ABSTRACT

LEE, JONG-HWA. Spatial Econometric Analysis of a Watershed Utilizing Geographic Information Systems: Water Quality Effects of Point and Non-Point Pollution Sources in the Neuse River Basin, NC. (Under the direction of Professor Kelly D. Zering.)

This study utilizes elements of several different fields of study to facilitate more effective and efficient policy development for water pollution control. In order to implement efficient environmental policy, spatial aspects of watersheds should be carefully incorporated into empirical analysis. The geographical attributes of a watershed induce various spatial stochastic processes, causing surface water quality data in streams to have a unique spatial structure. In this study, geographical data of watersheds are collected and manipulated to find a consistent basis for comparing measures of pollution sources with variations in water quality across hydrologic units in the Neuse River basin in North Carolina.

This research seeks to calibrate an empirical watershed model using available spatial (statistical) analytical techniques. Methods are demonstrated of utilizing Geographic Information Systems (GIS) to convert data from multiple sources to a common basis for water quality analysis. A spatial autoregressive response model is chosen considering spatial aspects of a regional watershed, and a corresponding structural watershed model is constructed. The empirical watershed model is designed to incorporate spatial effects and to produce accurate estimates. The model specifies that the spatially weighted sum of neighbor water qualities (total nitrogen [TN] concentrations) affects the TN concentration of each downstream monitoring unit, as do the standard covariates of local pollution sources and heterogeneous watershed characteristics. The completed standard econometric analysis includes cross-sectional estimation of several functions predicting TN concentration in streams conditional on watershed characteristics and potential sources of TN in the hydrologic unit.

Results show that a clear understanding of regional spatial capacity will help avoid overuse of water resources. Specific knowledge of spatial information and empirical relationships allows improved design of controls on economic activity across regions (e.g., Total Daily Maximum Daily Load [TMDL] and nutrient trading programs) to preserve environmental resources. The study concludes by recognizing that a more robust watershed analysis would require more spatial data refinement and the option of panel data analysis.

SPATIAL ECONOMETRIC ANALYSIS OF A WATERSHED UTILIZING GEOGRAPHIC INFORMATION SYSTEMS: WATER QUALITY EFFECTS OF POINT AND NON-POINT POLLUTION SOURCES IN THE NEUSE RIVER BASIN, NC

by

JONG-HWA LEE

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Chair of Advisory Committee

To
My wife, Kyong-Sook,
My beloved children, Woong-Soo and Yon-Soo,
and my mother

사랑하는 나의 아내와,
나의 천사들 웅수와 연수,
그리고 어머니께

BIOGRAPHY

Jong-Hwa Lee was born in Seoul, Korea, on March 7, 1966. He received his Bachelor of Science degree in Economics from Chung-Nam National University in Taejon, Korea, in 1993. After completing his undergraduate degree, he studied as a full-scholarship exchange student in a one-year program at Stephen F. Austin State University in Nacogdoches, Texas, from 1993 to 1994. Then he transferred to Texas Tech University in Lubbock, Texas, where he obtained a Master of Arts degree in Economics in 1996. Since then, he has been studying for the Ph.D. degree in Economics at North Carolina State University in Raleigh.

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I am very grateful to many people in the Department of Water Quality, the North Carolina Department of Environmental and Natural Resources, and the U.S. Geological Survey. These people shared with me a great deal of technical expertise and data information, helping me to understand many aspects of the topic of water quality—a subject in which I, as an economist, had no background on at all before I began this dissertation.

Last, but very specially, I wish to extend my deepest thanks to my wife, who always understood what I was going through and who shared every difficult moment with me during the course of my studies and the writing of my dissertation. Her love and her faithful heart have always been with me. My children, Woong-Soo and Yon-Soo, have always supported me with their pure and beautiful souls. They are very special to me.

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1. INTRODUCTION

Water pollution generates externalities and prevents socially optimal allocation of environmental resources. Theoretically, this market imperfection problem can be solved by the use of a price or control mechanism to curb externality-generating resource use. Despite the tremendous efforts of both economists and ecologists to solve these problems over the past several decades, water resources continue to be misallocated. In order to implement corrective mechanisms, we first need to gain a better understanding of the interaction between pollution sources and water quality degradation.

Due to the diffusive nature of pollution processes in watersheds, it has been almost impossible to precisely identify the effects of specific pollution sources. Now, however, rapid development of technology is making geographical data sets more accessible. There is a strong need to implement appropriate empirical methodology to account for common spatial effects based on this newly available spatial information (Anselin 2001).

The relationship between sources of pollution and water quality variations is well established in the literature. Perspectives on the complex spatial dimensions of the relationship are abundant in the ecological literature, but applications of appropriate statistical methodology are limited. Stream ecologists have recognized the solid effects of the surrounding land use activities of different spatial scales on streams (Harding *et al*. 1998). Landscape ecologists are looking for more useful methods to characterize relationships between landscape attributes and water quality at various spatial scales (Hunsaker *et al*. 1992). Many analyses have been done, but as Harding notes, understanding "of the linkages among ecological processes that shape biodiversity, biotic communities, and watershed conditions is far from complete" (1998:14846).

The present research seeks to calibrate an empirical watershed model using available geographical data and spatial (statistical) analytical techniques. It is now possible to develop better quantitative descriptions of complex spatial interactions between water quality variations and external pollution sources, based on the analysis of a model calibrated with spatial data. We hypothesize that the relationship between water quality and external pollution sources is affected by spatial features inherent in a regional watershed, and not just by specific features of certain regions.

The structure of this dissertation is based on the development of a spatial understanding of the watershed. Systematic applications of currently available spatial analysis techniques (Geographic Information Systems [GIS], geostatistics, and spatial econometrics) are employed. In Chapter 2, conceptual theories are introduced as a basis for empirical analysis. The externality problem is illustrated using a simple general equilibrium model. From this theoretical basis, a reaction function for water quality is generated, applying Brueckner's (2003) strategic interaction theory. Chapter 3 reviews the spatial characteristics of a watershed and discusses corresponding analytical issues and modeling. Methodologies for incorporating spatial effects (spatial dependence and spatial heterogeneity) are discussed. Chapter 4 discusses the importance of spatial analysis tools based on GIS. Utilizing GIS, data are manipulated into their final formats using general spatial data information relevant to water quality, pollution sources, and land cover data sets from various sources. Final watershed analyses and empirical test results are presented in Chapter 5, where responses to several statistical problems are also presented. Chapter 6 presents discussions of the validity of methods and data for the analyses and further interpretations of the results. Chapter 6 concludes with policy implications, limitations of the research, and issues for further research.

2. THEORIES

2.1 Motivation

Efficient resource allocation is a major goal in economics. However, socially optimal allocation cannot be achieved automatically due to market imperfection and incomplete information. This section presents a systematic review of how the externality problem of environmental pollution can occur, using a simple general equilibrium model of an economy characterized by suboptimal allocation of resources. This model will then be extended to a conceptual watershed model in Section 2.2.

We assume a model of a simple economy[1] in that we have two representative agents: one representative firm consuming the environmental resources for its production activity and one representative agent (society) enjoying the environmental resources. Also, there are two goods: an environmental resource and a consumption good produced by a representative firm. The firm is owned by society itself; that is, we assume that society is the sole owner of the firm. The society has an endowment of $\overline{E}$ units of environmental resources and no endowment of economic output. The society has continuous, convex, and strongly monotone preferences defined over its consumption of environmental resource e and economic output x. The firm utilizes environmental resources for output production corresponding to the increasing and strictly concave production function $f(r)$, where r is the firm's input, using environmental resources.

The fact that an industry discharges polluting substances into the environment means that environmental resources are used as a production input factor. Therefore, by purchasing

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[1] The model is a direct application of Mas-Colell *et al*. (1995).

the environmental resources, the firm produces output, and this causes the environmental degradation. Here we can regard *e* and *r* as the levels of environmental quality and environmental degradation respectively. The combination in which these marketable outputs and bad side effects are generated is not fixed but rather depends on the production method chosen. Generally, several production methods are available that vary both in their costs and in their environmental impacts. As long as environmental resources are free or underpriced, they are consumed as production inputs at higher-than-optimal rates.

Without loss of generality, we assume that there is a known positive price of using environmental resources. In that way we can avoid a situation in which the firm uses all of the resources for its production. We also suppose that, with the market prices given, the firm tries to maximize its profits. Then the firm's problem is

$$\text{Max} \quad p_1 f(r) - p_2 r, \tag{2.1.1}$$

where p_1 is the price of economic output and p_2 is the price of environmental resources (or p_2 is the cost the society needs to pay for the degradation of environmental quality). Given prices (p_1, p_2), the firm's optimal demand of environmental resources is $r(p_1, p_2)$, its output is $q(p_1, p_2)$, and its profits are $\pi(p_1, p_2)$.

Society's problem is

$$\begin{aligned} &\underset{(e,x)\in \mathrm{R}^2_+}{\text{Max}} \quad u(e, x) \\ &\text{s.t.} \;\; p_1 \mathrm{x} \leq p_2(\overline{E} - e) + \pi(p_1, p_2). \end{aligned} \tag{2.1.2}$$

The constraint in Equation 2.1.2 indicates the two sources of the society's purchasing power. The optimal demands of society in problem 2.1.2 for prices (p_1, p_2) are denoted by ($e(p_1, p_2), x(p_1, p_2)$).

Implicit in this constraint is the physical production or transformation function

$$q = f(r). \tag{2.1.2a}$$

Walrasian equilibrium in this simple model involves a price vector (p_1, p_2) at which the markets of consumption good and resource clear in the following manner:

$$x(p_1{*}, p_2{*}) = q(p_1{*}, p_2{*}) \tag{2.1.3}$$

and

$$r(p_1{*}, p_2{*}) = \overline{E} - e(p_1{*}, p_2{*}).$$

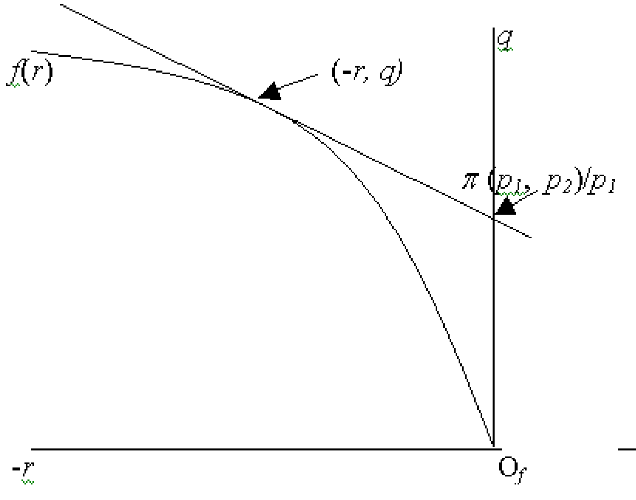

Figure 2.1: The Firm's Problem

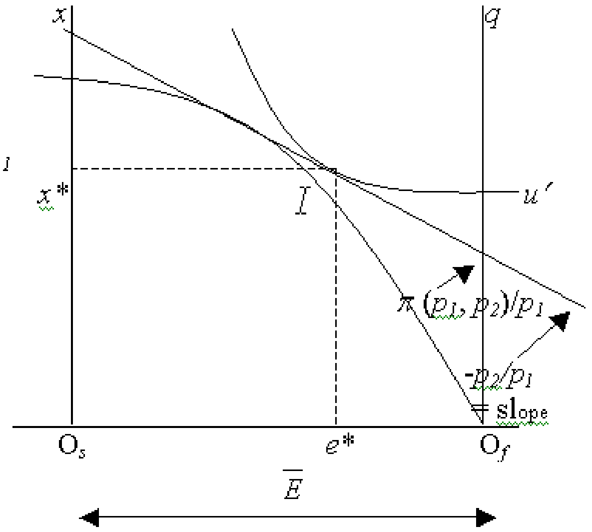

Figure 2.2: The Society's Problem

Figures 2.1 and 2.2 demonstrate the model analyzed so far. In Figure 2.1, negative quantity of the firm's environmental resources usage is measured on the horizontal axis. On the vertical axis, the output is delineated. Society's problem is shown in Figure 2.2. Environmental resources and consumption levels of society are measured from the origin, denoted $O_{s.}$

Note here that if the society consumes $\overline{E}$ units of environmental resources, then since the firm is not purchasing any resources, $\pi\,(p_1,p_2)/p_1 = q - (p_2/p_1)r$ units of economic output are available for society. For each unit of environmental resources the firm purchases, the society earns p_2 and thus can purchase p_2/p_1 units of x. The prices depicted in Figure 2.2 are not equilibrium prices. The firm is using too much of the environmental resources at these prices. The firm uses more resources than the quantity demanded by society at p_2 (i.e., $r(p_2) > E - e(p_2)$) and so is creating more than the optimal level of environmental pollution.

From the result above, it follows that with environmental resources being priced too low, the society will experience the generation of externalities. When the market fails to impose the appropriate social costs on generators of pollution, the level of pollutants generated is higher than socially optimal. From the firm's point of view, the economically efficient course of action is to ignore external damage costs, which leads to the production of residual pollutants at levels higher than socially optimal (Weersink *et al.* 1998:311).

The externality is unavoidable in the presence of market imperfection; thus, without sensible environmental policies, the problem will continue. We know that by raising p_2, creating a higher price for society's environmental attributes via social planners' decisions or other policy changes, the problem might be solved, achieving Pareto-optimal allocation – the Walrasian equilibrium. The question, however, is how society can achieve its goal.

Solutions derived in environmental policy theory generally require knowledge of the interaction between pollution sources and environmental (e.g., water) quality. In order to develop practical strategies for approaching the equilibrium, as represented in Equation 2.1.3, society must know the exact relationship between environmental quality problems and pollution sources, $q = f(r)$, or inversely, $e_i = f(x_i)$. In particular, before any price for the use of resources can be imposed or a market for pollution discharge rights can be established, it is crucial to know each source's contribution to the aggregate environmental degradation.

In the next section, the theoretical framework presented above is extended to a conceptual watershed model.

2.2 Conceptual Watershed Model

From the theoretical overview in Section 2.1, it follows that our interest should be directed toward the physical relationship between sources of pollutants and measures of environmental degradation (the externality), so that optimal strategies can be devised to limit and allocate pollutants across sources to achieve society's environmental (e.g., water quality) goals efficiently and effectively. We will use the model of societal preference from Section 2.1 to construct an empirical (physical) model of environmental quality control in a watershed.

A recent modeling effort by Brueckner (2003) showed the specification of the strategic interaction between agents that leads to the construction of the spatial reaction function. One of the frameworks used is a spillover model. The model shows "how the magnitude of a decision variable for an economic agent depends on the magnitudes of the decision variables set by other economic agents" (Anselin 2002). Anselin notes this view extends to the theoretical basis for a spatial autoregressive model (2002:4), and we can directly apply this model to our problem. In our case, the application deals with the interaction between the measures of water quality in various hydrologic units and their relationship to possible sources of pollutants upstream.

We can extend the preference function (Equation 2.1.2) to the following equation,

$$U = U\,(x_i,\ e_i;\ C), \tag{2.2.1}$$

where x_i is economic output in hydrologic unit i, e_i is environmental quality in hydrologic unit i, and C is a set of characteristics in a regional unit we consider.

Because we consider water quality, we replace e with y to obtain:

$$y_i = g\,(\sum_{j=1}^{n} y_j\,), \tag{2.2.2}$$

where y is the measure of water quality; y_i (the water quality in a unit) is a function g of the summation of the water quality measures of upstream units, $j < i$ and $j = 1, \ldots, n$; and n is the number of upstream hydrologic units that are contiguous with unit i. Thus, we can consider the water quality, y_i and y_j, of different units in a preference function. Note here that society's constraint function (Equation 2.1.2) in Section 2.1 can be generalized to the following specification:

$$\begin{aligned} X &= f\,(R) \\ &= f\,(E - e), \end{aligned} \tag{2.2.3}$$

where E is the societal resource, X is the economic output, R is the resource consumed in production, and e is the aggregate resource consumption/environmental quality by society.

For individual units, we have

$$
\begin{aligned}
x_i &= f(\mathrm{r_i}) \\
&= f(\mathrm{E_i} - e_i) \qquad (2.2.4)
\end{aligned}
$$

and

$$\mathrm{r_i} + e_i = \mathrm{E_i}.$$

After substituting Equation 2.2.4 into Equation 2.2.1, we can have a newly arranged preference function for agents in unit *i*.

$$\mathrm{U} = \mathrm{U}\ (f(\mathrm{r_i}), g\ (\sum_{j=1}^{n} y_j\ );\ \mathrm{C}) \equiv \mathrm{V} = \mathrm{V}(y_i, y_j;\ \mathrm{C}) \qquad (2.2.5)$$

where V represents the objective function of the hydrologic unit *i*'s agents, implying the spillover effects from the upstream neighbor(s). Note that an increase in water quality in the upstream unit y_j increases utility derived from water quality in downstream units *i* via the function *g* (Brueckner 2003:177).

In this model, agents in *i* choose water quality, y_i, to maximize the objective function (Equation 2.2.5), so that

$$\frac{\partial V}{\partial y_i} \equiv V_{y_i} = 0. \qquad (2.2.6)$$

Following Brueckner, the solution to this objective maximization problem is:

$$y_i = g(y_j;\ C_i). \qquad (2.2.7)$$

Equation 2.2.7 represents a reaction function, which gives unit *i*’s water quality response to the other unit's water quality and C of the unit itself (cf. Brueckner 2003: 177). That is, "the effect of explanatory variables, C_i, at any site may not be limited to the specific site" (Haining 1990: 30); rather, it is a function of neighborhood sites' attributes. As applied in spatial econometric modeling, the theoretical result is used here to construct an empirical model – the physical model of watershed assessment.

From the general reaction function (Equation 2.2.7), a spatial autoregressive (AR) model can be constructed as follows (Brueckner 2003: 182), "where the value of a variable at one point is related to its values in the rest of the spatial system" (Anselin 1988: 33):

$$\mathbf{y} = \rho\mathbf{W}\mathbf{y} + \mathbf{C}\beta + \varepsilon \tag{2.2.8}$$

$$= \rho\mathbf{W}\mathbf{y} + \mathbf{X_1}\beta_1 + \mathbf{X_2}\beta_2 + \varepsilon. \tag{2.2.8a}$$

This is a mixed regressive spatial AR model, where **y** represents the water quality indicator vector, **C** is the matrix of descriptors of the hydrologic unit including pollution sources ($\mathbf{X_1}$) and land use land cover (LULC) characteristics ($\mathbf{X_2}$), **W** is a weight matrix, ρ is a spatial autocorrelation parameter, and ε is a random error vector. The model specifies that the spatially weighted sum of neighbor water qualities affects the nutrient level of each downstream monitoring unit as well as the general covariates of pollution sources and heterogeneous characteristics in each geographical unit. This is a starting model that is intended to capture the spatial spillover effect.

As we see in Equation 2.2.7, there is a spatial endogeneity in the reaction function that is problematic in standard analytical procedures in regional science analyses. This is an important issue that needs to be addressed in application of the model to watershed analysis. Given the theoretical conceptual model of our topic, the question is how to construct the spatial econometric model. Our next step is to explore a link between a spatial dynamic and a cross-sectional behavioral model. Specification of a useful physical model can be supported and strengthened by clear understanding of the ecological and spatial processes of a watershed.

3. MODEL DEVELOPMENT

3.1 Background: Spatial Aspects of a Watershed

Watersheds are functional geographical areas that integrate a variety of environmental processes and human impacts on landscapes.[2] In Section 2.2, we used theory to conceptualize the spatial functional relationships that affect water quality in a watershed. In this section, we discuss practical spatial aspects of a regional watershed in order to link the conceptual model to the cross-sectional behavioral model. We ask, along with Anselin (2003), "What are the proper behavioral units, how do space and boundary matter, is space discrete or continuous, and how can the endogeneity of space be accounted for?"

Water quality data should reveal information on spatial structures that are the outcome of spatial processes associated with nutrient exports and imports in a particular watershed. Environmental processes do not uniformly and smoothly impact all regions, but may have differing consequences at a regional scale due to spatial effects. The spatial patterns in water quality data and their relationships to pollution sources can be identified quantitatively based on an understanding of spatial process mechanisms for generating spatial objects' attributes.

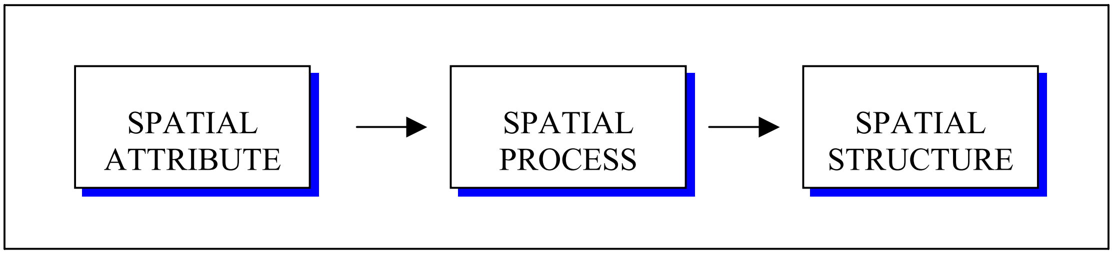

FIGURE 3.1: SPATIAL ATTRIBUTE VALUE ESTABLISHMENT

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[2] Related technical issues are discussed in chapter 4.

Figure 3.1 summarizes the discussion of the spatial attribute value establishment process. Spatial attribute properties produce "changes of states" in spatial processes, and the process functions constitute a spatial structure (Haining 1990). The resulting structure information can be obtained as spatially referenced data from which we seek empirical patterns. "The presence of spatial structure in the distribution of residuals is usually an indication of failure to account for important elements of the problem" (Haining 1990:45). Thus, for exact modeling of spatial interaction, it is important to first understand the dynamics of the process under investigation.

Haining (1990:24-5) points out four types of processes: (1) diffusion, (2) exchange and transfer, (3) interaction, and (4) dispersal and spread. The various spatial processes can be integrated in a watershed. For this study, we are interested in how variations of spatial effects across regions affect certain types of analyses of regional watershed water quality variation. Figure 3.2 shows a simple spatial feature of a watershed with various land use activities (A, B, and C). Land characteristics are assumed to differ between regions I and II. The observed values of the relevant variables are assumed to be the result of the processes represented in Figure 3.2.

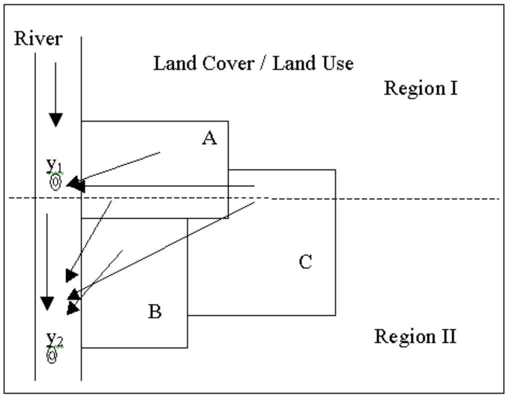

FIGURE 3.2. A SIMPLE EXAMPLE OF A SPATIAL PROCESS IN A WATERSHED

From Figure 3.2, we see that multiple processes transport pollutants from pollution sources and affect water quality *y* at the downstream end of regional units I and II. The geographical region is usually called a "hydrologic unit" of a segmented watershed.[3] Thus, the representation of all effects of the process can be measured as a level of each source indicator and shows the relevant structure of the spatial data information. When water quality is measured at the end of each hydrologic unit (at y_1 and y_2), the resulting indicator represents the spatial nature of all the processes that occurred in the entire hydrologic unit. Irregular spatial units may affect the delivery of pollution sources to the corresponding streams.

We expect two distinct types of spatial effects to be inherent in a watershed: the spatial externality of spillover, and heterogeneity. Based on the unique characteristics of a watershed, we may see the unidirectional spillover effect along the stream. The process of water quality determination may be consistent with a spatial diffusion process of nutrient exports around the specific region. A certain amount of information carried within each observation is duplicated by other observations (Haining 1990), and this may be important in explaining how water quality is affected by some sources. The magnitude of a spatial externality should be considered to the extent that water quality shocks in neighboring watersheds affect each other. Thus, the "neighbor" concept comes into play from a practical point of view. The spillover process between neighboring units can be affected by the physical boundary and corresponding characteristics of hydrologic units. A discussion of how to incorporate the spillover effect into analyses is presented in Section 3.2.

Ecological models may incorporate the effect of heterogeneity in a watershed. Land cover characteristics, such as soil permeability and slope, typically affect the process of

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[3] For more explanation of the "hydrologic unit," see Section 4.1.1 in Chapter 4.

nutrient delivery to streams (Smith et al. 1997). Also, any unobserved differences in regional economic conditions may result in errors being different in different parts of a region but related in nearby areas.

The reaction function (Equation 2.2.7),

$$y_i = g(y_j; C_i),$$

is specified in Section 2.2. It can include those effects and can be further specified as the following:

$$y_i = g(y_j, X_{\mathrm{i},1}(PP_i, NP_i), X_{\mathrm{i},2}(HC_i)), \tag{3.1.1}$$

where y_i and y_j represent the water quality indicator of each unit *i* and the upstream neighbor unit *j*. $X_{i,1}$ represents pollution sources as a functions of point and nonpoint sources, and $X_{i,2}$ represents heterogeneous hydrologic unit variables (as a function of land or stream characteristics variables) as the independent variables, where *i* corresponds to the spatial (hydrologic) unit of a regional watershed. *PP* represents point source pollution*,* *NP* represents nonpoint source pollution*,* and *HC* represents the heterogeneous characteristics (land cover or stream characteristics) respectively.[4] Equation 3.1.1 specifies that water quality varies due to pollution from nonpoint and point sources and that the process relating sources to water quality is associated with the land characteristics of the region in which the process occurs.

The mechanism that generates spatial effects throughout the watershed seems obvious, but careful judgment and knowledge are needed to correctly specify the process in the model. Initial qualitative hypotheses for estimated parameters from this general model

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[4] See Chapter 4 for more discussion of pollution source specifications.

are:

$$\frac{\partial y_i}{\partial y_j} = (+),$$

$$\frac{\partial y_i}{\partial X_1} = (+), \text{ and}$$

$$\frac{\partial y_i}{\partial X_2} = (+ \text{ or } -).$$

Quantitative descriptions of the complex interactions between pollution sources and water quality at various locations must be investigated. We are not able to predict the specific relationship between variables yet, because there are many complex spatial processes involved in the determination of numerical sign and magnitude of coefficients. There are several analytical issues involved in the correct determination of the functional relationship presumed above. General issues for empirical analysis are discussed in the next section before the specification of the empirical watershed model.

3.2 Issues of Spatial Analysis of Water Quality in a Regional Watershed

3.2.1 Spatial Econometric Modeling Issues[5]

The empirical model to be constructed should reflect the spatial processes proposed in Section 3.1. In this section we extend the model specification in Section 2.2, discuss the approach to developing an initial structural model, and introduce possible analytical problems.

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[5] Concepts guiding the work in this section are drawn from Pace et al. (1998), who show the applicability of spatial statistics in real estate market valuation. We follow their discussion format.

Water quality data collected from monitoring stations in each geographic location along the streams of a regional watershed will incorporate a structure that reflects both the large-scale pattern of environmental heterogeneity and small-scale variability of spatial effects from the complex watershed processes. Throughout the empirical analysis, the ultimate goal is to capture the effects of pollution sources and land cover via trends and stochastic process variation in the empirical model. The basic functional relationship incorporated in the watershed data is assumed to be as follows:

$$y_i = g(W_{ij}y_j, X_1(PP_i, NP_i), X_2(HC_i), \rho, \beta_1, \beta_2) + \varepsilon_i \qquad (3.2.1)$$

Equation 3.2.1 is an extension of the previous section, in which most of the variables are defined. Here, we include a weight matrix, W_{ij}, to represent the spatial externality (spillover) from the neighbors' water quality, and we have also added ε_i, the error term, which for the moment is assumed to be an independent normal variable with zero mean and variance $E(\varepsilon'\varepsilon) = \sigma^2 \boldsymbol{I}$. Thus, we initially assume a model that has a random error structure without spatial autocorrelation and heterogeneity, where we have identity matrix $\boldsymbol{I}$. This leaves us the possibility of testing for its validity.

Now we discuss modeling the large-scale trend to include explanatory variables, with proper consideration of heterogeneity and local patterns of the spillover effect in a watershed. In explaining small-scale variation, various methods of handling the spatial stochastic processes are employed in the analytical procedure.

3.2.1 (a) Mean Variation of Water Quality in a Regional Watershed

In spatial surface modeling of watershed water quality, patterns of water quality variations are associated with different processes operating at different scales within the region, with some processes being responsible for large-scale deterministic trends. Spatial dynamics must be properly incorporated. As a starting point, we hypothesize that the mean variation can be parameterized in a linear model, as follows from Equation 3.2.1:

$$y_i = g(W_{ij}y_j, X_1(PP_i, NP_i), X_2(LC_i, SC_i), \rho, \beta_1, \beta_2).$$

The initial model specification is based on the original (spatial) data availability.[6] All pollution sources and the relevant land and stream characteristics should be captured in the model by representing geographical and physical features of a regional watershed.

One of the most important and distinct spatial processes to capture in the model is the extent and the nature of the spatial externality (spillover). The unidirectional spatial spillover effect is that in which water quality of a downstream monitoring station (y_i) will be influenced by the upper part of the stream (y_j). A critical step is to have the appropriate definition of a neighborhood set for each monitoring station. This neighbor concept is well understood in the spatial statistics/econometrics literature. The definition of "neighbor" usually depends on the context and the purpose of the analysis (Messner et al. 1999: 434). In Cressie (1993:414), the neighbor is defined as the following:

> A site k is defined to be a neighbor of site i if the conditional distribution of $y(s_i)$, given all other site values, depends functionally on $y(\mathrm{s}_k)$, for $k \neq i$. Or the neighborhood set of i is
>
> $$\mathrm{N}_i \equiv \{\, k : k \text{ is a neighbor of } i \,\}.$$

The unidirectional process of streams is very clear, such that an upstream unit affects

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[6] See Section 4.1 for an explanation of the original data sources and their information.

its neighbor downstream unit; but the downstream unit cannot be a neighbor for the upstream unit. In this way, the effect of the spatially weighted average of water quality load can be assessed in the analysis of a watershed. The weight function measures the degree of spillover effect among neighboring stations, and this will indirectly affect the covariance structure of the error process, which is assumed to show spatial random behavior. Weight matrices (**W**) formally represent proximity based on the spatial configuration of observational units (area or points) and constitute intermediate input in three major areas: (1) the computation of certain descriptive analytical methods (such as spatial autocorrelation and association), (2) the estimation of spatial autoregressive models, and (3) the application of tests to detect spatial effects, e.g., spatial dependence and spatial heterogeneity in regression residuals (Can 1996:1010). A practical overview of the weight matrix specification for our watershed analysis is shown in Section 3.3.

For each monitoring station, there exists a different number of National Pollution Discharge Elimination System (NPDES) point source pollution monitoring stations to be considered. The combined effect from all upstream stations on each water quality monitoring station must be accounted for. A spatial weighting function is needed to account for the relative effects of different distances for the various point sources of pollution.

Nonpoint sources of pollution and heterogeneous watershed characteristics data that affect specific monitoring stations need to be constructed from the original raw data collected. Correct areal determination is required for each observation unit in order to extract accurate data information from covariates. With monitoring stations irregularly located in a watershed, the size of the corresponding hydrologic units for relevant monitoring stations will be different. In order to accurately ascribe pollution source effects to nonpoint sources of pollution and land cover types, characteristics of the hydrologic units that contain the pollution sources must be considered.

Finally, it is hypothesized here that the presences of neighboring stations and point source pollution cause distinct spatial dynamics. Thus, dummy variables are added to the model as regressors to account for the existence of a neighbor water quality load and for the existence of one or more point sources of pollution in the hydrologic unit.

Also, as specified in Section 3.1, the heterogeneous factors affecting the processes of nutrient delivery to the stream must be considered carefully in the model. Examples of such factors include soil permeability and slope.

3.2.1 (b) The 2nd Order Variation (Stochastic Process)

If errors are affected by spatial dependence or heterogeneity, then

$$\mathrm{E}(\varepsilon'\varepsilon) = \sigma^2 \boldsymbol{V},$$

where $\boldsymbol{V}$ is nondiagonal. Thus, the decomposition of $\boldsymbol{V}$ must be well understood to ensure correct model specification of spatial processes. Keeping in mind that observations at the monitoring sites are interdependent due to the clear spatial spillover effect through stream and spatial heterogeneity, the covariance structure will be $\boldsymbol{V}(s_i, s_j)$ for the error processes of different sites (s_i and s_j) if the spatial effects are not effectively incorporated into the model. Generally speaking, “systematic relationships in the residuals means that potentially valuable information has not yet been exploited” (Dubin, Pace, and Thibodeau, 1999:81). Therefore, it is necessary to investigate the behavior of spatial stochastic process in order to have the validity of our model specified.

Spatial Autocorrelation

A conceptual model was developed in Section 2.2, and the effect of a spatial externality in a regional watershed was discussed in Section 3.1. Unlike the usual spatial analysis in the regional sciences, in our model there is no endogeneity trap involved in the spatial process. However, there is a unidirectional spatial spillover effect between units that causes spatial autocorrelation if it is not incorporated into the model. Based on the discussion of our model, we can at this point infer a model with a lagged dependent variable as a covariate, where y_i is dependent on u_i; but if u_i is not autocorrelated, y_i is independent from u_{i-1}. Thus, the ordinary least squares (OLS) estimates are consistent (Johnston 1984:360-63).

The model proposed in the next section must incorporate the process, and the validity of the assumption must be satisfied by the absence of spatial autocorrelation. Measures for spatial autocorrelation explicitly take the spatial arrangement of the observations into account (Messner *et al*. 1999:434) with proper incorporation of numerical terms. This is done through the use of the spatial weight matrix discussed in Section 3.2.1 a). Spatial dependence can be incorporated in a model with appropriate choice of weight function (Anselin 1999:6). As long as tests on residuals fail to detect significant spatial autocorrelation, one can be confident that the proposed structural model successfully controls for the spatial dynamics of a regional watershed. As a result, we can be confident that the model will produce reliable estimation results via use of standard econometric techniques.

Heterogeneity

With the incorporation of the spillover effect into the model through a spatial weight matrix, we can partially indirectly choose the covariance structure of the stochastic process.

If there is distinct heterogeneity in the covariance structure, a decomposition of the error structure is required for additional improvement in representation of spatial variation.

With the model specified, the first choice to make is to assign a geographically referenced unit to the water quality measurement at a certain location. We might then expect a distinct heterogeneous effect to be associated with the specific hydrologic unit of each observation. We need to determine whether the estimation is affected by this problem.

3.2.2 Capturing Spatial Information about the Watershed: Aspects of GIS Spatial Analysis

Empirical understanding of spatial processes' effects on water quality begins with acquisition of accurate spatial data information in a watershed. For our structural watershed model, datasets must be manipulated and reallocated to the spatial units employed in this empirical model. The potential to acquire such information has recently been enhanced by the increasing availability of geo-referenced information on a watershed-spatial scale and by the rapid development of GIS spatial data analysis techniques. "The widespread growth in the availability of spatial data can be considered as one of the main drivers in the acceptance and increased demand for spatial analysis in conjunction with GIS," notes Anselin (2000:11-12). However, the availability of original spatial data does not guarantee provision of accurate spatial information for our statistical analysis. Several data manipulation techniques are needed, including careful application of spatial analysis features of the GIS, based on an understanding of the geographical and physical features of a regional watershed.

GIS spatial analysis may be best applied in watershed analysis to enhance understanding of the relevant space. "GIS spatial analysis allows us to solve problems having to do with where geographic features are located in relation to one another and make decisions based on the feature relationships you identify" (ESRI a). Three main categories of the spatial analysis tools are spatial extraction (creating subsets, clipping features, and dissolving features), proximity analysis (spatial join and buffering), and overlay analysis. GIS also facilitates the use of information about spatial conditions or restrictions derived from process specification to determine how the relevant space affects nutrient levels in streams. We can manipulate data using GIS spatial analysis operations to achieve a quantitative understanding of spatial stochastic process interactions between nutrient sources from various economic activities and resulting nutrient loads in the streams. The resulting dataset will reveal the spatial structure on which we have been focused. "Whatever is causing the patterns (spatial effects) is a matter for subsequent study at a different scale, using different methods (Openshaw 1990:158)." This is a line of inquiry worth following, but here our objective with GIS spatial analysis remains data manipulation and the application of statistical methods of analyzing the manipulated spatial information to better understand problems in a watershed. Much more study is required to understand causes of spatial patterns on a smaller scale in watershed analysis. Rather undertake that digression here, it is left to future study as a topic that will be a fundamental part of the role of GIS in the analysis of watersheds.

3.3 Structural Spatial Modeling for Surface Water Quality Data Analysis

In sections 3.1 and 3.2, we identified analytical problems arising from watershed analysis. Now we need to specify a framework for the watershed model, concentrating on large-scale variation. Based mainly on concepts explored in the background discussion, we will construct a structural watershed model for assessing water quality variations. Data manipulation in Chapter 4 will be based on this model. The remaining analytical issues will be dealt with as further analyses are developed in Chapter 5.

3.3.1 Model

The model incorporates the indirect and direct effects of nutrient sources in a regional watershed. It is based on the hypothesis that the spatially weighted sum of water quality in neighboring stations affects the water quality of each monitoring station (indirect effect), as do the standard explanatory variables of pollution sources (direct effects). The reaction function (Equation 2.2.7) here is in the form of a spatial AR model following Brueckner (2003):

$$\mathbf{y} = \rho\mathbf{W}\mathbf{y} + \mathbf{X}_1\boldsymbol{\beta}_1 + \mathbf{X}_2\boldsymbol{\beta}_2 + \boldsymbol{\varepsilon},$$

where **y** represents the water quality indicator vector, **W** is a weight matrix, $\mathbf{X}_1$is the matrix of pollution sources, $\mathbf{X}_2$ is the matrix of land cover and stream characteristics, ρ is a spatial autocorrelation parameter, and $\boldsymbol{\varepsilon}$ is a random error vector. The model specifies that the spatially weighted sum of neighbor water qualities affects the nutrient level of each downstream monitoring unit, as do the general covariates of pollution sources and heterogeneous characteristics in each geographical unit. It eventually states that the realization of y at hydrologic unit i is a function of its realization of **X** at i, plus realization of y at hydrologic unit j, plus an error. This type of AR model is useful for explaining the phenomena in a watershed because it allows us to observe the distinct spatial externality of spillover effects.

Then, we specifically propose a regional watershed model as follows (a more specific explanation of each potential variable follows the equation):

$$y_i = g(W_{i,j}\, y_j,\, X_{\mathrm{i},1}(PP_i, NP_i),\, X_{\mathrm{i},2}(HC_i)),$$

$$= \alpha + \sum_{d=1}^{2} \phi_d D_d + \rho\left(\frac{1}{F_i}\sum_{j \in J_i} q(d_{i,j}) \cdot f_j \cdot y_j\right) + \sum_{k=1}^{K} \theta_k^{np} \left({NP_{i,k}} \big/ {HU_i} \right)$$

$$+ \theta^{pp}\left(\frac{1}{SW_i}\sum_{p \in P_i} s(d_{i,p_i}) \cdot PL_{i,p}\right) + \sum_{h=1}^{H} \beta_h HC_{i,h} + \varepsilon_i\,,$$

where y_i: Water quality indicator measured at monitoring station for hydrologic unit i, ($i = 1, \ldots, n$).

y_j: Water quality of the upstream neighbor j of hydrologic unit $i, j \in J_i$

$g(\cdot)$: Reaction function

$W_{i,j}$: Weight matrix (see below 'Explicit Consideration of Spatial Effects' for more details)

$X_{\mathrm{i},1}$: Function of pollution sources in hydrologic unit i

$X_{\mathrm{i},2}$: Function of heterogeneous characteristics variables in hydrologic unit i

f_j : Flow Severity in hydrologic unit j (scaled 1 – 4)

F_i: Sum of the flow severity values of upstream neighbors of hydrologic unit i

J_i: Set of areal units (upstream neighboring hydrologic units).

$d_{i,j.}$: Distance from monitoring station site in HU i to site in j

$q(\cdot)$: A decreasing function of distance from upstream neighbor's water quality monitoring sites (see below for more explanation on this function.)

NP_i: Non-point source pollution in hydrologic unit i.

$NP_{i,k}$: k^{th} non-point sources pollution in hydrologic unit i.

K: k different types of non-point source pollution.

PP_i: Point source pollution concentrations in hydrologic unit i.

$PL_{i,p}$: Point source pollution load in hydrologic unit i. (see 'Additional Variable Explanation' for more details)

P_i: P number of NPDES stations in Hydrologic Unit i.

$s(\cdot)$: A decreasing function of distance.

d_{i,p_i} : Distance between the monitoring stations of unit i and the NPDES sites p_i.

SW_i : Stream width measured at the monitoring stations of hydrologic unit i

HC_i: Heterogeneous characteristics (land cover and stream characteristics) in hydrologic unit i.

$HC_{i,h}$: h^{th} heterogeneous characteristic in hydrologic unit i, $h = 1, \ldots\ldots, H$

HU_i : Size (acreage) of hydrologic unit i

D_d: d^{th} dummy variables for Neighbor and Point source pollution.

ε_i : Random term that is assumed to be spatially independent for the moment and will be tested later on.

The type of model used in most regional science analyses is the Mixed Regressive Spatial Autoregressive Model, alternatively called the Spatial Lag Model (Anselin 1988; Anselin and Bera 1998). Griffith and Layne (1999) distinguish this model from simultaneous autoregressive (SAR) and conditional autoregressive (CAR) models as the "AR Response Model" whose specification is focused on "spatial autocorrelation latent in Y's variables." The model is earlier classified as a regression model with AR terms using the simultaneous approach by Cliff and Ord (1981). They deal with the model by the simultaneous approach (Whittle 1954) or the conditional approach (Besag 1974). In Anselin (2001), the differences between two approaches to this model are explained. Feng (1995) also has some explanation of the difference between the full SAR model and the AR model. Here we have the AR response model using the simultaneous approach and based on the conceptual model applied from Brueckner (2003). This model captures the neighbor spatial externality of spillover effects well.

We selected a spatial AR model based upon a consideration of the watershed spatial process – a collection of random variables, each measuring water quality at various points in the watershed. The validity of parameter estimates from this model depends on the existence of the joint distribution. In fact, the model is intended to incorporate spatial association of the nearest neighbor structure into the model, thus enabling the model to efficiently estimate the parameters of interest. Therefore, it must be possible to construct the joint distribution from the conditional specification of the model. Brook's Lemma (Brook 1964) specifies that, given the conditional distribution, the joint distribution is uniquely determined. It is recognized that this type of model (the spatial lag model) is based on the simultaneous approach (Cliff and Ord 1981; Anselin and Bera 1998), and practically, it seems clear that the observed water quality values of y are jointly determined by the interaction (unidirectional spillover) between the units. Thus, the conditional specification of the model will be compatible with determination of the joint distribution.

3.3.2 Explicit Consideration of Spatial Effects

In order to represent the spatial dynamics of the neighborhood effect, water quality from the upper hydrologic units is specified as the following explanatory variable[7]:

$$\frac{1}{F_i}\sum_{j \in J_i} q(d_{i,j}) \cdot f_j \cdot y_j ,$$

where y_j = Water quality for the upper neighboring hydrologic units ($j = 1, \ldots, J_i$)
unit: mg/l

f_j = Flow severity in hydrologic unit j (scaled 1– 4)

$F_i = \sum_{j \in J_i} f_j$.

This specification shows the incorporation of the spatial interdependency structure into the model. The linkage structure construction is solidly based on the processes of the regional watershed. This should capture the spatial dynamics of a regional watershed in the model, and this feature can be checked by an appropriate spatial autocorrelation test. The actual weight matrix specification implied is:

---

[7] Hydrologic units can be defined as mutually exclusive areas of a watershed that drain water and other substances carried by water to a common outlet as concentrated drainage.

$$W_{ij} = \begin{cases} \frac{1}{F_i} \sum_{j \in J_i} q(d_{i,j}) \cdot f_j \text{, if i and j are neighbors } (i > j) \\ 0, \text{ otherwise,} \end{cases}$$

where W_{ij} indicates the element of the weight matrix with i having J upstream neighbor(s), and all other variables' definitions as specified above. The weight matrix reflects the strength of the explicit link between specific monitoring stations. The function $q(\cdot)$ represents a component of weights that are inversely related to distances $d_{i,j}$. Keeping Tobler's (1979) "First Law of Geography" ("Everything is related to everything else, but near things are more related than distant things") in mind, we define the weight matrix of spatial interaction in terms of a distance decay function between two monitoring stations. This generalized weight function gives us flexibility in defining spatial proximity (Can 1996:1010). Commonly used distance decay functions are the negative exponential $f(d_{ij}) = e^{-\gamma d_{ij}}$ and the inverse distance function $f(d_{ij}) = d_{ij}^{-\gamma}$ (Anselin 2002:6). Also keep in mind that the neighbor definition term "$i > j$" indicates the unidirectional influence between the units. The construction of the neighbor water quality variable is shown in Figure 3.3.

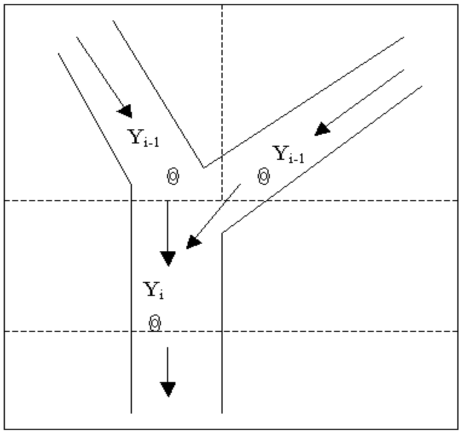

FIGURE 3.3 A SIMPLIFICATION OF A WATERSHED AND A SPATIAL PROCESS

In Figure 3.3, there are four different hydrologic units specified. From the process in the stream generally specified, it is clear that we have spatial spillover from the upper hydrologic units, and the water quality measured in Y_i is affected by the stations above, but not vice versa.

In this model, the usual endogeneity problem can be avoided due to the unidirectional spatial spillover effect along the stream. As long as the error shows spatial random behavior, the model can be estimated by OLS. This is analogous to the usual time series analysis problem. In order to test the error term, diagnostic procedures are needed for the error process of the model constructed. If the model does a good job of incorporating the unidirectional spillover effect, estimation with standard OLS is appropriate.

3.3.3 Additional Variable Explanations

(a) The total effect from the Point Source Pollution (PP) in a hydrologic unit is represented as the following:

$$\frac{1}{SW_i} \sum_{p \in P_i} s(d_{i,p_i}) \cdot PL_{i,p}^{k} \ ,$$

where we use the point source pollution loading (lbs./day), $PL_{i,p}$, which is calculated as:

$$PL_{i,p} = PP_{i,p} \times WF_{i,p} \times 8.34.$$

where $WF_{i,p}$ = Waste flow rate (MG/day), where MG: million gallon

$PP_{i,p}$ = Point source concentration (mg/liter), where mg: milligram

8.34 = Conversion factor for the total nitrogen nutrient load calculation (lbs./ gallon of water)

Point source pollution that affects a particular station's water quality measurements in each hydrologic unit *i* is also discounted by distance, and this pollution is summed for the total effect on the monitoring station in unit *i*.

(b) Non-point sources of pollution (NPP): $NP_{i,k}$, $k = 1, \ldots, 4$.

NPP types considered:

- $NP_{i,1} =$ Urban (Developed) Land Use (Acreage)
    - High Intensity Developed
    - Low Intensity Developed
- $NP_{i,2} =$ Animal Operation (Total Nitrogen)
- $NP_{i,3} =$ Fertilizer (Total Nitrogen Application)
- $NP_{i,4} =$ Forest (Acreage)

The nonpoint source pollution variables are modeled by dividing them by the hydrologic unit size to get the relative amount of each source. Note here that the specification of the explanatory variables is mostly based on the availability of the original data we have collected. One significant source of pollution in this study is commercial livestock operations. With sufficient data available for all animal operations, such as exact location and distance from streams, we can further refine variable definitions to reflect the actual contribution of nutrient amounts from livestock operations. For such non-point sources, as applied in point source variable modeling, we could estimate a distance function to determine the weighted contribution of nutrients that each animal operation makes to the streams.

(c) Heterogeneous characteristics: $HC_{i,h}$, $h = 1, \ldots, 5$,

where

$HC_{i,1} =$ slope
$HC_{i,2} =$ wetland

$HC_{i,3}$ = water temperature
$HC_{i,4}$ = stream width
$HC_{i,5}$ = flow.

Area data of the wetland follow the same restriction we mention in (b) above. Details of each variable are defined and explained more specifically in Chapter 4.

(d) Dummy variables: D_d , d = 1 and 2.

Two dummy variables are included as regressors to capture the fact that some monitoring stations do not have upstream pollution, and some lack point sources of pollution. This analytical fact is explained in Chapter 5.

4. DATA ISSUES: Spatial Identification of a Regional Watershed

We have gained an understanding of the spatial process in a regional watershed, and we have constructed an empirical watershed model. The next step is to manage the dataset. We discuss the importance of scale (level of spatial aggregation) and range (extent of spatial interaction) (Anselin 2003), which point to the need to use spatial analysis tools, such as GIS.

Special techniques are available to overcome many of the technical and organizational problems of handling spatial data (Haining 1990). We use GIS's spatial analysis functionality to manipulate the original watershed data to get the desired regional information for final spatial statistical analyses. Rationalization of spatial information about pollution sources is necessary to identify processes of the watershed (cf. Openshaw 1990) to ensure that the final spatial data allow appropriate analysis of the watershed. As Openshaw (1990) notes, "GIS is removing all the historic restrictions on the types of zoning systems available for reporting spatial data and it is important that this new found 'freedom' is properly controlled and used."

In Section 4.1, we introduce and preprocess various watershed spatial datasets and define the extent of the spatial domain of our study region with the relevant spatial objects. In Section 4.2, we show how they are integrated to meet the conditions of the "scale" and "range" of the spatial features of a regional watershed.

4.1 Sources and Information

Most of our GIS data come from the projection of the North Carolina State Plane Coordinate System 1983 (units of measurement: meters; scale: 1:24,000), the Geodetic Model of North American Datum of 1983 (NAD83), and the Lambert Conformal Conic projection. Differently projected data are converted to this geographic system, giving us a data set in a consistent format for a specifically defined study area. The details of the data used are shown below. Statewide datasets are collected, and we show the extracted data sets for the area of the Neuse River basin. For more information on all GIS datasets, the metadata source is shown so readers can find more specific data reports (see Table 4.3).

4.1.1 Watershed and River Data

4.1.1 (a) Basic Watershed Data

Our spatial domain of the regional watershed setting is based on the Neuse River basin in North Carolina (NC). Vector data of the watershed[8], "Hydrologic Units - North Carolina River Basins" and the North Carolina "Major Hydrography" GIS data files were obtained. "The Nuese River Basin encompasses 6192 square miles in 19 counties and contains roughly one sixth of the states's population. It is the third largest river basin in NC and is one of only three major river basins whose boundaries are located entirely within the state. The Neuse River originates northwest of Durham in the northern Piedmont region of NC and then flows southeasterly for over 200 miles past the cities of Raleigh, Smithfield, Goldsboro, Kinston and New Bern to the tidal waters of Pamlico Sound" (North Carolina Division of Environmental Management Water Quality Section 1993).

The Neuse River flows into the Pamlico Sound and drains a watershed with a significant amount of nutrients from various sources, such as agricultural and urban land uses. The Neuse River basin is mapped in Figure 4.1.

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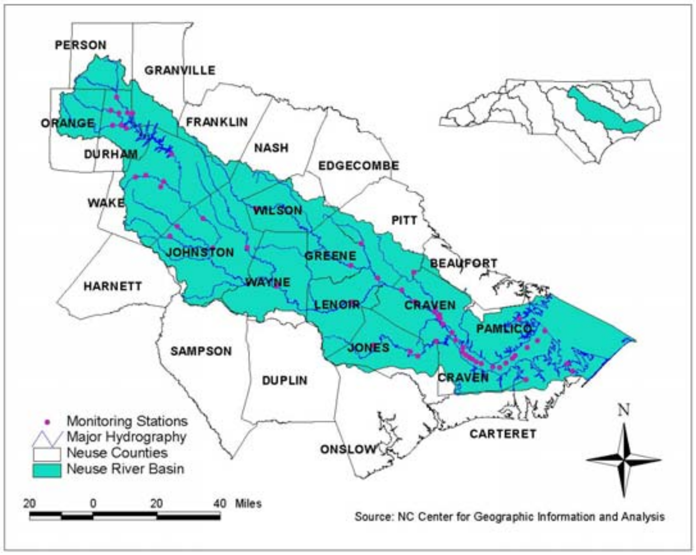
[8] A watershed is "an area that drains water and other substances carried by water to a common outlet as concentrated drainage. Other common terms for a watershed are basin, catchment, and contributing area. The contributing area is normally defined as the total area contributing water flow to a given outlet, also called a pour point" (ESRI b: "Introduction to ArcView Spatial Analyst Lesson 2").



Source: NC Center for Geographic Information and Analysis

FIGURE 4.1: THE NEUSE RIVER BASIN, NORTH CAROLINA

4.1.1 (b) Watershed of 14-digit Hydrologic Units

Well-defined regional boundaries need to be defined so all relevant pollution sources can be matched with specific monitoring stations. As Preston (2000) notes, "It is important to identify areas with similar geographical characteristics when a model is used to extrapolate water-quality information as part of the effort to develop regional management plans."

After identifying the space of a regional watershed, our next question is how to create regional boundaries to enable us to capture the processes of nutrient delivery to particular monitoring stations in smaller segmented units. We need to have the area delineated in such a way that spatial processes are relatively homogeneous, so we can identify pollution sources for each area in a watershed.

GIS data creation plays a crucial role in this regard. We obtained existing GIS data for the 14-digit hydrologic unit theme/layer.[9] These data show relatively homogeneous

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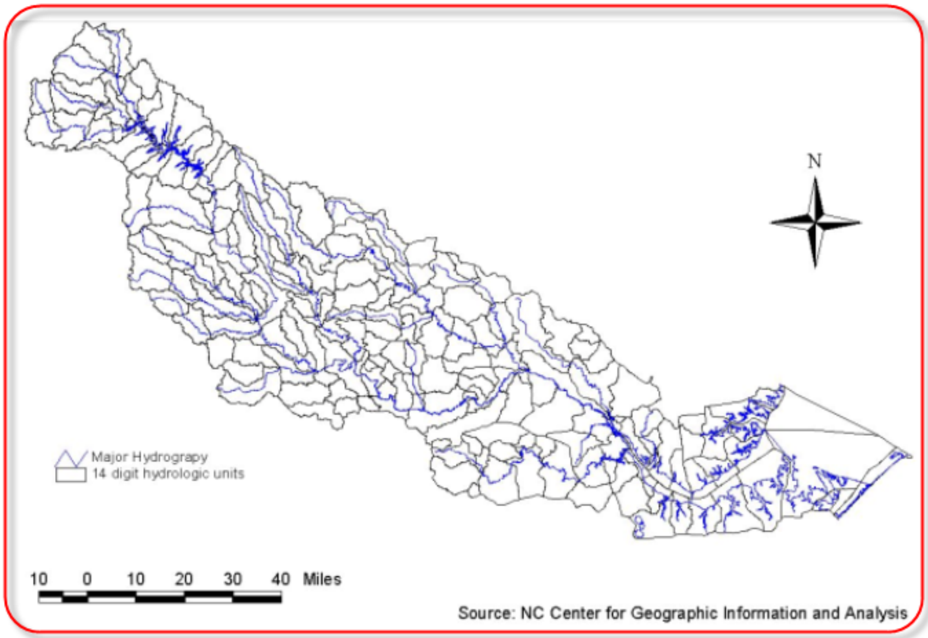
[9] Theme or layer: "a collection of common geographical elements, such as a road work, a collection of parcel boundaries, soil types, an elevation of surface, satellite imagery for a certain date, or well locations" (Arctur and Zeiler 2004: 4).

drainage areas in each of the 17 major river basins. "1995 Hydrologic Unit (HU) Study divides the state river basins … into smaller … units that will be useful in targeting project activities, resource inventories, and reporting conservation activities. These fourteen-digit hydrologic units of approximately 4,000 acres (6 square miles) to 50,000 acres (78 square miles) are small enough in size to be useful as a planning and reporting tool … " (cf. the metadata source specified in Table 4.3). The hydrologic units in the Neuse River basin are mapped in Figure 4.2.



Source: NC Center for Geographic Information and Analysis

FIGURE 4.2: 14 DIGIT HYDROLOGIC UNITS IN THE NEUSE RIVER BASIN

4.1.1 (c) (Detailed) Hydrography

The delineation of the major hydrography data layer mapped for the Neuse River basin is shown in Figures 4.1 and 4.2. For more detailed watershed analysis, we also obtained the statewide detailed hydrography, "Hydrography (1:100,000)," GIS coverage data, and we extracted the data layer for the Neuse River basin (Figure 4.3). "These files enable users to identify areas which have special restrictions for building and development based on the locations of these surface waters and their water quality classifications" (cf. the metadata source specified in Table 4.3).

This dataset plays a significant role in the spatial analysis for data management (see discussion in Section 4.2). First, the detailed hydrography can be used for more detailed identification of some pollution sources affecting particular monitoring stations. Distance measurement between sources and monitoring stations along streams is one useful advantage that GIS can provide. For example, the weight matrix construction discussed in chapter 3 has the major practical difficulty that intricate topological relationships exist and need to be identified (Can 1996). Regarding this point, Can (1996) says, "A GIS with a topological vector data model explicitly provides this type of information and thus can greatly facilitate the construction of weight matrices." Ding and Fotheringham (1992) also mention the advantage of using GIS to create spatial weight matrices in spatial statistical analysis. In our case, using detailed hydrography helps us obtain exact distances between monitoring stations and sources in the point layer, such as point source pollution or animal operations sites. Also, magnification of the detailed hydrography layer reveals the exact stream width at the location of each monitoring station. Together with the 14-digit hydrologic unit data, the detailed hydrography layer facilitates the creation or editing of a new hydrologic unit GIS data theme/layer, so as to make new geographical watershed delineations. New hydrologic units are defined where there are more than two monitoring stations involved in one hydrologic unit.

4.1.2 Ambient Water Quality Monitoring Sites

In the Neuse River basin, there are about 58 active ambient water quality monitoring stations. A table of the monitoring station data with the decimal degrees of latitude and longitude information was provided by the North Carolina Department of Water Quality (DWQ).[10]. Also, we obtained updated GIS point data information for the stations. Figure 4.1 presents the point theme/layer for the locations of the ambient monitoring stations in the basin.

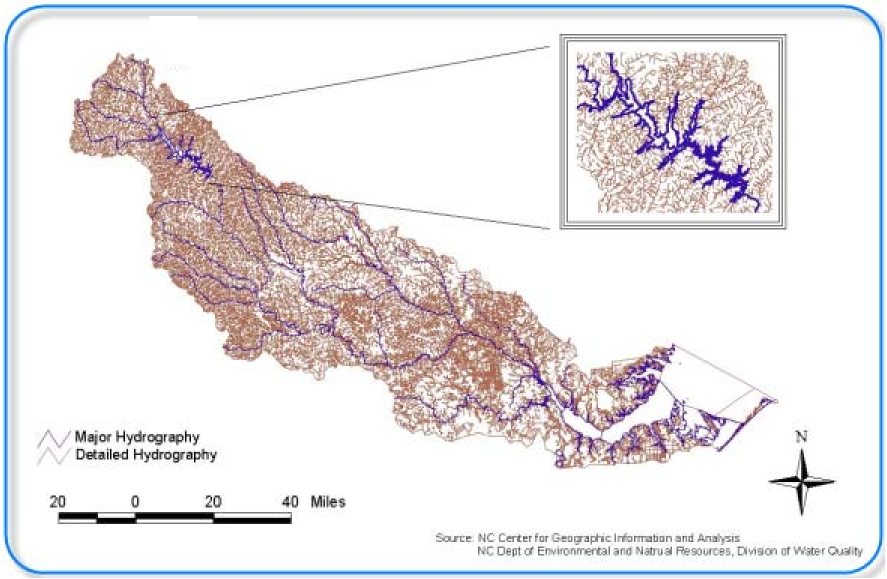


FIGURE 4.3: DETAILED HYDROGRAPHY IN THE NEUSE RIVER BASIN

4.1.3 Water Quality Indicators

In the literature, nutrient levels are commonly used as indicators of water quality. Nutrient pollution is the leading cause of water quality impairment in lakes and estuaries and the third-leading cause of impairment in rivers. Nutrients support the growth of algae in surface water, which leads to many harmful environmental effects, such as clogged pipelines,

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[10] More information can be obtained from the Ecosystem Units of the DWQ, NC.

fish kills, and reduced recreation opportunities (Line *et al*. 2002, Ribaudo *et al.* 1999).

From a water quality standpoint, important nutrients are nitrogen and phosphorus (Ribaudo *et al.* 1999). "The diverse and ubiquitous nature of total nitrogen (TN) and total phosphorus (TP) forms in the environment introduces significant complexity to the increasingly important task of managing nutrients in watersheds" (Smith and Alexander 2000). We have obtained nutrient data from DWQ. They are collected at the selected monitoring stations, usually on a monthly basis.

4.1.4 Land Use and Land Cover (LULC)

Land cover, "which is the pattern of ecological resources and human activities dominating different areas of the earth's surface, is one of the most important sources used in watershed analysis and the management of water resources throughout the country" (EPA). We use the compound term "land use and land cover" (LULC) for that category of variables, but the distinction between the two component terms is not clear. When we have a dataset containing all the classification schemes of the LULC, land use refers to the area where human disturbances occur, and land cover refers to the natural physical areas (NC CGIA 1994); but here we will use the terms jointly throughout the dissertation.[11]

We obtained two kinds of land use datasets from two agencies: the North Carolina Center for Geographic Information and Analysis (NC CGIA) and the EPA. The agencies have distinct but similar classification schemes for the creation of data layout, and we will

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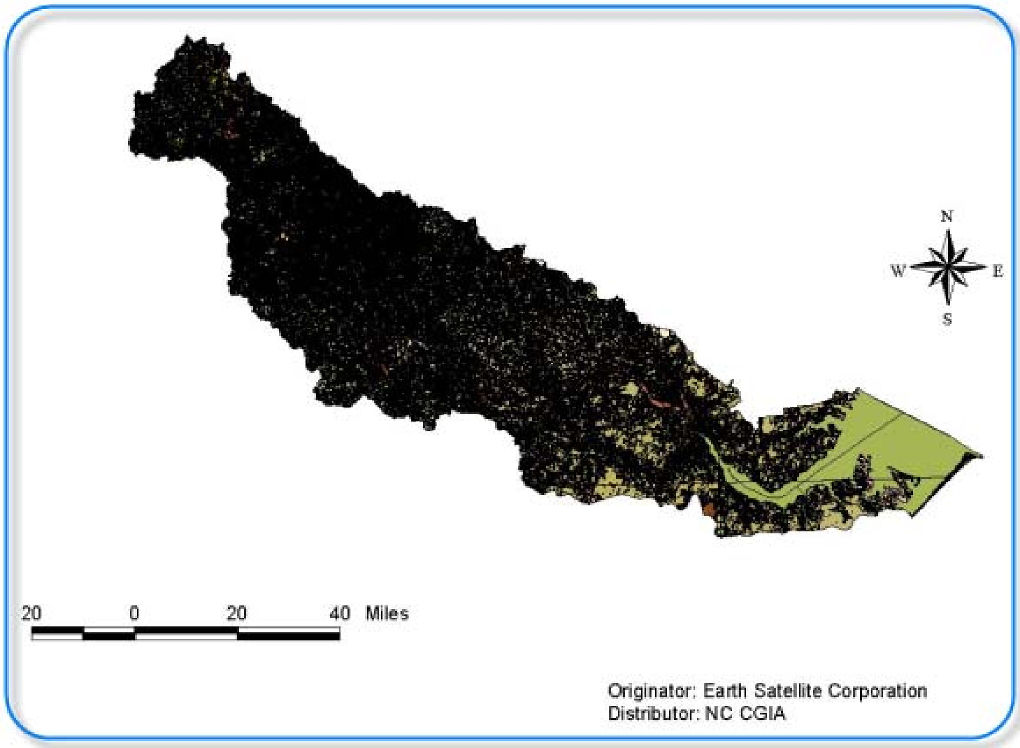
[11] "The Land Use and Land Cover (LULC) data files describe the vegetation, water, natural surface, and cultural features on the land surface. Strictly speaking, 'land use' refers to the type of use that a given feature represents, such as urban residential, while 'land cover' refers to the physical character of the land surface, such as the type of vegetation or the percent of impervious cover. Because the nature of the land cover reflects the way the land is being used, these two terms are used jointly. Land use and land cover data is interpreted from remotely sensed data, usually satellite imagery" (ESRI c).

use both for our own spatial analysis purposes. The scheme used by the EPA has eight categories, and the top levels are as follows[12]: (1) Urban Land, (2) Agricultural Land, (3) Woody Vegetation, (4) Herbaceous Vegetation, (5) Water, (6) Wetland, (7) Barren Land, and (8) Unknown/Other.

Figure 4.4 shows the map for the whole LULC geoprocessed for the area of the Neuse River basin from the "State Wide Land Cover – 1996" dataset provided by NC CGIA. The areas of some classifications of the LULC data will be used as proxies for some non-point source pollution variables. The methodology of utilizing the LULC datasets is explained in the section corresponding to each variable.



Originator: Earth Satellite Corporation
Distributor: NC CGIA

FIGURE 4.4: LAND USE LAND COVER IN THE NEUSE RIVER BASIN

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[12] More detailed information on these unpublished data ("Neuse River Basin Land Cover Land Use") can be obtained from Ross Lunetta (originator), EPA.

4.1.5 Pollution Sources Data

4.1.5 (a) Which Data to Collect?

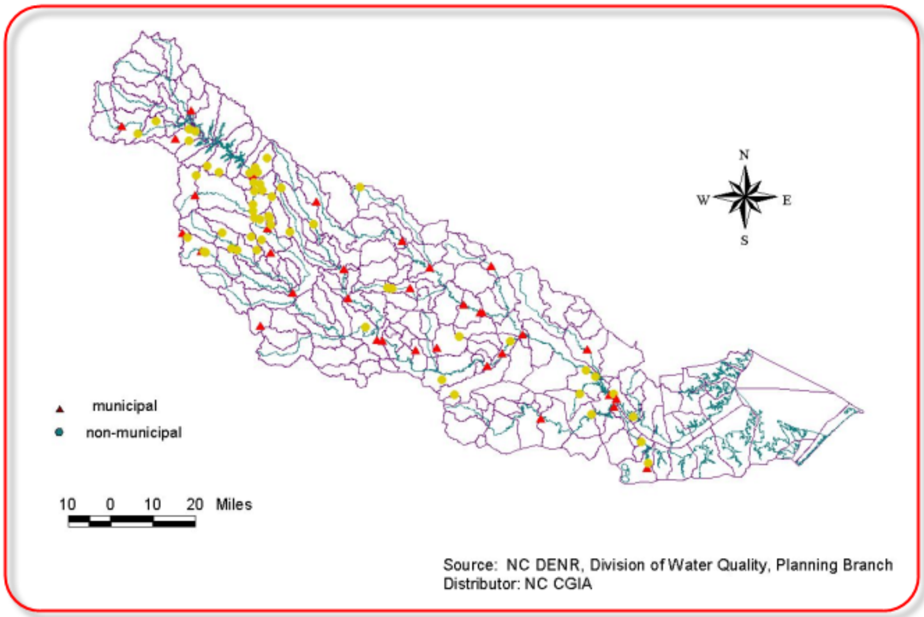
To facilitate estimation among watersheds within a region and across regions, "ecological risk assessments should be based on a model describing the underlying factors that influence watershed response to sources of stress, particularly vulnerability to change as a result of those stresses" (Detenback *et al*. 2000). Given the water quality indicators chosen (TN), our next task is to identify the spatial distribution of appropriate indicators of the pollution sources and the correct set of covariates to use in spatial analysis. "Recent studies indicate that stream hydrology, geomorphology, water chemistry, and biota are largely determined by a combination of regional factors, such as geology and climate, and local land cover and land use" (Wang *et al.* 2001:255).

The literature is in general agreement regarding the relevant pollution sources affecting water quality in a stream. First, it seems reasonable to introduce five types of pollution sources (Smith and Alexander 2000): (1) municipal and industrial point sources, (2) commercial fertilizer, (3) animal agriculture, (4) nonagricultural runoff, and (5) atmospheric deposition. Also, as discussed in Section 4.1.4, LULC variables (soil, slope, elevation, land use, and vegetation cover) are important for nonpoint source pollution area identification (Sivertun *et al*. 1988: 368). The general functional relationship can be specified as follows:

$$\text{TN} = f\,(\text{PP, NPP, LULC, Stream Characteristics}).$$

4.1.5 (b) Point Sources of Pollution (PP)

Point sources include wastewater treatment plants, industrial plants, and septic tanks. The DWQ provided the monthly average permitted discharge data of the total nitrogen concentration (mg/l) of NPDES sites. These are composite samples collected during the month. We will use the discharge data for the year 1995. The GIS point theme data will be created using the latitude and longitude coordinates of these point source discharge locations. The current GIS point layer data shown in Figure 4.5 contain outfall locations for individual NPDES permitted wastewater discharges to surface waters in North Carolina. From among them, we use the information relevant to the 1995 dischargers. Corresponding waste flow data (in millions of gallons per day) has been obtained and is used to calculate the load data (lbs./day) for each NPDES station that provided concentration data. For missing monthly flow, the yearly average flow has been substituted. See the Appendix for facility information and the point source data table.



Source: NC DENR, Division of Water Quality, Planning Branch
Distributor: NC CGIA

FIGURE 4.5: NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM SITES IN THE NEUSE RIVER BASIN

4.1.5 (c) Nonpoint Sources of Pollution (NPP)

Fertilizer Application

In order to have spatially explicit fertilizer application data, we used two sources of data. First, we used the agricultural land use area (see Figure 4.6) extracted from the GIS LULC data discussed in 4.1.4. In addition, we obtained the average fertilizer (total nitrogen (lbs./acre and year)) application rates in counties in the Neuse River basin for the base years 1991–1995.[13] The dataset contains the average total nitrogen application per acre and year for major crops and herbaceous vegetations.[14] We used both data sources to derive the area-specific total nitrogen application rate in each hydrologic unit modified. The reason we chose these base years is to closely match the period of the two original data construction periods. The methods of the data manipulation process are specified in the data management section, 4.2. Table 4.1 shows the summary statistics of the land use data collected from the GIS data, the survey data, and the countywide total nitrogen application data as calculated from the survey data in Table 8.6. Note that we managed to get the LULC data by county in the Neuse River basin by using the GIS functions. These data will be further analyzed and assigned to the changed hydrologic units.

Animal Operations

Figure 4.7 shows the GIS data about the animal operation locations for the Neuse River basin from the attribute data table. It provides the average populations of livestock inventories for cattle, horses, poultry, and swine. The population is predominantly swine associated with the large-scale hog farms in the middle section of the Neuse River basin.

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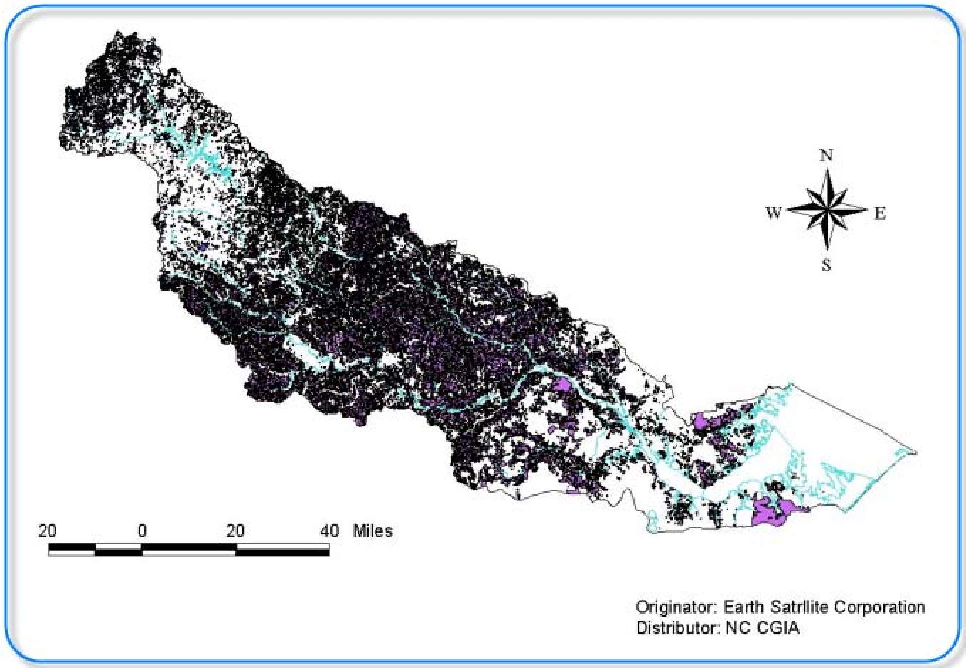
[13] The data have been obtained from the DWQ in the form of the survey data table constructed by the Local Advisory Committees, which are made up of representatives from the Division of Soil and Water, NCDA&CS, NC CES, Local Soil and Water Conservation Districts, and local farmers. For more information on the survey method, contact the DWQ.

[14] Major crops: Corn for grain-no till, corn for grain-conv, corn for silage-no till, corn for silage-conv, soybeans for beans, cotton, wheat for grain, tobacco, rye, oats for grain, barley for grain, sorghum for grain, peanuts, soybean waste, sweet potatoes, and Irish potatoes. Herbaceous vegetations: Bermuda grass and fescue.



Originator: Earth Satrllite Corporation
Distributor: NC CGIA

FIGURE 4.6: AGRICULTURAL LAND USE IN THE NEUSE RIVER BASIN

Table 4.1: LULC area and TN survey data of the Neuse River Basin Counties[*]

	Counties	LULC Cultivated (acre)	LULC Herb (acre)	LULC total (acre)	Survey total LU	Survey crop LU	Survey Bermuda LU	Total N for Crop (Survey)	Total N for Bermuda (Survey)	Total N
1	Person	4014.846	20383.87	24398.72	19499	10504	8995	942094	1160355	2102449
2	Orange	1604.44	30830.39	32434.83	17808	13794	4014	1198030	654282	1852312
3	Granville	5973.947	6017.228	11991.17	8219	4079	4140	292273	414000	706273
4	Durham	1972.554	14720.59	16693.14	13561	2892	10669	267198	704154	971352
5	Wake	65930.15	24043.42	89973.57	43419	38573	4846	2730038	1024929	3754967
6	Franklin	6634.096	2002.956	8637.052	6508	4508	2000	354105	270000	624105
7	Johnston	184565.1	8042.421	192607.5	129762	124182	5580	9106938	1395000	10501938
8	Nash	25986.35	1961.658	27948.01	19805	19020	785	1309445	222940	1532385
9	Wilson	75928.86	6946.271	82875.13	73719	73255	464	5988074	133632	6121706
10	Wayne	143038.5	10324.09	153362.5	129798	127301	2497	11782560	708400	12490960
11	Pitt	67223.34	4127.235	71350.57	69184	68248	936	5095696	339768	5435464
12	Greene	82485.02	4001.913	86486.94	75474	74941	533	6764015	193479	6957494
13	Lenoir	106825.8	8635.926	115461.7	99827	98887	940	6522800	70500	6593300
14	Jones	61549.17	4855.116	66404.29	50000	49500	500	6496500	120000	6616500
15	Craven	68222.79	8957.333	77180.13	60162	59537	625	5982180	150000	6132180
17	Carteret	27109.43	421.3673	27530.8	22607	22557	50	2520570	12000	2532570
18	Pamlico	38640.31	2315.077	40955.39	37406	37406	0	3573380	0	3573380

[*] The original base year survey data are shown in Table 8.6.

We chose the active animal operations in 1995, and we ignore later data. To assess the amount of nitrogen produced by these operations, we rely on publications that show the nutrient production rates (lbs./year) from each type of animal (Table 4.2). We multiply each animal inventory by estimates of annual per-animal waste nutrient content to obtain spatially specific total nitrogen production rates of animal operations for each hydrologic unit.

Table 4.2: Nitrogen in Animal Wastes Production (lbs/year)
- Source: McMahon and Woodside (1997)

		Cattle			Chickens			
source	Hogs	All Cattle	Dairy	Beef	All Chickens	Layers	Broilers	Turkeys
Fisher et al (1988)	31.9	75.8	122.7	60.9		0.95	0.77	3
NCDNRCD (1985)	21.9	142.7	237.2	113.1		1.46	0.73	7.3
Barker (1991)	20.3	106.5	156	90.8	0.9	0.95	0.89	2

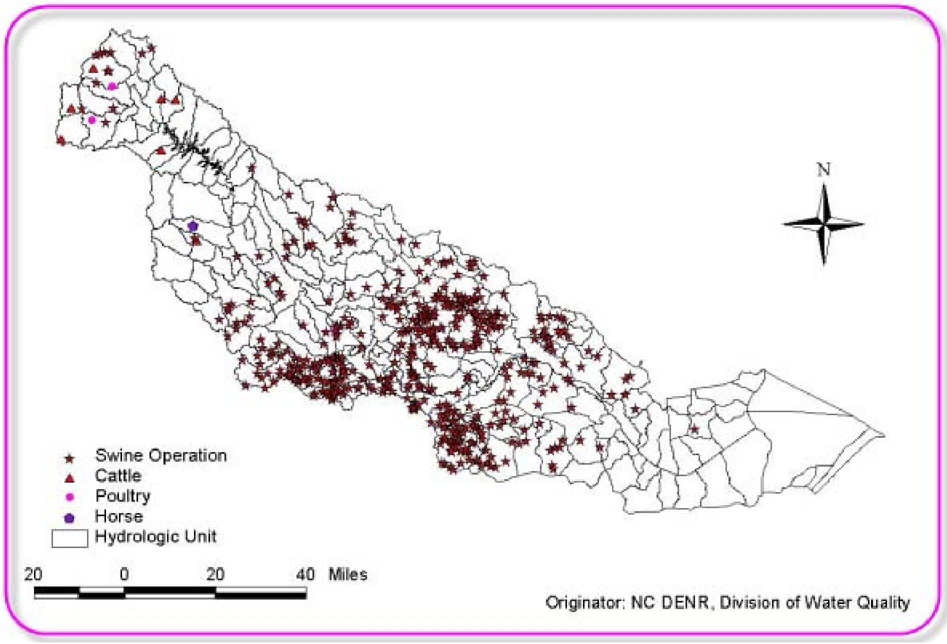
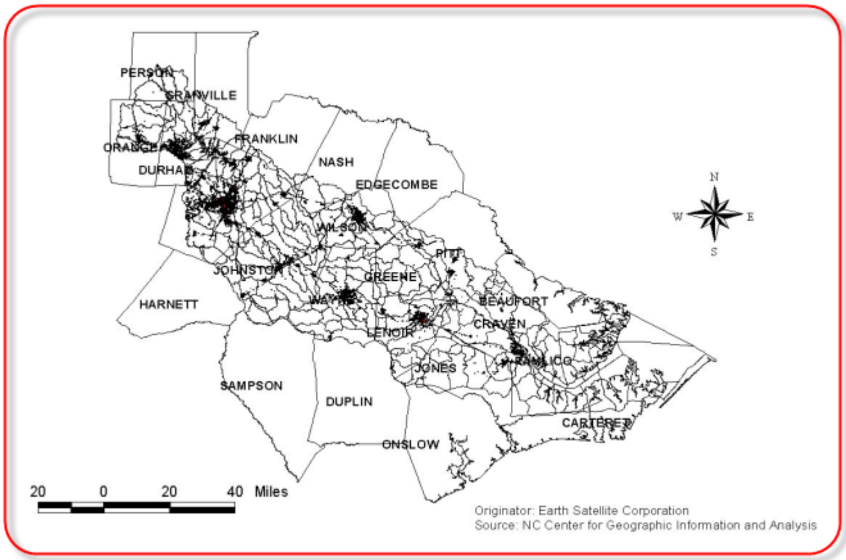


FIGURE 4.7: ANIMAL OPERATIONS IN THE NEUSE RIVER BASIN

Urban Source: Developed Land Use

We chose urban land use as one of the sources of pollution affecting water quality following Line *et al*. (2002), who see urban land uses as a significant cause of nutrient pollution. The urbanization effect is also well addressed in Wang *et al*. (2001:255).

The LULC data of the NC CGIA provides the land cover (LC) classification of the developed land use. We use the amount of each relevant area as a proxy for the urbanization effect variable. Figure 4.8 shows the urban developed land use (high- and low-developed land) distribution in the Neuse River basin.



Originator: Earth Satellite Corporation
Source: NC Center for Geographic Information and Analysis

FIGURE 4.8: DEVELOPED LAND USE IN THE NEUSE RIVER BASIN

Forested Area

As one of the nonpoint sources of pollution, forest area in the Neuse River basin is extracted from the LULC GIS data from the EPA. The area is used as a covariate affecting water quality variations. Figure 4.9 is a map of the forested area in the Neuse River basin.

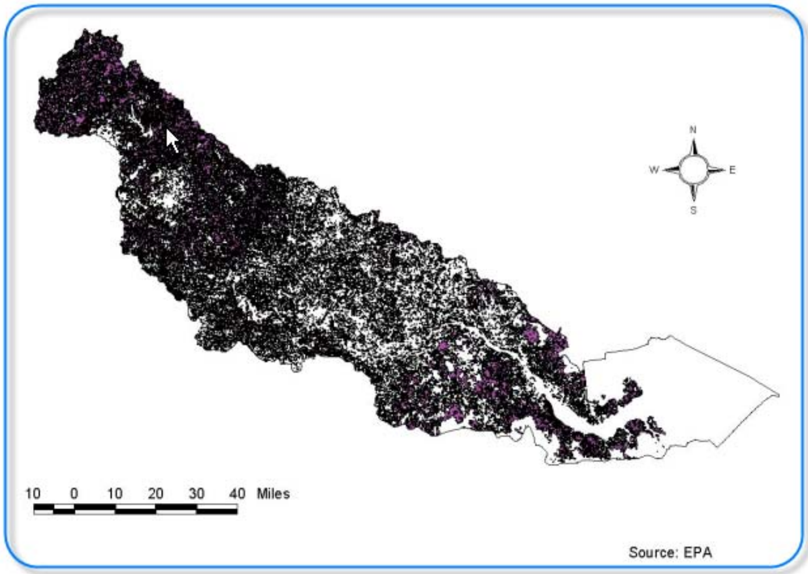


FIGURE 4.9: FOREST LAND COVER IN THE NEUSE RIVER BASIN

4.1.6 Land and Stream Characteristics of Heteroskedastic Factors

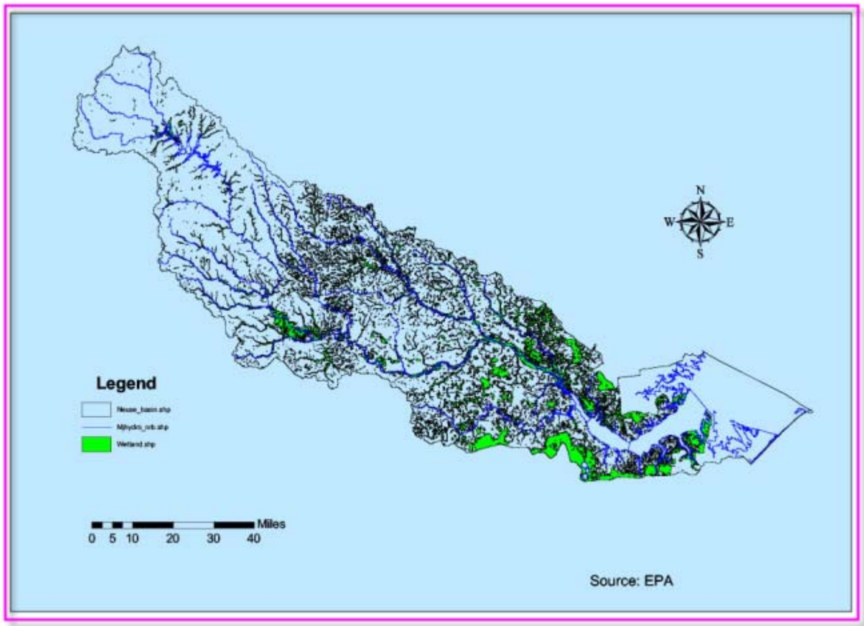
The speed or the strength of the nutrient delivery process in streams is affected by spatial characteristics such as soil quality and slope (Basnyat *et al*. 1999:540; Brakebill and Preston 1999). Also, some characteristics of the streams themselves are important in the transportation and delivery of nutrients, and these characteristics must be introduced into the model appropriately.

Elevation

Raster data sets of the counties in the Neuse River basin are extracted from the grid data of the "National Elevation Data Set: County" (Data Source: U.S. Geological Survey). We used ArcView software to merge all separate county grid data sets and extracted the relevant area based on the analysis mask of the Neuse River basin, with 100 m cell size. These regional raster data are manipulated further to represent each specific area of interest (hydrologic units).

Wetland

For our analysis, the GIS data are extracted from the EPA LULC data. From the geographic data, we see that wetlands are mostly located near streams, either on major or detailed hydrography. The map shows that wetlands are located mostly in the middle and lower part of the Neuse River basin. It should be interesting to see how this affects results of the analysis.



Source: EPA

FIGURE 4.10: WETLANDS IN THE NEUSE RIVER BASIN

Stream Flow

We have not been able to obtain flow data relevant to the water quality monitoring station locations. Instead, as a proxy of the flow rate, categorical (1 through 4) flow severity data were obtained (see Table 8.11) from the DWQ water quality database.

Stream Width

Stream width data were obtained from the DWQ water quality database. They are the monthly measurements of stream width done at each ambient monitoring station.

Table 4.3: Major Data Sources

Variable Title	Data Type	GIS File Name	(Map) Unit	Projection	Datum	Format	Source	Metadata Source
Ambient Monitoring Stations	DBF						Ecosystem Units, DWQ	
Ambient Monitoring Stations	GIS (Point)	uvawqms	Meters	State Plane 1983	NAD83	Arc/Info	NC CGIA	http://www.cgia.state.nc.us/cgdb/awqms.html
Animal Operation	GIS (Point)		Meters	State Plane 1983	NAD83	Arc/Info	NC CGIA	
Counties	GIS (Polygon)	cb100	Meters	State Plane 1983	NAD83	Arc/Info	NC CGIA	http://www.cgia.state.nc.us/cgdb/cb100.html
Elevation	Grid	varies	Meters	State Plane 1983	NAD83	Grid	USGS	http://edcnts12.cr.usgs.gov/ned/fgdcmetadata.htm
Fertilizer	DBF						DWQ	
Flow Severity	DBF						DWQ	
Hydrography (Major)	GIS (Line)	hydromaj	Meters	State Plane 1983	NAD83	Arc/Info	NC CGIA	http://www.cgia.state.nc.us/cgdb/hydromaj.html
Detailed Hydrography	GIS (Line)	varies	Meters	State Plane 1983	NAD83	Arc/Info	NC CGIA	
Hydrologic Units (14 digit)	GIS (Polygon)	hunc	Meters	State Plane 1983	NAD83	Arc/Info	NC CGIA	http://www.cgia.state.nc.us/cgdb/hunc.html
Hydrologic Units (River Basin)	GIS (Polygon)	hy100	Meters	State Plane 1983	NAD83	Arc/Info	NC CGIA	http://www.cgia.state.nc.us/cgdb/huncrb.html
LULC 1	Raster		Meters		NAD83	Grid	EPA	http://www.esri.com/metadata/esriprof80.html
LULC 2	Raster	landcover_all4.img	Meters	State Plane 1983	NAD83	Imagine	NC CGIA	http://www.cgia.state.nc.us/cgdb/lc96ras.html
Point Source	GIS (Point)	npdes	Meters	State Plane 1983	NAD83	Arc/Info	NC CGIA	http://www.cgia.state.nc.us/cgdb/npdes.html
Point Source	DBF						NC CGIA	
Stream Width	DBF						DWQ	
Water Temperature	DBF						DWQ	
Water Quality	DBF						DWQ	

4.2 Data Management

4.2.1 Setting the Spatial Domain of the Study Region

Sources and types of original data information have been introduced. Now, the design of data management from the integrated source datasets will follow the model developed, so that resulting data sets are newly combined and will fully support the final data analysis. The statistical watershed model we propose is[15]:

$$\mathrm{y_i} = \alpha + \sum_{d=1}^{2} \phi_d D_d + \rho\left(\frac{1}{F_i} \sum_{j \in J_i} q(d_{i,j}) \cdot f_j \cdot y_j\right) + \sum_{k=1}^{K} \theta_k^{np} \left(NP_{i,k} \big/ HU_i \right)$$

$$+ \theta^{pp}\left(\frac{1}{SW_i} \sum_{p \in P_i} s(d_{i,p_i}) \cdot PL_{i,p}\right) + \sum_{h=1}^{H} \beta_h HC_{i,h} + \varepsilon_i ,$$

where subscript i ($i = 1 \ldots n$) indicates the i^{th} number of hydrologic unit corresponding to each relevant ambient monitoring station. Then, given the water qualities monitored, we need to manage nutrient source data exclusively contributing to the water quality levels of the specific monitoring stations. We therefore need regional aggregation into n units from m ($n < m$) hydrologic units. Effective regional aggregation in a spatial setting is possible if the geographical features of the watershed are fully utilized.

Modification of hydrologic unit boundaries is needed, given the set of water quality monitoring stations at certain locations of a river basin. This mainly implies dissolving 14-digit m hydrologic units to make n regional areas and sometimes breaking areas into smaller units, depending on the location of the monitoring stations.

Data management practice for deriving the pollution source variables should meet the

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[15] For complete model description, see Section 3.3.

model criteria and is based on the newly constructed *n* hydrologic units. That is, we need to create region-specific data out of raw spatial data and information. There are five distinct categories of dataset for us to manage in the model. The first important step is to select the appropriate monitoring stations in the watershed.

4.2.2 Monitoring Station and Hydrologic Units Adjusted

4.2.2 (a) Choosing Monitoring Stations

We choose to use the year 1995; thus, the monitoring station selection process is based on the availability of data monitored in that year. In the original 1995 water quality data from the DWQ, there is a total of 53 monitoring stations. One monitoring station (J7210000) has data for only one month (August), so we decided to exclude that station. All other stations have at least five months' worth of data.

The next task was to get the point theme GIS data for the monitoring stations selected. Some of the monitoring stations that were active in the year 1995 are currently inactive, so the current GIS data for the current monitoring stations provided by the NC CGIA do not exactly provide all monitoring station information for the year 1995. We projected data based on the decimal degrees of latitude and longitude to the projection we are using (State Plane 1983, meters, NAD83) and created a point theme/layer of the monitoring stations in 1995. The data are mapped in Figure 8.1 in the Appendix. This was accomplished using ArcView GIS software and the data information as shown in Table 8.1.

Getting the point theme data for the monitoring stations is accomplished via a projection process of mathematical transformation for representing three-dimensional curved space in two-dimensional space. In this geographic reference system, the units of degrees, minutes, and seconds are not associated with a standard length, so they cannot be used as a consistent measure of distance or area. Map projection involves transforming data whose spatial coordinates are defined in terms of latitude and longitude of the geographic coordinate system (the spherical coordinate system) on a curved earth surface to data whose spatial coordinates are defined in terms of easting and northing; that is, (x, y) coordinates of the Cartesian coordinate system (planar coordinate systems) or a two-dimensional flat surface (Longley *et al*. 2001).[16]

For some spatial statistical analysis, we need the projected coordinates expressed in units of length with predefined origin so that we can have consistently defined distance, angle, and area within our spatial domain of an x-y plane. The projected easting and northing information of monitoring station location is shown in Table 8.1, and the x-y plane is plotted in Figure 4.11.

4.2.2 (b) Hydrologic Units Adjusted

We select the hydrologic units so that they represent well the drainage boundaries of

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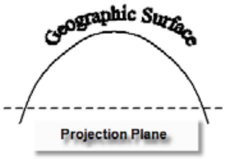
[16] The reference (spherical coordinate) system measures angles from the center of the earth measured in latitude and longitude, which are traditionally measured in degrees, minutes, and seconds. In this system, degrees aren't associated with a standard length. Although degrees of latitude and longitude can be used to locate exact positions on the surface of the globe, they are not uniform units of measurement on the surface. The distance for each degree of longitude varies at different latitudes, while the distance for each degree of latitude remains the same, so that these degree distances can't be used as an accurate measure of distance or area. Note that some distortion of the relative location of the points always occurs, because a curved surface cannot be exactly compressed onto a flat one. Some map projections preserve shape; others preserve area, distance, or direction. No projection preserves all properties. The following graphic indicates that the area has been distorted:



Projections essentially distort the Earth, but they can preserve certain properties such as conformal or equal area property (Longley et al. 2001). If we use the geographic coordinates to assess a process in the space, we cannot find the distance information, and we cannot obtain consistent estimates of the stochastic process.

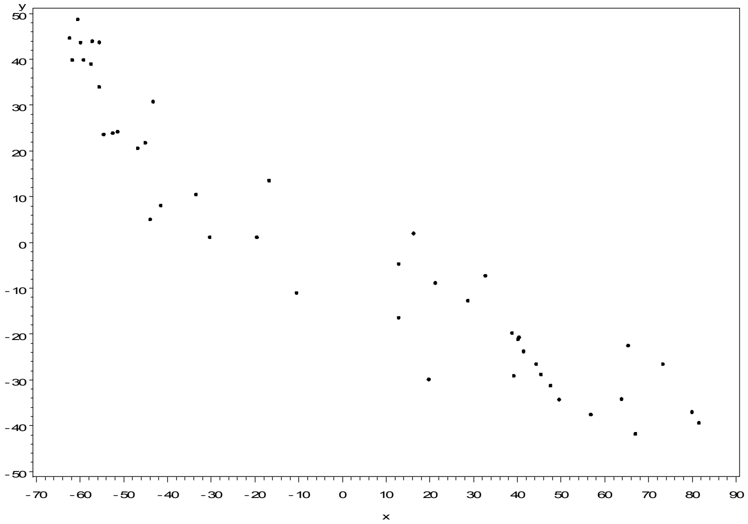


FIGURE 4.11 SCATTER PLOT OF MONITORING STATIONS LOCATIONS (EASTING AND NORTHING)

the small-segmented watershed that drains to a specific ambient monitoring station. Using GIS geoprocessing, we select and dissolve the boundaries of the previously defined units into new units of drainage area affecting the corresponding monitoring stations. The hydrologic units are merged, segmented, or edited depending on the locations of monitoring stations, so that we have a newly created hydrologic unit theme for our own purpose. Figure 4.12 shows the modified hydrologic units.

In this watershed model, the each different modified hydrologic unit occupies different sizes of land area depending on the monitoring station locations. All pollution sources are not uniformly distributed, which precludes their easy conversion into aggregate statistics in each specific unit. We will consider the distances between the sources and the monitoring stations to the extent possible.

In Figure 4.12, about 200 previously defined units are now rearranged into the same number of units (50) as the number of monitoring stations for which we have information. This rearrangement was made possible by using the detailed hydro and hydrologic

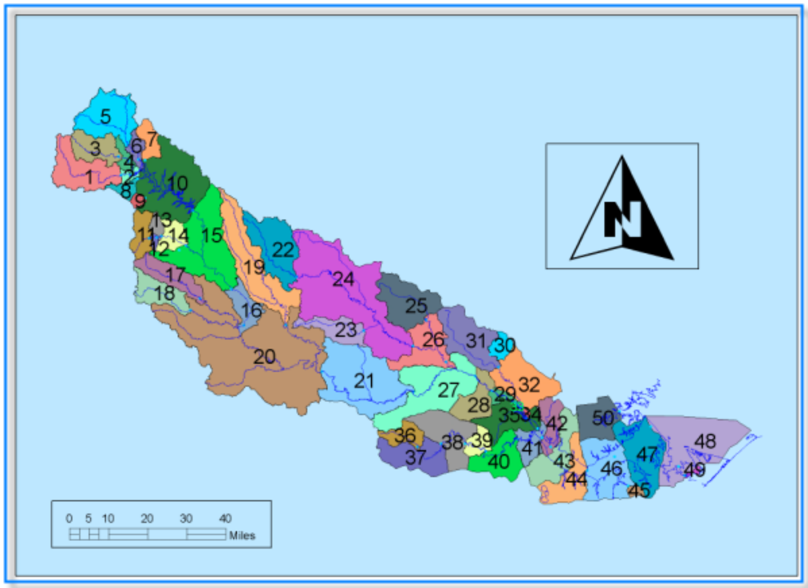


FIGURE 4.12: MODIFIED HYDROLOGIC UNIT

unit boundaries, so that we can keep the homogeneous spatial process of pollution sources. The hydrologic unit numbers (id) labeled in Figure 4.12 are identical to those assigned to the monitoring stations in the region (see Table 8.1). Information on the locations of monitoring stations, with appropriate labeling, is shown on the map in the Appendix.

4.2.3 Nutrient Data

The original data set provided by the DWQ does not contain TN itself, but it has measurements of NO_2-NO_3 (Nitrite – Nitrate) and TKN (Total Kjedahl Nitrogen), and we combined those two for the TN level, as follows:

$$TN = NO_2NO_3 + TKN.$$

The whole data set for 1995 is shown in Table 8.2 in the Appendix. The original data set contains station identification numbers, along with other attributes, and it can be allocated by using GIS overlay analysis as needed. We initially end up with data for 50 monitoring stations, most completed on a monthly basis. For missing monthly data on some stations, we use the average of the available monthly observations at each monitoring station. With the completed data, we get the yearly average data.

4.2.4 Managing Pollution Sources

4.2.4 (a) Point Sources

The average TN concentration (milligram/liter) data provided by the DWQ is missing some data for some dischargers, so we used the average value of the available data. Total volume of each discharger was calculated based on the waste flow data (million gallons/day) and pounds per gallon conversion factor, 8.34:

$$\text{TN Load (lbs./day)} = \text{TN Concentration (mg/L)} \times \text{Waste Flow (MG/d)} \times 8.34.$$

Original data information can be found in Tables 9.4 and 9.5 in the Appendix. The data table has been matched to the spatial data information of the GIS point theme provided. Through simple GIS functions, we are able to get discharger information relevant to each corresponding hydrologic unit. TN loads of dischargers are discounted by distance or the squared distance to the ambient monitoring stations. Total weight of TN discharged into each modified hydrologic unit is calculated.

4.2.4 (b) Nonpoint Sources[17]

Fertilizer

We assume that fertilizer application rates are uniformly distributed on the

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[17] All nonpoint source pollution will be adjusted to the corresponding hydrologic unit size within which the source is located. Thus, the amount of data will be divided by the area (acreage) of the hydrologic units.

appropriate type of land cover throughout each county (see Figure 4.6). The TN application quantity obtained for the area of each modified hydrologic unit is then used to approximate the weight of TN applied in each modified region. Using the GIS spatial analysis process, we get the area information of the LC data of counties extracted for each modified hydrologic unit. The proportion of each county area in each hydrologic unit was calculated, and then the fertilizer data provided by the DWQ for each relevant crop were used to apportion total nitrogen application to each hydrologic unit. In this way we are able to derive the total nitrogen application rate (lbs. / year / acre) for each modified hydrologic unit. The final modified data are presented in Table 8.7 in the Appendix.

Nitrogen from Animal Operations

The animal operation data in each hydrologic unit were collected from original GIS data using the GIS theme selection process. The calculated total nitrogen production in each hydrologic unit was manipulated using the information in Table 4.2. For some swine operations that have missing data for average swine population, the average population per operation in the data (swine: 3,152) was used. A specific problem in modeling this variable is discussed in Section 3.3.3.

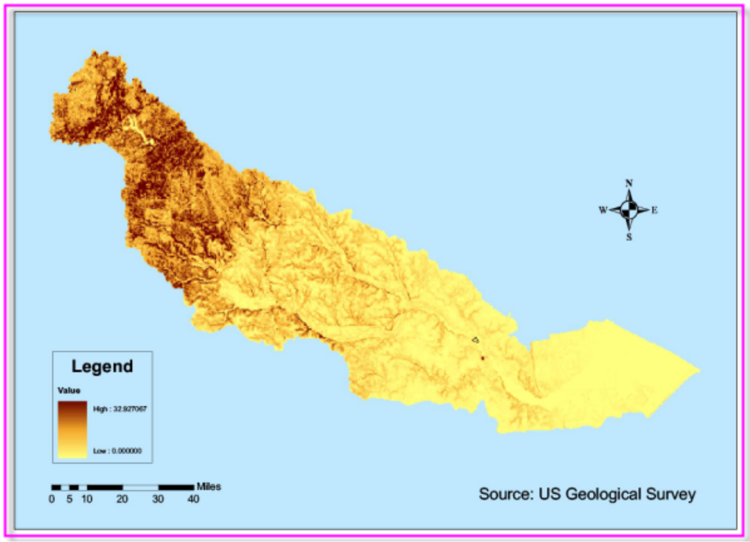
Urban Sources

Land use data chosen as a proxy for urban nonpoint pollution sources in our analysis were geoprocessed by clipping the source data based on the modified hydrologic unit area. The resulting GIS polygon theme/layer was exported to GeoDatabase to obtain the correct area estimates for the newly shaped polygon theme in each hydrologic unit. The area amounts for each unit are used as a pollution source proxy and are shown in Table 8.9.

4.2.5 Managing Spatial Heterogeneity

Slope

ArcView 3.x and the ArcGIS 8.x Spatial Analyst extension are used to get the slope data from the raster dataset for the Neuse River basin. We get the percent slope grid for the whole basin (see Figure 4.13), which is calculated as the maximum rate of altitude change between a cell and its neighbors. Using the “Zonal Statistics” function in the Spatial Analyst extension of ArcGIS, we get separate mean slopes for the area of the relevant modified hydrologic units. Table 8.10 shows the resulting slope data delineation.



Source: US Geological Survey

FIGURE 4.13: SLOPE IN THE NEUSE RIVER BASIN

Wetland

The wetland area of each modified hydrologic unit has been geoprocessed from the LC data from the EPA by clipping the source data based on the modified hydrologic unit area. We export the resulting GIS polygon shapefile to GeoDatabase of ArcGIS software to obtain the area for the newly constructed polygon theme in each hydrologic unit. The area estimates for each unit are used as a source and are shown in Table 8.10.

Stream Flow

We use flow severity data as a proxy for stream flow data. As was done in other data sets (e.g., point source pollution), missing data have been replaced with annual average data. This data set has been used to calculate the weighted nutrient load of neighboring upstream monitoring stations. Also, the variable itself has been used as a covariate to measure its own (stream characteristic) effect on water quality.

Stream Width

The estimated stream width data for each monitoring site does not cover all stations. There are many missing stream width data for the downstream monitoring stations in the basin. Some stations that were missing the data still had enough to allow us to use the average. For the remaining stations that were missing the data, we used the GIS layers (major hydro and detailed hydro) to get the approximate width of each stream. When we have only one line of the major hydrography observable from the GIS theme, we use the average of other similar streams with available data. Missing data approximations seem credible, because the average data from the DWQ and the GIS data layer show almost identical results. Thus, for stations without stream width data, we mostly use the detailed hydrography to approximate stream width at a particular point.

5. ESTIMATION

The spatial processes in a regional watershed are described in Chapter 3. We incorporated geographical features into the model. Chapter 4 details the manipulation of data using GIS spatial analysis methods so that the data can represent the spatial processes appropriately. We now want to be able to infer a relationship between water quality and pollution sources. Several tasks remain before appropriate statistical analysis can be applied to understand the relationships in the data.

5.1 Starting Analysis

We start with the estimation of the original spatial AR response model constructed in Section 3.3 by means of OLS[18]:

$$\mathrm{y_i} = \alpha + \sum_{d=1}^{2} \phi_d D_d + \rho\left(\frac{1}{F_i}\sum_{j \in J_i} q(d_{i,j}) \cdot f_j \cdot y_j\right) + \sum_{k=1}^{K} \theta_k^{np}\left(NP_{i,k} \big/ HU_i \right)$$

$$+ \theta^{pp}\left(\frac{1}{SW_i}\sum_{p \in P_i} s(d_{i,p_i}) \cdot PL_{i,p}\right) + \sum_{h=1}^{H} \beta_h HC_{i,h} + \varepsilon_i \, .$$

The regression was run including all the variables spatially identified in Chapter 4, and the results are shown in Table 5.1. Test results of Moran's *I* are reported for the residuals of each analysis to determine if the model correctly includes spatial spillovers into

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[18] For the explanation of each variable, see Section 3.3. The units of the variables are shown below:

Variable	Water Quality (TN)	Flow	Temperature	Stream Width	Point Source (PP)	PP Waste Flow	Urban LU	Animal Operation	Fertilizer Application	Forest LC	Slope	Wetland	Hydrologic Unit
Unit	mg/l	Severity (1,2,3,4)	Fahrenheit	Feet	lbs/day	mg/d	Acreage /HU	TN (lbs) /Acre /Year	TN (lbs) /Acre /Year	Acreage /HU	%	Acreage /HU	Acreage

The number of observations (n) is 40 for all analyses in this chapter.

the model. Also, we compare Akaike's Information Criteria (AIC) along with all other regression results.

Table 5.1 Initial Regression Analyses

Analysis 1	Model 1.1			Model 1.2		
Variable	Coefficient	t-value	p-value	Coefficient	t-value	p-value
intercept	-24.91163	-2.91	0.0075	-17.08524	-2.22	0.0359
Dummy_Neighbor (y_j)	-0.68133	-1.5	0.145	-0.27633	-0.68	0.502
Dummy_Point Source Pollution Load (PL_i)	0.07413	0.19	0.8534	0.30496	0.89	0.3843
Flow Severity ($HC_{i, \text{flow severity}}$)	2.41834	4.43	0.0002	2.9536	6.01	<.0001
Temperature ($HC_{i, \text{temperature}}$)	0.25556	2	0.0562	0.09268	0.77	0.4466
Stream Width ($HC_{i, \text{stream width}}$)	-0.000334	-1.43	0.1663	-0.000168	-0.82	0.4215
Neighbor Water Quality ($W_{ij}y_j$)	2.91422	9.5	<.0001	2.92265	11.21	<.0001
Point Sources of Pollution (PL_i)	0.30304	2.34	0.0277	0.3438	3.09	0.005
Developed Land Use ($NP_{i, \text{dev LU}}/HU_i$)	13.28607	3.79	0.0009			
High Intensity Developed Land Use ($NP_{i, \text{high dev LU}}/HU_i$)				-29.45656	-2.23	0.0352
Low Intensity Developed Land Use ($NP_{i, \text{high dev LU}}/HUi$)				41.91837	4.57	0.0001
Animal Agriculture ($NP_{i, \text{animal ag.}}/HU_i$)	0.0113	0.54	0.5912	0.0238	1.32	0.2002
Fertilizer Application ($NP_{i, \text{fertilizer}}/HU_i$)	0.00782	0.48	0.6368	0.00666	0.48	0.6369
Forest Land Cover ($NP_{i, \text{forest}}/HU_i$)	5.58399	2.88	0.008	3.50013	1.96	0.0614
Wetland ($HC_{i, \text{wetland}}/HU_i$)	1.67064	0.61	0.546	3.40532	1.43	0.1661
Slope ($HC_{i, \text{slope}}$)	0.39404	1.19	0.2442	1.09435	3.1	0.0049
Hydrologic Unit Size (HU_i)	-1.23E-06	-0.6	0.5571	-1.98E-06	-1.12	0.2741
R-Square	0.8814			0.9176		
F-Value (pr > F)	13.26 (< .0001)			17.82 (< .0001)		
AIC	2.6755			-9.9092		
Moran Test	-0.0607 (0.8377)			0.089 (0.4974)		

Comparing the results of the two models in Table 5.1, we see some improvement in the model fit when the "Developed Land Use" variable is separated into High- and Low-Intensity Developed land use variables. The results of Moran's *I* tests show no evidence of spatial autocorrelation for either of the models, so we can conclude that the model has incorporated the spatial effects into the model very well. We have rather high R^2 for the two models, and some variables (e.g., flow severity, neighbor water quality, and developed land use) are highly significant. However, although we have reasonable F values, with most variables having low *p* values (< .0001) for model fit, some variables are statistically insignificant. These results give us a reason to suspect multicollinearity among variables. We have models that fit well, but we believe some covariates are estimating similar phenomena (Freund and Littell 1991:96). Some pollution source covariates are more closely correlated with each other than they are with the water quality variable.

5.2 Multicollinearity Detection

The initial models (1.1 and 1.2) may have variables that are multicollinear and that may decrease the statistical significance of the parameter estimates. With variables subject to multicollinearity, the significance of similar variables may not be fully estimated individually, but by removing one, significant test values may be obtained. We decided to remove the variables involving distinct multicollinearity.

We use two statistics for detecting possible multicollinearity for models 1.1 and 1.2: the variance inflation factors (VIF) and an analysis of the structure of the $\mathbf{X'X}$ matrix. The VIF analysis is defined as $1/(1-R_i^2)$, where R_i^2 is the coefficient of determination for the 'regression' of the *i*th independent variable on all other independent variables (Johnston 1984; Rawlings 1988). Also used is a collinearity diagnostic analysis to support the results we obtained through the VIF analysis. We analyzed the structure of relationships among the set of pollution source variables by an analysis of the eigenvalues and eigenvectors of $\mathbf{X'X}$ (Freund and Littel 1991:97). Multicollinearity can be detected by the relative magnitudes of the eigenvalues. If eigenvalues are very small and close to zero, then we can identify the pollution source variables that cause the linear dependencies. In addition, the “Condition Index” was used simultaneously for the indication of multicollinearity (Rawlings 1988).

Using a continuous detection process, we have been able to eliminate some variables (slope, high-intensity developed land use, water temperature, flow severity). The results of two new models excluding two multicollinear variables are shown in the Tables 5.2 and 5.3.

Table 5.2 Regressions without the “Slope” and the “High Intensity Developed” variables

Analysis 2	Model 2.1			Model 2.2		
Variable	Coefficient	t-value	p-value	Coefficient	t-value	p-value
Intercept	-24.746	-2.87	0.0081	-22.3914	-2.72	0.0115
Dummy_Neighbor (y_j)	-0.5965	-1.32	0.1973	-0.43063	-1.01	0.3211
Dummy_Point Source Pollution Load (PL_i)	0.13746	0.35	0.7317	0.24655	0.66	0.5177
Flow Severity ($HC_{i,\text{ flow severity}}$)	2.33742	4.28	0.0002	2.46868	4.69	<.0001
Temperature ($HC_{i,\text{ temperature}}$)	0.27239	2.13	0.0428	0.23162	1.88	0.0714
Stream Width ($HC_{i,\text{ stream width}}$)	-0.0005	-2.44	0.0216	-0.00052	-2.73	0.0113
Neighbor Water Quality ($W_{ij}y_j$)	2.97131	9.73	<.0001	3.00986	10.22	<.0001
Point Sources of Pollution (PL_i)	0.2905	2.23	0.0345	0.29314	2.34	0.0271
Developed Land Use ($NP_{i,\text{ dev LU}}/HU_i$)	13.6946	3.89	0.0006			
Low Intensity Developed Land Use ($NP_{i,\text{ high dev LU}}/HUi$)				23.8182	4.29	0.0002
Animal Agriculture ($NP_{i,\text{ animal ag.}}/HU_i$)	-0.0003	-0.02	0.9869	-0.00267	-0.15	0.8814
Fertilizer Application ($NP_{i,\text{ fertilizer}}/HU_i$)	-0.0002	-0.01	0.9898	-0.00452	-0.33	0.7459
Forest Land Cover ($NP_{i,\text{ forest}}/HU_i$)	6.21525	3.31	0.0027	6.07567	3.5	0.0017
Wetland ($HC_{i,\text{ wetland}}/HU_i$)	-0.3746	-0.18	0.8624	-0.82206	-0.42	0.676
Hydrologic Unit Size (HU_i)	-2E-06	-0.81	0.4243	-2.1E-06	-1.09	0.286
R-Square	0.8746			0.8839		
F-Value (Pr > F)	13.95 (< .0001)			15.23 (< .0001)		
AIC	2.8897			-0.1956		
Moran Test	- 0.1264 (0.5534)			-0.133 (0.5229)		

Table 5.3 shows new results excluding additional variables detected in the multicollinearity analyses from the analyses result in Table 5.2. We checked again for multicollinearity, and models 3.1 and 3.2 satisfy the condition. Unfortunately, the results

aren't yet satisfactory, because we still have several variables that are statistically insignificant, although the models are fitting well overall. Moran's *I* tests for these models also show that we cannot reject the hypothesis of no spatial autocorrelation.

Table 5.3 Regressions without the Multicollinear Variables; Flow Severity and Temperature

Analysis 3	Model 3.1			Model 3.2		
Variable	Coefficient	t-value	p-value	Coefficient	t-value	p-value
Intercept	-2.4886	-1.56	0.1291	-2.30233	-1.52	0.1393
Dummy_Neighbor (y_j)	0.01294	0.03	0.979	0.12376	0.26	0.7965
Dummy_Point Source Pollution Load (PL_i)	0.73029	1.59	0.1236	0.82523	1.83	0.0775
Stream Width ($HC_{i,\ stream\ width}$)	-0.0003	-1.08	0.2898	-0.0003	-1.25	0.2217
Neighbor Water Quality ($W_{ij}y_j$)	2.70236	7.18	<.0001	2.74784	7.32	<.0001
Point Sources of Pollution (PL_i)	0.35315	2.3	0.0288	0.33913	2.22	0.0346
Developed Land Use ($NP_{i,\ dev\ LU}/HU_i$)	13.6058	3.03	0.0053			
Low Intensity Developed Land Use ($NP_{i,\ high\ dev\ LU}/HUi$)				22.62569	3.11	0.0043
Animal Agriculture ($NP_{i,\ animal\ ag.}/HU_i$)	0.02599	1.21	0.2347	0.02613	1.23	0.229
Fertilizer Application ($NP_{i,\ fertilizer}/HU_i$)	0.01357	0.72	0.4764	0.00853	0.48	0.6355
Forest Land Cover ($NP_{i,\ forest}/HU_i$)	4.29184	1.97	0.0591	4.15241	1.97	0.0592
Wetland ($HC_{i,\ wetland}/HU_i$)	2.39124	0.98	0.3351	2.10556	0.9	0.3742
Hydrologic Unit Size (HU_i)	1.91E-08	0.01	0.9941	-3.97E-07	-0.16	0.8743
R-Square	0.7798			0.7827		
F-Value (Pr > F)	9.02 (< .0001)			9.17 (< .0001)		
AIC	21.4086			20.8777		
Moran Test	0.1434 (0.2841)			0.1326 (0.2967)		

5.3 Consideration of the Relationships Among Area Variances in the Watershed

With the results still problematic, we suspect the validity of data; that is, we question whether it correctly incorporates the spatial processes in the basin. Considering that aggregate data for the new modified hydrologic units are made up from different numbers of original hydrologic units, we expect that this could affect our analytical results. We added a variable of "hydrologic unit size" in models 1, 2, and 3. All the estimates for the "hydrologic unit size" coefficients are negative but not statistically significant.

With considerable variations in the sizes of the new hydrologic units, we have pollution sources that would be differently explained – even with the same size or amount of covariates – depending on variation in the hydrologic unit size. We suspect unstable variances caused by this problem, as discussed by Haining (1990: Section 2.3.3). If data came from a larger unit, they are distributed more throughout the units of watershed. Thus, given the larger variations with which we are working, the aggregated data set cannot exactly account for water quality variations, because the monitoring stations are always located at the downstream end in every hydrologic unit. If this is the case, then the larger the unit, the larger the variance of water quality observation i, and the more unreliable the observations in the unit. Thus, we can expect the following:

$$\mathrm{Var}(Y_i) = \sigma^2 HU_i\,,$$

where HU_i represents the size of the i^{th} hydrologic unit. Weighted Least Squares (WLS) regression analysis is conducted with weight (w_i) set as the inverse of the hydrologic unit size ($w_i = HU_i^{-1}$), and we show the results in Table 5.4.

In Table 5.4, the "Hydrologic Unit Size" variable is used as the spatial weighting factor instead of being used as an explanatory variable. Here, there is still evidence that some variables are insignificant, with unexpected signs on the coefficients. To determine whether further diagnostics are needed, we show plots (see Figure 5.1) of the residuals by the size of the hydrologic unit. Differences between the OLS and the WLS results are compared.

Table 5.4 Weighted Least Squares Analyses

Analysis 4	Model 4.1			Model 4.2		
Variable	Coefficient	t-value	p-value	Coefficient	t-value	p-value
Intercept	-2.9974	-2.56	0.0159	-2.73127	-2.4	0.0228
Dummy_Neighbor (y_j)	0.19381	0.31	0.7606	0.55127	0.84	0.4065
Dummy_Point Source Pollution Load (PL_i)	2.47606	4.08	0.0003	2.69342	4.54	<.0001
Stream Width ($HC_{i,\text{ stream width}}$)	-0.0006	-1.26	0.218	-0.00067	-1.43	0.164
Neighbor Water Quality ($W_{ij}y_j$)	2.69212	7.89	<.0001	2.70133	7.82	<.0001
Point Sources of Pollution (PL_i)	0.22447	1.14	0.2648	0.24346	1.21	0.2359
Developed Land Use ($NP_{i,\text{ dev LU}}/HU_i$)	11.1909	2.81	0.0089			
Low Intensity Developed Land Use ($NP_{i,\text{ high dev LU}}/HUi$)				16.92232	2.67	0.0124
Animal Agriculture ($NP_{i,\text{ animal ag.}}/HU_i$)	0.03259	1.02	0.3175	0.03643	1.12	0.2722
Fertilizer Application ($NP_{i,\text{ fertilizer}}/HU_i$)	-0.0368	-1.29	0.2072	-0.04781	-1.74	0.093
Forest Land Cover ($NP_{i,\text{ forest}}/HU_i$)	6.39802	4.32	0.0002	5.83859	4.14	0.0003
Wetland ($HC_{i,\text{ wetland}}/HU_i$)	2.39258	1.21	0.2352	1.84182	0.97	0.3412
R-Square	0.8605			0.8575		
F-Value (Pr > F)	17.88 (< .0001)			17.45 (< .0001)		
AIC	-363.0613			-362.2247		
Moran Test	0.04409 (0.684)			0.00714 (0.8478)		

The results in Figure 5.1 need to be interpreted with caution. Most observations are hydrologic units with areas of around 100,000 acres or less. If more units with higher acreage were available, we might expect different results. Figures 5.1 (a) and (b) do not provide a clear reason to pursue WLS analysis. With WLS, we might not include all the unstable variance factors into the model. Considering the complex features of the watershed process, there is a considerable possibility of heterogeneity. It may be that the WLS alone is insufficient to explain the phenomena in this dataset. We do not, however, conclude from the plots in Figure 5.1 that the WLS is useless here. Some outliers disguise the relationship between residuals and the hydrologic unit size variable. For example, the point (circled) in the upper-left-hand corner in Figure 5.1 (a) is the residual value (= 4.3346) from hydrologic unit 12, which is a very small unit and has a point source outlet (North Cary Waste Water

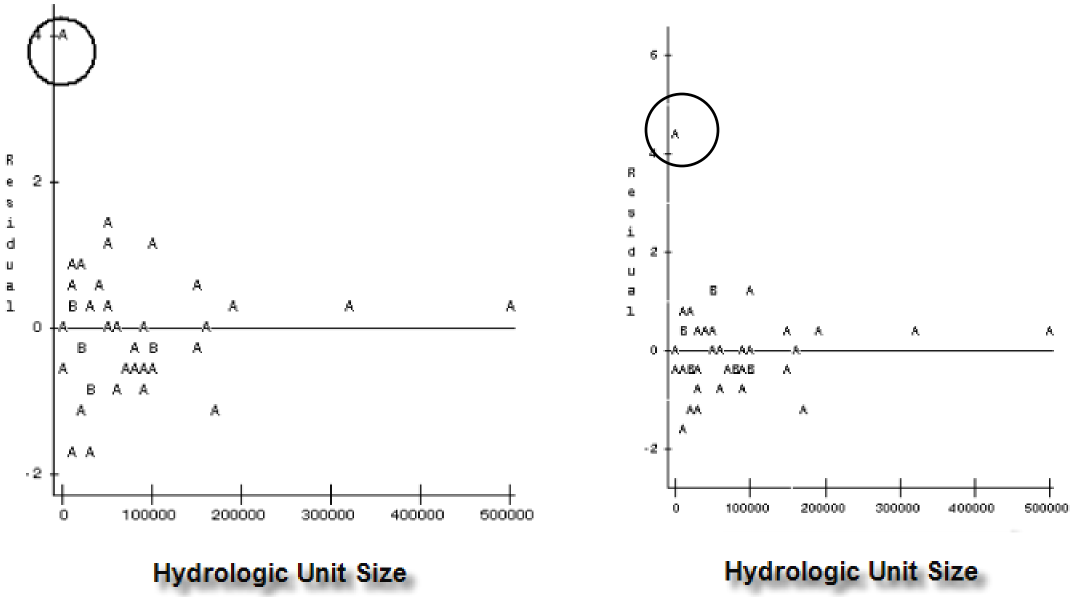


Figure 5.1 (a) Residual vs. Hydrologic Unit Size from model 3.1

Figure 5.1 (b) Residual vs. Hydrologic Unit Size from model 3.2

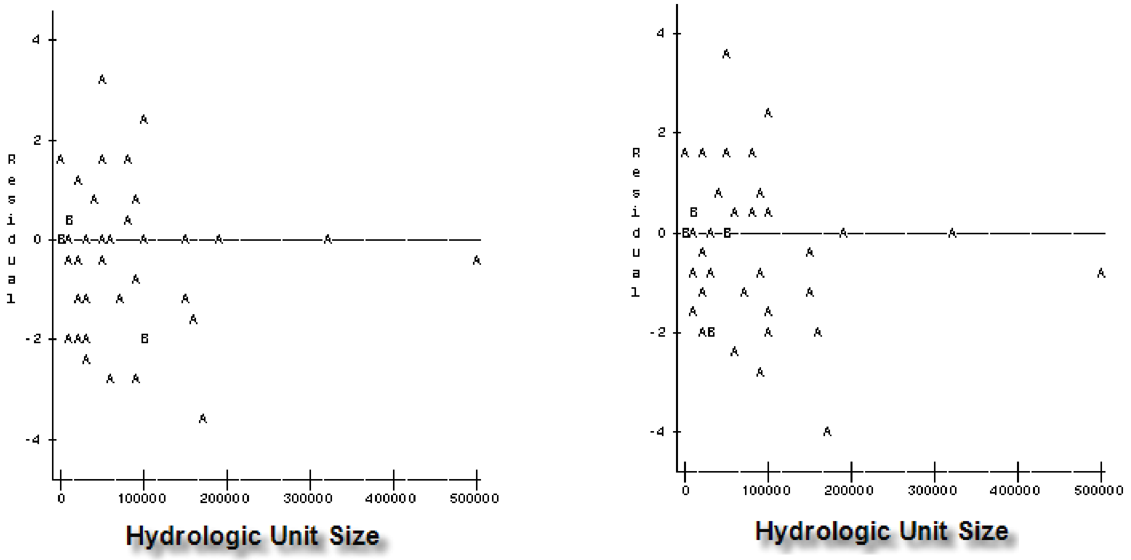


Figure 5.1 (c) Residual vs. Hydrologic Unit Size from model 4.1

Figure 5.1 (d) Residual vs. Hydrologic Unit Size from model 4.2

Figure 5.1: Plots (Residual vs. Hydrologic Unit Size) for Analyses 3 and 4

Treatment Plant) about three miles upstream as a major nutrient contribution source. This suggests that in the presence of NPDES stations, the hydrologic unit size has little effect on this type of source. Instead, the stream TN concentration depends heavily on the distance of point source pollution locations. Also, the monitoring station in hydrologic unit 12 is very close to the next monitoring station, in hydrologic unit 13 (about two miles away), so the upper hydrologic unit spillover effect is still strong at the next downstream unit.

We conclude that even when we incorporate the hydrologic unit size difference in the WLS, only part of the spatial process is captured. Water quality measured at each ambient monitoring station is affected by the processes of pollution sources that are not only coming from the land use area but also from the stream itself. While land use sources may steadily affect water quality, the indirect spatial externality effect of upstream land uses on downstream water quality and the effects of direct discharge into the stream from point source dischargers cause very significant variations in downstream water quality. The most drastic water quality variations of the current ambient monitoring stations appear to arise from large impacts from these two kinds of sources. A new approach may be needed to better incorporate these physical features into the model.

We show one more empirical check below (Figure 5.2) for the validity of the WLS (model 4). The residual plots versus predicted values of each model are shown, from which we conclude that the WLS of model 4 are not well specified. Two plots show U-shaped patterns, indicating poor model fits and the need to pursue other solutions to the problem.

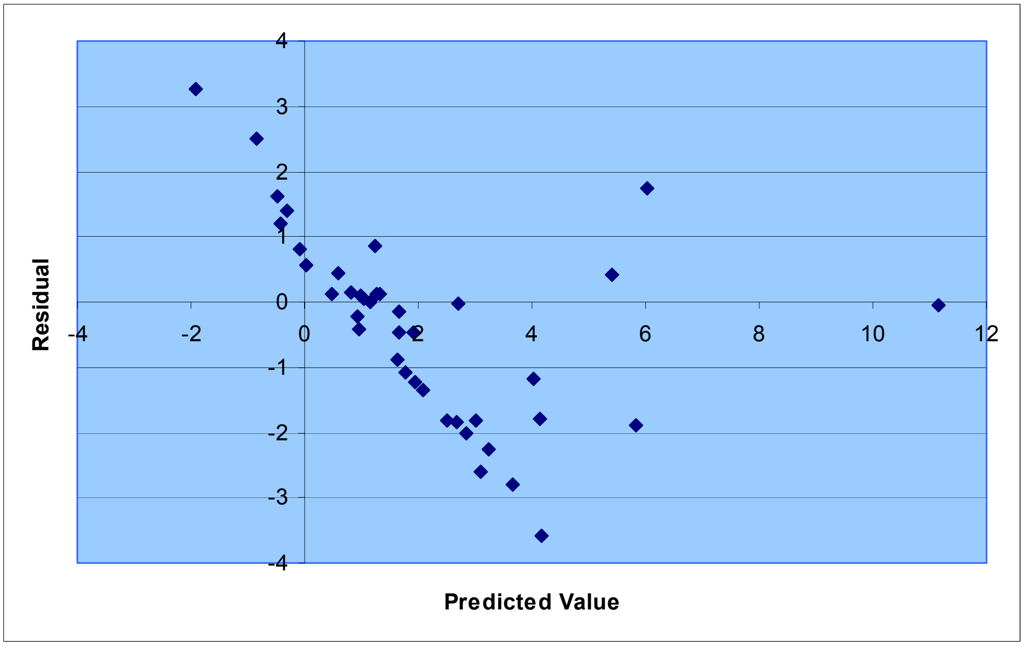


FIGURE 5.2 (A): RESIDUAL VS. PREDICTED VALUES FOR MODEL 4.1

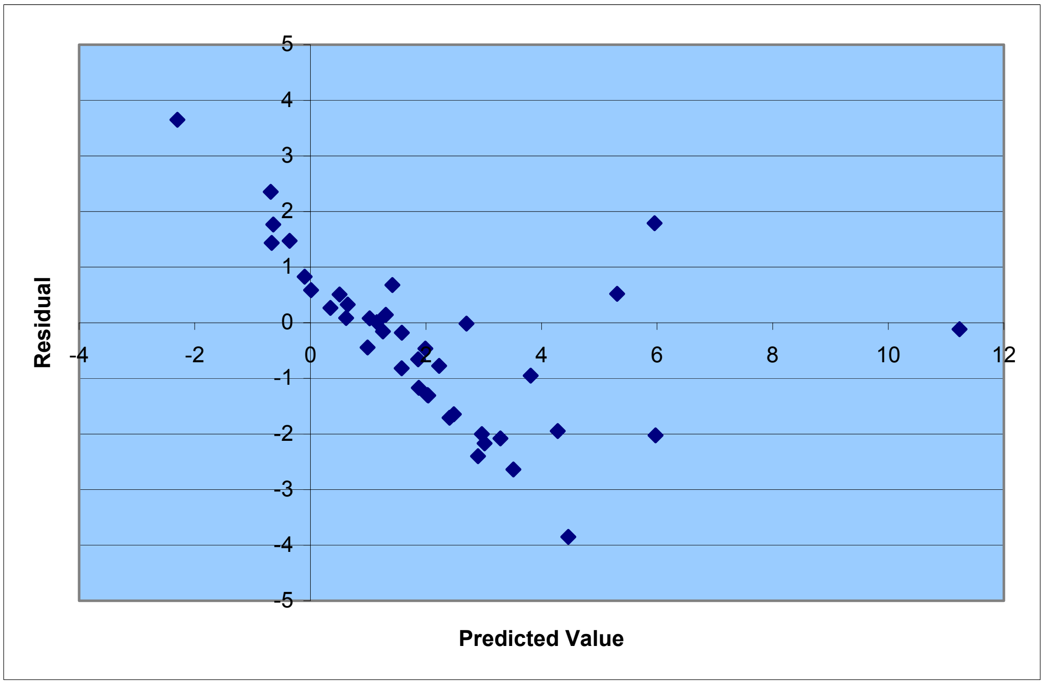


FIGURE 5.2 (B): RESIDUAL VS. PREDICTED VALUES FOR MODEL 4.2

The consistent pattern from the two plots of Figures 5.2 (a) and (b) may indicate the need for a model that can “achieve a linearizing transformation” (Johnston and DiNardo 1997:45) so that we can apply OLS or WLS analyses to properly transformed variables of spatial process in a regional watershed having complex relations. That is, the model involves two distinct spatial processes that affect the nutrient levels of relevant streams. Given the complexity of the spatial process, we may need some slight adjustment of the conventional transformation approach, introduced next.

5.4 Analyses with Transformations of Variables

We suppose the following specification for variable transformation:

$$y^{(\tau_1)} = \begin{cases} \dfrac{y^{\tau_1} - 1}{\tau_1} & \tau_1 \neq 0 \\[2ex] \ln Y & \tau_1 = 0, \end{cases}$$

and

$$X_i^{(\tau_2)} = \begin{cases} \dfrac{X_i^{\tau_{2,i}} - 1}{\tau_{2,i}} & \tau_{2,i} \neq 0 \\[2ex] \ln X_i & \tau_{2,i} = 0, \end{cases}$$

where y represents the water quality variable and X_i (i = 1 and 2) represents two sources of pollution: pollution from streams and pollution from land use. If we let X_1 = sources coming from streams and X_2 = sources coming from land use and land Cover, we then propose the following model:

$$\tau_1 = 0, \tau_{2,1} = 0, \text{ and } \tau_{2,2} = 1,$$

which may represent the spatial process well.

With the effective use of the dummy variables (for "Neighbor Water Quality" and the "Point Sources of Pollutions") and the data transformation as specified above, we have a slightly different transformed model, as follows:

$$\ln \mathrm{y}_i = \alpha + \sum_{d=1}^{2} \phi_d D_d + \rho \ln(\frac{1}{F_i} \sum_{j \in J_i} q(d_{i,j}) \cdot f_j \cdot y_j) + \sum_{k=1}^{K} \theta_k^{np} \left({NP_{i,k}} \big/ {HU_i} \right)$$

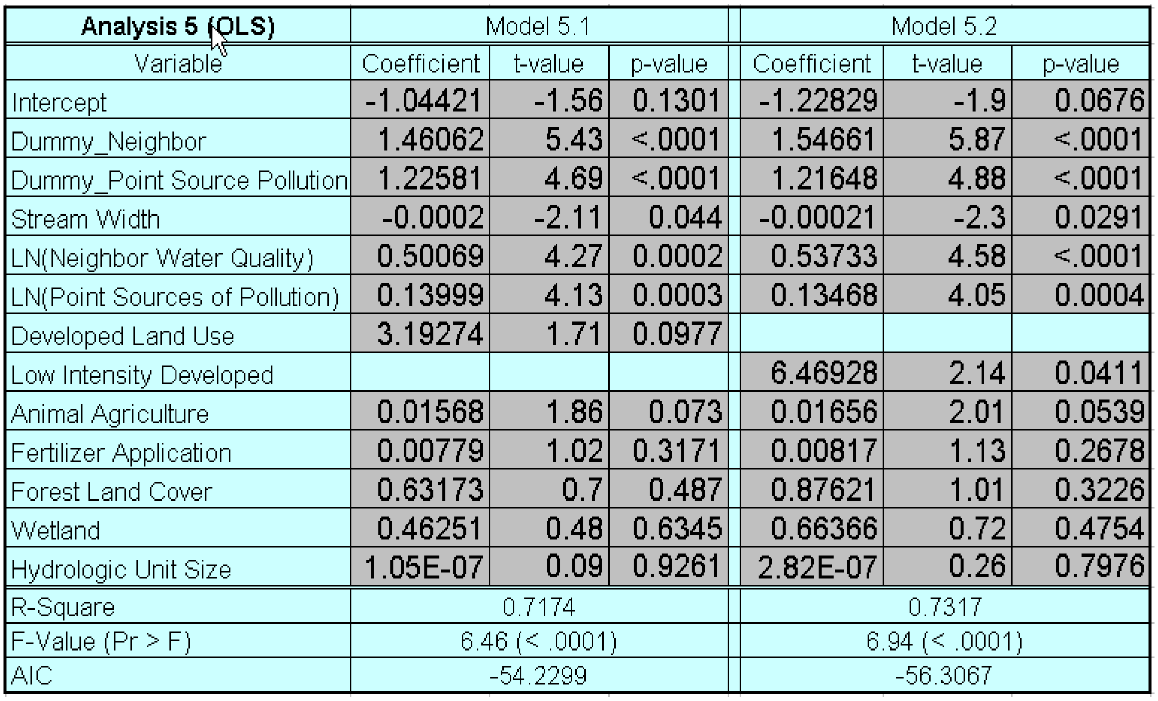
$$+ \theta^{pp} \ln(\frac{1}{SW_i} \sum_{p \in P_i} s(d_{i,p_i}) \cdot PL_{i,p}) + \sum_{h=1}^{H} \beta_h HC_{i,h} + \varepsilon_i,$$

where ρ and θ^{pp} represent point estimates of elasticity for each source, and θ_k^{np} and β_h represent the proportionate rate of change in Y per unit change in the nonpoint source pollution and land cover characteristics respectively.

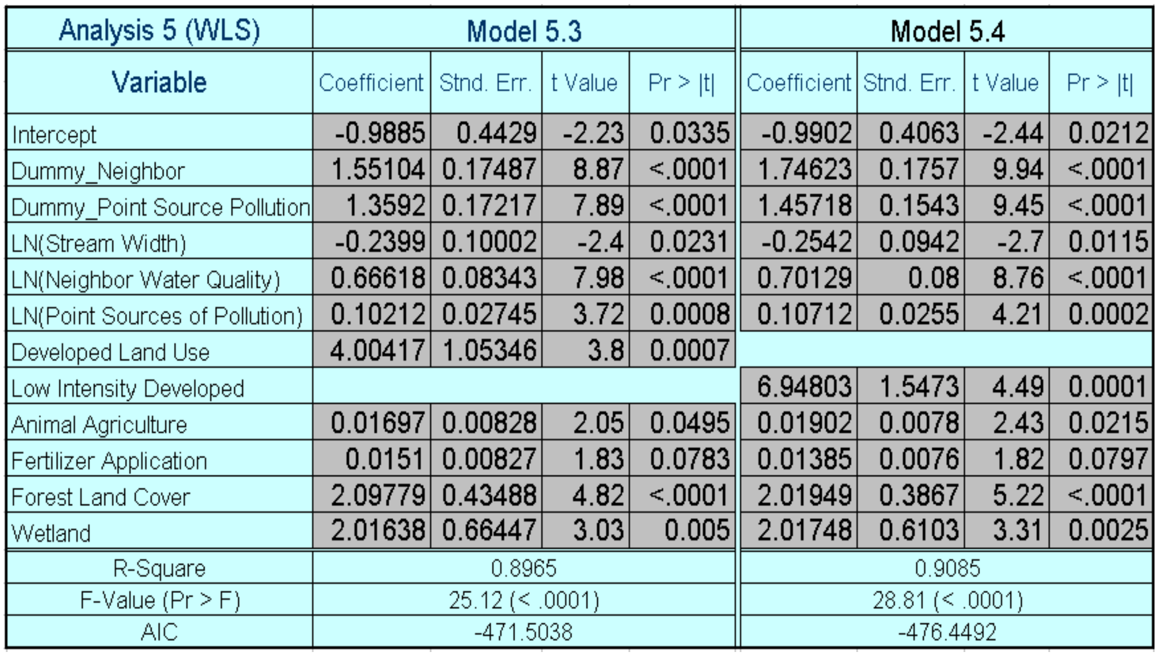
We run the OLS and the WLS for the model above. The results are shown in Tables 5.5 (a) and (b), which confirms the superiority of the WLS over the OLS, even with the transformation of the variables.

The WLS analyses fit better in terms of the statistical significance of variables. Models 5.3 and 5.4 are our final models. We checked the relationship between the residual and the predicted values for models 5.3 and 5.4, and they show much better behavior than model 4 (See Figures 5.3 and 5.4).

Table 5.5: Analyses Results (OLS & WLS) for the Natural Log Transformed Data



Analysis 5 (OLS)	Model 5.1			Model 5.2		
Variable	Coefficient	t-value	p-value	Coefficient	t-value	p-value
Intercept	-1.04421	-1.56	0.1301	-1.22829	-1.9	0.0676
Dummy_Neighbor	1.46062	5.43	<.0001	1.54661	5.87	<.0001
Dummy_Point Source Pollution	1.22581	4.69	<.0001	1.21648	4.88	<.0001
Stream Width	-0.0002	-2.11	0.044	-0.00021	-2.3	0.0291
LN(Neighbor Water Quality)	0.50069	4.27	0.0002	0.53733	4.58	<.0001
LN(Point Sources of Pollution)	0.13999	4.13	0.0003	0.13468	4.05	0.0004
Developed Land Use	3.19274	1.71	0.0977			
Low Intensity Developed				6.46928	2.14	0.0411
Animal Agriculture	0.01568	1.86	0.073	0.01656	2.01	0.0539
Fertilizer Application	0.00779	1.02	0.3171	0.00817	1.13	0.2678
Forest Land Cover	0.63173	0.7	0.487	0.87621	1.01	0.3226
Wetland	0.46251	0.48	0.6345	0.66366	0.72	0.4754
Hydrologic Unit Size	1.05E-07	0.09	0.9261	2.82E-07	0.26	0.7976
R-Square	0.7174			0.7317		
F-Value (Pr > F)	6.46 (< .0001)			6.94 (< .0001)		
AIC	-54.2299			-56.3067		



Analysis 5 (WLS)	**Model 5.3**				**Model 5.4**			
Variable	Coefficient	Stnd. Err.	t Value	Pr > |t|	Coefficient	Stnd. Err.	t Value	Pr > |t|
Intercept	-0.9885	0.4429	-2.23	0.0335	-0.9902	0.4063	-2.44	0.0212
Dummy_Neighbor	1.55104	0.17487	8.87	<.0001	1.74623	0.1757	9.94	<.0001
Dummy_Point Source Pollution	1.3592	0.17217	7.89	<.0001	1.45718	0.1543	9.45	<.0001
LN(Stream Width)	-0.2399	0.10002	-2.4	0.0231	-0.2542	0.0942	-2.7	0.0115
LN(Neighbor Water Quality)	0.66618	0.08343	7.98	<.0001	0.70129	0.08	8.76	<.0001
LN(Point Sources of Pollution)	0.10212	0.02745	3.72	0.0008	0.10712	0.0255	4.21	0.0002
Developed Land Use	4.00417	1.05346	3.8	0.0007				
Low Intensity Developed					6.94803	1.5473	4.49	0.0001
Animal Agriculture	0.01697	0.00828	2.05	0.0495	0.01902	0.0078	2.43	0.0215
Fertilizer Application	0.0151	0.00827	1.83	0.0783	0.01385	0.0076	1.82	0.0797
Forest Land Cover	2.09779	0.43488	4.82	<.0001	2.01949	0.3867	5.22	<.0001
Wetland	2.01638	0.66447	3.03	0.005	2.01748	0.6103	3.31	0.0025
R-Square	0.8965				0.9085			
F-Value (Pr > F)	25.12 (< .0001)				28.81 (< .0001)			
AIC	-471.5038				-476.4492			

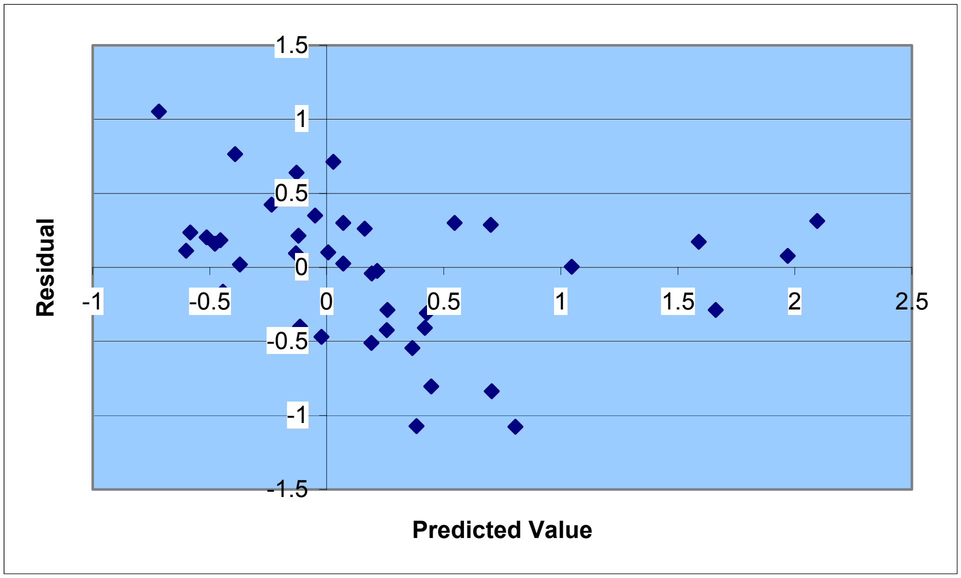


FIGURE 5.3 (A) RESIDUAL VS. PREDICTED VALUE FOR MODEL 5.3

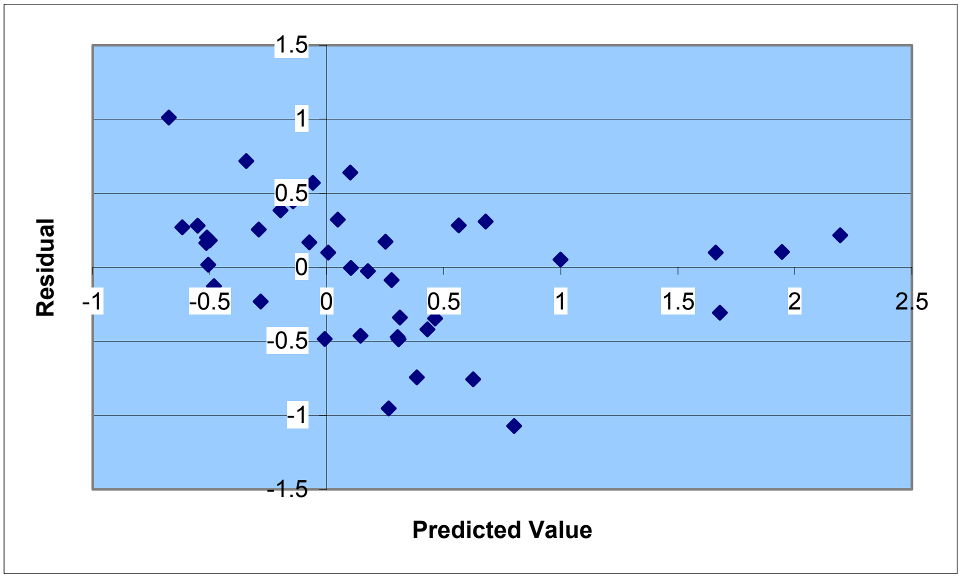


FIGURE 5.3 (B) RESIDUAL VS. PREDICTED VALUE FOR MODEL 5.4

From the plots in Figure 5.3, we can still see most distinct outlier effects caused by four data points. In general, negative correlations between residuals and predicted values appear to remain, particularly for the observations with TN < 4. Four points have larger TN concentrations arising from the presence of nearby point source outfalls in relatively small streams (two points being affected by a waste treatment facility from the town of Cary, and the other two points each being affected by waste treatment facilities from the city of Durham and the town of Butner respectively). Accordingly, dummy variables are included for the existence of point sources and upstream neighbors in each unit, treating these effects from point sources and neighboring units.

6. DISCUSSION AND CONCLUDING REMARKS

6.1 Method and Data

This study utilizes elements of several different fields of study to facilitate more effective and efficient policy development for water pollution control. This multidisciplinary research was focused on elucidating the complex relationships between environmental change (water quality) and patterns of economic behavior.

We started with the problem of persistent pollution externality in society. Upon consideration of the water quality problem, the externality problem was extended to a spatial conceptual model of a watershed. This led us to use the spatial AR response model, representing the watershed spatial spillover effect and multiple pollution processes. Then we discussed the spatial aspects of a watershed, to help us arrive at more constructive modeling insights. Possible problems arising from spatial effects were identified, including spatial autocorrelation and heterogeneity inherent in a regional watershed. Relevant spatial analysis problems have been considered relative to both geographic data manipulation and statistical analysis, to ensure we correctly incorporate their effects in our analysis.

Care was taken to determine the correct range and scale of spatial data information based on the geographical data and consistent with the physical features of the watershed. As we chose the Neuse River basin as our study region, total nitrogen (TN) was selected as the pollutant to be studied, with data provided by the North Carolina DWQ. Spatial data sets from several sources for pollutant sources and watershed characteristics were collected and manipulated to make them comparable for the region.

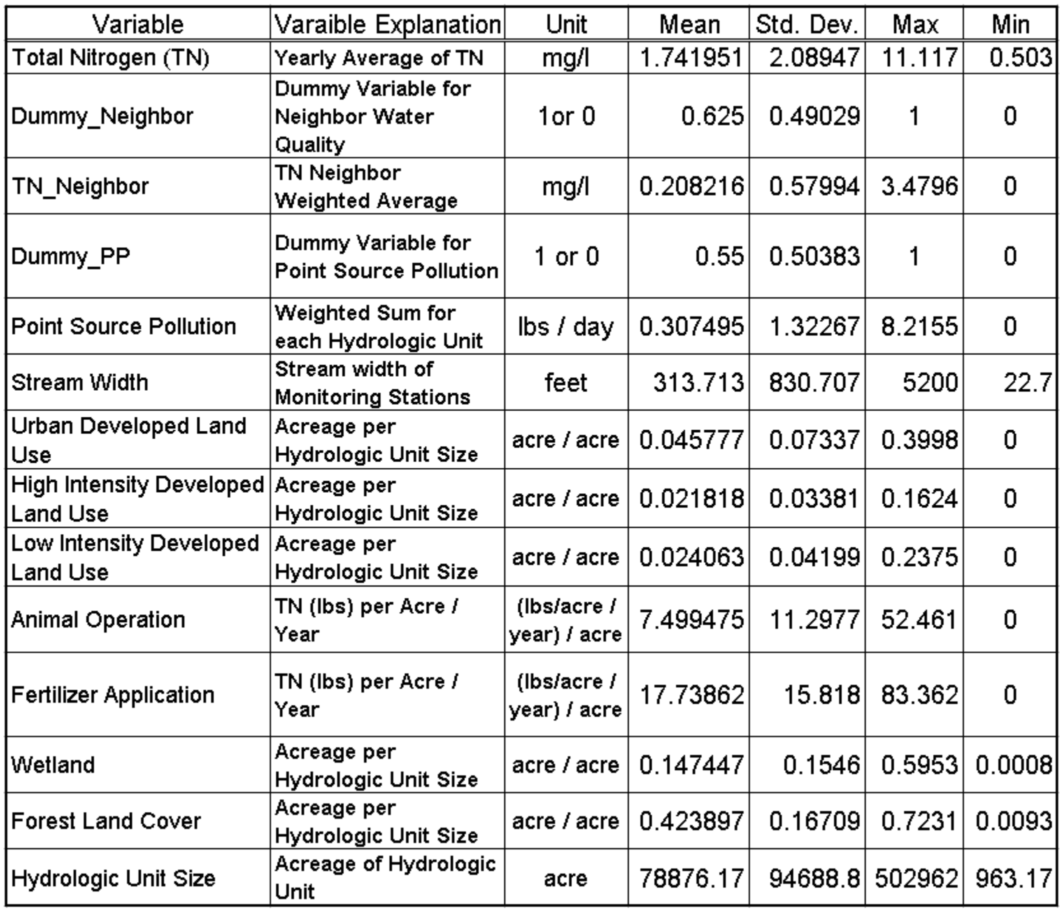
A structural model was constructed based on the spatial aspects of a regional watershed and the available data sets. Final data sets for the analysis of the model were produced by application of GIS manipulation techniques to data from several sources. The focus of the data manipulation process was to find a consistent basis for comparing the quantities of pollution sources in the region with the variations in water quality across hydrologic units. A multivariate database for 14-digit hydrologic units in the Neuse River basin in 1995 was assembled. Methods of converting data from multiple sources to a common basis for water quality analysis were demonstrated.

The empirical watershed model was designed to incorporate spatial effects and to produce efficient estimates. The model specifies that the spatially weighted sum of neighbor water qualities (TN concentrations) affects the TN concentration of each downstream monitoring unit, in addition to the effects of the standard covariates of pollution sources and heterogeneous characteristics. The completed analysis includes cross-sectional estimation of several functions predicting TN concentration in streams conditional on watershed characteristics and potential sources of TN in the hydrologic unit. Results also include demonstration of several statistical techniques for evaluating the validity of the estimates in a spatial setting and for addressing limitations of the dataset. During the analytical steps, we tested the spatial dependence of the model using the Moran coefficient. In each case, the test indicated no sign of significant spatial autocorrelation. Akaike's Information Criteria (AIC) was also checked, indicating that the final model produced the best result. Findings of the robustness and relative predicted contributions of various TN pollution sources in the watershed are discussed in the next section.

6.2 Results and Marginal Economic Effects on Water Quality

Our final empirical model is a log-transformed spatial AR response model that overcomes several statistical problems. Observing an apparent relationship between variance and the size of hydrologic units, we applied WLS analysis. The model employs dummy variables to reflect differences between hydrologic units in the existence of upstream neighboring units and point source pollution sources. The marginal effect of pollution sources and other watershed characteristics on the water quality indicator are explored here. Simple descriptive statistics are shown in Table 6.1.

Table 6.1: Summary Statistics of Variables

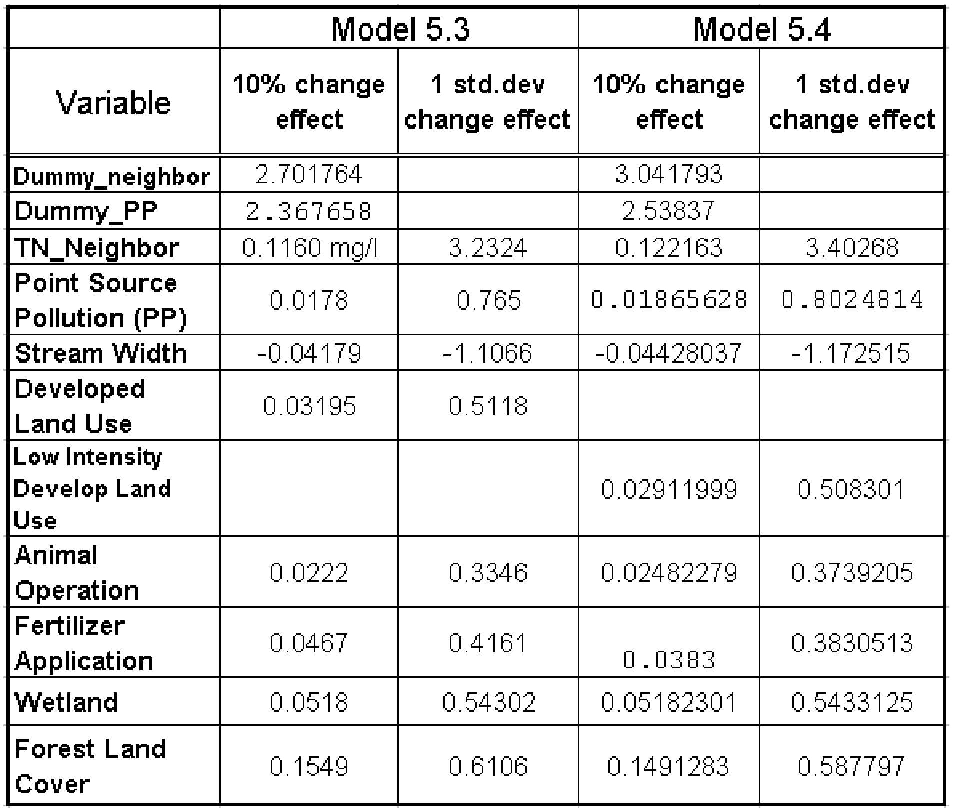


Variable	Varaible Explanation	Unit	Mean	Std. Dev.	Max	Min
Total Nitrogen (TN)	Yearly Average of TN	mg/l	1.741951	2.08947	11.117	0.503
Dummy_Neighbor	Dummy Variable for Neighbor Water Quality	1or 0	0.625	0.49029	1	0
TN_Neighbor	TN Neighbor Weighted Average	mg/l	0.208216	0.57994	3.4796	0
Dummy_PP	Dummy Variable for Point Source Pollution	1 or 0	0.55	0.50383	1	0
Point Source Pollution	Weighted Sum for each Hydrologic Unit	lbs / day	0.307495	1.32267	8.2155	0
Stream Width	Stream width of Monitoring Stations	feet	313.713	830.707	5200	22.7
Urban Developed Land Use	Acreage per Hydrologic Unit Size	acre / acre	0.045777	0.07337	0.3998	0
High Intensity Developed Land Use	Acreage per Hydrologic Unit Size	acre / acre	0.021818	0.03381	0.1624	0
Low Intensity Developed Land Use	Acreage per Hydrologic Unit Size	acre / acre	0.024063	0.04199	0.2375	0
Animal Operation	TN (lbs) per Acre / Year	(lbs/acre / year) / acre	7.499475	11.2977	52.461	0
Fertilizer Application	TN (lbs) per Acre / Year	(lbs/acre / year) / acre	17.73862	15.818	83.362	0
Wetland	Acreage per Hydrologic Unit Size	acre / acre	0.147447	0.1546	0.5953	0.0008
Forest Land Cover	Acreage per Hydrologic Unit Size	acre / acre	0.423897	0.16709	0.7231	0.0093
Hydrologic Unit Size	Acreage of Hydrologic Unit	acre	78876.17	94688.8	502962	963.17

In interpreting the results, one must keep in mind that the model is mixed with the log-log and semi-log transformations. As stated in the discussion of the final model in Chapter 5, we only transformed covariates showing peculiar error behavior. Three explanatory variables – neighbor water quality, point source of pollution, and stream width – are transformed, so their coefficients indicate elasticity. The rest of the coefficients indicate the proportionate change in water quality (TN) per unit change in the covariates.

Two predicted marginal effects are reported in Table 6.2: the effect of a 10 percent change in source quantity, and the effect of a one-standard-deviation change in source quantity on TN concentration.

Table 6.2 Predicted Marginal Effects of Changes in Explanatory Variables on TN*



	Model 5.3		Model 5.4	
Variable	10% change effect	1 std.dev change effect	10% change effect	1 std.dev change effect
Dummy_neighbor	2.701764		3.041793	
Dummy_PP	2.367658		2.53837	
TN_Neighbor	0.1160 mg/l	3.2324	0.122163	3.40268
Point Source Pollution (PP)	0.0178	0.765	0.01865628	0.8024814
Stream Width	-0.04179	-1.1066	-0.04428037	-1.172515
Developed Land Use	0.03195	0.5118		
Low Intensity Develop Land Use			0.02911999	0.508301
Animal Operation	0.0222	0.3346	0.02482279	0.3739205
Fertilizer Application	0.0467	0.4161	0.0383	0.3830513
Wetland	0.0518	0.54302	0.05182301	0.5433125
Forest Land Cover	0.1549	0.6106	0.1491283	0.587797

* In the case of dummy variables, the result indicates when dummy variable is 1 vs. 0.

Practical contributions of this work can be explained in comparison with other ecological analyses. Using a spatial econometric approach to address the problem of pollution externality, this study explicitly incorporates spatial effects into the model overcoming several statistical estimation problems. From the results, one can calculate the direct (from current unit) and indirect (from neighboring units) contributions of TN sources for the current hydrologic unit's water quality variations.

TN concentration data are used here as a dependent variable, while usually the nitrogen load (in pounds) is the dependent variable of choice in other ecological watershed models (e.g., Smith *et al*. 1997). Some pollution source variables excluded in our model are usually included in other ecological watershed analyses, such as the SPARROW by Smith *et al*. (1997). Also, the choice of pollution source variables to be included differs across watershed models. For example, while we choose an urban sources variable as a nonpoint source of pollution, an analysis such as the SPARROW by Smith *et al*. (1997) would not make that choice. Our fertilizer application data for each hydrologic unit are carefully defined and accurately assigned to each modified hydrologic unit. After applying a process to detect multicollinearity, remaining in the model are the variables specified in the final models (5.3 and 5.4). These variables generally have significant parameter estimates. The final SPARROW model included some variables that differed from this analysis. However, similar variables for major point and nonpoint sources remained in both models.

Our analysis addresses the estimation problem caused by point source pollution and tries to correct it. However, it seems we still need to find a treatment for the distinct outliers caused by big point sources close to monitoring stations. Regional data exploration has been in helping us understand specific regional performance more easily.

Among the parameters estimated, the positive coefficient and high value of the *t* statistic for “Forest Land Cover” seems contrary to accepted models of water quality. In explaining this result, we can go back to the process of multicollinearity detection, where we excluded the “Slope” variable due to its collinearity to the “Forest Land Cover” variable. It may be that the effect of the dropped or missing variables is included in the estimated parameter for the forest land cover variable. SPARROW avoids this issue by using the combined data of urban and forest land cover as a “Non-agricultural Land” variable.

More expected results of our study can be found in the next section.

6.3 Implications

The study shows the importance of space, from the beginning through the interpretation of the results. When considering all spatial processes in each watershed unit, one should consider the maximum degree (concentration, composition, and location) of any economic activities that can be supported in a geographical area. For example, for all nonpoint source pollution, data were transformed into ratios of the source quantities to the hydrologic unit size. In the case of animal operations, we assume each 1,000-swine operation produces 2,000 lbs./year. Considering that the average hydrologic unit size in our study (78,876 acres), a 1,000-swine operation could cause a 0.25-unit increase in TN per acre/year. Then, in the Neuse River basin,

$$0.01697 \times 0.25 = 0.424\ (\%)$$

is the predicted percentage increase in total nitrogen concentration based on the result of model 5.3, so that an increase in the nutrient concentration level of

$$1.74195 \times .00424 = 0.007386 \text{ (mg/l)}$$

can be predicted. Note that the predicted contribution of nutrients from each animal operation depends on the size of the watershed. However, a study of time series data shows that the substantial expansion of the hog industry during the 1980s and 1990s in North Carolina did not result in a considerable effect on water quality (Avery 2003). Careful understanding of the spatial aspects of the watershed and application of appropriate empirical analyses might help us develop more meaningful estimation results.

The externality generated by overuse of water resources may arise from the failure to consider the following two propositions, which Van den Bergh (1996) suggests are causes of unsustainable development: "(1) The size of a regional population and economy are not checked sufficiently by the region's carrying capacity, and therefore overshooting may occur. (2) The existence of the negative external impact of regional development, cross-boundary pollution, and global phenomena (e.g., climate change) from which regional control is separated."

Depending on the size variation of the hydrologic units, we need to interpret the results differently and identify any imminent externality threats to society. One could choose policy options including command and control regulations or market-based instruments based on the threats to each region.

One significant policy implication supported by this study is that the evaluation of any economic activities that deliver nutrients to the stream must consider the neighbor impact inherent in the basin as well as the current use of environmental resources in each hydrologic unit. Specific knowledge of spatial information and empirical relationships allows improved design of controls on economic activity across regions to preserve environmental resources (e.g., Total Maximum Daily Load [TMDL] and nutrient-trading programs). Thus, more exact model specification with correct spatial information collection is very important to determine causes of water quality variations through empirical analyses.

6.4 Research Issues

This dissertation research has some limitations that can be addressed in future research. Despite an investment of considerable time and effort in assembling the data for this study, limitations arising from the data remain. Additional data sets are available that can be useful in watershed analysis. Flow rate data sets provided by the U.S. Geological Survey are insufficient to match with each DWQ monitoring station in the Neuse River basin. Flow severity as measured by the DWQ was used as a proxy for flow rate and is employed in the weight matrix calculation. The current study considers a single river basin in a single time period. Expanding the study region to include more hydrologic units (i.e., adding more river basins) and limiting the number of monitoring station observations in a study to those with U.S. Geological Survey stream-gauge stations would allow construction of more units for statistical analysis and might improve empirical results. Inclusion of additional variables such as soil permeability and atmospheric deposition may produce more significant and rational results. Due to the multicollinearity problem, we chose to drop covariates such as flow severity, temperature, and slope. These variables are known to be important factors affecting water quality.

Second, there is a need to design more spatially refined data. Some data sets we have used, such as animal operations data, can be further manipulated to give us better spatial identification of the pollution source. Due to data limitations, specification of the "all animal operations" variable was restricted, so that aggregated data of TN from livestock operations per acre in the hydrologic unit were used as the explanatory variable. Precise location data on each source and knowledge of the nutrients' fate to the stream based on distance can allow estimation of a spatial weighting mechanism to better fit nonpoint pollutant transport within a hydrologic unit. As was assumed for the specification of point source pollution, the exact distance function (q(d)) between livestock operation locations and the water quality measurement point could be estimated if we could acquire sufficient location and quantity data. Actually, use of more spatially refined data for developed land use gave us more significant estimates with better analysis results.

There is also a need to further explore the functional form of the distance effect for neighbor water quality and point source covariate specifications. One approach could be to conduct geographically isolated analysis with more detailed data. Measurement of particular streams to analyze the distance effect could include collection of detailed data on distance, stream width, flow rate, and source volume and concentration.

We can also further expand data manipulation efforts to construct well-defined and well-designed databases by applying "GeoDatabase" modeling using ArcGIS software of ESRI.[19] Such an improved database system would allow us to perform more accurate and efficient spatial analyses. Construction of GeoDatabase modeling can be explained as an extension of the effort we discussed in Section 3.2, related to the role of GIS in watershed analysis. Many talk about the issue of linking GIS to statistics. In our point of view, such an effort must begin with this well-defined GeoDatabase construction in watershed analysis.

Finally, we suggest that some data analysis problems can be corrected by the panel

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[19] Readers interested in this can find useful information in Arctur and Zeiler (2004).

data analysis approach. Hsiao (1986) says, “By utilizing information on both the intertemporal dynamics and the individuality of the entities being investigated, one is better able to control in a more natural way for the effects of missing or unobserved variables.” We have used a single-period (1995) cross-sectional model. It may be that cross-sectional observations of the spatial process provide insufficient information to extract a fully simultaneous pattern of interaction. However, when a combination of cross sections and time series data is available, the additional information from the time dimension may better identify the process. Observation of the effect of sources through time could provide more robust results and may avoid spurious or ambiguous results such as those arising from multicollinearity. Sufficient years of water quality data will help us to identify longer period changes from short period irregular changes. Constructing data sets of several time periods (years) and conducting panel data analysis will be important in future studies. We expect the panel data approach to reduce the multicollinearity problem and allow retention of variables that were dropped in this analysis, thus enriching and enhancing future analyses.

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8. APPENDIX

Table 8.1. Monitoring Station used for 1995 TN measurement and Hydrologic Unit Size

id	Station	Location	x	y	County	Size (acre)
1	J0770000	ENO RIVER NEAR DURHAM	-65.51698	42.68815	Durham	91013.35
2	J0810000	ENO R ATSR1004 NR DURHAM INACT-801211	-62.93034	42.72758	Durham	8327.4426
3	J0820000	LITTLE RIVER AT SR 1461 NEAR ORANGE FACTORY NC	-66.11996	47.50474	Durham	51461.492
4	J0840000	LITTLE R RESERVOIR AT SR 1628 AT ORANGE FACTORY	-63.60658	46.50988	Durham	15683.638
5	J1070000	FLAT RIVER NEAR QUAIL ROOST	-64.25465	51.56031	Durham	95298.813
6	J1100000	FLAT RIVER AT SR 1004 NEAR WILLARDSVILLE NC	-60.96359	46.83089	Durham	16848.737
7	J1210000	KNAP OF REEDS CREEK NEAR BUTNER NC	-59.31242	46.56246	Granville	25794.937
8	J1330000	ELLERBE CR AT SR 1636 NR DURHAM	-61.21155	41.82473	Durham	13520.057
9	J1530000	LITTLE LICK CK AT SR1814 NR DURHAM NC	-59.3406	36.80958	Durham	6129.4602
10	J1890000	NEUSE RIVER NEAR FALLS	-47.00475	33.61121	Wake	167729.11
11	J2850000	CRABTREE CK AT SR 1795 NR UMSTEAD STATE PARK	-58.31496	26.47972	Wake	33681.742
12	J2860000	CRABTREE CREEK AT REEDY CREEK STATE PARK	-56.24114	26.70872	Wake	4336.5199
13	J3000000	CRABTREE CREEK AT SR 1649 NEAR RALEIGH NC	-55.13661	27.01658	Wake	10789.947
14	J3290000	CRABTREE CREEK AT US HWY #1 AT RALEIGH NC	-48.78835	24.62489	Wake	29286.654
15	J4170000	NEUSE RIVER AT NC HWY 42 NEAR CLAYTON NC	-37.17665	13.30915	Johnston	164768.1
16	J4370000	NEUSE RIVER AT SMITHFIELD	-34.03211	4.004593	Johnston	40810.016
17	J4510000	SWIFT CK AT NC HWY 42 NEAR CLAYTON NC	-45.22961	10.94444	Johnston	57150.323
18	J5000000	MIDDLE CREEK AT NC HWY 50 NEAR CLAYTON NC	-47.69227	7.886509	Johnston	53442.623
19	J5850000	LITTLE RIVER NEAR PRINCETON	-23.2629	3.983146	Johnston	147219.09
20	J5970000	NEUSE RIVER AT SR 1915 NEAR GOLDSBORO NC	-14.16176	-8.15173	Wayne	502961.95
21	J6150000	NEUSE RIVER AT NC HWY 11 BYPASS AT KINSTON NC	9.1574349	-13.5709	Lenoir	194810.43
22	J6740000	CONTENTNEA CREEK NEAR LUCAMA NC	-20.47339	16.36017	Wilson	100974.9
23	J7320000	NAHUNTA SWAMP NR SHINE NC	-3.381284	2.355938	Greene	50243.58
24	J7450000	CONTENTNEA CREEK AT NC HWY 123 AT HOOKERTON NC	9.202518	-1.82001	Greene	320011.59
25	J7739550	LITTLE CONTENTNEA CREEK AT SR 1125 NR FARMVILLE	12.583746	4.839644	Pitt	94642.083
26	J7810000	CONTENTNEA CREEK NR SR 1800 AT GRIFTON NC	17.582327	-5.98627	Pitt	78876.232
27	J7850000	NEUSE RIVER AT SR 1470 NEAR FORT BARNWELL NC	25.009757	-9.8585	Craven	154552.9
28	J7860000	NEUSE RIVER AT LANE LANDING NEAR PERFECTION NC	29.236291	-13.6685	Craven	52948.736
29	J7930000	NEUSE RIVER AT SR 1400 AT STREETS FERRY NC	35.125263	-16.9111	Craven	10987.999
30	J8150000	CREEPING SWAMP AT NC HWY 43 NR VANCEBORO NC	29.005241	-4.37982	Craven	18728.864
31	J8170000	SWIFT CREEK AT SR 1478 NEAR VANCEBORO NC	30.99453	-7.60656	Craven	97136.799
32	J8210000	SWIFT CREEK AT MOUTH NEAR ASKIN	36.714439	-17.8887	Craven	95212.901
33	J8250000	NEUSE R BELOW SWIFT CR NR ASKIN	36.477754	-18.2796	Craven	963.17137
34	J8290000	NEUSE R AT MOUTH OF NARROWS NR WASHINGTON FORKS	37.790797	-20.9224	Craven	2077.8122
35	J8570000	NEUSE RIVER AT US HWY 17 AT NEW BERN NC	40.642299	-23.6773	Craven	61763.023
36	J8670000	TRENT RIVER AT SR 1130 NEAR PLEASANT HILL NC	9.9745649	-27.8083	Jones	31045.529
37	J8690000	TRENT RIVER NEAR TRENTON	16.055139	-27.0722	Jones	75312.076
38	J8700000	TRENT RIVER AT NC HWY 41 AT TRENTON NC	22.146984	-27.1165	Jones	88350.296
39	J8720000	TRENT RIVER AT SR 1121 NEAR OAK GROVE NC	27.365345	-29.2335	Jones	23325.808
40	J8770000	TRENT R ABOVE REEDY BR NR RHEMS	35.485927	-26.2842	Craven	66827.883
41	J8900800	NEUSE R AT LIGHT #22 NEAR FAIRFIELD HARBOUR	41.713021	-25.941	Craven	33138.221
42	J8902500	NEUSE R AT MOUTH OF BROAD CR NR THURMAN NC	43.938996	-28.3991	Craven	40609.931
43	J8910000	NEUSE RIVER AT LIGHT #11 NEAR RIVERDALE NC	45.888837	-31.4467	Craven	73355.992
44	J9530000	NEUSE RIVER AT LIGHT #9 NR MINNESOTT BEACH NC	53.14157	-34.726	Pamlico	68765.095
45	J9690000	BACK CREEK AT SR 1300 NEAR MERRIMON NC	63.341606	-38.9462	Carteret	6399.084
46	J9810000	NEUSE RIVER AT MILE #12 NEAR ORIENTAL NC	60.157617	-31.3305	Pamlico	108940.3
47	J9930000	NEUSE R AT MOUTH NR PAMLICO NC	69.585607	-23.7168	Pamlico	104385.82
48	J9938000	WEST THOROFARE BAY AT CM R 10WB NR ATLANTI	76.302979	-34.1725	Carteret	175007.11
49	J9940000	THOROFARE CANAL AT NC HWY 12 NEAR ATLANTIC NC	77.858343	-36.5545	Carteret	7102.6973
50	J9950000	BAY RIVER AT LIGHT #5 NEAR VANDEMERE NC	61.673534	-19.6736	Pamlico	60505.027

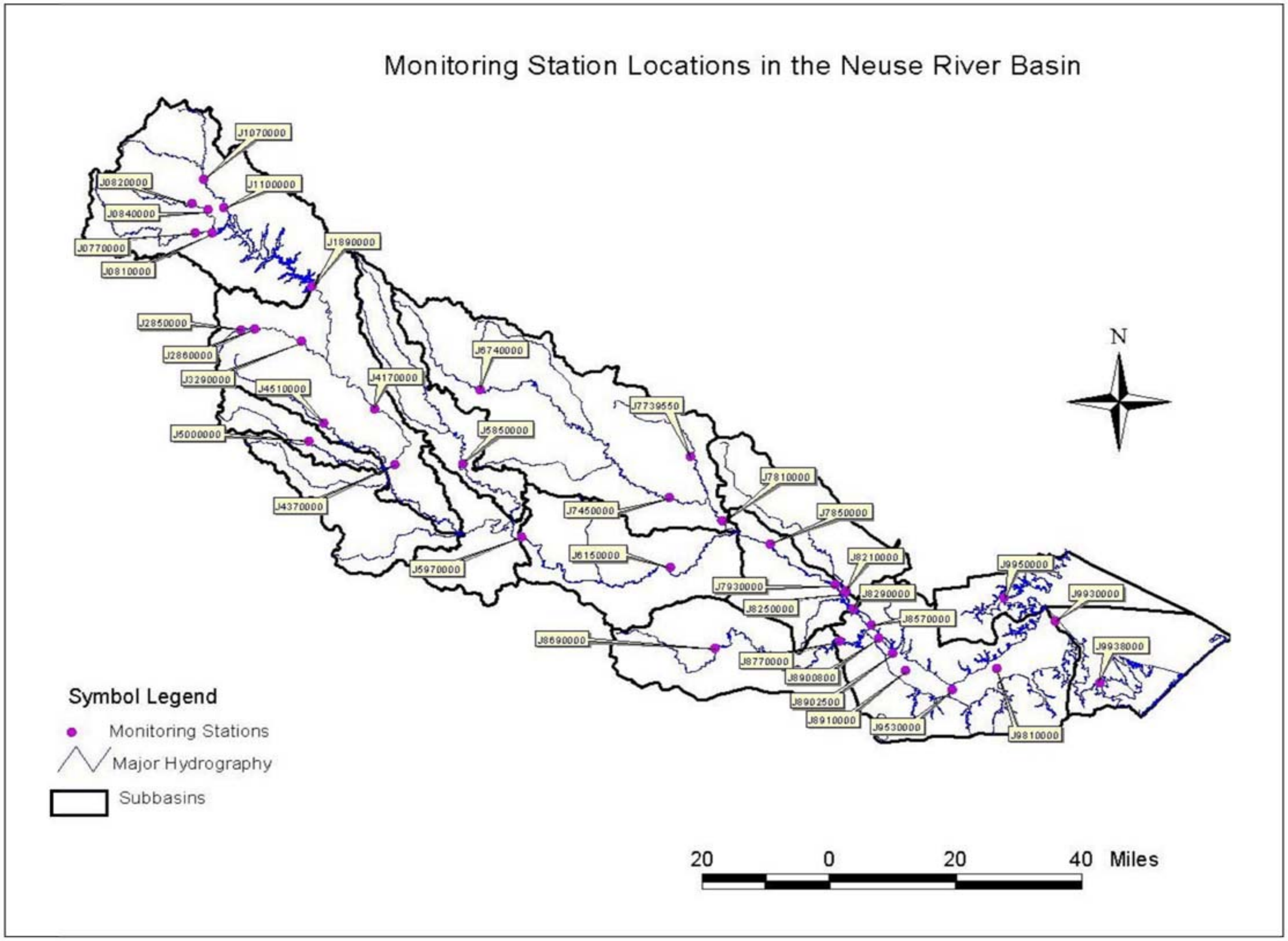


Figure 9.1 Monitoring Station Locations in the Neuse River Basin

Table 8.2. 1995 Total Nitrogen Concentration Data

	Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	J0770000	0.86	0.81	0.64	0.92	0.96	0.97	0.89	0.62	0.58	1.6	0.93	0.75
2	J0810000	0.89	0.79	0.47	0.82	0.5	0.89	0.95	0.5	0.71	1.5	0.9	1.12
3	J0820000	0.75	0.68	0.62	0.64	0.87	0.7	0.86	0.76	0.5	0.61	0.73	0.73
4	J0840000	0.68	0.75		0.42	0.53	0.33	0.41	0.41	0.53	0.59	0.71	0.62
5	J1070000	0.76	0.59	0.37	0.45	0.71	0.81	1.03	0.43	0.4	0.43	0.63	0.57
6	J1100000	0.83	0.79	0.73	0.76	0.49	0.75	0.61	0.71	0.55	0.51	0.81	0.93
7	J1210000	1.9	4.1	2.1	6.2	6.8	5.4	0.99	6.4	6.5	3	2.3	1.7
8	J1330000	8	15.2	6.7	3.1	5.7	7.5	2.5	2.2	2		5.4	5.8
9	J1530000	0.73	0.65	0.39	0.72	0.61	0.78	0.54			0.76	0.57	0.38
10	J1890000	0.59	0.86	0.83	0.64	0.66	0.41	0.51	0.31	0.51	0.74		0.66
11	J2850000	0.76	0.64	0.79	0.56	0.71	0.47	1.29	2.8	0.86	0.94		0.8
12	J2860000	2.7	1.23	6.3	19.1	9.4							
13	J3000000						2.2	18	24.1	14.9	3.7		3.8
14	J3290000	1.5	1.36	3.1	3.8	2.8	1.6	3.7	4.5	5.7	1.8		1.6
15	J3300000	2.1	2.7	1.7	2.3	2.1	2.1	2.5	2.4	2.8	2.4		2.4
16	J4170000	3	2.3	2.2	2.9	3.2	1.23	1.8	4.3	2.6	1.14		1
17	J4370000	2.1	2	1.4	3.2	2.6	1.38	1.3	4.4	2.5	1.14		1.04
18	J4510000	0.35	0.56	0.6	0.53	0.59	0.63	0.57	0.44	0.34			0.42
19	J5000000	2.5	2.3	2.3	2.9	2.4	1.33	2.9	5.8	3.3	1.9		1.9
20	J5850000	0.45	0.67	0.75	0.75	0.83	0.91	1	0.61	0.74	0.53		0.76
21	J5970000	1.7	1.38	0.92	1.3	2	1.35	1.34	2	1.7	1.4	0.89	
22	J6150000	1.53	1.33	1.36	1.7	1.7	1.8	0.94	1.8	1.3	1.13	0.82	1.4
23	J6740000	0.59	1.21	0.61	0.65	0.6	0.82	0.76	0.78	0.59	0.61		0.47
24	J7150000	0.42	0.45	1.21	0.64	0.51	0.71						
25	J7210000								1.8				
26	J7320000	0.86	1.33	1.8	1.42	1.26	1.44						
27	J7450000	1.13	1.27	1.26	1.11	1.13	1.17	0.75	1.22	1.08	1.09	0.98	0.98
28	J7739550	0.65	0.81	1.59	0.58	1.14	0.59	1.06	0.74	0.43	0.07	0.96	0.53
29	J7810000	1.41	1.55	1.31	1.21	1.23	0.98	0.96	1.07	0.95		0.72	0.99
30	J7850000	1.4	1.4		1.8	2.1	1.6	0.96	1.38	1.7			1.39
31	J7860000						1.5	0.74	1.5	0.71			
32	J7930000	1.5	1.6	1.14		2.2	1.4	0.84	1.35	0.61	0.63	0.71	1.3
33	J8150000	0.63	0.57	0.71	0.91	0.71	0.71	1.04	1.03	0.71			0.61
34	J8170000	2.7	3.1	1.6	1.04	1.05	0.51						
35	J8210000	1.44	1.7	1.19		1.35	1.46	1.05	1.21	0.83	1.03		0.85
36	J8250000	1.73	1.7	1.17		1.8	1.4	0.74	1.18	0.6	0.74	0.7	1.02
37	J8290000	1.03	1.5	1.15		2.1	1.32	0.78	0.96	0.62	0.8	0.61	1.26
38	J8570000	0.81	1.6	1.13		1.03	1.09	0.86	0.84	0.64	0.87	0.71	1.12
39	J8670000						1.43	1.06	1.65	1.81	1.29		
40	J8690000	1.1	1.16	1.09	0.88	0.98	1.08	1.29	1.11	0.81	0.77	0.99	0.87
41	J8700000						1.08	1.04	0.52	0.36	0.64		
42	J8720000						1.1	1.21	0.64	0.57	0.71		
43	J8770000	0.95	0.84	0.83		0.21	0.88	0.79	0.72	0.61	0.64	0.7	0.89
44	J8900800	1.19	1.38	1.21	1.49	0.62	1.25	0.9	0.51	0.59	0.97	0.68	0.87
45	J8902500	0.71	1.02	1.29	0.52	0.41	0.48	0.67	0.41	0.62	0.8		1.05
46	J8910000	0.71	1.22	1.19	0.51	0.41	0.41	0.74	0.41	0.51	0.75	0.72	0.65
47	J9530000	0.51	0.31	0.77	0.41	0.41	0.84	0.71	1.01	0.51	0.54	0.42	0.51
48	J9690000	1.95	1.37	0.69		0.31	0.63	1.42	1	1.95	0.7		0.62
49	J9810000	0.31	0.41	0.68	0.71	0.71	0.61	0.61	0.41	0.61	0.45	0.51	0.41
50	J9930000	0.41	0.41	0.41	0.51	0.41	0.41	0.51	0.31	0.61	0.41	0.61	0.51
51	J9938000	0.41	0.41	0.32	0.41	0.81	0.41	0.31		0.51		0.61	0.51
52	J9940000	0.41	0.31	0.63	0.41	0.51	0.51	0.41		0.51		0.71	0.41
53	J9950000	0.64	0.47	0.57	0.51	0.61	0.51	0.81		0.65	0.51	0.61	0.51

Table 8.3: NPDES – General Information (Source: DWQ)

Permit .	Facility Name	Original Issue Date	Major-Minor/ Industrial-Municipal	Latitude	Longitude
NC0001376	RIVERPLACE II, LLC	8/30/1979	MA/IN	3554320	7833200
NC0001881	PHILLIPS PLATING COMPANY	9/27/1975	MA/IN	3508560	7701460
NC0003191	WEYERHAEUSER / NEW BERN	12/31/1973	MA/IN	3511560	7706450
NC0003417	CP&L-LEE STEAM ELECTRIC PLANT	6/30/1977	MA/IN	3522390	7806070
NC0003760	DUPONT - KINSTON PLANT	12/29/1978 0:00	MA/IN	3519370	7727550
NC0003816	US MCAS CHERRY POINT	12/12/1974 0:00	MA/IN	3454510	7654410
NC0003859	PIEDMONT MINERALS CO., INC.	2/17/1981 0:00	MI/IN	0	0
NC0020389	BENSON, TOWN / WWTP	12/1/1982 0:00	MA/MU	3523210	7830330
NC0020541	KINSTON, CITY/PEACHTREE WWTP	9/28/1977 0:00	MA/MU	3514360	7733310
NC0020842	SNOW HILL, TOWN - WWTP	2/28/1979 0:00	MI/MU	3527200	7739290
NC0021253	HAVELOCK (CITY) - WWTP	2/3/1982 0:00	MA/MU	3453040	7654310
NC0021342	TRENTON (TOWN) - WWTP	9/30/1978 0:00	MI/MU	3503510	7720340
NC0021644	LA GRANGE (TOWN) - WWTP	1/13/1981 0:00	MI/MU	3518450	7746320
NC0023841	DURHAM, CITY-WWTP/NORTH	3/19/1982 0:00	MA/MU	3601470	7851490
NC0023906	WILSON, CITY - WWTP	12/30/1974 0:00	MA/MU	3540370	7754510
NC0023949	GOLDSBORO, CITY / WWTP	6/5/1978 0:00	MA/MU	3520020	7759080
NC0024236	KINSTON, CITY/NORTHSIDE WWTP	4/30/1979 0:00	MA/MU	3517280	7730000
NC0024520	G. & S. ASSOCIATES / DAYS INN	1/18/1983 0:00	MI/IN	3603250	7847440
NC0025348	NEW BERN, CITY / WWTP	6/30/1976 0:00	MA/MU	3508210	7703310
NC0025453	CLAYTON, TOWN/LITTLE CRK WWTP	4/13/1982 0:00	MA/MU	3538270	7827510
NC0025712	HOOKERTON (TOWN) - WWTP	6/30/1978 0:00	MI/MU	3525440	7735490
NC0026433	HILLSBOROUGH, TOWN - WWTP	5/17/1982 0:00	MA/MU	3606540	7905320
NC0026662	PRINCETON, TOWN / WWTP	4/6/1981 0:00	MI/MU	3527360	7809140
NC0026824	NC DHHS-BUTNER WWTP	11/30/1981 0:00	MA/MU	3607390	7846200
NC0029033	RALEIGH, CITY/NEUSE RIVER WWTP	12/1/1982 0:00	MA/MU	3543240	7828400
NC0029572	FARMVILLE (TOWN) - WWTP	1/13/1981 0:00	MA/MU	3535080	7732270
NC0029904	CRAVEN CO SCH - W. CRAVEN MIDD	9/30/1981 0:00	MI/IN	3513100	7709010
NC0030392	WAYNE CO/GENOA INDUSTRIAL WWTP	11/30/1981 0:00	MI/MU	3520190	7801290
NC0030406	RIVER BEND, TOWN - WWTP	5/24/1982 0:00	MI/IN	3504150	7708000
NC0030716	JOHNSTON COUNTY/CEN JOHNSTON	2/17/1981 0:00	MA/MU	3530040	7822320

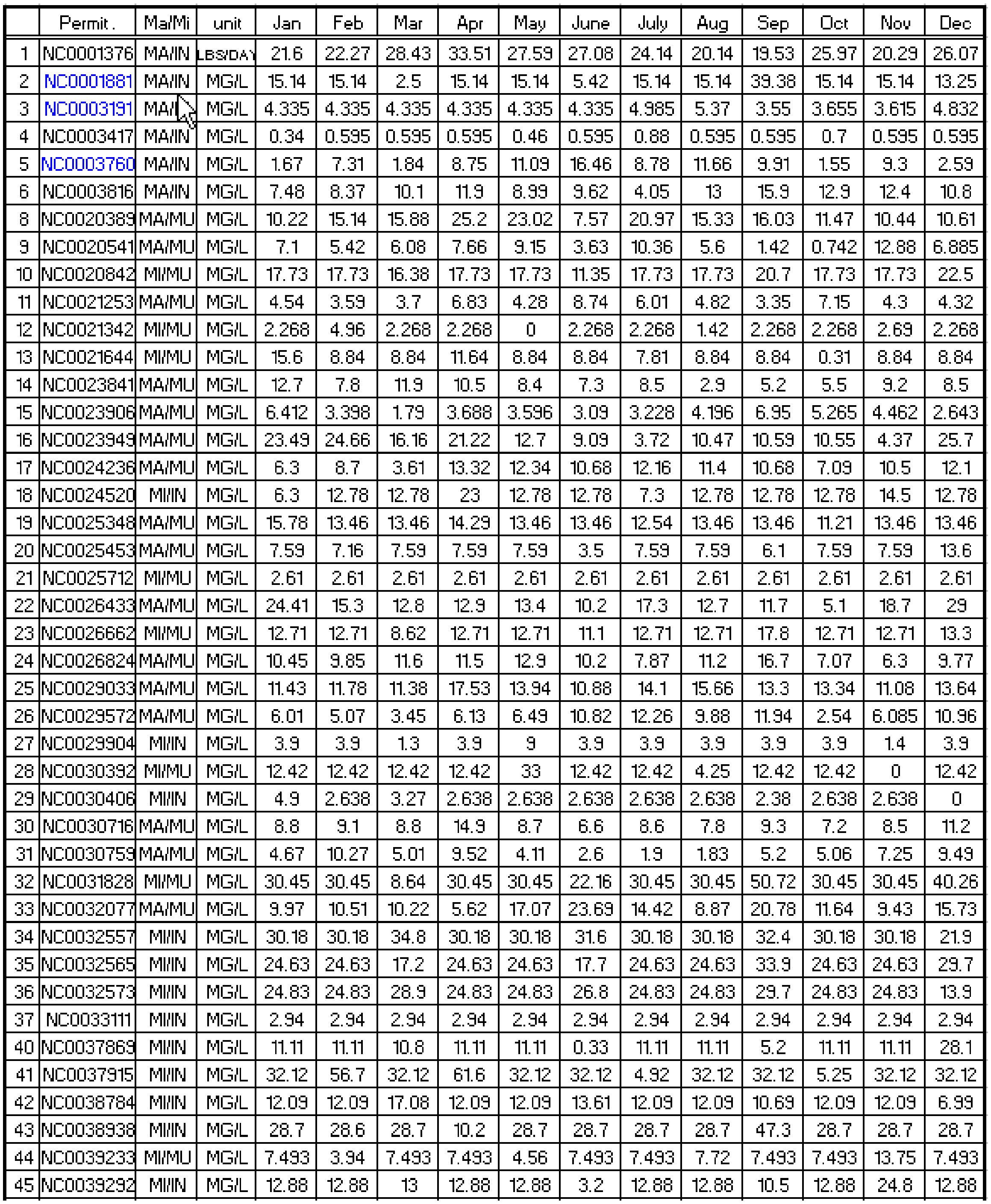
Table 8.3: NPDES – General Information (Source: DWQ) (Continued)

Permit .	Facility Name	Original Issue Date	Major-Minor/ Industrial-Municipal	Latitude	Longitude
NC0030759	WAKE FOREST, TOWN - WWTP	2/17/1981 0:00	MA/MU	3554280	7832180
NC0031828	VANCEBORO, TOWN / WWTP	12/31/1981 0:00	MI/MU	3517500	7708350
NC0032077	CONTENTNEA SEWERAGE DIST. WWTP	11/30/1981 0:00	MA/MU	3521020	7724590
NC0032557	LENOIR CO SCH-S. LENOIR HIGH	6/30/1982 0:00	MI/IN	3509100	7742100
NC0032565	LENOIR CO SCH-N. LENOIR HIGH	7/8/1982 0:00	MI/IN	3520400	7740440
NC0032573	LENOIR CO SCH-MOSS HILL ELEM.	6/30/1982 0:00	MI/IN	3511470	7745120
NC0033111	CAROLINA WTR SERV/NE CRAVEN	7/9/1982 0:00	MI/IN	3503270	7657330
NC0034801	WAYNE CO BOE-NORWAYNE JR HIGH	9/29/1978 0:00	MI/IN	3530400	7757150
NC0034819	WAYNE CO BOE-C. B. AYCOCK H.S.	9/29/1978 0:00	MI/IN	3530450	7758470
NC0037869	ARBOR HILLS MHP	4/30/1982 0:00	MI/IN	3603130	7903300
NC0037915	NASH ROCKY MT BOE/SO. NASH HS	12/31/1980 0:00	MI/IN	3551260	7805190
NC0038784	RIVERVIEW MOBILE HOME PARK	5/28/1982 0:00	MI/IN	3545170	7831570
NC0038938	JOHNSTON CO BOE-CORINTH HOLDER	2/24/1978 0:00	MI/IN	3543540	7818040
NC0039233	WALNUT CREEK, VILLAGE/WWTP	10/31/1977 0:00	MI/MU	3518130	7751520
NC0039292	UNIPROP, INC. / RIVERWALK MHP	8/31/1982 0:00	MI/IN	3550540	7831480
NC0040606	HEATER UTIL-BARCLAY DOWNS	1/30/1978 0:00	MI/IN	3546440	7832150
NC0045608	WARD TRANSFORMER COMPANY	11/5/1979 0:00	MI/IN	3554000	7846550
NC0048062	EUREKA, TOWN - WWTP	2/17/1981 0:00	MI/MU	3530570	7753030
NC0048879	CARY, TOWN/NORTH WWTP	9/30/1981 0:00	MA/MU	3550170	7846510
NC0049034	MOUNT AUBURN TRAINING CENTER	1/29/1982 0:00	MI/IN	3541300	7832380
NC0049042	RILEY HILL BAPTIST CHURCH INC.	10/30/1981 0:00	MI/IN	3551270	7825150
NC0049662	HEATER UTIL-HAWTHORNE SUBDIV.	11/30/1981 0:00	MI/IN	3555530	7843550
NC0051071	REDWOOD PARTNERS, LLC	8/5/1982 0:00	MI/IN	3601170	7848170
NC0051322	CAROLINA WTR SERV/ASHLEY HILL	9/30/1982 0:00	MI/IN	3544560	7827580
NC0056391	HEATER UTIL-CROSS CRK MOB.EST.	9/3/1983 0:00	MI/IN	3544560	7830230
NC0056499	UNIPROP, INC. / MILL RUN MHP	10/3/1983 0:00	MI/IN	3539090	7836590
NC0056545	CRAVEN CO W&S - TRENT RIVER	2/7/1984 0:00	MI/MU	3505580	7702230
NC0056618	CAROLINA WTR SERV/CAROLINA PIN	11/1/1983 0:00	MI/IN	3458150	7656050
NC0056731	SEDGEFIELD DEV.CORP-GRANDE OAK	2/21/1985 0:00	MI/IN	3505160	7856380
NC0057606	STANTONSBURG, TOWN - WWTP	2/7/1984 0:00	MI/MU	3534580	7748020

Table 8.3: NPDES – General Information (Source: DWQ) (Continued)

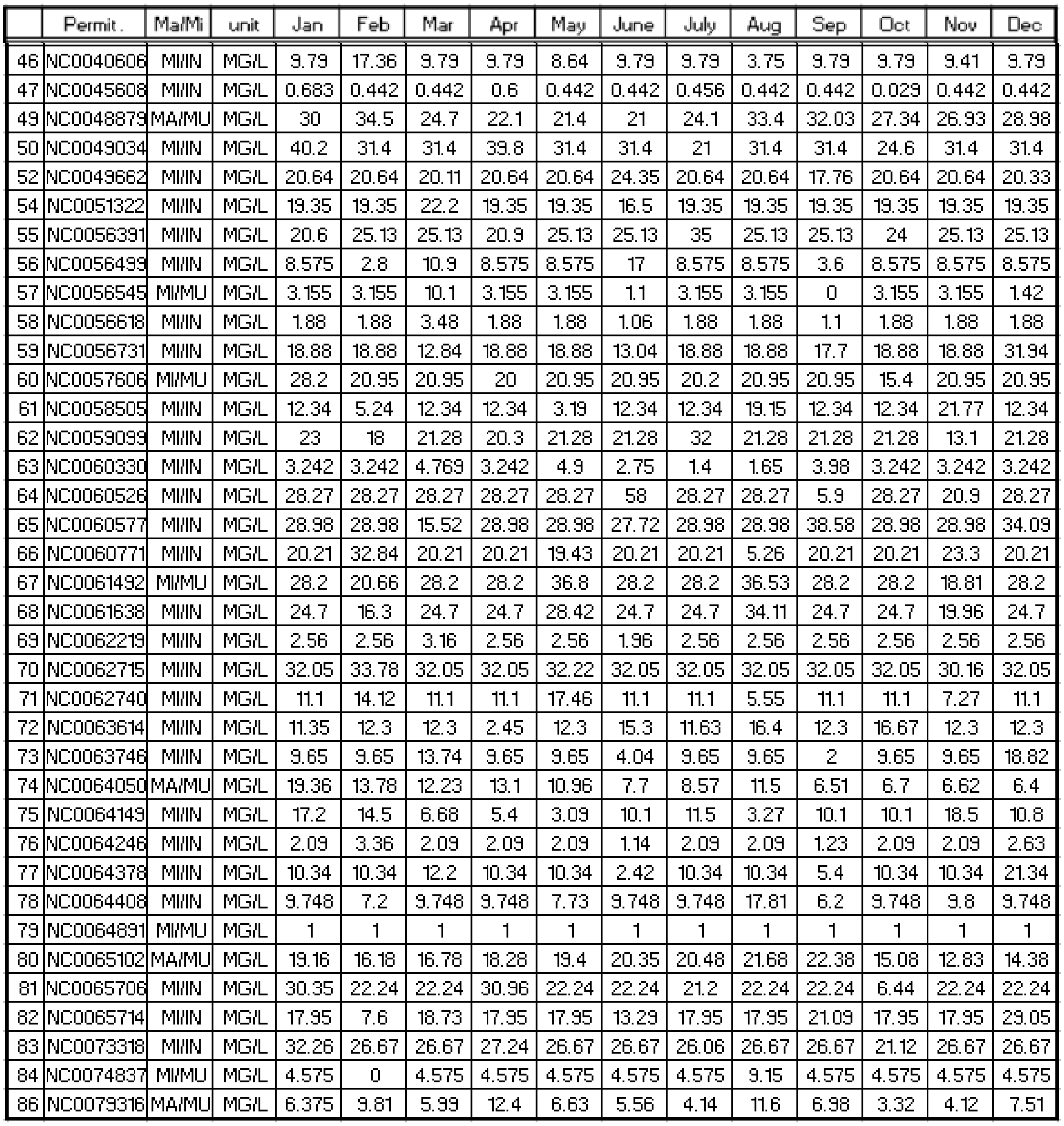
Permit .	Facility Name	Original Issue Date	Major-Minor/ Industrial-Municipal	Latitude	Longitude
NC0058505	HEATER UTIL-MALLARD CROSSING	4/3/1984 0:00	MI/IN	3551000	7829450
NC0059099	LAKE RIDGE AERO PARK	8/1/1984 0:00	MI/IN	3603110	7846430
NC0060330	JOHNSTON CO-WHITE OAK WWTP	2/1/1985 0:00	MI/IN	3538500	7831220
NC0060526	POPE INDUSTRIAL PARK II, LTD	4/1/1985 0:00	MI/IN	3542230	7839530
NC0060577	HEATER UTIL-BEACHWOOD	2/7/1985 0:00	MI/IN	3548040	7832180
NC0060771	INDIAN CREEK OVERLOOK	4/15/1985 0:00	MI/IN	3538470	7836120
NC0061492	MAURY SANITARY LAND DIST.	7/19/1985 0:00	MI/MU	3525400	7735000
NC0061638	UTILITIES, INC/AMHERST WWTP	7/1/1985 0:00	MI/IN	3538370	7843590
NC0062219	CAROLINA WTR SERV/KINGS GRT SU	3/3/1986 0:00	MI/IN	3543500	7827380
NC0062715	HEATER UTIL/CROOKED CREEK	8/1/1985 0:00	MI/IN	3538320	7844360
NC0062740	HEATER UTIL/BRIARWOOD FARMS	9/24/1985 0:00	MI/IN	3541350	7848300
NC0063614	HEATER UTIL-WILDWOOD GREEN	12/18/1986 0:00	MI/IN	3554440	7840540
NC0063746	IRA D. LEE & ASSOC/DEERCHASE	12/1/1985 0:00	MI/IN	3554480	7830560
NC0064050	APEX, TOWN/MIDDLE CREEK WWTP	2/17/1986 0:00	MA/MU	3542310	7850040
NC0064149	JONES DAIRY FARM UTIL	3/5/1986 0:00	MI/IN	3554300	7828000
NC0064246	PACE MOBILE HOME PARK	12/19/1985 0:00	MI/IN	3542320	7822550
NC0064378	CAROLINA WTR SERV/WILLOWBROOK	6/16/1986 0:00	MI/IN	3540510	7830010
NC0064408	WHITEWOOD PROP INC/NEUSE CROSS	2/12/1986 0:00	MI/IN	3552350	7832000
NC0064891	KENLY, TOWN - REGIONAL WWTP	4/1/1986 0:00	MI/MU	3534580	7809320
NC0065102	CARY, TOWN/SOUTH WWTP	5/16/1986 0:00	MA/MU	3538430	7845430
NC0065706	CROSBY UTILITIES/COTTONWOOD	7/1/1986 0:00	MI/IN	3545430	7828200
NC0065714	TRADEWINDS HOMEOWNERS ASSO.INC	7/1/1986 0:00	MI/IN	3552170	7830240
NC0073318	IRA D. LEE-WHIPPOORWILL VALLEY	8/1/1988 0:00	MI/IN	3555460	7831340
NC0074837	BRIDGETON, TOWN/WWTP	12/8/1988 0:00	MI/MU	3507400	7701400
NC0075281	CRAVEN COUNTY WOOD ENERGY	1/10/1989 0:00	MI/IN	3508250	7710440
NC0079316	ZEBULON, TOWN/LITTLE CRK WWTP	1/18/1991 0:00	MA/MU	3548570	7816200
NC0081540	SQUARE D COMPANY	8/24/1992 0:00	MI/IN	3549400	7827320

Table 8.4: Point Source Pollution (TN) Concentration



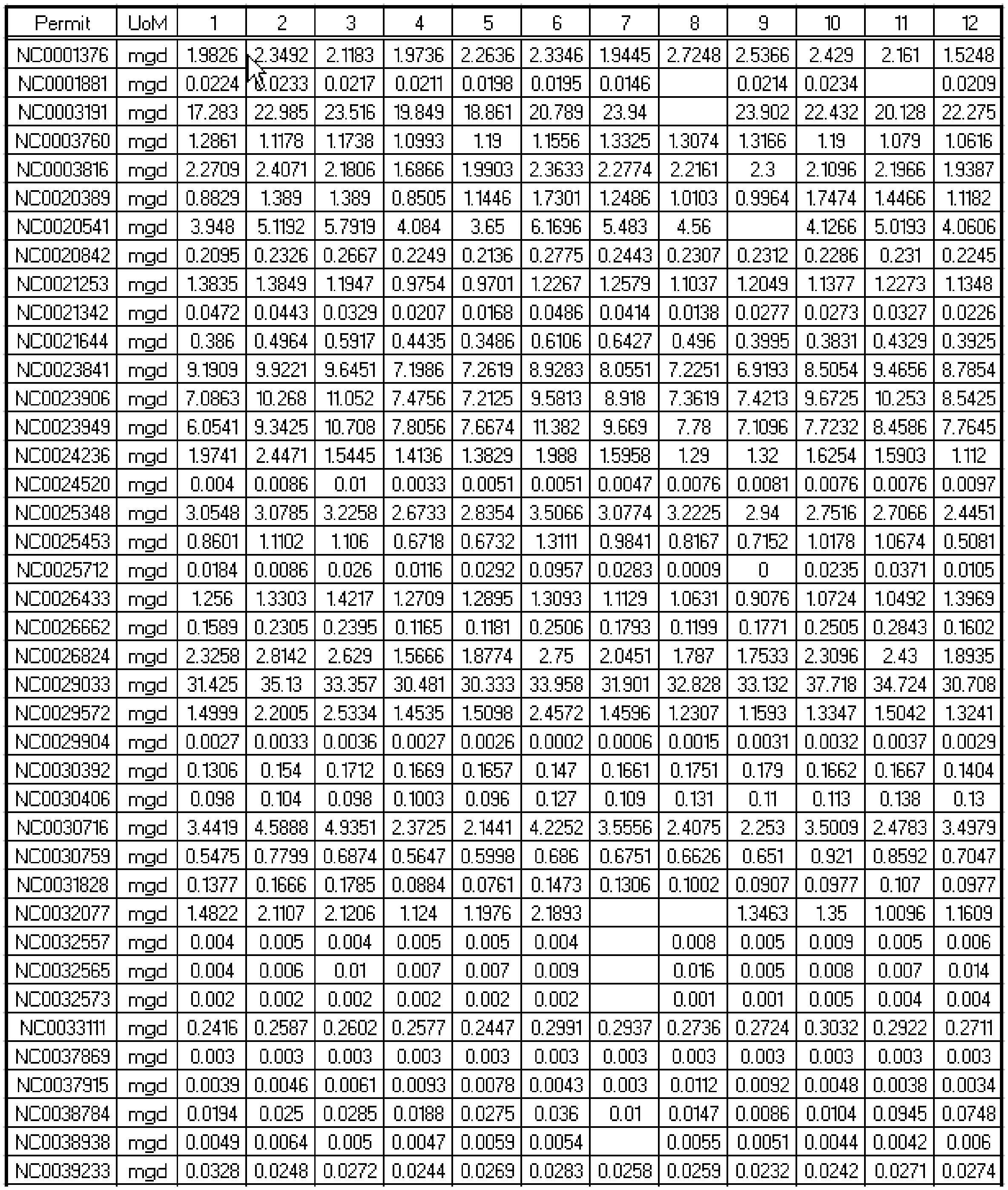
	Permit .	Ma/Mi	unit	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	NC0001376	MA/IN	LBS/DAY	21.6	22.27	28.43	33.51	27.59	27.08	24.14	20.14	19.53	25.97	20.29	26.07
2	NC0001881	MA/IN	MG/L	15.14	15.14	2.5	15.14	15.14	5.42	15.14	15.14	39.38	15.14	15.14	13.25
3	NC0003191	MA/I	MG/L	4.335	4.335	4.335	4.335	4.335	4.335	4.985	5.37	3.55	3.655	3.615	4.832
4	NC0003417	MA/IN	MG/L	0.34	0.595	0.595	0.595	0.46	0.595	0.88	0.595	0.595	0.7	0.595	0.595
5	NC0003760	MA/IN	MG/L	1.67	7.31	1.84	8.75	11.09	16.46	8.78	11.66	9.91	1.55	9.3	2.59
6	NC0003816	MA/IN	MG/L	7.48	8.37	10.1	11.9	8.99	9.62	4.05	13	15.9	12.9	12.4	10.8
8	NC0020389	MA/MU	MG/L	10.22	15.14	15.88	25.2	23.02	7.57	20.97	15.33	16.03	11.47	10.44	10.61
9	NC0020541	MA/MU	MG/L	7.1	5.42	6.08	7.66	9.15	3.63	10.36	5.6	1.42	0.742	12.88	6.885
10	NC0020842	MI/MU	MG/L	17.73	17.73	16.38	17.73	17.73	11.35	17.73	17.73	20.7	17.73	17.73	22.5
11	NC0021253	MA/MU	MG/L	4.54	3.59	3.7	6.83	4.28	8.74	6.01	4.82	3.35	7.15	4.3	4.32
12	NC0021342	MI/MU	MG/L	2.268	4.96	2.268	2.268	0	2.268	2.268	1.42	2.268	2.268	2.69	2.268
13	NC0021644	MI/MU	MG/L	15.6	8.84	8.84	11.64	8.84	8.84	7.81	8.84	8.84	0.31	8.84	8.84
14	NC0023841	MA/MU	MG/L	12.7	7.8	11.9	10.5	8.4	7.3	8.5	2.9	5.2	5.5	9.2	8.5
15	NC0023906	MA/MU	MG/L	6.412	3.398	1.79	3.688	3.596	3.09	3.228	4.196	6.95	5.265	4.462	2.643
16	NC0023949	MA/MU	MG/L	23.49	24.66	16.16	21.22	12.7	9.09	3.72	10.47	10.59	10.55	4.37	25.7
17	NC0024236	MA/MU	MG/L	6.3	8.7	3.61	13.32	12.34	10.68	12.16	11.4	10.68	7.09	10.5	12.1
18	NC0024520	MI/IN	MG/L	6.3	12.78	12.78	23	12.78	12.78	7.3	12.78	12.78	12.78	14.5	12.78
19	NC0025348	MA/MU	MG/L	15.78	13.46	13.46	14.29	13.46	13.46	12.54	13.46	13.46	11.21	13.46	13.46
20	NC0025453	MA/MU	MG/L	7.59	7.16	7.59	7.59	7.59	3.5	7.59	7.59	6.1	7.59	7.59	13.6
21	NC0025712	MI/MU	MG/L	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61
22	NC0026433	MA/MU	MG/L	24.41	15.3	12.8	12.9	13.4	10.2	17.3	12.7	11.7	5.1	18.7	29
23	NC0026662	MI/MU	MG/L	12.71	12.71	8.62	12.71	12.71	11.1	12.71	12.71	17.8	12.71	12.71	13.3
24	NC0026824	MA/MU	MG/L	10.45	9.85	11.6	11.5	12.9	10.2	7.87	11.2	16.7	7.07	6.3	9.77
25	NC0029033	MA/MU	MG/L	11.43	11.78	11.38	17.53	13.94	10.88	14.1	15.66	13.3	13.34	11.08	13.64
26	NC0029572	MA/MU	MG/L	6.01	5.07	3.45	6.13	6.49	10.82	12.26	9.88	11.94	2.54	6.085	10.96
27	NC0029904	MI/IN	MG/L	3.9	3.9	1.3	3.9	9	3.9	3.9	3.9	3.9	3.9	1.4	3.9
28	NC0030392	MI/MU	MG/L	12.42	12.42	12.42	12.42	33	12.42	12.42	4.25	12.42	12.42	0	12.42
29	NC0030406	MI/IN	MG/L	4.9	2.638	3.27	2.638	2.638	2.638	2.638	2.638	2.38	2.638	2.638	0
30	NC0030716	MA/MU	MG/L	8.8	9.1	8.8	14.9	8.7	6.6	8.6	7.8	9.3	7.2	8.5	11.2
31	NC0030759	MA/MU	MG/L	4.67	10.27	5.01	9.52	4.11	2.6	1.9	1.83	5.2	5.06	7.25	9.49
32	NC0031828	MI/MU	MG/L	30.45	30.45	8.64	30.45	30.45	22.16	30.45	30.45	50.72	30.45	30.45	40.26
33	NC0032077	MA/MU	MG/L	9.97	10.51	10.22	5.62	17.07	23.69	14.42	8.87	20.78	11.64	9.43	15.73
34	NC0032557	MI/IN	MG/L	30.18	30.18	34.8	30.18	30.18	31.6	30.18	30.18	32.4	30.18	30.18	21.9
35	NC0032565	MI/IN	MG/L	24.63	24.63	17.2	24.63	24.63	17.7	24.63	24.63	33.9	24.63	24.63	29.7
36	NC0032573	MI/IN	MG/L	24.83	24.83	28.9	24.83	24.83	26.8	24.83	24.83	29.7	24.83	24.83	13.9
37	NC0033111	MI/IN	MG/L	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94
40	NC0037869	MI/IN	MG/L	11.11	11.11	10.8	11.11	11.11	0.33	11.11	11.11	5.2	11.11	11.11	28.1
41	NC0037915	MI/IN	MG/L	32.12	56.7	32.12	61.6	32.12	32.12	4.92	32.12	32.12	5.25	32.12	32.12
42	NC0038784	MI/IN	MG/L	12.09	12.09	17.08	12.09	12.09	13.61	12.09	12.09	10.69	12.09	12.09	6.99
43	NC0038938	MI/IN	MG/L	28.7	28.6	28.7	10.2	28.7	28.7	28.7	28.7	47.3	28.7	28.7	28.7
44	NC0039233	MI/MU	MG/L	7.493	3.94	7.493	7.493	4.56	7.493	7.493	7.72	7.493	7.493	13.75	7.493
45	NC0039292	MI/IN	MG/L	12.88	12.88	13	12.88	12.88	3.2	12.88	12.88	10.5	12.88	24.8	12.88

Table 8.4: Point Source Pollution (TN) concentration (Continued)



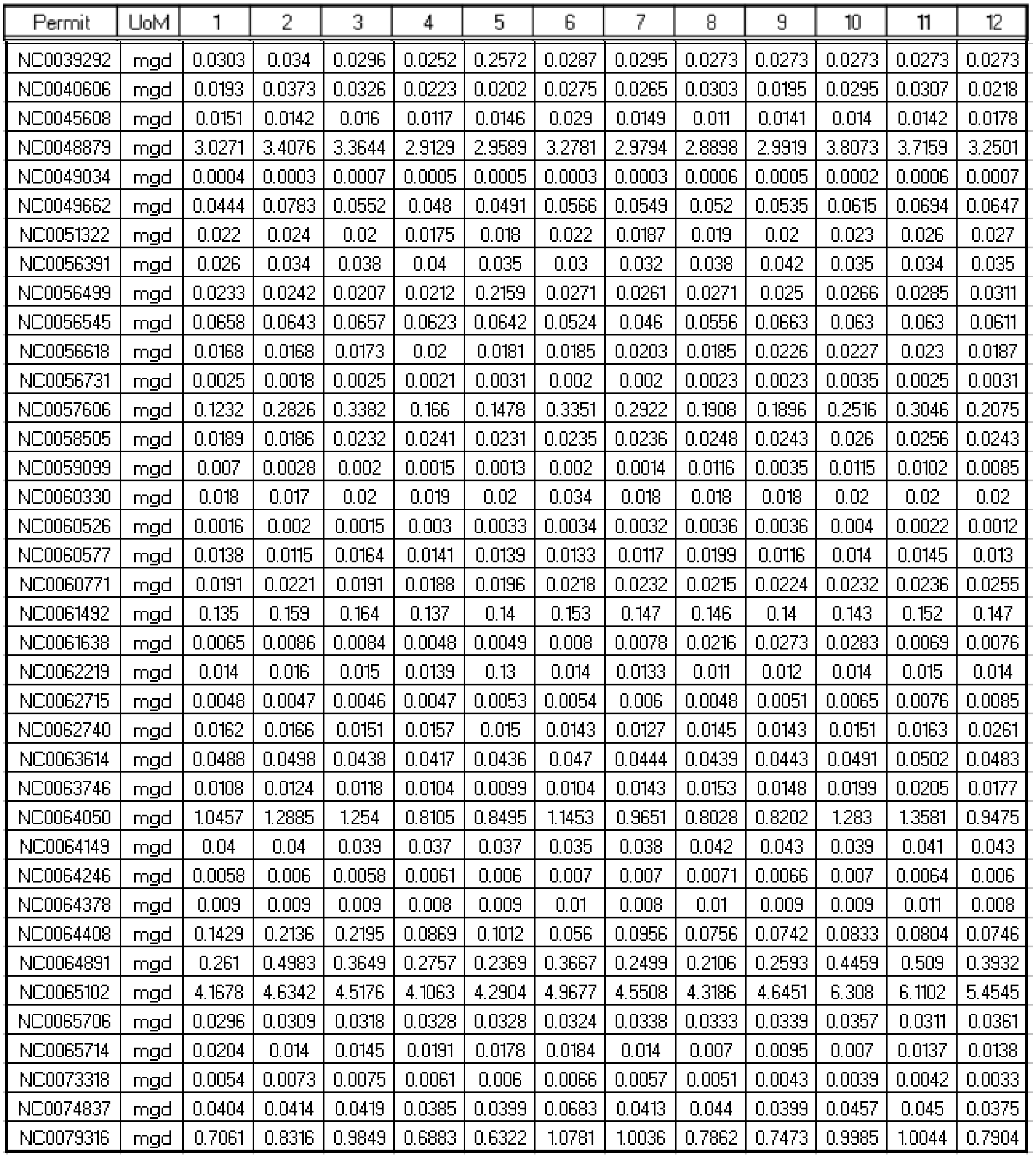
	Permit.	Ma/Mi	unit	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
46	NC0040606	MI/IN	MG/L	9.79	17.36	9.79	9.79	8.64	9.79	9.79	3.75	9.79	9.79	9.41	9.79
47	NC0045608	MI/IN	MG/L	0.683	0.442	0.442	0.6	0.442	0.442	0.456	0.442	0.442	0.029	0.442	0.442
49	NC0048879	MA/MU	MG/L	30	34.5	24.7	22.1	21.4	21	24.1	33.4	32.03	27.34	26.93	28.98
50	NC0049034	MI/IN	MG/L	40.2	31.4	31.4	39.8	31.4	31.4	21	31.4	31.4	24.6	31.4	31.4
52	NC0049662	MI/IN	MG/L	20.64	20.64	20.11	20.64	20.64	24.35	20.64	20.64	17.76	20.64	20.64	20.33
54	NC0051322	MI/IN	MG/L	19.35	19.35	22.2	19.35	19.35	16.5	19.35	19.35	19.35	19.35	19.35	19.35
55	NC0056391	MI/IN	MG/L	20.6	25.13	25.13	20.9	25.13	25.13	35	25.13	25.13	24	25.13	25.13
56	NC0056499	MI/IN	MG/L	8.575	2.8	10.9	8.575	8.575	17	8.575	8.575	3.6	8.575	8.575	8.575
57	NC0056545	MI/MU	MG/L	3.155	3.155	10.1	3.155	3.155	1.1	3.155	3.155	0	3.155	3.155	1.42
58	NC0056618	MI/IN	MG/L	1.88	1.88	3.48	1.88	1.88	1.06	1.88	1.88	1.1	1.88	1.88	1.88
59	NC0056731	MI/IN	MG/L	18.88	18.88	12.84	18.88	18.88	13.04	18.88	18.88	17.7	18.88	18.88	31.94
60	NC0057606	MI/MU	MG/L	28.2	20.95	20.95	20	20.95	20.95	20.2	20.95	20.95	15.4	20.95	20.95
61	NC0058505	MI/IN	MG/L	12.34	5.24	12.34	12.34	3.19	12.34	12.34	19.15	12.34	12.34	21.77	12.34
62	NC0059099	MI/IN	MG/L	23	18	21.28	20.3	21.28	21.28	32	21.28	21.28	21.28	13.1	21.28
63	NC0060330	MI/IN	MG/L	3.242	3.242	4.769	3.242	4.9	2.75	1.4	1.65	3.98	3.242	3.242	3.242
64	NC0060526	MI/IN	MG/L	28.27	28.27	28.27	28.27	28.27	58	28.27	28.27	5.9	28.27	20.9	28.27
65	NC0060577	MI/IN	MG/L	28.98	28.98	15.52	28.98	28.98	27.72	28.98	28.98	38.58	28.98	28.98	34.09
66	NC0060771	MI/IN	MG/L	20.21	32.84	20.21	20.21	19.43	20.21	20.21	5.26	20.21	20.21	23.3	20.21
67	NC0061492	MI/MU	MG/L	28.2	20.66	28.2	28.2	36.8	28.2	28.2	36.53	28.2	28.2	18.81	28.2
68	NC0061638	MI/IN	MG/L	24.7	16.3	24.7	24.7	28.42	24.7	24.7	34.11	24.7	24.7	19.96	24.7
69	NC0062219	MI/IN	MG/L	2.56	2.56	3.16	2.56	2.56	1.96	2.56	2.56	2.56	2.56	2.56	2.56
70	NC0062715	MI/IN	MG/L	32.05	33.78	32.05	32.05	32.22	32.05	32.05	32.05	32.05	32.05	30.16	32.05
71	NC0062740	MI/IN	MG/L	11.1	14.12	11.1	11.1	17.46	11.1	11.1	5.55	11.1	11.1	7.27	11.1
72	NC0063614	MI/IN	MG/L	11.35	12.3	12.3	2.45	12.3	15.3	11.63	16.4	12.3	16.67	12.3	12.3
73	NC0063746	MI/IN	MG/L	9.65	9.65	13.74	9.65	9.65	4.04	9.65	9.65	2	9.65	9.65	18.82
74	NC0064050	MA/MU	MG/L	19.36	13.78	12.23	13.1	10.96	7.7	8.57	11.5	6.51	6.7	6.62	6.4
75	NC0064149	MI/IN	MG/L	17.2	14.5	6.68	5.4	3.09	10.1	11.5	3.27	10.1	10.1	18.5	10.8
76	NC0064246	MI/IN	MG/L	2.09	3.36	2.09	2.09	2.09	1.14	2.09	2.09	1.23	2.09	2.09	2.63
77	NC0064378	MI/IN	MG/L	10.34	10.34	12.2	10.34	10.34	2.42	10.34	10.34	5.4	10.34	10.34	21.34
78	NC0064408	MI/IN	MG/L	9.748	7.2	9.748	9.748	7.73	9.748	9.748	17.81	6.2	9.748	9.8	9.748
79	NC0064891	MI/MU	MG/L	1	1	1	1	1	1	1	1	1	1	1	1
80	NC0065102	MA/MU	MG/L	19.16	16.18	16.78	18.28	19.4	20.35	20.48	21.68	22.38	15.08	12.83	14.38
81	NC0065706	MI/IN	MG/L	30.35	22.24	22.24	30.96	22.24	22.24	21.2	22.24	22.24	6.44	22.24	22.24
82	NC0065714	MI/IN	MG/L	17.95	7.6	18.73	17.95	17.95	13.29	17.95	17.95	21.09	17.95	17.95	29.05
83	NC0073318	MI/IN	MG/L	32.26	26.67	26.67	27.24	26.67	26.67	26.06	26.67	26.67	21.12	26.67	26.67
84	NC0074837	MI/MU	MG/L	4.575	0	4.575	4.575	4.575	4.575	4.575	9.15	4.575	4.575	4.575	4.575
86	NC0079316	MA/MU	MG/L	6.375	9.81	5.99	12.4	6.63	5.56	4.14	11.6	6.98	3.32	4.12	7.51

Table 8.5: Point Source Pollution Waste Flow



Permit	UoM	1	2	3	4	5	6	7	8	9	10	11	12
NC0001376	mgd	1.9826	2.3492	2.1183	1.9736	2.2636	2.3346	1.9445	2.7248	2.5366	2.429	2.161	1.5248
NC0001881	mgd	0.0224	0.0233	0.0217	0.0211	0.0198	0.0195	0.0146		0.0214	0.0234		0.0209
NC0003191	mgd	17.283	22.985	23.516	19.849	18.861	20.789	23.94		23.902	22.432	20.128	22.275
NC0003760	mgd	1.2861	1.1178	1.1738	1.0993	1.19	1.1556	1.3325	1.3074	1.3166	1.19	1.079	1.0616
NC0003816	mgd	2.2709	2.4071	2.1806	1.6866	1.9903	2.3633	2.2774	2.2161	2.3	2.1096	2.1966	1.9387
NC0020389	mgd	0.8829	1.389	1.389	0.8505	1.1446	1.7301	1.2486	1.0103	0.9964	1.7474	1.4466	1.1182
NC0020541	mgd	3.948	5.1192	5.7919	4.084	3.65	6.1696	5.483	4.56		4.1266	5.0193	4.0606
NC0020842	mgd	0.2095	0.2326	0.2667	0.2249	0.2136	0.2775	0.2443	0.2307	0.2312	0.2286	0.231	0.2245
NC0021253	mgd	1.3835	1.3849	1.1947	0.9754	0.9701	1.2267	1.2579	1.1037	1.2049	1.1377	1.2273	1.1348
NC0021342	mgd	0.0472	0.0443	0.0329	0.0207	0.0168	0.0486	0.0414	0.0138	0.0277	0.0273	0.0327	0.0226
NC0021644	mgd	0.386	0.4964	0.5917	0.4435	0.3486	0.6106	0.6427	0.496	0.3995	0.3831	0.4329	0.3925
NC0023841	mgd	9.1909	9.9221	9.6451	7.1986	7.2619	8.9283	8.0551	7.2251	6.9193	8.5054	9.4656	8.7854
NC0023906	mgd	7.0863	10.268	11.052	7.4756	7.2125	9.5813	8.918	7.3619	7.4213	9.6725	10.253	8.5425
NC0023949	mgd	6.0541	9.3425	10.708	7.8056	7.6674	11.382	9.669	7.78	7.1096	7.7232	8.4586	7.7645
NC0024236	mgd	1.9741	2.4471	1.5445	1.4136	1.3829	1.988	1.5958	1.29	1.32	1.6254	1.5903	1.112
NC0024520	mgd	0.004	0.0086	0.01	0.0033	0.0051	0.0051	0.0047	0.0076	0.0081	0.0076	0.0076	0.0097
NC0025348	mgd	3.0548	3.0785	3.2258	2.6733	2.8354	3.5066	3.0774	3.2225	2.94	2.7516	2.7066	2.4451
NC0025453	mgd	0.8601	1.1102	1.106	0.6718	0.6732	1.3111	0.9841	0.8167	0.7152	1.0178	1.0674	0.5081
NC0025712	mgd	0.0184	0.0086	0.026	0.0116	0.0292	0.0957	0.0283	0.0009	0	0.0235	0.0371	0.0105
NC0026433	mgd	1.256	1.3303	1.4217	1.2709	1.2895	1.3093	1.1129	1.0631	0.9076	1.0724	1.0492	1.3969
NC0026662	mgd	0.1589	0.2305	0.2395	0.1165	0.1181	0.2506	0.1793	0.1199	0.1771	0.2505	0.2843	0.1602
NC0026824	mgd	2.3258	2.8142	2.629	1.5666	1.8774	2.75	2.0451	1.787	1.7533	2.3096	2.43	1.8935
NC0029033	mgd	31.425	35.13	33.357	30.481	30.333	33.958	31.901	32.828	33.132	37.718	34.724	30.708
NC0029572	mgd	1.4999	2.2005	2.5334	1.4535	1.5098	2.4572	1.4596	1.2307	1.1593	1.3347	1.5042	1.3241
NC0029904	mgd	0.0027	0.0033	0.0036	0.0027	0.0026	0.0002	0.0006	0.0015	0.0031	0.0032	0.0037	0.0029
NC0030392	mgd	0.1306	0.154	0.1712	0.1669	0.1657	0.147	0.1661	0.1751	0.179	0.1662	0.1667	0.1404
NC0030406	mgd	0.098	0.104	0.098	0.1003	0.096	0.127	0.109	0.131	0.11	0.113	0.138	0.13
NC0030716	mgd	3.4419	4.5888	4.9351	2.3725	2.1441	4.2252	3.5556	2.4075	2.253	3.5009	2.4783	3.4979
NC0030759	mgd	0.5475	0.7799	0.6874	0.5647	0.5998	0.686	0.6751	0.6626	0.651	0.921	0.8592	0.7047
NC0031828	mgd	0.1377	0.1666	0.1785	0.0884	0.0761	0.1473	0.1306	0.1002	0.0907	0.0977	0.107	0.0977
NC0032077	mgd	1.4822	2.1107	2.1206	1.124	1.1976	2.1893			1.3463	1.35	1.0096	1.1609
NC0032557	mgd	0.004	0.005	0.004	0.005	0.005	0.004		0.008	0.005	0.009	0.005	0.006
NC0032565	mgd	0.004	0.006	0.01	0.007	0.007	0.009		0.016	0.005	0.008	0.007	0.014
NC0032573	mgd	0.002	0.002	0.002	0.002	0.002	0.002		0.001	0.001	0.005	0.004	0.004
NC0033111	mgd	0.2416	0.2587	0.2602	0.2577	0.2447	0.2991	0.2937	0.2736	0.2724	0.3032	0.2922	0.2711
NC0037869	mgd	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
NC0037915	mgd	0.0039	0.0046	0.0061	0.0093	0.0078	0.0043	0.003	0.0112	0.0092	0.0048	0.0038	0.0034
NC0038784	mgd	0.0194	0.025	0.0285	0.0188	0.0275	0.036	0.01	0.0147	0.0086	0.0104	0.0945	0.0748
NC0038938	mgd	0.0049	0.0064	0.005	0.0047	0.0059	0.0054		0.0055	0.0051	0.0044	0.0042	0.006
NC0039233	mgd	0.0328	0.0248	0.0272	0.0244	0.0269	0.0283	0.0258	0.0259	0.0232	0.0242	0.0271	0.0274

Table 8.5: Point Source Pollution Waste Flow (Continued)



Permit	UoM	1	2	3	4	5	6	7	8	9	10	11	12
NC0039292	mgd	0.0303	0.034	0.0296	0.0252	0.2572	0.0287	0.0295	0.0273	0.0273	0.0273	0.0273	0.0273
NC0040606	mgd	0.0193	0.0373	0.0326	0.0223	0.0202	0.0275	0.0265	0.0303	0.0195	0.0295	0.0307	0.0218
NC0045608	mgd	0.0151	0.0142	0.016	0.0117	0.0146	0.029	0.0149	0.011	0.0141	0.014	0.0142	0.0178
NC0048879	mgd	3.0271	3.4076	3.3644	2.9129	2.9589	3.2781	2.9794	2.8898	2.9919	3.8073	3.7159	3.2501
NC0049034	mgd	0.0004	0.0003	0.0007	0.0005	0.0005	0.0003	0.0003	0.0006	0.0005	0.0002	0.0006	0.0007
NC0049662	mgd	0.0444	0.0783	0.0552	0.048	0.0491	0.0566	0.0549	0.052	0.0535	0.0615	0.0694	0.0647
NC0051322	mgd	0.022	0.024	0.02	0.0175	0.018	0.022	0.0187	0.019	0.02	0.023	0.026	0.027
NC0056391	mgd	0.026	0.034	0.038	0.04	0.035	0.03	0.032	0.038	0.042	0.035	0.034	0.035
NC0056499	mgd	0.0233	0.0242	0.0207	0.0212	0.2159	0.0271	0.0261	0.0271	0.025	0.0266	0.0285	0.0311
NC0056545	mgd	0.0658	0.0643	0.0657	0.0623	0.0642	0.0524	0.046	0.0556	0.0663	0.063	0.063	0.0611
NC0056618	mgd	0.0168	0.0168	0.0173	0.02	0.0181	0.0185	0.0203	0.0185	0.0226	0.0227	0.023	0.0187
NC0056731	mgd	0.0025	0.0018	0.0025	0.0021	0.0031	0.002	0.002	0.0023	0.0023	0.0035	0.0025	0.0031
NC0057606	mgd	0.1232	0.2826	0.3382	0.166	0.1478	0.3351	0.2922	0.1908	0.1896	0.2516	0.3046	0.2075
NC0058505	mgd	0.0189	0.0186	0.0232	0.0241	0.0231	0.0235	0.0236	0.0248	0.0243	0.026	0.0256	0.0243
NC0059099	mgd	0.007	0.0028	0.002	0.0015	0.0013	0.002	0.0014	0.0116	0.0035	0.0115	0.0102	0.0085
NC0060330	mgd	0.018	0.017	0.02	0.019	0.02	0.034	0.018	0.018	0.018	0.02	0.02	0.02
NC0060526	mgd	0.0016	0.002	0.0015	0.003	0.0033	0.0034	0.0032	0.0036	0.0036	0.004	0.0022	0.0012
NC0060577	mgd	0.0138	0.0115	0.0164	0.0141	0.0139	0.0133	0.0117	0.0199	0.0116	0.014	0.0145	0.013
NC0060771	mgd	0.0191	0.0221	0.0191	0.0188	0.0196	0.0218	0.0232	0.0215	0.0224	0.0232	0.0236	0.0255
NC0061492	mgd	0.135	0.159	0.164	0.137	0.14	0.153	0.147	0.146	0.14	0.143	0.152	0.147
NC0061638	mgd	0.0065	0.0086	0.0084	0.0048	0.0049	0.008	0.0078	0.0216	0.0273	0.0283	0.0069	0.0076
NC0062219	mgd	0.014	0.016	0.015	0.0139	0.13	0.014	0.0133	0.011	0.012	0.014	0.015	0.014
NC0062715	mgd	0.0048	0.0047	0.0046	0.0047	0.0053	0.0054	0.006	0.0048	0.0051	0.0065	0.0076	0.0085
NC0062740	mgd	0.0162	0.0166	0.0151	0.0157	0.015	0.0143	0.0127	0.0145	0.0143	0.0151	0.0163	0.0261
NC0063614	mgd	0.0488	0.0498	0.0438	0.0417	0.0436	0.047	0.0444	0.0439	0.0443	0.0491	0.0502	0.0483
NC0063746	mgd	0.0108	0.0124	0.0118	0.0104	0.0099	0.0104	0.0143	0.0153	0.0148	0.0199	0.0205	0.0177
NC0064050	mgd	1.0457	1.2885	1.254	0.8105	0.8495	1.1453	0.9651	0.8028	0.8202	1.283	1.3581	0.9475
NC0064149	mgd	0.04	0.04	0.039	0.037	0.037	0.035	0.038	0.042	0.043	0.039	0.041	0.043
NC0064246	mgd	0.0058	0.006	0.0058	0.0061	0.006	0.007	0.007	0.0071	0.0066	0.007	0.0064	0.006
NC0064378	mgd	0.009	0.009	0.009	0.008	0.009	0.01	0.008	0.01	0.009	0.009	0.011	0.008
NC0064408	mgd	0.1429	0.2136	0.2195	0.0869	0.1012	0.056	0.0956	0.0756	0.0742	0.0833	0.0804	0.0746
NC0064891	mgd	0.261	0.4983	0.3649	0.2757	0.2369	0.3667	0.2499	0.2106	0.2593	0.4459	0.509	0.3932
NC0065102	mgd	4.1678	4.6342	4.5176	4.1063	4.2904	4.9677	4.5508	4.3186	4.6451	6.308	6.1102	5.4545
NC0065706	mgd	0.0296	0.0309	0.0318	0.0328	0.0328	0.0324	0.0338	0.0333	0.0339	0.0357	0.0311	0.0361
NC0065714	mgd	0.0204	0.014	0.0145	0.0191	0.0178	0.0184	0.014	0.007	0.0095	0.007	0.0137	0.0138
NC0073318	mgd	0.0054	0.0073	0.0075	0.0061	0.006	0.0066	0.0057	0.0051	0.0043	0.0039	0.0042	0.0033
NC0074837	mgd	0.0404	0.0414	0.0419	0.0385	0.0399	0.0683	0.0413	0.044	0.0399	0.0457	0.045	0.0375
NC0079316	mgd	0.7061	0.8316	0.9849	0.6883	0.6322	1.0781	1.0036	0.7862	0.7473	0.9985	1.0044	0.7904

Table 8.6: Fertilizer Application Rates and Acreage by County (Source: DWQ)

N	Carteret	Craven	Durham	Franklin	Granville	Greene	Johnston	Jones	Lenoir	Nash	Orange	Pamlico	Person	Pitt	Wake	Wayne	Wilson
Corn for Grain-no till			150		140						120		150		177		
Corn for Grain-conv	180	180	150	150	140	153	160	180	140	142	120	180	150	150	177	155	165
Corn for Silage -no till			150		145						120		190		177		
Corn for Silage-conv			150	180	145						120				177	155	
Soybeans for Beans	20	20	40	0	0	20	20	110	0	23	0	20	0	10	0	10	26
Cotton	110	110				104	75	110	35	85		110		88	85	77	78
Wheat for Grain	130	130	110	100	100	130	115	130	85	110	84	130	110	95	107	118	118
Tobacco	90	90	89	90	78	75	80	90	110	81	85	90	76	72	111	78	78
Bermuda Grass	240	240	66	150	0	363	250	240	75	284	163		129	363	268	400	288
Fescue			66	120	100				325	0					155		0
Rye			110			90											
Oats for Grain	240	120	110	203	100	111	118	240	110	105	82			110	96	116	118
Barley for Grain				95	0		118		95	105	82			110	85	117	118
Sorghum for Grain	100	100			0	83	165	100	85	142	85			110	112	130	165
Peanuts		0												0		0	26
Soybean-waste									35							130	
Sweet Potatoes									110	81				72	100	78	78
Irish Potatoes	0								0								

Acres	Carteret	Craven	Durham	Franklin	Granville	Greene	Johnston	Jones	Lenoir	Nash	Orange	Pamlico	Person	Pitt	Wake	Wayne	Wilson
Corn for Grain-no till			20	150							2106		298	0	870		0
Corn for Grain-conv	10800	17160	20	150	160	19868	16070	15000	27001	1125	2106	9480	1190	14010	870	25706	13648
Corn for Silage -no till			20		305						942		375		450		
Corn for Silage-conv			19		600						314				450	510	
Soybeans for Beans	8217	19560	343	1599	1447	23884	48493	11000	29125	6965	1875	14660	2052	22476	14603	28781	27616
Cotton	414	13660				13688	14360	18000	16935	4148		2000		12330	741	22636	8758
Wheat for Grain	2190	4260	758	1300	671	8828	17780	2500	11408	2500	4125	8496	4320	11720	7528	22556	12096
Tobacco	331	4522	1432	750	766	7798	21813	2900	8579	2485	1284	2770	2269	7222	9359	7619	7743
Bermuda Grass	50	625	5335	1000		533	5580	500	940	785				936	2423	1771	464
Fescue			5334	1000	4140					0	4014		8995		2423	726	
Rye			240			248											
Oats for Grain	155	240	40	500	118	576	4460	75	105	380	410			357	2703	1439	816
Barley for Grain	150			59	2		556		158	50	370			37	488	424	64
Sorghum for Grain		100			10	51	650	25	56	78	262			20	280	694	64
Peanuts		35														16	34
Soybean-waste									5135							15498	
Sweet Potatoes									232	1289				76	231	1422	2416
Irish Potatoes	300								153								

Table 8.7: Fertilizer Application Rates by Modified Hydrologic Units

#	Station	County	Ag LU by County&Type	HU LC (Acreage)	Total County LC	HU LC (% usage)	County TN Application	TN Application	TN Application by County	Tn Application by HU
1	J0770000	Orange	Cultivated	882.54301	1604.4401	0.55006294	1198030	658991.9	1017675.32	1045581.8
			Herbaceous	16901.503	30830.389	0.54820921	654282	358683.42		
		Durham	Cultivated	0	1972.5539	0	267198	0	27906.4327	
			Herbaceous	583.39389	14720.59	0.03963115	704154	27906.433		
2	J0810000	Durham	Cultivated	84.655696	1972.5539	0.0429168	267198	11467.282	29090.1066	29090.107
			Herbaceous	368.4114	14720.59	0.02502695	704154	17622.824		
3	J0820000	Orange	Cultivated	407.82538	1604.4401	0.25418549	1198030	304521.84	558148.252	650409.8
			Herbaceous	11951.117	30830.389	0.38764082	654282	253626.41		
		Durham	Cultivated	72.704515	1972.5539	0.03685806	267198	9848.4004	92261.5517	
			Herbaceous	1722.8762	14720.59	0.11703853	704154	82413.151		
4	J0840000	Durham	Cultivated	4.2148926	1972.5539	0.00213677	267198	570.94048	172797.013	172797.01
			Herbaceous	3600.4473	14720.59	0.2445858	704154	172226.07		
5	J1070000	Durham	Cultivated	321.40545	1972.5539	0.16293874	267198	43536.906	129146.923	2426090.1
			Herbaceous	1789.7078	14720.59	0.12157854	704154	85610.017		
		Orange	Cultivated	314.07167	1604.4401	0.19575158	1198030	234516.26	276488.435	
			Herbaceous	1977.7686	30830.389	0.06414997	654282	41972.172		
		Person	Cultivated	3803.1693	4014.8462	0.94727647	942094	892423.48	2020454.72	
			Herbaceous	19816.045	20383.874	0.97214321	1160355	1128031.2		
6	J1100000	Durham	Cultivated	27.497158	1972.5539	0.01393988	267198	3724.7071	133890.554	133890.55
			Herbaceous	2721.1633	14720.59	0.18485423	704154	130165.85		
7	J1210000	Durham	Cultivated	235.06696	1972.5539	0.11916884	267198	31841.675	55665.4504	288940.17
			Herbaceous	498.04449	14720.59	0.03383319	704154	23823.775		
		Person	Cultivated	180.09672	4014.8462	0.04485769	942094	42260.16	67402.6356	
			Herbaceous	441.6761	20383.874	0.02166792	1160355	25142.476		
		Granville	Cultivated	466.54441	5973.9468	0.07809651	292273	22825.502	165872.083	
			Herbaceous	2079.0915	6017.2279	0.34552314	414000	143046.58		
8	J1330000	Durham	Cultivated	5.98827	1972.5539	0.0030358	267198	811.15844	36807.7725	36807.773
			Herbaceous	752.52201	14720.59	0.05112037	704154	35996.614		
9	J1530000	Durham	Cultivated	83.658996	1972.5539	0.04241151	267198	11332.271	22262.2189	22262.219
			Herbaceous	228.49444	14720.59	0.0155221	704154	10929.947		
10	J1890000	Durham	Cultivated	973.26635	1972.5539	0.49340418	267198	131836.61	208671.594	970438.15
			Herbaceous	1606.2626	14720.59	0.10911673	704154	76834.984		
		Granville	Cultivated	5507.4023	5973.9468	0.92190349	292273	269447.5	529918.845	
			Herbaceous	3785.7862	6017.2279	0.62915784	414000	260471.35		
		Franklin	Cultivated	316.88619	6634.0963	0.04776629	354105	16914.283	87186.9609	
			Herbaceous	521.30764	2002.9557	0.26026918	270000	70272.677		
		Wake	Cultivated	1484.9817	65930.148	0.02252356	2730038	61490.178	144660.75	
			Herbaceous	1951.0666	24043.417	0.08114764	1024929	83170.572		
11	J2850000	Durham	Cultivated	65.848741	1972.5539	0.03338248	267198	8919.7317	45494.3947	166857.14
			Herbaceous	764.60633	14720.59	0.05194128	704154	36574.663		
		Wake	Cultivated	43.383428	65930.148	0.00065802	2730038	1796.4226	121362.749	
			Herbaceous	2804.8607	24043.417	0.11665815	1024929	119566.33		
12	J2860000	Wake	Cultivated	11.841842	65930.148	0.00017961	2730038	490.34742	10069.2246	10069.225
			Herbaceous	224.70722	24043.417	0.00934589	1024929	9578.8771		
13	J3000000	Durham	Cultivated	5.1852376	1972.5539	0.00262869	267198	702.38136	4408.36875	33966.005
			Herbaceous	77.474983	14720.59	0.00526304	704154	3705.9874		
		Wake	Cultivated	130.8679	65930.148	0.00198495	2730038	5418.9827	29557.6367	
			Herbaceous	566.25945	24043.417	0.02355154	1024929	24138.654		
14	J3290000	Wake	Cultivated	113.55198	65930.148	0.00172231	2730038	4701.9646	68818.39	68818.39
			Herbaceous	1504.0827	24043.417	0.06255694	1024929	64116.425		
15	J4170000	Franklin	Cultivated	449.68452	6634.0963	0.06778384	354105	24002.597	49542.3401	1296685.9
			Herbaceous	189.46287	2002.9557	0.09459164	270000	25539.743		
		Wake	Cultivated	16026.495	65930.148	0.24308296	2730038	663625.72	1009088.35	
			Herbaceous	8104.0757	24043.417	0.33706006	1024929	345462.63		
		Johnston	Cultivated	2445.1311	184565.11	0.01324807	9106938	120649.33	238055.211	
			Herbaceous	676.86558	8042.421	0.08416192	1395000	117405.88		
16	J4370000	Johnston	Cultivated	9726.1505	184565.11	0.05269767	9106938	479914.38	665737.39	665737.39
			Herbaceous	1071.3024	8042.421	0.13320646	1395000	185823.01		

Table 8.7: Fertilizer Application Rates by Modified Hydrologic Units (Continued)

#	Station	County	Ag LU by County&Type	HU LC (Acreage)	Total County LC	HU LC (% usage)	County TN Application	TN Application	TN Application by County	Tn Application by HU
17	J4510000	Wake	Cultivated	3897.2596	65930.148	0.05911195	2730038	161377.87	298797.746	388497.81
			Herbaceous	3223.6803	24043.417	0.13407746	1024929	137419.87		
		Johnston	Cultivated	970.67771	184565.11	0.00525927	9106938	47895.844	89700.0665	
			Herbaceous	241.00871	8042.421	0.02996718	1395000	41804.222		
18	J5000000	Wake	Cultivated	14675.195	65930.148	0.22258702	2730038	607671.03	682895.303	743467.2
			Herbaceous	1764.6575	24043.417	0.07339462	1024929	75224.277		
		Johnston	Cultivated	1227.576	184565.11	0.00665118	9106938	60571.896	60571.8957	
			Herbaceous	0	8042.421	0	1395000	0		
19	J5850000	Franklin	Cultivated	2330.6673	6634.0963	0.35131648	354105	124402.92	211831.129	2910129
			Herbaceous	648.57344	2002.9557	0.32380818	270000	87428.208		
		Wake	Cultivated	16159.651	65930.148	0.2451026	2730038	669139.41	789129.13	
			Herbaceous	2814.7929	24043.417	0.11707125	1024929	119989.72		
		Johnston	Cultivated	25309.441	184565.11	0.13713015	9106938	1248835.7	1746354.07	
			Herbaceous	2868.2808	8042.421	0.35664396	1395000	497518.32		
		Wilson	Cultivated	2048.9471	75928.864	0.02698509	5988074	161588.71	162814.668	
			Herbaceous	63.726014	6946.2706	0.00917413	133632	1225.9578		
20	J5970000	Wake	Cultivated	9939.3632	65930.148	0.15075597	2730038	411569.52	422104.853	12876750
			Herbaceous	247.14438	24043.417	0.01027909	1024929	10535.334		
		Johnston	Cultivated	137671.17	184565.11	0.74592199	9106938	6793065.3	6809173.09	
			Herbaceous	92.864205	8042.421	0.0115468	1395000	16107.782		
		Wayne	Cultivated	65338.551	143038.45	0.45679012	11782560	5382157	5645471.67	
			Herbaceous	3837.4975	10324.086	0.37170338	708400	263314.67		
21	J6150000	Wayne	Cultivated	36115.985	143038.45	0.25249144	11782560	2974995.6	3271788.23	6371662.8
			Herbaceous	4325.3992	10324.086	0.41896196	708400	296792.65		
		Greene	Cultivated	4941.6678	82485.024	0.05990988	6764015	405231.32	414873.516	
			Herbaceous	199.43884	4001.9129	0.04983588	193479	9642.1958		
		Lenoir	Cultivated	43490.435	106825.76	0.4071156	6522800	2655533.6	2685001.07	
			Herbaceous	3609.627	8635.9257	0.41797801	70500	29467.449		
22	J6740000	Franklin	Cultivated	3521.2974	6634.0963	0.53078781	354105	187954.62	274499.426	1790251.3
			Herbaceous	642.02008	2002.9557	0.32053633	270000	86544.81		
		Wake	Cultivated	3315.0923	65930.148	0.05028189	2730038	137271.46	163612.884	
			Herbaceous	617.93328	24043.417	0.02570073	1024929	26341.419		
		Johnston	Cultivated	4764.1411	184565.11	0.02581279	9106938	235075.51	361282.466	
			Herbaceous	727.60534	8042.421	0.09047093	1395000	126206.95		
		Wilson	Cultivated	2898.0445	75928.864	0.03816789	5988074	228552.15	233056.215	
			Herbaceous	234.12401	6946.2706	0.03370499	133632	4504.0658		
		Nash	Cultivated	11643.906	25986.35	0.44807777	1309445	586733.2	757800.264	
			Herbaceous	1505.226	1961.658	0.76732334	222940	171067.07		
23	J732000	Johnston	Cultivated	800.12078	184565.11	0.00433517	9106938	39480.107	49230.2456	2362912.6
			Herbaceous	56.211268	8042.421	0.00698935	1395000	9750.1385		
		Wayne	Cultivated	24509.369	143038.45	0.17134812	11782560	2018919.5	2094547.44	
			Herbaceous	1102.1877	10324.086	0.10675887	708400	75627.983		
		Greene	Cultivated	2535.8155	82485.024	0.03074274	6764015	207944.35	219134.927	
			Herbaceous	231.4656	4001.9129	0.05783874	193479	11190.582		
24	J7450000	Wilson	Cultivated	68816.161	75928.864	0.90632413	5988074	5427136	5551909.19	11395104
			Herbaceous	6485.7858	6946.2706	0.93370763	133632	124773.22		
		Nash	Cultivated	14342.444	25986.35	0.55192223	1309445	722711.8	774584.735	
			Herbaceous	456.43204	1961.658	0.23267666	222940	51872.936		
		Wayne	Cultivated	17074.539	143038.45	0.11937027	11782560	1406487.4	1479151.84	
			Herbaceous	1058.9974	10324.086	0.10257541	708400	72664.423		
		Greene	Cultivated	42509.103	82485.024	0.5153554	6764015	3485871.7	3589457.82	
			Herbaceous	2142.5727	4001.9129	0.53538713	193479	103586.17		
25	J7739550	Wilson	Cultivated	2165.7106	75928.864	0.02852289	5988074	170797.17	173925.931	2953130.7
			Herbaceous	162.63471	6946.2706	0.02341324	133632	3128.7583		
		Greene	Cultivated	14700.739	82485.024	0.17822312	6764015	1205503.9	1240734.7	
			Herbaceous	728.71291	4001.9129	0.18209115	193479	35230.813		
		Pitt	Cultivated	18755.547	67223.34	0.27900349	5095696	1421717	1538470.06	
			Herbaceous	1418.2244	4127.2345	0.34362584	339768	116753.07		

Table 8.7: Fertilizer Application Rates by Modified Hydrologic Units (Continued)

#	Station	County	Ag LU by County&Type	HU LC (Acreage)	Total County LC	HU LC (% usage)	County TN Application	TN Application	TN Application by County	Tn Application by HU
26	J7810000	Greene	Cultivated	17797.699	82485.024	0.21576886	6764015	1459463.8	1493293.04	6575288.6
			Herbaceous	699.72291	4001.9129	0.17484711	193479	33829.244		
		Pitt	Cultivated	10769.073	67223.34	0.16019842	5095696	816322.44	1335054.16	
			Herbaceous	6301.145	4127.2345	1.52672327	339768	518731.71		
		Lenoir	Cultivated	11670.517	106825.76	0.10924815	6522800	712603.84	3746941.45	
			Herbaceous	371692.4	8635.9257	43.0402498	70500	3034337.6		
27	J7850000	Pitt	Cultivated	5457.5682	67223.34	0.08118562	5095696	413697.22	433303.144	4138197.1
			Herbaceous	238.15735	4127.2345	0.05770386	339768	19605.924		
		Lenoir	Cultivated	35238.973	106825.76	0.32987335	6522800	2151697.9	2184511.58	
			Herbaceous	4019.5259	8635.9257	0.46544239	70500	32813.689		
		Jones	Cultivated	1938.7392	61549.174	0.03149903	6496500	204633.44	206837.485	
			Herbaceous	89.174008	4855.1158	0.01836702	120000	2204.0424		
		Craven	Cultivated	14829.719	68222.792	0.21737192	5982180	1300357.9	1313544.92	
			Herbaceous	787.46818	8957.3335	0.08791324	150000	13186.985		
28	J7860000	Jones	Cultivated	803.78343	61549.174	0.01305921	6496500	84839.141	85175.9426	1394253.6
			Herbaceous	13.626756	4855.1158	0.00280668	120000	336.80158		
		Craven	Cultivated	14802.511	68222.792	0.21697311	5982180	1297972.2	1309077.63	
			Herbaceous	663.16705	8957.3335	0.07403621	150000	11105.432		
29	J7930000	Craven	Cultivated	2141.9149	68222.792	0.03139588	5982180	187815.83	190342.46	190342.46
			Herbaceous	150.87903	8957.3335	0.01684419	150000	2526.6286		
30	J8150000	Pitt	Cultivated	786.09774	67223.34	0.01169382	5095696	59588.16	60827.6645	184341.22
			Herbaceous	15.056526	4127.2345	0.00364809	339768	1239.5045		
		Craven	Cultivated	1405.3703	68222.792	0.02059972	5982180	123231.22	123513.555	
			Herbaceous	16.859572	8957.3335	0.00188221	150000	282.33131		
31	J8170000	Pitt	Cultivated	31159.39	67223.34	0.46352041	5095696	2361959.1	2511409.68	2896493.3
			Herbaceous	1815.4079	4127.2345	0.43986061	339768	149450.56		
		Craven	Cultivated	4375.8833	68222.792	0.06414108	5982180	383703.46	385083.651	
			Herbaceous	82.418703	8957.3335	0.00920125	150000	1380.1881		
32	J8210000	Pitt	Cultivated	188.37489	67223.34	0.00280222	5095696	14279.284	15780.2051	1258253.4
			Herbaceous	18.232004	4127.2345	0.00441749	339768	1500.9207		
		Craven	Cultivated	14052.634	68222.792	0.20598151	5982180	1232218.5	1242473.2	
			Herbaceous	612.36563	8957.3335	0.06836472	150000	10254.709		
33	J8250000	Craven	Cultivated	0	68222.792	0	5982180	0	0	0
			Herbaceous	0	8957.3335	0	150000	0		
34	J8290000	Craven	Cultivated	10.609148	68222.792	0.00015551	5982180	930.27321	940.700594	940.70059
			Herbaceous	0.6226769	8957.3335	6.9516E-05	150000	10.427381		
35	J8570000	Jones	Cultivated	214.04144	61549.174	0.00347757	6496500	22592.021	22592.0211	801948.12
			Herbaceous	0	4855.1158	0	120000	0		
		Craven	Cultivated	8813.3588	68222.792	0.12918496	5982180	772807.7	779356.098	
			Herbaceous	391.04125	8957.3335	0.04365599	150000	6548.3984		
36	J8670000	Lenoir	Cultivated	984.83043	106825.76	0.00921903	6522800	60133.919	61840.1218	356290.76
			Herbaceous	209.00195	8635.9257	0.02420145	70500	1706.2024		
		Jones	Cultivated	2788.4638	61549.174	0.04530465	6496500	294321.66	294450.637	
			Herbaceous	5.2184388	4855.1158	0.00107483	120000	128.97996		
37	J8690000	Lenoir	Cultivated	12853.842	106825.76	0.12032529	6522800	784857.83	786979.001	2252861.3
			Herbaceous	259.8342	8635.9257	0.03008759	70500	2121.1752		
		Jones	Cultivated	13610.049	61549.174	0.22112481	6496500	1436537.3	1465882.27	
			Herbaceous	1187.2754	4855.1158	0.24454111	120000	29344.933		
38	J8700000	Lenoir	Cultivated	2303.0193	106825.76	0.02155865	6522800	140622.76	141764.13	2261463.9
			Herbaceous	139.81226	8635.9257	0.01618961	70500	1141.3674		
		Jones	Cultivated	19778.107	61549.174	0.32133831	6496500	2087574.3	2119699.75	
			Herbaceous	1299.7722	4855.1158	0.26771188	120000	32125.426		
39	J8720000	Jones	Cultivated	7784.0242	61549.174	0.12646838	6496500	821601.82	840191.501	840191.5
			Herbaceous	752.12528	4855.1158	0.15491398	120000	18589.677		
40	J8770000	Craven	Cultivated	561.38068	68222.792	0.00822864	5982180	49225.195	53460.4206	1586244.5
			Herbaceous	252.90884	8957.3335	0.02823484	150000	4235.2254		
		Lenoir	Cultivated	9.884E-07	106825.76	9.2526E-12	6522800	6.035E-05	5.4301E-05	
			Herbaceous	-7.41E-07	8635.9257	-8.584E-11	70500	-6.05E-06		
		Jones	Cultivated	14174.075	61549.174	0.23028864	6496500	1496070.1	1532784.13	
			Herbaceous	1485.423	4855.1158	0.30595007	120000	36714.008		

Table 8.8: Total Nitrogen (lbs/year) from Animal Operations

#	Station	Total Swine inventories	Total N (swine)	Total Broiler inventories	Total N (Broiler)	Total Cattle inventories	Total N (Cattle)	Total N (all AO)
1	J0770000	1400	28420	45000	40050	595	63367.5	131837.5
2	J0810000	0	0		0		0	0
3	J0820000	400	8120		0		0	8120
4	J0840000	0	0		0		0	0
5	J1070000	11488	233206.4	60000	53400	105	11182.5	297788.9
6	J1100000	0	0		0	250	26625	26625
7	J1210000	0	0		0	600	63900	63900
8	J1330000	0	0		0	0	0	0
9	J1530000	0	0		0	0	0	0
10	J1890000	0	0		0	120	12780	12780
11	J2850000	0	0		0		0	0
12	J2860000	0	0		0		0	0
13	J3000000	0	0		0	0	0	0
14	J3290000	0	0		0	0	0	0
15	J4170000	3152	63985.6		0	500	53250	117235.6
16	J4370000	15810	320943		0		0	320943
17	J4510000	1630	33089		0	320	34080	67169
18	J5000000	0	0		0		0	0
19	J5850000	12080	245224		0		0	245224
20	J5970000	368630	7483189	70000	62300		0	7545489
21	J6150000	172870	3509261		0	1650	175725	3684986
22	J6740000	12460	252938		0		0	252938
23	J7320000	50724	1029697.2		0		0	1029697
24	**J7450000**	154539	3137141.7		0		0	3137142
25	J7739550	125402	2545660.6		0		0	2545661
26	J7810000	110232	2237709.6		0		0	2237710
27	J7850000	86946	1765003.8		0		0	1765004
28	J7860000	17192	348997.6		0		0	348997.6
29	**J7930000**	0	0		0		0	0
30	J8150000	3152	63985.6		0		0	63985.6
31	J8170000	64208	1303422.4		0		0	1303422
32	**J8210000**	18048	366374.4		0		0	366374.4
33	J8250000	0	0		0		0	0
34	J8290000	0	0		0		0	0
35	J8570000	1760	35728		0		0	35728
36	J8670000	80230	1628669		0		0	1628669
37	**J8690000**	83850	1702155		0		0	1702155
38	J8700000	37440	760032		0		0	760032
39	J8720000	31020	629706		0		0	629706
40	**J8770000**	25600	519680		0		0	519680
41	J8900800	5200	105560		0		0	105560
42	J8902500	3100	62930		0		0	62930
43	J8910000	0	0		0		0	0
44	J9530000	0	0		0		0	0
45	J9690000	0	0	0	0	0	0	0
46	J9810000	0	0		0		0	0
47	J9930000	0	0		0		0	0
48	J9938000	0	0	0	0	0	0	0
49	J9940000	0	0	0	0	0	0	0
50	J9950000	4800	97440	0	0	0	0	97440

Table 8.9: Urban Source of Land Use Amount

#	Station	Developed Land Use	High Intensity Developed	Low Intensity Developed
1	J0770000	4032.011028	2187.576534	1844.434131
2	J0810000	1220.428725	626.2331845	594.1953847
3	J0820000	247.4255751	197.8837988	49.54174208
4	J0840000	192.733529	154.5195061	38.21415696
5	J1070000	981.8533962	822.7654747	159.0879971
6	J1100000	35.48889627	31.67542894	3.813483983
7	J1210000	468.3998638	118.4028803	349.996964
8	J1330000	5405.668203	2195.211316	3210.457111
9	J1530000	639.9462801	121.4298711	518.5165783
10	J1890000	3275.966468	1596.038082	1350.522716
11	J2850000	3968.257649	2225.230854	1743.026522
12	J2860000	361.0307752	251.2810802	109.7497717
13	J3000000	891.8852074	430.7131059	461.172206
14	J3290000	5743.329342	3349.472658	2601.806294
15	J4170000	18609.33417	9247.956049	9361.378104
16	J4370000	3337.190748	1117.609478	2219.581064
17	J4510000	4237.81453	2557.366566	1680.448112
18	J5000000	1517.762364	584.0814026	933.6809665
19	J5850000	2311.329908	809.9652451	1501.364731
20	J5970000	9296.69892	3619.701212	5676.998719
21	J6150000	5199.908982	1990.818859	3209.090069
22	J6740000	1479.198322	853.0102796	626.1882068
23	J7320000	102.1292001	17.37502275	84.75416253
24	J7450000	7622.476021	3225.400958	4397.074882
25	J7739550	1447.624648	745.6049845	702.019753
26	J7810000	803.3692822	40.54329417	762.8260581
27	J7850000	3709.796014	1194.987316	2514.808901
28	J7860000	538.5691616	342.7105253	195.8585733
29	J7930000	54.94859819	7.62698239	25.01333151
30	J8150000	3.612765252	3.61275722	0
31	J8170000	2033.228185	353.992385	1679.235967
32	J8210000	334.7060687	22.68014469	281.5950179
33	J8250000	28.04072851	29.30356538	0
34	J8290000	0	0	0
35	J8570000	2834.796511	1174.148951	1660.647917
36	J8670000	74.67381205	74.67377893	0
37	J8690000	565.8891809	484.6018633	81.28721053
38	J8700000	150.6322914	135.244604	15.38770705
39	J8720000	62.98483778	30.06855887	32.91633341
40	J8770000	781.642348	349.6354736	433.0762935

Table 8.10: Forest, Wetland, and Slope

HU id.	Station	Forest	Wetland	Slope
1	J0770000	58180.855	72.482916	3.77901
2	J0810000	4161.6596	889.21865	2.8892
3	J0820000	35037.615	162.25136	3.00528
4	J0840000	8819.1159	708.79963	4.01921
5	J1070000	62963.953	175.07953	3.02534
6	J1100000	12130.261	424.72168	3.60795
7	J1210000	18651.155	306.96023	3.22138
8	J1330000	2538.918	577.71392	3.09113
9	J1530000	1896.6482	95.770014	2.60797
10	J1890000	111226.55	8699.5515	3.61285
11	J2850000	13504.479	1046.058	3.3341
12	J2860000	3039.3972	17.305988	5.11965
13	J3000000	6399.5237	65.439383	3.89853
14	J3290000	7029.9619	271.46981	4.0335
15	J4170000	82253.29	5638.2922	3.31264
16	J4370000	18666.688	3191.3967	2.23568
17	J4510000	26097.766	2722.4701	3.24806
18	J5000000	27708.728	2687.6459	3.0333
19	J5850000	66463.906	14491.333	2.07714
20	J5970000	176921.54	68224.713	1.726673
21	J6150000	51961.201	20844.116	0.957754
22	J6740000	51214.519	9334.106	2.37108
23	J7320000	15355.501	4242.5908	1.20483
24	J7450000	83256.951	50368.525	1.15544
25	J7739550	29288.045	13325.383	0.674601
26	J7810000	18483.6	11087.746	0.750304
27	J7850000	45081.637	26458.793	0.667008
28	J7860000	16511.058	16150.219	0.381355
29	J7930000	2387.217	5370.2156	0.448413
30	J8150000	5437.1332	8052.0192	0.39131
31	J8170000	24372.026	18996.99	0.446894
32	J8210000	40212.579	33745.492	0.330676
33	J8250000	8.9523841	509.87776	0.385183
34	J8290000	669.39284	1236.9602	0.375116
35	J8570000	28599.541	11011.653	0.379529
36	J8670000	13438.878	4049.2008	0.807781
37	J8690000	33313.205	18852.643	0.606995
38	J8700000	36238.849	23945.086	0.430432
39	J8720000	11211.712	4132.008	0.600004
40	J8770000	27487.108	19952.517	0.466317

Table 8.11: Flow Severity

HU id.	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1	J0770000	4	3	2	2	2	2	4	1	1	3	2	2	2.33333
2	J0810000	3	3	2	2	2	2	3	1	1	2	2	2	2.08333
3	J0820000	4	3	2	2	2	2	4	1	1	2	2	2	2.25
4	J0840000					2	1		1	1	1	1	1	1.14286
5	J1070000	4	3	2	2	2	2	4	1	1	2	2	2	2.25
6	J1100000	3	3	2	1	2	2	4	2	1	1	2	2	2.08333
7	J1210000	3	2	2	1	2	2	3	1	1	2	2	2	1.91667
8	J1330000	3	3	2	2	2	2	3	1	1		2	2	2.09091
9	J1530000	3	3	1	1	1	1	2			2	2	2	1.8
10	J1890000	3	4	2	2	2	2	2	1	1	3		3	2.27273
11	J2850000	4	4	3	2	2	2	2	1	1	3		2	2.36364
12	J2860000	4	4	3	2	2	3	3	3	3	3	3	3	3
13	J3000000						2	2	1	1	3		2	1.83333
14	J3290000	3	3	3	2	2	3	1	1	1	2		2	2.09091
15	J4170000	3	3	2	2	2	3	2	2.5	3	3		2	2.5
16	J4370000	3	3	2	2	2	4	2	2	3	3		2	2.54545
17	J4510000	3	3	2	2	2	2	2	2	3			1	2.2
18	J5000000	3	3	2	2	2	3	2	2	3	3		1	2.36364
19	J5850000	3	3	2	2	2	4	2	2	3	2		2	2.45455
20	J5970000	3	3	4	3	3	3	3	1	3	3	4	3	3
21	J6150000	4	3	3	3	3	3	4	2	3	3	4	3	3.16667
22	J6740000	3	3	2	2	2	3	2	2	2	3		2	2.36364
23	J7320000	3	3	4	3	3	3							3.16667
24	J7450000	3	3	4	3	3	3	3	1	3	3	4	3	3
25	J7739550	3	3	4	3	3	3	3	1	3	3	3	3	2.91667
26	J7810000	4	3	3	3	3	3	4	1	3	3	4	3	3.08333
27	J7850000	4	3	3	3	3	3	4	2	3	4	4	3	3.25
28	J7860000	3	3	3	3	3	3	3	3	3	3	3	3	3
29	J7930000	3	3	3	3	3	3	3	3	3	3	3	3	3
30	J8150000	4	3	3	3	3	3	4	1	3	3	3	3	3
31	J8170000	4	3	3	3	3	3							3.16667
32	J8210000	3	3	3	3	3	3	3	3	3	3	3	3	3
33	J8250000	3	3	3	3	3	3	3	3	3	3	3	3	3
34	J8290000	3	3	3	3	3	3	3	3	3	3	3	3	3
35	J8570000	3	3	3	3	3	3	3	3	3	3	3	3	3
36	J8670000	3	3	3	3	3	3	3	3	3	3	3	3	3
37	J8690000	4	3	3	3	3	3	3	3	3	3	3	3	3.08333
38	J8700000	3	3	3	3	3	3	3	3	3	3	3	3	3
39	J8720000			1			3	3	3	3	3	3	3	2.75
40	J8770000	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 8.12: Stream Width

HU id.	Station	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Average
1	J0770000	40	35	50	50	30	60	60			35	50	60	47
2	J0810000	60	50	125	100	80	80	80			70	85	75	80.5
3	J0820000	50	30	100	100	100	60	90			50	70	80	73
4	J0840000	200	200		600		500	350			500	350	350	381.25
5	J1070000	40	35	100	80	100	60	60			45	50	60	63
6	J1100000	30	25	125	80	125	100	80			70	70	90	79.5
7	J1210000	25	20	30	20	12	25	20			30	25	20	22.7
8	J1330000	30	25	60	50	50	60	50				50	60	48.3333
9	J1530000	12	12	30	30	30	30	30				30	15	24.3333
10	J1890000	125	125	150	130	140	351	120					350	186.375
11	J2850000	30	45	55	45	50	50	60			50		50	48.3333
12	J2860000	50	50	60	45	55								52
13	J3000000						65	50			40		40	48.75
14	J3290000	80	80	65	50	45	35	60			50		60	58.3333
15	J4170000	100	80	120	100	105	150	240	120	120	140			127.5
16	J4370000	100	80	110	90	95	200	140	120	100	140			117.5
17	J4510000	30	30	45	40	50	60	60	60	40				46.1111
18	J5000000	40	20	40	40	45	80	60	65	60				50
19	J5850000	40	40	50	70	70	80	90	40	45	80			60.5
20	J5970000													290
21	J6150000													280
22	J6740000	40	40	50	50	45	60	60	50	60	60			51.5
23	J7320000													50
24	J7450000													95
25	J7739550								100					100
26	J7810000													220
27	J7850000													280
28	J7860000													320
29	J7930000													600
30	J8150000													120
31	J8170000													75
32	J8210000													220
33	J8250000													480
34	J8290000													1000
35	J8570000													5200
36	J8670000													140
37	J8690000													37
38	J8700000													60
39	J8720000													115
40	J8770000													1200