grass would have the greatest feedstock source for bio-energy and water quality benefits in the UPRW.

Annual studies in the watershed include the Mississippi Department of Environmental Quality (MDEQ) conducting surface and groundwater quality testing of the Pearl River basin, where the UPRW is located (MDEQ, 2007). 58% of streams are rated good or very good where adequate aquatic life can thrive, 23% are rated fair where aquatic life is somewhat impacted by pollution, and concerningly, 19% of streams are in poor or very poor condition, where aquatic life is significantly impaired by pollution. Most of the poor condition streams being in the UPRW (Khanal *et al.*, 2013; MDEQ, 2007). MDEQ found the major pollutants of concern and their sources in the Pearl River basin to be: “pathogens from animal wastes and failing septic tanks, pesticides from agricultural and urban runoff, eroded sediment from agricultural, timber harvesting, and construction sites, organic and nutrient enrichment from animal wastes and failing septic systems” (MDEQ, 2007).



Surface Water Quality

In the past, what was known about the condition of water bodies in the Pearl Basin was limited to a few well-studied lakes and streams. Recent monitoring has provided a better understanding of water quality conditions across the entire basin.

Figure 3.5 The figure on the left indicates surface water quality within the UPRW and the figure to the right shows where PCBs and methyl mercury associated in fish tissues (largemouth bass and catfish) were found by MDEQ in 2007. On the left, tributaries and streams range from good to very poor water quality.

On the western side of the UPRW, the Yockanookany River and its tributaries and surrounding streams flow to meet and join the Pearl River in southwestern Leake County (Fig. 3.5). Within the last ten years, the Yockanookany and some of its streams and surrounding lakes were found to contain mercury and polychlorinated biphenols (PCBs) (MDEQ, 2007). Methyl mercury was discovered in tissues of largemouth bass and large catfish within the UPR in a small section close to Hwy 25 near Carthage, downstream to the Leake County Water Park. Sources of mercury in the UPRW are believed to come from air emissions of incinerators and coal-fired plants outside the watershed. Mercury can diffuse many kilometers from its source before settling and being washed into lakes and streams. Before being banned in 1977, PCBs were used in transformers and other electrical equipment. In the UPRW, waste PCBs migrated into Conehoma Creek and the Yockanookany River from disposal pits used by a pipeline compressor station.

Regarding nutrient loading in the UPRW, a preliminary report of the UPRW assessment of phosphorous, nitrogen, and sediment loading to the RBR using a SWAT modeling approach was conducted by Parajuli in 2011. Based on the SWAT simulation, results indicated water yield, sediment yield, total nitrogen and total phosphorous were spatially and temporally variable. Pollutant loading was dependent on the source, topography, land-use conditions, and weather conditions within the watershed.

An evaluation of the impacts of forest clear cutting on water quality and sediment yields using the SWAT model within the UPRW was partaken in 2013 by Khanal and Parajuli. Since the region’s economy is dominated by the forestry industry, it was crucial to evaluate changes in water quality and sediment yields with regards to forest clear cutting. Khanal and Parajuli’s study demonstrates sustainable extraction of forest without degradation of the watershed. The SWAT model generated five different scenarios representing clear cutting of the UPRW at 10%, 20%, 30%, 55% and 75% of the total forested area. Conclusions show that forest clearing impacts sediment yield more than water yield. Since clear cutting increases the amount of available water for surface runoff due to increased water yield, increases in sediment yield after clear cutting is synonymous with increases in water yield after clear cutting. The SWAT model showed that an approximately 17%, 29%, 46%, 63% and 96% increase in water yield was noted in scenarios that represented clear cutting of the UPRW at 10%, 20%, 30%, 55% and 75%, respectively. More importantly, the UPRW drains directly into the RBR; with an increase in water yield comes an increase in sediment yield which will have detrimental effects on the RBR's water quality and environment.

3.5 Water Quality of the Ross Barnett Reservoir

The RBR is Jackson, Mississippi's surface drinking water supply, daily supplying approximately 200,000 people in the city (Parajuli, 2012 and 2010). The reservoir was created in 1965 to serve as the city of Jackson's surface drinking water source and to bring extra commerce into the area by creating recreational venues. During the Easter of 1979, the RBR area was flooded heavily; after the flood, the reservoir was used by the Pearl River Valley Water Supply District (PRVWSD) to help with flood control. The PRVWSD is a state agency that manages the reservoir and surrounding area without the help local or state taxes. The agency hosts about 2.5 million visitors annually to the 48 parks and recreational facilities of 22 boat launches, 5 marinas, and 27 meters (17 miles) of paved trails. Approximately 4,600 homes, 25% of which are waterfront properties, have been built on lands managed by the PRVWSD. Fishing is big in Mississippi and the

Ross Barnett offers excellent fishing year-round. Crappie and several species of bass are prevalent in the spring, with catfish being most available over the entirety of summer, fall, and winter seasons. In short, the RBR and surrounding area is a popular recreational and fishing center for the state, bringing in large numbers of visitors and revenue to the area each year (Parajuli, 2012; MDEQ, 2007).

One of the major ongoing threats to the RBR's water quality and environment is sediment loading from unprotected clearcutting and construction sites in the UPRW (MDEQ, 2007; Khanal *et. al*, 2013). Sediments can clog the gills of fish and bury spawning areas and food supplies (MDEQ, 2007). Heavy metals, phosphorous, pathogens, and other pollutants are usually chemically bonded to soil particles and enter water bodies with the sediments in which they compose.

A previous in-depth study of the RBR's surface water quality was done by Dash *et al.* in 2015 to determine HAB cyclicity, bioaccumulation of algal toxins, nutrient measurements, and heavy metal and trace element concentrations. Groundwater in the UPRW is being naturally filtered over time by percolating through the soils and sands; thusly, it has a low risk of contamination. However, surface water, being continually exposed to the atmosphere and surface runoff, tends to collect nutrients, pathogens, and heavy metals. Over the course of 2012 to 2015, Dash *et al.* took 5 trips to the RBR to collect 12 surface water samples that were chosen in a systemic sampling pattern (Fig. 3.6).

The results of Dash *et al.* water quality testing is of serious concern to both the people and ecosystem of the RBR area. Cyanobacteria (better known as blue-green algae), produces a wide range of toxins like phycocyanin and microcystin-LR, the most toxic one, microcystin-LR, being tested for in Dash *et al.* study. Microcystin-LR was found to exceed the EPA advisory level for children under six years old. The bioaccumulation of microcystin-LR is extremely dangerous to human health and aquatic ecosystems. One dominating feature of cyanobacteria that makes it so pervasive compared to other algae is its nitrogen fixing capabilities. Dash *et al.* concluded the RBR was eutrophic, having high nutrients with infrequent nitrogen limitations providing a competitive gain toward toxic cyanobacteria. Most concerning, was total coliforms and enterococci bacterial populations exceeding the EPA's guidelines on multiple sampling occasions in the recreational waters spanning the RBR.

Arsenic, a cancer-causing agent (carcinogen), exceeded the EPA's MCL drinking water standards at two sites on the RBR. Trace amounts of cadmium and lead was also found via ICP- MS analyses. Iron, aluminum, and manganese, being secondary EPA drinking water standards, were found in exceeding levels at most sample sites on the RBR. Mercury was not found within the RBR waters during the samplings of Dash *et al.* study from 2012-2014. *(*Appendix A, table A.1*)*.

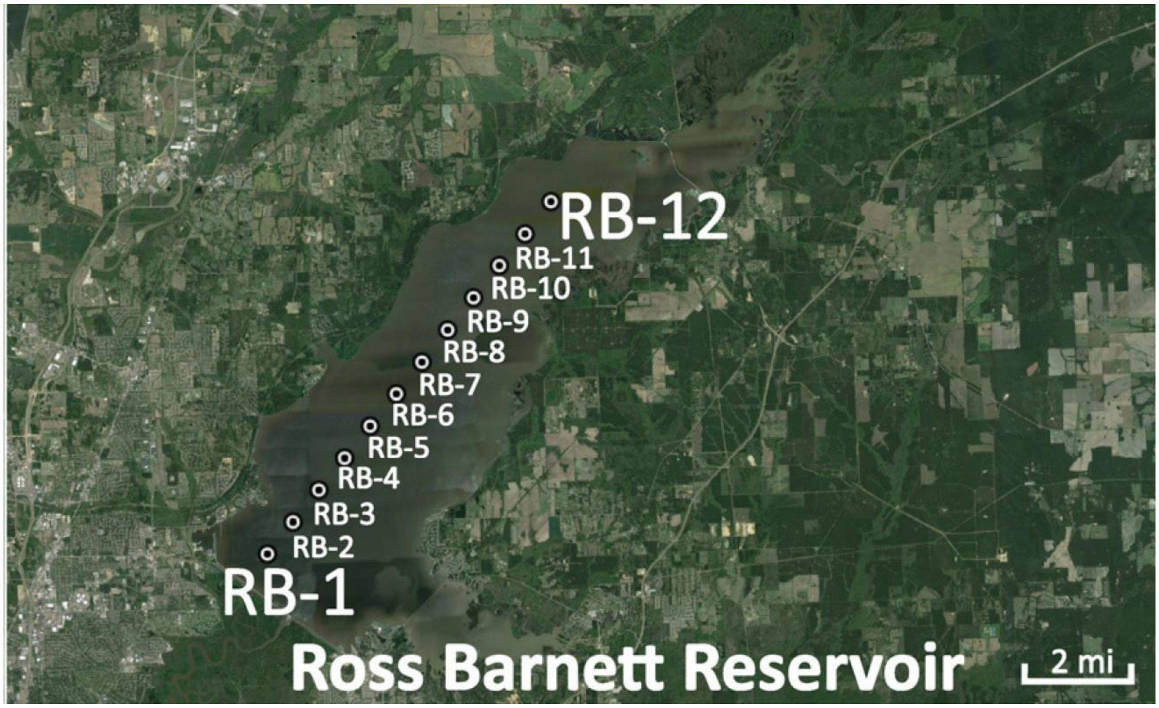


Figure 3.6 Dash *et. al*, systematic sampling sites at RBR. Five sampling trips in total were made, two in summer 2012, two in summer 2013, and one in summer 2014.

(Dash *et al.*, 2015)

Additional RBR surface water studies regarding bacteria, nutrient and sediment influences on phytoplankton abundance have been conducted between 2000 and 2010 (Sobolev et al., 2009; Kishinhi *et al.*, 2006; Tchounwou *et al.*, 2001). Sobolev *et al.* found that regardless of abundance of nutrients, turbidity caused by sediments was a limiting factor for algal growth near the shore of the RBR. The results were attained from five near-shore sites and were not indicative of the RBR as a whole. More appropriately, Dash *et al.* (2015) study followed a systematic sampling technique, whereas the aforementioned studies were not a spatial representation of the entire RBR.

Previous USGS studies in the Ross Barnett region (Spiers and Dalsin, 1979; Harvey et al., 1961) in conjunction with Mississippi Department of Natural Resources (Baughman *et al.*, 1971; Moore *et al.*, 1965; Priddy, 1960) and the Bureau of Land and Water Resources, include a series of hydrologic atlases describing various aquifers (Spiers, 1977a, 1977b; Boswell, 1976a, 1976b; Newcome, 1976;) and delineate water levels (Wasson, 1981, 1980a, 1980b, 1980c).

In the early 1980's, the USGS in cooperation with the PRVWSD conducted a series of extensive studies on groundwater within the RBR area (Oakley, 1984). By using well pumping data, well log data and geophysical log data, along with chemical analyses of water collected from wells near the reservoir, a description of the depth and thickness of principal water-bearing units was compiled along with groundwater quality and utilization. Oakley determined that the Sparta Sand and Cockfield Formations were the main aquifers used for public water supplies around the reservoir, the Sparta Sand being the most developed and highest yielding aquifer of the two. Before 1983 however, almost all groundwater in the region was pumped from the Cockfield aquifer. Recharge to the aquifers comes from precipitation on permeable outcrops to the northeast. Unfortunately, since 1940, aquifer levels have declined an average of 0.6 meters to 0.9 meters (2 - 3 feet) per year.

Geologic units within the RBR surrounding area range from the oldest outcrop of Zilpha Clay to the youngest deposits of Quaternary alluvium outside of the UPRW. Oakley determined there is a regional southwestward dip of approximately 9 meters per kilometer (30 feet per mile) before being interrupted by the structural Jackson dome feature located approximately 16 kilometers (10 miles) south of the UPRW's delineation.

The Jackson dome affects several hundred meters of deposition; thusly causing extreme variations aquifer characteristics and above normal geothermal gradients closer to the dome itself (Fig. 3.7). The basal Meridian-upper Wilcox aquifer serves as the base of freshwater except in the far northeastern portion of the RBR where the lower Wilcox aquifer contains freshwater.

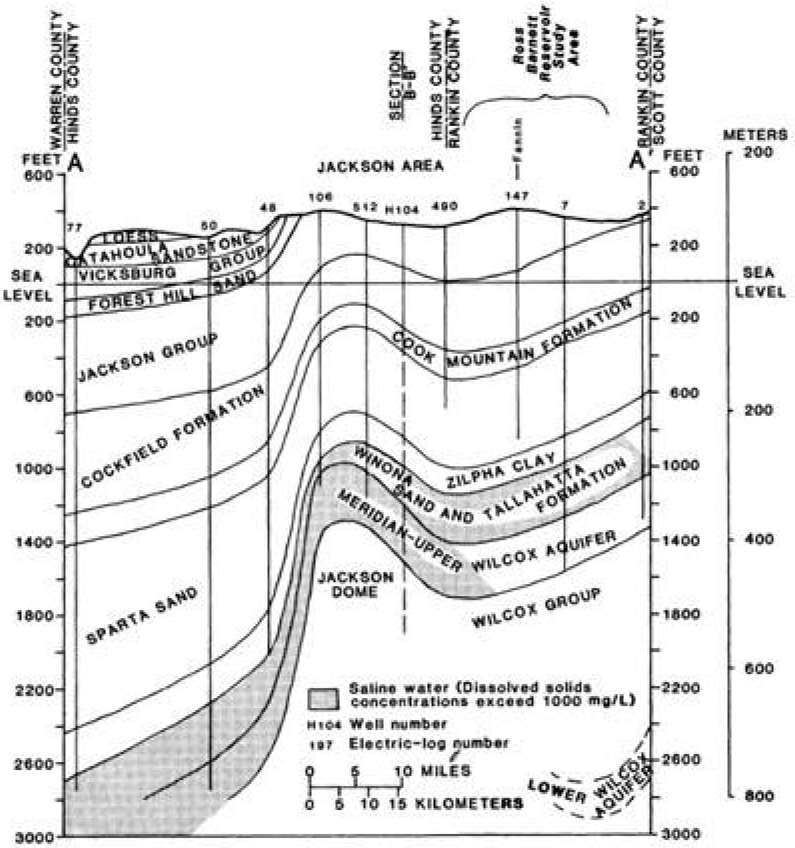


Figure 3.7 Geohydrologic section of RBR and surrounding area acquired by Oakley using geophysical logging. Particularly notable, is the Jackson dome feature, south of the RBR, uplifting the surrounding strata several hundred meters.

(Oakley, 1984)

Oakley's assessment of the groundwater in the RBR region showed groundwater movement southwestward in the Cockfield and Sparta aquifers; this was due to a cone of depression centered around the city of Jackson. Chemical analyses found iron concentrations were high in the groundwater, ranging from 0.10 to 9.3ppm (Appendix A, Fig. A.2). Iron concentrations in the Cockfield aquifer increase from recharge area to the downdip distance of the Jackson dome. Moving southwestward of the Jackson dome, iron concentrations in both Cockfield and Sparta aquifers decrease. Oakley also demonstrated that manganese concentrations were usually higher where iron concentrations were also high, following the distribution pattern iron followed.

Oakley tested for pH, hardness as, salinity, temperature, and water color intensity by Pt-Co methods. He demonstrated the groundwaters of the RBR area had pH ranging from 6.5 to 8.5 and had overall soft water with a calcium carbonate concentration less than 60mg/L. In both the Cockfield and Sparta aquifers, dissolved-solids increase as the aquifers progress from northeast to southwest. Within the lower Wilcox and Meridian-upper Wilcox aquifers of the RBR area, geophysical logs indicated waters become slightly saline, having greater than 1,000mg/L TDS. As both aquifers deepen downdip, the groundwater becomes sodium-bicarbonate dominated via increasing sodium levels and decreasing hardness.

Aquifer temperatures ranged from 20.0° to 31.0° C (68.0° to 89.0°F) in groundwater wells between 91 meters (300 feet) to approximately 1,300 meters (1,300 feet). The geothermal gradient increases about 2.1°F every 30 meters (100 feet) in wells deeper than 91 meters (300 feet), groundwater temperatures being highest near the Jackson dome. Color was also a noted problem in both the Cockfield and Sparta aquifers.

Color variations in groundwaters of the RBR is believed to be directly related to organic materials types and their concentrations. In some wells, color was attributed to the screen setting extending into the confining layers of the underlying clay. This was indicative of colored water being prevalent in the basal strata. Overall, Oakley determined that at any site, it was advisable to obtain water samples from the potential source due to unpredictable iron concentrations and color before drilling a well.

CHAPTER IV

HYPOTHESIS

By baseflow, common cations, anions, trace elements and pharmaceuticals are flowing into the Ross Barnett Reservoir from the Upper Pearl River watershed's groundwater.

CHAPTER V

OBJECTIVE

The objective of this project was to characterize the groundwater of the Upper Pearl River watershed by selecting a total of 49 groundwater pumps in the study area, and a gravity-driven groundwater spring in close proximity to the headwaters of the Upper Pearl River. The collected groundwater samples were analyzed for their hydrogeochemical properties both *in-situ* and in the laboratory.

Water quality data collected from these wells was combined with state-wide maps of surface geology and aquifer outcrops. A current regional land use and land cover classification scheme was created and incorporated for comparative analysis of possible point-source and non-point source pollution. Finally, a comparative analysis of the Upper Pearl River watershed with the Ross Barnett Reservoir was accomplished by creating a cross-sectional map of the watershed and its aquifers.

CHAPTER VI

METHODOLGY

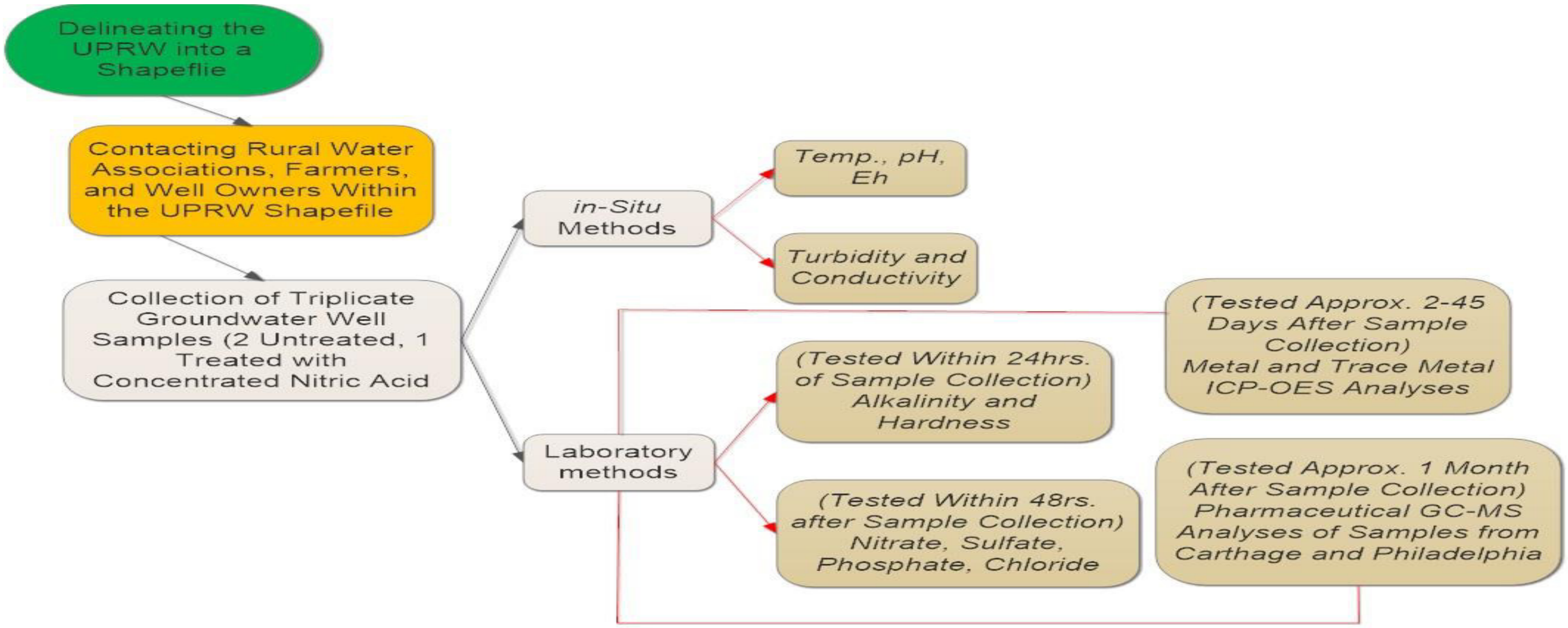


Figure 6.1 The flowchart above portrays the order of operation undertook in the study.

6.2 Creating the UPRW Delineation Shapefile and A Land Use/Land Cover Classification Scheme

The UPRW shapefile was originally created in ArcGIS by downloading a statewide digital elevation model (DEM), hydrological data, and hydrological unit code (HUC) units from the Mississippi Automated Resource Information System (MARIS) and USDA websites and extracting only the area within the watershed based on HUC partitions, slope, elevation, and most importantly stream flow order using the Strahler Stream Order hierarchy (Appendix C, Fig. C.1 – C.3). Other data files layered on top of the DEM that helped demarcate the watershed were statewide cities and counties, and geological data (Fig. 6.2, Fig. 6.3). All files were georeferenced and layered together in ArcGIS.

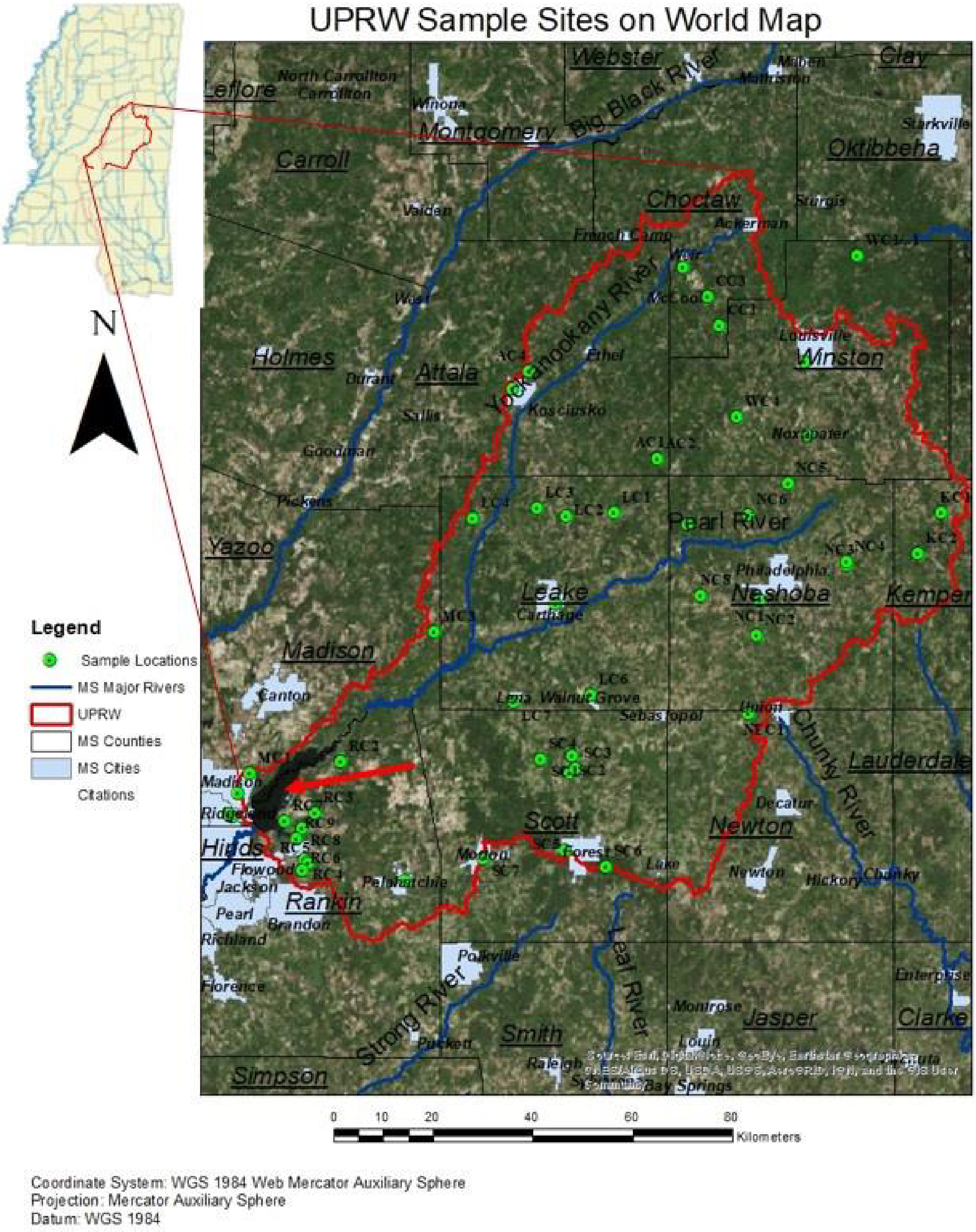


Figure 6.2 UPRW outlined in red illustrating the UPR, RBR (red arrow), counties, cities, and sample locations and scope of study area. Image generated by data shape files acquired from the Mississippi Automated Resource Information System (MARIS) website.

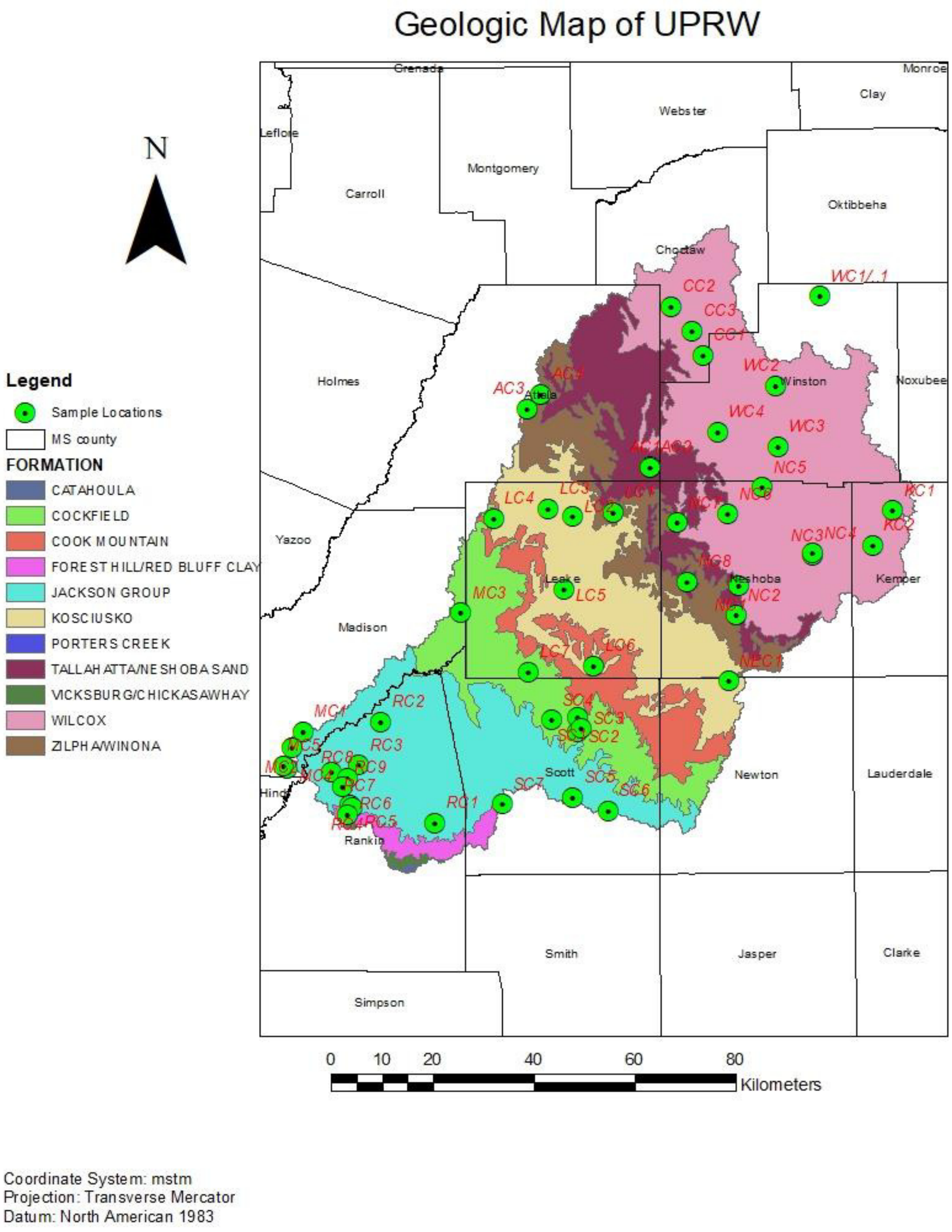


Figure 6.3 Geologic surface map of the UPRW. Geological data was used as a failsafe to stratigraphically determine correct water-bearing rock units. The image was generated by data files acquired from the Mississippi Automated Resource Information System (MARIS) website

It was pertinent in having a correct shapefile for the study area since multiple watersheds border each other on all sides. The shapefile allowed for proper selection of groundwater wells with waters flowing within the UPRW. The watershed shapefile was generated from the aforementioned attributes of the study area, and then extracted. Next, an extraction of the shapefile with current land use and land cover data showed the UPR's tributaries and formation of the RBR in detail (Fig. 6.4). The land use and land cover classification scheme created allowed for all land variability to be accounted for when sampling, making sure all land types were covered. Land use and land cover shapefile data was downloaded from the USDA National Landcover Dataset Gateway Portal. The data files were uploaded in ArcGIS along with the UPRW shapefile. Extraction of the land use and land cover in the UPRW was done with the 'extract by mask' function generating the 15 landcover types in the region (Fig. 6.5).

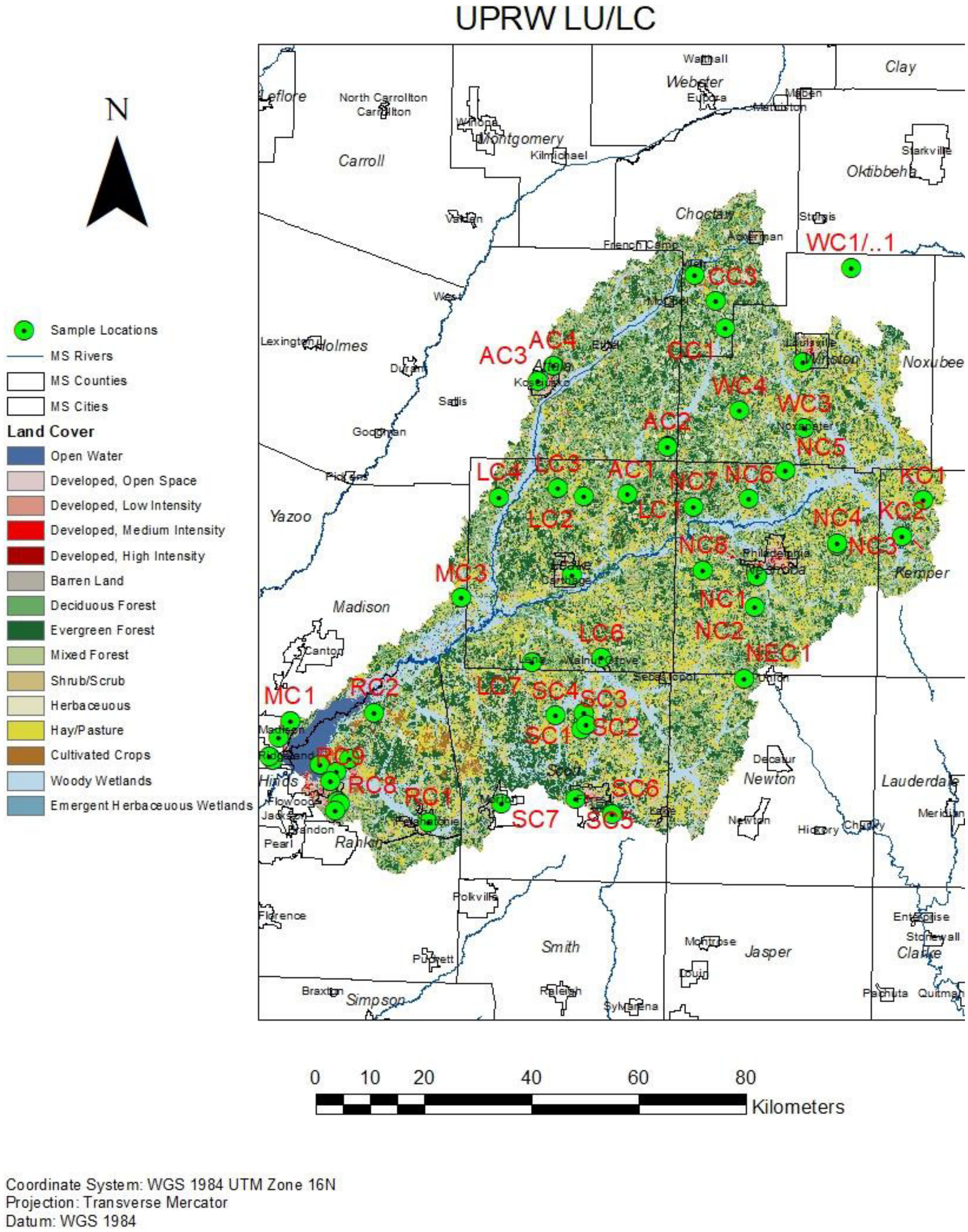


Figure 6.4 Generated map of the land use and land cover of the UPRW. The map illustrates the UPRW and its tributaries, and the diversity and complexity of land cover types throughout the region. Land use and land cover data files were accessed from USDA Geospatial Data Gateway- https://datagateway.nrcs.usda.gov/GDGOrder.aspx

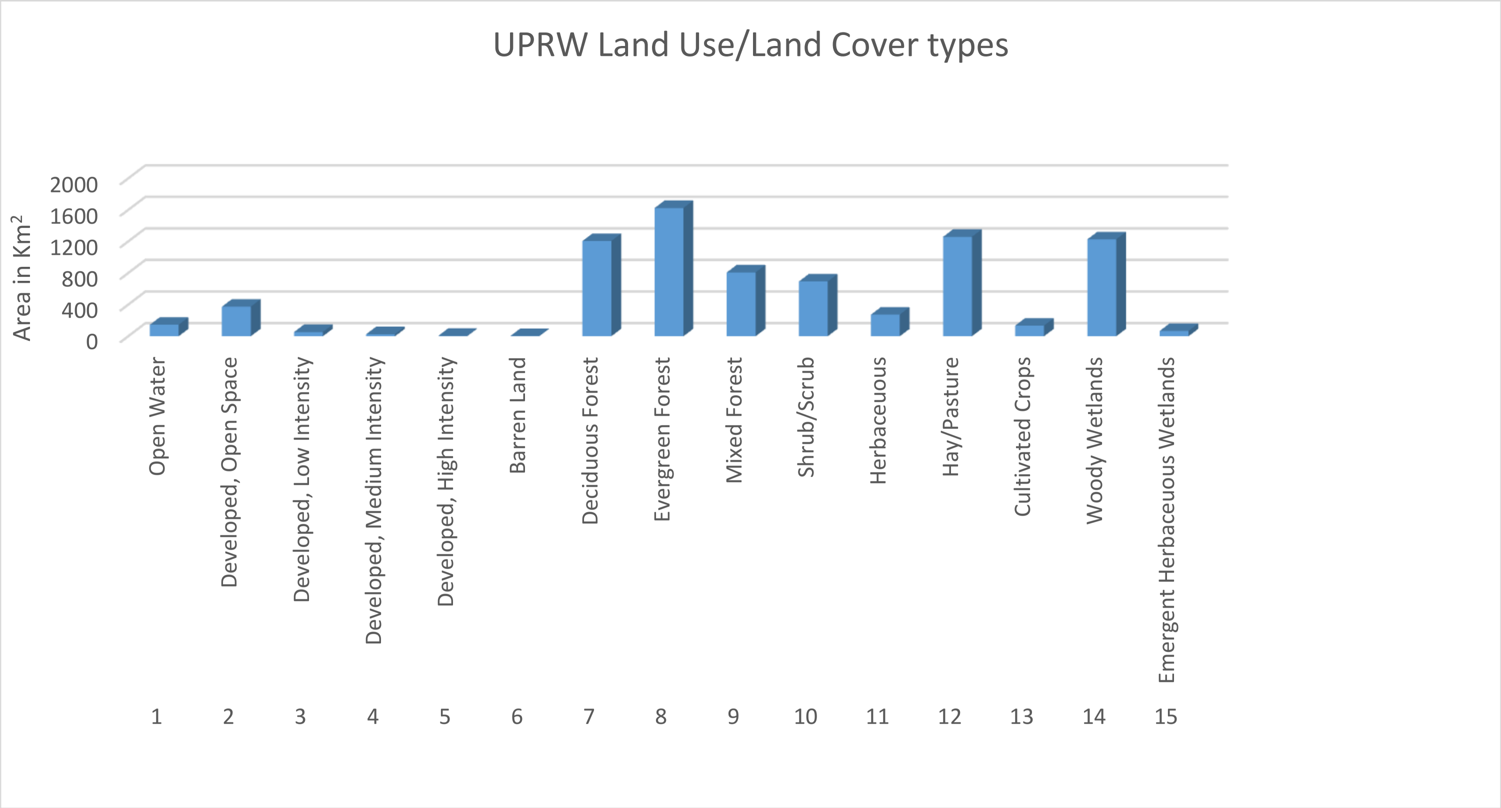


Figure 6.5 The UPRW land use and land cover types in square kilometers. The dominating land cover types being forest and wetlands. (Generated from USDA land use and landcover gateway portal files)

6.3 Contacting Well Owners

The UPRW covers a total of 10 counties. Because of the large scale of the watershed, calling utility companies and rural water associations on the county-level was the best approach to acquiring groundwater samples. The well owners were thoroughly informed of the study's undertaking and asked to participate in free in-depth water samplings. The final results would only be indicative of the overall characteristics of the UPRW and not the well owners' well itself; providing anonymity and protecting the well owner from possible litigation. When sampling with county utility companies, the owners would contact local farmers and industries consuming large amounts of groundwater and inquire if the business wanted groundwater testing as well (since the results were free-of-charge and anonymity was thoroughly discussed with all parties). Wells proximal to local poultry industries were frequently sampled independent of predetermined county well sites. Since poultry facilities use unfiltered groundwater for their livestock directly from a private groundwater pump, these businesses seemed most reasonable. Another factor in choosing poultry facilities was the abundant nitrate from chicken feces that could infiltrate into the groundwater. Upon arrival for groundwater testing at county-owned wells, the well owner contacted the poultry farmers furthest from the current well site, ensuring a wide-spread sampling range.

The well sites were individually selected by interacting with the water associations. A map of the UPRW, zoomed-in to their specific county was used to identify the wells equidistant from one another. In the northern portion of the UPRW, Kemper, Winston, Choctaw, and Attala Counties, sampling was conducted in small towns and cities based on availability of well personnel, as these were some of the least populated rural sections of the watershed. The Central Mississippi Water Association and PRVWSD especially facilitated in networking with well owners throughout the central and southern portions of the watershed. It is important to note that not all the well owners contacted agreed to testing. For example, it was difficult to sample in Neshoba, Newton, and Rankin Counties as multiple municipal water associations refused to help or never replied back after initial conferences. As a result, there are several gaps in the watershed's sampling site-to-site; some wells are very close to one another and some wells are spread over large areas, most noticeably in Neshoba, Newton, and Rankin Counties. All the samples were identified based on the county they were collected in and order of collection, using the notation of county initial and the letter 'C' for 'county' plus the sampling order of that county; for example, Winston County= WC1, WC2, WC3, etc., Neshoba County= NC1, NEC1= Newton County, Scott County= SC, etc. All except for Newton County (NEC), which begins with the same letter as Neshoba County (NC), are identified using this systematic notation.

6.4 Sample Collection, *in-Situ* Water Quality Analysis, and Storage

The water samples were collected when communication with the well owners was established and the well sites were identified. When acquiring groundwater samples at the site, if the groundwater pump was not already running upon arrival, a purge time was given to clear the well of stagnant water when the pump was started. A controlled constant discharge rate was executed for a specific period of time until the pH and temperature remained constant for at least two minutes. In sites where the groundwater pump was already running upon arrival, a controlled, constant step drawdown approach was taken. Essentially, a progressive increase in discharge from the groundwater pump's tap effectively ensured the tap and piping was clear of debris. All the groundwater wells were fitted with a surface tap, from which unfiltered samples were collected. An exception was the naturally flowing groundwater spring, WC1 and WC1..1, which had a PVC pipe emerging from a hillside for water collection. Purge time for each well is noted in the well information table in the appendix (Appendix B).

Once the groundwater well had been purged and tap cleared of debris, three acid-cleaned 500mL sample bottles were filled to the brim. One sample was acidified with concentrated nitric acid (Fisher Chemical, A200-212 Nitric Acid, Certified ACS Plus) to prevent the precipitation of any elements after sampling as per EPA standards for metal analysis. The other two samples were unacidified and were used for testing alkalinity, hardness, nitrate, phosphate, sulfate, chlorides. Two of the unacidified samples were later selected and screened for pharmaceutical analysis by gas chromatography mass spectrometry.

Temperature, pH, and Eh were measured by Hanna Instruments HI 991003 portable pH/mV meter after the groundwater well had been purged and tap cleared. The meter was calibrated via 2-step calibration test as manufacturer's instructions each day of sampling. Turbidity was determined by Thermo Scientific Orion Aquafast AQ3010 turbidity meter. The final in-situ test performed was specific conductivity by Hanna Instruments HI 9033-HI 9034 waterproof multi-range EC and TDS meter for field applications. pH, turbidity, and conductivity meters were calibrated as per manufacturer's instructions before each series of tests.

After collection and acid treatment of the samples, sample bottles were completely wrapped in aluminum foil and stored in a cooler with ice packs for transport to the Mississippi State University Geosciences lab, where they were stored at ~4°C until analysis. The aluminum foil remained on all samples bottles while in cold storage and during analyses to prevent contamination and any degradation after the sample had already been collected.

6.5 Laboratory Methods

Once samples were brought back to the lab, they were immediately transferred from transport cooler to cold storage to begin multiple analyses. Alkalinity and hardness were tested within 24 hours of sampling; alkalinity needing to be tested for first since pH changes will immediately begin to occur after sample collection, even in cold storage. Hach Test Kit for alkalinity 10-4,000 mg/L Model AL-DT, Cat. No. 20637-00, Method 8203 alkalinity titration test was used. Hach Test Kit for hardness, total and calcium, 10-4,000mg/L Model HAC-DT, Cat. No. 20639-00, Lot A7116 was used for all hardness measurements.

Within 48 hours of sample collection, common (nitrate, phosphate, sulfate, and chloride) anions were tested for in the lab. Nitrate being the most time-sensitive, was tested within 48 hours after sample collection. The kits used for anion analyses were as follows: Hach Nitrate Test Kit, Model NI-11, Cat. No. 146803, Lot A7233; Hanna Instrument HI 38061 Phosphate Kit with checker disc, method 0.0-0.5ppm Phosphate range; Hanna Instruments HI 38001 Sulfate low and high range test kit, low range (100-1000mg/L sulfate); and Hach Chloride Test Kit, Silver Nitrate Titration, CL-1,22820-88, Method 8207.

Acidified samples were filtered through 0.45µm syringe filters as per EPA protocol and stored immediately in 30 mL pre-washed sterile sample bottles at ~4°C cold storage the same day as collection. The samples were stored for two to 45 days after filtration before being tested for trace elements and heavy metals via inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma optical emission spectrometry (ICP-OES) analyses. Trace metal concentration for a few of the samples were analyzed using the ICP-MS (Varian 820-MS, Varian, Inc., Palo Alto, CA, USA) at the Department of Chemistry and Biochemistry, Jackson State University, MS. All other trace element and heavy metal analyses were performed via ICP-OES (Perkin Elmer Optima 2000DV) at the Department of Geology, Mississippi State University.

Standards and quality control for the ICP-MS and ICP-OES measurements used certified reference material (SRM 1640a Trace Elements in Natural Water) from the Institute of Standards and Technology, Gaithersburg, MD. All values were within a 95% confidence level of the certified ICP-MS and ICP-OES trace element analyses (Appendix D, table D.2). Maximum error percentages for trace elements compared with the 0.995 mg/L standards prepared (0.005 mg/L yttrium used as an internal standard): arsenic ± 11%, lead ± 4%, chromium ± 4 %, phosphorous ± 5 %, cadmium ± 3 %, copper ± 6 %, mercury ± 8 %, zinc ± 8 %, and strontium ± 6%.

Pharmaceutical, pesticide, and industrial chemical residue analyses of Carthage and Philadelphia's groundwater, the largest and most densely populated cities in the watershed (US Census, 2000), was performed by gas chromatography mass spectrometry (GC-MS) at Michigan State University Veterinary Diagnostic Laboratory, Section of Toxicology, Michigan State University, Lansing, MI. Unacidified groundwater samples from each of the two cities' were thoroughly wrapped with clear tape to prevent leakage and shipped to Michigan State University Veterinary Diagnostic Laboratory for analyses. Since a large portion of pharmaceuticals make their way into aquatic environments via human activities like excretion, bathing, and disposal of unwanted medications, it was most reasonable to collect a groundwater sample at wells closest to the UPRW's most densely populated cities' hospitals and medical hubs (Escher et al., 2011; Bartelt-Hunt et al., 2009; Larsson et al., 2007; Ternes, 1998).

CHAPTER VII

RESULTS

7.1 **Hydrogeochemical Results**

Groundwater temperature was generally around 19.0 - 22.0° C in shallow wells in Leake, Kemper, Neshoba, Attala, Winston, and Choctaw Counties, with the exception of some deeper wells showing slightly higher temperatures (23 - 35° C). In the southern portion of the UPRW, Scott, Madison, and Rankin Counties show an increase in geothermal gradient. Madison and Rankin Counties have much deeper wells than surrounding counties explaining higher temperatures, the highest being 35.5° C in the City of Madison; and as groundwater moves closer to the Jackson dome volcanic feature, past the RBR, groundwater temperatures increase. The samples with the highest groundwater temperatures (Scott, Rankin, and Madison Counties with average groundwater temperatures of 27° C) had the deepest groundwater wells and were closest to the Jackson dome indicative of a higher geothermal gradient (Appendix section B and D). Few samples from Leake and Winston County (LC3, LC4, and WC1) do not have temperature readings due to time restrictions with the well owner and the groundwater spring (WC1) have a line of locals filling drinking jugs.

Groundwater pH was inconsistent throughout the watershed except in the southern portions, Scott, Madison, and Rankin Counties, where pH remained fairly constant between pH 7-8.6. The deeper wells in the southern portion had a higher pH from 7-8.6. The northern and central portions of the watershed, Winston, Choctaw, Kemper, Neshoba, and Attala Counties indicate acidic groundwaters, ranging from just below neutrality to as low as pH 4.6 at Hamill Springs located near the headwaters of the UPR (Fig. 7.1).

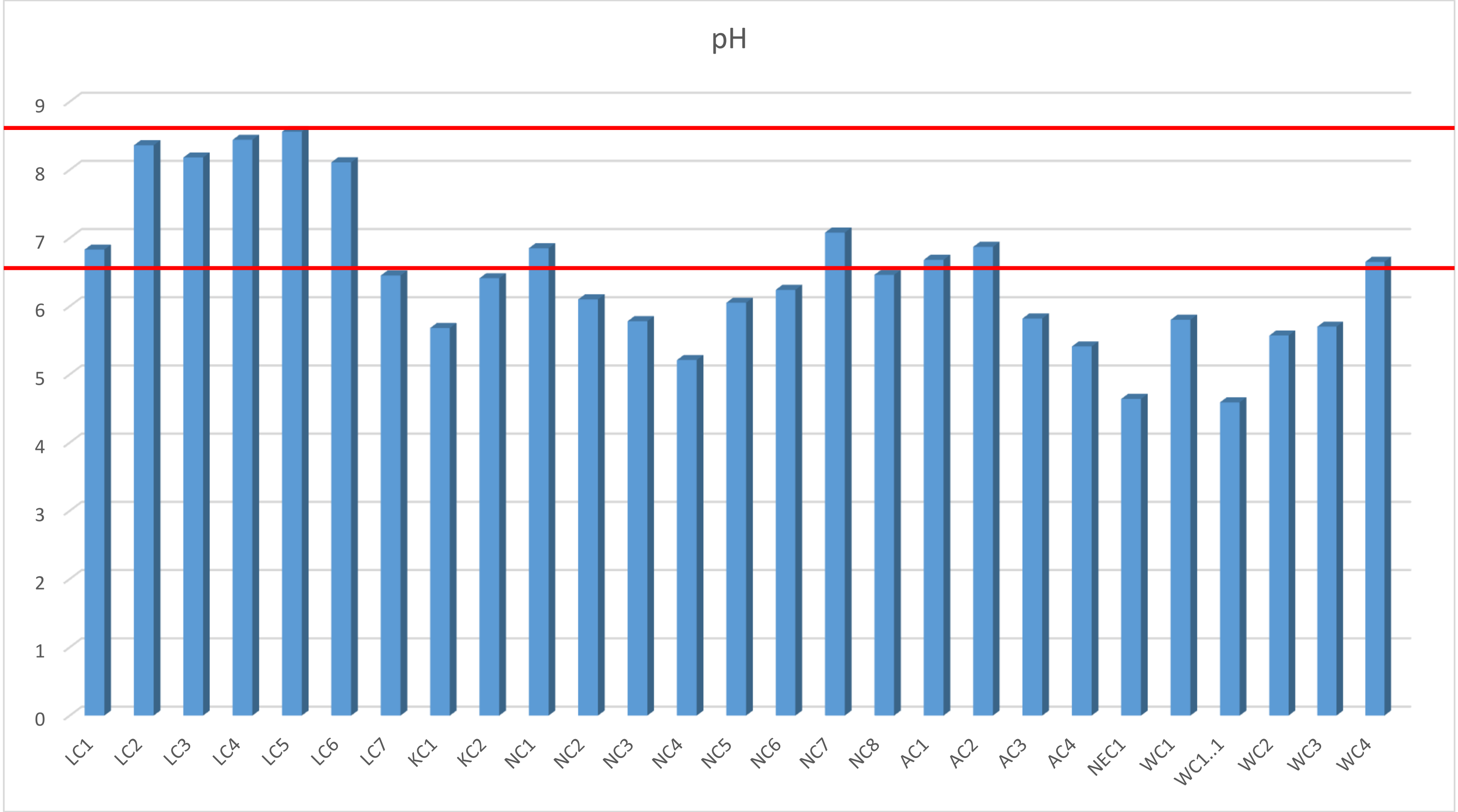


Figure 7.1 pH measured in the water samples. Any value above or below the red lines represent pH no within the EPA limits for drinking water (pH 6.5-8.5).

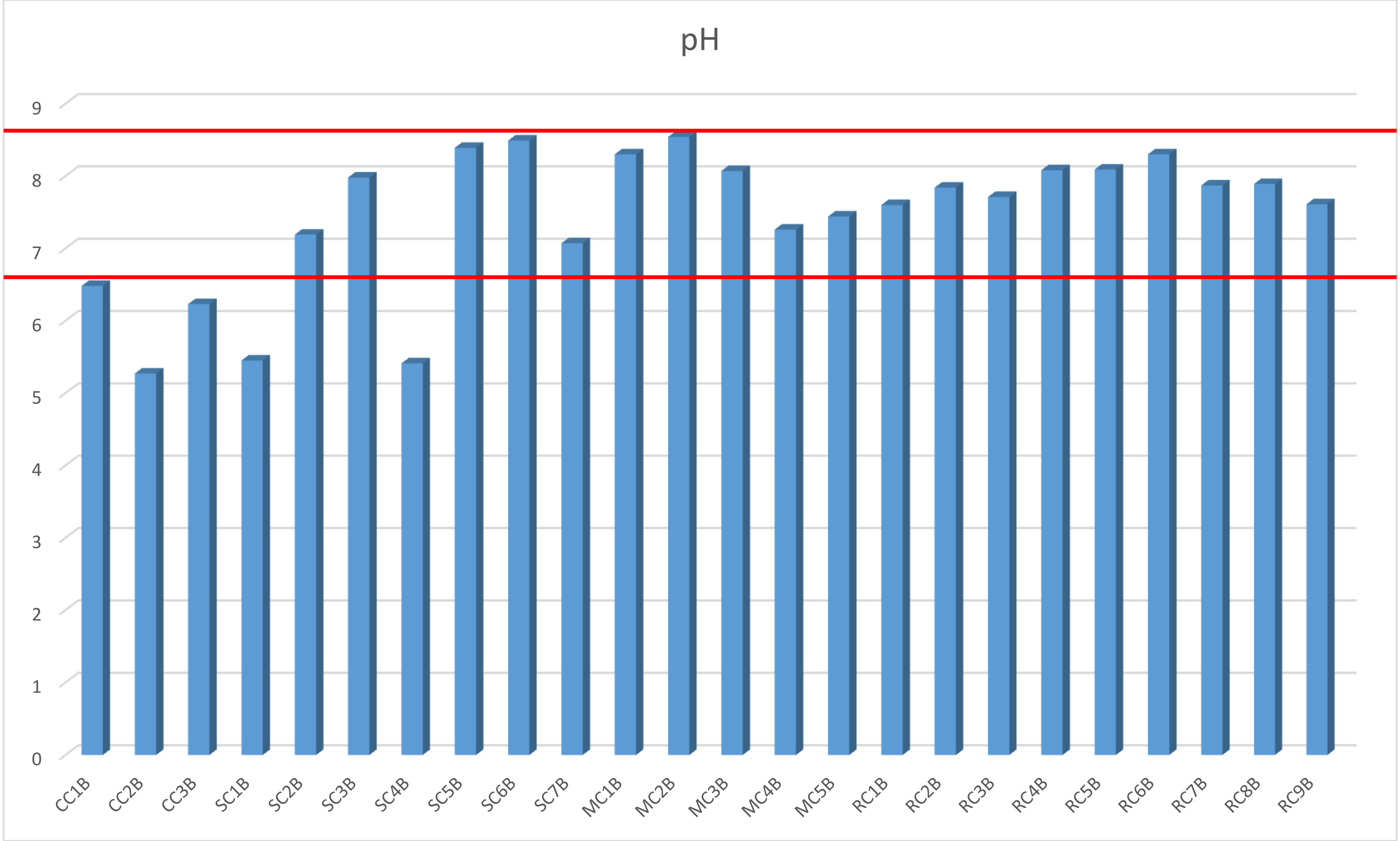


Figure 7.1 (continued)

Total alkalinity (determined as mg/L of calcium carbonate) varied throughout the watershed; highest seen in Scott, Rankin, and Madison Counties (southern portion of the watershed) with a range of 15 to 253 mg/L; lowest in Kemper, Winston, Attala, and Choctaw Counties (northern portion), where total alkalinity averages at 66 mg/L (Fig. 7.2). Neshoba and Leake Counties (central portion) showed an average total alkalinity of 103 mg/L. Phenolphthalein alkalinity (representing hydroxide ions) was absent as in all samples.

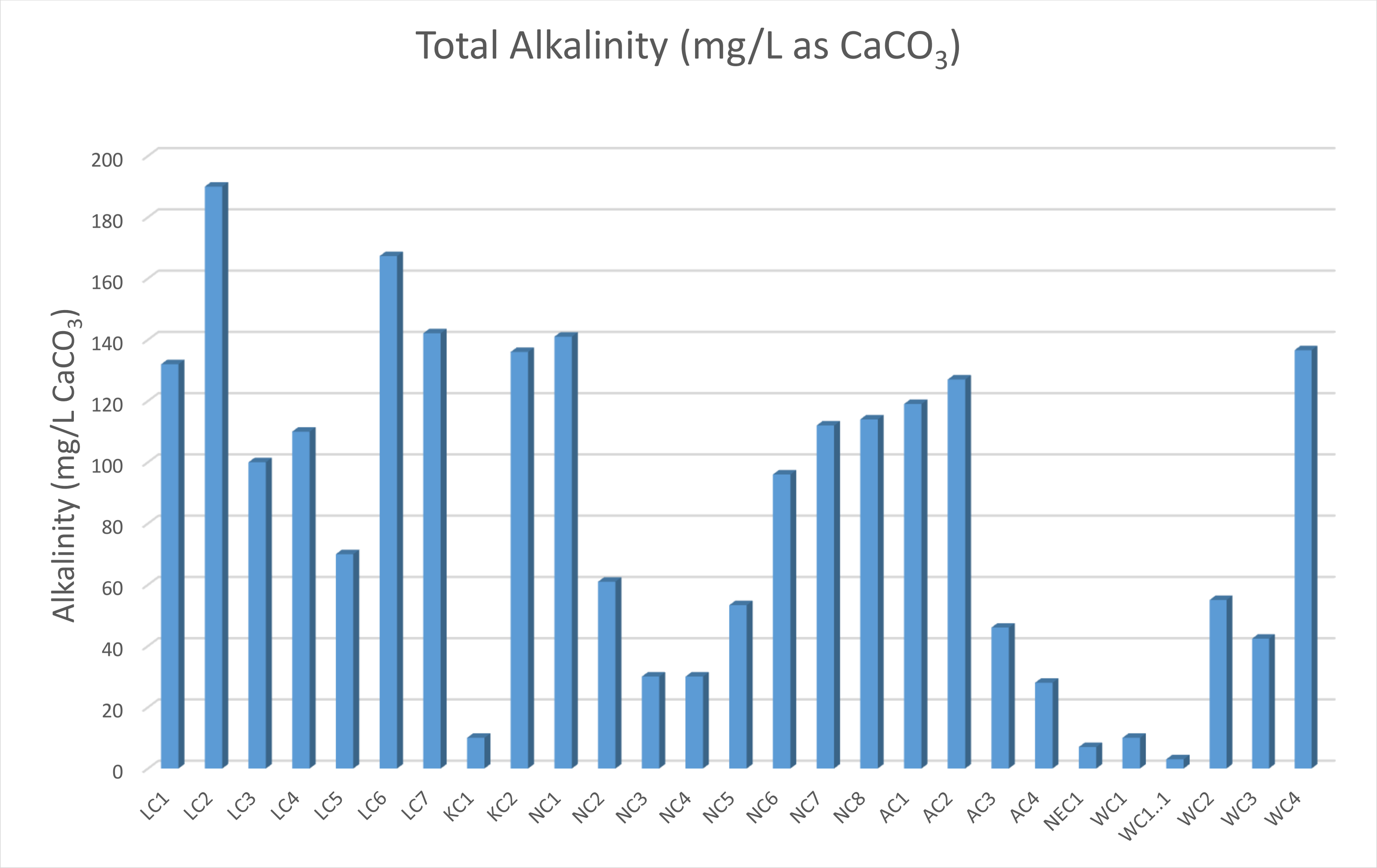


Figure 7.2 Total alkalinity determined as mg/L calcium carbonate.

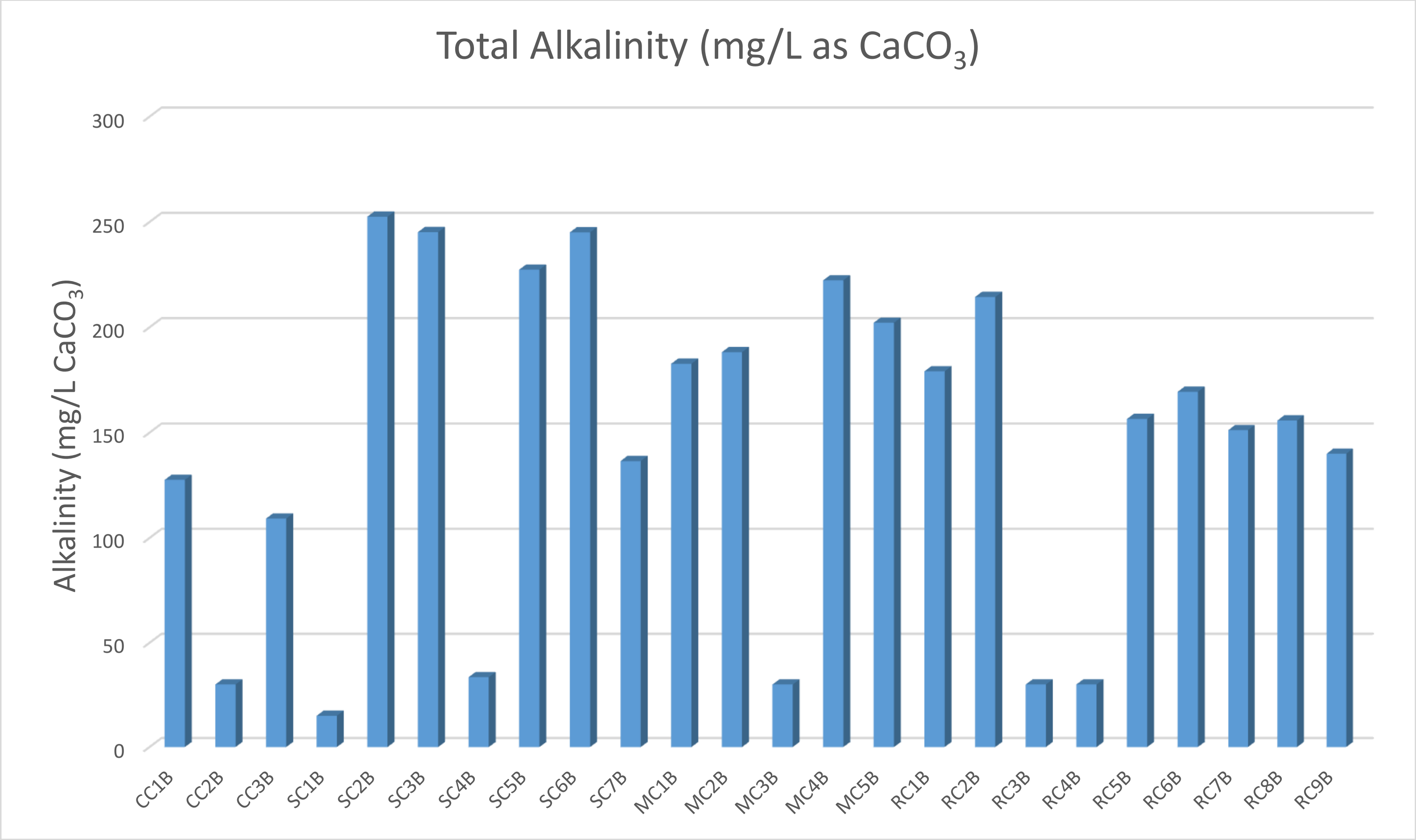


Figure 7.2 (continued)

Total hardness as calcium carbonate was highest (147 mg/L) in the central and upper portion of the UPRW (Fig. 7.3). Calcium and magnesium concentrations as determined by calcium and total hardness was highest in Leake, Kemper, Winston, Choctaw, Attala, and Neshoba Counties where total hardness ranged from 3 – 147 mg/L as calcium carbonate. In contrast, water was substantially softer in Scott, Madison, and Rankin Counties, where the average total hardness as calcium carbonate ranged from 2 – 28mg/L; the anomalous SC1 having 67 mg/L calcium carbonate, or hard water, is characteristic of high anions and cations produced as a by-product at the poultry facilities. Overall, groundwater was generally soft throughout the UPRW except in Attala and Neshoba Counties, where total hardness exceeded 60 mg/L.

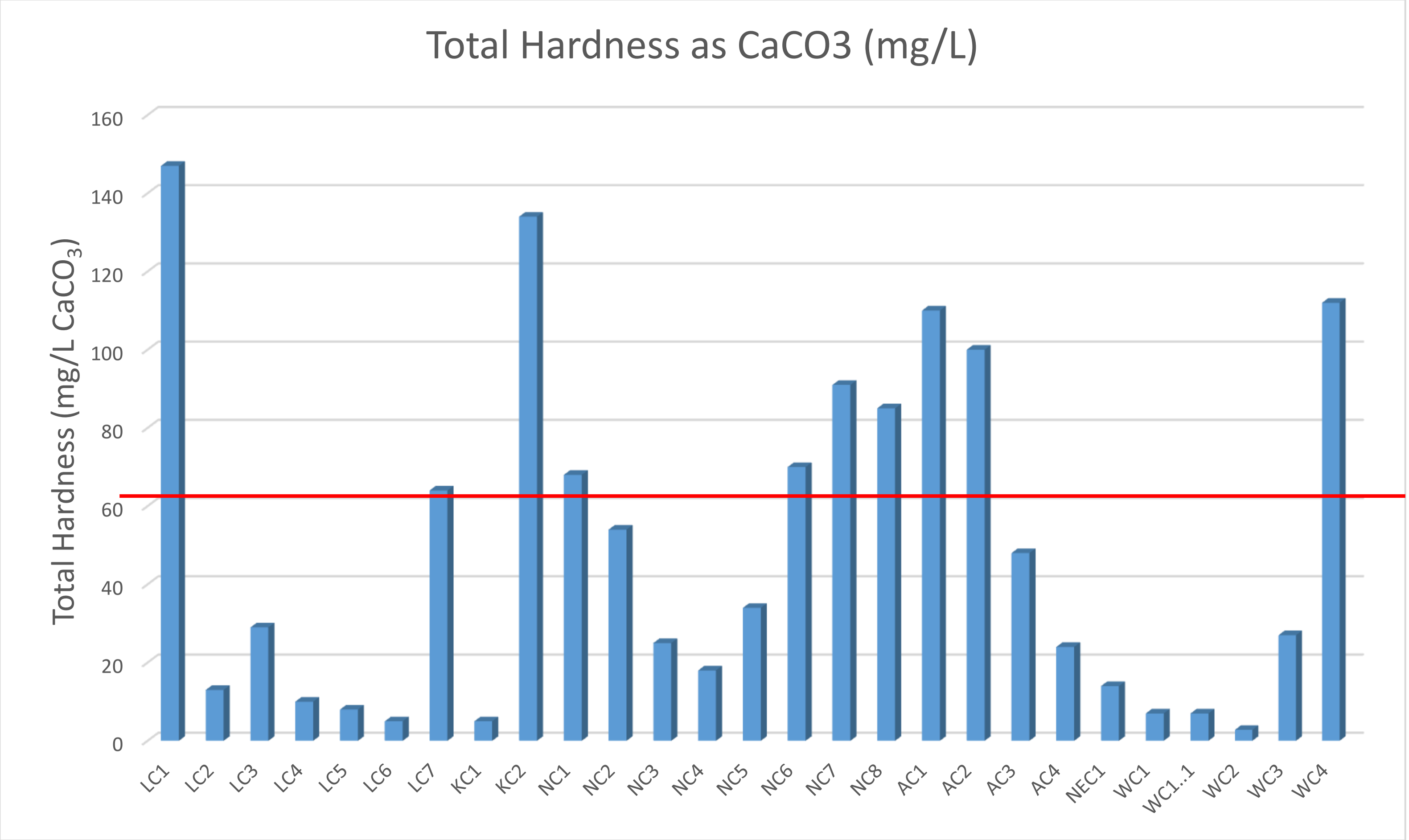


Figure 7.3 Total hardness values in the water samples. All values below 60mg/L calcium carbonate (red line) represent soft water.

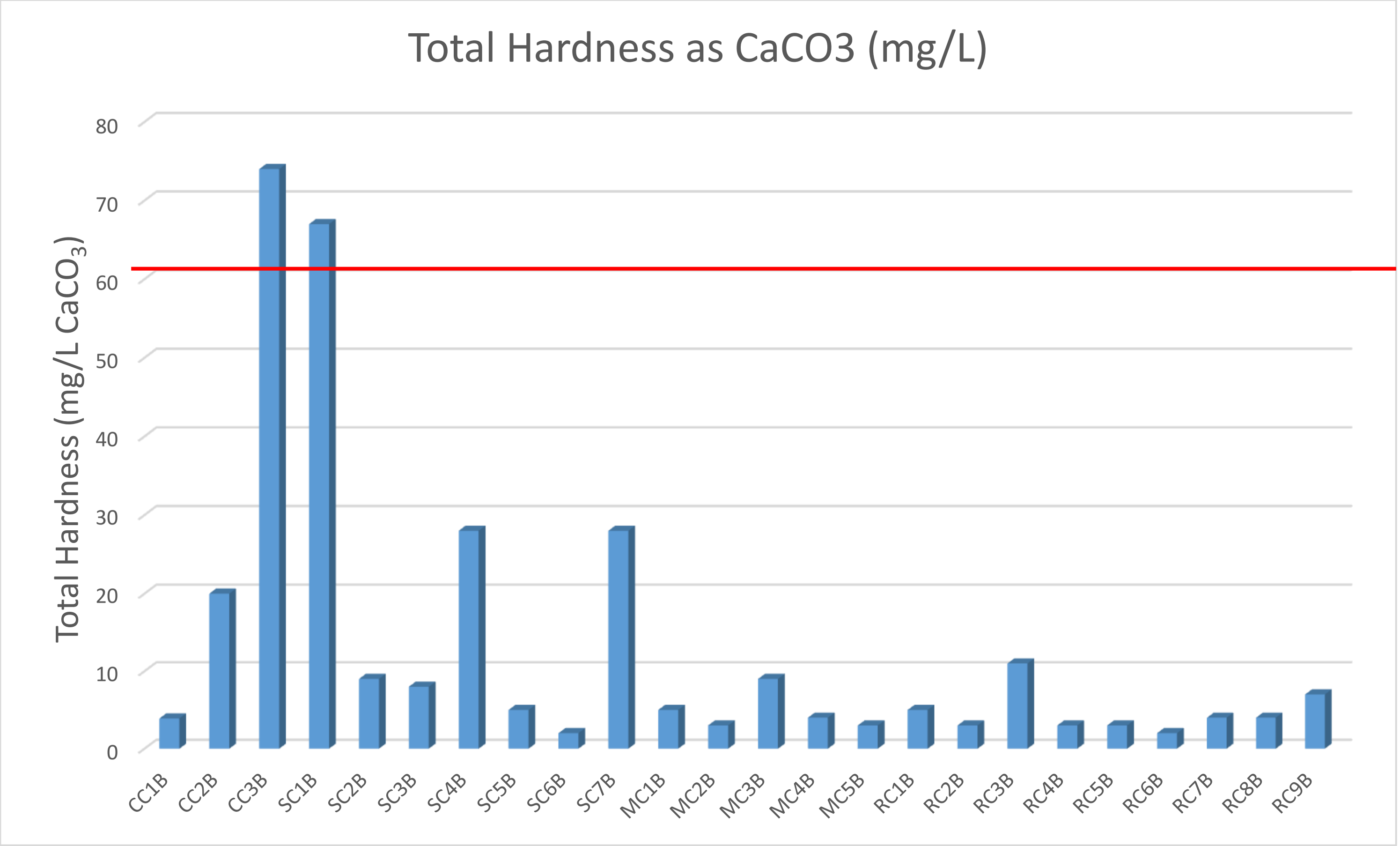


Figure 7.3 (continued)

Redox Potential, or E_h, was measured at all sites but three, LC3, LC4, and WC1 (Fig. 7.4). Redox potential varies drastically from one well site to another within the same county, ranging from +649 to -37 mV in Leake County, and +192 mV and -37 mV in Kemper County (at different well sites less than 20 miles apart). However, in Scott, Rankin, and Madison Counties, the southern portion of the UPRW, redox potential remains a negative value ranging from -4 to -242 mV, expect for SC1 at +153 mV.

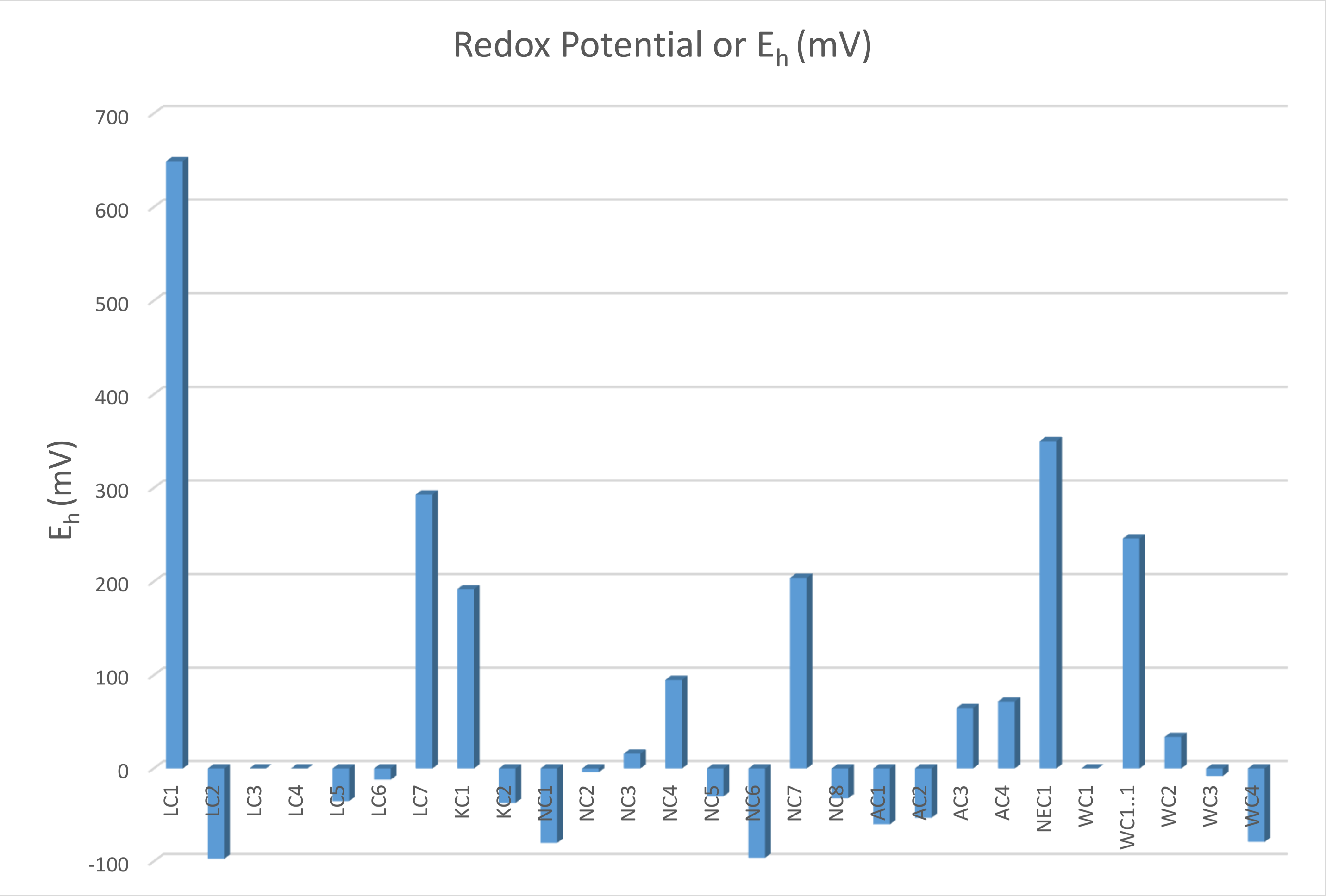


Figure 7.4 Redox potential; Positive values indicate the potential to be reduced. Negative values indicate the potential to be oxidized.

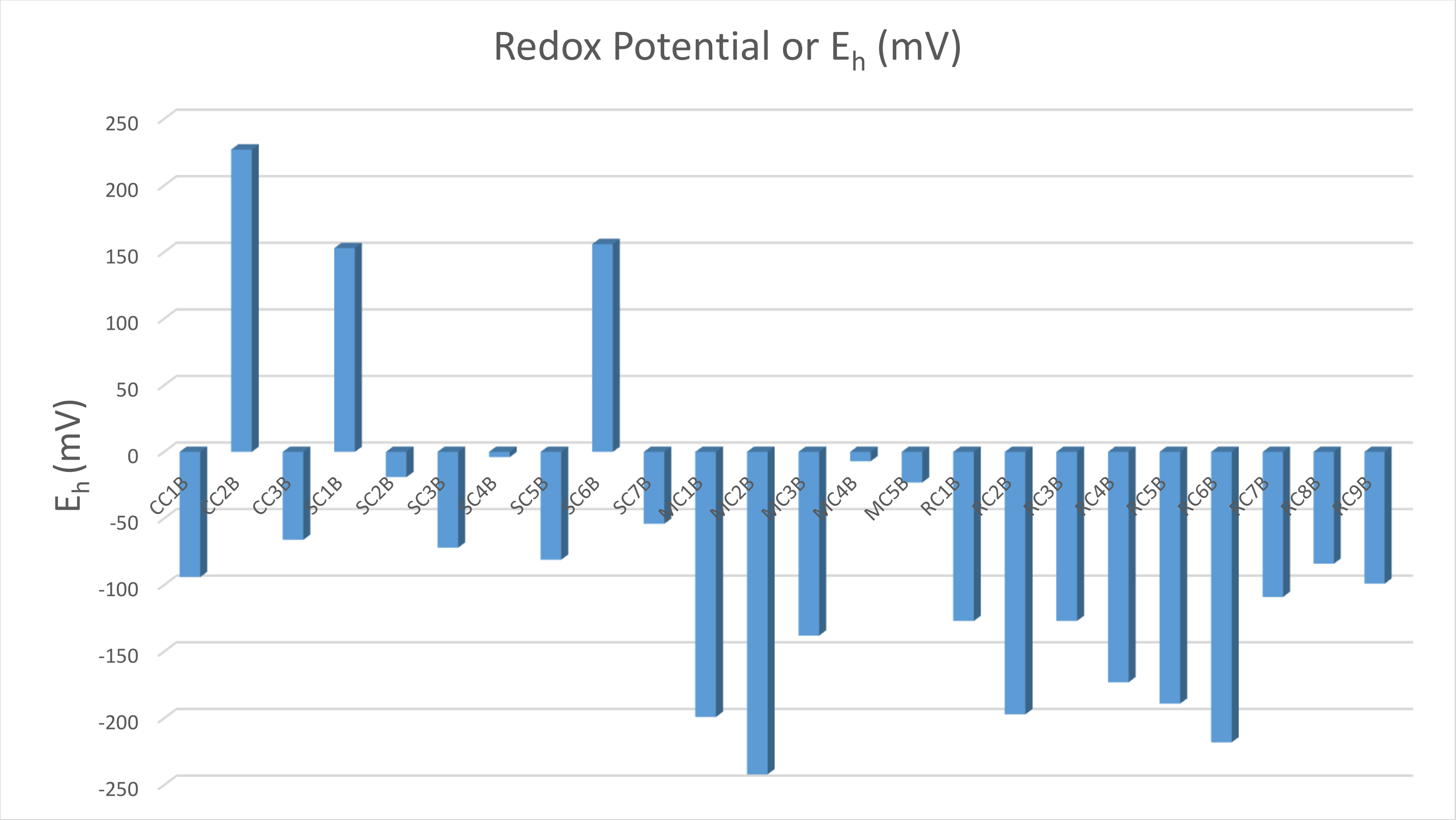


Figure 7.4 (continued)

Turbidity was lowest in the headwaters of the UPRW in Winston, Kemper, and Attala Counties generally being less than 1.0 NTU (Fig. 7.5). Turbidity increased dramatically in groundwaters at and around poultry facilities ranging from 0.04 – 60.7 NTU. In Neshoba County, turbidity increased significantly from 0.12 – 60.7 NTU. The most turbid groundwaters were in the City of Madison itself where turbidity reached 81.8 NTU. As the deepest groundwater wells in the watershed, Scott, Rankin, and Madison Counties turbidity increased from 0.44 to 81.8 NTU.

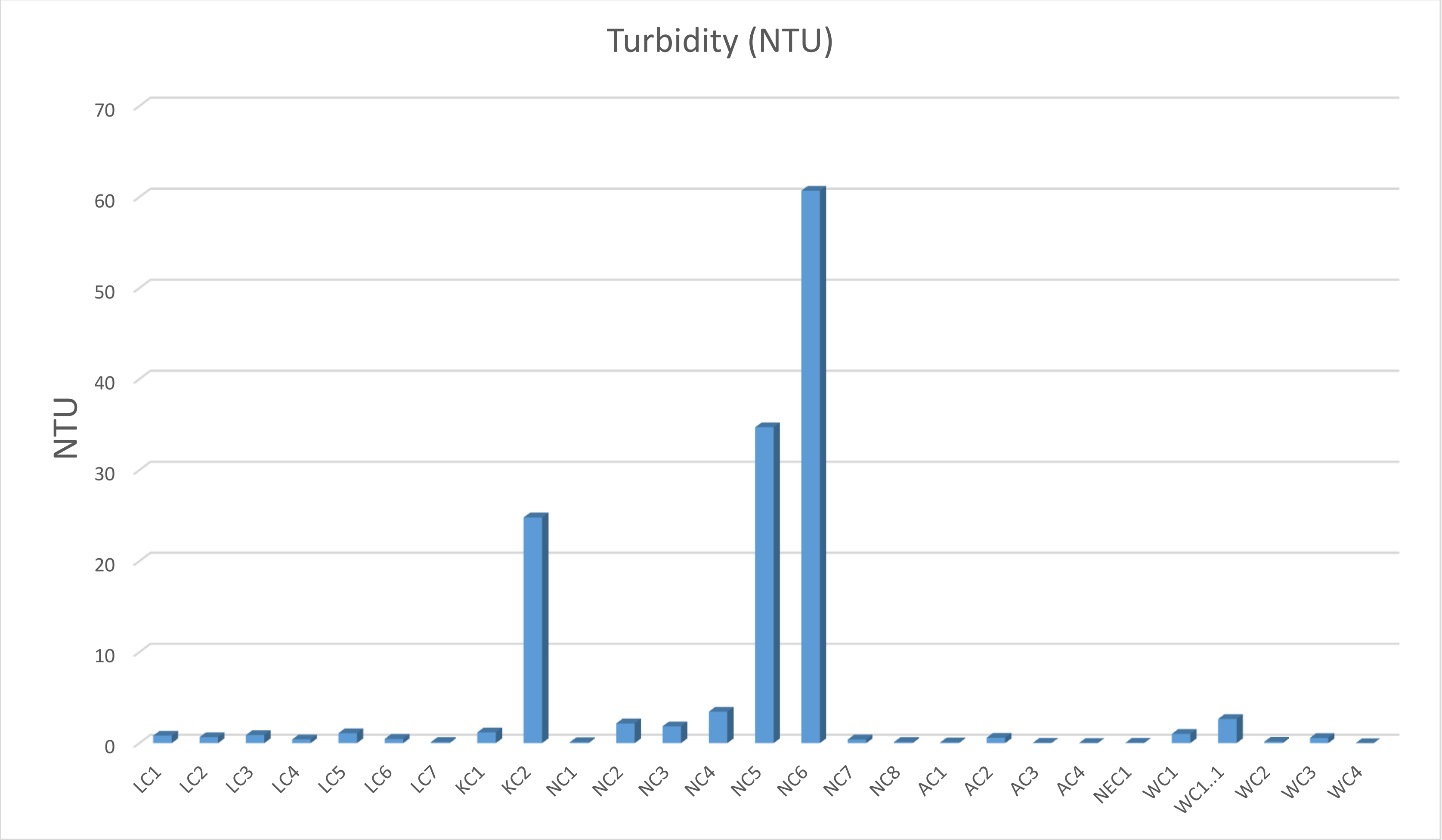


Figure 7.5 Turbidity within the UPRW mainly due to forest clear-cutting in Neshoba County and urban-growth and construction in Madison County respectively

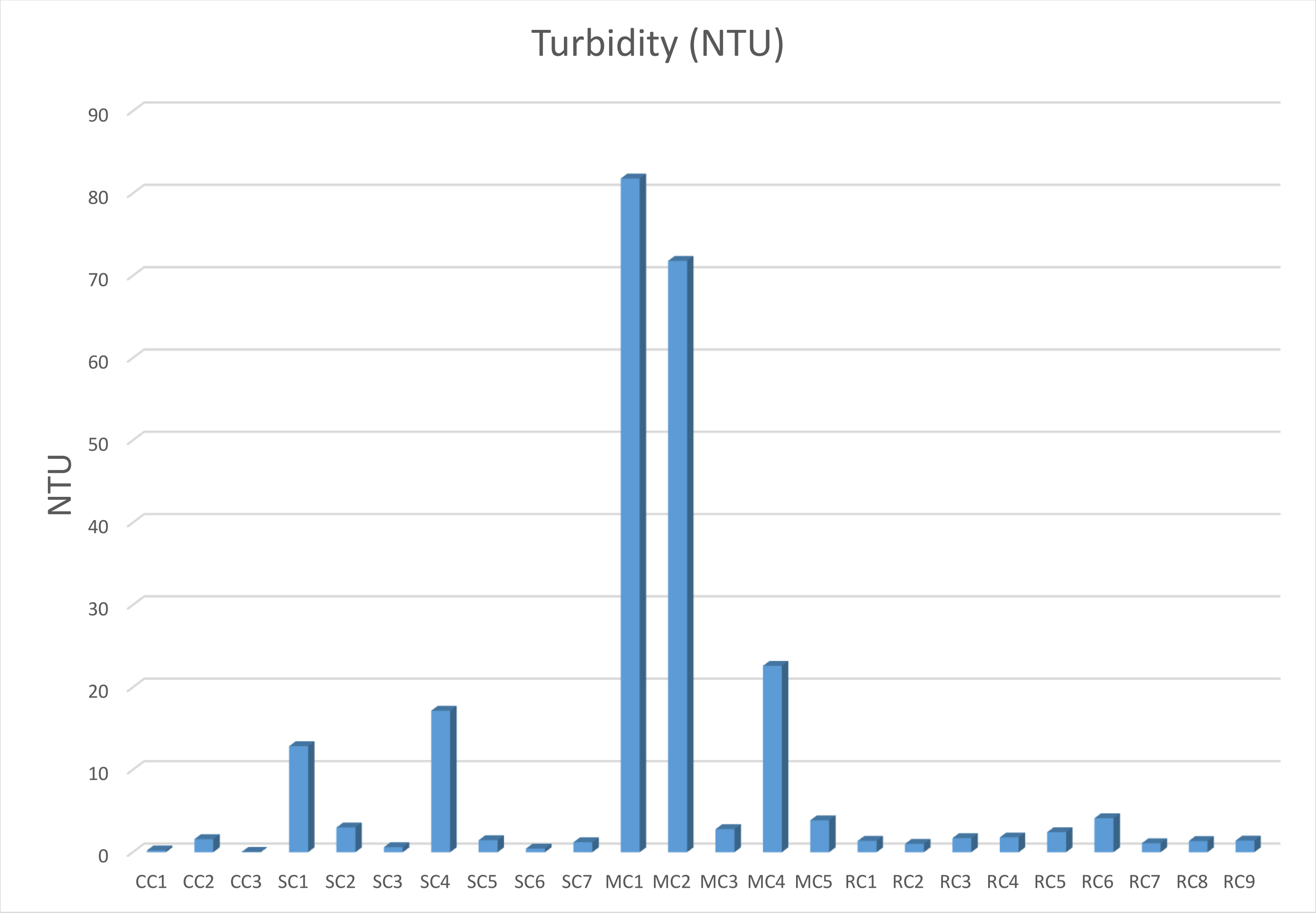


Figure 7.5 (continued)

Specific Conductivity was highest at poultry facilities and in Scott, Madison, and Rankin Counties ranging from 0.1 – 75 mS/cm at 25°C with an average conductivity of 0.40 mS/cm at 25°C (Fig. 7.6). The highest specific conductivity measured in the watershed was in Neshoba County (NC6) at 0.84 mS/cm at 25°C. Attala County had the highest average specific conductivity in the northern portion of the UPRW per county at 0.29 mS/cm at 25°C. The lowest specific conductivity was in the northeastern portion of the UPRW in Kemper, Winston, and Choctaw Counties ranging from 0.02 – 0.25 mS/cm at 25°C.

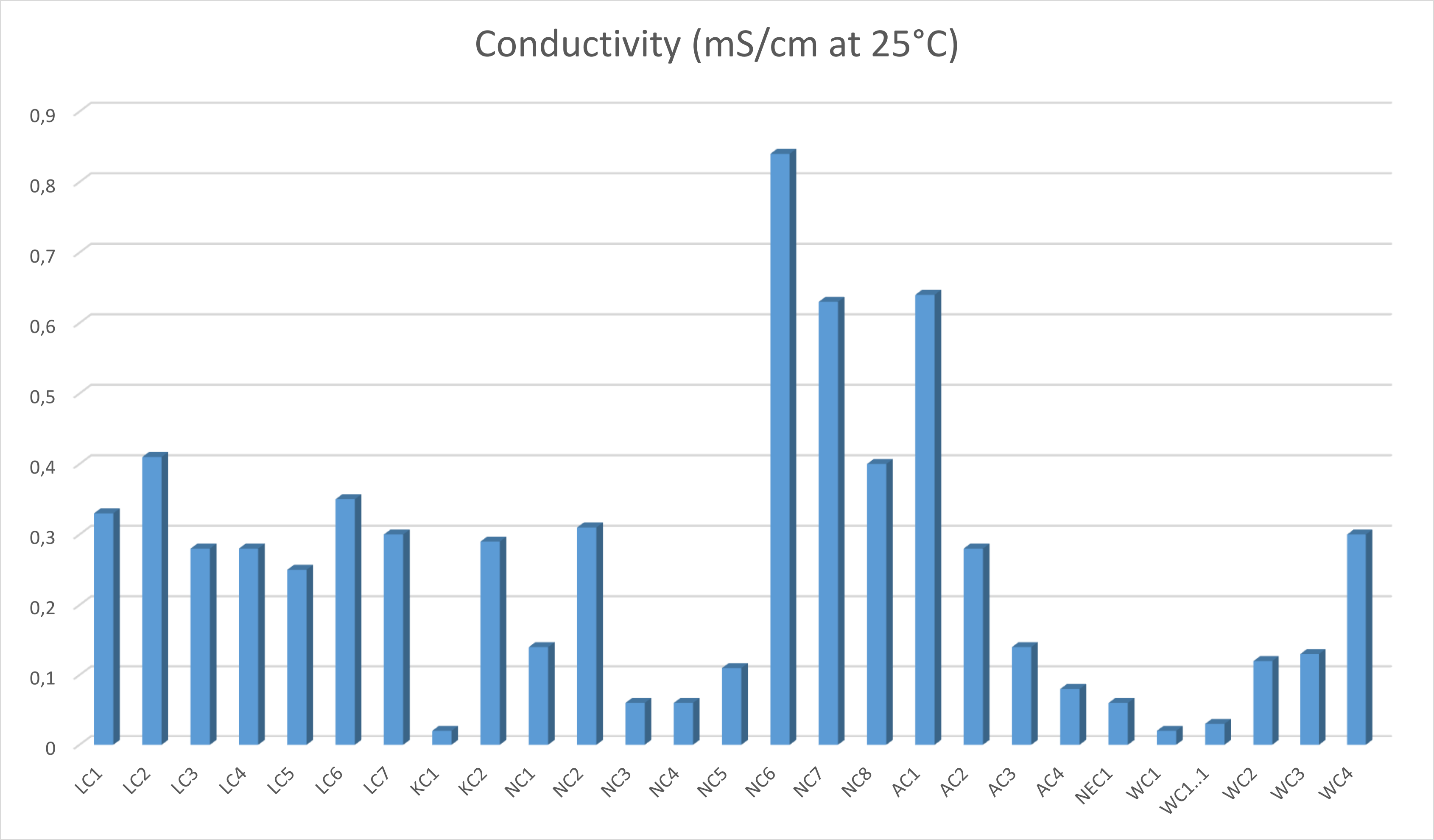


Figure 7.6 Specific Conductivity within the Upper Pearl River watershed.

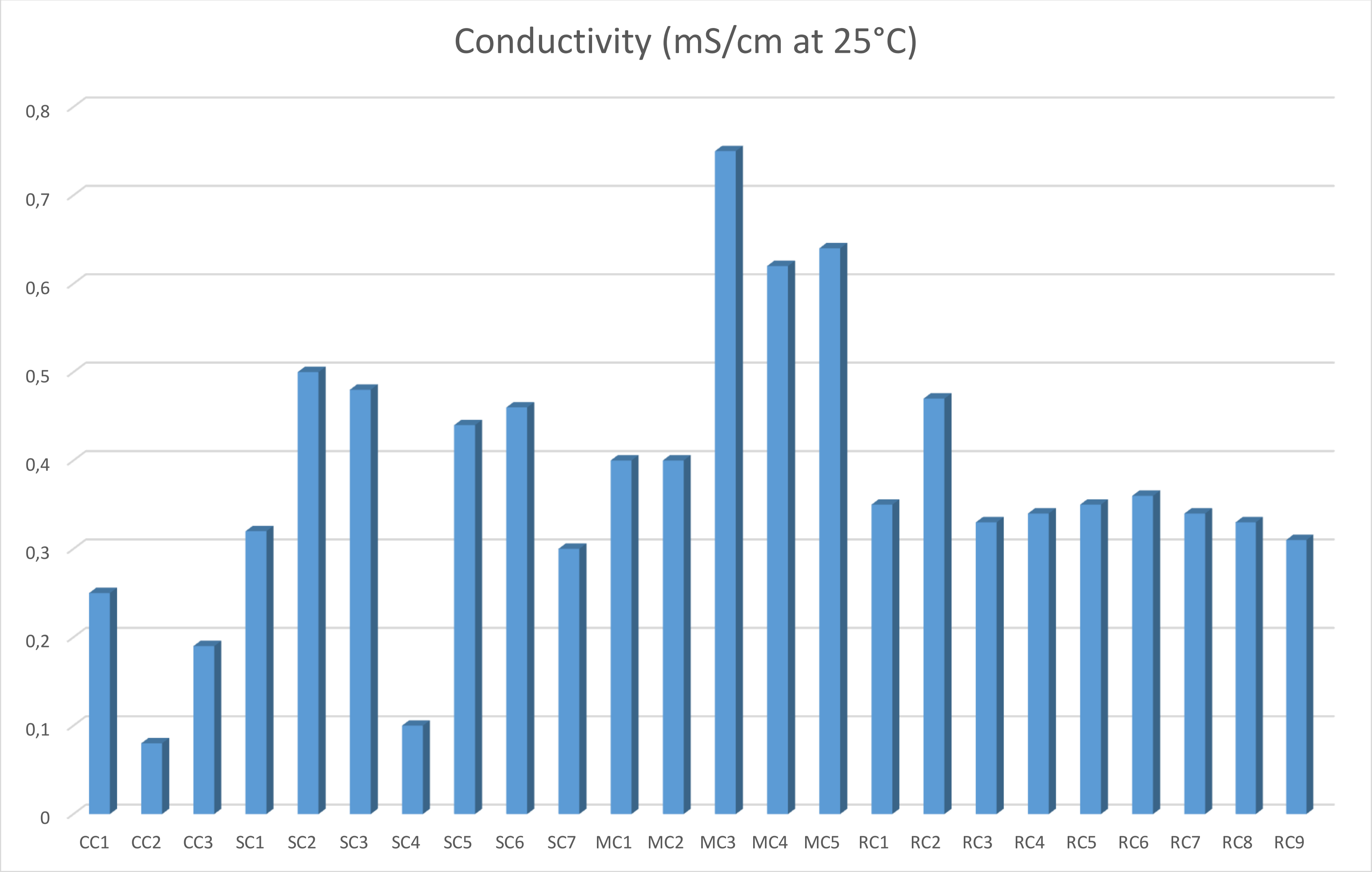


Figure 7.6 (continued)

7.2 Anion Results

Nitrate concentrations exceeded the EPA’s MCL of 10 mg/L in four of the sample sites ranging from 13.2 – 22 .0 mg/L (Fig. 7.7). Two of the five poultry facilities had nitrate concentrations above the MCL, the highest being 22 mg/L in Newton County, two others showed nitrate levels at 8.8 mg/L boarding the EPA’s MCL. Leake, Kemper, and Winston counties had the lowest nitrate concentrations in tested wells within 0.0 and 8.8 mg/L, all values below the MCL. Attala, Choctaw, Neshoba, Newton, Scott, Rankin, and Madison Counties had the highest nitrate concentrations usually at 4.4 mg/L and above to 22 mg/L.

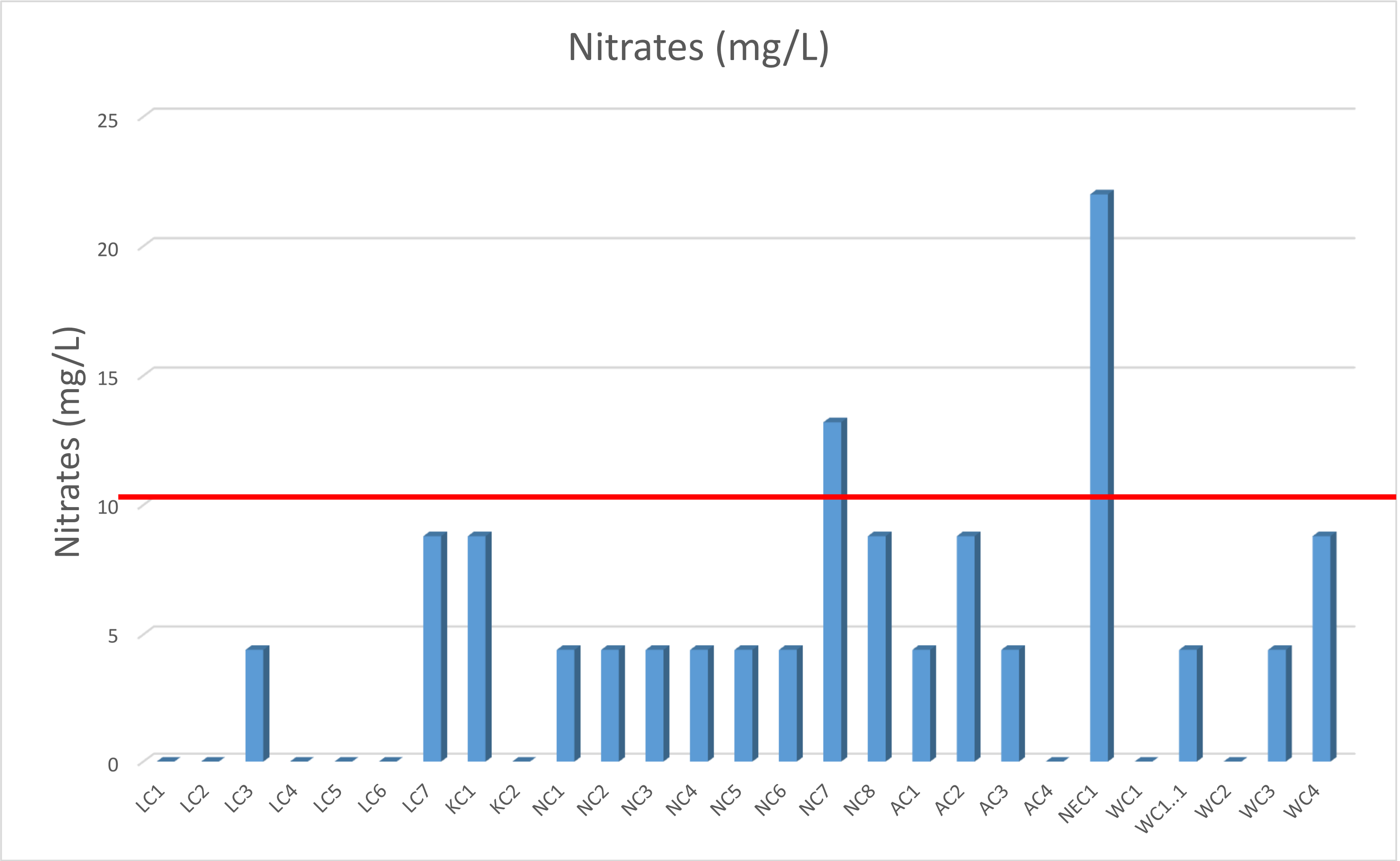


Figure 7.7 Nitrate levels within the UPRW. The red line indicates the EPA’s MCL for nitrates being 10mg/L.

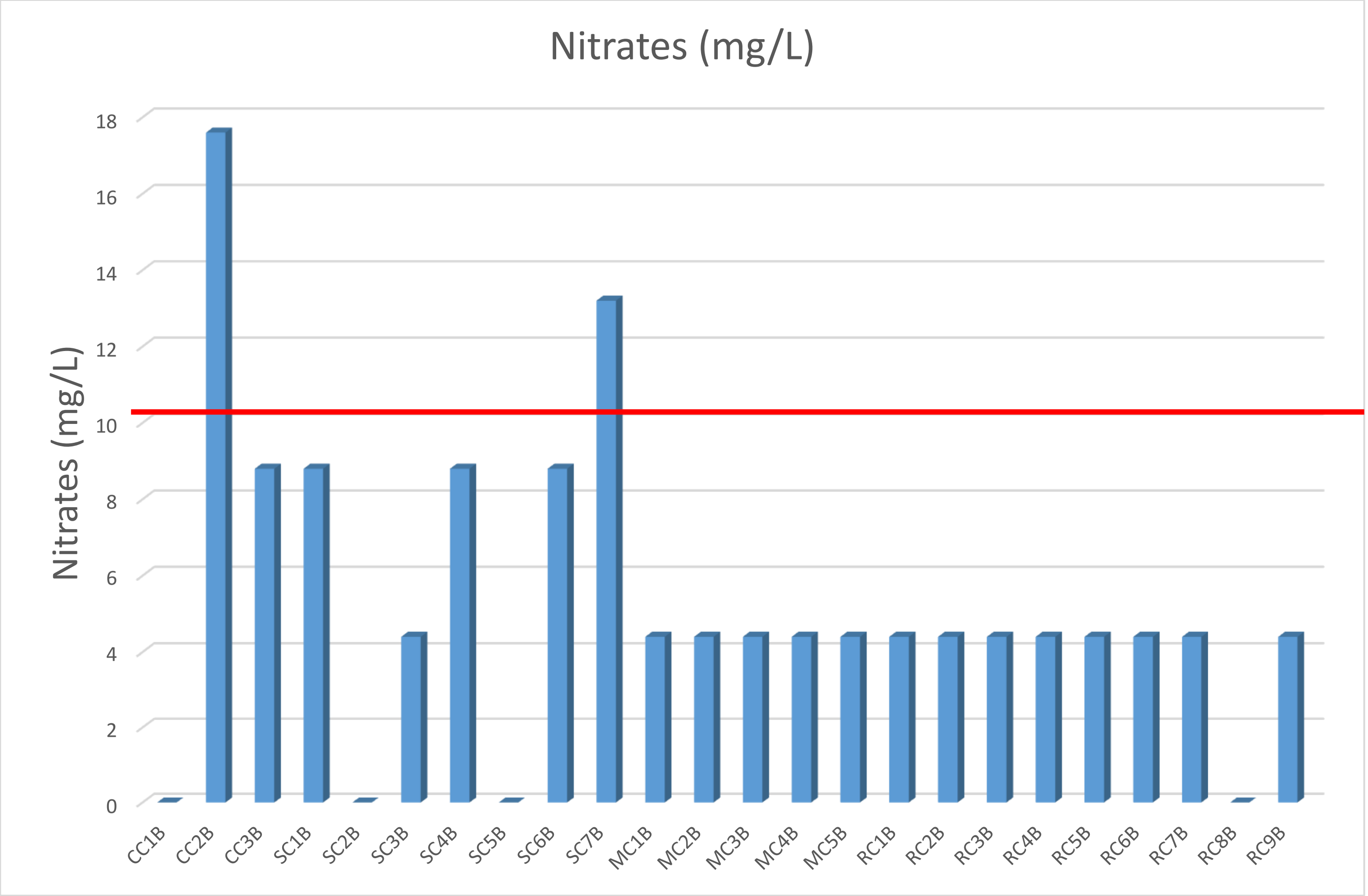


Figure 7.7 (continued)

Sulfate concentrations were below the EPA MCL of 250 mg/L in all wells tested throughout the UPRW (Fig. 7.8). Leake, Neshoba, Kemper, and Choctaw Counties had the highest sulfate concentrations ranging from 65 – 140 mg/L. Sulfate concentrations were lowest in Madison and Rankin Counties ranging 20 – 100 mg/L, counties closest to the reservoir (Appendix Fig. D.1). Phosphate concentrations ranged from 0 – 2 mg/L in the watershed, the mean being 0.6 mg/L. Phosphate concentrations were highest (averaging 0.9 mg/L) in Leake, Scott, Rankin, and Madison Counties, closest to the reservoir, a contrast to sulfate concentrations.

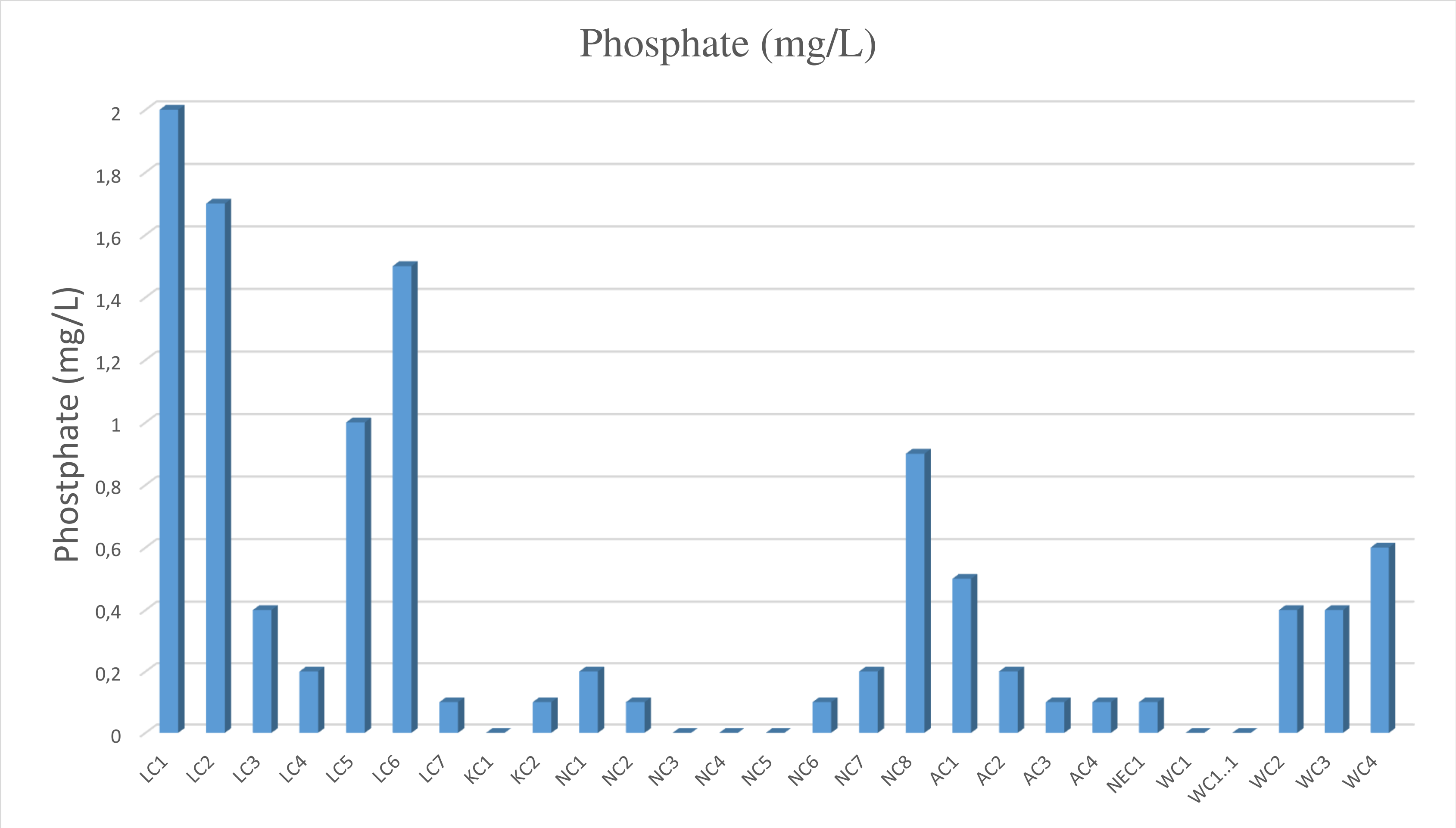


Figure 7.8 Phosphate concentrations within the UPRW.

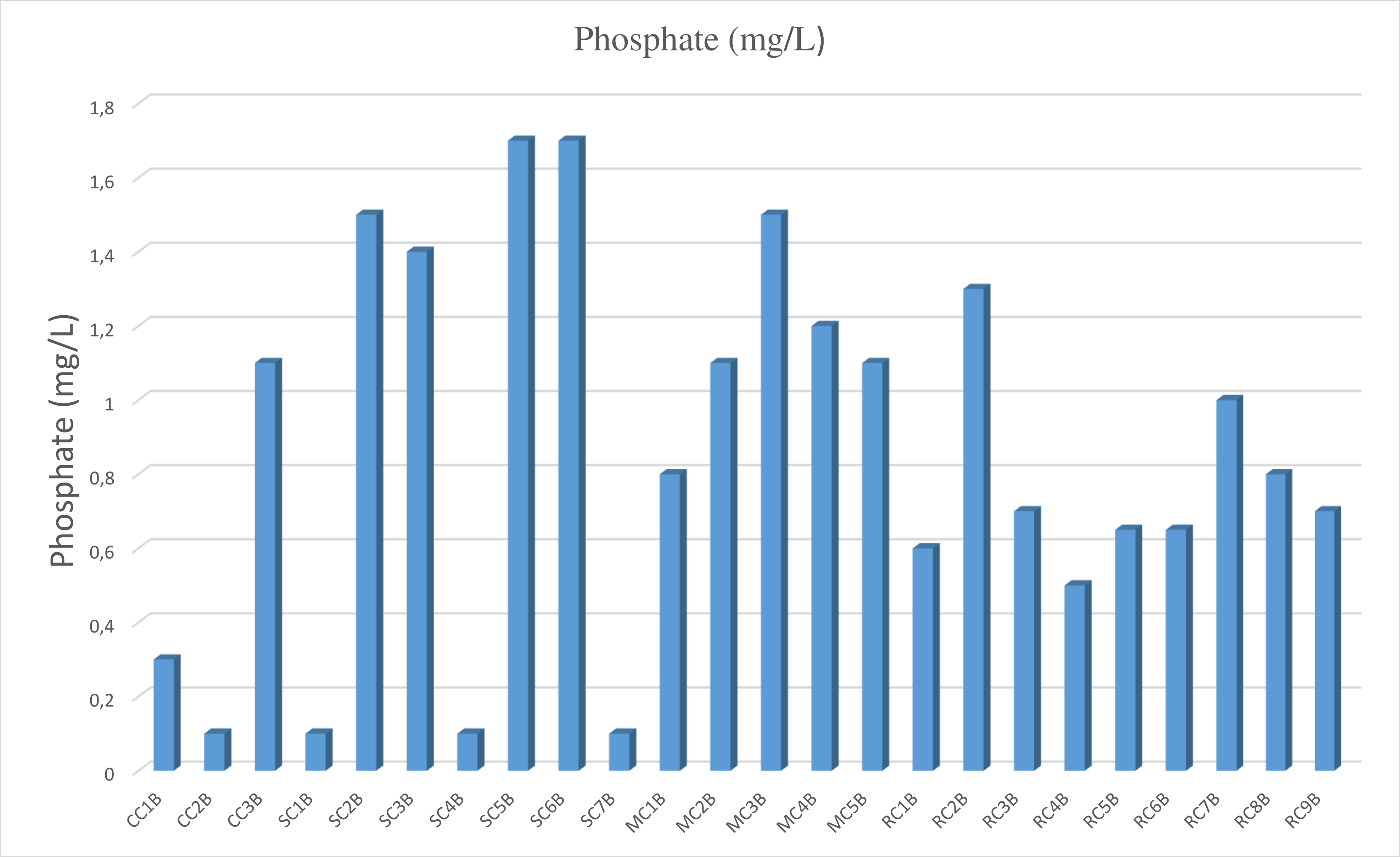


Figure 7.8 (continued)

Chloride concentrations exceeded the EPA MCL of 250 mg/L in all counties tested (Fig. 7.9). Throughout the watershed, mean chloride concentrations were at 342 mg/L. The highest chloride concentrations were in Scott, Madison, and Rankin Counties ranging from 200-500 mg/L, 500 mg/L being the highest concentration in all samples taken.

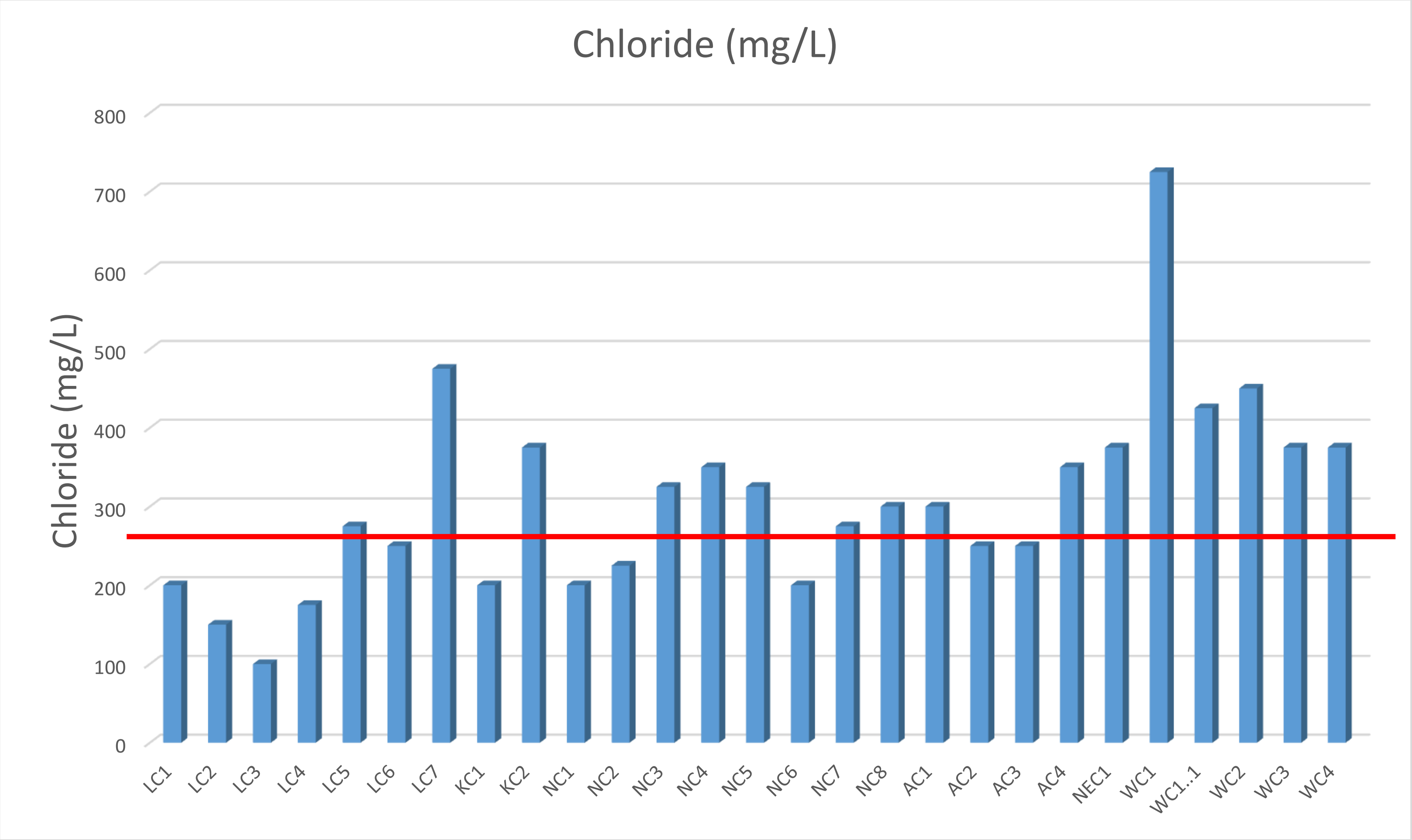


Figure 7.9 Chloride concentrations in the UPRW. The EPA MCL for chloride is 250mg/L; all values above the red line indicate groundwater chloride concentrations in excess of the EPA's drinking water standard.

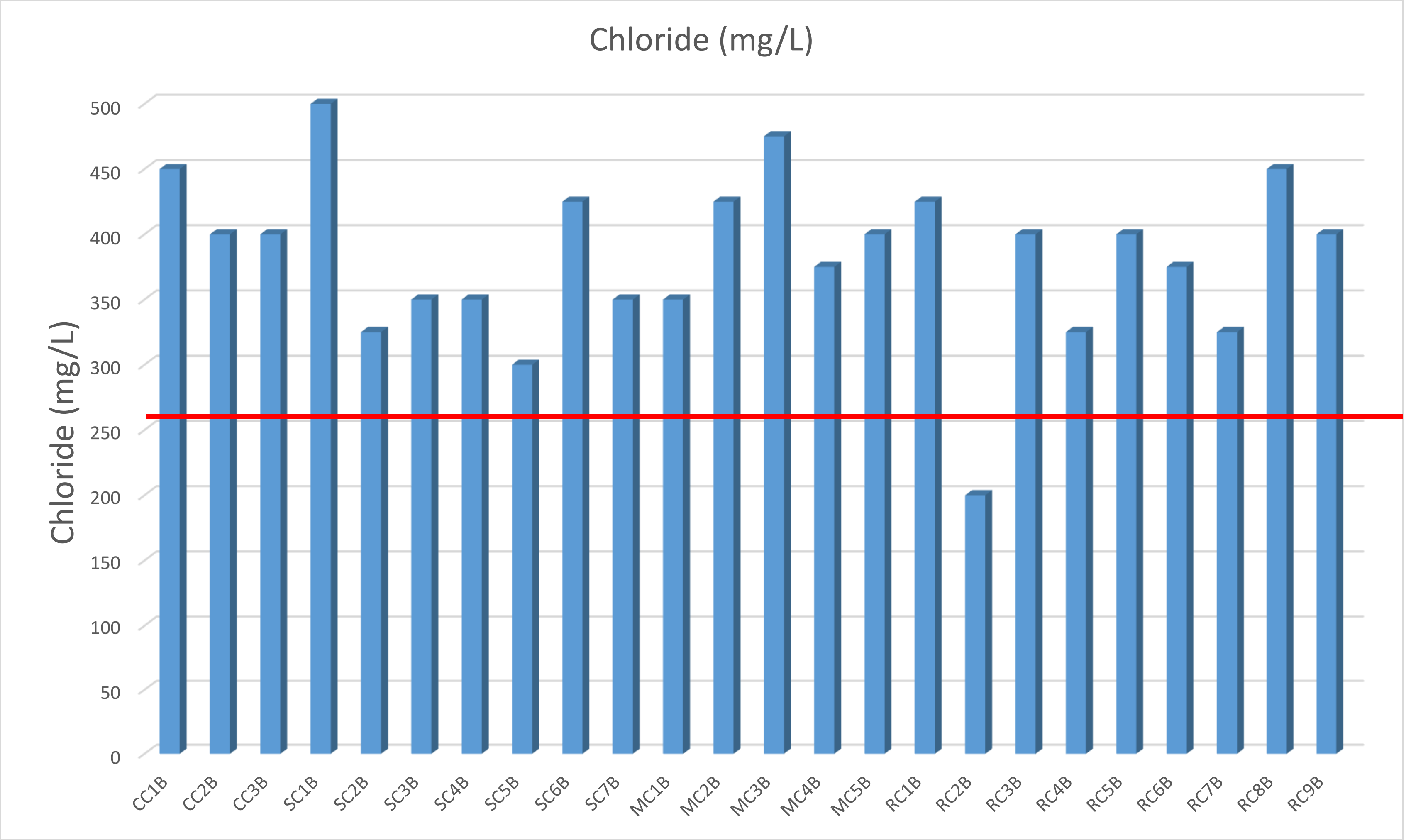


Figure 7.9 (continued)

7.3 Cation, Trace Element, and Pharmaceutical Results

Cation analysis, as determined by ICP-OES, tested for the following: Aluminum, iron, sodium, potassium, magnesium, calcium, manganese, and silicon. Sodium, potassium, magnesium, calcium, and silicon have no designated EPA MCL, so the ranges obtained will only defined. Aluminum, iron, and manganese are secondary MCLs and will be defined by their concentration exceeding the EPA allowable MCLs.

Sodium concentrations ranged 2.69 mg/L at a well in Kemper County (KC1) to 144.67 mg/L and beyond the highest measurable values of the machine's detection capabilities at > 150 mg/L (ppm); the highest values were in Scott, Rankin, and Madison Counties ranging from 4.39 mg/L to beyond the detection limits, the mean obtained value being 95.32 mg/L. Potassium in the watershed ranged from being 1 mg/L in Kemper County (KC1) to the highest concentration of 40.19 mg/L at the groundwater spring in Winston County (WC1). Manganese was absent in all wells tested for in Rankin County, however in other counties, manganese ranged from being absent to 7.44 mg/L (NC8), Neshoba County having the highest manganese concentrations per well than any other county. Calcium concentrations were lowest in Rankin and Madison Counties ranging from being absent to 1.28 mg/L. Calcium was highest in Attala County averaging at 23.45 mg/L, the highest concentration also in Attala County (AC1) at 40.04 mg/L. Other calcium concentrations in the watershed's counties varied between being absent to the highest concentration of observed, 40.04 mg/L at AC1. Silicon concentrations showed no particular pattern on the county level except being lowest in Leake County averaging 7.54 mg/L. Silicon concentrations from all other counties ranged between 1.83 – 28.07 mg/L at KC1 and AC3 respectively.

Aluminum concentrations did not exceed the MCL of 0.2 mg/L in any of the wells tested. Aluminum tests were positive in Leake, Attala, Choctaw, Scott, Rankin, and Madison Counties ranging from 0.01 – 0.039 mg/L, the later value from MC2 and RC9. Rankin and Madison County had the highest aluminum concentrations with all wells testing positive for aluminum with an average of 0.03 mg/L. In Kemper, Newton, and Winston Counties aluminum was absent.

Iron concentrations exceeded the MCL of 0.30 mg/L in wells of Kemper, Neshoba, Attala, Winston, Choctaw, and Scott Counties averaging 3.05 mg/L. Neshoba County had the highest concentration of iron at 8.74 mg/L (NC5). Leake, Newton, Rankin, and Madison Counties were absent of iron (Fig. 7.10).

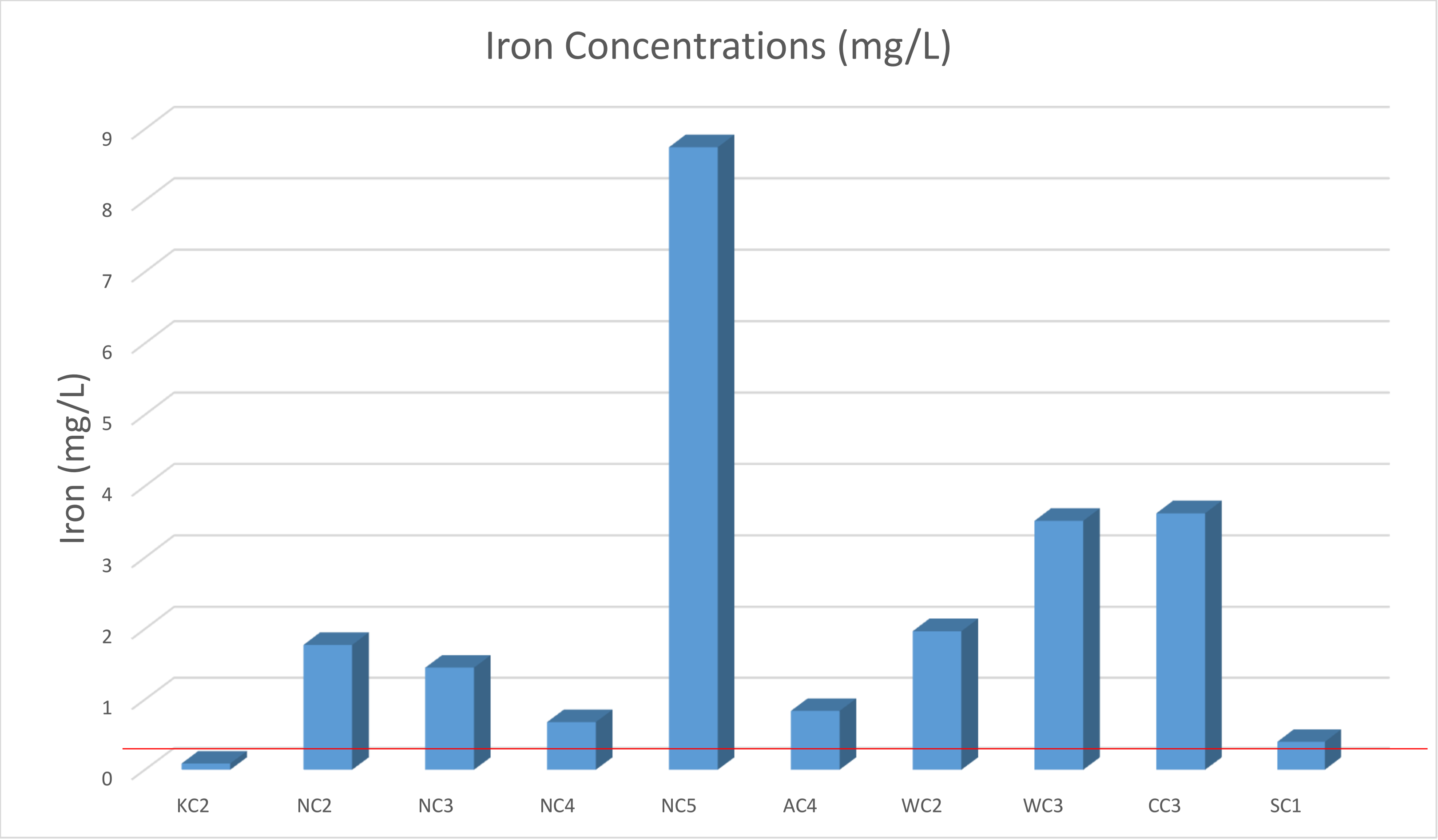


Figure 7.10 Iron concentrations in the watershed exceeding the MCL of 0.3 mg/L as indicated by the red line. All other samples were below the detection limit.

Manganese concentrations exceeded the MCL of 0.05 mg/L in all of Neshoba County's wells and one each in Kemper and Leake Counties (Fig. 7.11). In Winston County manganese tested positive but were below advisory levels. Choctaw, Scott, Rankin, and Madison counties were absent of manganese. AC1, AC2, WC1..1, WC2, and SC1 sample sites have no manganese value due to testing errors.

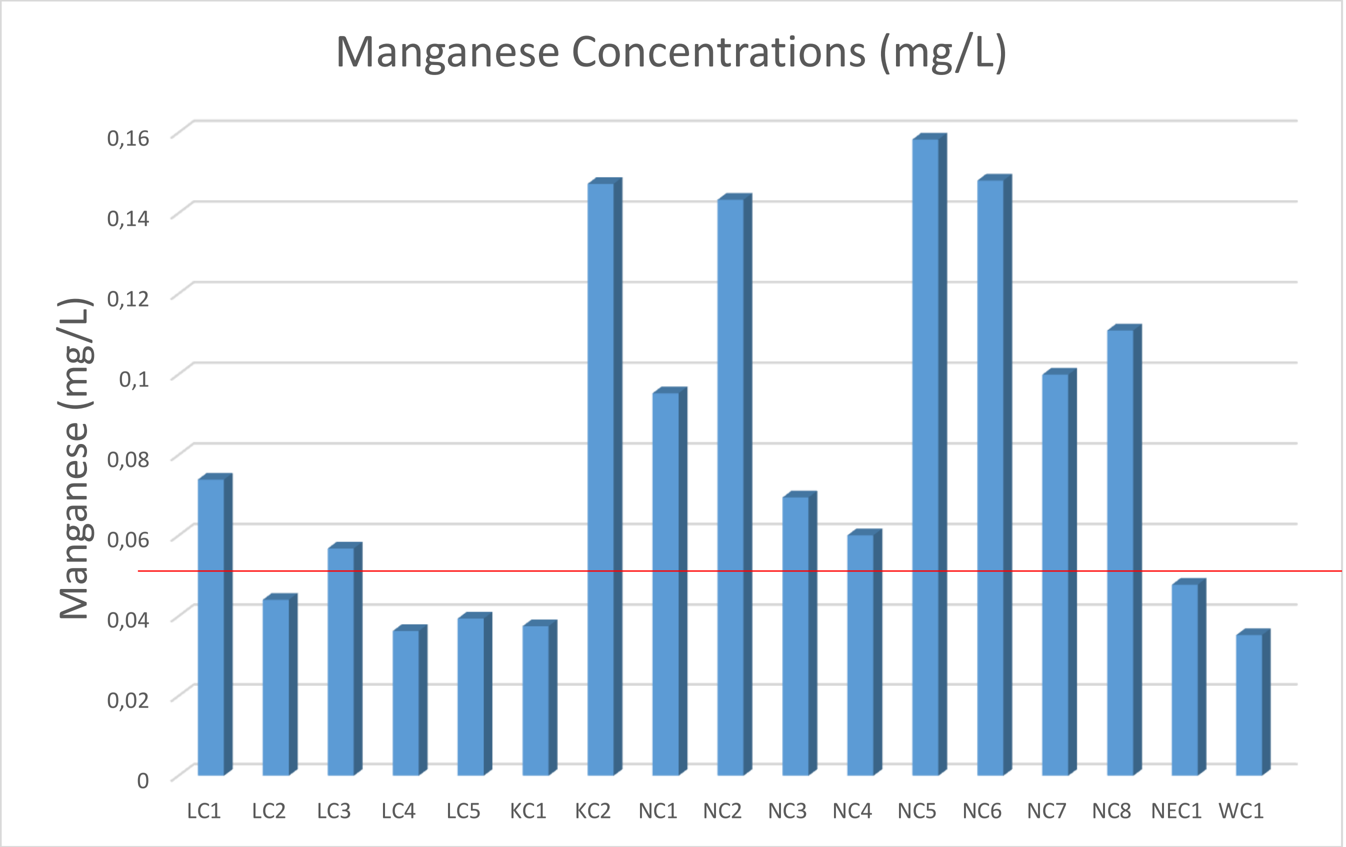


Figure 7.11 Manganese concentrations in the watershed exceeding the MCL of 0.05 mg/L as indicated by the red line. All other samples sites were below the MCL or either undetectable by the machine.

Trace element analysis was determined by both ICP-MS and ICP-OES. Samples LC1, LC2, LC3, LC4, LC5, LC6, LC7, KC1, KC2, NC1, NC2, NC3, NC4, NC5, NC6, NC7, NC8, AC1, AC2, WC1 were determined by ICP-MS, and all other samples were determined by ICP-OES. The detection limit of the ICP-MS was million counts per second for 1µg/L (Bruker 810/820 MS instruction manual), and that of ICP-OES was < 150 ppm, 100 ppm being the upper limit for all elements tested. Trace elements tested for were Arsenic, lead, chromium, phosphorus, cadmium, copper, mercury, zinc, and strontium; phosphorous and strontium being the only elements without a MCL designated by the EPA. Lead, chromium, cadmium, copper, and zinc, were all below their respective MCL of 0.015 mg/L, 0.1 mg/L, 1.3 mg/L, and 5 mg/L.

Arsenic exceeded the MCL of 0.01 mg/L in northern and southern portions of the watershed- Atalla, Winston, Choctaw, Scott, Rankin, and Madison Counties ranging from 0.02 – 0.06, MC1 having the highest concentration (Fig. 7.12). In the watershed's central portion, Leake and Neshoba Counties, arsenic was either below the MCL or absent. Arsenic was also absent in all Kemper and Newton County wells that were tested.

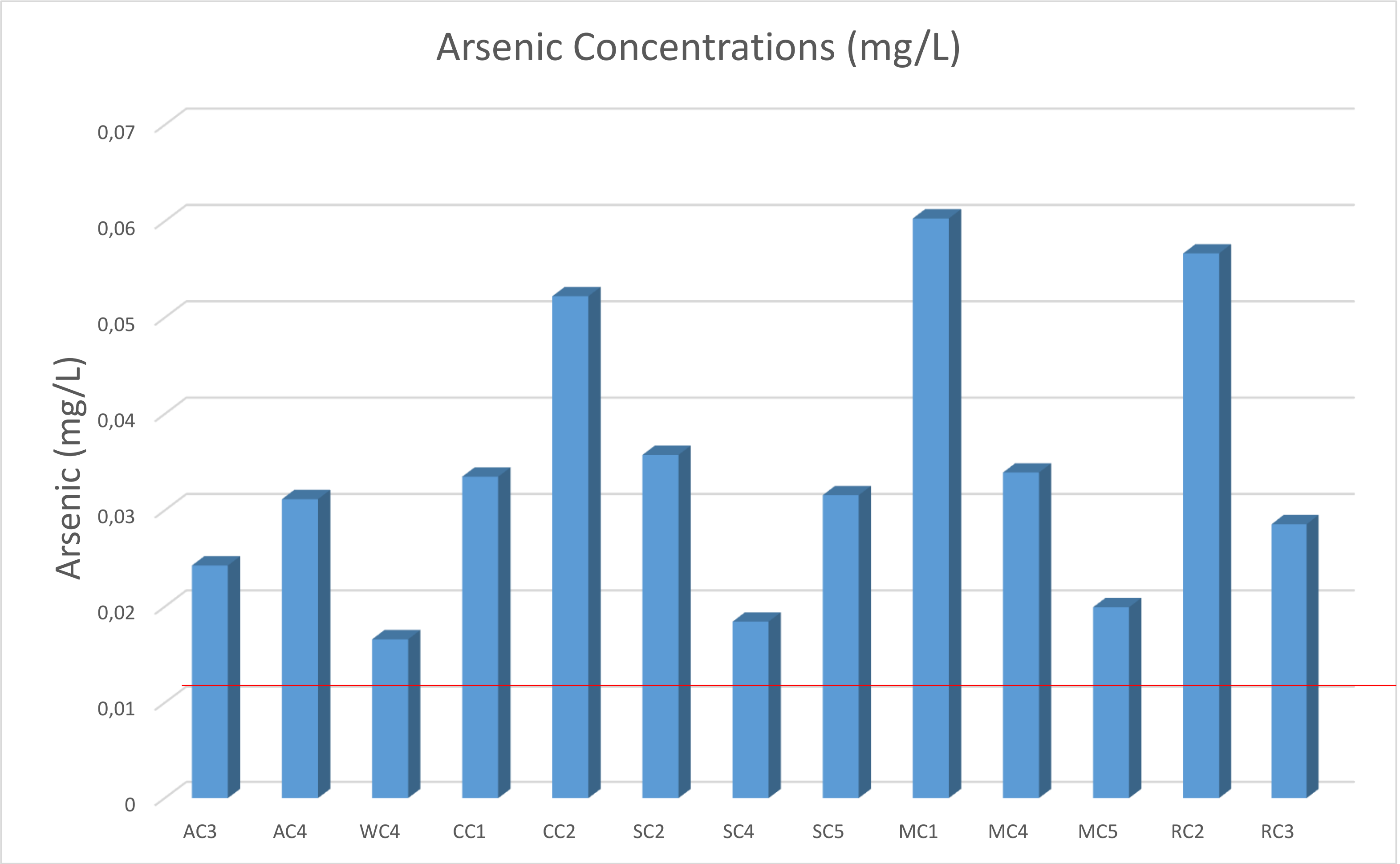


Figure 7.12 Arsenic concentrations within the watershed. All sample sites above the red line indicate they exceed the MCL of 0.01 mg/L. All other sample sites were below the MCL or either arsenic was undetectable by the machine.

Mercury concentrations exceeding the MCL of 0.002 mg/L were indicated in Winston, Leake, and Newton Counties ranging from 0.004 – 0.075 mg/L, the highest concentration located in Leake County at LC6 (Fig. 7.13). In Kemper, Neshoba, and Attala Counties, mercury was below the MCL the highest concentration being 0.0001 mg/L at KC2. Mercury was tested to be absent in Choctaw, Scott, Rankin, and Madison Counties, the closest counties to the RBR.

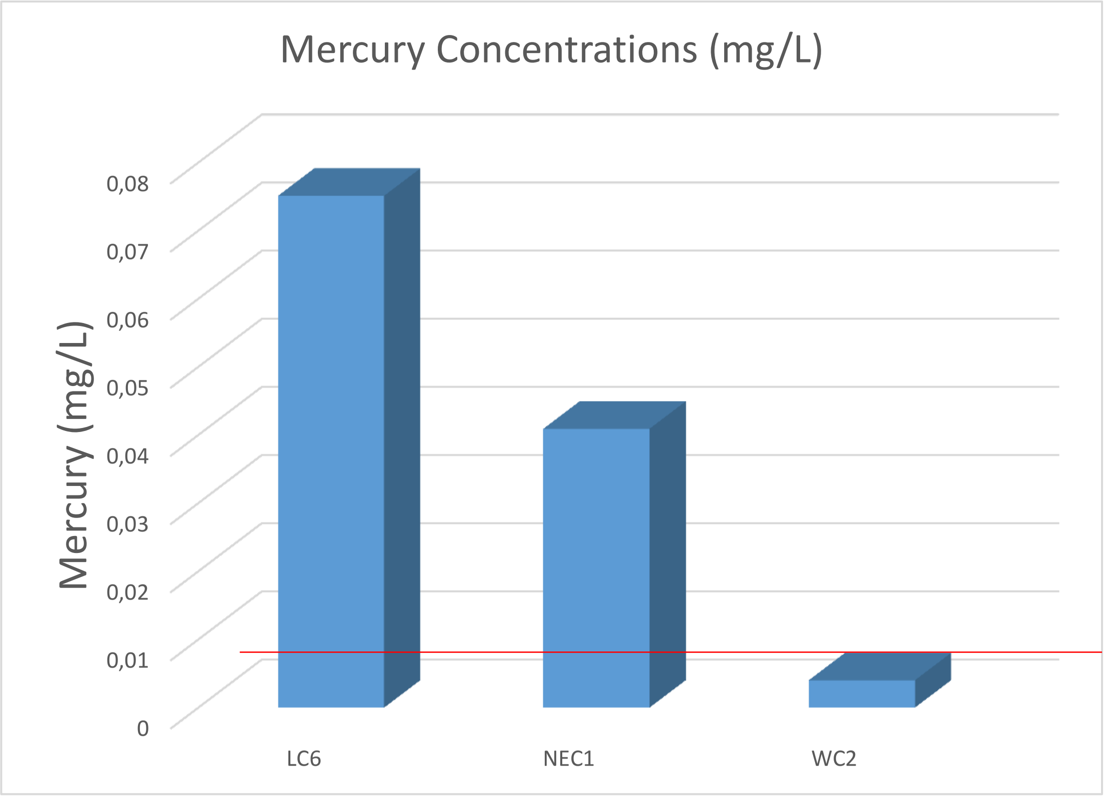


Figure 7.13 Mercury concentrations in the watershed indicating three samples sites, Leake, Newton, and Winston Counties groundwaters exceeded the MCL of 0.002 mg/L as noted by the red line. All other sample sites were below the MCL or mercury was undetectable by the machine.

Pharmaceutical and toxicology results of Carthage (LC5) and Philadelphia's (NC1) groundwater well's closest to their respective hospitals indicated none of the toxic organic compounds that can be detected by GC-MS screening were present in either sample. The GC-MS screen also revealed that the water samples were free from any type of drugs, pesticides, or industrial chemical residues (Appendix D5).

CHAPTER VIII

DISCUSSION

8.1 Hydrogeochemical and Anion Characteristics of the Upper Pearl River Watershed

The notably low pH in Kemper, Neshoba, Attala, and Winston Counties (Fig. 7.1) is likely due to a low total alkalinity as calcium carbonate, the topsoil being naturally slightly acidic, and high humic acid concentrations produced by decaying vegetation around the heavily-forested headwaters (Fig. 6.4). Total alkalinity was lower in these counties ranging from 3 - 141 mg/L. Higher calcium carbonate concentrations are exhibited in the northern portion of the watershed while also having the lowest sodium concentrations.

Other factors causing pH variations in the watershed are lower total hardness concentrations on average of 10 mg/L as determined by total hardness (Fig. 7.3), and higher sodium bicarbonate ion concentrations (Appendix D, table D.1 and D.2) in southern portions of the watershed (Scott, Madison, and Rankin County) causing slightly alkaline waters and pH to be above 7.0. The higher sodium concentrations ranging from 76 – 145 mg/L are due to pre-existing shallow-sea sodium deposits remaining in the Sparta and Cockfield aquifers (Crider and Johnson, 1906). USGS well logging also shows saline waters in deeper aquifers like the Wilcox and Winona Sand in Rankin, Madison, and Scott Counties (Oakley, 1984). Carbonaceous clays and fossils found in the Claiborne Group, especially in the Cockfield and Cook Mountain Formations, along with the high sodium concentrations contribute to the groundwater becoming a sodium-bicarbonate type in the southern portion.

Alkalinity values increase in the RBR area as sodium concentrations increase, and the water becomes sodium-bicarbonate dominated in the Cockfield and Sparta aquifers (Oakley, 1984). Total hardness is highest (from 3.9 to 134 mg/L, averaging 47 mg/L) in the upper portion of the watershed’s counties (Kemper, Attala, Neshoba, Leake, Winston, and Choctaw Counties) due to higher calcium and magnesium concentrations. The highest value of 147 mg/L being at northwestern most portion of Leake County. Previous geochemical analyses of the RBR area showed sodium increases, hardness decreases, and water becoming a sodium-bicarbonate type as aquifers deepen downdip (Oakley, 1984). This coincides with the current observations as shown in the results table (Appendix D, table D.1 and D.2).

Hardness in the southern portion of the UPRW decreases with corresponding sodium concentrations, especially in the Cockfield and Sparta Aquifers. This is not a consequence of exchanges with recharge water from the Pearl River or precipitation on exposed outcrops but is consistent with cation exchange reactions that naturally occur in the groundwaters during movement southwestward through the Kosciusko, Zilpha, and Cook Mountain clays, which possess water-softening properties observed in previous studies (Oakley, 1984). Further studies need to be conducted on the hydrogeology of this particular region to understand recharge effects in the Cockfield and Sparta Aquifers in the lower UPRW.

Redox potential (Eh) was highest where nitrate levels were highest (Appendix D, table D.1), especially at poultry facilities. For example, NC7 and NEC1, both poultry facilities, had an Eh of +204 mV and +350 mV and nitrate concentrations at 13.2 mg/L and 22 mg/L respectively, the highest nitrate levels observed in the watershed. This relationship between nitrate accumulation and increasing Eh value is due to nitrate being transformed in already nitrate-saturated soil to an increasing redox potential (Bailey and Beauchamp, 1971; Meek *et al.*, 1969; Patrick, 1960; Pearsall and Mortimer, 1939). When oxygen is the dominant electron acceptor, nitrate accumulation occurs. Reversely, denitrification is associated with decreasing Eh values as observed in the results where nitrate concentrations are absent, Eh is comparatively low or at negative value (Bailey and Beauchamp, 1973). In Madison and Rankin Counties, the water was more oxidizing, while in the northern ¾ of the watershed: Leake, Kemper, Neshoba, Newton, Winston, Choctaw, and Scott Counties, the water was generally more reducing. Most notable is the extreme Eh value of +649 mV in LC1. This value was not due to high nitrate concentrations or any other obvious measurements taken; the assumption is that the groundwater pumped had been resting outside of the main aquifer in metal pipes exposed to the outside atmosphere for quite some time, gathering oxygen ions before reaching the tap.

Turbidity was naturally lowest in the headwaters of the UPRW in Kemper, Winston, Choctaw, and Attala Counties generally being less than 1.0 NTU. Turbidity increased dramatically in groundwaters at and around poultry facilities due to poultry fecal matter runoff and infiltration into the soils. In Neshoba County, turbidity increased significantly from 0.12 – 60.7 NTU; this was likely due to local timber harvesting and clear-cutting. Direct communique with Mr. Leon Johnson, a local logging trucker in the northern portion of the watershed also attested to the logical results, citing daily logging routes to and from lumber yards. Clear-cutting and timber harvesting are the main source of revenue within the watershed (Khanal et al., 2013; MDEQ, 2009). These sites are also indicative of areas with high sedimentation rates within the UPRW. The City of Madison had the most turbid groundwaters at 81.8 NTU. As groundwater wells in Scott, Rankin, and Madison Counties are deeper, turbidity increased indicating the Cockfield and Sparta Aquifers waters are highly mineralized in deep groundwaters. Overall, groundwater turbidity gradually increased as the UPR drained southwestward into the RBR and groundwater wells deepened, delivering sediments from clear-cutting and timber-harvesting sites and poultry activities.

Specific Conductivity was highest in Scott, Madison, and Rankin Counties (ranging from 0.1 – 75 mS/cm at 25°C) as sodium concentrations and alkalinity increased in the Sparta and Cockfield aquifers. As sodium and chloride concentrations increase in groundwaters of the southern portion of the UPRW due to dissociations of ions, the electrical conductivity correspondingly increases (Appendix D, table D.1). A high total alkalinity allows for these ions to essentially build-up without ever drastically affecting the overall local groundwater geochemistry in the aquifer. Such a trend coincided with an almost steady pH throughout the three Counties with fluctuating concentrations of tested hydrogeochemical parameters.

Groundwater becomes more saline in the lower portions of the UPRW (Scott, Rank, and Madison Counties) as residual Cretaceous Seaway oceanic waters remain in the Sparta and Cockfield aquifers as determined by Oakley (1984) via geophysical logging in the RBR region (Cushing *et al.,* 1964). In the central portion of the watershed, Leake County sodium concentrations are somewhat higher than the adjacent county of

Neshoba (Appendix D, table D.1 and table D.2). The geology of southern Leake County is carbonaceous and sandy in the Kosciusko Formation and clayey in the Zilpha/Winona Formation towards the north. Sodium in the Sparta Aquifer of Leake County (including residual salt left by the Cretaceous shallow sea) forms a sodium-bicarbonate type groundwater (as determined by Oakley, 1984) as the water flows by inter- and baseflow into the RBR.

Nitrate levels were highest in the central and southern portions of the UPRW- southern Leake, Neshoba, Scott, Rankin, and Madison Counties (Fig. 7.5). Comparing with the land use and land cover map (Fig.6.3), the highest nitrate levels were in pastures and cultivated croplands that dominate the landscape of these counties and northeastern portions of Rankin and Madison Counties. In both Scott and Newton Counties, poultry is the dominating livestock. The large rearing and egg-laying facilities have high nitrate concentrations indicative of avian fecal matter (MDEQ, 2009). The land use map illustrates the most common sources of nitrates in the UPRW would include agricultural fertilizer runoff and sewage from poultry industries and local farms cultivating crops and rearing livestock. Notably Leake, Neshoba, Scott, Rankin, and Madison configure the south and central portions of the UPR flowing into the RBR; these counties are closest to the RBR. Nitrogen is an essential nutrient for all aquatic plants and animals, however, excess concentrations of nitrogen and nitrate in surface waters can cause harmful algal blooms (HABs) and eutrophication, ensuring water quality degradation (Dash *et al.,* 2015; Paerl *et al.,* 2001).

Sulfate concentrations were all below the MCL of 250 mg/L in all groundwater wells sampled. In Kemper, Leake, and Choctaw Counties sulfate concentrations were the highest averaging 107 mg/L, far above other counties whose sulfate concentrations ranged from 20 – 160 mg/L and averaged 69 mg/L. Kemper and Leake Counties are dominated by agricultural hay and pasture lands as observed in the land use map (Fig. 6.4), indicating higher sulfate concentrations in the watershed are a product of livestock and agriculture runoff and fertilizers (Sharpley *et al.,* 1990). As Choctaw County is dominated by forest, the likely source for high sulfate concentrations are microbial organisms in the soil producing it as a bi-product of metabolic respiration (Kertesz and Mirleau, 2004). Rankin and Madison Counties sulfate concentrations averaged 39 mg/L, the lowest of all counties. Since these two counties are the most developed and densely populated in the watershed, livestock and forested areas are not as prolific as in the central and northern portions of the watershed, ergo decreasing microbial respiration in the highly urban-developed soils, and in turn decreasing sulfur/sulfate concentrations.

Phosphate is highest in Leake, Scott, Rankin, and Madison Counties. Based on the land use map this is likely due to agricultural runoff from feed lots and fertilized fields, including sewage from poultry facilities and farms that contains total phosphorous as a bi-product of livestock rearing. Phosphorous is essential for metabolic reactions of plants and animals; a measure of total phosphate gives an estimate of the amount of phosphorous potentially available to the plants and animals (MacKintosh, 1990). Rapid algal growth arises when excess phosphorous is present in streams and surface waters resulting in HAB’s that can lead to eutrophication and consequent water quality degradation (Dash *et al.,* 2015; MacKintosh, 1990). Eutrophication is a huge ongoing problem in the RBR as this is Jackson’s surface drinking water supply and the region’s primary recreational and designated fishing area (Dash *et al.,* 2015; MDEQ, 2009).

Chloride concentrations increase along with sodium concentrations moving from the UPR headwaters to the RBR region, the highest of both sodium and chloride being in the RBR area. This would suggest that sodium chloride salts are being readily dissociated in the groundwater due to free available sodium ions and natural chloride-containing-minerals from residual marine waters; the main source of chloride ions being from sodium and chlorine dissociation in sea water which naturally contains both elements' ions in high concentrations. Another contributing factor to high chloride concentrations is the low total hardness values. A large amount of readily available chloride ions exhausts calcium ions. Thusly a decrease in calcium concentrations likely are reflective of higher chloride concentrations.

8.2 Cation, Trace Element, and Pharmaceutical Characteristics of the Upper Pearl River Watershed

Cation analysis indicated that aluminum, iron, and manganese were above their respective secondary MCL of 0.2 mg/L, 0.3 mg/L, and 0.05 mg/L. Sample sites in Scott, Rankin, and Madison Counties indicated the presence of aluminum at low concentrations due to the shrink-swell rate of the underlying highly expandable Yazoo (Clay) Formation in the Jackson Group, and clay's natural affinity to incorporate aluminum into its expandable matrix. As clay's composition is usually composed of minerals that have high aluminum, like micas, this observation is normal. When sampling in the town of Lena (LC7), the well owner mentioned that during heavy precipitation events his groundwater wells would test high for aluminum and iron, much higher concentrations than when arid or low precipitation conditions existed. LC7 is at the southwestern most portion of Leake County that was sampled and closest to Scott, Rankin, and Madison Counties, the

Counties where aluminum where also indicated below MCLs, further indicating the regional influence of Yazoo Clay.

KC2, NC2 – NC5, WC2 and WC3, and CC3 iron concentrations exceeded the MCL of 0.3 mg/L. All these sample sites are in the Wilcox Group, with Neshoba County having the highest concentrations. The Wilcox is composed of shaley clays, sandy clays, and irregularly cross-bedded sands and sandy clays which account for the high iron concentration seen in this area's specific iron-rich clayey geology compared with other geology in the watershed. The Yazoo and Zilpha Formation's clays, as seen in SC1 and AC4, also exhibited high iron (Fig. 6.3). This is most apparent when comparing aluminum, iron, magnesium, and manganese concentrations as these heavy metals are highest in the Counties (Kemper, Winston, Choctaw, Attala, Neshoba, Scott, Rankin, and Madison) with clayey surface geology.

Manganese concentrations were highest in groundwater wells of Kemper, Neshoba, and northern portions of Leake Counties exceeding the MCL of 0.05 mg/L. Kemper and western portions of Neshoba (NC3, NC4, NC7) are in the Wilcox Group which has beds of clays in the upper division confining the water below to form artesian basins. These clay-confining-layers are indicative of containing and exchanging heavy metals like aluminum, iron, and magnesium as exhibited in the results and discussion, in higher concentrations than others sampled regionally. The Nanafalia Formation, at the basal Wilcox, has kaolinitic clays and bauxitic minerals spread throughout with local deposits occurring. Extremely high regional concentrations of these heavy metals are found in the groundwaters of these local ferromagnesian silicate deposits within the Nanafalia. Ferromagnesian silicate presence in the Wilcox and Jackson Formations is obvious as the highest silicon concentrations also correspond with the highest heavy metal concentrations throughout the watershed.

Northern Leake County (LC1) is in the Zilpha/Winona Formations. The Zilpha's composition of glauconitic and carbonaceous clays explains why manganese, commonly found in clays, was highest at LC3. In other well tested in Leake County, manganese concentrations were low or non-existent in the sands of the Kosciusko and Cook Mountain Formations. Central and northwestern Neshoba County wells (NC1, NC2, NC7, NC8) are in the Tallahatta/Neshoba Formation which is dominated by glauconitic claystone and clay with intermixed sand and sandstone lenses. The geology of the Tallahatta/Neshoba can be compared to that of the Zilpha/Winona Formations' geology. Manganese (and other heavy metals) seems to be a major element in the composition of the clay's matrix.

NEC1 and WC1 had manganese concentrations below the MCL. The trace manganese concentrations observed are indicative of the composition and characteristics of the clayey geology of the Wilcox Group and the Jackson Group's expandable Yazoo Clay Formation where these wells are located. Choctaw, Scott, Rankin, and Madison Counties were absent of manganese indicating the clays of the Wilcox and Jackson Groups are filtering out the small amounts of manganese present elsewhere. The Zilpha Formation's clays seem to be a barrier for groundwater inter- and baseflow between the UPR's northern and southern regions, as manganese in non-existent in counites south of the Zilpha Formation.

Silicon concentrations were highest where aluminum, iron, magnesium, and manganese concentrations were highest. The correlation shows that ferromagnesian silicates are prevalent throughout the watershed, especially in clayey surface geology. In scenarios where clay is the dominant strata in which the groundwater well was dug and constructed, silicon, aluminum, iron, magnesium, and manganese concentrations will be higher in that groundwater than their surrounding counterpart wells dugs in non-clayey stratum as indicated in the results table (Appendix D, table D.2).

Other cations detected were potassium, magnesium, and calcium which do not have current MCL designated by the EPA. These cations will be described based on concentrations levels and their absences with regards to geology and land use interpretations encompassing the watershed.

Potassium concentrations throughout the watershed were indicative of the glauconitic geology prevailing in most of the units (below 5 mg/L). In WC1, the only groundwater spring tested, however, potassium was tested at 40.19 mg/L. The assumption is that potassium concentrations are highest here since the spring was the shallowest groundwater tested and closest to the vadose (unsaturated) zone where biological activity occurs at the surface and in the soils. The land use map shows that WC1 is in the heavily forested, sparsely populated headwaters of the UPRW; decomposing leaf-litter, which forms the over-burden of the groundwater spring's outcrop, is the likely culprit for high potassium concentrations as organisms release this salt in their excrement.

Magnesium was present in Kemper, Choctaw, Attala, and Neshoba Counties due to the Wilcox Group's composition of magnesium containing minerals incorporated into the clay's matrix. Notably, in the southern portion of the watershed (Newton, Scott, Rankin, and Madison Counties), where Yazoo clay is located, the trend is not there for the clay to contain/retain much magnesium as has exhibited with other heavy metals like aluminum. Calcium concentrations are highest were magnesium concentrations are highest in the central and northern portions of the watershed. This is understandable as groundwaters were tested to be mostly hard (> 60 mg/L $CaCO_3$) in the northern and central portions, and soft in the southern portions (Scott, Rankin, and Madison Counties).

Trace elements that were above the EPA MCL were arsenic and mercury; other trace elements tested, lead, chromium, cadmium, copper, and zinc were below their respective MCL of 0.015 mg/L, 0.1 mg/L, 0.005 mg/L, 1.3 mg/L, and 5 mg/L. Phosphorous and strontium do not have MCL designated by the EPA; both being below 1 mg/L throughout the UPRW.

Arsenic concentrations were above the MCL in Attala County, Winston, Choctaw, Scott, Rankin, and Madison Counties (AC3, AC4, WC4, CC1, CC2, SC2, SC3, SC5, MC1, MC4, MC5, RC2, RC3); at the headwaters of the UPRW and the southern-most portion at and around the RBR. These locations are in the Zilpha Clay (AC3, AC4), Wilcox Group (WC4, CC1, CC2), and Jackson Group (SC5, MC1, MC4, MC5, RC2, RC3); all strata dominated by clay. The results indicate, from the geologic and land use map (Figs. 6.3 and 6.4), that arsenic is coming from local towns and cities (probably from leaking dump sites or uncontrolled pollution) and being stored and released in the clays of these surface geology units. The highest concentrations of arsenic (0.06 mg/L at RC2 and MC1) were closest to the RBR in Rankin and Madison Counties where the expandable Yazoo clay (having a shrink-swell percentage of up to 200%) is dominant (Dockery and Thompson, 2016).

Mercury concentrations exceeded the MCL of 0.002 mg/L at LC6, NEC1, and WC2. Comparing with the land use map (Fig. 6.4), LC6 is a small town (Walnut Grove), and WC2 is the City of Louisville, the third largest city in the watershed (USCB, 2000). This indicates mercury is being released from these two populated places by either pollution, dumping, or improper disposal of trash, or a combination of these. NEC1 is a poultry facility in Newton County that did not exhibit any other anomaly regarding cation and trace element testing. The probable cause of mercury being above the MCL at this location is its close proximity to Union, a small town roughly 8 kilometers (5 miles) east of the sample site.

Pharmaceutical and toxicology results, of Carthage (LC5) and Philadelphia's (NCl) groundwater (closest to their respective hospitals) indicated none of the toxic organic compounds that can be detected by GC-MS screening were present in either sample. No drug, pesticide, or industrial chemical residues were observed in the largest and most densely populated cities of the UPRW (Fig. 6.2). The overlying sandy and clayey geology of the Kosciusko and Tallahatta/Neshoba Sands Formations at Carthage and Philadelphia respectively, act as excellent filtrating materials, partitioning the upper and lower parts of the watershed from groundwater interactions via inter- and baseflow.

8.3 Upper Pearl River Watershed Results Related to the Ross Barnett Reservoir

The UPRW showed similarities with the RBR's surrounding area based on: (i) the hydrogeochemical parameters of pH, redox potential, alkalinity, total hardness, turbidity, and conductivity (Oakley, 1984); (ii) anion nutrient loading of chloride into the RBR via groundwaters of the UPRW (Dash *et. al,* 2015; MDEQ; 2007; Oakley, 1984); (iii) the heavy metal concentrations of aluminum, iron, and manganese exceeding secondary MCLs in both regions, but not in wells nearest to the reservoir (Dash *et al.,* 2015; Oakley, 1984); (iv) the presence of the trace elements such as arsenic, cadmium, chromium, and lead being found in the surface waters of the RBR and throughout the groundwaters of UPRW. Since comparison of collected groundwater samples were done with the RBR's surface water, unfiltered groundwater samples were collected instead of samples that had already undergone filtration and/or chemical additive processes.

Ion exchange within the clays of the UPRW and dissolution within the aquifers around the RBR, play a heavy role in the exceedingly high anion and cation concentrations, lowest at headwaters in the northeast, progressively increasing in concentrations moving downstream the UPR, until in the bottom southwestern portion of the watershed concentrations are highest at the RBR (Appendix D, table D.1 and D.2). Both sodium and chloride ions have similar atomic radii, they are interchangeably attracted to each other within clay matrices. This would explain why chloride concentrations are highest in wells around the RBR and at the headwaters (WC1 at 725 mg/L). Groundwater progressively increases in the headwaters, until flowing into the Zilpha Clay and Winona Sands Formations in Leake County where chloride is filtered and perhaps stored, then flowing southwestward towards the reservoir, groundwater again gathers chloride ions (most likely from local agriculture and livestock) from the southern-most counties in the watershed (Appendix D, table D.1).

Excess nitrate and phosphate concentrations in the UPRW have contributed to eutrophication and subsequent degradation of stream water quality flowing into the RBR, and the RBR's surface waters itself (Dash *et al.,* 2015). Noted by Dash *et al*. (2015), the

RBR's surface waters were considered eutrophic according to chlorophyll *a* concentrations ranging from 10 to 35 µg/L. Throughout the watershed, the highest nitrate concentration was at a poultry facility in Neshoba county (NEC1) at 22 mg/L, varying lower concentrations were measured had no apparent pattern within all sample locations. Nitrates were measured in high concentrations at poultry facilities in the UPRW. In two of the five measured poultry facilities (NC7 and NEC1), nitrate concentrations exceeded the MCL of 10 mg/L (Appendix D, table D.1). Nitrate concentrations averaged highest at 8.3 mg/L in Scott and Newton Counties, the leading poultry producing counties in the state, and close to the RBR. Nitrates loading in the RBR leading to eutrophication seems to be more dominated by surface water runoff directly from the Pearl river and its tributaries in these poultry-producing counties rather than groundwaters. Nitrates and phosphates in groundwater may be a lesser contributing factor to eutrophication in the RBR surface waters, however this is hard to conclude due to the varying concentrations of both anions throughout the watershed. Most likely, phosphates and nitrates in groundwater are site-specific and aquifer-specific.

Clays within the UPRW are naturally composed ferromagnesian silicates (Dockery and Thompson, 2016; Stover *et al.*, 1988). Iron and magnesium have a similar atomic radius, allowing for easy substitution of each into the clays matrix. Yazoo Clay, having one of the highest shrink-swell rates (up to 200%) of any known clay, is locally overlain by strata in upper portions of the RBR area comprising of Rankin, Madison and southern Scott Counties (personal communication, Darrel Schmitz, 2018; Dockery and Thompson, 2016; Stover et al., 1988). As indicated by correlating all hydrogeochemical results with a local geologic cross-section, the groundwater wells of the RBR area have the highest potential for CEC. Indicative of this would be locally high anion (chloride) and cation (aluminum, iron, and magnesium) concentrations in the RBR region's groundwater wells; high toxin concentrations would also be expected as toxic elements and pollutions are interchangeable within the clay's matrix (Appendix D, table D.1 and table D.2).

Aluminum concentrations were highest in groundwater wells at and around the RBR in Scott, Rankin, and Madison Counties. In the central and northern portions of the watershed, aluminum concentrations were low or undetectable, indicating aluminum concentrations are highest where Yazoo clay is prevalent (Appendix D, table D.2). There is no distinct correlation between aluminum concentrations in the central and northern portions of the watershed with the RBR region and the counties that encompass it. Previous RBR surface water aluminum concentrations measured by Dash *et. al* (2015) averaged at 0.02 mg/L; and groundwater samples measured now around the RBR area had an average sample concentration of 0.02 mg/L, remaining unchanged (Appendix A, table A.1; Appendix D, table D.2). This indicates aluminum in groundwater around the RBR (wells in the Sparta and Cockfield Aquifers) is infiltrating into the reservoir by inter- and baseflow, but not from other parts of the watershed.

Iron concentrations around the RBR were absent, except in Scott County at SC4, and again at SC1 where concentrations of 0.4 mg/L exceeded the MCL of 0.3 mg/L (Appendix D, table D.2). Iron concentrations were higher in central and northern portions of the watershed (Neshoba, Winston, and Choctaw Counties), but undetected around the reservoir. Ergo, the dividing Zilpha clay and Winona Sand Formations in the central portion of the watershed have the ability to separate the northern and southern portions from continuous heavy element transport within the groundwaters. Previous iron concentrations in the RBR surface waters determined by Dash *et al.* (2015) averaged at 1.48 mg/L, whereas iron concentrations were absent when averaged and undetectable at wells nearest to the reservoir (Appendix A, table A.1; Appendix D, table D.2). This also indicates iron is not infiltrating into the RBR surface water via surrounding groundwater, but instead is probably being received from surface runoff.

Manganese was detected in the central and northern portions of the watershed (Kemper, Winston, Neshoba, and Leake Counties), but not in southern portions of the watershed and in groundwater wells around the reservoir in Scott, Rankin, and Madison Counties (Appendix D, table D.2). Thusly, manganese is lower in groundwaters of the UPRW compared to surface waters of the RBR, and groundwaters of the UPRW do not contribute to manganese concentrations in the RBR. Previous manganese measurements by Dash *et al.* indicated RBR surface waters to be above the MCL of 0.05 mg/L (Appendix A, table A.1).

The trace elements cadmium, chromium, and lead were found in surface waters of the RBR below their respective MCL in 2015 (Dash *et al.,* 2015; Appendix A, table A.1). Chromium was found in Leake, Scott, Rankin, and Madison Counties below the MCL of 0.1 mg/L; and lead was found in Leake, Scott, and Madison Counties below the MCL of 0.015 mg/L, indicating chromium and lead are in the groundwaters of the UPRW and are infiltrating by inter- and baseflow into RBR surface waters. Cadmium was found in Leake County, but not in Scott, Rankin, or Madison Counties; it is inconclusive to state whether cadmium in entering the RBR surface waters by inter- and/or baseflow.

Arsenic was found to exceed the MCL of 0.01 mg/L in two samples sites of the RBR surface waters as tested by Dash *et al.* (2016) (Appendix A, table A.1). In this study, arsenic was found to exceed the MCL in the headwaters of the watershed (Winston, Attala and Choctaw Counties) and in wells at and around the RBR (Scott, Rankin, and Madison Counties). The Wilcox and Yazoo seem to be holding and releasing arsenic in their respective aquifers. Notably, the groundwater wells with arsenic concentrations exceeding the MCL are closest to large towns and cities in and around the watershed. This suggests dumping of pollution or runoff from these urban centers is infiltrating into the soils, clays, and groundwaters of the UPRW. The trend of groundwater filtration by clays in the central portion of the watershed still adheres to arsenic it seems. As groundwater flows from urban centers further downstream, it again collects arsenic and begins and accumulate.

The presence of mercury, while being largely absent throughout the watershed and RBR, still exists, and was found to exceed the MCL at two sample sites in the UPRW (Appendix D, table D.3) (Dash *et al.,* 2015; MDEQ, 2007). Mercury was absent in previous RBR surface water test conducted by Dash *et al.* (2015). Mercury was also absent in groundwater wells around the RBR. Newton County (NEC1) was the closest well with mercury concentrations exceeding the MCL of 0.002 mg/L, however mercury concentrations did exceed the MCL in Winston (WC2) and Leake Counties (LC6) both sites being cities (Louisville and Walnut Grove). Mercury seems to be a localized measurement coming from certain urban cities found within the watershed and does not seem to be flowing from the UPRW into the RBR either by groundwater or surface waters according the results (Appendix D, table D.3).

Results indicate the RBR’s surface water chemistry is different from that of the watershed’s northern portions, but similar to that in the southern portion around Scott, Madison, and Rankin Counties. This demonstrates that the RBR could likely receive a majority of its water from surface waters of the central and northern portions of the UPRW and not groundwater. However, in the southern portions of the watershed, groundwater flow to the RBR seems to be more prevalent as cations and arsenic values in these counties as compared to RBR surface water results are similar (Appendix A, table A.1 and table A.2; Appendix D, table D.1 and table D.2). In Leake County and above, the redox potential, pH, alkalinity, hardness, and manganese and magnesium concentrations are generally the same values indicating some commonality. For example, magnesium concentrations were higher were calcium concentrations were higher in the central and northern portions of the watershed, but at and around the RBR (Scott, Rankin, and Madison Counties) these concentrations decrease (Appendix D, table D.2). This is indicative of groundwater being harder in northern portions of the watershed than that of the RBR and its surrounding region. It seems that below Leake County, the southern parts of the watershed exhibit similar geochemical parameters, however these parameters are comparatively different than the northern portion. Therefore, by interflow or baseflow or both, the RBR water chemistry is influenced by the surrounding aquifers in the southern portion of the watershed. Since this was one of the first studies characterizing the groundwater’s of the UPRW with the RBR’s surface water, many parameters could not be correlated as they were not published or cited in literature.

CHAPTER IX

CONCLUSION

Groundwater characterization of the UPRW showed that hydrogeochemical analysis is effective to certain extents and can be used as a tool to correlate inter- and baseflow to the RBR. Once in the groundwater, cation and anions disperse by baseflow and interflow into the clay and sandy geology. The geology of the UPRW, specifically the Zilpha, Winona/Tallahatta, and Cook Mountain Formations, separates the groundwater geochemistry of the northern portion (Counties in the Wilcox Formation) and southern portion (Counties in the Jackson Formation). The northern portion's groundwaters having a higher redox potential, being more acidic, and having a higher total hardness, while the southern portions of the watershed groundwaters are generally softer, more alkaline, with a neutral or basic pH. Partitioning best described parameters into three categories, the northern, central, and southern portions of the watershed. Yazoo clay facilitated absorption and dispersion of aluminum and arsenic throughout the UPRW's southern-most aquifers (located in southern Leake County, Newton, Scott, Rankin, and Madison Counties) into the RBR via interflow and baseflow within the region.

Groundwater pH was slightly acidic in the northern portion of the watershed and slightly basic as groundwaters became more alkaline in the southern portion around the reservoir. Redox potential (E_h) indicated that groundwater samples around the reservoir had the lowest Eh. Groundwater was generally soft throughout the UPRW except in Attala and Neshoba Counties, where total calcium carbonate concentrations exceeded 60 mg/L.

Nitrate concentrations were below the EPA standard, excluding two poultry facilities using groundwater to supply water to livestock and one well in both Scott and Choctaw Counties. Chloride concentrations exceeded the MCL in all counties throughout the UPRW. The high chloride and nitrate concentrations may be a contributing factor to the eutrophic surface waters of the RBR. Turbidity was lowest sites in the headwaters of the UPRW, groundwaters becoming more turbid at poultry facilities, and in Neshoba and especially Madison Counties, and in general as the UPR flows into the RBR. Specific Conductivity was highest at poultry facilities and in Scott, Rankin, and Madison Counties as sodium and chloride concentrations, turbidity, and alkalinity increased in the Sparta and Cockfield aquifers.

Aluminum, iron, and manganese exceeded MCLs in the RBR, but not in the groundwater wells in the southern portions of closest to the reservoir itself, indicating groundwater is not a major contributor to heavy metal concentrations in the reservoir. Trace metal analysis indicated arsenic and mercury were likely infiltrating into the groundwater wells located next to towns and cities in the watershed. Arsenic was high in Rankin and Madison County wells around the RBR and was found to exceed the MCL of 0.01 mg/L in five of the 14 tested wells in these two counties. Arsenic also exceeded the MCL in surface water tests conducted in 2015 indicating that arsenic is probably infiltrating into the RBR surface waters by inter- and baseflow.

The current groundwater analysis along with the geologic and land use and land cover maps was designed to further help hydrogeologists characterize the groundwater of the UPRW and understand its relationship with local surface waters and the RBR. As this was one of the first studies comparing the UPRW's groundwater with the RBR's surface waters, many geochemical parameters like pH, alkalinity, hardness, and redox potential were not available in literature.

Future directions in understanding dynamic hydrogeochemical processes in the UPRW with relation to the RBR would be to collect seasonal data emphasizing heavy precipitation events, arid periods or drought, and if seasonal variability was comparable over a given number of yearly datasets for proper correlations. For instance, seasonal time-series datasets can help to develop daily loads for sediments, nutrients and pathogens negatively impacting the UPRW's surface and groundwater quality.

Future studies directed towards the highly developed Cockfield and Sparta Sand Aquifers in the southern portion of the watershed would be a priority as both seem to have large amounts of free anions and cations. Climate change could also adversely impact water flow into the RBR by increasing the daily delivered from the UPRW. As the human population increases, clear-cutting and demand for natural resources within the watershed will increase, putting pressure on the watershed's water quality and RBR. It is crucial in understanding and managing groundwater flow in the UPRW to ensure the water quality and quantity of the RBR, Jackson's primary drinking water source.

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APPENDIX A

BACKGROUND FIGURES AND TABLES

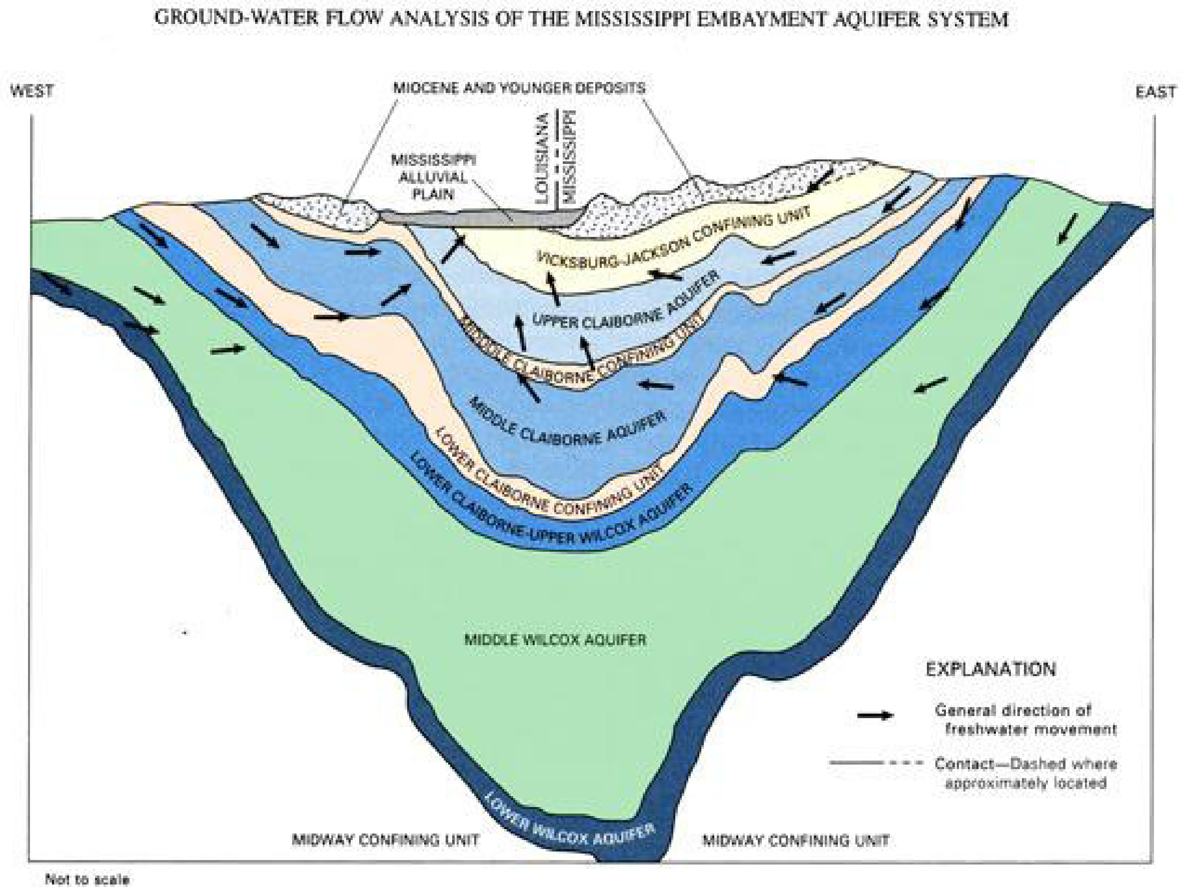

Figure A.1 Idealized hydrogeologic cross section of the Mississippi Embayment developed by Arthur and Taylor (1998). The cross section extends from northern Louisiana to central Mississippi indicating the Wilcox and Claiborne Aquifer

Table A.1 Dash *et al.* elemental concentration results from surface water samples taken at the RBR in the years of 2012 and 2014.

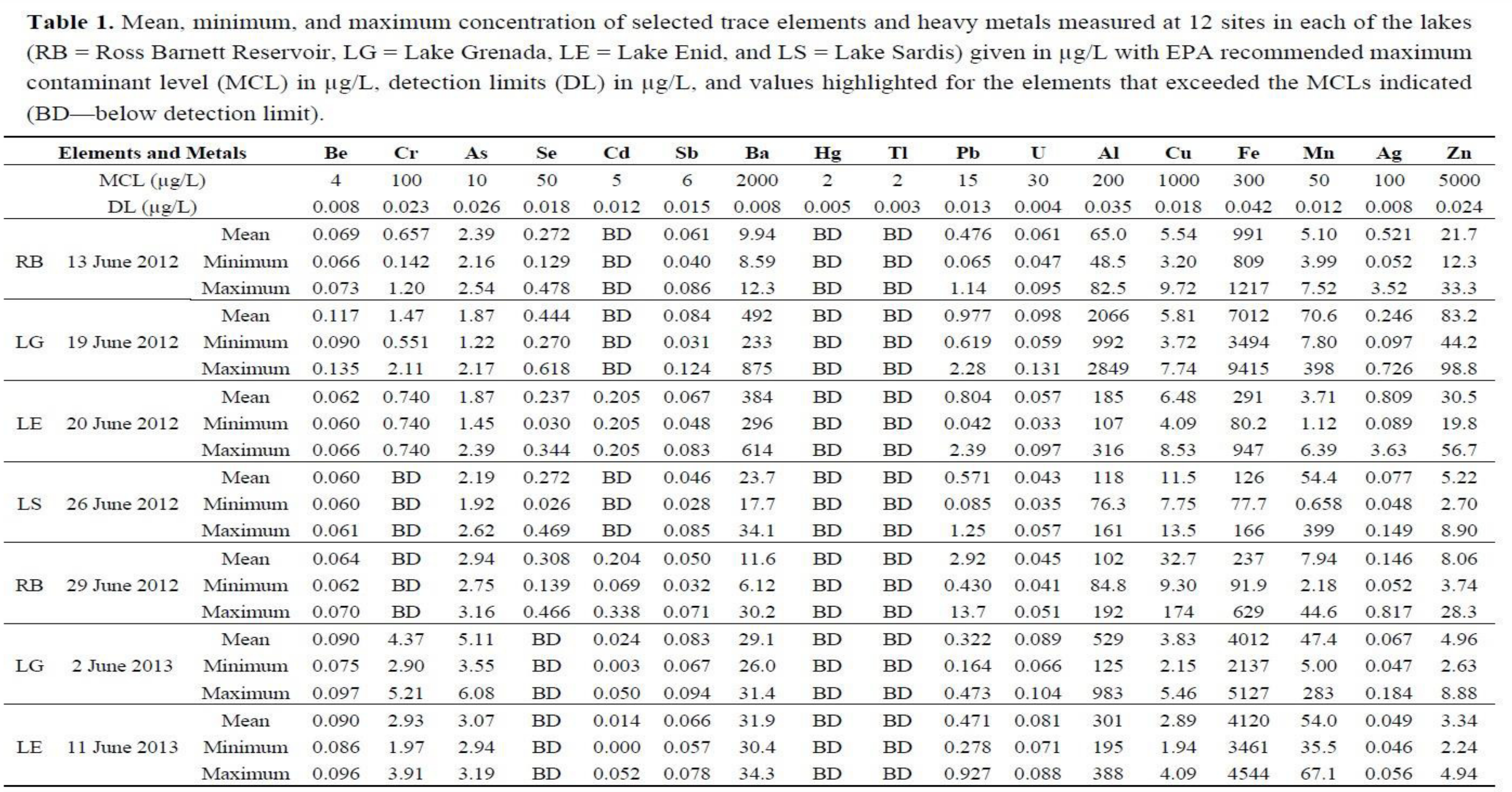

Table 1. Mean, minimum, and maximum concentration of selected trace elements and heavy metals measured at 12 sites in each of the lakes (RB = Ross Barnett Reservoir, LG = Lake Grenada, LE = Lake Enid, and LS = Lake Sardis) given in μg/L with EPA recommended maximum contaminant level (MCL) in μg/L, detection limits (DL) in μg/L, and values highlighted for the elements that exceeded the MCLs indicated (BD—below detection limit).

Elements and Metals			Be	Cr	As	Se	Cd	Sb	Ba	Hg	Tl	Pb	U	Al	Cu	Fe	Mn	Ag	Zn
	MCL (μg/L)		4	100	10	50	5	6	2000	2	2	15	30	200	1000	300	50	100	5000
	DL (μg/L)		0.008	0.023	0.026	0.018	0.012	0.015	0.008	0.005	0.003	0.013	0.004	0.035	0.018	0.042	0.012	0.008	0.024
RB	13 June 2012	Mean	0.069	0.657	2.39	0.272	BD	0.061	9.94	BD	BD	0.476	0.061	65.0	5.54	991	5.10	0.521	21.7
		Minimum	0.066	0.142	2.16	0.129	BD	0.040	8.59	BD	BD	0.065	0.047	48.5	3.20	809	3.99	0.052	12.3
		Maximum	0.073	1.20	2.54	0.478	BD	0.086	12.3	BD	BD	1.14	0.095	82.5	9.72	1217	7.52	3.52	33.3
LG	19 June 2012	Mean	0.117	1.47	1.87	0.444	BD	0.084	492	BD	BD	0.977	0.098	2066	5.81	7012	70.6	0.246	83.2
		Minimum	0.090	0.551	1.22	0.270	BD	0.031	233	BD	BD	0.619	0.059	992	3.72	3494	7.80	0.097	44.2
		Maximum	0.135	2.11	2.17	0.618	BD	0.124	875	BD	BD	2.28	0.131	2849	7.74	9415	398	0.726	98.8
LE	20 June 2012	Mean	0.062	0.740	1.87	0.237	0.205	0.067	384	BD	BD	0.804	0.057	185	6.48	291	3.71	0.809	30.5
		Minimum	0.060	0.740	1.45	0.030	0.205	0.048	296	BD	BD	0.042	0.033	107	4.09	80.2	1.12	0.089	19.8
		Maximum	0.066	0.740	2.39	0.344	0.205	0.083	614	BD	BD	2.39	0.097	316	8.53	947	6.39	3.63	56.7
LS	26 June 2012	Mean	0.060	BD	2.19	0.272	BD	0.046	23.7	BD	BD	0.571	0.043	118	11.5	126	54.4	0.077	5.22
		Minimum	0.060	BD	1.92	0.026	BD	0.028	17.7	BD	BD	0.085	0.035	76.3	7.75	77.7	0.658	0.048	2.70
		Maximum	0.061	BD	2.62	0.469	BD	0.085	34.1	BD	BD	1.25	0.057	161	13.5	166	399	0.149	8.90
RB	29 June 2012	Mean	0.064	BD	2.94	0.308	0.204	0.050	11.6	BD	BD	2.92	0.045	102	32.7	237	7.94	0.146	8.06
		Minimum	0.062	BD	2.75	0.139	0.069	0.032	6.12	BD	BD	0.430	0.041	84.8	9.30	91.9	2.18	0.052	3.74
		Maximum	0.070	BD	3.16	0.466	0.338	0.071	30.2	BD	BD	13.7	0.051	192	174	629	44.6	0.817	28.3
LG	2 June 2013	Mean	0.090	4.37	5.11	BD	0.024	0.083	29.1	BD	BD	0.322	0.089	529	3.83	4012	47.4	0.067	4.96
		Minimum	0.075	2.90	3.55	BD	0.003	0.067	26.0	BD	BD	0.164	0.066	125	2.15	2137	5.00	0.047	2.63
		Maximum	0.097	5.21	6.08	BD	0.050	0.094	31.4	BD	BD	0.473	0.104	983	5.46	5127	283	0.184	8.88
LE	11 June 2013	Mean	0.090	2.93	3.07	BD	0.014	0.066	31.9	BD	BD	0.471	0.081	301	2.89	4120	54.0	0.049	3.34
		Minimum	0.086	1.97	2.94	BD	0.000	0.057	30.4	BD	BD	0.278	0.071	195	1.94	3461	35.5	0.046	2.24
		Maximum	0.096	3.91	3.19	BD	0.052	0.078	34.3	BD	BD	0.927	0.088	388	4.09	4544	67.1	0.056	4.94

Table A.2 (continued)

Table 1. *Cont.*

Elements and Metals			Be	Cr	As	Se	Cd	Sb	Ba	Hg	Tl	Pb	U	Al	Cu	Fe	Mn	Ag	Zn
LS	18 Jun 2013	Mean	0.070	12.4	2.07	BD	0.017	0.080	25.2	BD	BD	0.057	0.047	330	2.80	2898	13.1	0.051	3.21
		Minimum	0.067	10.9	1.52	BD	0.005	0.070	22.5	BD	BD	0.004	0.039	136	1.91	1983	3.37	0.049	2.76
		Maximum	0.075	13.7	3.72	BD	0.043	0.096	30.7	BD	BD	0.129	0.062	708	4.51	5552	92.4	0.055	3.83
RB	10 Jul 2014	Mean	0.072	14.4	7.36	BD	0.281	0.088	18.1	BD	BD	1.84	0.066	292	3.57	3226	10.2	0.093	3.03
		Minimum	0.066	8.39	4.94	BD	0.056	0.061	14.7	BD	BD	0.018	0.055	153	2.46	2629	7.60	0.046	1.68
		Maximum	0.078	49.2	14.5	BD	1.77	0.105	29.1	BD	BD	4.22	0.101	620	6.39	4163	25.1	0.440	5.84

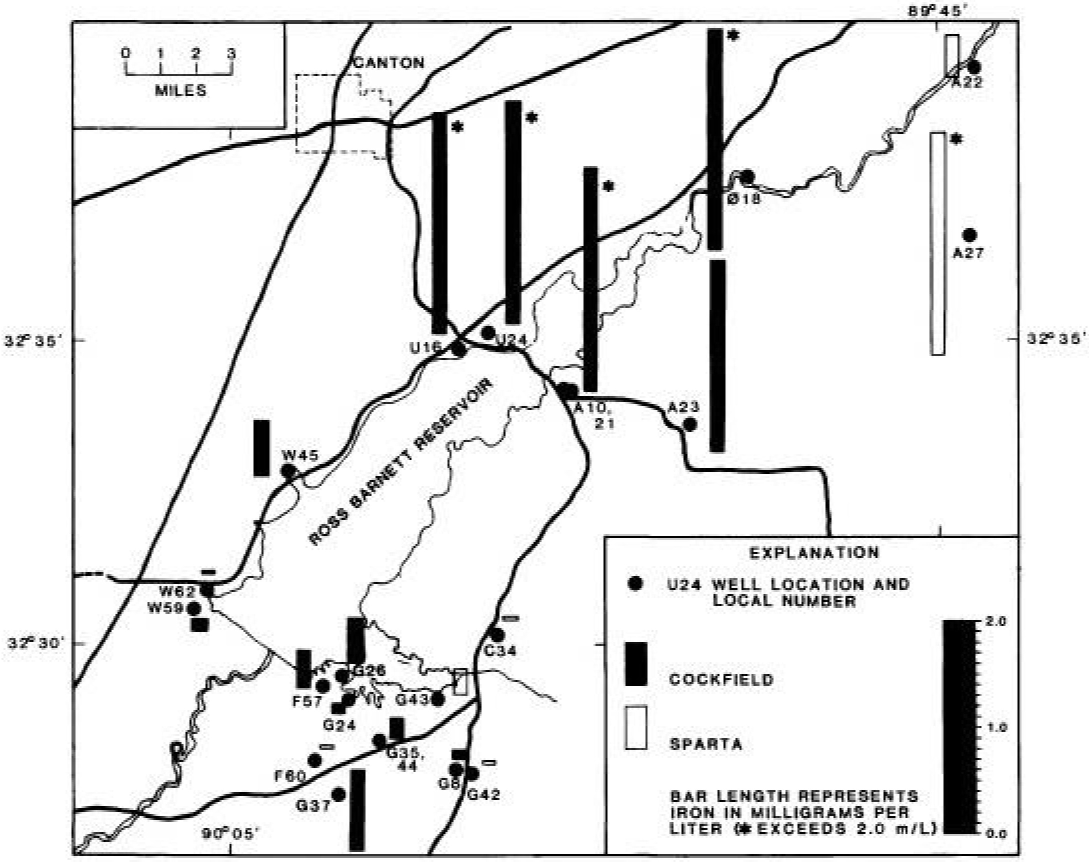

Figure A.2 Iron concentrations in the RBR tested by Oakley in 1984.

(Oakley, 1984)

Table A.3 Create a short, concise table title and place all detailed caption, notes, reference, legend information, etc in the notes section below

Table 4.--Results of chemical analyses of water from selected wells in the Ross Barnett Reservoir area
(location of wells shown on figure 1)

[Aquifer: C, Cockfield Formation; S, Sparta Sand. Temperature, pH, and specific conductance measured in field]

Well number	Well name or location	Date of collection	Screened interval (feet)	Temperature (C°)	Silica (SiO$_2$)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity as CaCO$_3$	Sulfate (SO$_4$)	Chloride (Cl)	Fluoride (F)	Dissolved solids (ROE at 180°C)	Hardness as CaCO$_3$	Specific conductance (micromhos at 25°C)	pH (units)	Color (Pt-Co units)	Aquifer code
					Milligrams per liter																
MADISON COUNTY																					
O18	Ratliff Ferry	8/81	284-304	20.5	49	9.30	0.20	11	1.7	8.9	2.3	48	5.3	4.2	0.1	114	34	114	7.1	100	C
U16	Highway 43	8/81	482-502	22.0	56	2.90	.16	16	4.5	49	2.9	115	35	8.7	.1	245	58	345	6.9	5	C
U24	Dept. of Wildlife	7/82	500-520	20.0	54	9.10	.14	9.8	2.6	64	2.4	117	40	8.0	.1	260	35	360	6.9	120	C
W45	Twin Harbor	8/81	560-610	24.0	39	.52	.13	7.1	3.3	96	3.1	180	35	15	.1	327	31	500	6.8	<1	C
W59	Ridgeland	3/82	500-595 660-720	25.5	20	.13	.00	.6	.2	130	1.8	218	37	28	.2	387	2	606	7.6	5	C
W62	Tavern Hill	8/81	597-667	24.5	19	.03	.01	1.4	.5	150	2.7	--	53	35	.2	380	6	600	7.6	<1	C
RANKIN COUNTY																					
A10	Lake Harbor #1	8/81	440-492	22.5	57	2.50	0.18	18	4.7	44	3.3	90	53	9.5	0.1	248	64	316	6.5	20	C
A21	Lake Harbor #2	8/81	440-490	21.5	57	--	.35	17	4.5	45	3.2	107	37	10	.1	249	61	308	6.7	40	C
A23	Pisgah	7/82	382-442	21.0	48	1.80	.29	40	11	45	3.6	172	60	9	.1	319	150	476	6.8	1	C
C34	Fannin	7/82	1129-1190	28.5	34	.01	.00	.3	.1	74	.2	166	9.0	2.2	.2	235	1	334	8.4	16	S
D21	C. H. Wright	7/82	831-846	24.0	20	2.40	.10	12	3.5	120	1.6	249	22	8.4	.3	352	44	525	8.5	110	S
F57	Shop Well	6/78	646-711	25.0	32	.34	.02	3.1	1.2	128	2.8	197	34	17	.1	320	13	480	7.2	20	C
		8/81	646-711	25.0	33	.19	.03	3.3	1.4	98	2.3	197	34	15	.2	314	14	490	7.2	<1	C
F60	Flowood	7/82	984-1064	31.0	17	.02	.00	.3	.0	92	.2	184	6.0	2.2	.2	229	1	360	8.5	7	S
G08	Langford	7/82	732-772	25.5	30	.10	.01	1.6	.7	89	1.7	152	26	9.6	.2	258	7	361	7.4	4	C
G24	Bay Park	8/81	591-631	24.0	31	.10	.02	3.3	1.3	120	2.6	197	36	16	.2	325	14	485	7.2	<1	C
G26	Pelahatchie	8/81	650-690	25.0	29	.42	.09	3.9	1.7	120	3.1	205	36	16	.1	330	17	505	7.2	5	C
G35	Noranco	7/82	601-616	25.0	25	.16	.02	.8	.3	110	1.1	196	31	16	.3	323	3	498	7.4	8	C
G37	Castlewood	5/77	718-768	--	32	.75	--	.9	2.0	100	2.1	172	31	19	.1	303	10	395	6.8	0	C
G42	Langford	7/82	1262-1302	30.0	24	.02	.00	.2	.1	86	.7	167	10	2.3	.1	233	1	310	8.3	3	S
G43	Waterwood	8/81	1110-1190	29.0	47	.24	.02	.9	.2	74	1.7	148	8.6	1.5	<.1	216	3	300	7.4	70	S
		11/83	1110-1168	29.0	42	.08	.00	.9	.2	71	1.8	151	7.8	2.6	.1	214	3	295	7.5	7	S
G44	Noranco	7/82	620-710	25.5	27	.20	.02	.8	.2	110	1.1	190	32	15	.2	316	3	481	7.4	6	C
SCOTT COUNTY																					
A22	Low Head Dam	9/82	583-593	--	46	0.39	0.01	5.1	1.0	22	1.9	53	9.0	5.0	<.1	102	17	133	7.0	9	S
A27	J. D. McFarland	9/82	691-706	20.0	37	2.10	.02	34	8.4	86	12	319	3.0	2.0	.2	328	120	328	7.6	20	S

(Oakley, 1984)

APPENDIX B

NOTES ON WELLS BY COUNTY

Notes taken on each groundwater well were directly from the well owner or operator on site. These notes were also used in correlating results and discussions and are mentioned frequently in that particular section of the paper.

County Name	**Sample Site Well ID**	**Notes on Well**
		Date/Time sampled; Well Purge time; Background (from well owner(s)) on well, well site, groundwater, etc.
LEAKE	LC1	07-13-17/11:15AM; 15MIN; N/A
LEAKE	LC2	07-13-17/12PM; 10MIN; Less Fe than other groundwater wells in surrounding area, More Ammonia in this well
LEAKE	LC3	07-13-17/12:15PM; 5MIN; Oldest well in LC series samples
LEAKE	LC4	07-13-17/1PM; 10MIN; Best water quality in Leake Co. according to MS Dept. of Health
LEAKE	LC5	07-13-17/1:30PM; Pump running on arrival, duration unknown; Closest well to Carthage (Leake Co) Hospital (1.5mi away), Leake Co Jail .25mi away
LEAKE	LC6	11-29-17/1:30PM; 8MIN; N/A
LEAKE	LC7	11-29-17/4:08PM; 3MIN; N/A
KEMPER	KC1	09-15-17/10AM; Well's tap purged for10MIN, pump running on arrival, duration unknown; Wilcox Aquifer, Well's tap was extremely dirty from non-use
KEMPER	KC2	09-28-17/10:50AM; Constantly running; 2 wells connected=170ft & 180ft well depth, both wells drilled at same time, May contain high Fe, all water here flows to Owl Creek to Bogue Chitto to UPR, Used for PECO poultry houses
NESHOBA	NC1	09-20-17/8:21AM; Pump running on arrival, duration unknown (Waited 23min before sampling); Up. Wilcox Aquifer, Well 500ft deep; Drilled in 1962, Approx. 220gal/min; High Mn- phosphate added at treatment plant (Gotten worse over the years), Closest well to Neshoba Co. Hospital in Philadelphia, MS (approx. 3.5mi South of Hospital)

NESHOBA	NC2	09-20-17/9:03AM; 12MIN; Up. Wilcox, Drilled in 1991, approx. 500gal/min, High Fe (Should be close to 1ppm)
NESHOBA	NC3	10-02-17/8:30AM; 12MIN; N/A
NESHOBA	NC4	10-02-17/8:53AM; Pump running on arrival, duration unknown (Waited 11min before sampling); N/A
NESHOBA	NC5	10-02-17/9:33AM; 7MIN; Less than 1mi from Co. line, 5mi. From town of Noxapater
NESHOBA	NC6	10-02-17/10:30AM; 9MIN; N/A
NESHOBA	NC7	10-02-17/12:14PM; 6MIN; Shallowest of all 5 connected wells at 150ft deep, High Fe, Used for poultry houses water
NESHOBA	NC8	10-02-17/1:40PM; 10MIN; Used for poultry houses water
ATTALA	AC1	10-02-17/10:56AM; Pump running on arrival, duration unknown (Waited 7min before sampling); Middle Wilcox aquifer
ATTALA	AC2	10-02-17/11:20AM; 14min; Up. Wilcox aquifer- Meridian Formation
ATTALA	AC3	11-28-17/2:15PM; Pump running on arrival, duration unknown; Fe is higher than AC4B
ATTALA	AC4	11-28-17/2:50PM; 10MIN; Water Treatment Facility
NEWTON	NEC1	10-09-17/2:15PM; Pump running on arrival (Waited 10min before sampling); Well owner not available on site, water supply for Tyson poultry houses
WINSTON	WC1	07-14-14/10:15AM; Gravity Driven Spring (Hamill Springs); Flow rate upon arrival 500 gal/hr (measured using 1liter water bottle)
WINSTON	WC1..1 (re-sample)	11-02-14/12PM; Gravity Driven Spring (Hamill Springs); Flow rate not measured due to local peoples waiting in line with Kenwood water jugs
WINSTON	WC2	11-02-17/1:20PM; 8MIN; This is a Water Treatment Plant
WINSTON	WC3	11-13-17/10:45AM; Pump running on arrival, duration unknown; N/A
WINSTON	WC4	11-14-17/9:08AM; 4MIN; Up. Wilcox, Well Depth 162ft
CHOCTAW	CC1	11-13-17/1:05PM; Pump running on

		arrival, duration unknown; Lower Wilcox, Well depth 560ft, High Fe and Mn
CHOCTAW	CC2	11-13-17/1:17PM;7MIN; Up. Wilcox, Well depth 162ft
CHOCTAW	CC3	11-13-17/1:41PM; 5MIN; Lower Wilcox, Well depth 550ft
SCOTT	SC1	10-9-17/12:20PM; Pump running on arrival, duration unknown (Waited 5min before sampling); Approx. 90ft deep, emergency water supply for Tyson poultry houses
SCOTT	SC2	11-29-17/11:10AM; 7MIN; Found lignite, Hydrogen sulfide during well construction, Well depth 2300ft, Brand new well and water tower (>1 mo.), 11.5million gal. have been ran through well so far
SCOTT	SC3	11-29-17/11:45AM; 5MIN; Well depth 900ft
SCOTT	SC4	11-29-17/12:15PM; N/A; Found Hydrogen sulfide in well water previously, Well depth 120-140ft, Well drilled approx. 1 year ago of date sampled
SCOTT	SC5	12-01-17/12:40PM; 8MIN; N/A
SCOTT	SC6	12-01-17/1:30PM; 6MIN; N/A
SCOTT	SC7	12-01-17/2:50PM; 7MIN; N/A
MADISON	MC1	12-04-17/11:20AM; Pump running on arrival, duration unknown; Well depth 1500-1600ft, Cockfield or Sparta Aquifer
MADISON	MC2	12-04-17/11:47AM; 5MIN; Well Depth 1300ft
MADISON	MC3	12-04-17/12:52PM; N/A; Well Depth 2800ft
MADISON	MC4	12-05-17/1:30PM; 6MIN; Well depth approx. 650ft
MADISON	MC5	12-05-17/1:45AM; Pump running on arrival, duration unknown; N/A
RANKIN	RC1	12-01-17/3:21PM; 5MIN; N/A
RANKIN	RC2	12-05-17/8AM; Pump already running on arrival, duration unknown; Well Depth approx. 900ft, Sparta Sand Aquifer
RANKIN	RC3	12-05-17/8:45AM; N/A; N/A
RANKIN	RC4	12-05-17/9:10AM; 5MIN; Well depth approx. 400ft, Sparta Sand Aquifer
RANKIN	RC5	12-05-17/9:30AM; 6MIN; Well depth

		approx. 400ft, Sparta Sand Aquifer
RANKIN	RC6	12-05-17/9:50AM; 6MIN; Well depth approx. 400ft, Sparta Sand Aquifer
RANKIN	RC7	12-06-17/8:30AM; 5min; N/A
RANKIN	RC8	12-06-17/8:50AM; 5min; N/A
RANKIN	RC9	12-06-17/9AM; 5min; N/A

APPENDIX C

METHODOLOGY

C.1 Creating the Upper Pearl River Watershed Delineation Shapefile

It was imperative to firstly create a delineated land use and land cover shapefile of the UPRW based on stream flow within the watershed itself. This was accomplished by outlining a state-wide digital elevation model of the Upper Pearl River and its tributaries and incorporating hydrological unit codes in ArcGIS.

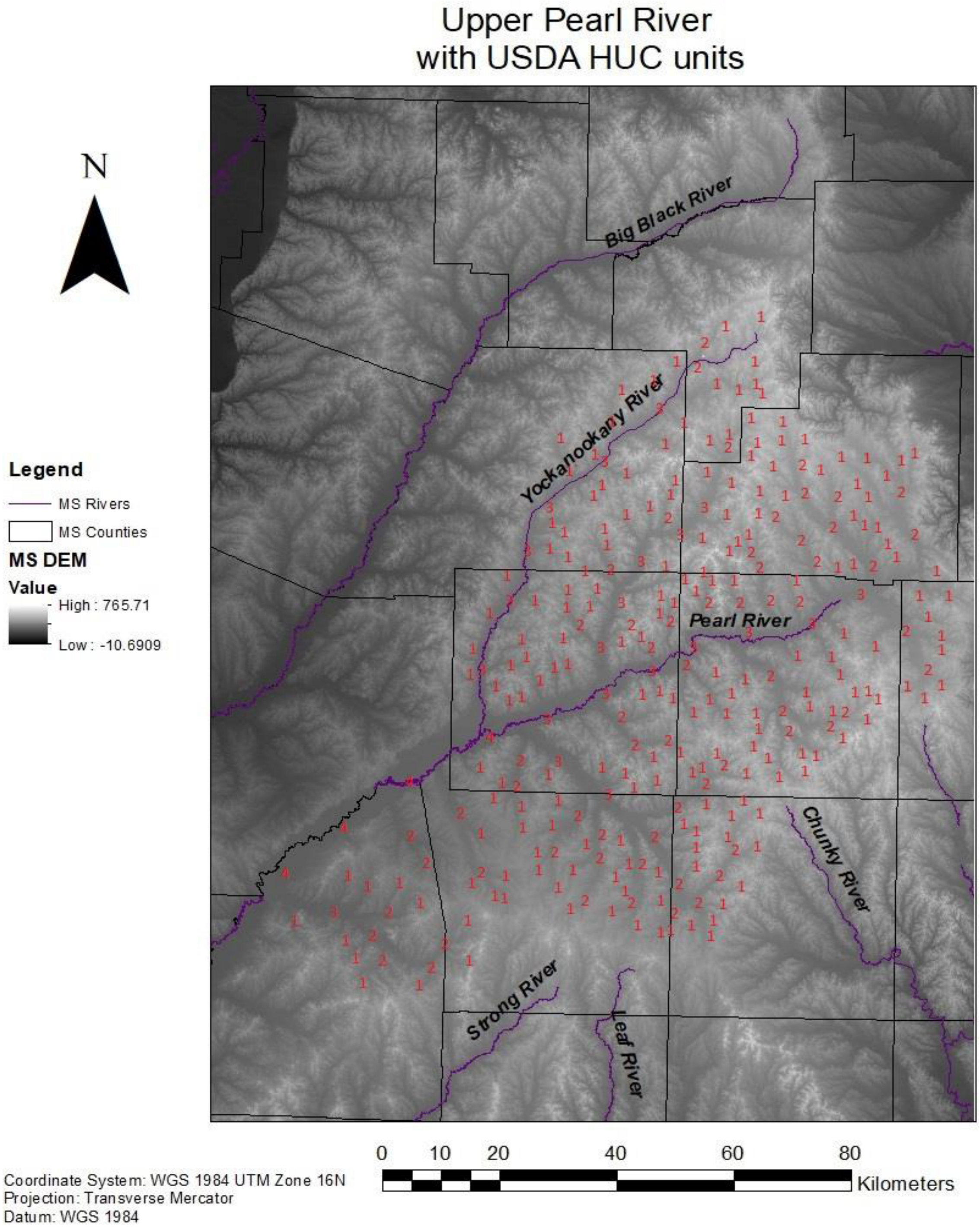

Figure C.1 Digital Elevation Model files downloaded from the USDA Gateway Portal show the Upper Pearl River based on elevation. Strahler Stream Order Hierarchy was used to determine streams flowing into and out of the Upper Pearl River basin; 4 being the Upper Pearl River itself.

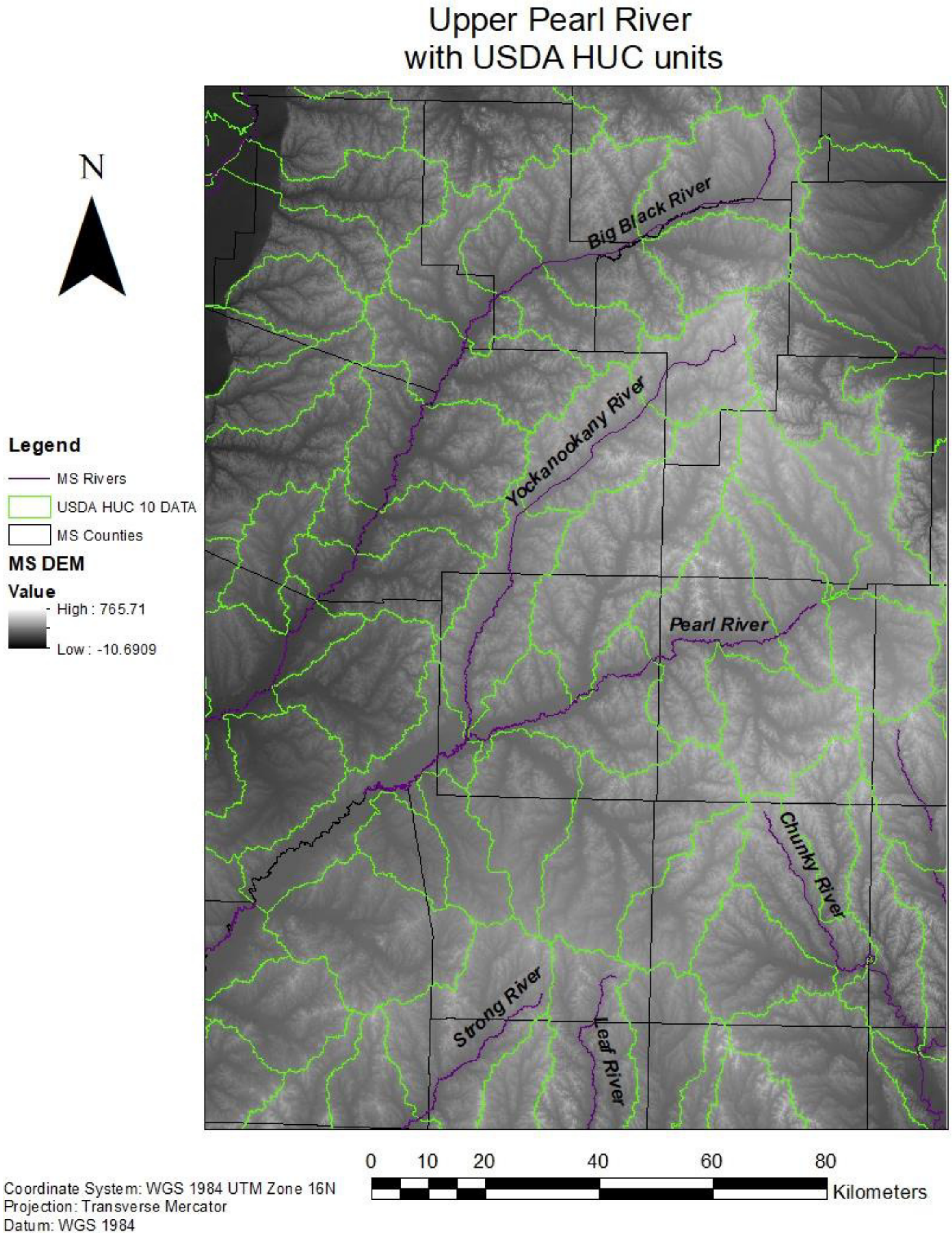

Figure C.2 HUC 10 data files, also downloaded from the USDA Gateway Portal, illustrating sub-watersheds layered on top of elevation.

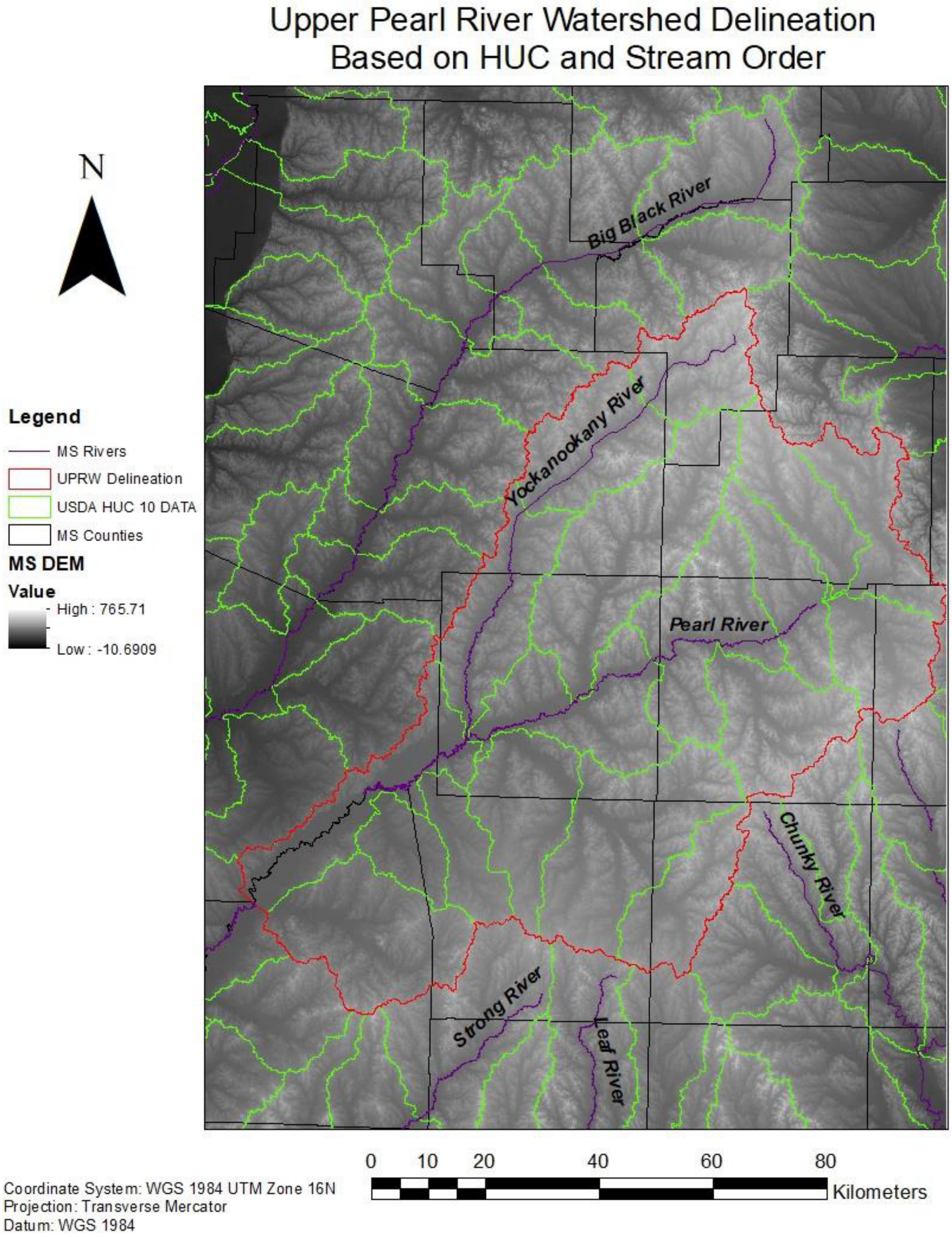

Figure C.3 Digital Elevation Model of UPRW indicating slope and stream flow and HUC units. The UPRW was delineated (red) by selecting HUC units that followed the stream order designed by using the Strahler Stream Order of Hierarchy illustrated in Fig. C.1.

C.2 Upper Pearl River Watershed Land Use and Land Cover Delineation Steps:

1. Download USDA HUC 8, HUC 10, and HUC 12 from the USDA gateway.
2. HUC 12 is the large data, HUC 8 is the smallest data (less classified).
3. Download National Landcover dataset.
4. Download River dataset and Lake dataset.
5. Open ArcGIS and load these files.
6. Select the watershed cover the pond/reservoir/river understudy.
7. Then go to the 'mask' function (search- mask→extract by mask).
8. Incorporate LU/LC as input raster in the mask TIF as input raster.
9. Input raster or feature mask data as HUC 12, or HUC 10, etc.
10. Output raster as, go to the specific folder where the mask file to be saved, and give a name, click ok.
11. Unselect all layers in the TOC except the saved file from step 10.
12. Now open the attribute table of the created layer on step 10.
13. Add field to the attribute table, go to 'table options' (extreme left icon just below table).
14. Add field name as 'area in square meters', type 'double', click ok.
15. Right click on the new column in the attribute table and click 'calculate'.
16. Click on the field calculator and select '(count)* x '; x= go to properties of LU/LC data→source icon→cell size (x, y)→multiply together to get x.
17. Export attribute table by selecting 'export attribute table' and save file as .txt.
18. Message prompt: "Do you want to add a new table to the current map.", select 'no'.

19. Open the .txt file in Excel and convert sq. meters to sq. km. by dividing 10^6.

C.3 Sample Bottle Sterilization Sequence

All Nalgene 500mL, 30mL, and ICP sample bottles were new from the distributor. Since the 500mL and 30mL sample bottles would represent the collection and storage phase up to 4 months, a systematic two-day sterilization sequence of both the 500mL and 30mL sample bottles, and the 10L storage container holding the 5% nitric acid wash was designed and rigorously followed. 30mL sample bottles were cleaned independently of 500mL sample bottles, insuring that the nitric acid wash in the storage container was never used more than three times, as on the third sterilization, the wash is discarded to ensure maximum efficacy of the designed sterilization sequence. The sample bottle cleaning procedure was performed three times throughout the study period (6 months):

Day 01 (Wash the 10L storage container first with DIW (de-ionized water), then rinse with 5% HNO3, finally using it.)

Part I

Sterilizing the Nitric Acid(HNO_3) Wash Storage Container with 1 liter of 5% Nitric Acid(HNO_3):

Calculations:

Formula: $c_1 v_1 = c_2 v_2$

Converting 100% Nitric Acid (HNO_3) to 5% Nitric Acid (HNO_3)

c_1= 100%(HNO_3), v_1= ?, c_2= 5%(HNO_3), v_2= 1,000mL (DIW)

Answer: 50mL 100% HNO_3 & 950mL of DIW (de-ionized water)

Steps:

1. Wash container with DIW twice.

2. Rise container with 1 liter of 5% nitric acid (HNO_3) wash solution and use container for storage.

Part II

Making 10 liters of 5% nitric acid (HNO_3) to fill 20 sample bottles @ 500mL:

Calculations:

Formula: $c_1 v_1 = c_2 v_2$

Converting 100% Nitric Acid (HNO_3) to 5% Nitric Acid (HNO_3)

$c_1 = 100\%(HNO_3)$, $v_1 = ?$, $c_2 = 5\%(HNO_3)$, $v_2 = 10{,}000mL$ (DIW)

Answer: 500mL 100% HNO_3 & 9500mL of DIW (de-ionized water)

Steps:

1. Make 10 liters of 5% nitric acid(HNO_3) solution.

2. After making 10 liters of nitric acid(HNO_3) wash, store in storage container.

Part III

The procedure for cleaning sample bottles:

Steps:

1. Wash the new samples bottles with DIW once.

2. Fill the sample bottles to the brim with 5%HNO3 from the storage container and leave it overnight (24hrs).

Note: If this wash has exceeded the third-time usage, then discard the solution and prepare a new one.

Day 02 (Empty nitric acid from sample bottles and then air/oven dry; if air drying, then for 24hrs; if oven drying then for approximately 1 hour slightly higher ~50°C)

Part IV

After 24hrs of bottles filled entirely with 5% nitric acid HNO_3 solution

Steps:

1. Empty nitric acid HNO_3 solution from the sample bottles into the large storage container originally used to store the sample wash.
2. Wash the bottles with DIW thrice and then air dry both bottles and lids (if you feel the place is not clean enough to air dry, put the bottles in the oven at a slightly higher temperature ~50° C).

APPENDIX D

RESULTS

D.1 Sulfate Concentrations

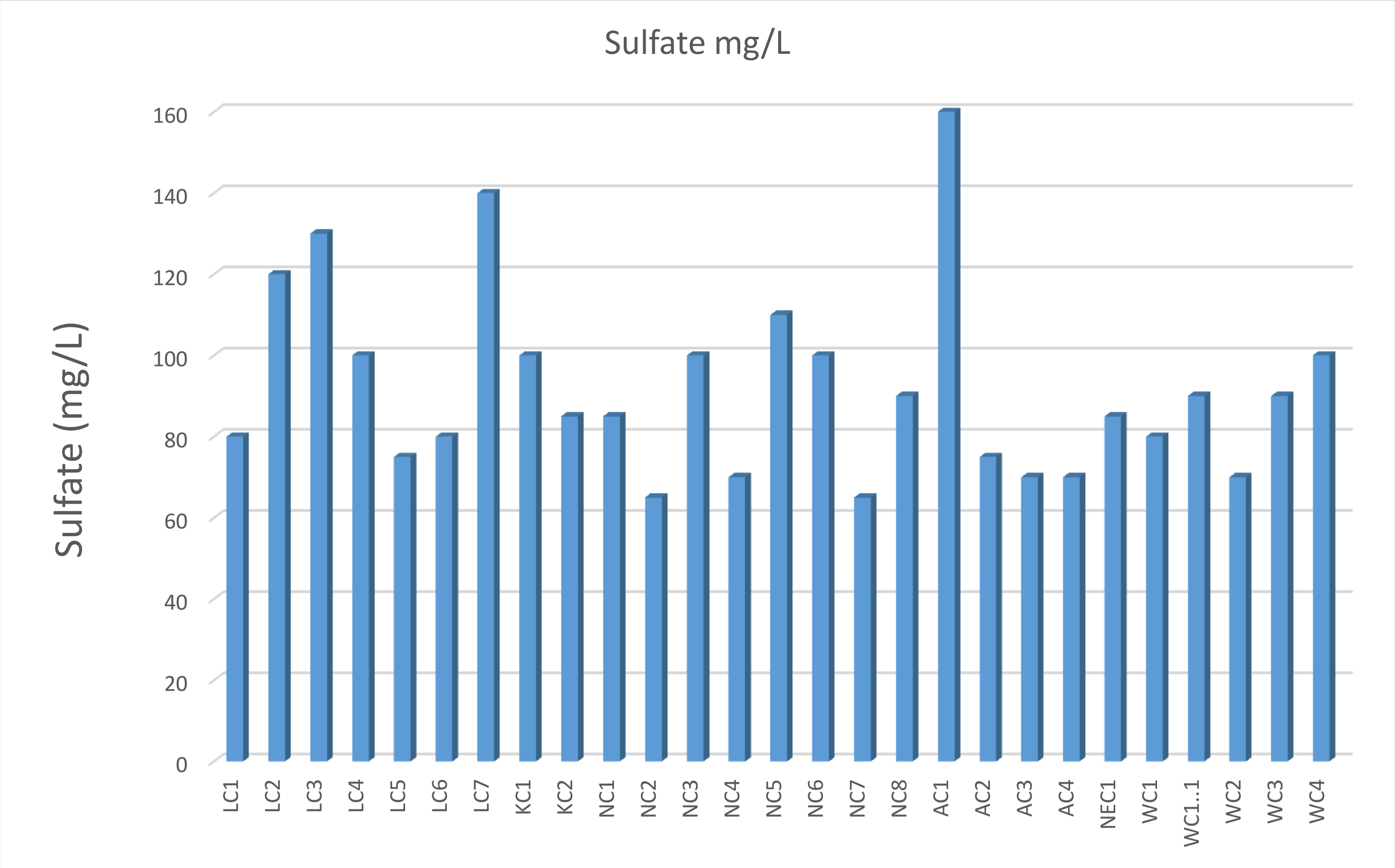

Figure D.1 Sulfate Concentrations in the UPRW. All concentrations are below the EPA MCL of 250 mg/L

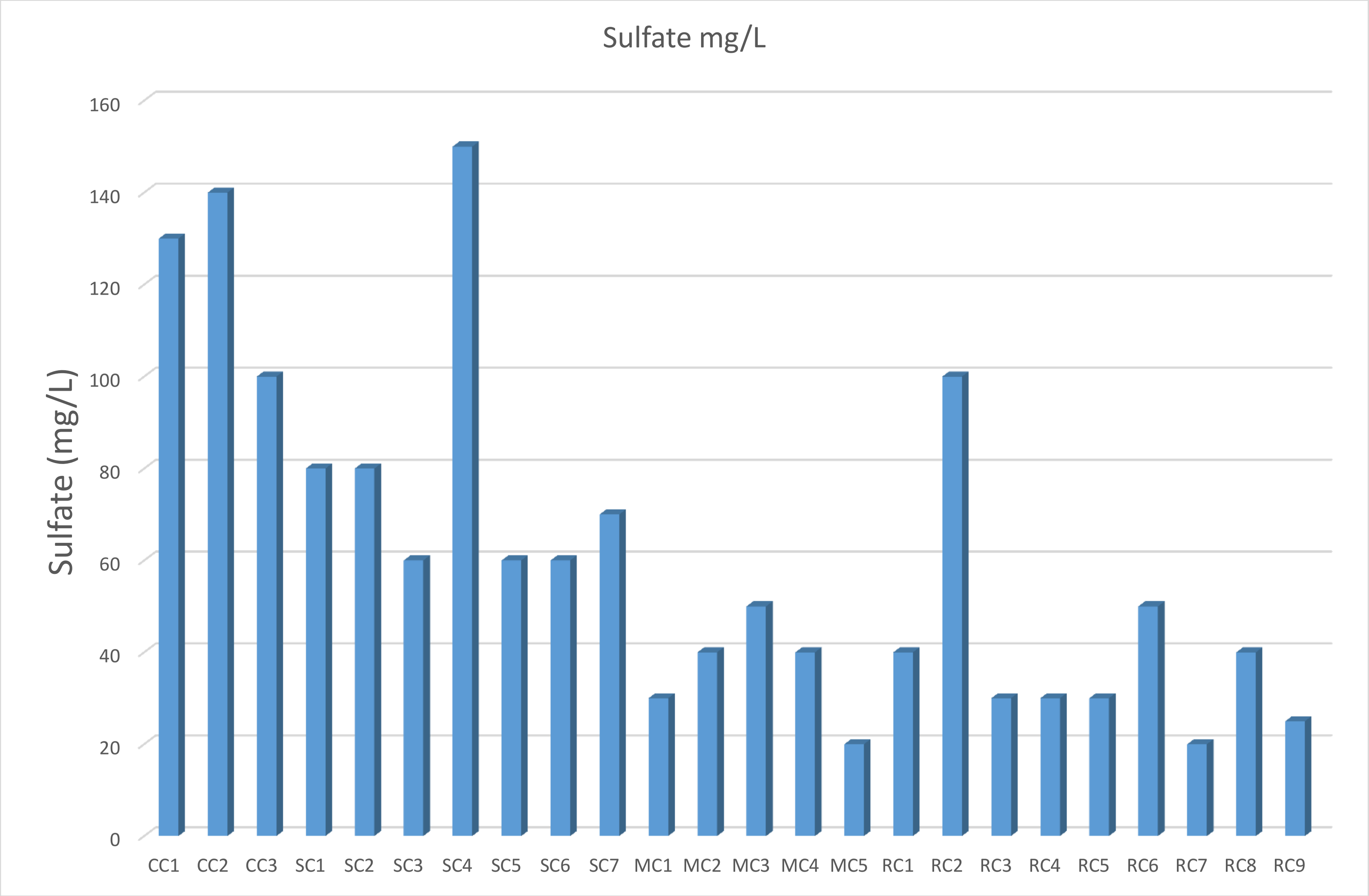

Figure D.1 (continued)

D.2 Hydrogeochemical Results

Table D.1 The table below shows all 50 samples hydrogeochemical results of the groundwater samples. Keeping in mind, WC1 and WC1..1 represent Hamill Springs, a gravity-driven groundwater spring in close proximity to the headwaters of the UPR, a baseline used for natural groundwater quality within the area. Orange cells represent poultry facilities, yellow indicate not tested, and red indicates values exceeding MCLs.

Sample Name	Temp (°C)	Eh (mV)	pH	Total Alkalinity (mg/L as CaCO3)	Phenolpthale in (P) Alkalinity	Ca Hardness as CaCO3 (mg/L)	Ca Hardness as Ca (mg/L)	Total Hardness as CaCO3 (mg/L)	Total Hardness as Ca (mg/L)	Nitrate (mg/L)	Sulfate (ppm)	Phosphate (ppm)	Chloride (mg/L)	Turbidity (NTU)	Conductivity (mS/cm @ 25°C)
LC1	25.3	649	6.83	132	0	77	30.8	147	58.8	0	80	2	200	0.83	0.33
LC2	26.2	-97	8.36	190	0	11	4.4	13	5.2	0	120	1.7	150	0.66	0.41
LC3	N/A	N/A	8.18	100	0	18	7.2	29	11.6	4.4	130	0.4	100	0.88	0.28
LC4	N/A	N/A	8.44	110	0	6	2.4	10	4	0	100	0.2	175	0.41	0.28
LC5	22	-35	8.56	70	0	7	2.8	8	3.2	0	75	1	275	1.1	0.25
LC6	22.1	-12	8.11	167.3	0	3	1.2	5	2	0	80	1.5	250	0.47	0.35
LC7	19.7	293	6.45	142.1	0	46	18.4	64	25.6	8.8	140	0.1	475	0.13	0.3
KC1	22	192	5.68	10	0	4	1.6	5	2	8.8	100	0	200	1.19	0.02
KC2	24.4	-37	6.41	136	0	123	49.2	134	53.6	0	85	0.1	375	24.8	0.29
NC1	23	-80	6.85	141	0	48	19.2	68	27.2	4.4	85	0.2	200	0.12	0.14
NC2	21.7	-4	6.1	61	0	36	14.4	54	21.6	4.4	65	0.1	225	2.17	0.31
NC3	20.7	16	5.78	30	0	22	8.8	25	10	4.4	100	0	325	1.85	0.06
NC4	20.6	95	5.21	30	0	12	4.8	18	7.2	4.4	70	0	350	3.46	0.06
NC5	21.6	-30	6.05	53.3	0	24	9.6	34	13.6	4.4	110	0	325	34.7	0.11
NC6	22.8	-96	6.24	96	0	66	26.4	70	28	4.4	100	0.1	200	60.7	0.84
NC7	27.1	204	7.08	112	0	72	28.8	91	36.4	13.2	65	0.2	275	0.4	0.63
NC8	21.7	-32	6.46	114	0	56	22.4	85	34	8.8	90	0.9	300	0.13	0.4
AC1	21	-60	6.68	119	0	97	38.8	110	44	4.4	160	0.5	300	0.09	0.64
AC2	20.7	-53	6.87	127	0	91	36.4	100	40	8.8	75	0.2	250	0.6	0.28
AC3	20.1	65	5.82	46	0	24	9.6	48	19.2	4.4	70	0.1	250	0.04	0.14
AC4	19	72	5.41	28	0	13	5.2	24	9.6	0	70	0.1	350	0.03	0.08
NEC1	22.7	350	4.64	7	0	13	5.2	14	5.6	22	85	0.1	375	0.05	0.06
WC1	N/A	N/A	5.8	10	0	5	2	7	2.8	0	80	0	725	1.02	0.02
WC1..1	18.7	246	4.59	3	0	4	1.6	7	2.8	4.4	90	0	425	2.66	0.03
WC2	21.5	34	5.57	55	0	11	4.4	2.8	11.2	0	70	0.4	450	0.17	0.12
WC3	19.7	-8	5.7	42.4	0	15	6	27	10.8	4.4	90	0.4	375	0.58	0.13
WC4	19.9	-79	6.65	136.6	0	93	37.2	112	44.8	8.8	100	0.6	375	N/A	0.3

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CC1	21.6	-94	6.48	127.6	0	31	12.4	3.9	15.6	0	130	0.3	450	0.22	0.25
CC2	20.1	227	5.27	30	0	10	4	20	8	17.6	140	0.1	400	1.58	0.08
CC3	19.9	-66	6.23	109.2	0	40	16	74	29.6	8.8	100	1.1	400	0.04	0.19
SC1	25.9	153	5.45	15	0	67	26.8	67	26.8	8.8	80	0.1	500	12.85	0.32
SC2	31.3	-19	7.19	252.5	0	6	2.4	9	3.6	0	80	1.5	325	2.99	0.5
SC3	23.5	-72	7.98	245.2	0	2	0.8	8	3.2	4.4	60	1.4	350	0.6	0.48
SC4	18	-4	5.41	33.5	0	19	7.6	28	11.2	8.8	150	0.1	350	17.16	0.1
SC5	27	-81	8.39	227.4	0	2	0.8	5	2	0	60	1.7	300	1.45	0.44
SC6	26.2	156	8.49	245.1	0	2	0.8	2	0.8	8.8	60	1.7	425	0.44	0.46
SC7	24.7	-54	7.07	136.5	0	20	8	28	11.2	13.2	70	0.1	350	1.2	0.3
MC1	28.6	-199	8.3	182.7	0	2	0.8	5	2	4.4	30	0.8	350	81.8	0.4
MC2	31.1	-242	8.54	188.2	0	1	0.4	3	1.2	4.4	40	1.1	425	71.8	0.4
MC3	35.5	-138	8.07	30	0	4	1.6	9	3.6	4.4	50	1.5	475	2.79	0.75
MC4	23.8	-7	7.26	222.3	0	3	1.2	4	1.6	4.4	40	1.2	375	22.6	0.62
MC5	23.4	-23	7.44	202.2	0	1	0.4	3	1.2	4.4	20	1.1	400	3.87	0.64
RC1	26.3	-127	7.6	179.1	0	4	1.6	5	2	4.4	40	0.6	425	1.37	0.35
RC2	26.4	-197	7.84	214.4	0	2	0.8	3	1.2	4.4	100	1.3	200	1.01	0.47
RC3	27.9	-127	7.71	30	0	1	0.4	11	4.4	4.4	30	0.7	400	1.7	0.33
RC4	28.6	-173	8.08	30	0	2	0.8	3	1.2	4.4	30	0.5	325	1.79	0.34
RC5	27.1	-189	8.09	156.5	0	2	0.8	3	1.2	4.4	30	0.65	400	2.43	0.35
RC6	29.3	-218	8.3	169.4	0	2	0.8	2	0.8	4.4	50	0.65	375	4.12	0.36
RC7	23.4	-109	7.87	151.2	0	2	0.8	4	1.6	4.4	20	1	325	1.09	0.34
RC8	23.8	-84	7.89	155.8	0	1	0.4	4	1.6	0	40	0.8	450	1.36	0.33
RC9	26.3	-99	7.61	140	0	3	1.2	7	2.8	4.4	25	0.7	400	1.4	0.31
EPA Primary Drinking Water Max Standards (ppm)	none	none	6.5-8.5	none	none	No SMCL exist	No SMCL exists	No SMCL exists	No SMCL exist	10	250	none	250	none	none
EPA Seondary Drinking Water Max Standards (ppm)										45	250		250		
Poultry Facilities															
N/A= could not test															

D.3 Cation Results

Table D.2 Concentrations of selected Cations measured at 50 groundwater sites throughout the Upper Pearl River watershed (Orange = Poultry Facilities, Green = Below MCL, Red = Above MCL, Yellow = Above detection range). Given in mg/L. Negative values indicate below the ICP-OES detection limit.

Cations								
SampleID	Al (mg/L)	Fe (mg/L)	Na (mg/L)	K (mg/L)	Mg (mg/L)	Ca (mg/L)	Mn (mg/L)	Si (mg/L)
LC1	-0.13276334	-0.48975815	21.8426442	1.95619851	1.2612262	9.95232634	0.07391031	5.18359189
LC2	-0.10213349	-0.57307896	93.5288326	1.60079923	-0.20147344	0.9867434	0.04410251	7.81766565
LC3	-0.11528475	-0.55818203	54.0848854	1.62334814	-0.06725171	4.29840791	0.05683548	8.51629104
LC4	-0.11040023	-0.5827414	44.3229375	1.5639089	-0.34487589	0.56801933	0.03630324	7.5721399
LC5	-0.10045174	-0.56933456	51.0508485	1.55419218	-0.37383898	0.09390835	0.03944162	6.5116998
LC6	0.04285619	-0.50301623	106.104278	1.52834681	-0.15837032	0.73331087	-0.70378925	6.07004222
LC7	-0.00724777	-0.38163842	40.1418649	5.14395052	4.70563886	17.6945688	-0.67742343	11.1179368
KC1	-0.1209799	-0.58366521	2.69479136	0.9643594	-0.25882641	0.18518194	0.03754067	1.83323148
KC2	-0.14493131	0.08769853	4.95241758	1.72216889	3.68093743	11.3733022	0.14728316	6.14152684
NC1	-0.12857283	-0.51053705	33.3280214	3.75160454	3.873228	18.9569542	0.09533523	8.75890833
NC2	-0.12298711	1.77465414	10.7038706	3.08261094	3.78804012	12.2005273	0.14332929	23.4684036
NC3	-0.10970819	1.45263998	4.78665868	2.71022047	1.65089969	3.204803	0.06947215	8.86024623
NC4	-0.10779757	0.67772318	5.05677251	2.71901092	1.46814511	2.68372487	0.06009323	8.33675547
NC5	-0.1268022	8.7440318	7.90442155	2.71745006	2.59848676	8.50380106	0.15829193	12.8795303
NC6	No Value	No Value	No Value	No Value	No Value	No Value	No Value	No Value
NC7	-0.13949178	-0.57551167	14.7317699	3.24447916	4.11537152	29.9837973	0.09993976	11.3337997
NC8	-0.13422117	-0.33817131	19.5884824	5.04827423	7.44181278	22.2036343	0.11091065	26.4222106
AC1	-0.15030455	-0.26511488	12.5417783	2.76005919	3.22490791	40.0445531	No Value	16.7685358
AC2	-0.15597018	-0.51194873	16.181379	2.60512789	2.31523404	37.8489123	No Value	11.9065281
AC3	0.00026818	0.1590338	5.15397782	3.31622388	3.46343985	11.318782	-0.61666675	28.0656987
AC4	0.0057598	0.836104	1.88373492	2.19721508	2.17032174	4.69345896	-0.66836516	21.861187
NEC1	-0.10704665	-0.58378694	4.22182025	1.49672813	1.33161161	2.83172337	0.04784245	8.52895145
WC1	-0.09903559	-0.56938826	3.38669171	40.1917098	0.06778637	0.07363804	0.03529212	5.12362961
WC1..1	-0.09382192	-0.5605908	2.0735268	1.00992387	-0.01413472	0.0105433	No Value	4.64193344
WC2	-0.13186878	1.96735888	3.45896081	1.31394032	0.1938717	0.52927295	No Value	3.42756633
WC3	-0.01045661	3.51359265	14.4338942	2.8604031	4.29776385	15.1706417	-0.43034375	22.467782
WC4	-0.03163718	-0.36434598	19.5421933	2.86305239	5.40005259	33.1662183	-0.52752582	10.1658355

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CC1	-0.00159522	-0.39015151	51.0137235	2.64686005	1.27293916	12.4201992	-0.56039535	8.67566763
CC2	0.01628351	-0.53978632	7.35012018	1.30662232	1.79305839	3.77318366	-0.71794159	8.58057993
CC3	-0.00655347	3.61865541	14.6331748	2.84539503	4.41727492	16.1082017	-0.404287	24.0086105
SC1	-0.14303342	0.39590922	24.8455934	2.8144704	4.51659225	19.2427495	No Value	10.6856774
SC2	0.02808448	-0.42264382	N/A	1.73351422	-0.10211921	0.32684538	-0.71339533	7.65913822
SC3	0.02516261	-0.51279435	N/A	1.76647481	-0.15597815	0.69519178	-0.71420649	5.41431438
SC4	0.0030756	0.01718836	4.38856843	2.17047805	2.84916791	6.26135834	-0.70055007	12.2261026
SC5	0.02842091	-0.27540639	144.673339	1.56475464	-0.25373072	0.16077731	-0.71507152	6.32317533
SC6	0.02927208	-0.48969618	N/A	1.8274601	-0.21194465	0.40022888	-0.71448358	6.51120878
SC7	0.00814035	-0.40170362	75.643226	3.3406236	1.5383087	6.61488601	-0.71373056	18.8004341
MC1	0.02613874	-0.53850157	124.536844	1.35750361	-0.30030479	0.9196394	-0.72110534	8.92314666
MC2	0.03880546	-0.52098427	131.236566	1.32755416	-0.33014128	0.32258711	-0.69873439	8.65305762
MC3	0.02446441	-0.50289659	N/A	1.87429036	0.07392732	1.27559509	-0.71762504	7.97417791
MC4	0.02313763	-0.50583612	N/A	2.72474913	-0.09579581	0.37511817	-0.71894892	9.43065155
MC5	0.02133487	-0.52981359	N/A	2.35286049	-0.19762943	0.33818459	-0.72062539	8.97245949
RC1	0.02600112	-0.51476489	110.222137	1.69776658	-0.35755521	-0.12789167	-0.72134091	9.95209531
RC2	0.0253144	-0.5016189	N/A	1.52600849	-0.2468396	0.27580789	-0.71413359	17.1091382
RC3	0.02508792	-0.52405251	101.174959	1.41775061	-0.33424057	-0.09712042	-0.72126119	21.1367087
RC4	0.02924039	-0.51863417	102.077349	1.4751833	-0.33611436	-0.06027987	-0.72082232	10.7944602
RC5	0.02266444	-0.46415314	97.6355174	1.53387038	-0.33634453	-0.07243587	-0.71801879	11.0481361
RC6	0.0352647	-0.53461702	116.634784	1.44040418	-0.34093116	-0.07419474	-0.7212402	9.49350795
RC7	0.02381734	-0.5349923	103.61975	1.26483141	-0.31740001	0.18533682	-0.72162514	13.8715858
RC8	0.02597479	-0.52285543	103.840686	1.37383399	-0.31952251	0.03217562	-0.7206853	16.1213617
RC9	0.03881481	-0.42955753	94.0119687	1.97667306	-0.23244129	0.39612158	-0.72023555	21.2624245
EPA MCL (mg/L)	0.2	0.3	none		none	none	0.05	none
Above MCL								
N/A= Conc. Levels Exceed Detection								
No Value= Test Error								
Element Detected								
Poultry Facilities								

D.4 Trace Element Results

Table D.3 Concentrations of selected trace metals measured at 50 groundwater sites throughout the Upper Pearl River watershed (Orange = Poultry Facilities, Blue = ICP-MS, Green = ICP-OES, Red = Above MCL). Given in mg/L. Negative values indicate below the machine's detection limit.

	Trace Element									
	Site Locatio	As (mg/L)	Pb (mg/L)	Cr (mg/L)	P (mg/L)	Cd (mg/L)	Cu (mg/L)	Hg (mg/L)	Zn (mg/L)	Sr (mg/L)
	LC1	0.00043	0.0006	0.00009	1.33	-0.00004	0.00191	0.0003	-0.00814	0.24669
	LC2	0.00048	0.00327	0.00458	1.11	0.00009	0.01428	0.00026	-0.00627	0.16717
	LC3	0.00043	0.00134	0.00413	1.15	-0.00005	0.01522	0.00018	-0.00692	0.11221
	LC4	0.00038	0.00385	0.0046	1.38	0.00008	0.0255	0.00015	-0.00288	0.02839
	LC5	0.00023	0.00177	0.00124	1.08	0.00001	0.01333	0.00019	-0.01115	0.00755
	LC6	-0.0163779	-0.0150858	-0.00032313	0.43948326	-0.00518708	0.00382535	0.07511708	0.018454182	0.029417004
	LC7	-0.02522505	-0.00522788	-0.00050689	0.1344574	-0.00586535	0.26005739	-0.01440447	0.209291856	0.388053124
	KC1	0.00017	0.00121	0.00119	1.21	0.00007	0.00773	0.00009	-0.0103	0.00476
🟧	KC2	0.00022	0.00304	0.00485	0.87	0.00003	0.02038	0.0001	-0.00179	0.91915
	NC1	0.00012	-0.00002	0.00188	1	-0.00002	0.00318	0.00002	-0.00903	0.60241
	NC2	0.00012	0.00027	0.00126	1.05	0.00001	0.00499	0.00008	-0.00476	0.32416
	NC3	0.00012	0.00089	0.00202	1.12	0.00002	0.00467	0.00007	-0.0088	0.11092
	NC4	0.00014	0.00117	0.00226	0.94	0.00002	0.00487	0.00008	-0.01074	0.05148
	NC5	0.00008	0.00169	0.00327	1.17	0.00004	0.00606	0.00001	-0.01026	0.22427
	NC6	0.00013	0.00262	0.00774	1.39	0.00005	0.01253	0.00001	-0.00961	0.44559
🟧	NC7	0.00015	0.00245	0.00709	1.05	0.00003	0.01184	0.00007	-0.00975	0.64434
🟧	NC8	0.00014	0.00161	0.00575	1.61	0.00004	0.00935	0.00005	-0.0077	0.45373
	AC1	0.00017	0.00025	0.00296	1.46	0.00005	0.00276	0.00004	-0.00345	0.45729
	AC2	0.00016	0.00001	0.00194	0.78	0.00003	0.00203	0.00001	-0.00068	0.53291
	AC3	0.02427009	0.00368481	-9.31E-05	0.08120091	-0.00593008	0.00695658	-0.04606793	0.021598522	0.210779811
	AC4	0.03115948	-0.00235861	-0.00032237	0.03604894	-0.00596691	0.0055273	-0.03500273	0.022543109	0.166205038
🟧	NEC1	-0.04959287	-0.00753024	-0.00265962	0.01110978	-0.00140205	0.06123682	0.04090991	0.063258087	0.0334813
	WC1	0.00022	0.0007	0.00091	1.02	-0.00004	0.00344	0.00013	-0.788818826	0.00614
	WC1..1	-0.0818623	-0.00630762	-0.00276261	0.0006971	-0.00207908	-0.00083214	-0.03481172	0.019696906	0.011420196
	WC2	-0.04457608	-0.01553546	-0.00218537	0.1530199	-0.0039474	-0.0009836	0.00401076	0.035734427	0.06719996
	WC3	-0.03259894	-0.00648132	-0.00055213	0.31082445	-0.00649416	0.00328637	-0.0190952	0.024200753	0.289981275
	WC4	0.01660983	0.00643753	-0.00095293	0.11348939	-0.00539032	0.00326742	-0.05570511	0.01961261	0.834673196

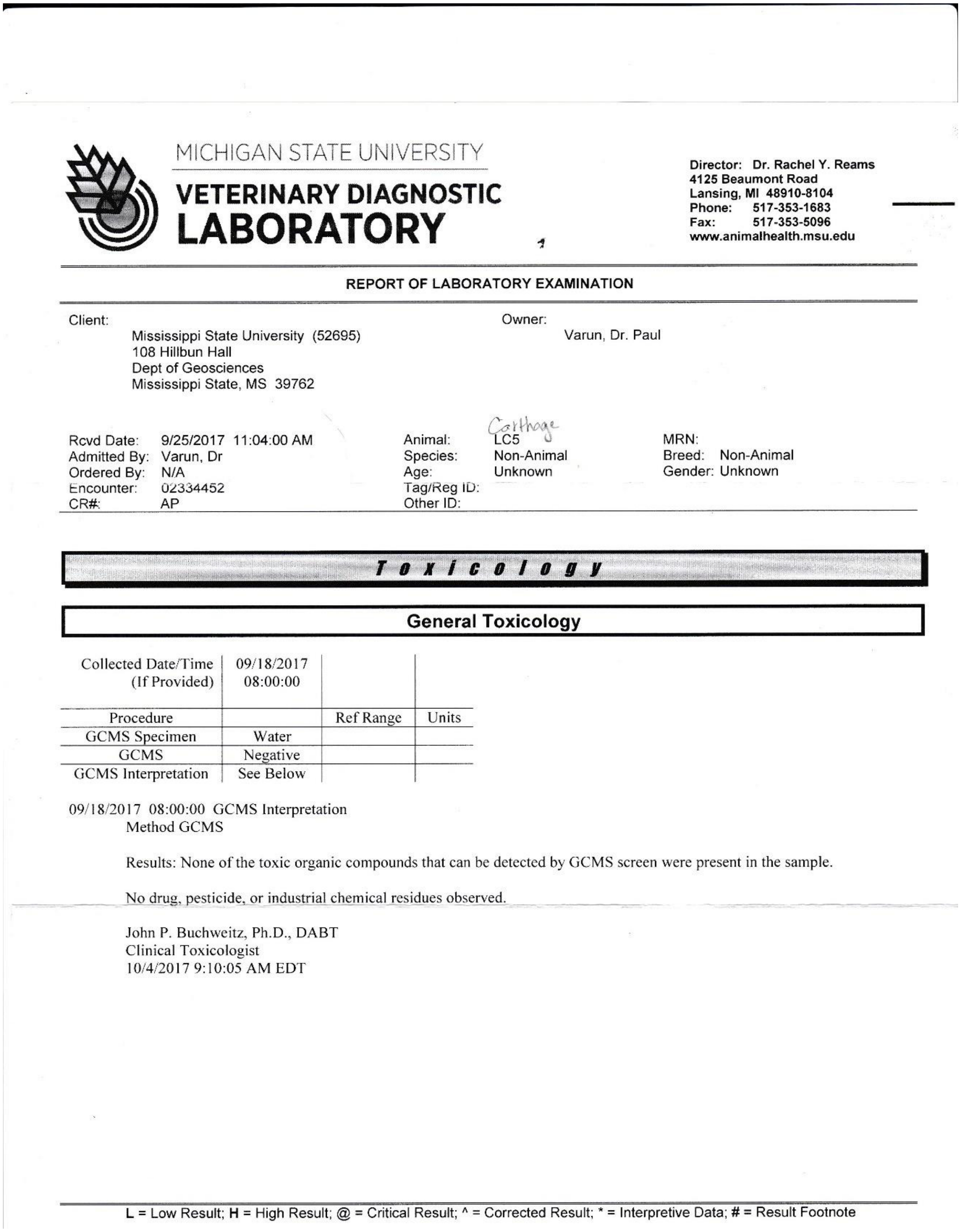
Fehler! Kein Text mit angegebener Formatvorlage im Dokument. (continued)

	CC1	0.03348786	-0.00542114	-0.00021505	0.15419979	-0.00576135	0.00433026	-0.05125319	0.019140117	0.142248555
	CC2	0.05221744	-0.00084929	-0.00055193	0.01914804	-0.0060061	0.00572272	-0.05039057	0.067039459	0.025496811
	CC3	-0.01435167	-0.01869952	-0.00014642	0.34659999	-0.00683346	0.0022355	-0.02494235	0.01836942	0.318573716
	SC1	-0.11412337	-0.00774348	-0.00261935	0.02594973	-0.00301834	0.01458054	-0.03864589	0.976480016	0.231886706
	SC2	0.03574767	-0.00558388	-0.00048137	0.40647731	-0.0058466	0.0034385	-0.06131797	0.017684085	0.040419068
	SC3	-0.05630927	-0.00354823	-3.30E-05	0.41192894	-0.00556305	0.00422279	-0.02234044	0.019058182	0.024304632
	SC4	0.01844225	0.00218416	3.07E-06	0.02732841	-0.00546423	0.00326693	-0.03793041	0.015012866	0.085591723
	SC5	0.03156699	-0.00055777	-0.00028584	0.49456652	-0.00622758	0.00481149	-0.05220998	0.019733784	0.016842077
	SC6	-0.01985199	-0.00696169	-0.00024802	0.46744271	-0.00528394	0.00557191	-0.06024247	0.017336348	0.023448311
	SC7	0.00071316	-0.00646007	-0.00049968	0.06203054	-0.00541115	0.00391124	-0.05849144	0.024757796	0.208267634
	MC1	0.0602877	-0.01170495	-4.33E-05	0.24281895	-0.00592781	0.00505038	-0.06005626	0.01830932	0.030712855
	MC2	-0.01145491	-0.01012195	-0.00019932	0.27540589	-0.00533457	0.0029937	-0.05693884	0.017095708	0.02095299
	MC3	0.0033138	-0.01013443	0.00022699	0.38384394	-0.00563708	0.00849589	-0.05495294	0.031927882	0.052140618
	MC4	0.03391505	-0.00587624	0.00070339	0.31903906	-0.00544225	0.00451449	-0.05325673	0.019298293	0.040311716
	MC5	0.0199378	0.00680378	0.00081449	0.27231768	-0.00549065	0.00482159	-0.06035017	0.007929587	0.026627891
	RC1	-0.01937927	-0.00887261	-0.00059461	0.1704325	-0.00571578	0.00426417	-0.02618558	0.004917771	0.013467291
	RC2	0.05666022	-0.00115791	1.40E-05	0.31216334	-0.00633217	0.00316524	-0.05043127	0.014356679	0.016561412
	RC3	0.02855326	-0.00103497	-0.00014772	0.15291684	-0.00674734	0.00631877	-0.05621598	0.031642075	0.01316412
	RC4	-0.08289042	-0.00703435	-0.00076933	0.15668567	-0.00588006	0.00369152	-0.06320777	0.020603097	0.013961308
	RC5	-0.06231176	-0.01262067	-0.00129105	0.11225239	-0.00629181	0.00415423	-0.05530032	0.017812821	0.014707483
	RC6	-0.04163926	-0.00710303	-0.00080026	0.14852564	-0.00574797	0.00469516	-0.06410529	0.024096061	0.01412104

Fehler! Kein Text mit angegebener Formatvorlage im Dokument. (continued)

	RC7	-0.01685398	-0.01539631	-0.00058535	0.23089946	-0.00615942	0.00315485	-0.05879961	0.012545124	0.014400366
	RC8	-0.07674282	-0.01524831	0.00091183	0.22336193	-0.00604577	0.00362498	-0.05568381	0.006574505	0.013169232
	RC9	-0.10586664	-0.00047063	0.00041004	0.10260014	-0.00647215	0.00420149	-0.05814986	0.008333962	0.029360541
EPA drinking water MCL		0.01mg/L	0.015mg/L	0.1	N/A	0.005mg/L	1.3mg/L	0.002mg/L	5mg/L	N/A
Above MCL										
Ran by ICP-MS										
Ran by ICP-OES										
Poultry Facilities										

D.5 Pharmaceutical Results



MICHIGAN STATE UNIVERSITY
VETERINARY DIAGNOSTIC LABORATORY

Director: Dr. Rachel Y. Reams
4125 Beaumont Road
Lansing, MI 48910-8104
Phone: 517-353-1683
Fax: 517-353-5096
www.animalhealth.msu.edu

REPORT OF LABORATORY EXAMINATION

Client:
Mississippi State University (52695)
108 Hillbun Hall
Dept of Geosciences
Mississippi State, MS 39762

Owner:
Varun, Dr. Paul

Rcvd Date: 9/25/2017 11:04:00 AM
Admitted By: Varun, Dr
Ordered By: N/A
Encounter: 02334452
CR#: AP

Animal: Carthage LC5
Species: Non-Animal
Age: Unknown
Tag/Reg ID:
Other ID:

MRN:
Breed: Non-Animal
Gender: Unknown

Toxicology

General Toxicology

Collected Date/Time (If Provided)	09/18/2017 08:00:00		
Procedure		Ref Range	Units
GCMS Specimen	Water		
GCMS	Negative		
GCMS Interpretation	See Below		

09/18/2017 08:00:00 GCMS Interpretation
Method GCMS

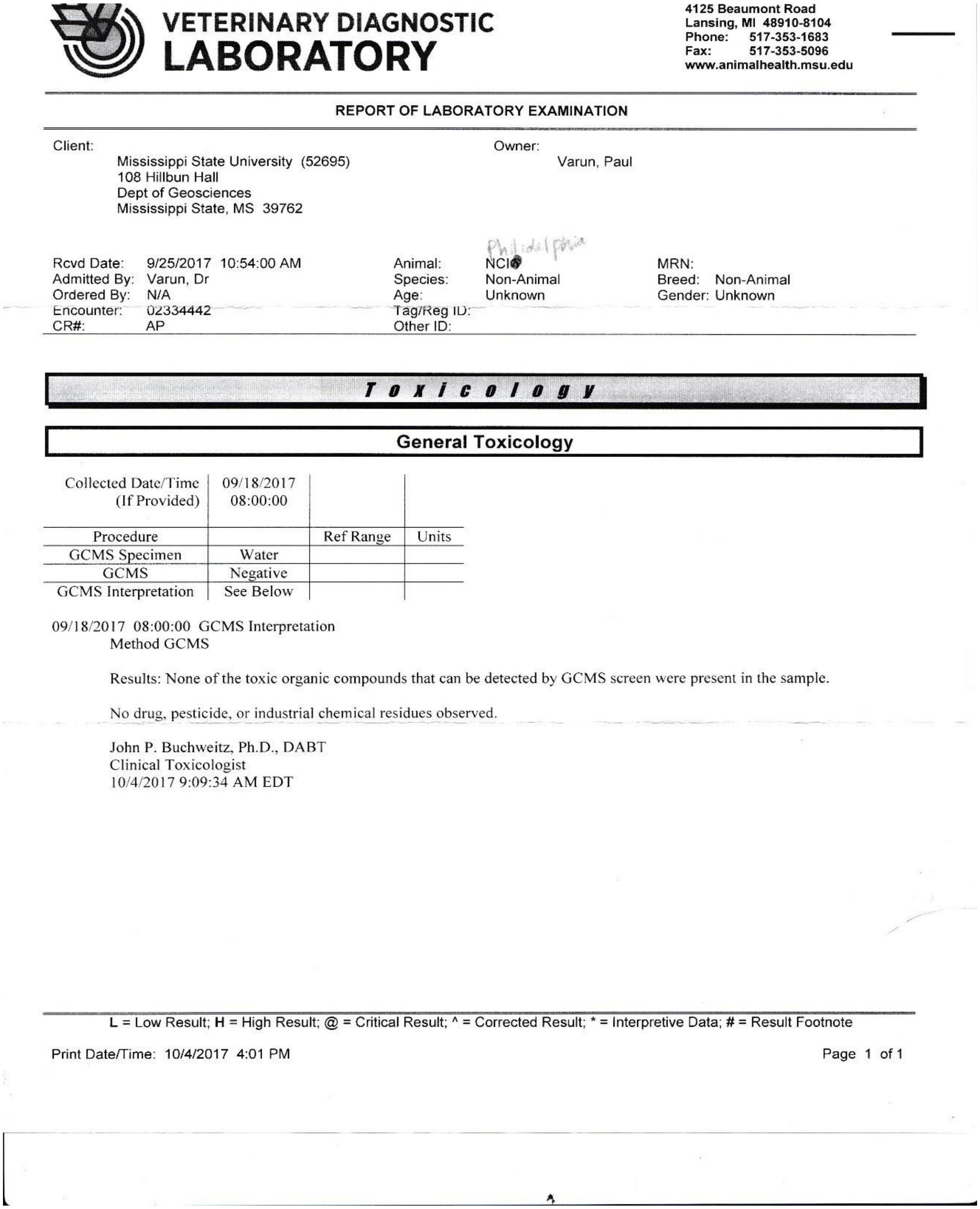
Results: None of the toxic organic compounds that can be detected by GCMS screen were present in the sample.

No drug, pesticide, or industrial chemical residues observed.

John P. Buchweitz, Ph.D., DABT
Clinical Toxicologist
10/4/2017 9:10:05 AM EDT

L = Low Result; **H** = High Result; @ = Critical Result; ^ = Corrected Result; * = Interpretive Data; # = Result Footnote

Figure D.2 Pharmaceutical results of Carthage, LC5.



VETERINARY DIAGNOSTIC LABORATORY

4125 Beaumont Road
Lansing, MI 48910-8104
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REPORT OF LABORATORY EXAMINATION

Client:
Mississippi State University (52695)
108 Hillbun Hall
Dept of Geosciences
Mississippi State, MS 39762

Owner:
Varun, Paul

Rcvd Date: 9/25/2017 10:54:00 AM
Admitted By: Varun, Dr
Ordered By: N/A
Encounter: 02334442
CR#: AP

Animal: NCI Philadelphia
Species: Non-Animal
Age: Unknown
Tag/Reg ID:
Other ID:

MRN:
Breed: Non-Animal
Gender: Unknown

Toxicology

General Toxicology

Collected Date/Time (If Provided)	09/18/2017 08:00:00		
Procedure		Ref Range	Units
GCMS Specimen	Water		
GCMS	Negative		
GCMS Interpretation	See Below		

09/18/2017 08:00:00 GCMS Interpretation
Method GCMS

Results: None of the toxic organic compounds that can be detected by GCMS screen were present in the sample.

No drug, pesticide, or industrial chemical residues observed.

John P. Buchweitz, Ph.D., DABT
Clinical Toxicologist
10/4/2017 9:09:34 AM EDT

L = Low Result; H = High Result; @ = Critical Result; ^ = Corrected Result; * = Interpretive Data; # = Result Footnote

Print Date/Time: 10/4/2017 4:01 PM

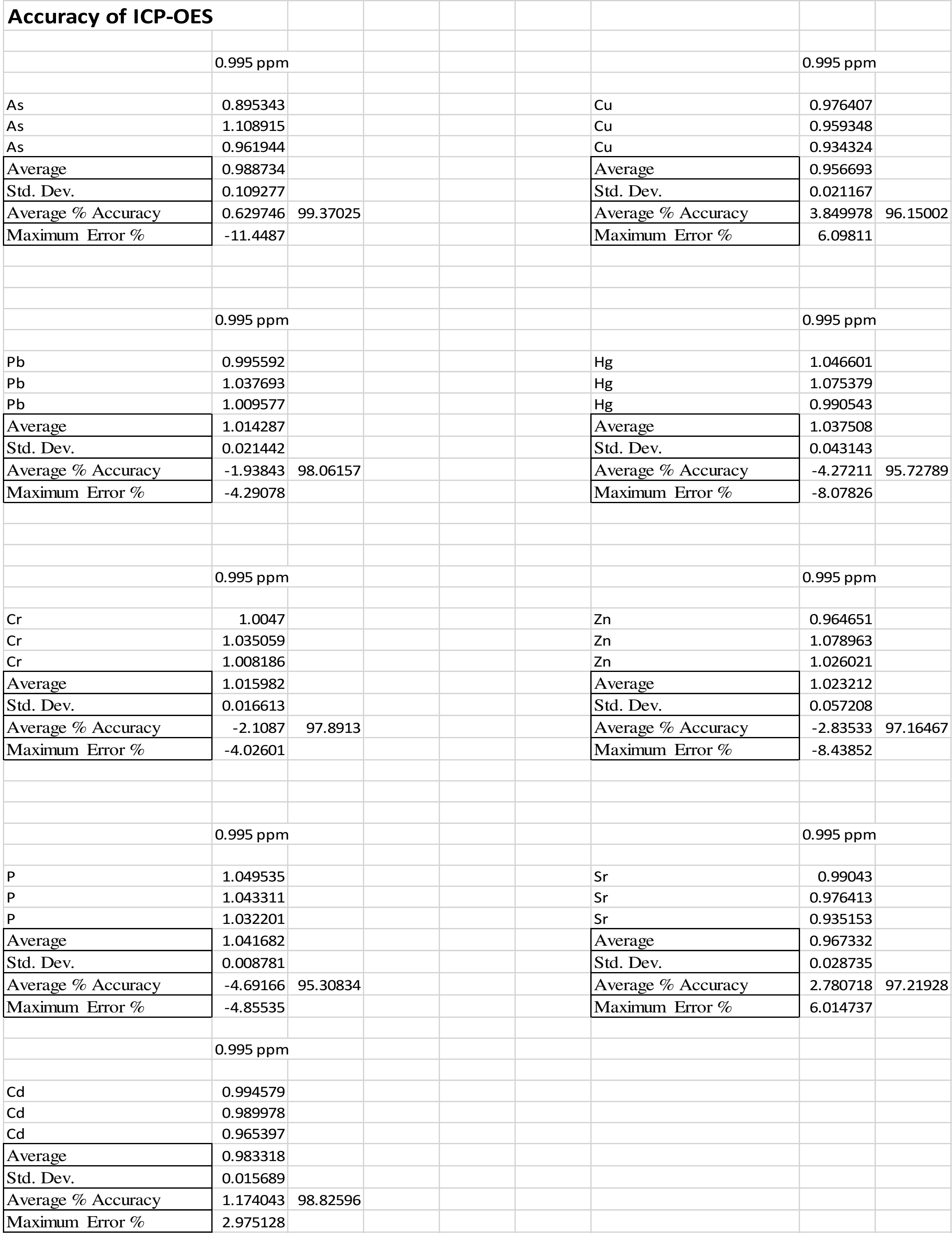
Page 1 of 1

Figure 7.13D.2 (continued)

Pharmaceutical results of Philadelphia, NC1.

D.6 Accuracy and Error Percentages of ICP-OES

Table D.4 ICP-OES trace metal accuracy and error percentages.



Accuracy of ICP-OES					
	0.995 ppm			0.995 ppm	
As	0.895343		Cu	0.976407	
As	1.108915		Cu	0.959348	
As	0.961944		Cu	0.934324	
Average	0.988734		Average	0.956693	
Std. Dev.	0.109277		Std. Dev.	0.021167	
Average % Accuracy	0.629746	99.37025	Average % Accuracy	3.849978	96.15002
Maximum Error %	-11.4487		Maximum Error %	6.09811	
	0.995 ppm			0.995 ppm	
Pb	0.995592		Hg	1.046601	
Pb	1.037693		Hg	1.075379	
Pb	1.009577		Hg	0.990543	
Average	1.014287		Average	1.037508	
Std. Dev.	0.021442		Std. Dev.	0.043143	
Average % Accuracy	-1.93843	98.06157	Average % Accuracy	-4.27211	95.72789
Maximum Error %	-4.29078		Maximum Error %	-8.07826	
	0.995 ppm			0.995 ppm	
Cr	1.0047		Zn	0.964651	
Cr	1.035059		Zn	1.078963	
Cr	1.008186		Zn	1.026021	
Average	1.015982		Average	1.023212	
Std. Dev.	0.016613		Std. Dev.	0.057208	
Average % Accuracy	-2.1087	97.8913	Average % Accuracy	-2.83533	97.16467
Maximum Error %	-4.02601		Maximum Error %	-8.43852	
	0.995 ppm			0.995 ppm	
P	1.049535		Sr	0.99043	
P	1.043311		Sr	0.976413	
P	1.032201		Sr	0.935153	
Average	1.041682		Average	0.967332	
Std. Dev.	0.008781		Std. Dev.	0.028735	
Average % Accuracy	-4.69166	95.30834	Average % Accuracy	2.780718	97.21928
Maximum Error %	-4.85535		Maximum Error %	6.014737	
	0.995 ppm				
Cd	0.994579				
Cd	0.989978				
Cd	0.965397				
Average	0.983318				
Std. Dev.	0.015689				
Average % Accuracy	1.174043	98.82596			
Maximum Error %	2.975128				