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A Framework For Assessing Water Quality, Prioritizing Recovery Potential, And Analyzing Placement Of Best Management Practices

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A FRAMEWORK FOR ASSESSING WATER QUALITY, PRIORITIZING RECOVERY POTENTIAL, AND ANALYZING PLACEMENT OF BEST MANAGEMENT PRACTICES

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ABSTRACT

Motivated by the U.S. EPA goals, this research developed a framework to support identification and restoration of nutrient-impaired water bodies. The study objectives were developing total nitrogen (TN) and total phosphorus (TP) prediction models, evaluating the impact of social indicators on assessing recovery potential, and developing a spatial decision support system for choice and placement of best management practices (BMPs). An artificial neural network was used to develop TN and TP predictive regional models for U.S. lakes using easily measurable and cost-effective variables. The performance of models was superior for regions trained with larger datasets and/or regions with lower temperature and precipitation variability. The use of datasets larger than existing records and obtained from homogeneous climatic region was suggested to achieve the desired performance. The impact of social indicators on assessing a recovery potential was studied by comparing four watersheds using ecological, stressor, and social indicators. Social indicators were grouped into Socio-Economic, Organizational, and Information and Planning subcategories. The existing U.S. EPA Recovery Potential Screening tool prioritizes restoration for a water body with the most favorable ecological and social condition as well as the least stressing factors. In the present study, water bodies ranked lowest were observed with lower social scores associated with lower Socio-Economic conditions. This could mean a manager would take a water body with lower Socio-Economic condition as the lowest priority for restoration. It is suggested that such prioritization plan should carefully incorporate community goals in a prioritization effort because restoration supports an improvement of quality of life. A spatial decision support system was developed with the necessary information to assess nitrogen (N) pollution and methods to estimate an annual exported N load into Beasley Lake, Mississippi. A decision analysis of choice and placement of BMPs was performed based on performance, site suitability, and establishment cost criteria. From this analysis, a BMP scenario that reduces 25% of the exported load at an establishment and an annual opportunity cost-to-performance ratios of 148 $/kg and 29 $/kg, respectively, was developed. The presented approach supports similar efforts when the use of existing watershed models is limited by data availability.

DEDICATION

This work is dedicated to my parents, Animaw Sinshaw and Tsehayneshi Taye, and my wife, Yalemzerf Belete, who have been a constant source of support and encouragements during the challenges of this work.

LIST OF ABBREVIATIONS

A	Area
AD	Atmospheric Deposition
AL	Atmospheric Loss
ANOVA	Analysis of Variance
ARS	Agricultural Research Service
ASE	Average of Squared Error
BLW	Beasley Lake Watershed
BMP	Best Management Practice
CH	Crop Harvest
cm	Centimeter
CP	Conservation Practice
CRP	Conservation Reserve Program
D_a	Drainage Area
DAR	Drainage Area Ratio
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
F	Fertilizer
FL	Fixation by Legumes
FromElev	From Elevation

GIS	Geographical Information System
GW	Ground Water
H	Hidden
ha	Hectare
HN	Hidden Node
HUC	Hydrologic Unit Code
I	Input
IRP	Integrated Recovery Potential
K	Decay Coefficient
Km	kilometer
l	Liter
L	Livestock
LIDAR	Light Detection and Ranging
Log	Logarithm
m	Meter
MARE	Mean Absolute Relative Error
Max	Maximum
MCDA	Multi-Criteria Decision Analysis
MDEQ	Mississippi Department of Environmental Quality
MDMESA	Mississippi Delta Management Systems Evaluation Area
mg	Milligram
Min	Minimum
mm	Millimeter

MS	Mississippi
N	Nitrogen
NADP	National Atmospheric Deposition Program
No.	Number
NTU	Nephelometric Turbidity Unit
O	Output
ºC	Degree Centigrade
ΔP	Precipitation difference
P	Phosphorus
PPM	Parts Per Million
Q	Discharge
QOL	Quality of Life
R	Region
R^2	Coefficient of Determination
RPI	Recovery Potential Index
RPS	Recovery Potential Screening
s	Segment Slope
S	Soil Potential Maximum Retention
SCS	Soil Conservation Service
SDSS	Spatial Decision Support System
SI	Sensitivity Index
SSURGO	Soil Survey Geographic Database
ΔT	Temperature difference

T	Time
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
ToElev	To Elevation
TP	Total Phosphorus
TT	Trapped by Trees
U.S.	United States
USDA	United States Department of Agriculture
USGS	United States Geological Survey
V	Velocity
WQS	Water Quality Standard
Y	Year
µg	Microgram
µs	Micro-Siemens
3D	Three-dimensional

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Nutrient pollution, mainly by excess nitrogen (N) and phosphorus (P), is one of the most common types of water quality problems. N and P are primary nutrients in water required by algae and aquatic plants and are also a source of food and habitat for aquatic organisms. However, the presence of excess N and P in the water leads to excess growth of algae. The decomposition of excess algae can severely reduce the dissolved oxygen in the water and cause eutrophication, which is harmful to fish and aquatic life (Portielje and Van der Molen 1999; U.S. EPA 2017b).

The U.S. EPA identified nutrient pollution as the most widespread water quality problem in the U.S. About 50% of streams and 45% of assessed lakes in the U.S. are identified to be in fair to poor conditions for N and P concentrations (U.S. EPA 2013). Water bodies that do not meet water quality standards or designated use criteria for N and P are listed as nutrient-impaired water bodies under the Clean Water Act Section 303(d). Nutrients are identified as the third general cause of impairments in assessed rivers and streams and the second general cause of impairments in assessed lakes, reservoirs, and ponds (U.S. EPA 2017a).

The Clean Water Act established the regulatory structure for water quality management in the U.S. (Figure 1). This regulatory structure requires states to establish water quality standards first, then the water quality condition of waters has to be assessed, followed by prioritization for total maximum daily load (TMDL) development or restoration, and implementation of restoration action. Currently, the level of assessed water bodies the U.S. is below 50% (Table 1). States and local agencies are making further efforts in order to foster identification and restoration processes.

This Ph.D. dissertation is triggered by the key challenges highlighted by the U.S. EPA related to identification and restoration of impaired waters.

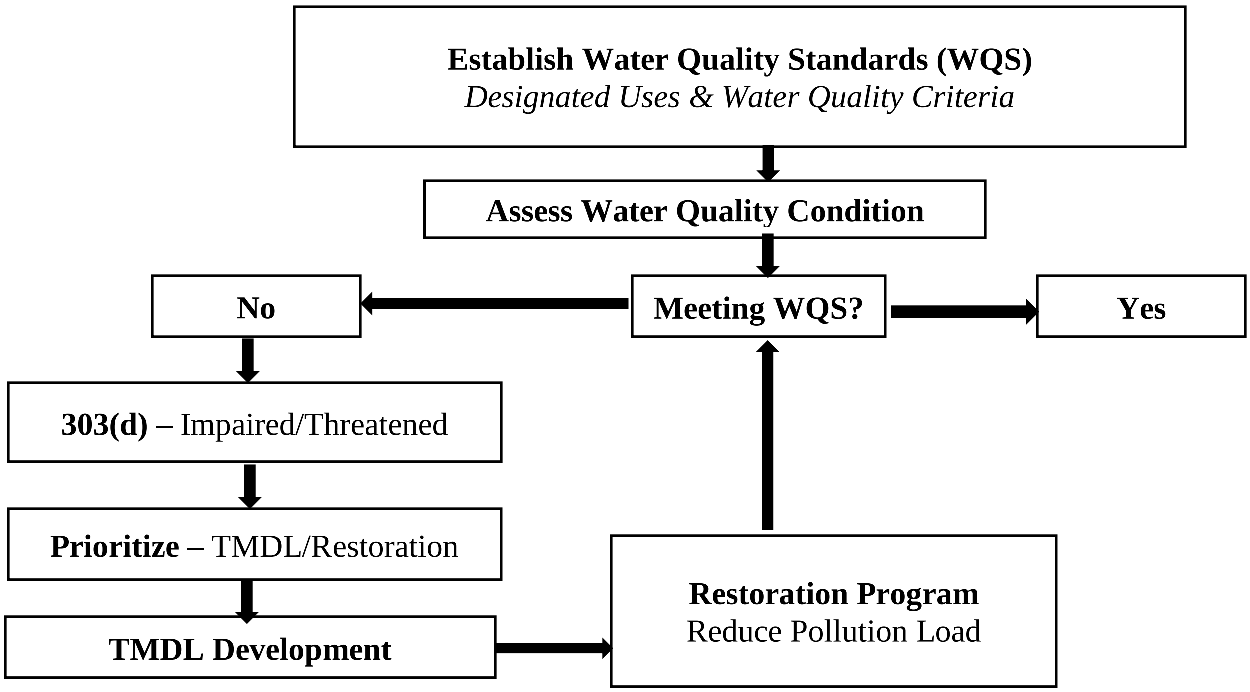

Figure 1. The Clean Water Act regulatory structure for water quality management in the U.S. (U.S. EPA 2016).

Table 1. A summary of assessed waters in the U.S.

	Rivers and Streams (km)	**Lakes, Reservoirs, and Ponds (ha)**	**Bays and Estuaries (ha)**
Total assessed waters	1,789,668	7,621,187	9,089,304
Total waters	5,686,142	16,861,652	22,737,765
Percent of assessed waters	31.5	45.2	40.0

Information summarized in Table 1 is based on water quality data reported by states to EPA under Section 305(b) and 303(d) of the Clean Water Act (U.S. EPA 2017a).

1.2 RESEARCH NEEDS

As described in section 1, addressing nutrient pollution in the U.S. water bodies has become one of the top U.S. EPA priorities. The U.S. EPA and states have developed six goal statements (time plan for completion shown in brackets): prioritization (2016), assessment (2020), protection (2016), alternatives (2018), engagement (2014), and integration (2016) (U.S. EPA 2015). The U.S. EPA strongly encourages further research to develop analysis tools to support these goals. The research goals of this dissertation were aligned with three of the U.S. EPA goals: assessment, prioritization, and alternatives.

There is a strong need for new innovative approaches for sound nutrient assessment strategies using advanced tools. In the present study, an artificial neural network (ANN) was used to develop a nutrient prediction model, a multi-criteria decision analysis was applied to understand the impact of social indicators on assessing a water body recovery potential, and a spatial decision support system developed to guide the choice and placement of nutrient-reducing best management practices (BMPs). The research outcomes from this dissertation provide an alternative tool and approach for assessing and restoring nutrient-impaired water bodies.

1.3 RESEARCH OBJECTIVES

This research was aimed at developing a framework that supports efforts to identify and restore nutrient-impaired water bodies. The primary objectives of this research are listed below:

1. Exploring the possibilities of Total Nitrogen (TN) and Total Phosphorus (TP) prediction from mutually interrelated and cost-effective water quality parameters.
2. Examining the impact of social indicators on assessing the recovery potential of nutrient-impaired water bodies.
3. Developing a spatial decision support system to analyze choice and placement of nitrogen source reducing BMPs.

1.4 RESEARCH SIGNIFICANCE

The significances of this research to administrative agencies and communities is described as follows:

- TN and TP predictions based on mutually interrelated parameters provide a cost-effective monitoring strategy. Further, the application of an artificial neural network for model development improves the accuracy of counterpart prediction models. This will enhance the practicality of models for nutrient monitoring.
- The study outcomes from the impact of social indicators on assessing a recovery potential provide insight for watershed manager on how social indicators can be best considered to support restoration prioritization tasks.
- The GIS-based spatial decision support system model can be used to evaluate several nutrient-reducing BMP scenarios and assists watershed managers to make flexible decision against conflicting criteria.

1.5 ORGANIZATION OF THE DISSERTATION

This dissertation is divided into five chapters. Chapter I discusses the introduction, which describes background and motivation, research needs, research objectives, research significances, and organization of the report.

Chapter II presents the development of an ANN model to predict TN and TP based on cost-effective and easily measurable parameters. The chapter begins with background information about previous efforts, followed by model development processes. Finally, results from optimized regional models and the validation processes are discussed.

Chapter III presents the study of the impact of social indicators on assessing a recovery potential. The chapter begins with an overview of the U.S. EPA Recovery Potential Screening tool and its application to four water bodies is presented. Then, scoring methods and what if analysis are explained. Finally, results from the what if analysis are discussed.

Chapter IV presents the application a spatial decision system (SDSS) for evaluating choice and placement of BMPs. The chapter begins with an overview of the process of developing a SDSS applied to the Beasley Lake Watershed, followed by strategies to map feasible BMP alternatives to reduce N load from sources.

Chapter V includes concluding remarks, limitations, and suggestions for further studies.

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CHAPTER II

APPLICATION OF ARTIFICIAL NEURAL NETWORKS FOR PREDICTION OF TOTAL NITROGEN AND TOTAL PHOSPHORUS IN U.S. LAKES

ABSTRACT

Modeling is an important aspect of water quality management because it saves material and labor costs. The non-linearity of water quality variables due to the complex chemical and physical processes in a body of water makes the modeling process difficult. Here, an artificial neural network (ANN) approach was used to develop a model that estimates the summer concentration of total nitrogen (TN) and total phosphorus (TP) in U.S. lakes using interrelated and easily measurable water quality parameters. Two ANN models, using regional and national datasets, and one linear regression model were trained, validated, and tested using three inputs (pH, conductivity, and turbidity) that are statistically correlated to the outputs. The prediction accuracy of the ANN models consistently outperformed the linear regression model. The statistical accuracy of the ANN models for regional datasets was superior to that of the national dataset. A sensitivity analysis showed that pH was the most predictive parameter for nutrients. These results indicate that the use of the ANN modeling technique can provide an alternative tool for estimating nutrient concentrations in lakes.

2.1 INTRODUCTION

Water quality monitoring is a process of collecting, measuring, and analyzing water samples to understand the physical, chemical, and biological condition of a water body. The testing procedures and methods used for examination of water quality vary for physical, chemical and biological characteristics of water. The assessment of water quality parameters, such as fecal coliform bacteria, total nitrogen (TN), and total phosphorus (TP), usually requires intensive testing procedures of sampling, laboratory processing, and analyzing of results. Some other parameters, such as pH, turbidity, conductivity, and dissolved oxygen, can be easily measured in-situ using field sensors (U.S. EPA 2016a).

TN and TP are the two primary nutrients causing undesired eutrophication in lake water (Portielje and Van der Molen 1999; U.S. EPA 2016e). Routine monitoring of TN and TP is often required to assess the trophic level of a lake. However, the complexity of the biophysical and chemical processes in lake water make TN and TP laboratory testing difficult (Kosten et al. 2009; Varol 2013; Hatvani et al. 2015). Forms of nitrogen and phosphorus are measured using several laboratory methods, such as colorimetry, manual distillation, and ion chromatography (U.S. EPA 2018a). One common laboratory challenge is that nutrient tests should be conducted as soon as the sample is collected because as the sample sits longer, organisms living in the water will consume nutrients, and, consequently, the concentrations in the sample water will be modified. A second common challenge is that laboratory procedures require measuring all the various forms of nitrogen (N) and phosphorus (P) separately. The results of all the various forms under each group have to be combined to determine TN and TP. For example, N can be found in water in a variety of forms, such as nitrate, nitrite, ammonia, and organic N. The concentration of TN can be measured by converting all N forms to nitrate equivalent and then adding them together (APHA 1995). These procedures are difficult and time-consuming.

The use of a prediction model provides an alternative method for water quality monitoring. Water quality models are advantageous over the experimental methods when they save time and material and labor costs. Models can also support assessment when onsite experiments are inconvenient. Several water quality models have been developed for estimation of N and P concentrations. Jones et al. (2001) used landscape metrics to predict nutrient and sediment yield in streams. Zelenakova et al. (2013) developed a dimensional analysis model to predict N and P concentration in a river using parameters of discharge, catchment area, and velocity and temperature of the stream water. Milstead et al. (2013) integrated the U.S. Geological Survey Spatially Referenced Regressions on Watershed (SPARROW) attributes model and Vollenweider equations to predict TN and TP concentrations in lakes based on nutrient loads and residence. These models used different theories and algorithms, developed with different model parameters, and vary in scope and applicability. The suitability of these models depends on the availability of data and the complexity of the situation.

The performance of the majority of water quality models is weak in practice due to the difficulty of mathematically representing the complex inland water system and the appropriateness of input variables. This challenge is repeatedly mentioned in the literature. Stow et al. (2003) demonstrated the low prediction accuracy of three models: a Neuse Estuary Eutrophication Model, a Water Analysis Simulation Program, and a Neuse Estuary Bayesian Ecological Response

Network while developing a total maximum daily load (TMDL) estimation. Another illustration of low accuracy is shown by Rode et al. (2010), who noticed challenges of mathematical representation of in-stream biogeochemical processes and landscapes in an integrated water quality model and the associated high model uncertainties. Boomer et al. (2013) also discussed uncertainties in the prediction of flow, N, and P discharges while analyzing an ensemble of watershed models (the accuracy of six models was examined for prediction of N and P discharges to the river). The model predictions showed no consistency to the observations of the average annual, annual time series, and monthly discharge leaving the three studied basins. It is clear from the reviewed papers that further effort is needed to better account for model uncertainties.

This study considers that the integration of field sample collection, laboratory analysis, and modeling approaches provides a convenient water quality estimation technique. A prediction model for summer TN and TP in U.S. lakes was developed using cost-effective and easily measurable parameters. A feed-forward back-propagation artificial neural network (ANN) was used to develop the desired model.

2.2 BACKGROUND

2.2.1 Basics of Artificial Neural Network

ANNs are mathematical models that are built to mimic the neural structure of a human brain (Haykin 1999). ANNs are useful in estimating functions or patterns through their learning ability from a large body of datasets. For this reason, creating a robust ANN model requires a big-data framework that is sufficient for dividing into subsets for training, testing, and cross-validation purposes. Generally, the bigger the database, the better will be the generalizing ability of the model. The available data is divided into these subsets either randomly (unsupervised methods) or using the user's specific rules (supervised methods) (Maier et al. 2010). The development of an ANN model involves the choice of network variables, determining the network structure, the choice of performance criteria, and network training-testing-validation procedures. Network variables are first determined based on the availability of data. The candidate variables are further screened based on the significant relationship between the input and output variables. The input-output relationships can be examined using model-free or model-based techniques (Wu et al. 2014). Model-free techniques are based on the availability of data, the use of domain knowledge, or correlation analysis; whereas model-based techniques include the use of trial and error or sensitivity analysis methods, such as by training the model and testing if the input is a potential predictor to the output.

The structure of ANNs is formed from neurons (processing units), which are analogous to biological neurons, and the connection weights between them. There are many types of neural networks, such as feed-forward back-propagation, radial basis function, recurrent, and modular neural networks (Sibanda and Pretorius 2012). These neural networks vary in structure and information flow, but all have neurons and connection weights. The feed-forward back-propagation neural network is a widely used architecture in most of the literature cited in this paper (Jones et al. 2001; Khalil et al. 2011; Gazzaz et al. 2012; Olawoyin et al. 2013; Anmala et al. 2015). A review of papers on the applications of ANN in the field of environment and water resources also showed that 66 out of the 97 studies used a feed-forward back-propagation neural network technique (Wu et al. 2014). The feed-forward back-propagation network consisted of an input layer, at least one hidden layer, and an output layer. An input layer consists of input nodes that receive raw information and feed the network. Input nodes are independent variables that collectively affect the value of the output parameters. The information collected at the input nodes should sufficiently represent the condition of the problem domain. An output layer comprises output nodes that represent the response of the network to the given conditions of inputs. A hidden layer connects the input and output layers, and its activity depends on the activities of the input layer and connection weights. A decision on the number of hidden layers and the number of hidden nodes is an important aspect of a neural network design process because it significantly affects the final output. For many practical problems, it is reasonable to use one hidden layer, as shown in the literature cited in this review (Khalil et al. 2011; Wu et al. 2015). The input, hidden, and output layer nodes are interconnected by adjustable connection weights to recognize different patterns of information.

The training-testing-validation process involves determining network parameters, such as connection weights, threshold values, and an optimum number of hidden nodes. ANN models are built on an activation function that responds to a given input of stimulus. The activation function is designed distinctly to substitute the natural neuron activation. A feed-forward neural network commonly uses a back propagation algorithm (Rumelhart and McClelland 1986). Its activation function is sigmoidal, where an output varies hyperbolically to changes in inputs (Haykin 1999). The neurons are organized to pass signals in the forward flow, and the error propagates back to adjust the connection weights and threshold values. The training process in the feed-forward pass begins by feeding data to the network. Connection weights are randomly assigned during the initial feed-forward pass. The data in the first layer gets summed and enters into the second layer nodes. The output from the second layer nodes gets summed to the next layer of nodes. This information pass continues to the final output layer node. The back-propagation uses a supervised learning algorithm, which the network uses to map the input with the desired output. Once the first output is obtained, the error is mapped as the difference between the network predicted output and the desired output. The training process continues to the back pass to adjust the weights based on the calculated error. The feed-forward and back-propagation processes continue until the error is minimized. Once the optimum network is developed, the model's ability to produce accurate and reliable predictions needs to be validated. This process is essential to evaluate whether the model produces acceptable predictions. One common way of validation is by testing the model response with data outside of the training set. Another method of validation is by comparing the prediction of the current model with the prediction from other existing traditional models, such as linear regression models. A sensitivity analysis is also another method of validation to understand the model performance by changing the input variables if their relationship to each other and the output(s) is known. The use of the three validation methods helps to verify the reliability of the model.

Statistical accuracy measures, such as the average of squared error (ASE) (Equation 1), the mean absolute relative error (MARE) (Equation 2), and the coefficient of determination (R^2) are commonly used performance evaluation criteria in statistical modeling. These statistical measures examine the model's generalizing abilities during the training process by evaluating the level of agreement between the observed outcomes and the predicted values. ASE is a significant measure of the error. It is one way of indicating how close the set of data points is to the fitting line. The smaller the ASE value, the closer the predicted value is to the observed value. MARE is used to measure how close the forecast or prediction is to the predicted outcome. The smaller the MARE value, the higher is the level of agreement between the predicted and the observed value. R^2 is the measure of model's goodness of fit. It indicates how much the variance in the data is illustrated by the fit. The R^2 values range from 0 to 1, with 1 indicating the model is perfect.

$$\mathrm{ASE} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{n}({Y_{ij}}^{p} - {Y_{ij}}^{o})^2}{(N)(n)} \qquad \text{(Equation 1)}$$

$$\mathrm{MARE} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{n}\left|\frac{{Y_{ij}}^{p} - {Y_{ij}}^{o}}{{Y_{ij}}^{o}}\right|}{(N)(n)} \qquad \text{(Equation 2)}$$

Where for variable the Y, Y^p is the predicted output, Y^o is the observed output, N is the number of datasets, and n is the number of outputs.

2.2.2 Artificial Neural Networks in the Environmental Field

ANNs can be applied to solve a wide range of problems in many domains, including the environment. Environmental problems, such as watershed water quality, are complex systems that are often ill-defined (Wu et al. 2015). Artificial neural networks techniques are an efficient method to understand these complexities through the capability to generalize patterns and trends from a given database.

For example, previous studies on the application of ANNs to real-world water quality problems include predictions of water quality index (WQI), pattern classifications, and developing protocols and methods for the application of ANNs in the field of water resources. A WQI is the description and quantification of a wide range of physical, chemical, and biological parameters. An example of WQI prediction is shown by Anmala et al. (2015). A wide variety of water quality variables was found to be dependent on hydrologic and land-use data. The relationship between 13 water quality parameters, hydrologic data, and land-use data was established using a GIS-based feed-forward back-propagation neural network. Gazzaz et al. (2012) used ANN to determine the six most relevant parameters (among 23) as the primary factors for estimating WQI. A prediction model was created for WQI characterization using the reduced number of variables. This study illustrated the potentials of ANN in minimizing the computation efforts. The ANN was used to predict the water quality at ungauged stations using data from gauged sites (Khalil et al. 2011). Thirteen water quality variables were used for model development. This study demonstrated the capacity of ANN in modeling spatial relations.

Environmental systems, such as soil, air, and water are vulnerable to contaminants from a wide variety of anthropogenic and natural sources. Pollution risk management needs comprehensive information to assist in prioritizing mitigation and remediation activities. ANNs were used effectively for pollution risk assessment. Olawoyin et al. (2013) provide a good example of an ANN application in identifying and characterizing pollution risks. A self-organizing map (SOM), an ANN based mathematical model, was used to categorize the soil, water, and sedimen contamination risk levels to petrochemical pollutants. Several physicochemical variables were used to understand the crude soil dispersion processes in water, soil, and sediments. The ANN model was demonstrated as a powerful tool to classify the local trends of contamination. A similar study by Wu et al. (2015) successfully used SOMs to understand the seasonal climatological change and anthropogenic effects on the water quality. This study is a good example of ANN modeling to recognize spatial and temporal water quality trends. Keskin et al. (2015) also employed ANN to detect sources of groundwater contaminants. Fourteen water chemistry parameters from several possible contamination sources were used to classify water susceptibility to contaminants. The results of the contamination source classification demonstrated that the ANN model performed better than other methods. The importance of ANN modeling in water quality management is shown by the increasing number of such studies. This also led to the establishment of methods and protocols for developing ANN-based models in the water quality and environmental fields (Maier et al. 2010; Wu et al. 2014).

In this study, a feed-forward back-propagation ANN was used to create a prediction model for TN and TP in U.S. lakes. As was noted before, the practicality of existing water quality models is low due to the complex chemical and physical processes in a body of water. These processes induce a non-linear relationship between nutrients and indicator parameters. ANN models are non-linear models convenient for predicting this complex relationship.

2.3 METHODOLOGY

2.3.1 Description of Training Datasets

A record of 1217 datasets sampled from approximately 1,000 U.S. lakes, representing 49,546 lakes (29,308 natural and 20,238 man-made), were downloaded from the U.S. EPA National Aquatic Resource Surveys (NARS). The datasets represent the 2007 measured values of chemical, physical, and biological water quality parameters monitored by the National Lakes Assessment (NLA) program. The sampled water bodies consist of lakes, ponds, and reservoirs of sizes larger than 4 hectares, at least 1 meter deep, and with a minimum of 0.1 hectares of open water (Figure 2).

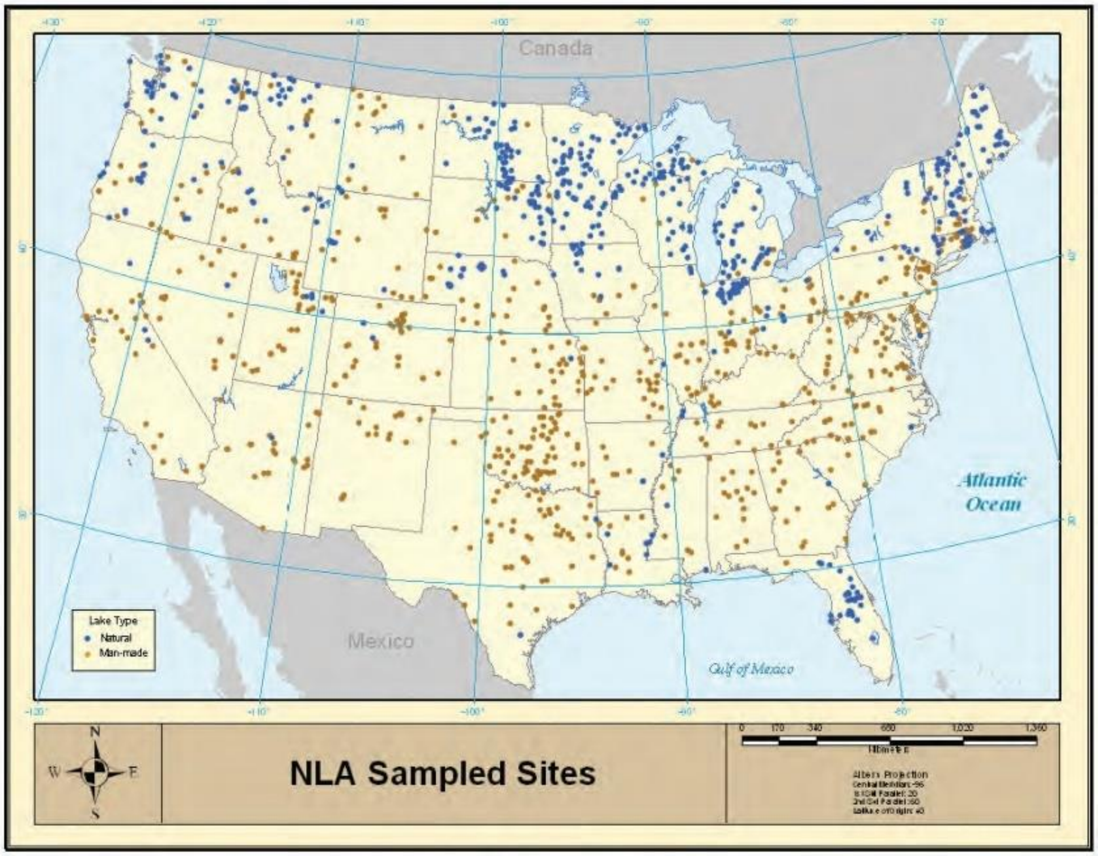

Figure 2. Lake monitoring sites of the U.S. EPA-NARS (reprinted from U.S. EPA, 2013). The blue dots represent the natural lakes, and the brown dots indicate the man-made reservoirs.

2.3.2 Choice of Network Input Variables

This study assumed that the physical, chemical, and biological characteristics of water are interrelated. For this purpose, all water quality parameters present in the database in large numbers were treated as candidate network input variables. The proposed network variables were further screened using two criteria: (1) variables that are statistically correlated to the output parameters (TN and TP) and (2) variables that have a relatively easier testing procedure than the output parameters. For the first criterion, a preliminary analysis of the available datasets was performed by running a correlation test in Microsoft Excel to obtain the Pearson correlation coefficient (R) between all variables. The correlation coefficient provided the linear association between the output and the proposed variables. An input variable was assumed to be strongly correlated to the outputs if the R value was greater than or equal to 0.28. This screening analysis was applied to all the datasets for the year 2007. But when the datasets were separated by season, the summer season data best fulfilled the screening criteria and was therefore used as the training dataset for the proposed model. Additional descriptive statistics were performed for input and output variables using Microsoft Excel. Cross-plots of input and output variables were developed using the statistical software R to demonstrate the distribution of the collected datasets. For the second criterion, the existing U.S. EPA testing procedures were reviewed to identify easily measurable variables among those significantly correlated with the output variables.

2.3.3 Data Normalization

The raw values of the network variables were normalized to create a comparable range suitable for the activation function. This was done using a linear transformation using Equation 3.

$$X_n = \frac{X_R - X_{MIN}}{X_{MAX} - X_{MIN}} \quad \text{(Equation 3)}$$

Where for a parameter X, X_n is the normalized value, X_r is the raw value, and X_{min} and X_{max} are the minimum and maximum observed values of X, respectively.

2.3.4 Development of the ANN Model

2.3.4 .1 Structure of the ANN Model

The proposed model is based on a feed-forward back-propagation neural network structure training using TR-SEQ1 software developed by Najjar (1999). Constructing a feed-forward back-propagation network involves determining the input layer, output layer, hidden layer(s), and connection weights. Because the purpose of the ANN model developed in this study was to perform prediction, the number of nodes in the input and output layer was matched with the number of selected input variables and the number of parameters to be predicted, respectively. The number of hidden nodes was determined based on a trial and error technique. This was made by initially training and testing the network with a small number of hidden nodes. Then, the number of hidden nodes was continuously increased to a point where the overall performance of training and testing was improved. The magnitudes of connection weights were determined in the process of training.

2.3.4.2 Setting the number of hidden nodes

The initial maximum number of hidden nodes that likely indicates the limit where the best performance of training and testing will be obtained was estimated based on Equation 4 (Najjar 1999).

$$HN_{Max} = \frac{1}{c}\left(\frac{Number\ of\ training\ datasets - Number\ of\ output\ variables}{Number\ of\ input\ variables + Number\ of\ \ output\ variables + 1}\right) \qquad \text{(Equation 4)}$$

Here, c is the adjustment factor that represents the number of datasets assigned for each set of connection during the training process.

Previous experiences have shown that the best network is typically obtained within a hidden node range of 2 to 15 (Najjar et al. 1996, Najjar 1999, Itani and Najjar 2000, Najjar and Haung 2007). The estimated maximum numbers of hidden nodes were also adjusted to the recommended range.

2.3.4.3 Data Splitting

The recorded datasets at the U.S. national level were separated into U.S. EPA region levels (smaller geographical units) to optimize the performance of the model. The quality and quantity of environmental resources within each U.S. EPA region is similar. Therefore, the datasets within each region were clustered to create relatively homogeneous data categories, named here as regional datasets. To fulfill the data requirements of the training-testing-validation process, the datasets of each category (national and regional) were split to 55% for training, 23% for testing, and 22% for validation.

2.3.4.4 Training of the ANN Model

The network was trained using the TR-SEQ1 program, which was built on the back-propagation algorithm (Najjar 1999). This program enables the user to perform training and testing simultaneously. Each block of datasets, the regional and the national, were trained on hidden nodes from 1 to 10, sequentially. The training process was performed by feeding the network with training (55%) and testing (22%) datasets, then validating with 22% of the datasets to assess the performance of the developed models. Once the best performing model with its hidden nodes was identified, all datasets (100%) were fed to the model to obtain the most reliable model. In this case, the model was able to slightly adjust its connection weights to account for all the patterns in the full database. The best performing networks were selected based on the criteria of minimum ASE, minimum MARE, and maximum R^2, in this order of priority.

The learning processes were performed by the following equations.

The input activation function of a back-propagation algorithm for inputs X_i and their respective weight W_{ij} is represented by Equation 5.

$$A_j(X,W) = \sum_{i=0}^{n} X_i W_{ij} \qquad \text{(Equation 5)}$$

The output activation (O_j) of a back-propagation algorithm mathematically expressed in Equation 6.

$$O_j(X,W) = \frac{1}{1+e^{A(X,W)}} \qquad \text{(Equation 6)}$$

The error function in the back propagation algorithm is based on mean squared error. The error (E_j) is defined as the difference between the computed output (O_i) and the desired output (d_i), as shown in Equation 7.

$$E_j(X, W, d) = (O_j(X, W) - d_j)^2 \qquad \text{(Equation 7)}$$

The network error is calculated as the error of all neurons using Equation 8.

$$E_j(X, W, d) = \sum_j (O_j(X, W) - d_j)^2 \qquad \text{(Equation 8)}$$

The back-propagation algorithm then calculates how the error depends on the input, weight, and output. Then, weights are adjusted by a gradient descendent method. The adjustment of each weight (ΔW_{ji}) is the negative of a constant eta *(*η*)* multiplied by the dependence of the previous weight on the error of the network ($\frac{\partial E}{\partial W_j}$), as shown in Equation 9.

$$\Delta W_{ji} = -\eta \frac{\partial E}{\partial W_j} \qquad \text{(Equation 9)}$$

A good introduction on the equation used for training with a backpropagation algorithms can be found in Haykin (1998).

2.3.5 Development of Linear Regression Model

To compare the prediction ability of ANN models to regression models, linear regression models were developed, as shown in Equation 10.

$$Y = a_0 + \sum_{i=1}^{N} a_i X_i \qquad \text{(Equation 1)}$$

Where Y is the dependent variable (TN and TP concentrations), a_o is the intercept, N is the number of independent variables, a_i is the coefficient of the independent variable, and X_i is an independent variable.

2.3.6 Sensitivity Analysis

A sensitivity analysis was carried out to evaluate how the output parameters responded when the input variables varied around their average values. The input variables were subjected to variability in a range of -10% to +10% of the average measured values. Each of the model input variables was tested at one time by keeping the others at their average values. Further, the relative significance of these input variables was ranked based on a sensitivity index. A sensitivity index gives information on the relative sensitivity of output variables to the different model inputs. A simple index was used, as shown in Equation 11.

$$SI = \left(\frac{\hat{Y}_i}{\bar{Y}} - 1\right) * 100 \qquad \text{(Equation 2)}$$

Where SI is the sensitivity index, $\hat{Y}_i$ is the predicted output parameter value when input variables varied, and $\bar{Y}$ is the average output parameter value.

2.3.7 Excel Application

A predictive Excel application was developed for each regional network using connection weights and threshold values of the best performing networks (Figure 3). In this Excel interface, by entering the values of pH, conductivity, and turbidity, TN and TP can be calculated automatically. A controlling combo box was developed to allow selection of a region of interest. The applicable ranges for the input variables will be displayed automatically upon selecting a region of interest. Any value of input variable that is outside of the applicable range may cause the model to produce unreliable predictions. Further instruction on the use of the Excel application was provided in the Excel file.

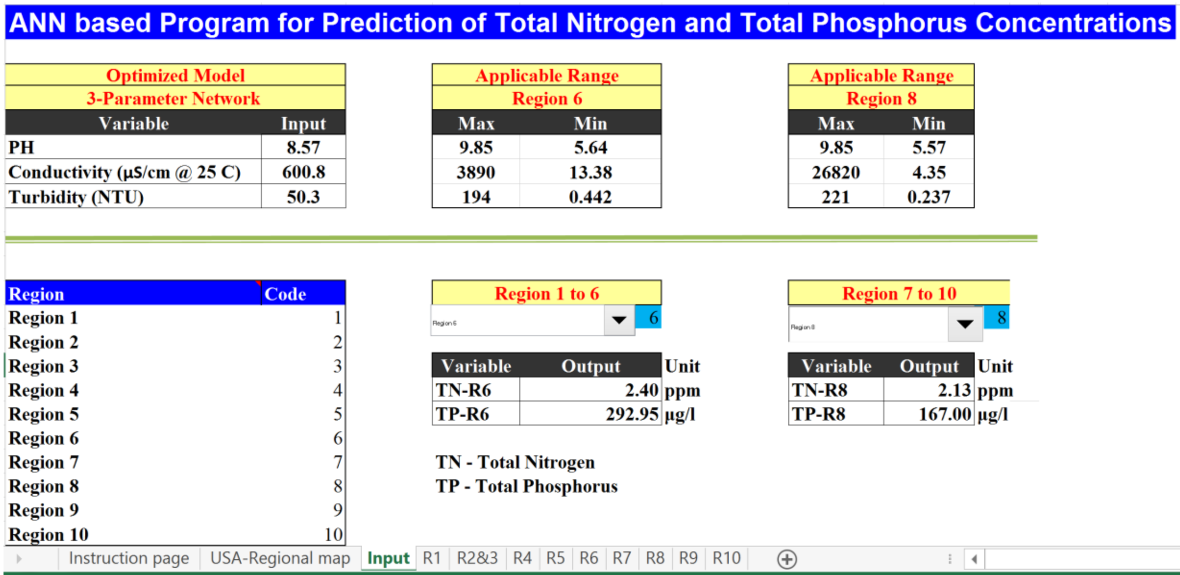

Figure 3. A screenshot of the Excel application of regional networks.

2.4 RESULTS AND DISCUSSION

2.4.1 Results from the Choice of Network Input Variables

The results of the preliminary statistical analysis of available datasets are discussed in this section. The correlation coefficient matrix, the descriptive statistics, and the cross plots of log-transformed training datasets for selected network variables are presented in Table 2, Table 3, and Figure *4*, respectively. Based on the specified criteria in the methodology section, pH, conductivity, and turbidity were selected as network input variables, which were statistically correlated to outputs for the summer season dataset with R value ≥ 0.28. The pH is an important indicator for the presence of nutrients because it affects many chemical and biological processes in water. The correlation analysis results between pH and output parameters were also in close agreement. Conductivity in water indicates the presence of dissolved salts and inorganic materials, such as chlorides, nitrates, sulfates, phosphates, sodium, magnesium, calcium, iron, and aluminum ions. Conductivity was also significantly correlated with output parameters. Turbidity was selected as an important indicator for output parameters because a higher nutrient load is likely associated with a higher turbidity **(**USGS 2016 and U.S. EPA 2016c). These inputs are measurable with electronic sensors in the field with direct immersion in water (U.S. EPA 2016e). The use of field sensors is an inexpensive way of testing when compared to laboratory analysis.

Table 2. Correlation coefficient (R) matrix of selected network variables.

	Input variables			Output variables	
	pH	**Conductivity**	**Turbidity**	**TN**	**TP**
pH	1.00				
Conductivity	0.23	1.00			
Turbidity	0.18	0.03	1.00		
TN	0.35	0.40	0.44	1.00	
TP	0.28	0.45	0.37	0.50	1.00

Table 3. Descriptive statistics of selected network variables.

	pH	**Conductivity** (µS/cm @ 25ºC)	**Turbidity** (NTU)	**TN** (mg/l)	**TP** (µg/l)
Maximum	10	36,000	570	26	4,900
Minimum	4.2	4.4	0.2	0.01	0
Average	7.9	480	7.1	0.76	48
Standard Deviation	0.76	1,700	21	1.1	170

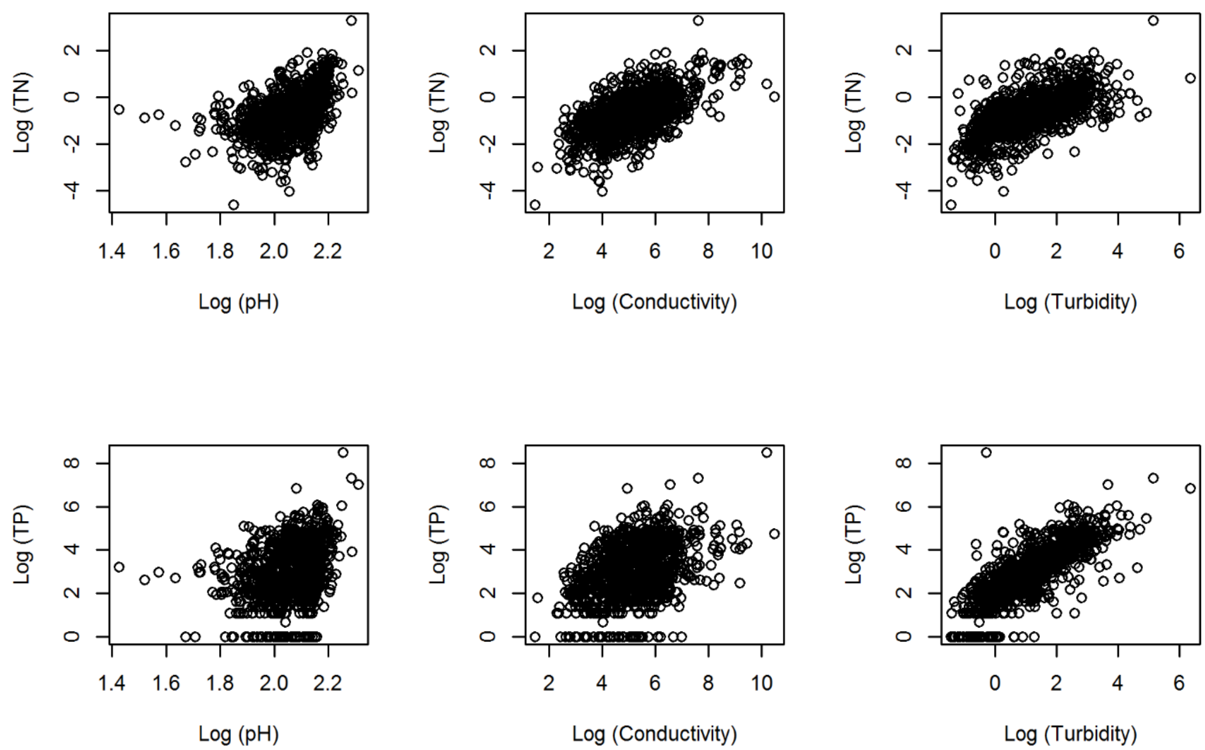

Figure 4. Log-distributions of training datasets. TP is total phosphorus; TN is total nitrogen (data from U.S. EPA 2013).

2.4.2 Results from the ANN Model

The proposed feed-forward back-propagation ANN structure for the present study is presented in Figure 5, which connects the input and output layers with one hidden layer. The nodes in the input layer are the network input variables: pH, conductivity, and turbidity. The nodes in the output layer are the output variables: TN and TP. The optimum number of hidden nodes and connection weights (W) was determined during the training process.

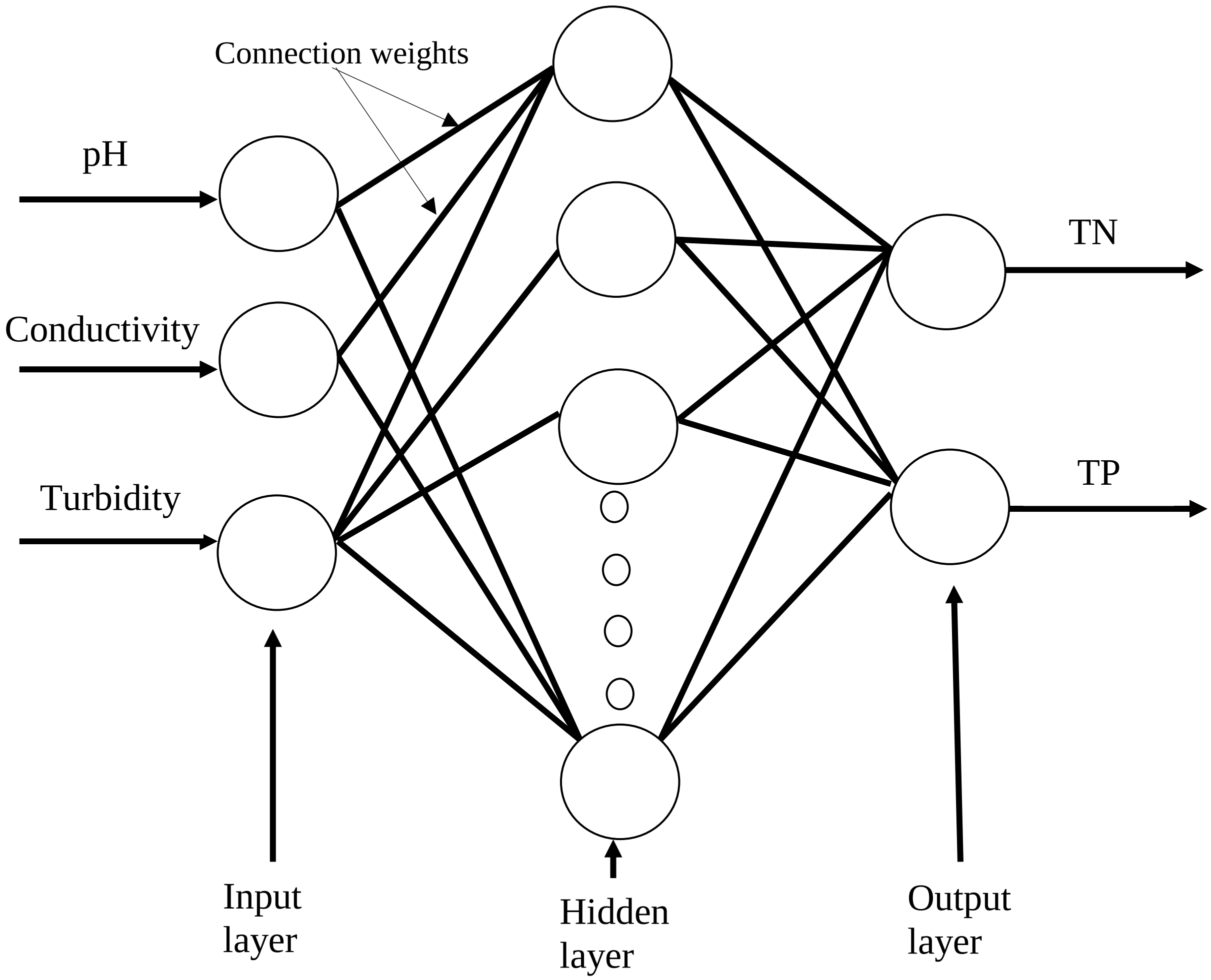

Figure 5. The structure of a feed-forward back-propagation neural network for pH, conductivity, and turbidity nodes in the input layer, and TP and TN nodes in the output layer.

The available datasets used for training the feed-forward back-propagation neural networks were classified into two categories. The first category consisted of the entire U.S. dataset and the second category was comprised of datasets for the ten U.S. EPA regions (Figure 6). Using these categories of datasets, two neural networks were fully developed and optimized: the regional and the national datasets-based models. Overall statistical accuracy measures for all the models are summarized in Table 3. The number of training datasets used for regional models varied between

25 and 258 for Region 2 and Region 5, respectively. Regions 2 and 3 were combined to provide sufficient datasets for training.

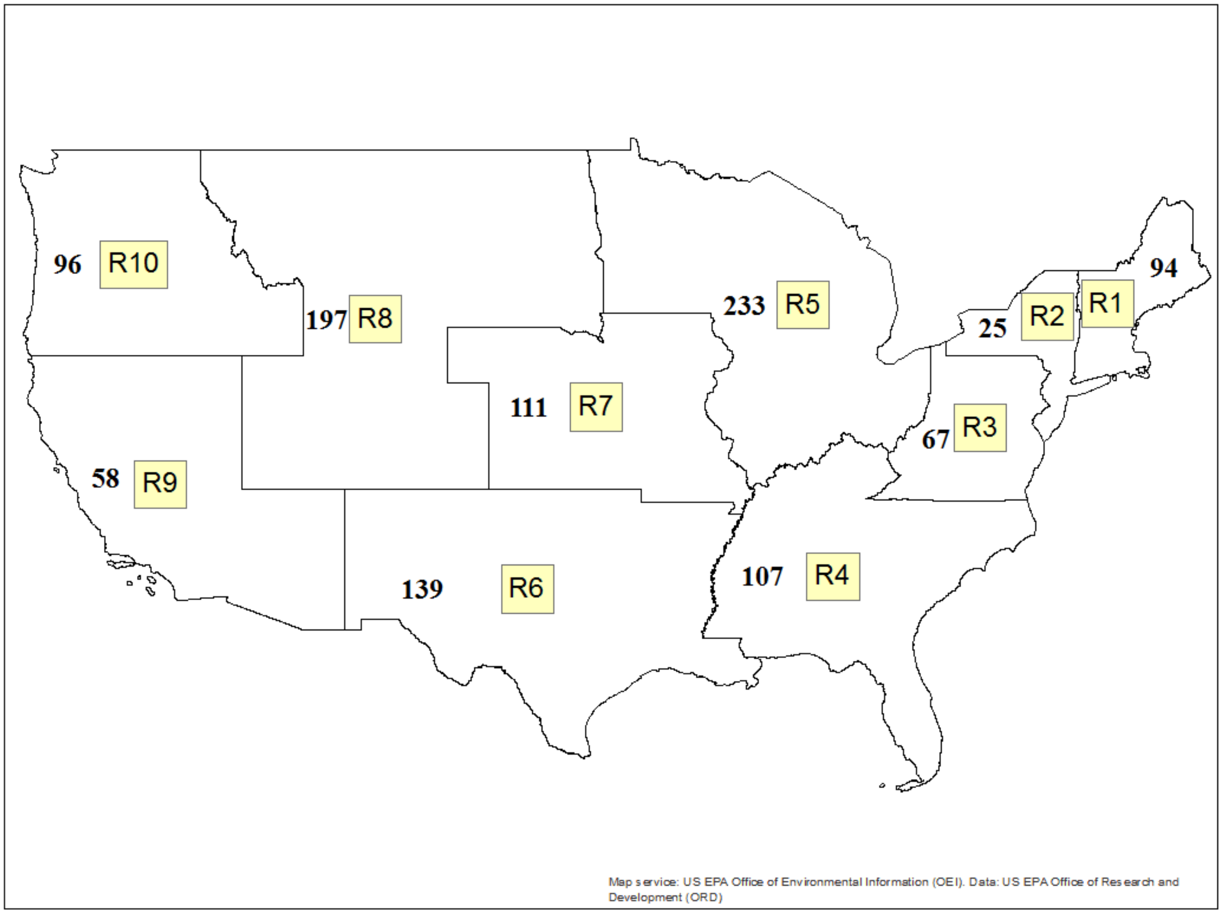

Figure 6. U.S. EPA regional map (modified from U.S. EPA 2016f). R represents the U.S. EPA region and numbers in each region indicate the size of datasets.

The optimized model parameters are described in Table 4 were between 5 and 10, except for the Region 2 + Region 3 and Region 10 data categories. This implied that the network performance was better at a higher number of hidden nodes, as large numbers of hidden nodes give a higher degree of freedom during the network training.

The optimum numbers of iterations, which are the number of adjustments made on the connection weights to a point where a network performance approximately matches the target precision, were varied from 100 to 20,000. The maximum number of iterations was preset to 20,000. About 50% of the best networks for each category were obtained at 20,000 iterations.

On testing, the accuracy measures for the optimized regional networks varied from 0.00011 to 0.00140 for ASE, from 99.0 to 192.1 for MARE, and from 0.22 to 0.73 for R^2. On training all, the accuracy measures varied from 0.00025 to 0.00456 for ASE, from 75.36 to 176.48 for MARE, and from 0. 41 to 0.94 for R^2. The accuracy measures for the optimized ANN model of the national data were ASE = 0.00094, MARE = 155.5, and R^2 = 0.41 on testing, and ASE = 0.00017, MARE = 102.14, and R^2 = 0.88 on training all.

According to the ASE and MARE, the performance of nine out of the ten regional ANN models was better than the national. The corresponding R^2 values for the two categories of models were also in close agreement with the ASE and MARE results. This is because of the relatively higher degree of environmental homogeneity within the regional categories compared to the combined national network. This implies that the complexity of mapping the nonlinear relationship between water quality parameters can be simplified with the use of training data from lower level geographical units, which have a relatively higher environmental homogeneity.

Table 4. Optimized model parameters for national and regional networks.

				Testing			Training All		
	No. of Datasets	Network (I-H-O)*	Optimum Iteration	ASE	MARE	R^2	ASE	MARE	R^2
Regional Networks									
R1	94	3-7-2	20000	0.00073	121.4	0.61	0.00031	139.5	0.68
R2 + R3	92	3-2-2	18100	0.00036	125.0	0.33	0.00074	141.5	0.94
R4	107	3-7-2	20000	0.00073	121.4	0.61	0.00063	130.2	0.94
R5	233	3-8-2	20000	0.00017	125.6	0.56	0.00025	117.3	0.94
R6	139	3-9-2	900	0.00144	153.1	0.73	0.00456	75.36	0.41
R7	111	3-8-2	1900	0.00030	99.0	0.72	0.00030	116.6	0.95
R8	197	3-9-2	2900	0.00021	144.8	0.60	0.00027	115.5	0.94
R9	58	3-5-2	20000	0.00059	107.5	0.62	0.00105	114.4	0.55
R10	96	3-3-2	100	0.00011	192.1	0.22	0.00366	176.48	0.58
National Network									
National	1127	3-9-2	20000	0.00094	155.5	0.41	0.00017	102.14	0.88

*I-H-O represents the numbers of input nodes – the numbers of hidden nodes – the numbers of outputs, respectively.

According to the ASE results on testing, the Region 10, Region 5, and Region 8 networks were the three most statistically accurate models. The Region 6 network was the lowest performing model. One reason for the networks' performance difference was the number of datasets. In general, the model learns better when trained with larger datasets. The highest performing networks were trained with the highest number of training datasets when compared to other regions, which were 233 for Region 5 and 197 for Region 8 (186% and 157% of the average number of regional datasets, respectively). This indicated that the ANN model's generalizing ability in predicting water quality was superior at a higher number of training datasets. However, the performance of the Region 6 and Region 9 models is not consistent with the conclusion that a higher number of training datasets results in a higher network performance. The Region 9 network, trained with the smallest number of datasets (66), performed better than other regions trained with a larger number of datasets. Region 6, trained with 139 datasets, was the lowest performing network.

To understand more of what influenced the accuracy of the models, four regional characteristics were defined and examined: total area, water area, summer temperature, and summer precipitation (Table 5). The regions were trained with a different number of datasets. The land and water areas were used to determine if the number of training datasets weighted with area affect the performance of the regional networks. For this purpose, the land area and the water area originally recorded at the state level were aggregated to a regional total, and a factor was calculated. The total area factor was calculated as the total area of water and land per dataset. The water area factor was similarly calculated as the total area of water per dataset (Table 6). These two characteristics provided a general idea of the relative number of training datasets within a given total land or water area. A higher area factor means a smaller number of training datasets.

The temperature (ΔT) and precipitation (ΔP) factors were used to examine if the regional climatic difference influenced the performance of the regional networks. The climate factors were calculated from a 30-year average of summer temperature and precipitation data. The maximum (Max) and minimum (Min) values represented the highest and lowest selected records for states within a given region. The ΔT and ΔP factors were calculated as simply the difference between the maximum and minimum records of a given region.

Table 5. Regional variability characteristics of the summer season datasets.

		Area		**Temperature (°C)**		**Precipitation (mm)**	
Region	**Number of Datasets**	**Total Area (km^2)**	**Water Area (km^2)**	**Max**	**Min**	**Max**	**Min**
R1	94	186,446	24,084	20.7	17.6	107	91
R2 + R3	92	495,287	43,576	23.4	19.2	111	99
R4	107	1,021,557	68,165	27.2	23.6	181	106
R5	233	1,005,708	170,359	23.0	19.0	105	84
R6	139	1,465,006	49,929	27.3	21.9	125	52
R7	111	739,715	6,280	24.7	22.0	111	79
R8	197	1,506,488	17,877	21.1	17.5	69	22
R9	58	1,005,581	23,577	25.1	20.6	35	7
R10	96	655,904	21,132	17.7	17.6	33	22

Sources: reprinted from Current Results (2017) and U.S. Census Bureau (2012).

Table 6. Regional variability factors.

Region	Total Area Factor	Water Area Factor	ΔT Factor	ΔP Factor	Performance
	Total Area/#Datasets	Water Area/#Datasets	ΔT (Max-Min)	ΔP (Max-Min)	ASE_{test}
R1	1,983	256	3.1	16	0.00073
R2 + R3	5,384	474	4.2	12	0.00036
R4	9,547	637	3.6	75	0.00073
R5	4,316	731	4.0	21	0.00017
R6	10,540	359	5.4	73	0.00144
R7	6,664	57	2.7	32	0.00030
R8	7,647	91	3.6	47	0.00021
R9	17,338	407	4.5	28	0.00059
R10	6,832	220	0.1	11	0.00011

The other reasons that affected the performance, other than the number of datasets, were climatic factors related to water quality. The calculated average summer season range was observed as lowest in Region 10, with ΔT of 0.1°C and ΔP of 11 mm, and highest in Region 6, with ΔT of 5.4°C and ΔP of 73 mm. Region 10 was the highest performing network. In contrast, Region 6 was the lowest performing network. This implies that a higher variability of ΔT and ΔP made the regional data non-uniformly noisy to the extent that its performance could not be improved by more datasets.

A further comparison of the regional networks' performance was made using a correlation analysis between ASE on testing and the four factors (Table 7). According to this correlation analysis, the performance of the regional models was strongly correlated to temperature and precipitation, with R of 0.60 and 0.65, respectively. The average of the four normalized factors was further used to produce an aggregated factor. The correlation between the aggregated factor and performance was 0.62. The lowest performing networks, as was seen in Region 6, were associated with a higher regional climate difference. A higher climatic variability due to a higher

ΔT or ΔP likely means a higher ASE value, or a lower performance of the regional network. These results revealed the regional data dependence on climatic factors. The use of a dataset within a homogenous climactic region is likely to improve the learning ability of ANN models.

Table 7. Correlation coefficient matrix between the ASE on testing and the regional variability factors.

	Total Area Factor	**Water Area Factor**	**ΔT Factor**	**ΔP Factor**	**Aggregated Factor**
ASE_{test}	0.31	0.13	0.60	0.65	0.62

2.4.3. Results from the Regression Model

A linear regression model was developed using the training datasets used for ANN model development. Its input and output variables were the same as those used in the ANN models. Using a linear regression approach, Equations 12 and 13 were developed.

TN = -3.75 + 0.553pH + 0.000272Conductivity + 0.0240Turbidity (Equation 3)

TP = -349.82 + 48.617pH + 0.04640Conductivity + 3.0036Turbidity (Equation 4)

The R^2 statistical measure of the linear regression models was 0. 39 for TN and 0.35 for TP.

A comparison of the linear regression and ANN models was performed using the Region 7 and Region 1 networks as examples. With the same validation datasets, a prediction was made for TN using the developed ANN and linear regression models. The plots for predicted and observed responses are shown in Figure 7. The R^2 results for predictions from the linear regression model were 0.41 and 0.79 for Region 1 and Region 7, respectively; and from ANN model were 0.61 and 0.96 for Region 1 and Region 7, respectively. The R^2 results for predictions from the linear regression model were 0.41 and 0.79 for Region 1 and Region 7, respectively; and from the

ANN model were 0.61 and 0.96 for Region 1 and Region 7, respectively. The R^2 for predictions obtained from the ANN model in both regions was higher than that obtained from the linear regression model. The performance of the regional networks was further validated using a database from the 2012 survey of the U.S. EPA National Lake Assessment. The R^2 results for prediction of TN and TP using the Region 7 network were 0.75 and 0.60, respectively (Figure 8). These results indicate that the ANN models consistently outperformed the linear regression model. This implies that the non-linear behavior of water quality parameters was better handled by the ANN model.

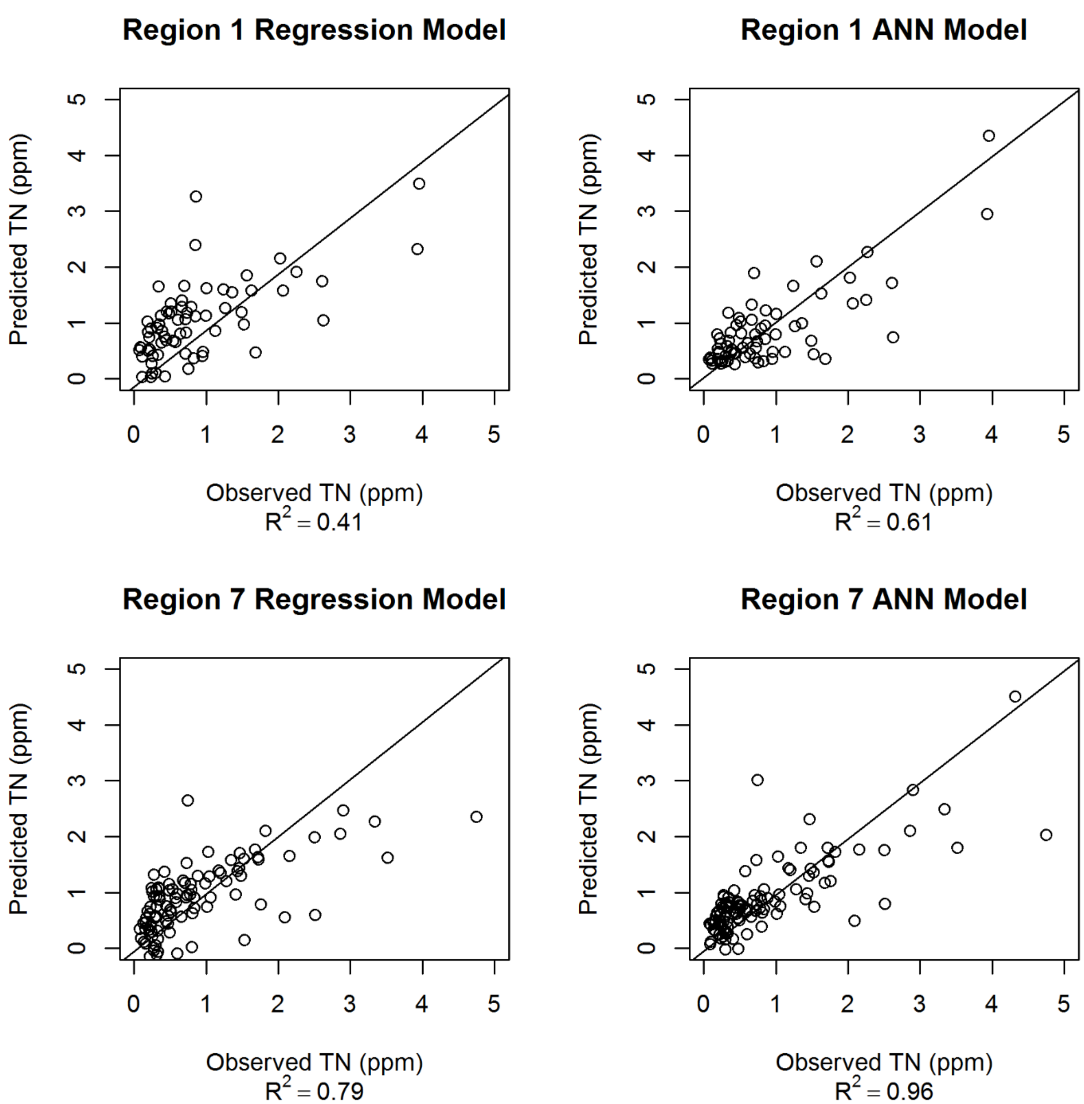

Figure 7. Prediction accuracy for linear regression and ANN models using the 2007 datasets.

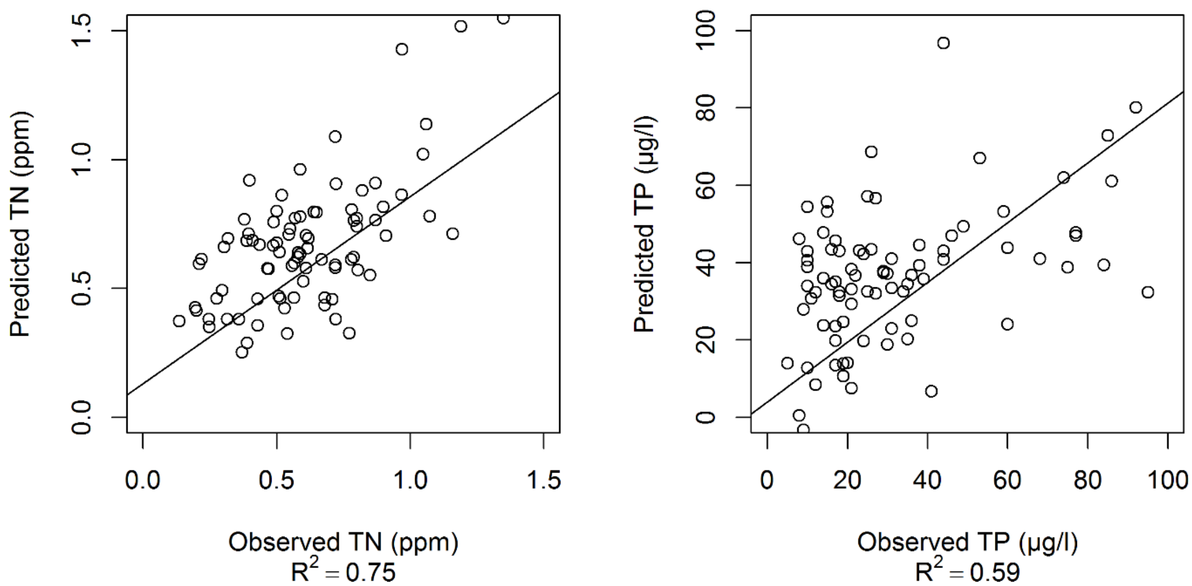

Figure 8. Prediction accuracy of Regional ANN model using the 2012 U.S. EPA National Lake Assessment data.

2.4.4 Results from the Sensitivity Analysis

The sensitivity analysis was performed using the Region 1 network as an example. The results of the sensitivity analysis are presented in Figure 9 and Table 8. Figure 9 demonstrated that the output parameters were impacted by the change in the values of each of the values of the input variable. Table 7 showed sensitivity index results, where a 10% change of each input resulted in a maximum of 80.00% and a minimum of 1.73% change in TN, and a maximum of 47.89% and a minimum of 0.27% change in TP. TN was most to least sensitive to pH, turbidity, and conductivity, respectively. TP was most to least sensitive to pH, conductivity, and turbidity, respectively. Overall, pH had the most substantial influence on the prediction of both TN and TP. These results imply that a small change in the value of the selected input variables can considerably influence the output values.

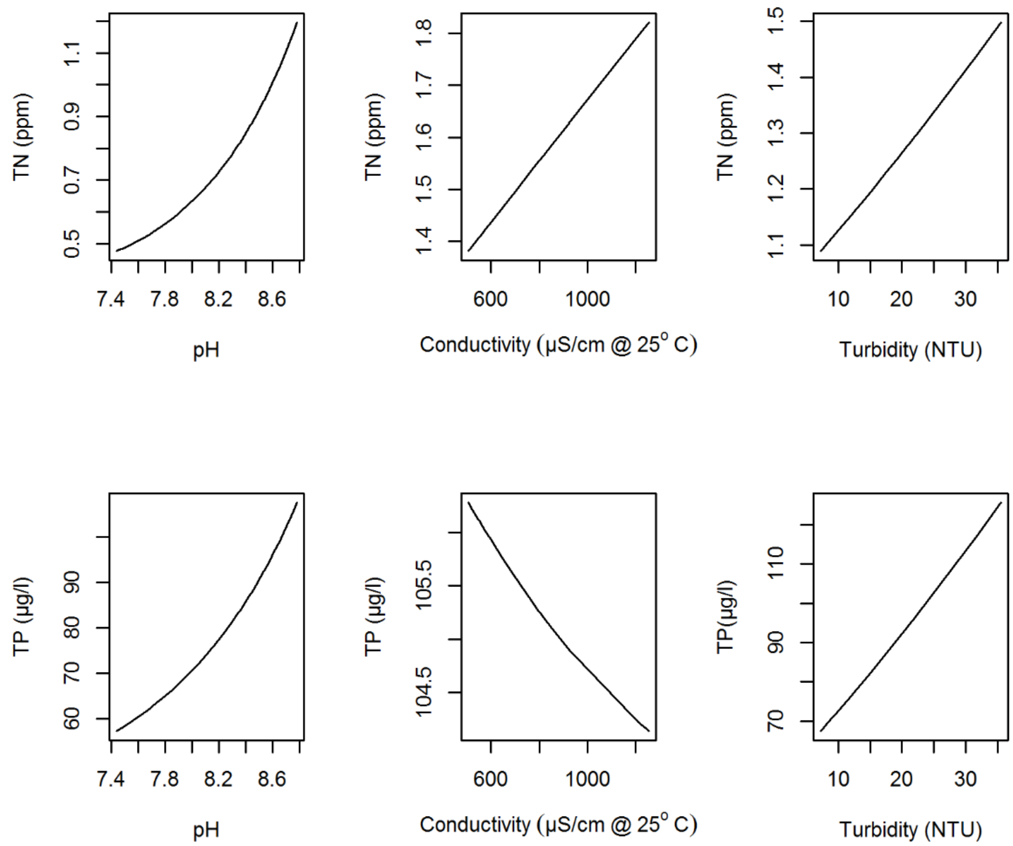

Figure 9. Sensitivity results of outputs TN and TP to inputs pH, conductivity, and turbidity using Region 1 as an example.

Table 8. Sensitivity index values of network outputs to input variables.

		pH		**Conductivity**		**Turbidity**	
Changes in input variables		+10.00%	-10.00%	+10.00%	-10.00%	+10.00%	-10.00%
Associated responses of outputs	TN	+80.00%	-30.00%	+2.45%	-1.73%	+3.52%	-3.50%
	TP	+47.89%	-23.90%	+5.01%	-3.53%	+0.27%	-0.29%

2.5 CONCLUSIONS

In this study, the ability of the ANN model to predict TN and TP concentrations using easily measurable water quality variables, namely pH, conductivity, and turbidity, was explored and justified in the case of U.S. lakes during summer months. This study developed two ANN models that were trained by regional and national datasets. The performance of the ANN models' prediction accuracy was assessed using the average of squared error, mean absolute relative error, and coefficient of determination.

The ANN models were found suitable to estimate TN and TP concentrations in both the national and the regional datasets when compared to counterpart linear regression models. This observation indicates that the ANN-based models are superior to linear regression models in water quality modeling tasks. The statistical accuracy of the ANN models was improved when the network was trained using regional datasets rather than the national dataset. This implies that their generalizing capabilities are better in geographically and climatologically homogenous regions. Further, a better network performance was observed for models developed with a relatively higher number of datasets and located in relatively homogenous temperature and precipitation zones. The regional ANN models that consider all three water quality variables can be suggested as a tool for estimation of TN and TP summer concentrations in U.S. lakes. A sensitivity analysis showed that pH, turbidity, and conductivity were the most to the least important indicators of nutrient concentrations. The proposed ANN model can be a useful alternative to laboratory analysis of TP and TN for lakes in the summer season.

This study suggests the following procedures to achieve a desired level of accuracy: (1) using large training datasets, and (2) using datasets with relatively homogeneous temperature and precipitation. Large datasets are rarely available for water quality variables. The use of training datasets that represent a certain class of climatic zones can compensate for small datasets. It is further suggested to investigate the impact of other environmental factors, such as land use, geology, soil, and other climatic factors to understand ANN modeling of water quality parameters discussed in this study.

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APPENDIX

A description of water quality data used in this research is provided in this appendix.

1. Sampled lakes

The U.S. EPA National Lake Assessment (NLA) surveys U.S. lakes every 5 years to assess their water quality condition. This study used the 2007 survey for developing regional networks. The 2012 survey (which was published in December 2017) was used to validate the regional models. About 1,038 sampled lakes were considered as reference lakes to represent approximately 50,000 freshwater natural or man-made lakes, ponds, and reservoirs. The survey excluded Great Lakes, commercial treatment and disposal ponds, brackish lakes, or ephemeral lakes.

2. Sampled Water Quality Indicators

The purpose of the U.S. EPA NLA survey is to assess the biological, chemical, physical and recreational condition of lakes. Approximately 52 indicators were used to characterize the conditions of lakes. Examples of measured indicators are shown in Table 9.

Table 9. Examples of measured indicators under the U.S. EPA NLA program.

Biological	Chemical	Physical	Recreational
Benthic macroinvertebrates	Acidification	Lakeshore habitat/riparian vegetative cover	Algal toxins (Microcystin)
Chlorophyll a	Atrazine	Human disturbance	Cyanobacteria
Fish assemblage	Conductivity	Physical habitat complexity	Enterococci
Fish tissue contaminants	Dissolved oxygen	Shallow water habitat/in-stream fish habitat	Fish tissue contaminants
Macrophytes	Nitrogen	Streambed sediments	Algal toxins (Microcystin)
Phytoplankton	Phosphorus	Water clarity	Cyanobacteria
Sediment diatoms	Salinity	Lakeshore habitat/riparian vegetative cover	
Wetland vegetation (introduced species)	Sediment enzymes	Human disturbance	

3. Data Used for Training the Regional Networks

The data used for model development for network variables are summarized in Table 10.

Table 10. Measured data for selected network variables.

Site ID	EPA Region	Sampling Date	pH	Conductivity (µS/cm @ 25ºC)	Turbidity (NTU)	TN (mg/l)	TP (µg/l)
NLA06608-0001	Region_1	7/31/2007	7.63	96.28	0.474	0.151	6
NLA06608-0005	Region_1	8/22/2007	7.7	56.1	0.591	0.048	2
NLA06608-0005	Region_1	8/22/2007	7.7	54.96	0.609	0.068	3
NLA06608-0024	Region_1	8/14/2007	7.33	142.5	3.83	0.943	29
NLA06608-0025	Region_1	7/18/2007	7.73	89.09	1.42	0.097	4
NLA06608-0025	Region_1	6/18/2007	7.63	84.96	1.56	0.195	10
NLA06608-0025	Region_1	7/18/2007	7.75	89.23	1.12	0.089	5
NLA06608-0037	Region_1	7/13/2007	7.15	98.02	2.59	0.239	14
NLA06608-0038	Region_1	8/27/2007	7.48	62.84	0.654	0.113	3
NLA06608-0071	Region_1	9/6/2007	8.72	245.2	12.9	2.369	399
NLA06608-0071	Region_1	9/8/2007	8.72	248	10.7	2.268	390
NLA06608-0077	Region_1	9/8/2007	8.54	308.4	17.4	1.461	116
NLA06608-0083	Region_1	6/13/2007	8.86	4281	1.37	3.925	50
NLA06608-0089	Region_1	6/17/2007	7.44	62.86	3.14	0.333	35
NLA06608-0091	Region_1	7/10/2007	9.03	325.9	35.5	2.021	170
NLA06608-0110	Region_1	7/31/2007	8.56	260.1	1.17	0.491	12
NLA06608-0128	Region_1	6/21/2007	8.42	517.7	21.9	1.356	76
NLA06608-0167	Region_1	7/23/2007	9.75	1523	193	15.625	1184
NLA06608-0175	Region_1	8/30/2007	8.47	365.2	5.18	0.698	55
NLA06608-0208	Region_1	9/6/2007	6.72	124.9	20.7	1.687	162
NLA06608-0209	Region_1	7/19/2007	8.09	107.9	0.597	0.205	4
NLA06608-0223	Region_1	6/27/2007	7.68	81.15	7.01	0.569	45
NLA06608-0237	Region_1	7/17/2007	8.33	685.3	1.23	0.588	25
NLA06608-0239	Region_1	7/24/2007	8.1	194.4	3.98	0.383	36

NLA06608-0240	Region_1	7/25/2007	8.57	552.7	1.52	0.396	14
NLA06608-0247	Region_1	7/17/2007	8.55	1652	7.24	1.625	202
NLA06608-0281	Region_1	6/20/2007	7.87	131	8.1	0.639	44
NLA06608-0294	Region_1	6/26/2007	8.4	310.7	0.85	0.343	1
NLA06608-0303	Region_1	8/7/2007	8.46	584	8.94	1.523	79
NLA06608-0328	Region_1	9/15/2007	7.88	179.1	9.31	1.12	75
NLA06608-0343	Region_1	8/21/2007	8.78	1554	10.4	2.606	117
NLA06608-0377	Region_1	7/12/2007	8.53	153.6	5.51	0.85	46
NLA06608-0421	Region_1	6/28/2007	7.78	451.6	1.08	0.537	9
NLA06608-0426	Region_1	9/17/2007	8.31	206.2	1.48	0.574	5
NLA06608-0440	Region_1	8/8/2007	8.16	201.9	103	0.853	182
NLA06608-0442	Region_1	8/14/2007	8.84	2360	8.19	6.559	385
NLA06608-0456	Region_1	8/9/2007	8.44	450.7	3.66	0.681	29
NLA06608-0484	Region_1	7/12/2007	7.7	79.49	19.4	1.519	190
NLA06608-0529	Region_1	9/4/2007	8.83	276.1	7.01	0.508	42
NLA06608-0540	Region_1	8/27/2007	8.29	1255	31.7	2.25	235
NLA06608-0550	Region_1	8/1/2007	6.85	27.88	0.454	0.234	1
NLA06608-0562	Region_1	8/21/2007	6.87	113.2	1.24	0.28	4
NLA06608-0562	Region_1	8/21/2007	6.88	112.9	1.27	0.25	5
NLA06608-0580	Region_1	8/7/2007	8.36	688	0.775	0.183	10
NLA06608-0594	Region_1	8/9/2007	7.19	58.43	6.31	0.821	41
NLA06608-0606	Region_1	8/8/2007	7.33	151	5.18	0.708	15
NLA06608-0616	Region_1	7/25/2007	8.3	1211	1.15	0.483	14
NLA06608-0659	Region_1	6/26/2007	8.44	888.5	8.74	1.593	432
NLA06608-0661	Region_1	8/8/2007	8.31	204	7.39	0.601	22
NLA06608-0662	Region_1	8/7/2007	7.46	68.4	1.64	0.256	12
NLA06608-0783	Region_1	8/14/2007	8.57	600.8	50.3	1.896	819
NLA06608-0785	Region_1	9/12/2007	8.42	406.2	2.15	2.621	15
NLA06608-0794	Region_1	6/9/2007	6.59	20.49	0.416	0.091	3
NLA06608-0807	Region_1	7/11/2007	8.76	1893	14.2	1.505	511
NLA06608-0825	Region_1	9/6/2007	8.46	793.6	21	1.001	88

NLA06608-0851	Region_1	6/5/2007	8.29	4321	5.17	1.104	44
NLA06608-0863	Region_1	7/2/2007	7.75	225.7	4.88	0.446	36
NLA06608-0865	Region_1	9/12/2007	8.34	187.9	12.6	1.489	100
NLA06608-0875	Region_1	9/14/2007	8.07	294.2	2.38	0.72	16
NLA06608-0972	Region_1	7/9/2007	7.54	311.8	140	0.938	619
NLA06608-0979	Region_1	5/30/2007	7.46	392.1	1.07	0.952	68
NLA06608-1014	Region_1	9/13/2007	8.31	683.3	1.33	0.568	15
NLA06608-1060	Region_1	8/14/2007	8.94	113.9	19.5	2.372	243
NLA06608-1086	Region_1	8/27/2007	9	7200	13.8	3.95	92
NLA06608-1261	Region_1	6/25/2007	8.9	821.2	3.01	1.014	32
NLA06608-1360	Region_1	8/19/2007	8.22	289.7	11.8	0.734	60
NLA06608-1387	Region_1	7/20/2007	8.43	437.1	5.02	0.994	25
NLA06608-1641	Region_1	6/19/2007	8.14	179.3	67.6	0.845	185
NLA06608-1742	Region_1	7/18/2007	6.07	14.87	0.596	0.244	7
NLA06608-1811	Region_1	6/25/2007	8.97	2137	3.39	1.558	27
NLA06608-1874	Region_1	8/14/2007	8.49	466.5	3.68	0.374	26
NLA06608-1893	Region_1	7/12/2007	8.53	391	76.1	0.581	302
NLA06608-1998	Region_1	8/6/2007	6.82	23.05	1.51	0.43	13
NLA06608-2463	Region_1	7/19/2007	8.33	595.2	1.52	0.183	6
NLA06608-2477	Region_1	6/26/2007	8.93	1399	2.52	1.238	32
NLA06608-2481	Region_1	8/1/2007	7.7	216.1	8.75	0.421	36
NLA06608-2523	Region_1	7/31/2007	8.58	506.3	6.61	1.259	56
NLA06608-2566	Region_1	7/12/2007	7.79	261	1.88	0.376	9
NLA06608-2714	Region_1	8/11/2007	7.25	923	1.49	0.216	8
NLA06608-2715	Region_1	8/17/2007	8.48	572.7	11.7	0.369	36
NLA06608-2726	Region_1	9/12/2007	8.24	152.3	0.61	0.191	5
NLA06608-2753	Region_1	8/30/2007	9.15	1514	1.88	1.496	16
NLA06608-2759	Region_1	8/30/2007	7.51	382.4	1.93	0.206	9
NLA06608-2776	Region_1	10/16/2007	7.72	208.6	5.82	1.144	36
NLA06608-2779	Region_1	7/18/2007	8.45	476.3	1.66	0.713	21
NLA06608-2797	Region_1	6/28/2007	8.69	646.2	3.27	0.664	24

NLA06608-2800	Region_1	9/25/2007	8.17	380.3	2.3	0.235	11
NLA06608-2801	Region_1	8/1/2007	8.45	808.5	22.5	0.339	36
NLA06608-2807	Region_1	8/13/2007	8.54	1380	3.39	0.66	32
NLA06608-2823	Region_1	9/5/2007	6.96	52.1	3.5	0.751	31
NLA06608-2824	Region_1	8/13/2007	8.78	144.1	6.81	0.794	208
NLA06608-2831	Region_1	8/1/2007	8.29	205.1	13.2	0.738	107
NLA06608-2891	Region_1	7/16/2007	8.61	439.5	1.53	0.79	8
NLA06608-2916	Region_1	39288	8.33	186.5	1.33	0.324	15
NLA06608-2924	Region_1	8/1/2007	8.31	2795	3.5	0.693	13
NLA06608-2954	Region_1	7/26/2007	8.94	124.3	214	7.684	876
NLA06608-2955	Region_1	6/28/2007	8.65	207.9	5.65	0.513	58
NLA06608-3484	Region_1	8/20/2007	9.25	847.7	78.1	4.319	180
NLA06608-3608	Region_1	8/16/2007	8.85	544.1	15.3	1.821	191
NLA06608-3616	Region_1	7/30/2007	8.42	772.1	4.78	0.455	15
NLA06608-3644	Region_1	8/15/2007	8.75	922.3	11	2.063	58
NLA06608-3656	Region_1	8/22/2007	7.38	425.6	23.3	5.813	471
NLA06608-3660	Region_1	8/23/2007	8.06	135.2	312	2.263	1329
NLA06608-3698	Region_1	7/19/2007	6.92	92.81	1.09	0.3	6
NLA06608-3846	Region_1	7/12/2007	6.83	45.2	0.387	0.11	3
NLA06608-3890	Region_1	7/11/2007	6.31	51.33	0.665	0.098	1
NLA06608-0010	Region_2	8/18/2007	8.59	648.6	1.42	0.485	10
NLA06608-0010	Region_2	39274	8.74	650.1	3.05	0.473	10
NLA06608-0015	Region_2	8/29/2007	8.41	706.4	17.7	0.423	98
NLA06608-0015	Region_2	7/10/2007	8.36	743.6	32.7	0.47	109
NLA06608-0038	Region_2	8/27/2007	7.48	61.5	0.447	0.101	3
NLA06608-0038	Region_2	7/12/2007	7.62	59.7	0.549	0.158	4
NLA06608-0057	Region_2	39322	7.78	151.8	12.3	1.219	188
NLA06608-0057	Region_2	39296	7.76	152.3	12.5	0.939	212
NLA06608-0168	Region_2	6/13/2007	8.21	211.5	16.9	0.866	61
NLA06608-0225	Region_2	8/24/2007	8.22	369.4	1.61	0.506	46
NLA06608-0228	Region_2	8/6/2007	7.9	851	9.19	0.71	96

NLA06608-0295	Region_2	6/26/2007	8.65	1240	10.5	2.026	242
NLA06608-0407	Region_2	7/23/2007	8.96	1403	1.8	2.872	762
NLA06608-0614	Region_2	6/27/2007	8.03	219.4	0.825	0.259	8
NLA06608-0622	Region_2	39261	8.59	379.6	3.66	0.508	16
NLA06608-0637	Region_2	8/6/2007	8.63	249	9.23	0.454	21
NLA06608-0862	Region_2	8/8/2007	7.26	60.21	1.16	0.654	11
NLA06608-0899	Region_2	39273	8.85	6864	20.4	4.472	495
NLA06608-0913	Region_2	9/6/2007	7.99	98.49	3.4	0.697	10
NLA06608-0944	Region_2	39279	7.92	404.2	296	1.419	523
NLA06608-1035	Region_2	8/14/2007	8.71	411.4	34.3	4.348	160
NLA06608-1124	Region_2	39342	9.08	423.7	2.16	0.433	9
NLA06608-1172	Region_2	6/27/2007	8.19	181.5	1.48	0.241	4
NLA06608-1210	Region_2	8/15/2007	9.12	12600	2.8	4.184	75
NLA06608-2740	Region_2	39372	8.5	205.8	9.8	0.359	121
NLA06608-0020	Region_3	7/2/2007	8.33	220.1	3.98	0.444	20
NLA06608-0020	Region_3	6/11/2007	8.43	214.1	4.55	0.605	30
NLA06608-0029	Region_3	7/2/2007	7.37	141.7	25.1	2.106	247
NLA06608-0029	Region_3	9/11/2007	8.56	146.7	16.4	2.146	162
NLA06608-0036	Region_3	7/12/2007	8.23	133.5	1.57	0.178	8
NLA06608-0036	Region_3	7/16/2007	8.64	130.1	1.33	0.348	9
NLA06608-0044	Region_3	7/18/2007	8.67	274.1	121	4.108	601
NLA06608-0045	Region_3	8/2/2007	7.33	116.9	9.17	0.43	60
NLA06608-0085	Region_3	8/20/2007	8.83	236.9	72.9	1.518	395
NLA06608-0089	Region_3	7/17/2007	8.17	68.27	4.61	0.401	31
NLA06608-0090	Region_3	7/25/2007	6.14	38.67	0.858	0.449	16
NLA06608-0120	Region_3	9/26/2007	7.78	914.7	17.1	1.256	180
NLA06608-0124	Region_3	7/19/2007	9.49	7382	15.9	0.34	213
NLA06608-0126	Region_3	6/21/2007	8.96	1482	46.8	5.728	502
NLA06608-0149	Region_3	7/18/2007	7.83	118	1.12	0.22	12
NLA06608-0203	Region_3	8/2/2007	7.42	55.09	1.15	0.239	1
NLA06608-0222	Region_3	6/27/2007	8.72	1705	3.54	2.008	114

NLA06608-0235	Region_3	7/16/2007	8.51	443.2	3.22	0.626	8
NLA06608-0257	Region_3	7/18/2007	8.65	217.6	0.784	0.079	1
NLA06608-0271	Region_3	6/27/2007	8.36	418.1	35.7	0.857	99
NLA06608-0286	Region_3	8/8/2007	6.53	22.17	0.762	0.413	5
NLA06608-0291	Region_3	7/11/2007	8.64	496.1	1.68	0.553	13
NLA06608-0341	Region_3	9/18/2007	8.34	358.7	1.51	0.333	23
NLA06608-0363	Region_3	7/21/2007	8.52	475	1.93	0.567	18
NLA06608-0367	Region_3	8/23/2007	8.63	339.3	8.2	2.157	54
NLA06608-0388	Region_3	8/16/2007	7.14	40.34	1.37	0.085	3
NLA06608-0399	Region_3	7/16/2007	8.43	460.7	1.08	0.586	13
NLA06608-0408	Region_3	6/20/2007	8.19	346.4	6.58	0.27	15
NLA06608-0414	Region_3	7/31/2007	7.41	58.79	3.06	1.296	40
NLA06608-0453	Region_3	7/31/2007	6	93.31	2.36	1.056	48
NLA06608-0537	Region_3	6/6/2007	7.17	150.2	2.81	0.256	11
NLA06608-0560	Region_3	9/12/2007	8.49	3256	8.15	0.532	27
NLA06608-0587	Region_3	7/9/2007	8.3	257.7	4.99	1.153	29
NLA06608-0610	Region_3	8/2/2007	7.65	300.7	2.52	0.549	11
NLA06608-0625	Region_3	9/19/2007	6.82	21.56	0.53	0.055	1
NLA06608-0651	Region_3	7/17/2007	8.7	222.4	2.08	0.29	12
NLA06608-0738	Region_3	8/16/2007	6.27	30.48	0.539	0.223	3
NLA06608-0830	Region_3	8/30/2007	8.61	5769	233	15.563	1617
NLA06608-0860	Region_3	8/21/2007	8.1	421.7	21.7	1.71	232
NLA06608-0871	Region_3	7/12/2007	8.6	848.5	68.5	5.378	407
NLA06608-0990	Region_3	7/30/2007	8.7	200.8	6.59	0.96	40
NLA06608-1056	Region_3	9/27/2007	7.58	93.75	4.02	0.464	22
NLA06608-1189	Region_3	9/21/2007	6.71	89.54	0.74	0.281	9
NLA06608-1191	Region_3	8/6/2007	7.78	445.7	8.81	0.984	152
NLA06608-1240	Region_3	7/18/2007	7.92	244.9	2.56	0.771	141
NLA06608-1241	Region_3	6/23/2007	7.66	82.43	5.75	0.526	34
NLA06608-1256	Region_3	7/17/2007	8.46	406.2	3.47	0.346	20
NLA06608-1266	Region_3	7/12/2007	8.02	140.7	574	2.228	933

NLA06608-1303	Region_3	8/8/2007	8.81	425.4	5.86	2.338	817
NLA06608-1347	Region_3	6/28/2007	8.09	121.2	1.72	0.551	12
NLA06608-1358	Region_3	9/18/2007	7.65	80.57	1.02	0.359	7
NLA06608-1365	Region_3	8/21/2007	8.48	426.2	4.01	0.257	13
NLA06608-1420	Region_3	9/18/2007	7.9	121.2	79.1	1.154	112
NLA06608-1508	Region_3	8/20/2007	8.22	561.8	13	1.68	313
NLA06608-1537	Region_3	7/15/2007	8.07	80.23	0.67	0.138	8
NLA06608-1572	Region_3	8/20/2007	7.92	554.9	7.6	0.42	26
NLA06608-1781	Region_3	10/2/2007	7.81	198.9	12.5	0.789	58
NLA06608-1856	Region_3	7/24/2007	10.09	706.9	38.9	3.159	1129
NLA06608-1871	Region_3	7/19/2007	7.46	39.65	3.23	0.139	5
NLA06608-4686	Region_3	9/12/2007	6.85	79.17	36.2	0.446	84
NLA06608-4698	Region_3	9/16/2007	7.81	297.2	7.44	1.333	142
NLA06608-4828	Region_3	9/4/2007	8.32	366.8	4.87	0.421	24
NLA06608-4929	Region_3	7/17/2007	8.15	289.9	3.67	0.954	121
NLA06608-4949	Region_3	8/29/2007	7.84	229.2	9.66	0.623	82
NLA06608-9999	Region_3	7/31/2007	7.17	28.99	0.516	0.149	1
NLA06608-ACAD_LAKES_0435	Region_3	8/1/2007	6.67	27.54	0.555	0.151	10
NLA06608-ALPS-1218	Region_3	8/3/2007	4.57	18.23	2.47	0.414	14
NLA06608-ALSC:020149	Region_3	9/11/2007	7.02	28.61	0.752	0.191	5
NLA06608-ELS:1C2-032	Region_3	7/12/2007	6.78	29.79	4.86	0.264	11
NLA06608-ELS:1C3-003	Region_3	8/15/2007	6.81	18.07	0.64	0.256	9
NLA06608-ELS:1D1-035	Region_3	7/25/2007	7.2	54.16	6.3	0.444	23
NLA06608-ELS:1D2-087	Region_3	7/27/2007	6.54	57.59	3.92	0.532	35
NLA06608-ELS:1E1-052	Region_3	8/7/2007	6.85	21	0.458	0.13	10
NLA06608-ELS:1E1-096	Region_3	8/9/2007	6.67	20.48	1.46	0.236	9
NLA06608-0002	Region_4	7/23/2007	5.93	43.18	3.87	0.469	22
NLA06608-0002	Region_4	39301	6.05	44.8	3.55	0.695	36
NLA06608-0019	Region_4	39277	9.15	3952	29.7	5.603	1414
NLA06608-0019	Region_4	39343	9.05	3950	33.8	6.578	1376
NLA06608-0041	Region_4	7/11/2007	7.46	85.47	0.936	0.37	1

NLA06608-0041	Region_4	39343	7.37	82.91	0.601	0.476	1
NLA06608-0048	Region_4	8/2/2007	8.46	223.9	16.7	0.773	111
NLA06608-0048	Region_4	9/18/2007	8.33	245.6	18.2	0.943	82
NLA06608-0066	Region_4	39273	7.37	126	2.71	0.626	6
NLA06608-0066	Region_4	39254	7.36	126.6	2.54	0.574	6
NLA06608-0091	Region_4	8/13/2007	9.31	329.2	40.9	2.411	164
NLA06608-0126	Region_4	39295	9.15	1494	50.7	7.019	609
NLA06608-0129	Region_4	7/21/2007	8.36	248.8	3.09	0.139	4
NLA06608-0129	Region_4	7/21/2007	8.4	244	0.264	0.108	5
NLA06608-0130	Region_4	8/13/2007	8.41	159.2	1.97	2.234	36
NLA06608-0144	Region_4	9/13/2007	7.83	433.3	20.3	0.751	68
NLA06608-0152	Region_4	7/17/2007	8.55	473.6	4.44	0.521	21
NLA06608-0153	Region_4	8/30/2007	7.61	95.33	4.09	0.656	34
NLA06608-0174	Region_4	8/28/2007	8.88	663.2	1.68	0.786	12
NLA06608-0179	Region_4	8/29/2007	8.56	16930	18.1	7.522	272
NLA06608-0181	Region_4	9/20/2007	8.54	303.3	0.58	0.514	6
NLA06608-0196	Region_4	39296	8.67	170.3	11.4	1.25	94
NLA06608-0198	Region_4	7/24/2007	6.85	106.3	2.06	0.353	25
NLA06608-0209	Region_4	39254	8.07	106.8	0.7	0.201	6
NLA06608-0219	Region_4	39301	8.59	383.9	22.1	1.826	36
NLA06608-0221	Region_4	39302	7.98	190.7	11.2	0.594	38
NLA06608-0223	Region_4	8/29/2007	7.64	89.63	8.65	0.713	43
NLA06608-0223	Region_4	8/29/2007	7.58	89.51	8.62	0.705	44
NLA06608-0242	Region_4	39303	6.78	61.6	1.5	0.3	20
NLA06608-0275	Region_4	39256	8.82	4584	11.2	3.084	331
NLA06608-0276	Region_4	39324	5.96	33.9	0.354	0.254	7
NLA06608-0279	Region_4	8/8/2007	8.65	313.3	43.4	4.6	239
NLA06608-0302	Region_4	6/23/2007	8.8	1383	28.9	6.934	1871
NLA06608-0324	Region_4	39287	8.44	441.8	2.8	0.248	21
NLA06608-0326	Region_4	39275	7.14	86.44	0.98	0.225	5
NLA06608-0328	Region_4	9/15/2007	7.92	182.3	9.56	1.078	73

NLA06608-0332	Region_4	9/4/2007	8.26	190.4	1.24	0.26	11
NLA06608-0333	Region_4	7/24/2007	7.63	197	1.88	0.282	15
NLA06608-0350	Region_4	39316	7.93	85.38	5.39	0.902	18
NLA06608-0359	Region_4	7/10/2007	8.57	979.1	23.5	1.296	191
NLA06608-0388	Region_4	8/26/2007	7.07	40.38	1.04	0.049	49
NLA06608-0405	Region_4	8/30/2007	7.51	55.28	3.19	0.458	16
NLA06608-0458	Region_4	7/25/2007	7.78	99.35	5.74	0.947	39
NLA06608-0469	Region_4	8/29/2007	7.41	63.1	1.19	0.191	11
NLA06608-0471	Region_4	6/25/2007	8.69	407.3	3.25	0.839	24
NLA06608-0483	Region_4	7/11/2007	8.4	989.6	0.851	0.461	4
NLA06608-0494	Region_4	7/11/2007	8.37	280.4	3.64	0.401	4
NLA06608-0526	Region_4	7/18/2007	7.02	36.09	1.46	0.651	17
NLA06608-0542	Region_4	39287	8.13	129.7	1.62	1.303	15
NLA06608-0579	Region_4	8/19/2007	8.71	1074	65.5	2.694	229
NLA06608-0611	Region_4	7/2/2007	8.67	541.6	11.6	0.903	53
NLA06608-0660	Region_4	39312	8.41	864.6	2.76	1.546	8
NLA06608-0674	Region_4	7/26/2007	7	35.85	0.559	0.243	3
NLA06608-0677	Region_4	7/17/2007	9	894.9	35.9	1.864	150
NLA06608-0678	Region_4	8/7/2007	8.07	40.06	3.14	0.462	52
NLA06608-0690	Region_4	8/22/2007	7.01	187.5	2.51	0.314	14
NLA06608-0690	Region_4	39338	7.04	187.2	2.89	0.352	17
NLA06608-0710	Region_4	7/24/2007	6.99	175.5	3.17	0.302	21
NLA06608-0720	Region_4	39253	8.63	795.4	10.6	1.435	195
NLA06608-0733	Region_4	6/27/2007	8.77	1158	37.7	0.993	28
NLA06608-0734	Region_4	39300	7.3	55.55	1.68	0.364	16
NLA06608-0794	Region_4	6/28/2007	7.2	20.16	0.269	0.069	1
NLA06608-0823	Region_4	7/26/2007	8.55	160.9	0.725	0.331	7
NLA06608-0857	Region_4	6/22/2007	7.72	86	4.01	0.469	31
NLA06608-0868	Region_4	39280	8.79	140	11.6	1.184	61
NLA06608-0904	Region_4	7/31/2007	8.46	631	25.7	1.603	135
NLA06608-0906	Region_4	6/12/2007	7.53	117.3	0.446	0.111	1

NLA06608-0935	Region_4	39279	7.89	375.3	4.72	1.198	36
NLA06608-0962	Region_4	39279	7.92	330.7	1.29	0.19	6
NLA06608-0967	Region_4	7/30/2007	8.5	1136	9.74	1.998	1016
NLA06608-1016	Region_4	39280	7.31	273.1	20.2	0.749	69
NLA06608-1022	Region_4	39280	8.72	1441	45.4	5.003	553
NLA06608-1034	Region_4	8/16/2007	8.55	631.2	1.13	0.563	5
NLA06608-1060	Region_4	8/14/2007	8.84	115	19.7	2.213	246
NLA06608-1091	Region_4	39281	9.04	4378	9.06	2.503	90
NLA06608-1102	Region_4	39274	7.1	24.94	0.83	0.23	4
NLA06608-1113	Region_4	39324	7.55	54.55	2.07	0.118	9
NLA06608-1155	Region_4	39261	9.05	1856	14.9	3.069	122
NLA06608-1164	Region_4	9/11/2007	7.31	168.5	9.95	0.424	23
NLA06608-1170	Region_4	39302	8.36	417.8	1.6	0.24	6
NLA06608-1195	Region_4	7/2/2007	8.43	407.6	4.98	0.753	26
NLA06608-1209	Region_4	8/15/2007	7.08	100.4	1.99	0.437	22
NLA06608-1220	Region_4	39273	7.39	36.06	8.63	0.478	31
NLA06608-1244	Region_4	8/7/2007	8.45	338.2	44.6	3.772	253
NLA06608-1259	Region_4	6/21/2007	7.13	42.62	0.734	0.129	9
NLA06608-1312	Region_4	9/27/2007	8.69	146	0.93	0.287	5
NLA06608-1323	Region_4	6/26/2007	8.43	174.9	1.75	0.233	9
NLA06608-1370	Region_4	8/31/2007	8.56	314.4	4.27	1.063	39
NLA06608-1372	Region_4	39300	8.22	421.3	12.9	0.878	113
NLA06608-1434	Region_4	8/1/2007	8.55	287.2	1.01	0.458	5
NLA06608-1439	Region_4	7/17/2007	8.21	294	1.92	0.273	12
NLA06608-1481	Region_4	8/14/2007	7.31	20.34	0.351	0.135	3
NLA06608-1489	Region_4	8/29/2007	7.35	46.67	1.9	0.721	18
NLA06608-1527	Region_4	39295	8.7	396.8	109	5.191	587
NLA06608-1538	Region_4	7/26/2007	7.88	101	1.13	0.252	1
NLA06608-1568	Region_4	39373	8.1	981.5	42.6	0.76	115
NLA06608-1576	Region_4	9/9/2007	8.13	343.4	18.6	1.344	255
NLA06608-1579	Region_4	7/24/2007	8.42	522.3	1.4	0.501	7

NLA06608-1600	Region_4	7/19/2007	8.58	998	2.93	1.011	63
NLA06608-1626	Region_4	8/8/2007	8.41	390.6	1.62	0.623	30
NLA06608-1711	Region_4	9/4/2007	7.09	41.53	2.53	0.19	12
NLA06608-1736	Region_4	8/1/2007	8.45	495.3	14.8	1.453	53
NLA06608-1753	Region_4	8/22/2007	8.57	111.6	0.58	0.267	6
NLA06608-1782	Region_4	9/13/2007	8.4	696	6.25	0.606	32
NLA06608-1808	Region_4	9/13/2007	6.85	39.5	5.97	0.628	48
NLA06608-1824	Region_4	7/25/2007	8.79	301.1	13.9	0.824	56
NLA06608-1959	Region_4	6/11/2007	8.57	1077	17.5	1.494	493
NLA06608-1992	Region_4	9/20/2007	7.7	87.19	23.9	2.041	108
NLA06608-1998	Region_4	9/11/2007	6.73	23.79	1.39	0.326	8
NLA06608-2005	Region_4	7/12/2007	7.79	178	45.5	1.398	276
NLA06608-2037	Region_4	6/14/2007	8.69	518	24.3	1.19	175
NLA06608-2134	Region_4	8/1/2007	7.5	40.14	2.89	0.211	21
NLA06608-2187	Region_4	7/10/2007	8.27	426.5	3.31	0.366	20
NLA06608-2322	Region_4	8/23/2007	8.5	313.2	1.57	0.388	31
NLA06608-2972	Region_4		9.06	191.4	73.5	5.35	347
NLA06608-2987	Region_4		8.4	509.6	9.54	1.336	29
NLA06608-2996	Region_4		7.91	294	39.2	1.44	130
NLA06608-3032	Region_4		7.6	205.8	28.6	1.543	94
NLA06608-3035	Region_4		8.63	343.5	1.4	0.738	7
NLA06608-0005	Region_5	7/18/2007	7.75	52.62	0.475	0.085	4
NLA06608-0006	Region_5	7/17/2007	7.06	74.74	0.901	0.184	7
NLA06608-0007	Region_5	7/24/2007	6.07	26.65	1.05	0.493	8
NLA06608-0007	Region_5	9/6/2007	6.84	25.5	1.02	0.523	7
NLA06608-0014	Region_5	8/23/2007	9.35	8635	6.81	4.325	161
NLA06608-0015	Region_5	8/29/2007	8.47	714.3	19.1	0.454	100
NLA06608-0020	Region_5	7/2/2007	8.31	219.4	3.78	0.466	20
NLA06608-0021	Region_5	7/27/2007	8.33	366.8	0.574	0.39	7
NLA06608-0023	Region_5	8/9/2007	8.16	175.7	3.79	0.349	12
NLA06608-0024	Region_5	7/11/2007	7.69	181.4	5.68	0.86	35

NLA06608-0031	Region_5	6/13/2007	8.28	357.1	8.82	0.428	32
NLA06608-0033	Region_5	8/28/2007	8.01	100.9	3.19	0.44	32
NLA06608-0068	Region_5	9/12/2007	7.87	230.8	0.35	0.131	1
NLA06608-0069	Region_5	9/26/2007	6.25	131.1	3.31	0.771	45
NLA06608-0069	Region_5	7/18/2007	7.24	145.9	2.74	0.42	39
NLA06608-0069	Region_5	9/26/2007	6.22	130.6	3.1	0.754	48
NLA06608-0073	Region_5	6/12/2007	9.45	26620	0.519	1.055	4679
NLA06608-0076	Region_5	9/4/2007	8.76	254.1	7.51	0.71	32
NLA06608-0076	Region_5	9/4/2007	8.71	254.8	7.88	0.725	34
NLA06608-0076	Region_5	7/27/2007	8.37	254.1	3.88	0.436	24
NLA06608-0077	Region_5	9/13/2007	7.9	321.8	14	1.63	151
NLA06608-0083	Region_5	8/9/2007	9.07	4674	3.69	3.741	58
NLA06608-0085	Region_5	8/20/2007	8.85	239.6	69.1	1.016	425
NLA06608-0086	Region_5	9/20/2007	8.17	124.5	8.97	0.789	31
NLA06608-0090	Region_5	7/25/2007	6.09	35.04	0.597	0.35	15
NLA06608-0090	Region_5	6/26/2007	7.16	34.4	1.45	0.253	11
NLA06608-0099	Region_5	7/3/2007	8.57	557.8	4.98	0.601	6
NLA06608-0099	Region_5	9/5/2007	8.25	550.7	1.43	0.623	11
NLA06608-0104	Region_5	7/24/2007	8.49	308.8	17	1.123	91
NLA06608-0105	Region_5	7/5/2007	8.42	485.8	5.4	0.339	45
NLA06608-0105	Region_5	9/12/2007	8.46	481.8	41.3	0.433	134
NLA06608-0105	Region_5	9/12/2007	8.48	484.8	51.3	0.456	143
NLA06608-0116	Region_5	6/28/2007	8.4	353.7	5.55	0.271	26
NLA06608-0126	Region_5	8/28/2007	9.14	1485	49.2	7.038	605
NLA06608-0128	Region_5	8/25/2007	9.89	614.7	23.5	3.956	480
NLA06608-0139	Region_5	7/11/2007	8.53	496.6	2.59	0.763	33
NLA06608-0140	Region_5	6/20/2007	8.49	276.7	18.6	1.158	173
NLA06608-0141	Region_5	8/23/2007	8.1	214.6	9.66	0.975	73
NLA06608-0144	Region_5	39261	7.74	405.8	4.78	0.898	69
NLA06608-0169	Region_5	7/5/2007	8.69	192.1	1.39	0.353	33
NLA06608-0169	Region_5	7/5/2007	8.68	193.7	1.14	0.281	25

NLA06608-0173	Region_5	7/11/2007	8.31	3526	26.8	2.218	57
NLA06608-0189	Region_5	6/11/2007	7.46	396.7	20.2	0.871	77
NLA06608-0193	Region_5	7/11/2007	7.68	52.98	2.18	0.071	3
NLA06608-0204	Region_5	9/12/2007	8.58	421.6	22.4	1.355	125
NLA06608-0207	Region_5	7/18/2007	7.37	45.16	2.07	0.384	14
NLA06608-0211	Region_5	8/7/2007	8.99	326.6	3.45	1.34	42
NLA06608-0215	Region_5	8/22/2007	8.36	389.1	15.6	1.463	83
NLA06608-0220	Region_5	8/2/2007	9.36	1376	168	22.613	872
NLA06608-0224	Region_5	9/23/2007	7.69	175.5	1.91	0.375	8
NLA06608-0237	Region_5	6/26/2007	8.63	642.8	1.52	0.678	23
NLA06608-0243	Region_5	7/18/2007	8.52	658.1	1.07	0.203	7
NLA06608-0244	Region_5	6/20/2007	8.18	4505	3.64	0.436	15
NLA06608-0245	Region_5	7/24/2007	9.12	373.6	0.65	0.329	11
NLA06608-0280	Region_5	7/25/2007	7.65	111	5.39	1.229	81
NLA06608-0285	Region_5	7/24/2007	7.91	151.3	11.6	4.222	138
NLA06608-0293	Region_5	7/25/2007	8.65	340.5	7.91	0.759	30
NLA06608-0299	Region_5	7/30/2007	8.51	447.4	2.12	0.915	18
NLA06608-0306	Region_5	7/16/2007	8.43	329.6	96.3	1.525	271
NLA06608-0325	Region_5	7/17/2007	8.57	214.5	5.74	0.814	50
NLA06608-0334	Region_5	6/27/2007	8.51	781.8	19	1.834	142
NLA06608-0337	Region_5	7/12/2007	8.13	276.6	2.17	0.586	23
NLA06608-0339	Region_5	6/25/2007	8.92	2413	6.02	1.659	376
NLA06608-0354	Region_5	7/19/2007	6.42	34.03	0.432	0.188	5
NLA06608-0366	Region_5	7/31/2007	8.52	330.1	1.96	0.601	14
NLA06608-0369	Region_5	7/26/2007	8.23	153	0.53	0.163	1
NLA06608-0385	Region_5	7/6/2007	8.73	929.5	5.25	1.834	51
NLA06608-0402	Region_5	6/26/2007	7.26	100.9	10.2	2.287	176
NLA06608-0418	Region_5	7/19/2007	6.63	66.51	0.919	0.296	8
NLA06608-0425	Region_5	8/1/2007	8.41	216.8	8.09	1.433	234
NLA06608-0432	Region_5	7/16/2007	7.33	66.2	60.1	0.644	218
NLA06608-0433	Region_5	8/9/2007	8.01	171	0.712	0.422	7

NLA06608-0435	Region_5	7/23/2007	7.28	79.65	9.08	1.824	78
NLA06608-0462	Region_5	8/20/2007	6.68	14.28	0.647	0.194	3
NLA06608-0463	Region_5	8/19/2007	8.36	716.6	9.38	1.031	82
NLA06608-0468	Region_5	8/1/2007	7.16	28.49	0.377	0.179	8
NLA06608-0480	Region_5	9/25/2007	8.47	314.2	1.03	0.232	4
NLA06608-0488	Region_5	7/19/2007	7.84	180.3	16.3	1.07	162
NLA06608-0495	Region_5	9/5/2007	8.2	196.3	0.72	0.136	11
NLA06608-0496	Region_5	39259	9.22	3410	2.27	4.372	620
NLA06608-0497	Region_5	8/17/2007	8.49	236.8	4.91	0.156	17
NLA06608-0498	Region_5	7/31/2007	8.01	127.6	5.56	0.82	44
NLA06608-0501	Region_5	7/24/2007	8.35	164.4	0.806	0.182	6
NLA06608-0503	Region_5	8/1/2007	8.58	2575	63.2	5.916	430
NLA06608-0528	Region_5	6/28/2007	8.28	818.9	8.87	0.814	65
NLA06608-0533	Region_5	7/18/2007	8.01	129.4	0.852	0.178	6
NLA06608-0547	Region_5	7/31/2007	8.28	311.1	2.16	0.519	10
NLA06608-0558	Region_5	8/9/2007	8.39	407.1	1.94	1.154	17
NLA06608-0561	Region_5	8/9/2007	7.25	18.72	0.683	0.086	5
NLA06608-0593	Region_5	7/10/2007	7.7	68.98	0.722	0.203	4
NLA06608-0596	Region_5	7/30/2007	7.43	82.31	0.787	0.096	1
NLA06608-0599	Region_5	7/19/2007	7.82	330.4	6.31	1.012	90
NLA06608-0608	Region_5	9/18/2007	8.59	470.8	29	2.184	327
NLA06608-0619	Region_5	7/18/2007	8.53	429.3	2.38	0.733	7
NLA06608-0632	Region_5	6/12/2007	8.55	448.8	4.46	0.746	44
NLA06608-0641	Region_5	7/25/2007	8.6	156	3.98	0.737	49
NLA06608-0648	Region_5	8/1/2007	8.95	1277	37.1	8.603	349
NLA06608-0672	Region_5	7/26/2007	8.84	803.6	23.1	2.273	213
NLA06608-0679	Region_5	6/27/2007	8.46	509.2	2.22	0.635	13
NLA06608-0711	Region_5	9/10/2007	6.82	50.55	8.67	0.523	74
NLA06608-0712	Region_5	7/24/2007	7.95	355.2	0.909	0.417	14
NLA06608-0721	Region_5	7/5/2007	7.77	56.28	2.75	0.441	21
NLA06608-0726	Region_5	8/14/2007	7.31	52.39	0.681	0.202	6

NLA06608-0727	Region_5	6/23/2007	8.75	1284	34.8	3.722	191
NLA06608-0744	Region_5	7/18/2007	8.57	142.4	13.7	1.243	100
NLA06608-0753	Region_5	7/19/2007	8.54	293.5	2.46	0.367	15
NLA06608-0754	Region_5	7/2/2007	6.42	46.5	0.724	0.251	3
NLA06608-0756	Region_5	6/25/2007	8.41	361.2	7.4	0.326	3
NLA06608-0765	Region_5	6/5/2007	7.39	158.3	5.3	0.507	29
NLA06608-0769	Region_5	7/24/2007	7.8	48.69	4.14	0.384	16
NLA06608-0775	Region_5	7/25/2007	8.2	287.6	1.28	0.569	18
NLA06608-0792	Region_5	8/16/2007	7.42	277.6	4.19	0.76	47
NLA06608-0804	Region_5	8/19/2007	8.16	158.9	2.04	0.335	13
NLA06608-0811	Region_5	7/23/2007	8.58	379.2	7.84	1.224	51
NLA06608-0812	Region_5	6/28/2007	7.26	46.23	3.3	0.357	11
NLA06608-0820	Region_5	8/6/2007	8.69	291.2	20.3	2.841	323
NLA06608-0831	Region_5	7/19/2007	6.98	16.53	1.72	0.044	4
NLA06608-0843	Region_5	7/18/2007	7.9	91.89	2.27	0.196	8
NLA06608-0847	Region_5	8/30/2007	8.51	412.3	51.2	3.572	395
NLA06608-0850	Region_5	8/7/2007	8.57	388.8	1.71	0.486	19
NLA06608-0859	Region_5	7/5/2007	8.55	841.4	5.26	0.913	33
NLA06608-0860	Region_5	7/19/2007	8.35	594.2	24.4	6.672	222
NLA06608-0870	Region_5	8/9/2007	7.77	55.48	0.552	0.087	43
NLA06608-0873	Region_5	6/20/2007	7.98	122.3	111	0.433	141
NLA06608-0878	Region_5	8/1/2007	8.38	325.4	1.74	0.63	18
NLA06608-0885	Region_5	7/11/2007	8.24	1396	8.74	0.865	1386
NLA06608-0891	Region_5	8/18/2007	7.51	555.2	42.2	1.137	133
NLA06608-0900	Region_5	6/18/2007	8.06	213.3	3.91	0.7	48
NLA06608-0916	Region_5	8/8/2007	6.5	32.53	10.8	0.237	16
NLA06608-0924	Region_5	8/12/2007	9.54	2023	239	14.4	447
NLA06608-0925	Region_5	10/3/2007	8.29	1091	0.3	1.16	1
NLA06608-0926	Region_5	8/6/2007	6.82	36.25	1.03	0.252	4
NLA06608-0930	Region_5	8/21/2007	7.18	84.67	0.863	0.174	4
NLA06608-0946	Region_5	8/14/2007	7.29	77.46	1.82	0.552	30

NLA06608-0950	Region_5	8/2/2007	8.36	670.6	1.19	0.234	20
NLA06608-0957	Region_5	6/21/2007	6.93	61.78	0.846	0.276	8
NLA06608-0958	Region_5	8/15/2007	7.95	151.2	3.19	0.511	18
NLA06608-0961	Region_5	7/25/2007	7.54	49.25	1.27	0.189	11
NLA06608-0968	Region_5	8/1/2007	8.65	569.7	22.2	3.553	145
NLA06608-0982	Region_5	8/14/2007	7.47	57.62	0.561	0.248	6
NLA06608-0984	Region_5	9/26/2007	7	105.3	21.9	0.878	115
NLA06608-0986	Region_5	7/18/2007	7.1	38.27	1.61	0.186	7
NLA06608-0989	Region_5	7/31/2007	7.29	45.5	12.2	0.856	56
NLA06608-0996	Region_5	6/26/2007	8.67	712.3	1.66	0.449	9
NLA06608-1003	Region_5	7/23/2007	7.81	83.8	1.23	0.524	12
NLA06608-1005	Region_5	7/19/2007	6.66	75.16	16.6	0.425	40
NLA06608-1007	Region_5	8/2/2007	8.13	234.2	3.41	0.479	30
NLA06608-1008	Region_5	7/12/2007	8.42	319.5	1.17	0.086	4
NLA06608-1012	Region_5	10/17/2007	7.75	195.6	3.71	0.88	41
NLA06608-1015	Region_5	8/14/2007	8.65	394.2	15.6	1.704	77
NLA06608-1018	Region_5	8/2/2007	7.43	45.16	3.48	1.174	36
NLA06608-1038	Region_5	8/3/2007	7.44	51.32	2.02	0.561	20
NLA06608-1039	Region_5	8/28/2007	7.33	48.19	21.4	1.454	81
NLA06608-1041	Region_5	8/16/2007	9.34	4217	1.11	1.878	190
NLA06608-1045	Region_5	8/29/2007	7.33	300.5	1.5	0.236	6
NLA06608-1047	Region_5	6/26/2007	7.51	116.6	1.7	0.285	3
NLA06608-1073	Region_5	8/13/2007	7.71	59.04	0.891	0.068	3
NLA06608-1087	Region_5	7/20/2007	7.23	24.99	3.22	0.273	14
NLA06608-1096	Region_5	8/2/2007	8.54	235.6	37.9	0.665	171
NLA06608-1100	Region_5	6/28/2007	8.31	555.5	0.94	0.262	8
NLA06608-1108	Region_5	7/2/2007	8.63	334.2	9.51	1.038	110
NLA06608-1111	Region_5	7/10/2007	8.38	1120	19.7	1.5	193
NLA06608-1125	Region_5	8/7/2007	8.66	301	1.62	0.315	17
NLA06608-1134	Region_5	8/7/2007	8.48	232.6	5.15	0.826	24
NLA06608-1151	Region_5	7/17/2007	8.02	104	5.28	0.648	129

NLA06608-1166	Region_5	8/14/2007	6.16	13.92	0.678	0.197	1
NLA06608-1174	Region_5	8/15/2007	7.32	39.99	0.629	0.298	4
NLA06608-1175	Region_5	8/21/2007	8.49	375.2	15.3	1.328	69
NLA06608-1183	Region_5	8/29/2007	6.8	10.65	0.393	0.133	3
NLA06608-1190	Region_5	6/25/2007	7.56	61.93	13.2	0.096	3
NLA06608-1199	Region_5	8/15/2007	9.01	336.1	8.77	0.836	44
NLA06608-1204	Region_5	8/28/2007	7.43	51.15	1.34	0.23	10
NLA06608-1207	Region_5	7/26/2007	8.41	223.3	1.08	0.24	11
NLA06608-1208	Region_5	7/25/2007	8.31	903.9	11.1	1.237	148
NLA06608-1208	Region_5	7/25/2007	8.32	916.5	10.3	1.359	124
NLA06608-1222	Region_5	7/31/2007	7.13	130.4	2.65	0.391	12
NLA06608-1224	Region_5	7/12/2007	8.58	205.8	5.85	0.616	23
NLA06608-1238	Region_5	8/16/2007	7.22	55.34	0.516	0.131	1
NLA06608-1239	Region_5	7/24/2007	8.96	409.4	13.7	3.309	117
NLA06608-1242	Region_5	7/10/2007	7.81	369.7	0.876	0.849	11
NLA06608-1243	Region_5	8/7/2007	8.51	474.4	8.63	0.949	42
NLA06608-1255	Region_5	8/15/2007	8.58	4825	137	13.825	1326
NLA06608-1271	Region_5	8/7/2007	9.06	391.8	25.1	3.534	604
NLA06608-1273	Region_5	9/7/2007	8.98	397.3	27.7	2.297	197
NLA06608-1283	Region_5	6/27/2007	7.34	70.29	9.27	1.012	68
NLA06608-1284	Region_5	8/24/2007	8.28	212.5	1.24	0.18	5
NLA06608-1288	Region_5	8/27/2007	8.77	62.6	12.5	0.619	86
NLA06608-1332	Region_5	8/21/2007	7.73	256.7	53.2	0.932	148
NLA06608-1334	Region_5	7/31/2007	8.57	299.1	3.54	0.388	7
NLA06608-1336	Region_5	9/19/2007	7.73	176.3	25.7	1.136	94
NLA06608-1346	Region_5	7/12/2007	7.41	59.83	0.76	0.125	3
NLA06608-1355	Region_5	8/21/2007	8.4	387.5	1.65	0.462	4
NLA06608-1359	Region_5	7/31/2007	8.6	392.2	8.22	1.166	108
NLA06608-1383	Region_5	8/22/2007	8.56	404.5	9.31	1.444	35
NLA06608-1403	Region_5	7/2/2007	8.3	590.6	2.08	0.389	7
NLA06608-1432	Region_5	6/19/2007	8.09	193.9	15	0.754	91

NLA06608-1435	Region_5	8/1/2007	8.5	991.9	21.4	1.26	50
NLA06608-1450	Region_5	7/24/2007	8.51	302	1.26	0.469	10
NLA06608-1454	Region_5	7/25/2007	8.81	762.1	1.29	2.341	125
NLA06608-1455	Region_5	8/13/2007	7.55	48.62	2.2	0.429	37
NLA06608-1461	Region_5	9/26/2007	8.92	348	6.81	0.708	47
NLA06608-1473	Region_5	7/22/2007	7.37	26.03	0.722	0.181	8
NLA06608-1476	Region_5	6/14/2007	8.08	723.4	35.1	1.891	183
NLA06608-1488	Region_5	7/31/2007	8.92	982.5	28.5	3.409	160
NLA06608-1510	Region_5	8/17/2007	8.79	1040	4.83	2.44	653
NLA06608-1517	Region_5	8/1/2007	7.29	44.69	4.53	0.339	14
NLA06608-1521	Region_5	8/14/2007	9.2	352.2	8.06	1.351	113
NLA06608-1524	Region_5	6/12/2007	8.28	389.5	50.7	0.968	157
NLA06608-1532	Region_5	7/24/2007	9.16	406.1	8.36	6.203	59
NLA06608-1558	Region_5	9/12/2007	6.73	25.52	1.44	0.28	8
NLA06608-1577	Region_5	7/19/2007	8.55	249.2	2.09	0.484	16
NLA06608-1586	Region_5	7/10/2007	6.78	74.11	0.981	0.369	7
NLA06608-1617	Region_5	8/8/2007	7.92	106.2	1.61	0.239	45
NLA06608-1643	Region_5	7/19/2007	8.45	246.6	1.25	0.488	5
NLA06608-1652	Region_5	6/13/2007	8.22	256.7	7.13	0.848	99
NLA06608-1703	Region_5	8/28/2007	8.66	1747	24.8	1.949	304
NLA06608-1704	Region_5	9/5/2007	7.88	101.3	5.12	0.749	42
NLA06608-1740	Region_5	8/10/2007	8.33	200.3	8.2	0.949	67
NLA06608-1810	Region_5	7/16/2007	8.42	955.4	15.3	0.611	69
NLA06608-1835	Region_5	7/24/2007	8.08	312.7	1.22	0.531	16
NLA06608-1839	Region_5	9/20/2007	6.53	40.55	5.13	0.42	20
NLA06608-1862	Region_5	7/12/2007	8.65	638	125	1.058	520
NLA06608-1863	Region_5	9/7/2007	7.13	73.95	2.61	0.506	32
NLA06608-1968	Region_5	8/23/2007	8.89	797	33.1	2.076	255
NLA06608-1985	Region_5	7/21/2007	7.57	49.63	0.241	0.027	3
NLA06608-2027	Region_5	6/20/2007	6.92	93.7	9.21	0.551	49
NLA06608-2076	Region_5	9/12/2007	6.44	30.31	3.33	0.124	11

NLA06608-2095	Region_5	7/8/2007	7.87	114.3	12.5	0.316	48
NLA06608-2162	Region_5	7/9/2007	6.94	61.52	0.846	0.295	21
NLA06608-2170	Region_5	8/24/2007	9.11	10470	3.63	5.109	65
NLA06608-2196	Region_5	8/9/2007	8.17	138.4	1.59	0.407	15
NLA06608-2241	Region_5	9/6/2007	7.86	89.9	0.45	0.256	9
NLA06608-2266	Region_5	6/23/2007	6.93	136.8	1.96	0.35	21
NLA06608-2833	Region_5	8/15/2007	8.65	454.3	0.835	0.64	16
NLA06608-2874	Region_5	9/26/2007	8.23	442.8	1.79	0.487	76
NLA06608-2881	Region_5	9/21/2007	6.94	171.3	0.47	0.05	1
NLA06608-2889	Region_5	7/18/2007	9.4	19040	0.905	1.476	577
NLA06608-3083	Region_5	8/6/2007	8.59	319.5	3.92	0.685	96
NLA06608-3096	Region_5	9/25/2007	7.93	131.9	2.25	0.559	17
NLA06608-3121	Region_5	8/7/2007	8.41	61.49	5.72	0.455	46
NLA06608-3147	Region_5	8/21/2007	8.46	365	6.19	0.999	46
NLA06608-3153	Region_5	9/25/2007	7.75	104.9	0.42	0.116	1
NLA06608-3157	Region_5	7/11/2007	7.51	64.77	1.79	0.07	8
NLA06608-3160	Region_5	8/15/2007	9.54	241.7	42.8	2.655	237
NLA06608-3169	Region_5	8/21/2007	8.7	545.9	28.6	1.2	105
NLA06608-3228	Region_5	10/9/2007	7.91	463.6	9.65	0.658	74
NLA06608-3265	Region_5	9/5/2007	8.6	259.4	0.561	0.338	7
NLA06608-3303	Region_5	10/17/2007	7.9	1754	3.21	1.535	81
NLA06608-3313	Region_5	8/16/2007	8.46	245	5.67	0.316	41
NLA06608-3320	Region_5	9/17/2007	7.34	90.9	28.6	0.612	88
NLA06608-3329	Region_5	7/19/2007	6.58	35.58	1.05	0.374	10
NLA06608-3480	Region_5	8/14/2007	8.44	260.2	14.1	1.612	88
NLA06608-4206	Region_5	9/19/2007	8.11	8300	7.74	1.627	61
NLA06608-4252	Region_5	8/23/2007	7.86	73.17	0.59	0.188	1
NLA06608-ELS:1E1-128	Region_5	39304	6.79	22.66	1.06	0.394	8
NLA06608-ELS:1E2-027	Region_5	39308	6.97	27.03	4.03	0.629	28
NLA06608-NELP-1041	Region_5	39295	6.98	32.04	0.659	0.286	9
NLA06608-NELP-1330	Region_5	39322	7.02	21.43	0.549	0.168	1

NLA06608-0002	Region_6	39245	5.92	42.87	4.43	0.507	25
NLA06608-0003	Region_6	9/6/2007	8.54	1120	9.53	0.843	50
NLA06608-0008	Region_6	8/22/2007	8.9	197.8	17.6	1.525	79
NLA06608-0008	Region_6	7/12/2007	8.48	238.1	8.62	0.801	66
NLA06608-0012	Region_6	9/18/2007	8.31	229.8	45.1	1.052	142
NLA06608-0013	Region_6	9/4/2007	5.64	47.52	4.21	0.384	28
NLA06608-0016	Region_6	6/27/2007	8.48	1060	16.5	0.49	6
NLA06608-0016	Region_6	7/11/2007	8.47	1085	19.3	0.685	39
NLA06608-0016	Region_6	7/11/2007	8.47	1091	18.6	0.704	39
NLA06608-0019	Region_6	6/11/2007	8.4	3327	45.5	7.047	801
NLA06608-0048	Region_6	9/18/2007	8.37	241.3	17.7	1.004	84
NLA06608-0049	Region_6	8/15/2007	7.91	91.89	1.55	0.256	15
NLA06608-0050	Region_6	8/30/2007	6.89	24.82	3.41	0.399	18
NLA06608-0050	Region_6	7/2/2007	7.05	25.53	1.78	0.303	16
NLA06608-0062	Region_6	8/9/2007	8.98	3835	12.3	2.834	152
NLA06608-0062	Region_6	8/27/2007	8.99	3890	4.97	2.813	120
NLA06608-0077	Region_6	9/13/2007	7.88	322.2	17.8	1.87	188
NLA06608-0078	Region_6	8/21/2007	9.21	2156	11.4	4.294	108
NLA06608-0078	Region_6	8/8/2007	9.18	2086	18.8	4.541	111
NLA06608-0086	Region_6	8/2/2007	8.59	110	4.01	0.288	20
NLA06608-0086	Region_6	9/20/2007	8.17	125.1	8.71	0.865	32
NLA06608-0089	Region_6	39352	8.46	68.93	4.57	0.478	32
NLA06608-0107	Region_6	6/25/2007	8.23	208.6	1.28	0.52	3
NLA06608-0113	Region_6	7/16/2007	8.19	129.7	1.83	0.19	9
NLA06608-0129	Region_6	9/16/2007	8.35	249.6	1.11	0.15	1
NLA06608-0132	Region_6	8/28/2007	8.53	352.2	6.4	0.466	56
NLA06608-0177	Region_6	8/22/2007	7.69	56.16	1.28	0.177	6
NLA06608-0185	Region_6	8/14/2007	7.24	123.6	1.14	0.284	9
NLA06608-0189	Region_6	7/10/2007	8.44	440.6	12.8	0.648	65
NLA06608-0195	Region_6	6/12/2007	8.43	1120	10.3	1.955	447
NLA06608-0201	Region_6	9/18/2007	7.32	27.1	1.03	0.04	3

NLA06608-0224	Region_6	7/19/2007	7.36	176.4	2.6	0.283	14
NLA06608-0224	Region_6	9/23/2007	7.75	175.3	1.52	0.385	7
NLA06608-0225	Region_6	7/11/2007	8.48	345.9	0.788	0.178	8
NLA06608-0228	Region_6	6/26/2007	8.37	806.2	0.942	0.411	25
NLA06608-0238	Region_6	39310	8.48	224.1	1.04	0.265	7
NLA06608-0255	Region_6	8/7/2007	7.78	86.06	1.45	0.276	4
NLA06608-0290	Region_6	9/10/2007	8.19	183.7	194	1.231	629
NLA06608-0312	Region_6	7/16/2007	8.6	253.9	5.08	0.355	35
NLA06608-0318	Region_6	7/20/2007	8.58	371.1	4.1	0.847	43
NLA06608-0330	Region_6	9/5/2007	8.23	333.5	1.27	0.289	13
NLA06608-0345	Region_6	6/21/2007	7.88	118.6	2.66	0.511	22
NLA06608-0358	Region_6	7/17/2007	6.79	20.58	1.15	0.209	7
NLA06608-0378	Region_6	6/26/2007	8.28	471.5	1.77	0.223	9
NLA06608-0413	Region_6	6/27/2007	7.28	64.83	10.6	0.581	106
NLA06608-0436	Region_6	9/5/2007	7.4	73.1	2.41	0.398	29
NLA06608-0444	Region_6	7/12/2007	6.82	26.13	15.5	0.383	42
NLA06608-0480	Region_6	8/24/2007	8.44	321.9	0.679	0.194	3
NLA06608-0491	Region_6	7/17/2007	8.37	429.4	1.59	0.665	16
NLA06608-0502	Region_6	8/18/2007	8.42	612.4	1.36	0.648	5
NLA06608-0569	Region_6	8/7/2007	9.85	481	14.5	2.188	518
NLA06608-0581	Region_6	7/3/2007	8.48	257.4	0.711	0.241	8
NLA06608-0582	Region_6	7/19/2007	7.77	328.1	4.63	2.709	315
NLA06608-0618	Region_6	7/24/2007	7.8	89.58	8.6	0.257	23
NLA06608-0634	Region_6	8/22/2007	8.87	2748	42.1	6.8	288
NLA06608-0650	Region_6	7/25/2007	8.5	244.7	2.5	0.466	23
NLA06608-0681	Region_6	6/14/2007	6.97	56.11	2.84	0.249	9
NLA06608-0718	Region_6	7/18/2007	9.13	3595	83.2	1.869	616
NLA06608-0846	Region_6	8/28/2007	7.23	102.2	12.6	0.875	39
NLA06608-0856	Region_6	6/19/2007	8.33	293.6	5.17	0.483	31
NLA06608-0864	Region_6	6/25/2007	8.33	3630	6.67	0.973	11
NLA06608-0881	Region_6	7/30/2007	8.64	106.5	4.24	0.513	42

NLA06608-0914	Region_6	8/2/2007	6.66	21.48	0.455	0.171	10
NLA06608-0974	Region_6	7/16/2007	8.07	100.3	0.637	0.101	4
NLA06608-1006	Region_6	6/19/2007	9.08	2095	23.5	3.391	278
NLA06608-1037	Region_6	9/5/2007	8.76	241.5	1.79	0.441	25
NLA06608-1044	Region_6	7/10/2007	8.05	193.5	3.38	0.344	54
NLA06608-1070	Region_6	7/11/2007	8.72	759.5	12.7	1.183	774
NLA06608-1083	Region_6	6/29/2007	8.78	600.9	27.6	2.784	530
NLA06608-1089	Region_6	7/20/2007	8.18	134.8	0.468	0.293	8
NLA06608-1130	Region_6	8/21/2007	8.36	555	6.39	0.634	65
NLA06608-1143	Region_6	7/31/2007	8.3	243.3	2.44	0.768	59
NLA06608-1147	Region_6	7/27/2007	8.89	621.2	13	1.414	775
NLA06608-1150	Region_6	7/19/2007	7.74	59.14	1.78	0.5	11
NLA06608-1177	Region_6	6/28/2007	6.31	27.1	6.57	0.328	24
NLA06608-1206	Region_6	8/2/2007	7.64	121.8	2.39	0.834	17
NLA06608-1219	Region_6	8/20/2007	9.02	1497	21.6	3.794	99
NLA06608-1223	Region_6	7/24/2007	9.47	269.3	51.6	4.053	422
NLA06608-1236	Region_6	8/16/2007	8.44	340.6	24.9	0.504	52
NLA06608-1263	Region_6	8/23/2007	8.32	391.9	7.88	0.453	33
NLA06608-1270	Region_6	39308	7.27	30.14	8.94	0.223	15
NLA06608-1274	Region_6	8/1/2007	7.28	30.3	0.868	0.285	4
NLA06608-1329	Region_6	8/8/2007	6.33	15.82	0.758	0.181	9
NLA06608-1333	Region_6	9/24/2007	7.41	42.01	0.78	0.166	3
NLA06608-1334	Region_6	8/14/2007	8.45	299.9	3.75	0.306	6
NLA06608-1339	Region_6	8/30/2007	8.24	3491	23.6	3.372	184
NLA06608-1349	Region_6	8/23/2007	8.1	248.8	2.82	0.804	30
NLA06608-1364	Region_6	6/20/2007	7.88	132.6	17.7	2.072	213
NLA06608-1368	Region_6	9/18/2007	8.28	856.6	21.7	1.18	110
NLA06608-1369	Region_6	6/21/2007	7.83	98.69	8.2	0.679	50
NLA06608-1396	Region_6	6/21/2007	8.36	221.9	2.86	0.255	19
NLA06608-1401	Region_6	7/11/2007	8.19	124.6	13.6	0.494	29
NLA06608-1413	Region_6	7/11/2007	8.59	374.2	29.4	1.614	25

NLA06608-1445	Region_6	7/18/2007	8.32	447.4	11.4	5.009	2670
NLA06608-1482	Region_6	7/24/2007	8.52	101.6	4.43	1.099	80
NLA06608-1492	Region_6	39313	8.57	242	9.66	0.758	41
NLA06608-1556	Region_6	8/14/2007	8.56	675.6	2.1	0.474	19
NLA06608-1560	Region_6	8/21/2007	7.6	161.5	3.75	0.852	42
NLA06608-1561	Region_6	6/19/2007	6.73	202.2	2.61	0.263	10
NLA06608-1608	Region_6	8/26/2007	7.05	75.78	4	0.498	64
NLA06608-1623	Region_6	7/19/2007	6.85	67.78	6.72	1.231	134
NLA06608-1679	Region_6	7/15/2007	8.44	316.4	1.33	0.366	8
NLA06608-1695	Region_6	9/6/2007	6.9	16.1	3.13	0.216	19
NLA06608-1735	Region_6	9/11/2007	5.95	28.14	7.27	0.679	60
NLA06608-1739	Region_6	7/20/2007	7.47	36.4	0.517	0.157	7
NLA06608-1755	Region_6	8/20/2007	8.44	383.9	2.7	0.646	30
NLA06608-1758	Region_6	7/23/2007	8.48	151.7	1.67	0.892	8
NLA06608-1789	Region_6	9/19/2007	7.06	100.4	1.06	0.501	1
NLA06608-1989	Region_6	8/2/2007	8.01	92.7	9.06	0.658	71
NLA06608-2039	Region_6	8/9/2007	8.61	315.9	97.6	4.691	277
NLA06608-2072	Region_6	8/30/2007	6.82	65.5	9.38	1.134	78
NLA06608-2074	Region_6	6/13/2007	8.07	93.76	13.4	1.004	72
NLA06608-2092	Region_6	9/15/2007	7.28	59.47	9.23	1.804	135
NLA06608-2094	Region_6	7/11/2007	7.13	28.45	5.55	0.438	35
NLA06608-2120	Region_6	7/25/2007	6.94	132.3	4.5	0.869	28
NLA06608-2123	Region_6	8/13/2007	9	1596	35	3.009	613
NLA06608-2177	Region_6	9/14/2007	8.34	221.8	0.5	0.334	3
NLA06608-2217	Region_6	6/5/2007	6.91	22.36	1.65	0.3	9
NLA06608-2219	Region_6	7/10/2007	8.55	344.3	3.99	0.634	33
NLA06608-2250	Region_6	7/29/2007	7.69	111.3	0.758	0.14	11
NLA06608-2253	Region_6	7/12/2007	7.85	236.5	10.2	3.591	86
NLA06608-2332	Region_6	8/9/2007	8.62	701.6	5.69	0.779	318
NLA06608-2345	Region_6	8/16/2007	7.71	899.5	3.76	0.391	15
NLA06608-2372	Region_6	8/28/2007	8.36	191.5	11.5	0.439	54

NLA06608-2418	Region_6	7/11/2007	7.52	187.9	7.57	0.366	35
NLA06608-2438	Region_6	9/11/2007	7.94	152.2	152	1.674	636
NLA06608-2492	Region_6	7/24/2007	7.59	83.32	7.05	0.337	33
NLA06608-2497	Region_6	7/17/2007	6.77	41.77	6.16	0.868	64
NLA06608-2507	Region_6	7/11/2007	8.61	371	4.26	1.101	34
NLA06608-2513	Region_6	8/21/2007	8.12	115.7	0.795	0.259	5
NLA06608-2524	Region_6	9/14/2007	8	151.9	4.87	0.58	33
NLA06608-2565	Region_6	8/22/2007	6.56	156.7	2.99	0.41	19
NLA06608-2593	Region_6	7/26/2007	8.56	248.6	4.74	1.337	41
NLA06608-2629	Region_6	7/10/2007	8.21	1924	6.21	1.188	66
NLA06608-2634	Region_6	7/30/2007	6.78	13.38	0.981	0.278	16
NLA06608-2640	Region_6	8/9/2007	8.64	371.4	13	1.113	48
NLA06608-2644	Region_6	8/20/2007	8.16	453.5	15.4	1.24	121
NLA06608-2655	Region_6	8/29/2007	9.46	174.6	3.15	2.286	102
NLA06608-2657	Region_6	9/13/2007	7.3	217.2	1.28	0.488	6
NLA06608-2663	Region_6	7/10/2007	8.35	449.8	1.16	0.561	13
NLA06608-2673	Region_6	9/18/2007	7.56	45.23	0.53	0.423	72
NLA06608-2685	Region_6	9/14/2007	6.72	16.61	2.41	0.169	7
NLA06608-2696	Region_6	7/26/2007	8.29	343.7	8.77	0.733	75
NLA06608-2704	Region_6	9/11/2007	7.93	687.3	52.2	1.672	105
NLA06608-2708	Region_6	8/8/2007	8.59	201.4	2.46	0.388	12
NLA06608-MN:51-0063	Region_6	9/5/2007	8.5	743.7	32.2	1.174	140
NLA06608-MN:56-0306	Region_6	9/17/2007	8.54	349.2	1.63	0.54	8
NLA06608-MN:61-0037	Region_6	9/25/2007	8.67	382.3	1.32	0.835	19
NLA06608-MN:74-0023	Region_6	9/12/2007	8.34	317.5	5.06	0.88	34
NLA06608-MN:75-0200	Region_6	9/7/2007	8.63	1041	21.8	2.647	446
NLA06608-MN:77-0019	Region_6	9/16/2007	8.44	397.9	3.44	1.065	17
NLA06608-MN:87-0030	Region_6	9/8/2007	8.55	1218	14.3	1.987	82
NLA06608-NELP-0253	Region_6	8/8/2007	6.69	20.1	0.465	0.183	4
NLA06608-NELP-0955	Region_6	8/29/2007	7.58	48.86	0.442	0.118	1
NLA06608-0006	Region_7	8/30/2007	7.49	77.04	1.15	0.229	6

NLA06608-0006	Region_7	8/30/2007	7.47	77.14	1.24	0.223	4
NLA06608-0013	Region_7	9/14/2007	5.62	48.51	4.15	0.264	20
NLA06608-0013	Region_7	9/14/2007	5.6	48.74	3.59	0.233	20
NLA06608-0033	Region_7	7/17/2007	7.54	109.5	12.2	0.835	67
NLA06608-0033	Region_7	8/28/2007	8	100.6	3.29	0.439	34
NLA06608-0036	Region_7	7/16/2007	8.66	129.9	1.32	0.241	9
NLA06608-0037	Region_7	9/5/2007	7.72	103.2	2.2	0.301	11
NLA06608-0053	Region_7	9/27/2007	8.14	215.6	6.23	0.275	19
NLA06608-0057	Region_7	6/16/2007	7.5	158.3	15.4	1.756	218
NLA06608-0071	Region_7	9/6/2007	8.79	241.7	14.4	2.441	415
NLA06608-0072	Region_7	7/26/2007	8.96	224.1	14.5	1.724	174
NLA06608-0078	Region_7	8/8/2007	9.18	2086	20.2	4.747	136
NLA06608-0085	Region_7	7/10/2007	8.24	213.8	137	1.581	417
NLA06608-0101	Region_7	8/21/2007	5.32	15.73	0.401	0.063	1
NLA06608-0120	Region_7	6/18/2007	8.03	569.6	80.3	1.174	315
NLA06608-0142	Region_7	8/13/2007	6.83	101.8	0.622	0.293	7
NLA06608-0148	Region_7	7/26/2007	8.33	251.6	1.5	0.342	16
NLA06608-0155	Region_7	7/31/2007	8.81	937.5	10.3	1.52	114
NLA06608-0158	Region_7	9/5/2007	7.74	72.24	1.52	0.651	16
NLA06608-0217	Region_7	6/24/2007	7.71	78.24	5.7	0.508	6
NLA06608-0234	Region_7	8/23/2007	8.14	271.5	1.23	0.584	14
NLA06608-0356	Region_7	7/16/2007	8.61	1269	47.4	2.897	167
NLA06608-0357	Region_7	7/27/2007	6.66	30.1	1.5	0.276	14
NLA06608-0361	Region_7	7/15/2007	7.67	99.69	1.92	0.171	19
NLA06608-0402	Region_7	9/6/2007	9.3	107.5	14	1.027	96
NLA06608-0467	Region_7	7/9/2007	8.37	396.5	3.53	0.788	15
NLA06608-0480	Region_7	9/25/2007	8.47	314.8	0.92	0.247	4
NLA06608-0508	Region_7	7/10/2007	7.8	76.03	86.2	0.756	283
NLA06608-0514	Region_7	7/24/2007	8.01	219.9	1.01	1.009	7
NLA06608-0564	Region_7	8/22/2007	7.73	84.09	3.69	0.217	14
NLA06608-0588	Region_7	7/13/2007	7.86	130.1	429	1.729	589

NLA06608-0591	Region_7	8/21/2007	7.88	72.58	2.12	0.182	5
NLA06608-0609	Region_7	7/25/2007	9.45	228.9	31.8	3.334	239
NLA06608-0624	Region_7	6/5/2007	8.6	280.3	6.3	1.274	49
NLA06608-0665	Region_7	6/27/2007	5.51	11.32	1.88	0.086	1
NLA06608-0723	Region_7	8/18/2007	9.01	395.3	2.74	1.433	24
NLA06608-0724	Region_7	8/13/2007	8.31	314	1.18	0.273	9
NLA06608-0749	Region_7	7/17/2007	7.5	61.33	7.95	0.464	50
NLA06608-0766	Region_7	7/18/2007	8.83	1973	5.34	1.673	40
NLA06608-0779	Region_7	7/31/2007	9.04	540.6	49	3.916	1543
NLA06608-0797	Region_7	6/28/2007	8.56	1049	5.32	0.418	24
NLA06608-0815	Region_7	7/17/2007	6.6	33.44	5.25	0.269	39
NLA06608-0837	Region_7	7/19/2007	8.74	500.6	9.95	1.46	109
NLA06608-0877	Region_7	39286	8.14	1774	3.84	0.878	14
NLA06608-0880	Region_7	7/17/2007	7.83	784.6	39.1	1.463	134
NLA06608-0893	Region_7	6/28/2007	8.28	176.1	3.28	0.303	14
NLA06608-0895	Region_7	7/9/2007	8.63	474.3	136	0.52	237
NLA06608-0915	Region_7	8/8/2007	8.14	392.8	5.19	1.41	102
NLA06608-0918	Region_7	8/14/2007	7.31	30.88	0.623	0.244	4
NLA06608-0942	Region_7	7/10/2007	8.58	241.9	0.942	0.306	6
NLA06608-0943	Region_7	9/11/2007	7.05	21.02	1.91	0.093	5
NLA06608-0971	Region_7	7/26/2007	8.57	326.8	4.05	0.787	54
NLA06608-0994	Region_7	8/23/2007	6.49	29.94	1.2	0.214	5
NLA06608-1052	Region_7	6/27/2007	8.54	982.6	11.2	1.329	295
NLA06608-1055	Region_7	7/24/2007	8.48	149.3	14.4	1.477	88
NLA06608-1060	Region_7	8/14/2007	8.95	116	18.7	2.153	232
NLA06608-1075	Region_7	8/27/2007	6.14	25.9	1.09	0.406	8
NLA06608-1101	Region_7	9/9/2007	8.68	397.7	20.8	1.713	109
NLA06608-1107	Region_7	8/27/2007	8.8	2870	63.9	7.75	733
NLA06608-1115	Region_7	7/30/2007	8.68	631.2	3.8	1.041	19
NLA06608-1122	Region_7	7/26/2007	7.23	131.2	2.01	0.318	9
NLA06608-1145	Region_7	9/12/2007	8.82	179.9	15.5	0.724	60

NLA06608-1153	Region_7	7/19/2007	8.11	104.8	0.358	0.224	3
NLA06608-1208	Region_7	7/12/2007	8.22	923.4	23.1	1.34	182
NLA06608-1227	Region_7	7/3/2007	8.41	353.3	2.68	0.487	8
NLA06608-1295	Region_7	7/12/2007	8.35	1697	55.9	0.74	138
NLA06608-1338	Region_7	6/27/2007	8.92	27370	1.5	4.316	182
NLA06608-1354	Region_7	7/28/2007	8.56	644	0.618	0.48	6
NLA06608-1358	Region_7	8/28/2007	7.7	79.23	1.48	0.288	11
NLA06608-1376	Region_7	9/26/2007	8.52	275.7	2.48	0.346	18
NLA06608-1389	Region_7	8/7/2007	7.53	151.5	6.81	2.506	86
NLA06608-1425	Region_7	8/7/2007	7.5	50.86	2.32	0.468	22
NLA06608-1469	Region_7	7/10/2007	7.59	96.29	18.7	0.576	112
NLA06608-1496	Region_7	9/6/2007	7.98	447.5	4.69	0.356	16
NLA06608-1504	Region_7	8/27/2007	8.6	198.8	13.2	1.199	68
NLA06608-1575	Region_7	7/24/2007	8.99	1429	16.6	2.503	215
NLA06608-1578	Region_7	8/21/2007	8.08	568.2	2.79	1.062	110
NLA06608-1637	Region_7	8/28/2007	7.48	62.85	4.34	0.44	32
NLA06608-1655	Region_7	6/6/2007	9.19	4557	69.5	12.241	896
NLA06608-1668	Region_7	7/17/2007	9.04	149.2	2.32	0.269	18
NLA06608-1684	Region_7	6/27/2007	8.45	334.8	4.27	0.338	17
NLA06608-1717	Region_7	9/25/2007	7.39	43.1	0.83	0.079	3
NLA06608-1723	Region_7	6/20/2007	7.73	999.7	1.05	3.516	1537
NLA06608-1733	Region_7	7/12/2007	8.68	349.5	20.9	3.516	45
NLA06608-1804	Region_7	6/27/2007	8.14	1132	5.59	0.699	120
NLA06608-1868	Region_7	8/15/2007	8.4	1040	2.47	0.676	21
NLA06608-2010	Region_7	7/19/2007	7.19	38.85	2.91	0.494	24
NLA06608-2082	Region_7	9/4/2007	7.87	118.4	3.35	0.496	17
NLA06608-2087	Region_7	7/25/2007	8.98	963.7	24.9	2.859	197
NLA06608-2131	Region_7	6/26/2007	8.9	2170	15.4	1.82	14
NLA06608-2193	Region_7	8/22/2007	5.12	79.71	1.44	0.294	15
NLA06608-2305	Region_7	7/16/2007	6.63	47.45	1.05	0.329	9
NLA06608-2426	Region_7	9/27/2007	9.18	50590	10.8	25.663	1697

NLA06608-2429	Region_7	8/14/2007	6.94	101.8	0.764	0.133	9
NLA06608-2450	Region_7	7/24/2007	7.38	87	0.817	0.148	3
NLA06608-2453	Region_7	7/10/2007	8.06	147.9	27.5	0.765	283
NLA06608-2457	Region_7	8/23/2007	7.84	325.5	4.23	0.314	16
NLA06608-ELS:1E3-002	Region_7	8/7/2007	8.39	90.23	2.52	0.731	14
NLA06608-ELS:1E3-012	Region_7	8/28/2007	7.59	53.73	0.822	0.161	4
NLA06608-ELS:1E3-071	Region_7	8/8/2007	7.81	68.89	2.61	0.807	17
NLA06608-ELS:2B2-008	Region_7	8/21/2007	6.21	16.88	0.587	0.299	8
NLA06608-ELS:2C2-048	Region_7	8/24/2007	6.6	13.65	0.834	0.593	8
NLA06608-ELS:2C3-018	Region_7	8/25/2007	7.06	26.08	1.11	0.328	10
NLA06608-ELS:2D3-008	Region_7	8/10/2007	8.32	252	0.52	0.722	13
NLA06608-EMAP:ME011L	Region_7	9/14/2007	7.14	34.56	0.97	0.246	13
NLA06608-EMAP:ME012L	Region_7	8/28/2007	7.59	52.52	0.399	0.129	1
NLA06608-EMAP:ME254L	Region_7	9/5/2007	7.38	44.85	0.681	0.204	5
NLA06608-EMAP:ME263L	Region_7	8/9/2007	6.55	19.48	1.14	0.314	11
NLA06608-EMAP:ME518L	Region_7	8/10/2007	6.95	22.32	0.495	0.156	7
NLA06608-FL:107895579	Region_7	8/1/2007	7.97	1634	3.68	0.985	33
NLA06608-FL:16674741	Region_7	8/3/2007	5.88	18.19	1.22	0.098	8
NLA06608-FL:18261987	Region_7	8/5/2007	4.82	76.14	2.92	0.474	20
NLA06608-FL:99324403	Region_7	8/4/2007	6.7	51.7	2.91	0.801	24
NLA06608-FL:99344895	Region_7	8/6/2007	6.6	41.05	10.7	1.531	166
NLA06608-IN:646	Region_7	7/31/2007	7.57	489.1	0.424	2.089	4
NLA06608-MI:7007	Region_7	8/1/2007	8.24	349.5	1.24	0.828	9
NLA06608-MN:03-0029	Region_7	8/8/2007	8.43	185.1	1.07	0.779	9
NLA06608-MN:06-0002	Region_7	9/6/2007	8.65	968.2	12.3	2.475	271
NLA06608-MN:11-0102	Region_7	8/11/2007	8.1	103.8	0.784	0.447	9
NLA06608-MN:15-0010	Region_7	8/9/2007	8.56	264.3	0.945	0.529	9
NLA06608-MN:22-0074	Region_7	9/11/2007	8.56	368.9	13.9	1.175	62
NLA06608-MN:49-0140	Region_7	9/24/2007	8.41	307.8	0.59	0.595	7
NLA06608-0003	Region_8	8/29/2007	8.47	1089	7.67	0.738	43
NLA06608-0004	Region_8	9/11/2007	8.24	326.7	7.41	0.584	44

NLA06608-0010	Region_8	39277	8.59	645.7	2.13	0.549	10
NLA06608-0012	Region_8	6/13/2007	7.64	219.5	50.3	1.026	159
NLA06608-0014	Region_8	8/6/2007	9.39	8722	7.1	4.147	175
NLA06608-0014	Region_8	8/23/2007	9.35	8625	6.18	4.456	175
NLA06608-0029	Region_8	9/11/2007	8.76	142.4	16.8	2.232	157
NLA06608-0031	Region_8	9/5/2007	8.19	347.9	6.24	0.394	24
NLA06608-0042	Region_8	7/6/2007	7.14	19.69	0.508	0.147	5
NLA06608-0042	Region_8	6/22/2007	6.6	21.54	0.712	0.246	17
NLA06608-0043	Region_8	7/31/2007	8.48	438.1	3.74	0.645	9
NLA06608-0043	Region_8	8/15/2007	8.52	414.2	2.94	0.714	11
NLA06608-0044	Region_8	7/30/2007	8.49	306.7	117	6.741	523
NLA06608-0044	Region_8	7/30/2007	8.47	310.2	117	7.216	554
NLA06608-0045	Region_8	8/2/2007	7.37	114.2	6.5	0.488	59
NLA06608-0045	Region_8	6/26/2007	7.52	103.3	9.45	0.648	54
NLA06608-0061	Region_8	6/12/2007	8.5	779.4	3.49	0.481	19
NLA06608-0061	Region_8	6/12/2007	8.5	775.8	3.02	0.495	20
NLA06608-0061	Region_8	8/22/2007	8.69	750.4	3.11	0.562	16
NLA06608-0062	Region_8	8/27/2007	9.02	3889	6.48	3.131	141
NLA06608-0064	Region_8	8/26/2007	8.77	3009	25.2	3.663	1331
NLA06608-0065	Region_8	9/12/2007	8.5	210.5	0.92	0.055	3
NLA06608-0068	Region_8	9/12/2007	7.82	231.7	0.29	0.127	0
NLA06608-0068	Region_8	7/9/2007	7.9	190.4	0.887	0.168	1
NLA06608-0072	Region_8	8/15/2007	7.91	218.2	39.8	2.265	176
NLA06608-0073	Region_8	7/18/2007	9.53	26820	0.752	1.75	4865
NLA06608-0079	Region_8	7/12/2007	8.03	84.35	0.278	0.097	4
NLA06608-0079	Region_8	8/16/2007	8.39	88.29	0.474	0.108	7
NLA06608-0080	Region_8	9/10/2007	8.46	406.4	8.44	1.063	116
NLA06608-0080	Region_8	9/9/2007	8.46	410.6	9.4	0.956	100
NLA06608-0080	Region_8	9/10/2007	8.39	407.4	11.9	1.047	113
NLA06608-0081	Region_8	9/19/2007	7.43	64.73	1.35	0.826	23
NLA06608-0102	Region_8	8/3/2007	6.69	20.01	0.515	0.137	1

NLA06608-0104	Region_8	6/22/2007	8.32	308.9	27.3	1.076	102
NLA06608-0111	Region_8	8/1/2007	7.96	395.2	3.45	0.343	6
NLA06608-0112	Region_8	7/9/2007	8.9	195.4	11.2	1.266	96
NLA06608-0128	Region_8	8/25/2007	9.74	613.5	26	3.963	549
NLA06608-0150	Region_8	8/2/2007	8.6	103.7	3.05	0.366	16
NLA06608-0161	Region_8	8/15/2007	8.28	768.1	3.56	1.069	30
NLA06608-0162	Region_8	8/28/2007	6.15	51.8	1.12	0.244	14
NLA06608-0167	Region_8	8/29/2007	8.5	1491	123	14.45	1061
NLA06608-0167	Region_8	8/29/2007	8.51	1469	122	14.538	1076
NLA06608-0174	Region_8	8/28/2007	8.85	663.1	1.62	0.803	13
NLA06608-0176	Region_8	9/7/2007	7.29	509.7	25.6	0.848	207
NLA06608-0179	Region_8	8/29/2007	8.59	16900	19.2	8.013	263
NLA06608-0180	Region_8	8/29/2007	8.56	285.3	33.1	0.721	61
NLA06608-0183	Region_8	7/25/2007	8.04	244.7	7.83	0.907	68
NLA06608-0184	Region_8	6/15/2007	8.2	446.6	16.9	1.049	100
NLA06608-0189	Region_8	39274	8.42	440.2	14.2	0.678	72
NLA06608-0190	Region_8	8/14/2007	7.8	76.11	1.16	0.666	16
NLA06608-0209	Region_8	9/27/2007	8.08	106.7	0.61	0.238	5
NLA06608-0212	Region_8	7/12/2007	7.81	130.6	2.53	0.088	8
NLA06608-0225	Region_8	7/11/2007	8.57	347.2	0.744	0.13	4
NLA06608-0228	Region_8	6/26/2007	8.43	801.8	0.826	0.408	25
NLA06608-0229	Region_8	9/13/2007	6.8	38.96	0.97	0.219	4
NLA06608-0241	Region_8	8/15/2007	8.3	825.5	14.9	0.774	80
NLA06608-0253	Region_8	8/8/2007	7.04	122.4	12	0.968	127
NLA06608-0259	Region_8	6/14/2007	7.99	1154	14.5	3.172	613
NLA06608-0260	Region_8	8/30/2007	8.22	203.4	3.72	0.136	8
NLA06608-0268	Region_8	9/10/2007	7.64	182.7	6.29	0.464	20
NLA06608-0290	Region_8	9/10/2007	8.17	184.3	196	1.316	573
NLA06608-0297	Region_8	7/24/2007	6.7	49.16	3.92	0.587	31
NLA06608-0313	Region_8	7/13/2007	6.61	48.25	2.93	0.279	24
NLA06608-0319	Region_8	7/22/2007	7.34	44.05	6.26	0.251	16

NLA06608-0328	Region_8	8/25/2007	8.24	160.8	9.92	1.093	82
NLA06608-0340	Region_8	6/21/2007	7.11	66.59	4.97	0.333	23
NLA06608-0344	Region_8	7/5/2007	8.68	404.3	6.15	0.848	53
NLA06608-0372	Region_8	8/3/2007	7.88	177.9	3.39	0.229	16
NLA06608-0373	Region_8	7/12/2007	8.04	178.8	0.36	0.104	1
NLA06608-0386	Region_8	8/7/2007	7.11	155.3	0.803	0.475	9
NLA06608-0388	Region_8	8/26/2007	7.07	39.83	1.09	0.035	1
NLA06608-0393	Region_8	7/23/2007	7.44	61.3	1.67	0.101	8
NLA06608-0395	Region_8	6/27/2007	8.33	266.6	5.01	0.231	13
NLA06608-0401	Region_8	8/27/2007	7.85	87.11	5.17	0.279	10
NLA06608-0402	Region_8	9/6/2007	9.24	108.4	38.5	1.523	154
NLA06608-0406	Region_8	8/21/2007	7.24	23.52	0.792	0.172	4
NLA06608-0449	Region_8	7/26/2007	8.96	215.3	2.56	0.404	16
NLA06608-0452	Region_8	6/15/2007	8.17	694.1	3.59	0.604	37
NLA06608-0472	Region_8	7/16/2007	7.34	90.94	25	0.803	78
NLA06608-0473	Region_8	6/19/2007	8.45	99.57	4.81	0.714	55
NLA06608-0509	Region_8	6/20/2007	7.75	352.4	1.09	0.821	4
NLA06608-0510	Region_8	6/27/2007	8.79	1329	20.1	2.916	165
NLA06608-0511	Region_8	9/6/2007	7.81	147.8	3	0.112	13
NLA06608-0531	Region_8	7/11/2007	8.4	9751	6.34	2.697	57
NLA06608-0541	Region_8	7/12/2007	7.31	275.6	2.71	0.329	14
NLA06608-0546	Region_8	7/18/2007	8.49	746.2	2.19	4.022	181
NLA06608-0562	Region_8	7/13/2007	7.03	105.6	1.03	0.334	9
NLA06608-0570	Region_8	7/27/2007	8.41	335.1	1.44	0.3	12
NLA06608-0585	Region_8	6/15/2007	7.87	261.3	38.4	0.505	105
NLA06608-0587	Region_8	8/14/2007	8.38	245.7	7.01	1.271	30
NLA06608-0595	Region_8	6/12/2007	8.53	2668	31.7	3.828	258
NLA06608-0617	Region_8	6/19/2007	7.77	84.62	11	0.513	40
NLA06608-0623	Region_8	6/20/2007	8.34	369.8	3.28	0.628	43
NLA06608-0627	Region_8	7/19/2007	7.79	168	1.62	0.616	11
NLA06608-0635	Region_8	8/22/2007	7.97	139.7	2.63	0.224	18

NLA06608-0654	Region_8	8/14/2007	6.83	22.1	2.68	0.698	22
NLA06608-0657	Region_8	9/13/2007	6.97	28.69	5.41	0.559	20
NLA06608-0663	Region_8	8/8/2007	9.12	2425	39.2	6.603	618
NLA06608-0686	Region_8	7/11/2007	9.31	553.4	1.3	1.343	122
NLA06608-0687	Region_8	8/14/2007	8.2	81.22	1.06	0.198	13
NLA06608-0690	Region_8	7/3/2007	7.21	137.9	1.1	0.479	15
NLA06608-0692	Region_8	7/10/2007	8.52	796.6	2.7	0.631	23
NLA06608-0709	Region_8	9/18/2007	7.45	190.1	16	2.492	202
NLA06608-0715	Region_8	7/6/2007	7.1	22.77	0.588	0.123	4
NLA06608-0717	Region_8	6/14/2007	8.22	209.9	29	2.03	225
NLA06608-0731	Region_8	8/7/2007	8.49	428.8	1.38	1.221	17
NLA06608-0759	Region_8	8/7/2007	8.94	392.9	73.6	4.153	360
NLA06608-0771	Region_8	8/13/2007	8.56	67.58	3.1	0.622	20
NLA06608-0782	Region_8	7/31/2007	6.74	35.02	1.41	0.443	7
NLA06608-0793	Region_8	6/18/2007	6.82	260	3.28	0.34	19
NLA06608-0794	Region_8	39257	7.15	21.86	0.361	0.079	0
NLA06608-0805	Region_8	8/22/2007	8.11	242.4	3.6	0.755	51
NLA06608-0806	Region_8	9/7/2007	6.89	39.13	3.31	0.427	20
NLA06608-0824	Region_8	9/5/2007	8.22	207	7.08	0.309	22
NLA06608-0827	Region_8	7/5/2007	8.48	476	5.75	0.543	23
NLA06608-0828	Region_8	7/11/2007	7.37	117.2	9.73	1.51	114
NLA06608-0834	Region_8	6/1/2007	8.63	1201	2.54	0.583	23
NLA06608-0836	Region_8	8/29/2007	9.85	339.4	3.3	1.184	51
NLA06608-0842	Region_8	8/1/2007	6.34	14.46	0.643	0.071	13
NLA06608-0849	Region_8	7/31/2007	7.18	44.35	0.649	0.189	5
NLA06608-0869	Region_8	8/9/2007	6.43	53.98	3.16	0.479	44
NLA06608-0872	Region_8	6/21/2007	8.11	287	60.8	1.129	276
NLA06608-0874	Region_8	8/30/2007	8.6	421.8	4.82	3.441	29
NLA06608-0889	Region_8	7/11/2007	8.41	295.1	33.8	0.404	204
NLA06608-0890	Region_8	7/30/2007	7.49	60.97	1.11	0.449	8
NLA06608-0927	Region_8	8/15/2007	9.29	425.4	1.11	0.498	18

NLA06608-0933	Region_8	7/31/2007	7.16	141.1	15.5	0.775	136
NLA06608-0934	Region_8	8/28/2007	6.35	4.35	0.237	0.01	1
NLA06608-0938	Region_8	8/7/2007	8.57	387.7	5.41	0.519	34
NLA06608-0940	Region_8	8/17/2007	8.81	683	11.2	0.866	37
NLA06608-0955	Region_8	6/3/2007	7.52	92.07	2.1	0.288	10
NLA06608-0970	Region_8	6/10/2007	6.48	28.38	0.564	0.14	3
NLA06608-0993	Region_8	9/20/2007	6.65	29.65	0.32	0.551	1
NLA06608-1001	Region_8	6/15/2007	5.57	17.19	3.33	0.416	24
NLA06608-1002	Region_8	6/28/2007	9.43	2695	1.49	1.536	378
NLA06608-1010	Region_8	8/9/2007	8.08	323.1	7.73	0.901	38
NLA06608-1024	Region_8	8/7/2007	8.54	690.8	2.98	0.439	19
NLA06608-1057	Region_8	8/14/2007	7.69	47.27	0.555	0.028	1
NLA06608-1059	Region_8	7/30/2007	8.71	388.9	13.1	1.406	161
NLA06608-1103	Region_8	8/28/2007	8.13	364.8	18.3	6.469	224
NLA06608-1108	Region_8	7/2/2007	8.66	333.7	11.1	1.083	102
NLA06608-1120	Region_8	8/27/2007	8.53	274.5	2.8	0.165	144
NLA06608-1129	Region_8	6/6/2007	7.86	77.69	3.01	0.336	12
NLA06608-1141	Region_8	7/9/2007	8.23	508.5	2.7	0.824	45
NLA06608-1162	Region_8	9/6/2007	8.43	279	0.851	0.541	8
NLA06608-1163	Region_8	7/2/2007	8.64	279.1	1.7	0.778	11
NLA06608-1179	Region_8	8/1/2007	8.88	989.5	22	2.741	133
NLA06608-1181	Region_8	6/26/2007	7.91	101.3	11.4	0.251	9
NLA06608-1185	Region_8	8/16/2007	8.51	628	17	2.869	62
NLA06608-1198	Region_8	7/25/2007	8.67	310.9	1.88	0.611	9
NLA06608-1217	Region_8	7/24/2007	7.89	67.61	6.76	0.547	64
NLA06608-1232	Region_8	8/22/2007	8.25	191.4	2.61	0.483	12
NLA06608-1258	Region_8	8/22/2007	7.55	100.2	0.86	0.712	16
NLA06608-1278	Region_8	8/21/2007	8.84	2466	11.1	1.965	303
NLA06608-1292	Region_8	7/20/2007	8.46	296	3.9	0.395	17
NLA06608-1300	Region_8	8/15/2007	8.48	850.3	2.68	0.229	5
NLA06608-1319	Region_8	8/7/2007	8.07	2435	29.3	4.791	241

NLA06608-1326	Region_8	8/6/2007	8.8	238.9	102	0.854	24
NLA06608-1342	Region_8	7/17/2007	7.3	41.04	2.89	0.279	12
NLA06608-1344	Region_8	7/10/2007	8.63	684.6	3.39	0.419	27
NLA06608-1367	Region_8	8/14/2007	8.51	850.5	46	5.338	242
NLA06608-1375	Region_8	9/4/2007	7.62	296.6	10.5	2.169	79
NLA06608-1380	Region_8	7/18/2007	8.62	481.7	1.29	0.524	21
NLA06608-1389	Region_8	8/29/2007	7.51	152.8	7.24	2.919	51
NLA06608-1390	Region_8	7/19/2007	8.65	397	3.01	0.553	15
NLA06608-1397	Region_8	7/10/2007	8.67	573.5	40.9	3.559	367
NLA06608-1414	Region_8	8/28/2007	7.14	135.5	1.97	0.319	17
NLA06608-1417	Region_8	7/31/2007	8.06	67.61	0.77	0.251	7
NLA06608-1436	Region_8	6/21/2007	7.94	536.2	3.93	0.478	20
NLA06608-1446	Region_8	8/29/2007	6.97	10.97	0.664	0.228	4
NLA06608-1447	Region_8	7/18/2007	8.74	436.7	1.25	0.76	13
NLA06608-1460	Region_8	7/26/2007	8.43	260.4	2.05	0.781	22
NLA06608-1462	Region_8	8/20/2007	8.85	913.7	221	1.404	450
NLA06608-1465	Region_8	8/21/2007	7.18	70.81	1.04	0.497	5
NLA06608-1484	Region_8	8/26/2007	7.22	33.52	2.75	0.105	11
NLA06608-1487	Region_8	8/20/2007	8.44	737.5	5.3	1.071	61
NLA06608-1499	Region_8	8/8/2007	8.4	308	1	0.483	17
NLA06608-1511	Region_8	6/12/2007	8.6	1546	2.22	1.446	373
NLA06608-1515	Region_8	8/29/2007	8.53	171.2	4.36	0.845	33
NLA06608-1562	Region_8	6/11/2007	7.77	493.1	1.65	0.348	16
NLA06608-1564	Region_8	6/26/2007	8.32	385.5	79.8	1.159	161
NLA06608-1569	Region_8	8/14/2007	8.09	252.2	4.32	0.978	22
NLA06608-1593	Region_8	8/8/2007	8.95	438.9	2.29	0.746	126
NLA06608-1595	Region_8	6/28/2007	8.5	1369	3.9	0.392	18
NLA06608-1596	Region_8	8/20/2007	9.82	2054	169	26.1	1491
NLA06608-1610	Region_8	8/15/2007	6.53	9.9	0.517	0.048	3
NLA06608-1631	Region_8	8/8/2007	8.46	185.8	7.98	1.209	130
NLA06608-1633	Region_8	7/13/2007	8.31	630.6	1.19	0.366	19

NLA06608-1672	Region_8	9/5/2007	8.28	346.3	56.5	0.51	15
NLA06608-1675	Region_8	7/23/2007	8.22	1410	1.35	0.521	16
NLA06608-1684	Region_8	8/21/2007	8.23	311.5	4.31	0.612	53
NLA06608-1707	Region_8	7/22/2007	8.5	379.5	4.36	0.723	8
NLA06608-1715	Region_8	9/6/2007	7.81	741.6	4.23	0.582	27
NLA06608-1724	Region_8	8/7/2007	9.06	548.1	13	1.282	55
NLA06608-1748	Region_8	7/31/2007	7.23	28.21	0.361	0.131	4
NLA06608-1771	Region_8	8/28/2007	8.37	302.4	1.15	0.603	10
NLA06608-1775	Region_8	8/24/2007	8.22	351.2	12.3	0.548	74
NLA06608-1791	Region_8	8/8/2007	8.51	177.1	1.18	0.401	5
NLA06608-1793	Region_8	7/23/2007	7.63	62.04	1.51	0.139	9
NLA06608-1802	Region_8	9/12/2007	8.45	533.6	3.82	0.536	18
NLA06608-1812	Region_8	8/27/2007	7.83	192.1	3.21	0.303	61
NLA06608-1818	Region_8	7/10/2007	6.81	17.62	5.47	0.09	7
NLA06608-1851	Region_8	8/21/2007	8.18	262.2	6.33	0.228	23
NLA06608-1861	Region_8	8/1/2007	8.12	1025	3.2	1.216	75
NLA06608-1867	Region_8	7/18/2007	8.48	497.1	8.46	2.091	74
NLA06608-1873	Region_8	9/11/2007	7.62	66.61	0.446	0.037	1
NLA06608-1884	Region_8	7/18/2007	8.72	324.5	4.15	2.334	39
NLA06608-1894	Region_8	8/8/2007	7.34	24.82	1.5	0.162	36
NLA06608-1906	Region_8	7/20/2007	7.44	202.1	3.58	0.368	14
NLA06608-1936	Region_8	9/13/2007	8.15	455.5	16.7	0.788	89
NLA06608-1948	Region_8	8/21/2007	9	490.5	7.91	2.981	486
NLA06608-2007	Region_8	6/24/2007	8.62	641.1	3.2	1.331	59
NLA06608-2036	Region_8	7/11/2007	8.28	389.7	3.13	0.278	11
NLA06608-2056	Region_8	8/22/2007	9.01	251.1	33	2.082	572
NLA06608-2078	Region_8	8/24/2007	7.38	33.39	1.66	0.569	7
NLA06608-2114	Region_8	7/25/2007	7.43	793.4	1.82	0.402	1
NLA06608-2152	Region_8	10/2/2007	8.12	266.2	1.65	0.535	29
NLA06608-2154	Region_8	7/23/2007	8.61	110.1	9.52	1.007	112
NLA06608-0041	Region_9	39280	7.46	85.32	0.922	0.4	1

NLA06608-0042	Region_9	6/22/2007	6.61	21.52	0.791	0.213	15
NLA06608-0050	Region_9	8/30/2007	6.9	24.99	2.88	0.361	17
NLA06608-0053	Region_9	8/23/2007	8.02	196	8.12	0.246	29
NLA06608-0079	Region_9	8/16/2007	8.33	88.31	0.478	0.126	6
NLA06608-0081	Region_9	7/3/2007	7.31	61.72	0.73	0.741	22
NLA06608-0081	Region_9	9/19/2007	7.48	64.05	1.63	0.904	31
NLA06608-0083	Region_9	8/9/2007	9.07	4698	5.78	4.009	60
NLA06608-0104	Region_9	7/24/2007	8.48	303	20.2	1.101	90
NLA06608-0115	Region_9	7/18/2007	7.41	324.2	0.616	0.54	5
NLA06608-0129	Region_9	9/16/2007	8.37	248.7	1.12	0.176	1
NLA06608-0169	Region_9	9/13/2007	8.45	215.9	9.32	0.726	95
NLA06608-0170	Region_9	9/21/2007	8.62	239.1	0.75	0.78	8
NLA06608-0179	Region_9	6/4/2007	8.29	12710	11.7	5.181	209
NLA06608-0254	Region_9	6/21/2007	8.74	1655	10.3	2.816	175
NLA06608-0277	Region_9	7/20/2007	8.54	471.3	11.7	0.451	117
NLA06608-0384	Region_9	6/28/2007	8.88	3714	2.61	4.291	68
NLA06608-0445	Region_9	6/28/2007	8.23	385.2	3.55	0.336	15
NLA06608-0447	Region_9	8/25/2007	7.32	96.98	0.573	0.079	3
NLA06608-0459	Region_9	7/16/2007	7.83	87.02	1.35	0.2	8
NLA06608-0493	Region_9	7/11/2007	7.96	174.8	3.3	0.353	15
NLA06608-0515	Region_9	6/28/2007	8.83	1895	14.2	4.984	335
NLA06608-0565	Region_9	7/19/2007	8.5	361.3	9.26	0.704	81
NLA06608-0583	Region_9	6/26/2007	8.94	210.9	32.5	4.897	590
NLA06608-0597	Region_9	7/9/2007	8.16	172.3	5.82	0.361	22
NLA06608-0630	Region_9	7/30/2007	9.06	153.1	1.34	0.771	8
NLA06608-0658	Region_9	7/26/2007	7.28	59.18	0.732	0.11	5
NLA06608-0671	Region_9	8/16/2007	6.75	12.98	2.4	0.38	19
NLA06608-0693	Region_9	7/25/2007	7.29	31.29	0.743	0.079	4
NLA06608-0696	Region_9	7/16/2007	7.98	183.1	12.6	0.829	252
NLA06608-0751	Region_9	7/25/2007	7.29	54	1.01	0.099	1
NLA06608-0755	Region_9	6/20/2007	8.32	1394	13.6	2.216	1104
NLA06608-0762	Region_9	8/16/2007	9.04	1054	53.7	3.94	264

NLA06608-0764	Region_9	6/26/2007	8.46	769.8	5.99	1.386	58
NLA06608-0770	Region_9	5/8/2007	8.52	1911	8.25	1.455	28
NLA06608-0781	Region_9	7/26/2007	8.62	404	4.39	0.729	34
NLA06608-0802	Region_9	7/20/2007	6.07	115.2	2.41	0.361	18
NLA06608-0980	Region_9	7/12/2007	7.89	120.4	11.5	0.923	176
NLA06608-0987	Region_9	7/30/2007	9.07	301.3	5.59	1.8	40
NLA06608-0997	Region_9	8/3/2007	8.47	200.3	0.54	0.204	4
NLA06608-1108	Region_9	6/21/2007	8.82	346.4	10.8	1.328	126
NLA06608-1119	Region_9	8/30/2007	7.08	30.1	6.14	0.265	16
NLA06608-1245	Region_9	6/29/2007	4.16	53.05	15.4	0.596	25
NLA06608-1262	Region_9	7/9/2007	8.45	191.6	5.26	0.788	33
NLA06608-1297	Region_9	9/13/2007	8.72	362.9	2.54	1.235	17
NLA06608-1321	Region_9	8/1/2007	8.39	363.4	2.26	0.168	10
NLA06608-1355	Region_9	7/3/2007	8.53	389.6	3.65	0.584	5
NLA06608-1377	Region_9	7/22/2007	7.08	15.99	0.473	0.101	8
NLA06608-1389	Region_9	8/29/2007	7.58	153.6	7.4	2.981	53
NLA06608-1391	Region_9	9/5/2007	8.21	870.3	27.5	1.36	172
NLA06608-1426	Region_9	7/23/2007	6.53	63.69	1.73	0.557	35
NLA06608-1483	Region_9	7/25/2007	7.3	27.26	0.873	0.274	13
NLA06608-1529	Region_9	6/19/2007	8.58	964.1	9.48	0.649	55
NLA06608-1602	Region_9	5/30/2007	8.5	1263	2.24	0.474	18
NLA06608-1638	Region_9	8/6/2007	6.46	4.84	0.339	0.05	6
NLA06608-1719	Region_9	6/18/2007	8.94	1582	44.5	8.803	441
NLA06608-1821	Region_9	8/9/2007	7.56	481.5	35.6	2.709	255
NLA06608-1836	Region_9	8/13/2007	8.06	224.6	31.4	2.766	246
NLA06608-1879	Region_9	8/22/2007	8.73	1875	27.7	4.075	328
NLA06608-1930	Region_9	7/24/2007	8.58	149.4	1.15	0.178	31
NLA06608-1953	Region_9	8/25/2007	8.2	147.8	2.13	0.226	15
NLA06608-2103	Region_9	6/13/2007	8.59	4562	7.96	3.503	170
NLA06608-2155	Region_9	7/25/2007	8.58	486.9	2.43	0.644	1
NLA06608-3911	Region_9	9/17/2007	7.53	150.8	5.78	0.643	43
NLA06608-4056	Region_9	7/5/2007	8.5	1320	5.71	0.651	75

NLA06608-4064	Region_9	7/31/2007	8.33	857.1	4.49	0.77	47
NLA06608-0004	Region_10	9/11/2007	8.25	326.7	7.33	0.596	46
NLA06608-0004	Region_10	7/10/2007	8.25	303.3	3.81	0.344	18
NLA06608-0021	Region_10	8/30/2007	8.48	358.5	2.36	0.463	11
NLA06608-0023	Region_10	9/19/2007	7.5	191.7	2.81	0.562	24
NLA06608-0037	Region_10	9/5/2007	7.73	100.1	2.23	0.338	14
NLA06608-0064	Region_10	8/26/2007	8.76	3016	25.3	4.075	1359
NLA06608-0064	Region_10	6/18/2007	8.7	2504	13.6	3.366	2047
NLA06608-0065	Region_10	9/12/2007	8.48	210.8	0.67	0.081	5
NLA06608-0065	Region_10	7/17/2007	8.39	197.1	0.253	0.07	1
NLA06608-0065	Region_10	7/17/2007	8.42	194.2	0.257	0.071	1
NLA06608-0066	Region_10	6/12/2007	7.36	114.6	1.92	0.665	7
NLA06608-0127	Region_10	7/11/2007	9.01	508	1.98	0.641	19
NLA06608-0134	Region_10	7/24/2007	7.17	57.55	0.468	0.156	4
NLA06608-0137	Region_10	9/17/2007	7.53	55.59	0.43	0.082	3
NLA06608-0174	Region_10	7/25/2007	8.88	642	2.22	1.002	19
NLA06608-0191	Region_10	7/21/2007	7.07	16.32	0.793	0.048	1
NLA06608-0207	Region_10	9/5/2007	7.22	46.4	2.42	0.419	18
NLA06608-0207	Region_10	9/5/2007	7.24	46.38	2.22	0.359	17
NLA06608-0216	Region_10	7/6/2007	8.48	329.7	30	1.367	619
NLA06608-0226	Region_10	7/9/2007	6.79	51.43	1.59	0.328	8
NLA06608-0283	Region_10	7/9/2007	8.08	382.9	5.45	0.381	33
NLA06608-0284	Region_10	7/30/2007	8.23	869.2	17.5	0.865	79
NLA06608-0290	Region_10	7/11/2007	8.1	142	46.7	0.273	178
NLA06608-0327	Region_10	6/27/2007	8.55	344.4	33.9	0.281	13
NLA06608-0376	Region_10	8/22/2007	7.62	249.5	2.4	0.324	6
NLA06608-0403	Region_10	8/6/2007	8.65	274.7	3.26	0.485	20
NLA06608-0439	Region_10	6/27/2007	8.6	2682	103	19.2	1056
NLA06608-0454	Region_10	7/25/2007	7.53	326.6	1.67	0.367	16
NLA06608-0470	Region_10	7/24/2007	7.23	65.55	0.663	0.193	8
NLA06608-0479	Region_10	8/16/2007	8.06	580.7	2.39	0.318	14

NLA06608-0489	Region_10	7/10/2007	8.81	135.3	14.6	1.275	107
NLA06608-0500	Region_10	9/14/2007	7.17	40.9	2.09	0.266	21
NLA06608-0512	Region_10	8/13/2007	8.78	684.7	8.27	2.447	61
NLA06608-0523	Region_10	7/16/2007	8.49	1799	8.86	1.738	115
NLA06608-0530	Region_10	8/7/2007	8.1	36000	3.66	1.016	117
NLA06608-0551	Region_10	8/20/2007	8.5	509.6	4.34	1.361	54
NLA06608-0555	Region_10	7/23/2007	8.53	682.4	3.91	0.578	8
NLA06608-0590	Region_10	8/7/2007	6.77	134.2	5.06	0.884	46
NLA06608-0628	Region_10	6/25/2007	8.34	461.7	13.2	0.793	40
NLA06608-0649	Region_10	9/19/2007	7.1	18.37	1.23	0.095	9
NLA06608-0707	Region_10	7/12/2007	8.93	9379	3	4.034	127
NLA06608-0713	Region_10	9/12/2007	7.82	71.25	1.86	0.138	7
NLA06608-0743	Region_10	6/26/2007	8.49	420.4	6.66	0.406	5
NLA06608-0761	Region_10	9/6/2007	8.81	381.8	13.3	0.403	12
NLA06608-0808	Region_10	9/6/2007	7.69	144.6	18.5	1.748	126
NLA06608-0809	Region_10	7/24/2007	8.51	324.5	2.01	0.546	13
NLA06608-0833	Region_10	8/7/2007	8.11	123.3	0.489	0.104	1
NLA06608-0905	Region_10	6/21/2007	7.64	44.69	0.534	0.358	12
NLA06608-0921	Region_10	6/25/2007	7.7	96.26	5.68	0.34	7
NLA06608-0922	Region_10	6/8/2007	8.28	661	2.45	0.226	12
NLA06608-0929	Region_10	6/16/2007	8.32	207.7	1.09	0.354	14
NLA06608-1036	Region_10	6/14/2007	8.21	419.3	12.6	0.856	94
NLA06608-1058	Region_10	9/5/2007	7.41	31.35	0.559	0.171	1
NLA06608-1114	Region_10	6/21/2007	7.25	806	7.24	0.558	63
NLA06608-1131	Region_10	6/26/2007	8.5	444.2	3.53	0.504	1
NLA06608-1148	Region_10	7/31/2007	9.01	1602	172	6.934	242
NLA06608-1167	Region_10	9/20/2007	8.43	429.5	1.92	0.461	5
NLA06608-1268	Region_10	7/17/2007	8.45	290.7	10.7	0.99	69
NLA06608-1269	Region_10	7/24/2007	9.64	746.7	13	1.911	646
NLA06608-1279	Region_10	8/26/2007	7.8	72.36	2.19	0.496	40
NLA06608-1281	Region_10	7/18/2007	8.88	139.3	0.658	0.4	4

NLA06608-1316	Region_10	8/17/2007	7.97	214.8	76.3	2.606	269
NLA06608-1334	Region_10	8/14/2007	8.45	302.4	3.93	0.314	7
NLA06608-1348	Region_10	8/8/2007	8.42	191.5	1.3	0.396	5
NLA06608-1356	Region_10	8/13/2007	7.01	78.42	3.03	0.416	21
NLA06608-1398	Region_10	8/17/2007	6.56	38.65	2.41	0.624	24
NLA06608-1421	Region_10	7/17/2007	9.39	156.4	19.9	1.1	41
NLA06608-1544	Region_10	7/25/2007	8.6	523	12.5	2.228	69
NLA06608-1630	Region_10	7/12/2007	8.36	729.6	9.33	0.806	57
NLA06608-1640	Region_10	7/26/2007	8.21	182.9	9.96	0.777	90
NLA06608-1654	Region_10	7/9/2007	7.78	76.29	1.65	0.354	6
NLA06608-1674	Region_10	7/27/2007	8.66	950.9	1.33	1.043	35
NLA06608-1687	Region_10	7/9/2007	8.66	639.5	10.8	0.918	441
NLA06608-1690	Region_10	9/10/2007	8.45	280.2	1.13	0.317	7
NLA06608-1706	Region_10	9/17/2007	8.47	640.8	0.72	0.563	6
NLA06608-1741	Region_10	7/9/2007	8.68	193.5	26.8	2.156	124
NLA06608-1800	Region_10	8/27/2007	7.64	133	6.04	0.604	50
NLA06608-1825	Region_10	9/11/2007	6.82	176.7	9.27	0.839	45
NLA06608-1840	Region_10	8/15/2007	9.19	301.3	10.7	1.361	216
NLA06608-1857	Region_10	7/25/2007	7.97	242.2	0.823	0.198	1
NLA06608-1866	Region_10	7/23/2007	8.01	446.3	0.733	0.232	11
NLA06608-1908	Region_10	8/7/2007	7.79	150.4	0.887	0.185	10
NLA06608-1910	Region_10	7/11/2007	8.57	186.1	6.14	0.83	37
NLA06608-1958	Region_10	8/27/2007	7.8	54.33	1.31	0.018	10
NLA06608-1960	Region_10	8/23/2007	7.68	185.2	37.3	0.403	108
NLA06608-1975	Region_10	8/8/2007	8.44	463.8	2.26	0.739	18
NLA06608-2049	Region_10	9/17/2007	8.41	292.9	0.88	0.276	5
NLA06608-2086	Region_10	8/29/2007	8.18	167	0.651	0.276	5
NLA06608-2091	Region_10	7/2/2007	8.04	144.4	5.1	0.401	53
NLA06608-2117	Region_10	9/25/2007	8.94	416.7	34.7	5.572	169
NLA06608-2135	Region_10	8/20/2007	8.47	1943	4.61	1.117	24
NLA06608-2185	Region_10	7/19/2007	8.25	142.7	2.01	0.188	15

NLA06608-2257	Region_10	8/24/2007	7.35	34.2	0.468	0.214	6
NLA06608-2267	Region_10	8/6/2007	8.56	420.5	3.42	0.793	25
NLA06608-2283	Region_10	7/17/2007	8.47	465	1.47	0.559	7
NLA06608-2333	Region_10	7/31/2007	7.6	77.06	19.2	2.311	75
NLA06608-2354	Region_10	7/13/2007	7.51	293.9	2.64	0.331	12
NLA06608-2379	Region_10	7/31/2007	8.16	9694	0.686	2.076	12
NLA06608-4320	Region_10	9/10/2007	7.73	640.7	11.2	1.871	177
NLA06608-4382	Region_10	9/10/2007	7.86	302.4	10.5	0.571	35
NLA06608-4413	Region_10	7/18/2007	6.37	90.21	1.05	0.251	8
NLA06608-4414	Region_10	8/29/2007	7.44	94.85	5.3	0.48	38
NLA06608-4440	Region_10	9/4/2007	8.37	262.4	7.32	0.803	38
NLA06608-4472	Region_10	8/7/2007	8.67	658.3	35.1	0.816	282
NLA06608-4504	Region_10	6/5/2007	7.42	141.9	4.32	0.68	32
NLA06608-4610	Region_10	7/24/2007	8.37	358	2.01	0.426	22
NLA06608-4643	Region_10	8/21/2007	7.15	156.2	4.67	0.557	19
NLA06608-4650	Region_10	9/13/2007	7.21	79.2	5.94	0.681	43
NLA06608-4659	Region_10	9/19/2007	8.1	949.9	15.6	1.247	90

CHAPTER III

IMPACTS OF SOCIAL INDICATORS ON ASSESSING THE RECOVERY POTENTIAL OF IMPAIRED WATERSHEDS

ABSTRACT

An analysis was carried out to understand how watersheds' potential for restoration was impacted by social indicators. This study employed the USEPA Recovery Potential Screening tool, a decision support system, to compare 51 watersheds in the state of Mississippi, USA, using ecological, stressor, and social indices, and the recovery potential integrated (RPI) index. An in-depth analysis was performed on four watersheds in the Delta region of Mississippi (Lake Washington, Harris Bayou, Steele Bayou, and Coldwater River), each impaired by sediments and nutrients. Sixteen social indicators were categorized into three subcategories: Socio-Economic, Organizational, and Informational.

Watersheds with lower social indices had lower RPI scores. In the particular watersheds studied, the Socio-Economic subcategory was observed to be the most impactful to the overall recovery potential when compared to the other two social subcategories. As a sensitivity analysis, a "what if" simulation was performed to explore alternatives to upgrade a watershed's social index and, consequently, the relative recovery potential of the watershed to a target level. This analysis is useful for understanding how particular social indicators of a community impact the relative potential for recovering a watershed, beyond just the ecological and stressor conditions. It also sheds light on assessing which social indicators can be improved.

3.1 INTRODUCTION

Surface waters are adversely influenced by a wide variety of pollutants generated from human activities. When the water quality of a watershed is degraded to the point that it can no longer meet its water quality standards or designated uses—such as supporting fish and wildlife or recreation —it is listed as an impaired watershed. According to the U.S. Clean Water Act, section 303(d), impaired watersheds can be restored to ensure the continuation of their benefits for communities and natural aquatic environments (Clean Water Act 1972). However, when a large number of watersheds is impaired in a given geographical area, the capacity of governing agencies to restore all of them at once is limited. Therefore, agencies need to develop a prioritized restoration schedule.

The concept of prioritizing watersheds for restoration has been developed and applied to a wide set of environmental problems. A method to prioritize watersheds based on their recovery potential, applicable for different environments and program goals, was explored by Norton et al. (2009). This approach is currently offered by the US Environmental Protection Agency (EPA) as a Recovery Potential Screening (RPS) Tool to compare watersheds in support of surface water quality management programs in states (USEPA 2018a). The RPS Tool allows users to select indicators and weights relevant to a specific screening objective, generating a gradient of relative scores among the watersheds compared.

Other examples of water body prioritization include the work by Lin and Morefield (2011), who prioritized management options for coastal communities based on socio-economic, land use, and estuary condition indices. Several other studies prioritized water bodies using ecological and economic factors for the implementation of best management practices; an example is demonstrated by Jang et al. (2013). This approach prioritized watersheds to understand suites of agricultural best management practices for reducing sediment load. Jang et al. (2015) prioritized water bodies for conservation actions to reduce erosion and sedimentation. A similar study by Merovich et al. (2013) established priority sites for conservation by classifying watershed conditions into hierarchical spatial scales. Hall et al. (2014) established an ecological function and services approach for prioritizing water bodies for the development of total maximum daily loads for nonpoint source–related impairments. The prioritization approaches, as shown in the reviewed literature, focus on a holistic approach that considers the conditions of the human dimension and the biophysical environment.

The objective of this study was to understand the implications of how social indicators can affect the comparison and ranking of the impaired watersheds for recovery potential. This was studied using the RPS Tool and conducting an analysis of the impact of the selected social indicators.

3.2 BACKGROUND

Decision-making on a large number of watersheds compared for their relative recovery potential is a multi-criteria process and is described in Norton et al. (2009) as needing a multi-metric index. There are several watershed features that indicate the likelihood of restoration success or a watershed’s readiness for restoration action. These indicators can be used for prioritizing the recovery potential of impaired watersheds. The relevance of these indicators to recovery potential ranking can vary with the varying circumstances of impairments. For example, one might need to choose which watersheds are likely the most restorable from a particular impairment type; which watersheds are the most restorable based on a particular indicator; which watersheds might be significantly more difficult to restore; or which set of criteria can upgrade the relative recovery potential score of a watershed to the next level. This process involves a multi-criteria decision-making process, where the choices of alternatives are made using indicator values and their assigned weights as criteria. A multi-criteria decision analysis (MCDA) method enables users to select indicators and assign weights in a flexible manner for decision-making processes for problems involving multiple objectives (Mabin and Beattie 2006). A decision on the multiple objectives is made by evaluating a number of alternatives that best fulfill the objectives.

Previous applications of MCDA in watershed-related areas include natural resource management (Mendoza and Martins 2006), water resource planning and management (Hajkowicz and Collins 2007), and environmental projects (Haung et al. 2011). The reviewed literature indicated the complexities of natural systems and noted the need to embrace the social, biophysical, and ecological issues to address the multiple concerns and the conflicting objectives of stakeholders. The MCDA methods in these references share the same theoretical approach, where the decision model is built on a set of criteria, a set of decision options, and a set of performance measures. The weighted summation algorithm was the most commonly used method, which is mathematically represented as Equation 14.

$$S_i = \sum_{i=1}^{m} V_{i,j} W_j \quad \text{(Equation 14)}$$

where Si is the overall performance score in a scale of -1 to 1, Vi,j is the transformed performance score of a given criteria [i,j] on a scale of -1 to 1, and Wj are the weights that sum to 1.

To compare large numbers of water bodies and their watersheds, the RPS Tool was developed by using indicators within ecological, stressor, and social categories that influence the success of a restoration effort (USEPA 2018b). The ecological category represents the biophysical condition and ability of a watershed to regain functionality. The stressor category reflects the disturbances to the watershed's condition from a variety of pollutant sources. The social category is related to the capacity of organizations and the condition of communities in a watershed's surrounding area linked to favoring activities that improve the quality of that water body. Social indicators are broad, and their subcategories include leadership, organization, and engagement; protective ownership or regulation; level of information, certainty, and planning; restoration cost, difficulty or complexity; socio-economic considerations; and human health, beneficial uses, recognition and incentives (USEPA 2018b). The user's choice of indicators and their weights for a given restoration assessment depends on what is most appropriate to the watersheds being assessed, the availability of data, and the management objectives of the restoration. By measuring the same indicators on all watersheds of interest, an objective comparison can be performed. The recovery potentials are compared based on separate ecological, stressor, and social indices and the Recovery Potential Integrated (RPI) index that combines the indices of the three categories.

The focused analysis presented in this paper is on social indicators' impact on the recovery potential of a watershed, and we present here some background on the literature. The relationship between social indicators and quality of life (which is in part described by social indicators) of a region can relate to the opportunities that are provided to meet human needs in the forms of built, human, social, and natural capital, and the policy options that are available to enhance these opportunities (Costanza et al. 2006). Felce and Perry (1995) discussed five dimensions of quality of life: physical well-being, social well-being, material well-being, emotional well-being, and development and activity. The European Union defined the so-called '8+1' dimensions of quality of life: living condition, productivity, health, education, social interaction, economic and physical safety, governance and basic rights, natural and living environment, and overall life experience (European Union 2015). Other studies attribute people themselves (mainly via socio-economic indicators), and the condition of the physical and the policy environments in which people live, as important domains of quality of life (Ferrans 1990; Cella 1994; Mandzuk and McMillan 2005).

The numerical value assigned to each social indicator can vary among the surrounding communities of different watersheds. According to the EPA's research in developing the RPS Tool, social indicators can affect the recovery potential of a watershed. Therefore, it follows that if the values of a social indicator vary among watersheds, then recovery potential will also vary. Other examples of the relationship between environmental quality and well-being are documented in a literature review by Kamp et al. (2003). Case studies conducted by Pacione (2003) discussed that quality of life needs to be viewed in the geographical scale, and the problems associated with it should be addressed in a socio-spatial context. This is consistent with the RPS approach that recommends consideration of social metrics for comparing restoration potential across a range of geographically separate impaired watersheds.

3.3 STUDY AREA

This study first screened 51 watersheds at the 12-digit hydrologic unit code (HUC) subwatershed level, from different regions in the State of Mississippi, USA. Major water bodies included in these 51 watersheds were the Noxubee, Biloxi, Pearl, Little Tallahatchie, and Big Black Rivers and Pickwick Lake. The further in-depth analysis was narrowed to four impaired watersheds of elevated interest to the Mississippi Department of Environmental Quality (MDEQ) and located in the Yazoo River Basin, in the Delta region of Mississippi. These watersheds -- Lake Washington, Harris Bayou, Steele Bayou, and Coldwater River (Figure 10)– are impaired for sediments and nutrients that are harmful to fish and wildlife. The Mississippi Department of Environmental Quality (MDEQ) considers these to be priority water bodies. A restoration effort for these watersheds is expected to improve water quality by reducing sediment and nutrient loads. Some general characteristics of the four selected watersheds are shown in Table 11.

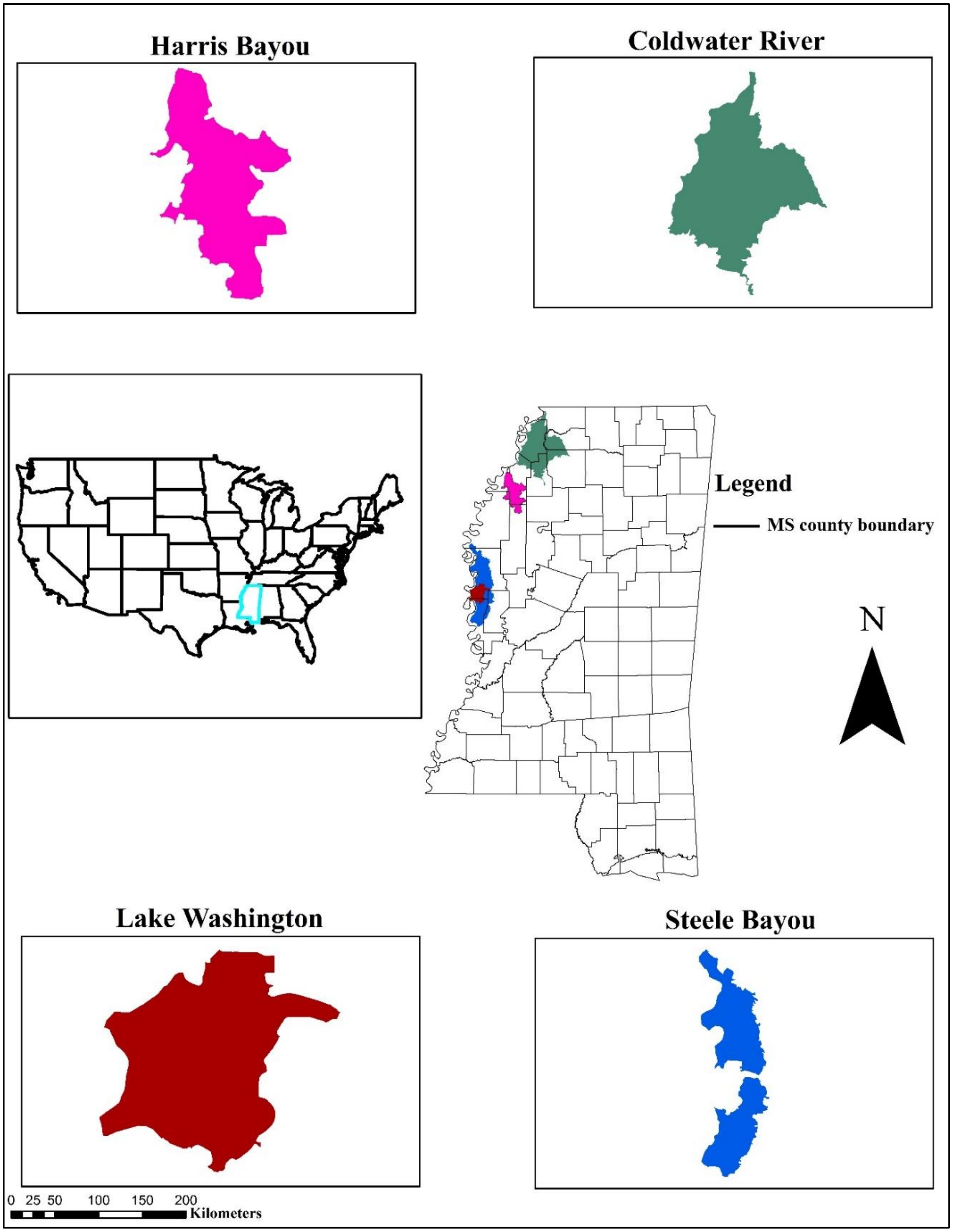


Figure 10. Watershed boundaries of the four studied water bodies in the Delta region of Mississippi.

Table 11 Hydrological, geographical, and demographic characteristics of the studied water bodies[a].

	Lake Washington	**Harris Bayou**	**Steele Bayou**	**Coldwater River**
Hydrologic unit code[b]	08030209	08030207	08030209	08030204
Counties[c]	Washington	Sunflower and Coahoma	Bolivar, Washington, and Issaquena	Tunica and Coahoma
Type of water body	Lake	River	River	River
County level population in 2013	49,688	53,179	85,132	291,273
Type of impairment	Sediments and nutrients	Sediments and nutrients	Sediments and nutrients	Sediments and nutrients

Sources: MDEQ (2016) and the US Census Bureau (2016).
[a]8-digit hydrologic unit code (HUC-8) assigned by the United States Geological Survey.
[b]Counties are listed only if at least half of the county area is within the watershed.

3.4 METHODS

The basic steps applied in this watershed comparison, for both the screening and in-depth analysis, include indicator selection, data collection, recovery potential scoring, and ranking. The in-depth analysis of the four selected watersheds included the development of a "what if" sensitivity analysis based on changing the numerical values of social indicators.

3.4.1 Indicator Selection and Measurement

This study employed the RPS Tool for selection and measurement of candidate indicators. This tool contains 285 recovery potential indicators—within the ecological, stressor, and social categories —that likely indicate the success of a restoration effort. These indicators are pre-installed in the tool, which is a Microsoft Excel workbook specific for each U.S. state, the U.S. Virgin Islands, and Puerto Rico (USEPA 2018c). Users can add more indicators as available and modify their weights as appropriate. In the case of this study, additional social indicators were added as explained later. The process of indicator selection requires a clear idea of the impairment type of the watersheds being assessed, the availability of data, and the objectives of the assessment.

For this study, we screened the RPI of 51 watersheds throughout the state by using the Mississippi-specific RPS Tool (USEPA 2018d). The Mississippi RPS Scoring Tool automatically calculated the RPI scores. We performed this initial step to obtain an overall view of how watersheds in Mississippi compared with one another since that is the main purpose of the RPS Tool. Then, seeing that four priority watersheds obtained low RPI scores, we focused on those four in detail.

For the four priority watersheds, we considered indicators outside of the pre-installed Mississippi RPS Scoring Tool, especially in the social category. Indicators that have data available for all four watersheds were selected (Table 12 and Table 13). Most indicators were represented by quantitative measurements, while some were represented by qualitative measurements. Qualitative measurements were converted to numbers based on the available RPS literature for the relationships between the indicators and restorability (see, for example, watershed shape in Table 12).

Table 12 Measured values of candidate indicators within the ecological and stressor fields[a].

Indicator	**Code**	**Lake Washington**	**Harris Bayou**	**Steele Bayou**	**Coldwater River**
Natural land cover (%)[a]	Eco1	29.0	12.0	25.6	29.0
Forest land cover (%)	Eco2	1.00	0.56	16.5	5.0
Wetlands land cover (%)	Eco3	16.0	11.0	5.0	6.0
No. of impairments	Eco4	2	2	2	2
Approximate watershed shape[a]	Eco5	Circular	Needle	Needle	Circular
Watershed size (hectares)	Eco6	11,169	28,699	81,223	236,872
[a]Natural land cover represents a vegetated portion of land					
Indicator	**Code**	**Lake Washington**	**Harris Bayou**	**Steele Bayou**	**Coldwater River**
Agricultural land cover (%)	Stressor1	69.0	79.4	71.5	67.1
Urban land cover (%)	Stressor2	4.0	7.3	3.3	1.0
Aquatic barriers[b]	Stressor3	0	0	1	0
Relative water level change[c]	Stressor4	2	0	1	2

Sources: MDEQ (2016) and the US Census Bureau (2016).
[a]A circular watershed shape (scored value of 0) is associated with poor water quality with a higher risk of destabilized channels when compared to an elongated shape watershed (scored value of 2) (Potter et al. 2005).
[b]The presence of barriers, such as weirs and dams, may fragment or diminish aquatic population. A higher score reflects a higher number of barriers that put more stress to restoration.
cA change during the summer season. A higher score indicates a higher water level reduction, whereas a lower score reflects that the water is kept at or near the same level due to the supply of water from irrigation returns or regulating hydraulic structures.

Because the focus of this study was on the social category related to the recoverability of the four selected watersheds, sixteen social indicators were selected, and values were determined for each (Table 13). The social indicators were categorized into three subcategories: Socio-Economic, Organizational, and Informational. The Socio-Economic subcategory is composed of indicators related to the well-being of a watershed's community. This subcategory was used because integrating Socio-Economic measures helps in the decision of efficient and effective management systems (Bowen and Riley 2003; Curtis et al. 2005; Morton and Padgitt 2005; Chaves and Alipaz 2007). The Organizational subcategory includes indicators related to the availability of adequate organizational capacities. Natural resources are too complex to be managed effectively by a single agency, and their management requires a partnership among multiple parties to develop the necessary institutional capacity. Watershed organizations can contribute to environmental sustainability through knowledge, resources, and the power to bring about positive attitudes, and develop an institutional capacity for better water management (Shrivastava 1995; Pahl-wostl et al. 2007). The Informational subcategory reflects indicators related to the availability of information about the status of the watersheds and the availability of pre-existing restoration plans. For example, Norton et al. (2003) discussed that adequacy of information is a key factor for evaluating an aquatic system. Ducros and Joyce (2003) also indicated that the information from a pre-existing general management plan could serve as a basis for a restoration plan. Further information can be found in the RPS Tool literature (USEPA 2018e)

Table 13. Measured values of candidate indicators within the social field[a].

Indicator	Lake Washington	Harris Bayou	Steele Bayou	Coldwater River	Sub-categories[a]
Population change, from 2000 to 2010	-18.80	-17.98	-5.42	-14.45	S-E
Median income per household, 2013	28,093	28,241	27,880	26,519	S-E
Unemployment rate, 2013[b]	(-)21.40	(-)19.99	(-)16.71	(-)20.61	S-E
Population below poverty level, 2013 (%)[b]	(-)37.30	(-)36.02	(-)35.87	(-)37.09	S-E
Employment change, between 2000 and 2013	-9.82	-6.29	-3.11	-5.85	S-E
Bachelor's degree or higher graduates (%), 2008–2012	18.50	15.20	15.07	14.56	Org
Number of watershed-level organizations	1	1	9	9	Org
Number of universities/colleges	0	2	1	2	Org
Assessed miles/acres (%) of a water body	100	100	33	100	I&P
Known no. of probable sources of pollutants	1	0	0	1	I&P
Years since last update on watershed implementation plans	6.19	5.89	2.17	4.19	Org
Recreational resources	2	1	0	2	I&P
Monitored water quality data availability, in years	2	5	3	4	I&P
Ratio of number of completed TMDL/number of impairments	0.70	1.00	1.00	0.25	I&P
Number of existing beneficial uses of a water body	2.0	2.0	3.0	2.0	S-E
Large watershed management potential[c]	0.5	0.5	1.0	1.0	Org

Source: MDEQ (2016) and the US Census Bureau (2016).
[a]S-E = Socio-Economic; Org = Organizational; Info = Informational
[b]Values were entered in the RPI formula as negative because these indicators contribute negatively to recovery potential.
[c]This indicates the portion of a watershed impaired within a HUC-10 unit. A score of 1 indicates a major section of the HUC-10 unit is impaired and better attracts state water programs for restoration action. A score of 0.5 indicates only a small portion is identified as impaired.

3.4.2 Development of the Sensitivity Analysis Model

This study used the RPS Tool, which uses MCDA techniques, to normalize, and auto-calculate the ecological, stressor, social, and RPI indices as set up by the user. For this analysis, the set of criteria focused on the social indicators. A higher RPI index indicates a higher recovery potential. The RPI index is based on Equation 15.

$$\mathrm{IRP}(c) = \frac{[Ecological + Social\ (c) + (100 - Stressor)]}{3} \qquad \text{(Equation 15)}$$

Here, RPI(c) is the integrated recovery potential index as a function of evaluation criterion *c*, the social index is the aggregated score of social context indicators as a function of evaluation criterion *c*, the ecological index is the aggregated score of ecological indicators based on the baseline data, and the stressor index is the aggregated score of stressor indicators based on the baseline data. A higher ecological index indicates a higher recovery potential, whereas a higher stressor index indicates a lower recovery potential. The ecological or stressor indices were calculated Equation 16.

$$\text{Ecological or Stressor index} = \frac{\sum_{i}^{n} f(Ecological\ or\ Stressor)_i}{\sum_{i}^{n} W_i} \qquad \text{(Equation 16)}$$

Here, f is the sum of normalized values of n number of ecological indicators (in the case of the ecological index) or stressor indicators (in the case of the stressor index); and W is the sum of the allocated weights. All indicators used in this study were considered at equal weights for demonstration purposes, although a decision maker can change the weights according to the knowledge of the site conditions.

Normalization was accomplished by a general linear transformation formula to standardize the raw data to (0, 1) intervals using Equation 17.

$$X_s = \frac{X_0 - X_{min}}{X_{max} - X_{min}} \qquad \text{(Equation 17)}$$

Here, X_s is the normalized value, X_o is the raw value, X_{min} and X_{max} represent the minimum and maximum observed values of X, respectively.

The social index was the decision analysis factor subjected to vary for different criteria and was calculated using an MCDA-based formula as shown Equation 18.

$$\text{Social index}(c) = \frac{S_1(c)+S_2(c)+S_3(c)+\ldots+S_n(c)}{W_1(c)+W_2(c)+W_3(c)+\ldots+W_n(c)} \qquad \text{(Equation 18)}$$

Here, the social index is a function of evaluation criterion *c*, $S_n(c)$ is the normalized social indicator value as a function of evaluation criterion *c*, and *W* is the weight allocated to evaluation criterion *c*. A higher social index indicates a higher recovery potential. In this study, equal weights were used, and the four watersheds' social indices were compared based on the three social subcategories defined in this study: Socio-Economic, Organizational, and Informational.

3.4.3 Sensitivity Analysis on the Four Priority Watersheds

After all of the indices were calculated, a set of alternatives was generated for evaluating the sensitivity of the RPI index to social indicators. Social indicator values were changed iteratively to understand what set of alternatives could upgrade the recovery potential score of a watershed to a target level. This analysis approach was conducted in the form of a "what if" simulation to upgrade a watershed's social index. This gives decision makers a chance to compare and understand a wide range of social efforts that may be necessary for a restoration plan. This information can be used to support restoration plans for different management goals. This approach evaluated the level of difference in watersheds' social subcategories and simulated a set of alternatives that could satisfy the target level.

A Microsoft Excel–based sensitivity analysis interface was developed for selected indicators and the four water bodies by employing Equations (15), (16), (17), and (18). In this application, by assigning different combinations of indicators and weight criteria, the recovery potential scores can be calculated. The 16 social context indicators are listed in six control boxes (Figure 11). The user can select six combinations of indicators and weights at one time. The measured baseline values of each indicator and the corresponding default weights display automatically upon selection of indicators. Each control box is underlain by an entry row to allow users to enter a "what if" criterion. In the data spaces provided in the "what if" row, either a new value should be provided, or a default value should be copied from the previous row. Further instructions on the use of the Excel application are included as a separate sheet in the Excel file.

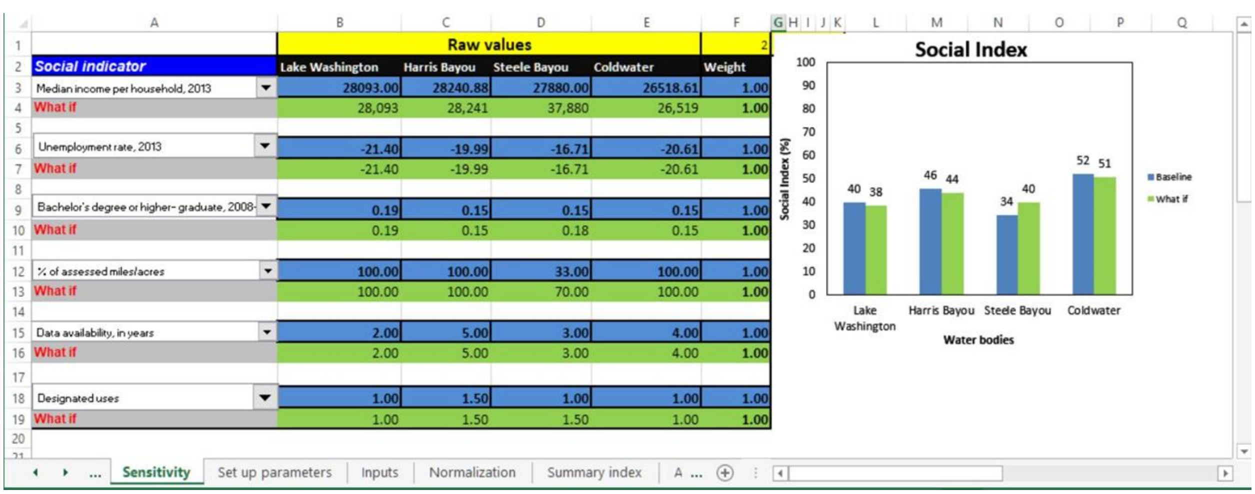


Figure 11. A screenshot of the Microsoft Excel-based sensitivity analysis interface.

3.5 RESULTS AND DISCUSSION

In this section, the screening and in-depth analysis are reported. The RPI scores of 51 watersheds were compared to obtain a state-level context. The four target watersheds in this paper were some of the lowest-scoring. The RPI indices for the four watersheds were calculated using revised indicators. These indices served as a reference to evaluate the social indicator values in depth. Further, using the potential future improvements in the social conditions, several possible alternatives were evaluated to explain what future developments and improvements would be necessary to improve the recovery potential.

3.5.1 Initial Results using the U.S. EPA-RPS Tool

The RPI scores of 51 watersheds in Mississippi are displayed in Figure 12, which shows the relative recovery potential distribution across the state (for the full tool, see Supplementary Materials, Microsoft Excel spreadsheet ms-rps-scoring-tool-Sinshaw&Surbeck.xlsx). RPIs varied from 28 to 64. The RPI scores of four priority watersheds in the Delta region (western part of the state) were in the lower end of the indices, from 28 to 36. As a result, we further analyzed the Delta region watersheds' RPI score using other easily available ecological, stressor, and social indices of relevance to those watersheds that were not necessarily pre-installed in the RPS Tool. The next section discusses the comparison of the four selected watersheds in the Delta region.

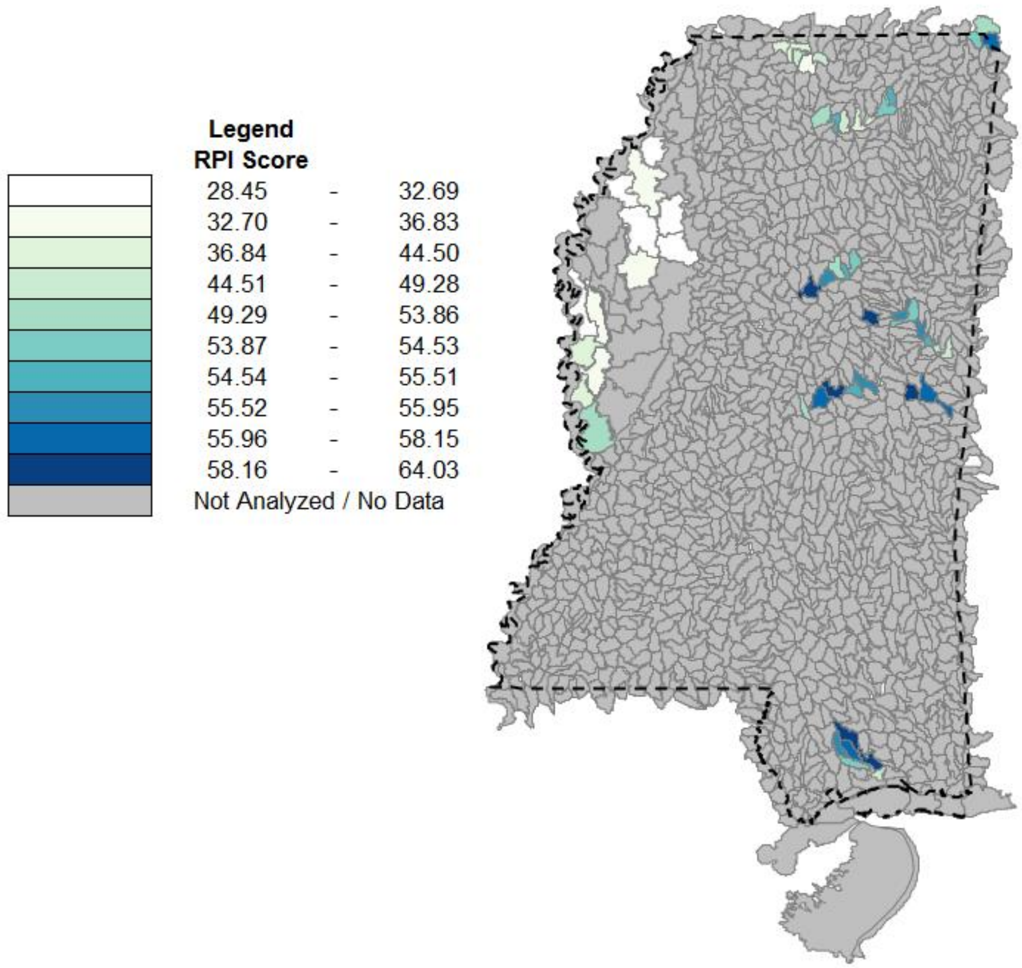


Figure 12. Screened watersheds in the state of Mississippi.

3.5.2. Evaluation of Indices for Four Priority Watersheds

The indices of the three indicator categories (ecological, stressor, and social) from Tables 12 and 13 were aggregated as an RPI index. The social, ecological, and stressor index results, calculated using Equations 16 and 18, are shown in Figure 13. The RPI indices, calculated using Equation 15, for Coldwater River, Harris Bayou, Steele Bayou, and Lake Washington were 54.61, 49.99, 46.18, and 35.14, in the order of most to least restorable, respectively. It is evident from Equation 15 that a watershed with a lower social index will have a lower RPI index. This result could be interpreted by a user as watersheds having lower social index being the lower priority for a restoration project. It is important for watershed managers to understand that the RPS Tool ranks relative differences in difficulty, rather than desirability, of restoration, and that even the choice of indicators will influence the RPI index. Lower social scores may be evidence of the need to raise social context for otherwise promising (e.g., ecologically healthy or lower-stressed) watersheds. Therefore, in practice, the ecological and stressor indices are used more frequently than the social index (Norton 2017).

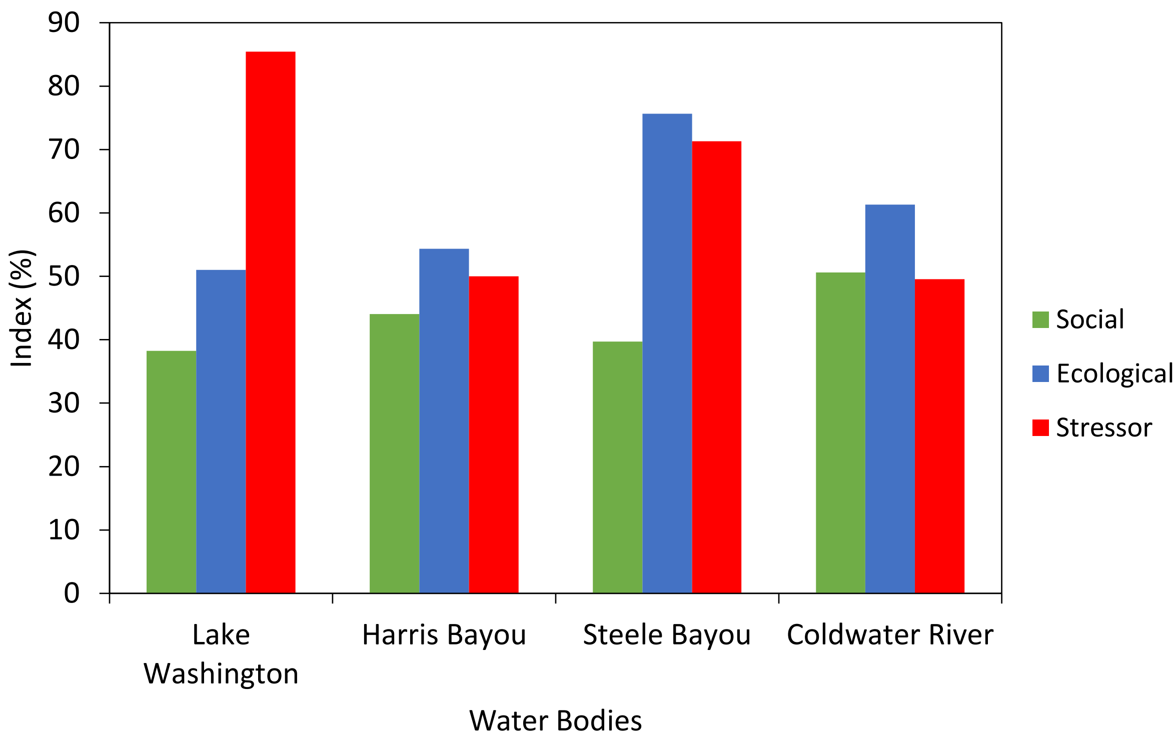
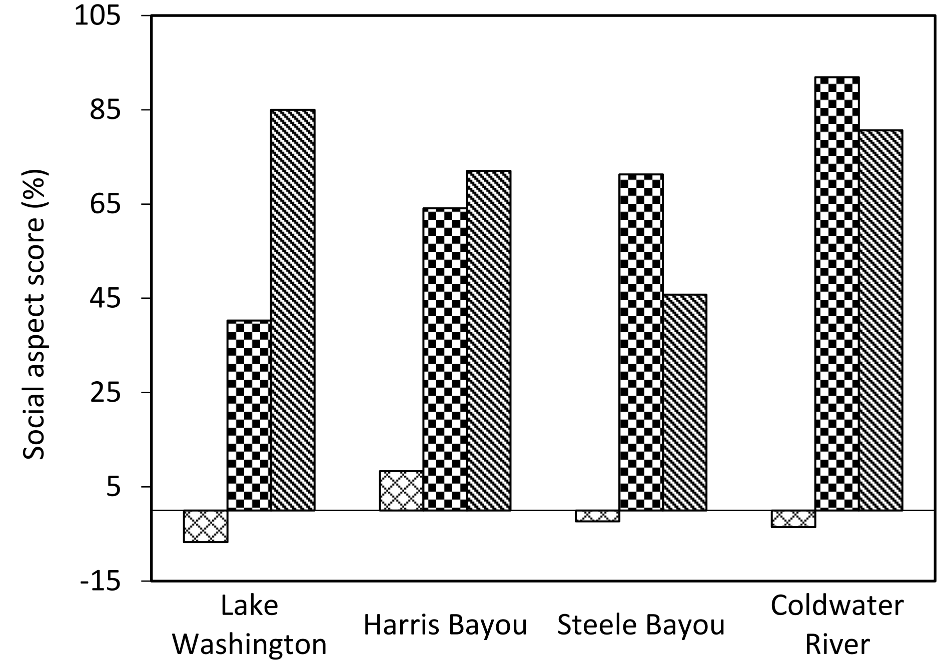


Figure 13. Index scores of social, ecological, and stressor fields based on the baseline data.

Next, the four watersheds were compared separately, using the Socio-Economic, Organizational, and Informational subcategories of the social category (Figure 14). The Socio-Economic subcategory scores varied from -6.77% for Lake Washington to 8.32% for Harris Bayou. Scores for Organizational and Informational subcategories were higher than Socio-Economic scores. Overall, the combination of the three subcategories for the social indices shown in Figure 13 would be heavily influenced by the low Socio-Economic scores. Therefore, the overall RPI indices are also heavily influenced by the Socio-Economic scores. Lake Washington was the lowest ranked watershed based on the Socio-Economic aspect, despite the highest rank on the Informational aspect. It is worth noting that a low Socio-Economic rank could render a community eligible for water quality improvement grants that would not be available for other communities. This shows that a final decision on how to prioritize watersheds for restoration has to lie upon staff with in-depth knowledge of the community and that the RPS Tool should be used only as a guide do the differences among the four compared watersheds. It is worth noting that water quality improvements then could help a community improve its Socio-Economic subcategories. Evidence for this comes from a study by Acuna et al. (2013), demonstrated that restoration could greatly increase ecosystem services at which the benefit surpasses the cost of restoration. From this perspective, it may be desirable to link the restoration action to other local community development goals. This research recommends restoration practitioners to adopt a prioritization approach that best suits their local needs.



	Lake Washington	Harris Bayou	Steele Bayou	Coldwater River
Socio-Economic	-6.77	8.32	-2.35	-3.58
Organizational	40.28	64.07	71.26	91.92
Information and Planning	85.00	72.03	45.74	80.62

Figure 14. Values of the three social aspects based on the baseline data; the bars represent the Socio-Economic, Organizational, and Information and Planning aspects, which aggregately reflect the social summary score.

3.5.3 "What If" Sensitivity Analysis

The "what if" analysis allows decision makers to perform a sensitivity analysis of particular interest, using the spreadsheet shown on Figure 11, often in the low-ranked watersheds, to generate an alternative criterion that could upgrade their existing social index score to a target level. The target score for the "what if" analysis is the point at which a watershed's score would be equal to the next higher ranked watershed for restoration. As seen in this section, the social score can be simulated for a target result by selecting any combination of the baseline criteria and iteratively altering the indicator values.

Steele Bayou had the lowest social index of 34% (Figure 13). A "what if" simulation was then applied to that watershed to explain what it would take for its social index to improve from

34% to 40%, the score of the third-place social index (Lake Washington). For this, the baseline information was revisited to identify indicators that most contributed to the low score. Compared to the other watersheds, the following social indicators for Steele Bayou were the lowest: household median income, unemployment rate, percent of assessed miles of a river section, information on the probable source of pollution, availability of watershed implementation plans, and availability of recreational resources. If Steele Bayou were to experience future improvements in these indicators as part of overall community development in a given time frame, then it would be ranked more favorably for restoration. Therefore, the baseline values of the influential indicators were changed in the sensitivity analysis interface (Figure 11) to simulate what it takes for Steele Bayou to upgrade its social indicator rank from fourth to third. The purpose of this analysis was to provide a demonstration of what social indicator value changes would be necessary for a watershed to improve its rank for restorability. It is intended to be used as a technique, using Steele Bayou and select indicators as examples. The analysis could address any change in rankings deemed useful and realistic by the watershed manager.

The results showed that several alternatives could satisfy the “what if" simulation to upgrade Steele Bayou’s social index. Two of many possible alternatives are discussed as follows. Alternative 1: This alternative considered a change in the Socio-Economic aspect. The target social index of 40% was achieved by using an assumption that the unemployment rate decreased from 16.71% to 10.71%. Improvement in employment would likely be associated with an increase in household income (DiPrete and McManus 2000). By considering this rationale, the median income per household was assumed to grow concurrently from $27,880 to $30,880. The growth of income also creates more resources that could help to monitor watersheds (Larson and Lach 2008). This led to the assumption that the percent of assessed river miles would grow from 33% to 90%. With the above-mentioned alternative, the social index for Steele Bayou increased from 34% to 40% (Figure 15, top panel), and the corresponding rank shifted from fourth to third. Because the recovery potential score is a relative score of compared watersheds, the newly calculated results are also changed slightly for the other three watersheds.

Alternative 2: This alternative considered a change in the Organizational and Informational subcategories. The target score for this alternative was found using an assumption that the number of graduates with a bachelor's degree or above increased from 15% to 18%. The RPS Tool identified educational attainment as a key social indicator because studies show that with generally higher levels of education, the community's understanding of complex restoration projects will be improved (Søndergaard and Jeppesen 2007). In turn, community awareness often triggers participation in the protection of the health of the biophysical environment. This led to a concurrent assumption of an improvement in the percent of assessed miles (increasing from 33% to 70%), more data availability (from 3 to 4), and putting the water resource to more beneficial uses (from 1 to 1.5). These assumptions increased Steele Bayou's social index from 34% to 40%, and its rank shifted from fourth to third (Figure 15, bottom panel).

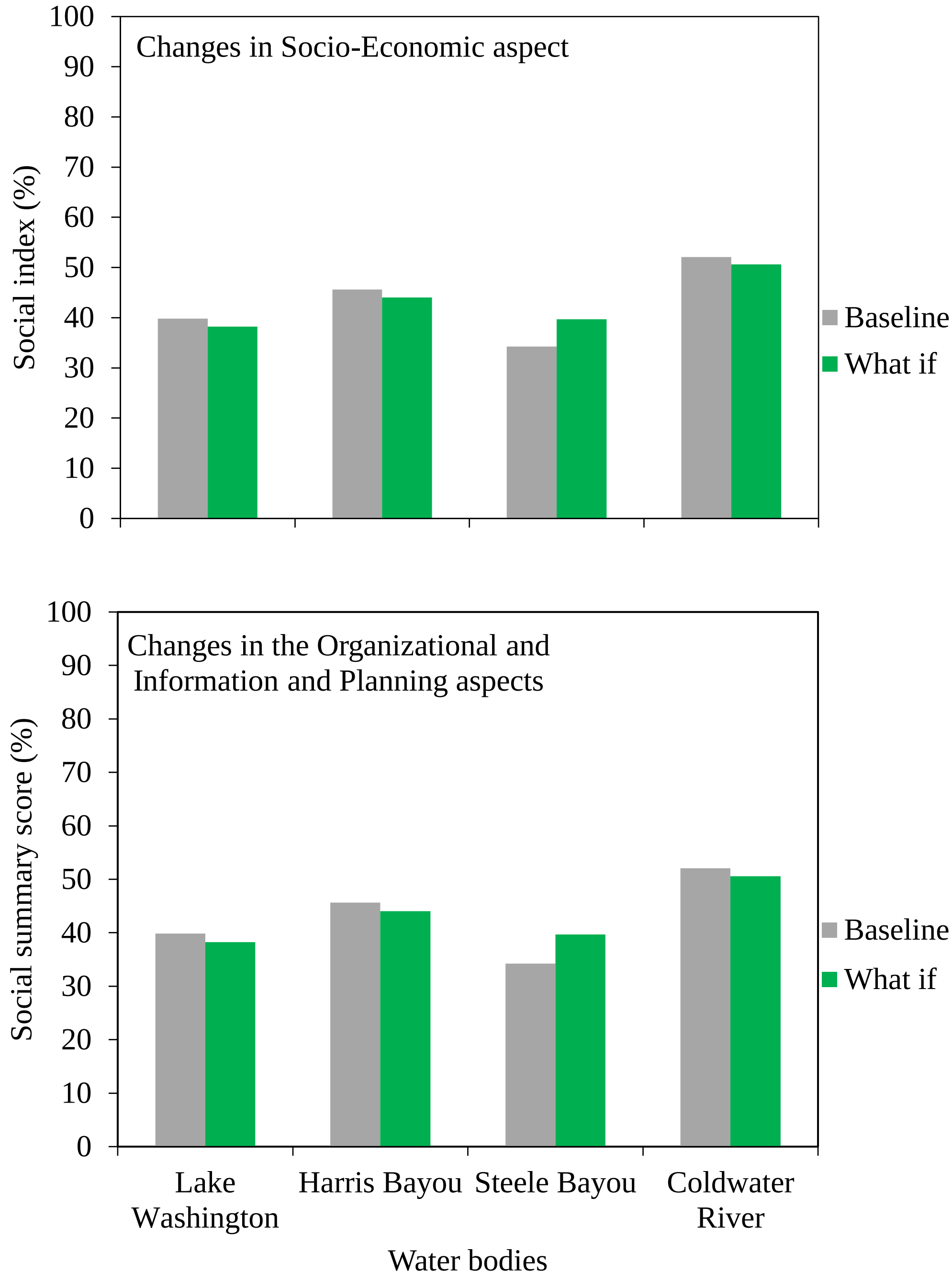


Figure 14. Examples of “what it takes” simulations applied to the social index of the lowest-ranked water body, Steele Bayou.

The results of the two alternatives indicate the type of change in indicators required to change the priority for restoration according to the RPS Tool. This analysis, therefore, is a method that can be used by watershed managers knowledgeable with the communities to provide information on changes in social indices that may improve the probability of watershed recovery.

3.6 CONCLUSIONS

The success of a restoration effort of an impaired watershed is often dependent on the social context of the surrounding communities and the biophysical conditions of the watershed. These factors are estimated by the recovery potential indicators within the ecological, stressor, and social categories in the RPS Tool. This study applied the RPS Tool, a weighted summation MCDA technique, as a screening of 51 Mississippi watersheds. Then, to understand the sensitivity of a watershed's recovery potential integrated (RPI) score to the social field, four selected impaired watersheds were compared based on ecological, stressor, and social indices and their aggregated RPI index.

The results from the RPI comparison showed that for the watersheds studied, low RPI indices were associated with lower social, rather than ecological or stressor, indices. Of the three subcategories of social indicators used, the Socio-Economic was the lowest scoring.

To evaluate the significance of social indicators in the overall RPI index, a "what if" sensitivity analysis was conducted. The "what if" analysis was performed to provide scenarios among the four watersheds in which social indicators would need to be improved to change the relative ranking of the watersheds.

This analysis is useful for understanding how particular social indices of a community impact the relative potential for recovering a watershed. The analysis also sheds light on what improvements could be made to increase the watershed's recovery potential. It is evident that in-depth knowledge of the local communities is imperative for making comparisons and management decisions, especially when it comes to selecting and weighting social indicators. It is also important for decisions not to be based solely on Socio-Economic subcategories because those are difficult to change. However, social indices, and consequently RPI indices, can be improved, especially through grants related to the Organizational and Informational subcategories.

Further studies of site-specific Socio-Economic subcategories, and weights assigned to them, would be necessary to link the restoration priority plan to other community developmental goals. For instance, it would be desirable in some situations to weight the social indicators in such a way to prioritize restoration for a watershed with lower social indicator scores to support Socio-Economic activities.

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CHAPTER IV

APPLICATION OF A SPATIAL DECISION SUPPORT SYSTEM FOR CHOICE AND PLACEMENT OF NITROGEN SOURCE REDUCING BEST MANAGEMENT PRACTICES IN THE BEASLEY LAKE WATERSHED

ABSTRACT

Nutrient reduction efforts are planned based on spatially complex watershed information. These efforts encompass a series of activities, such as identifying sources, quantifying source loads, estimating exported load, and establishing source reducing best management practices (BMPs). The choice and placement of BMPs require a decision on three conflicting objectives: performance, site suitability, and establishment cost.

The present study applied a spatial decision support system (SDSS) for the Beasley Lake Watershed (BLW) in Mississippi to optimize a nitrogen (N) source reduction plan. The watershed information required to assess N pollution was stored in a database pool with a central and updatable data view. The nutrient movement on the landscape was tracked from the source to the receiving Beasley Lake using a mass balance method. The watershed critical sites for N load and watershed suitable sites for establishment of buffer strips and wetlands were identified. This information served as a decision guide for choice and placement of BMPs within the watershed. Three BMP scenarios were identified through an iterative BMP placement process. With the BMP scenarios, it was possible to reduce up to 25% of the annual exported N load at the establishment and the annual opportunity cost-to-performance ratios of 148 $/kg and 29 $/kg, respectively. The approach presented in this study can be an alternative N assessment method when the availability of data and resources limit the use of existing watershed models for water quality assessment.

4.1 INTRODUCTION

Nutrient pollution is identified as widespread and the most challenging water quality issue in U.S. water bodies (USEPA 2017b). As a result, the USEPA along with state agencies are taking the necessary efforts to reduce nutrient pollution. The existing nutrient pollution management in U.S. water bodies follows a watershed approach, where efforts are coordinated within hydrologically defined geographical areas to tackle priority problems (USEPA 2017a and USEPA, 2017c). However, the strong connection between human activities and natural resources makes watersheds spatially complex systems (Wu et al. 2015). Because of this, the watershed approach for managing nutrient pollution needs to address three spatially complex issues: (i) understanding the watershed activities linked to fate and transport of nutrients, (ii) evaluating the suite of a variety of nutrient reducing measures, and (iii) understanding stakeholders interest, which often is in conflict with other objectives.

Water bodies receive nutrients from multiple locations and a wide variety of sources. Watershed activities, such as agricultural practices and urbanization, are major sources of nutrients to water bodies. Among others, agriculture is the major nonpoint source of nutrients. The diffusive nature of nonpoint source pollutants from agricultural sources makes it difficult to measure and regulate nutrients (Carpenter et al. 1998). Moreover, tracking the movement of nutrients from sources to the receiving water requires a thorough assessment of soil, topographic, and climatic factors (Burwell et al. 1975). These tasks are spatially complex and make the watershed process difficult to understand.

A wide variety of best management practices (BMPs) is available to effectively control nutrient pollution. These BMPs can be categorized into in-field, edge of field, and in-stream control measures. In-field control measures reduce nutrients lost to overland flow; edge of field reduce N from surface runoff before it enters into main streams; and in-stream control measures remove N by intercepting runoff from the stream or overland flow. Widely used in-field control measures are conservation tillage, agricultural nutrient management, and land use change. Grass and forest buffers are the two commonly used edge of field practices. An example of an effective in-stream BMP to reduce N load is the placement of wetlands to intercept runoff. The applicability and effectiveness of these control measures vary with watershed factors as demonstrated in several studies. Chaubey et al. (2010) and Bosch et al. (2014) showed that the effectiveness of BMPs for improving water quality was greatly influenced by climatic factors. Liu et al. (2008) indicated that BMP effectiveness varies with the hydrological condition and its placement areas in the watershed. Another study by Arabi et al. (2006) demonstrated that the cost-effectiveness of implementing BMPs is crucial because budgets are limited. From the reviewed literature, it was clear that the choice of BMPs and implementation strategy is challenged by a range of factors.

Stakeholders are an integral part of a watershed management plan. The key to the successful implementation of the nutrient management process is the full participation of a broad range of stakeholders (Beegle et al. 2000). The major challenge is that scientific models do not address all stakeholder concerns, and development of an adaptive management system is suggested (Borsuk et al. 2001).

In the present study, a spatial decision support system (SDSS) was applied to handle three spatial complexities for supporting efforts to reduce nitrogen (N) pollution in the Beasley Lake

Watershed (BLW). SDSS is a systematic approach to support a decision in a flexible manner for spatially complex problems (Densham 1991). SDSS allows the analysis of geographical information. The SDSS input can integrate spatial data, incorporate analytical models, and generate output in a variety of spatial forms. Densham (1991) characterized SDSS as an iterative system that can generate a series of feasible alternatives to be evaluated by the user. The knowledge generated from evaluated alternatives is also integrative to future decision-making processes. These important features of SDSS enable a better visualization of the spatial complexity of the watershed system.

This research used SDSS to understand watershed processes linked to N pollution and to support a decision on choice and placement of N reducing BMPs. Due to data and information gaps on stakeholders for this research, the stakeholder concerns were not incorporated. The spatial and non-spatial datasets necessary to assess N pollution were collected from publicly available sources. Because pollution assessment using existing watershed models, such as the Soil and Water Assessment Tool (SWAT) (SWAT, 2018), was limited for this research because of lack of data and resource availability, a simplified mass balance method was used to estimate the exported N load into Beasley Lake. This was performed on an ArcGIS 10.3 environment. A decision-making process was demonstrated by evaluating three sets of BMP scenarios, at which BMP choice and placement were flexibly modified to obtain an optimum result against cost and performance criteria.

4.2 STUDY AREA

BLW is located in the Delta region of Mississippi (latitude 33^{0}24’15" and longitude 90^{0}24’15"), part of the Big Sunflower River Basin. The watershed is relatively small but represents the Mississippi Delta region landscape. Agriculture, dominated by soybean and corn, is the major land use. The lake receives sediments and nutrients from agricultural practices, which caused a water quality problem. These concerns brought the attention of agencies and made Beasley Lake a benchmark research watershed for the USDA Agricultural Research Service (ARS) program (U.S.DA 2017b). Since 1995, the watershed land use shifted from cotton-dominated to mixed crop cultivation, and management practices were established at different parts of the watershed (Figure 15). One-third of the watershed cropland was converted to a conservation reserve program (CRP), and cotton cultivation decreased from 63.3% to 8.9%. These practices resulted in 70% and 41% sediment and total phosphorus concentration reductions, respectively, in the lake water (Locke et al. 2008; Yuan et al. 2011). Also, ammonia and nitrate concentrations, respectively, were reduced by 85% and 19% between 2004 and 2008 (Cullum et al. 2010). The research in this dissertation provides a framework for choice and placement of BMPs to further support efforts to sufficiently address the N pollution problem in BLW.

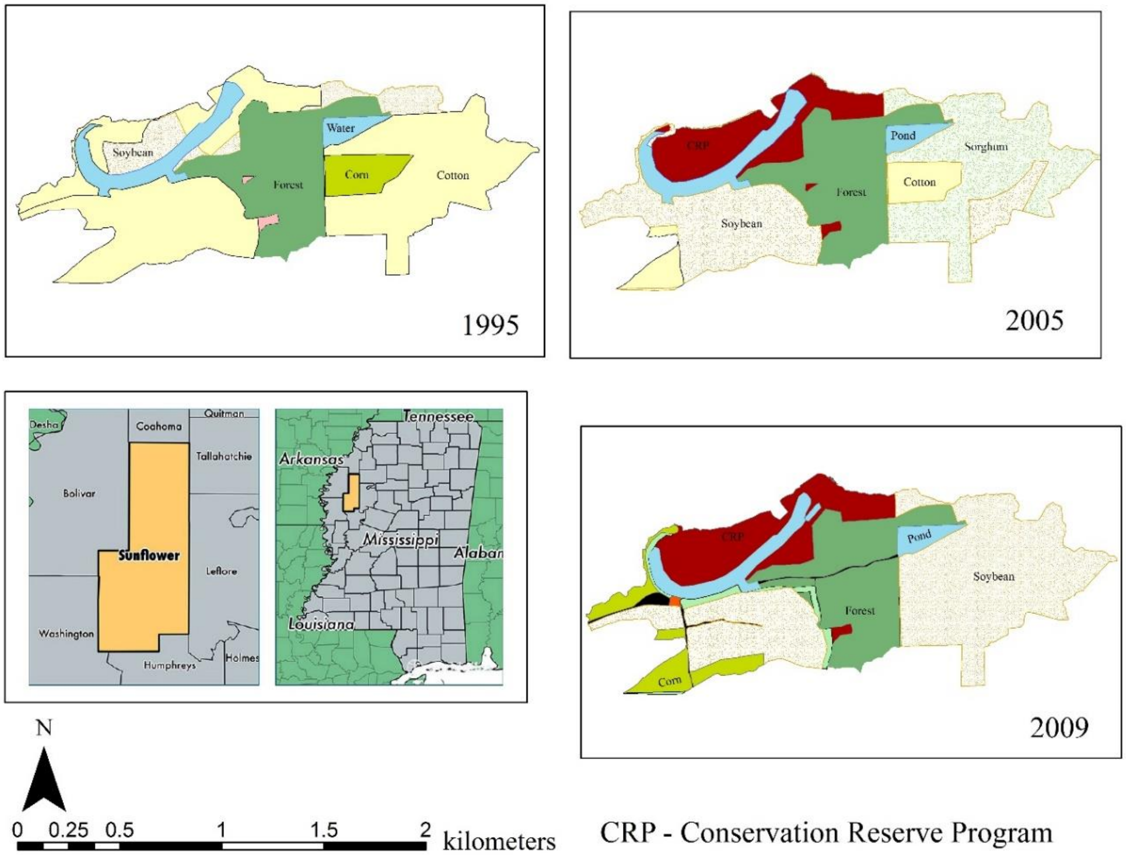

Figure 15. Location and land use of the Beasley Lake Watershed.

4.3 RESEARCH OBJECTIVE

The objective of this research was to assess the exported N load into the BLW and to analyze the choice and placement of N-reducing BMPs. This was addressed using the following specific tasks:

- Identification and quantification of the N yield
- Estimation of the N load exported into Beasley Lake
- Spatial decision analysis on choice and placement of BMPs

4.4 METHODOLOGY

This section discusses the development processes of the three SDSS components: the analytical model, the database pool, and the modeling approach. The analytical model incorporated methods to assess N fate and transport under the different conditions of the watershed. The database pool encompassed a digital storage of all the necessary datasets required to assess N pollution. The modeling approach provided a schematic description of the model processes built on the ArcGIS 10.3.3 environment.

4.4.1 Analytical Model

The analytical model included methods for identification and quantification of N sources, characterization of flow pathways in the landscape, and estimation of the exported N load into Beasley Lake.

4.4.1.1 Identification and Quantification of N Sources

The N yield from the landscape was estimated with two consecutive steps: (i) identification of N sources and (ii) quantification of the unit area N yield. For the first step, the potential sources of N in the watershed were studied. For the second step, a nutrient mass balance approach (Equation 19) was applied. A given land use was assumed to yield a relatively constant N rate per unit area when considered on an annual basis. The annual N yield from the landscape was calculated using a unit area approach (kg/ha/y). For this purpose, the watershed was divided into 2.4 m by 2.4 m grid cells that serve as a unit area. The annual N input into a unit area was the sum of N added from fertilizer (F), livestock (L), atmospheric deposition (AD), and fixed by legumes (FL). The annual N exported from a unit area was the amount removed through crop harvest (CH), leached to groundwater (GW), taken by trees (TT), lost to the atmosphere (AL), and removed by conservation practices (CP).

$$N = \sum F + \sum L + \sum AD + \sum FL - \sum CH - \sum TT - \sum GW - \sum AL - \sum CP \qquad \text{(Equation 19)}$$

4.4.1.2 Characterization of Flow Pathways

N is lost from the landscape to water bodies through surface runoff in dissolved and particulate forms. To understand this process at a watershed scale, a hydrologic network of streams was generated. The following GIS procedures were applied.

Digital Elevation Model (DEM) – A high-resolution DEM was generated using LIDAR data, which was used for subsequent steps of this research (Figure 16). LIDAR data, collected in 2009, is publicly available in Las file from the USGS data sources. The ESRI ArcMap 10.3.3 general procedures for this process are as follows:

Convert Las to Multipoint (3D Analyst > Conversion > File > Las to Multipoint)

Interpolate using Natural Neighbor (Spatial Analyst Tools > Interpolation > Natural Neighbor)

These procedures require specifying the elevation of interest and the size of a grid cell. The LIDAR points in Las file are classified into returns from bare ground, vegetation cover, building, water surface, and others. For the present research, a bare ground elevation was used to establish a hydrologic network of streams. An adequate grid cell size that represents surface details need to be used. For this reason, a 2.4 m by 2.4 m grid cell size was selected.

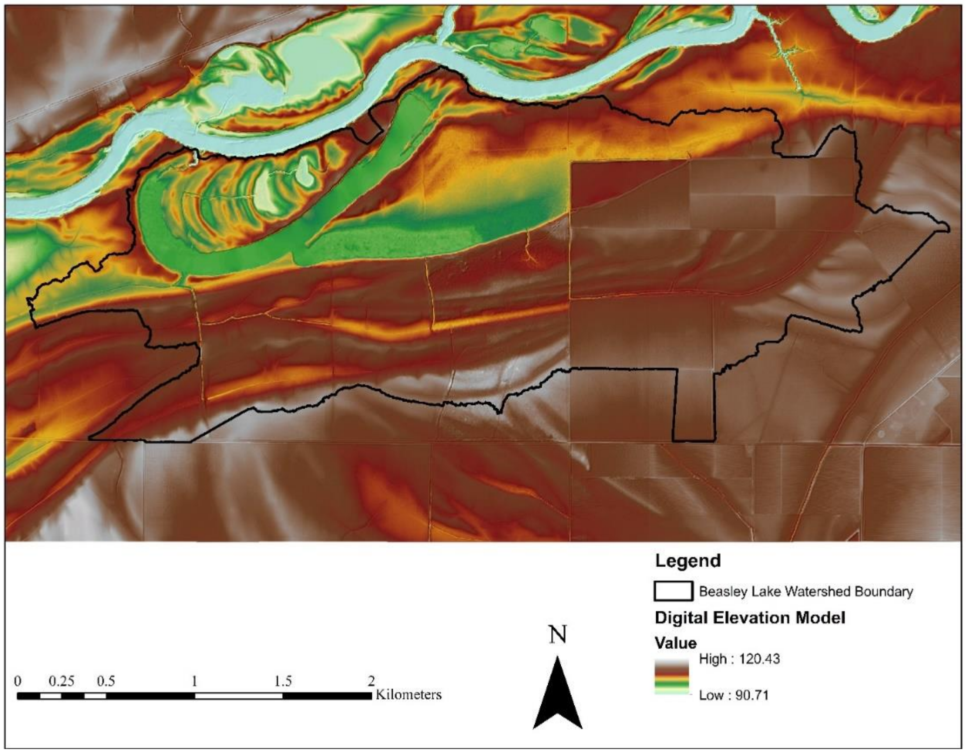

Figure 16. Digital Elevation Model of the Beasley Lake Watershed.

3D Surface Representation– A hill shade, a 3D representation of the surface area, was generated for visualization of the terrain (Figure 17). This was performed using the sun's illumination information to make a clear view of the shadow in the terrain map. The sun's illumination of the Beasley Lake area at the time of LIDAR data capture was used (the sun's altitude and azimuth were 71.93 and 139.25, respectively). The ESRI ArcMap 10.3.3 procedure is as follows:

Tool Reference > Tools > 3D Analyst toolbox > Raster Surface toolset > Hill shade

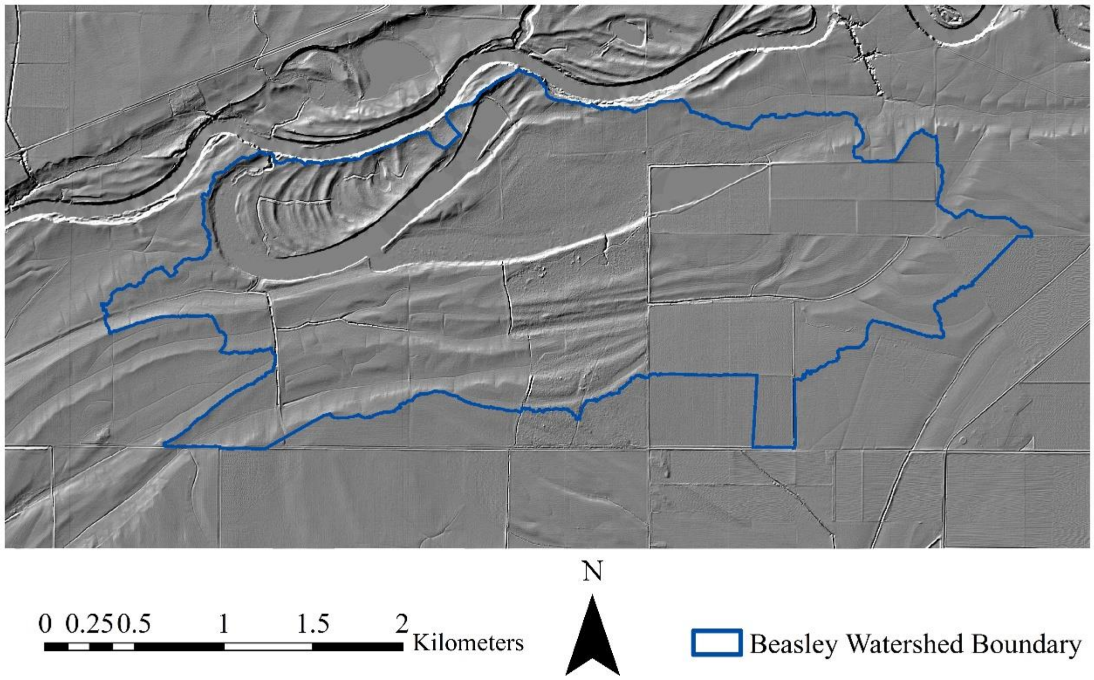

Figure 17. A 3D surface representation of the Beasley Lake Watershed.

DEM Reconditioning – The DEM was reconditioned using stream information obtained from version 2 of the National Hydrography Datasets, NHDPlusV2 sources (Horizon System Corporations 2017), to minimize surface representation errors (Figure 18). The NHDPlusV2 comprises of a spatial datasets of U.S. water bodies, such as elevation, watershed boundary, and stream reaches. The surface elevation of the original DEM was adjusted using stream elevation obtained from the NHDPlusV2 sources. The Arc Hydro 2.0 procedure is as follows:

Terrain preprocessing > DEM manipulation> DEM reconditioning

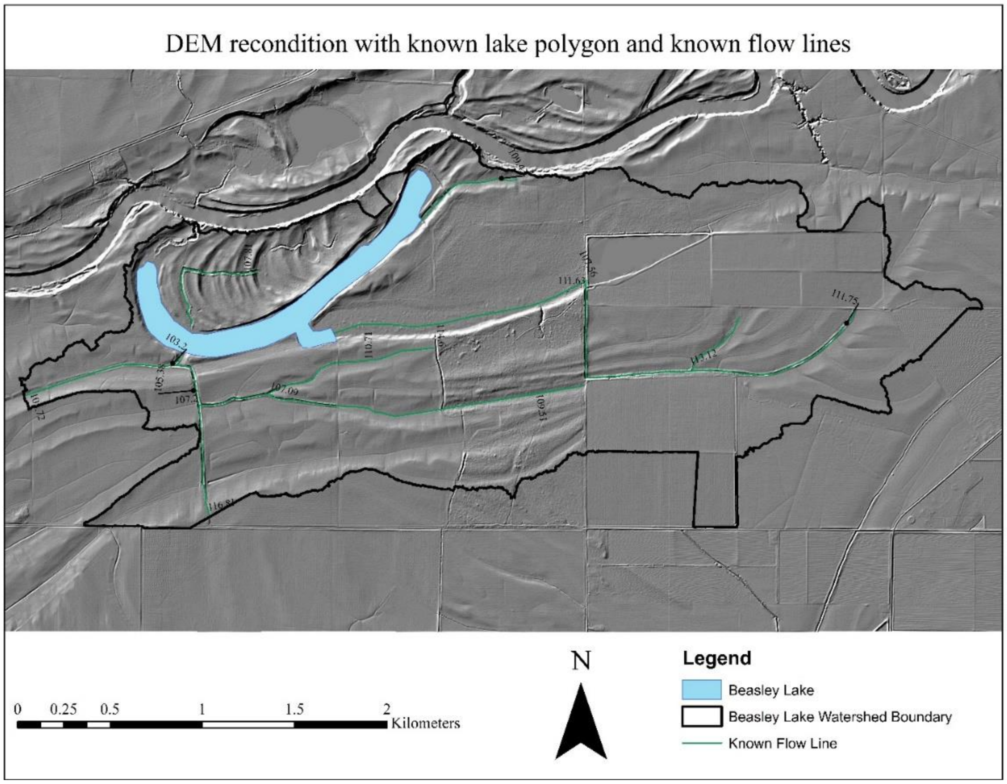

Figure 18. Known flow lines in the Beasley Lake Watershed.

Burn stream slope – This procedure is a continuation of DEM reconditioning where the stream slopes were adjusted based on FromElev and ToElev information of a known stream segment. This ensures the water flow in the correct direction. The Arc Hydro 2.0 procedure is as follows:

Terrain preprocessing > DEM manipulation> DEM reconditioning

Fill sinks – This step was applied to modify a grid cell surrounded by higher elevation cells. The Arc Hydro 2.0 procedure is as follows:

Terrain preprocessing > DEM manipulation> DEM reconditioning> Fill sinks

Flow accumulation and stream definition – Flow direction was determined as the direction of the steepest descent from the grid cells. Based on a specified accumulated number of upper stream cells, a stream network was generated (Figure 19). The Arc Hydro 2.0 procedures are as follows:

Terrain preprocessing > Flow direction

Terrain Preprocessing > Flow Accumulation

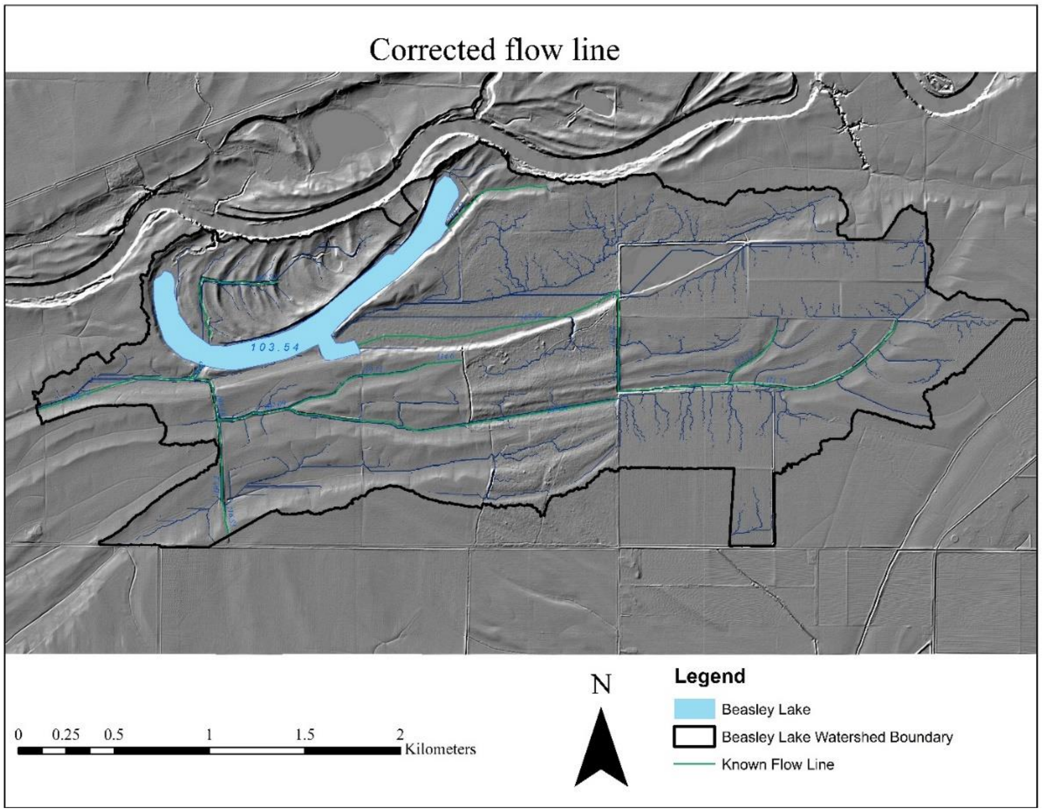

Figure 19. Stream networks of the Beasley Lake Watershed.

Sub-basin delineation – This step was used to delineate basins from each grid cell associated with the accumulated cell point (Figure 20). The catchment grids were then used to produce sub-basin polygons. The Arc Hydro 2.0 procedures are as follows:

Terrain preprocessing > catchment grid delineation

Terrain preprocessing > catchment polygon processing

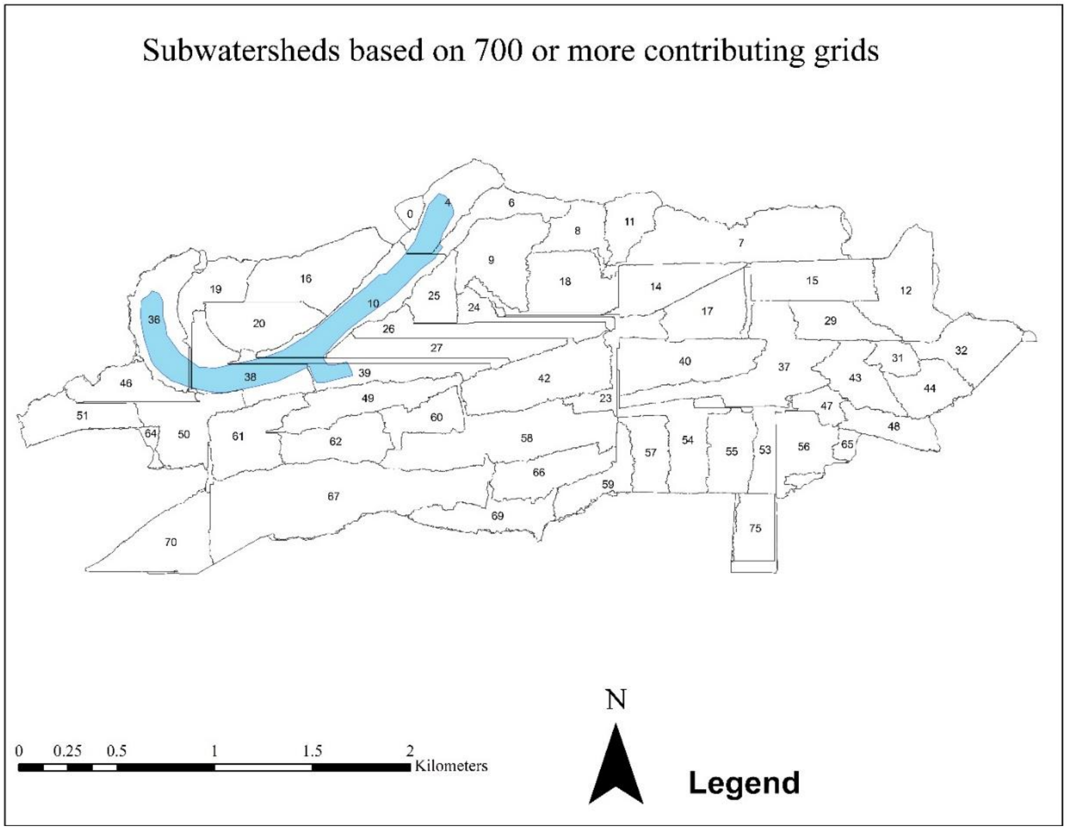

Figure 20. Sub-basins of the Beasley Lake Watershed.

4.4.1.3 Estimation of Exported N Load

N available in the soil is lost to surface runoff in dissolved and particulate forms. About 15% and 21% of N available in the soil is lost to surface runoff in dissolved and particulate forms, respectively, for the South Central Region of the U.S. (USDA 2006). Using this information, the N carried in surface runoff was calculated. The total available N estimated in section 4.4.1.1 was used as an input for this calculation.

N carried in runoff, as overland flow and stream flow, is trapped by either control measures or natural watershed processes as it flows downstream. To account for this, the mass removed by existing BMPs (Figure 21) was calculated using removal efficiencies extracted from literature (discussed in section 4.4).

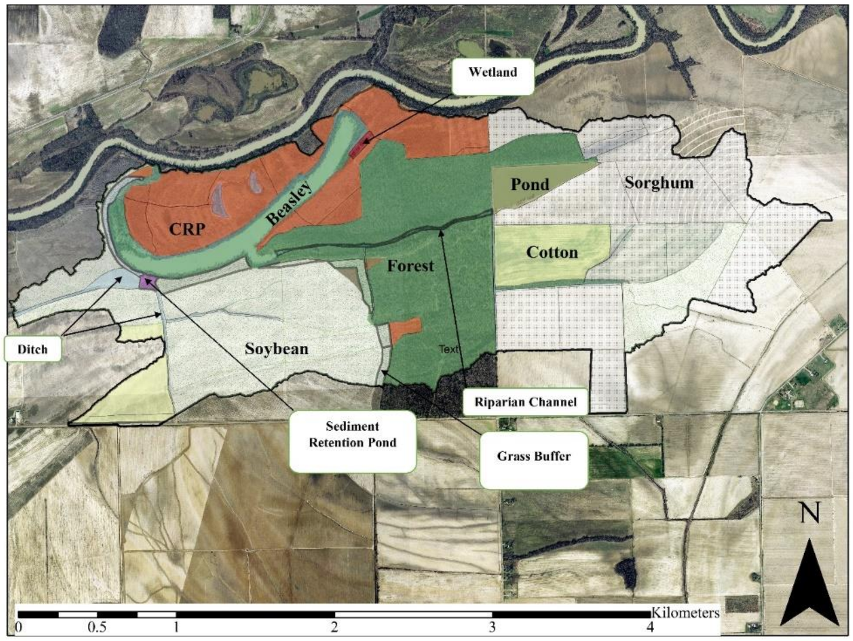

Figure 21. Location of the existing BMPs in the Beasley Lake Watershed (2005).

N is removed through natural processes as runoff moves to downstream reaches.Watershed factors governing N loss to natural processes are less variable over space for smaller watersheds like the BLW. For this reason, the rate of N loss over space through natural watershed processes, such as leaching to groundwater, plant uptake, and denitrification was assumed to follow constant decay pattern (Zhang 2011). The general decay of pollutants during transport processes is mathematically expressed in Equation 20.

$$C_{out} = C_{in}e^{(-kT)} \qquad \text{(Equation 20)}$$

Where C_{out} is the mass of a pollutant after a decay, C_{in} is the original mass of a pollutant, k is a decay coefficient and indicates a loss of pollutant, and T is a unit of time. To transform this equation into distance-decay, a conversion from time to distance is made, which will be explained in the next several paragraphs.

Estimation of N load was performed for the network of streams and their corresponding sub-basins. For a given stream, the sum of all N loads from its sub-basin and its upstream reaches are calculated, named as an incremental load for this research. The annual incremental load at a given stream reach is the combination of the decayed load from an overland flow and an in-stream flow from upstream and tributary segments. To account for this, the exponential time-decay equation was solved as shown in Equation 21.

$$L_i = L_{oi}e^{(-k*T)} + L_{si}e^{(-k*T_C)} \qquad \text{(Equation 21)}$$

Here, $L_{oi}e^{(-k*T)}$ and $L_{si}e^{(-k*T_C)}$ represent the decayed loads from overland flow and stream flow, respectively. L_i is the total annual incremental load at the downstream end of a given segment (kg/y), L_{oi} is the unit area yield at a given sub-basin (kg/y), L_s is the sum of all N load from upstream reaches (kg/y), k is the decay coefficient (y^{-1}), T is the total travel time (y) (Equation 22), T_{lag} is the overland flow lag time (y) (Equation 23), and T_c is in-stream flow time (y) (Equation 24).

The value of L_o was obtained from the unit area yield calculation (Equation 19). k represents the rate of N mass loss as the pollutant transported to the downstream reach. As noted above, the BLW is a small agricultural watershed, and factors governing the N loss over space are likely homogenous. For this reason, the annual rate of N mass loss in the watershed is assumed constant and the decay rate was considered as 1.

The total travel time (T) is estimated as the sum of lag time (T_{lag}) and in-stream travel time (T_c) (Equation 22).

$$T = T_{lag} + T_c \qquad \text{(Equation 22)}$$

The lag time (hours) was estimated using the SCS lag time method (Equation 23) (Mockus 1991). The SCS lag time method is an empirical model developed with information collected from basins with 0.5 ha to 2,382 ha in size. The use of SCS lag time method is recommended to a basin with somewhat homogenous nature and less than 810 ha in size.

$$T_{lag} = \frac{L^{0.8}(S+1)^{0.7}}{1900 * Y^{0.5}} \qquad \text{(Equation 23)}$$

Where L is the length of the longest flow path (ft), S is the soil potential maximum retention (in), and Y is the average watershed slope (%).

The in-stream travel time was estimated using Equation 24.

$$T_c = \frac{L}{V} \qquad \text{(Equation 24)}$$

Where L is the length of stream segment (m), and V is the velocity of stream flow at a peak concentration of a pollutant (m/s).

The length of stream segments was calculated using the geometric function of the ArcGIS tool. The width of channel, required to calculate the loss by denitrification process, was estimated using Q, L, and V values calculated from previous steps.

The velocity of stream flow at a peak concentration of a conservative pollutant was estimated using Jobson (1996) (Equations 25, 26, and 27). The Jobson (1996) regression equations were developed based on a dye-cloud dispersion theory, where a dye is injected to understand the transport processes of different flow conditions. The regression equations were developed based on information collected from river segments with flow velocity from low (0.01 m/s) to medium (1.51 m/s) and discharge as low as 0.1 m^3/s. There is no sign of applicability limitation to the Beasley Lake from regression equations information. According to Lizotte and Locke (2017) flow estimates for segments in the BLW varied from 0.0 to 0.4 m^3/s. The Jobson (1996) equation could serve for velocity information in the absence of other reliable methods.

$$V = 0.094 + 0.0143 * \left({D'}_a^{0.919}\right)\left({Q'}_a^{-0.469}\right)\left(s^{0.159}\right) * (Q/D_a) \quad \text{(Equation 25)}$$

$$D'_a = (D_a^{1.25} * g^{0.5})/Q_a \quad \text{(Equation 26)}$$

$$Q'_a = Q/Q_a \quad \text{(Equation 27)}$$

Where V is the flow velocity at a peak concentration of a pollutant (m/s), D_a' is the dimensionless drainage area, Q_a' is the dimensionless relative discharge, Q_a is the mean annual flow rate (m^3/s), Q is the flow rate at the time of interest (m^3/s), D_a is the drainage area (m^2), and s is the slope of the stream. As noted before, the April and May mean flow rates were the time of interest for this research, as these months were fertilizer application times and the N concertation would likely be the peak in a stream flow.

The hydrologic network of streams generated for this research is ungauged. Flow for ungauged basins can be predicted using a hydro-statistical approach. This involves the selection of an index gauge, characterization of the various statistical properties of the stream flow record at a gauged site, and transfer of the streamflow information from the gauged to the ungauged site. The drainage area ratio (DAR) is a commonly used transfer method for ungauged streams using information from a nearby gauged sites (Equation 28) (Farmer and Vogel 2012**)**. The DAR method requires little data and is applicable when precipitation-runoff models are not developed (Emerson et al. 2005). The present study applied the DAR method to estimate the mean annual and mean monthly flows of streams in BLW using information from the nearest gauged site.

$$\frac{Q}{A}(\text{gauged}) = \frac{Q}{A}(\text{ungauged}) \quad \text{(Equation 28)}$$

The nearest gauged site for BLW is the USGS 07288521 at Porter Bayou near Shaw, MS. However, there is no sufficient record of streamflow data for this analysis. For example, there are only two and three records of stream flow for April and May (months of interest for this research), respectively. For this reason, the next nearest gauged site, USGS 07288500 at Big Sunflower River in Clarksdale, MS, with streamflow records from 1935 to 2016 was used as an index site (Figure 22). The drainage area contributing to this index site and the corresponding mean annual and monthly flow records were used to estimate the flow rate for BLW streams.

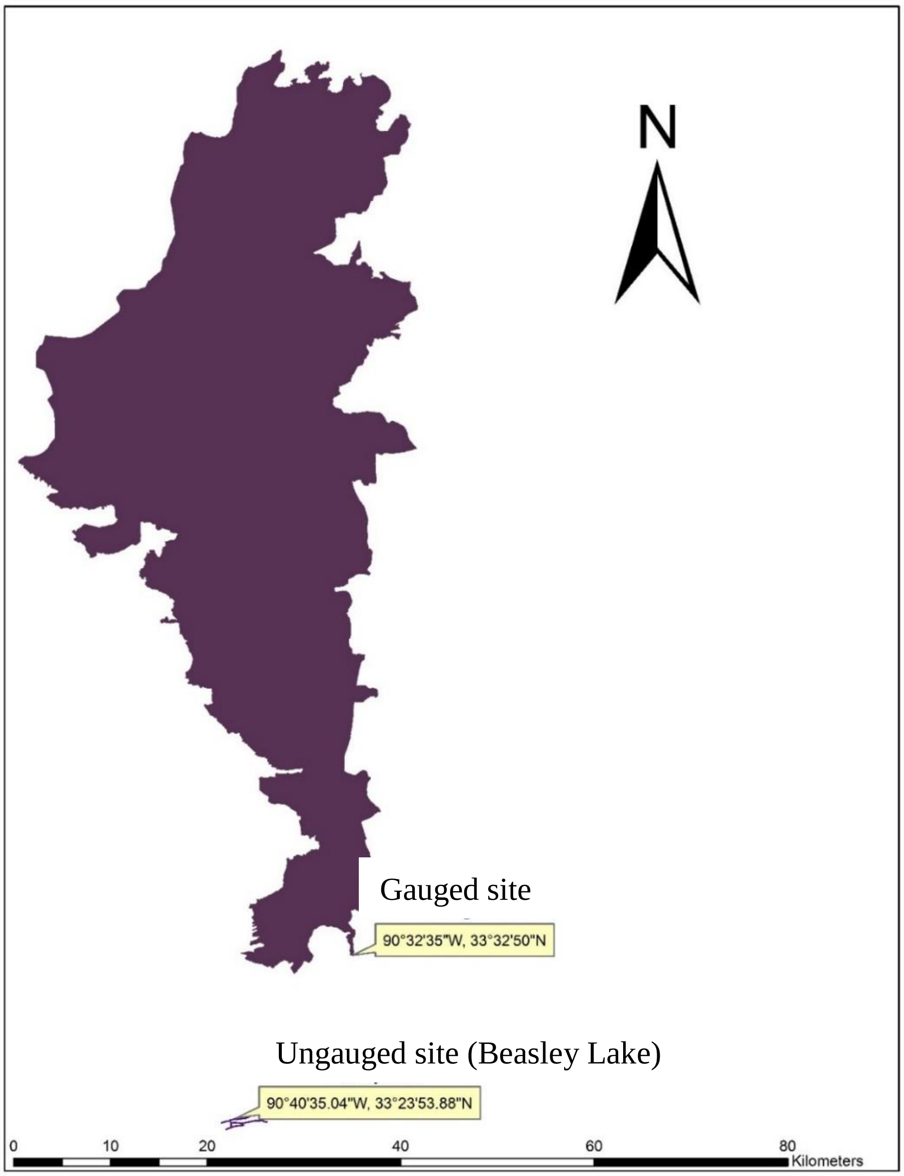

Figure 22. An index gauged site for the Beasley Lake Watershed.

4.4.2 Database Pool

All required watershed information and spatial and non-spatial datasets were digitally stored in a database pool. These datasets include a raster that stores information in a grid cell and a vector that represents surface features as points, lines, and polygons. The description of data sets and their sources used for the present study are summarized in Table 14. List of data sets stored in the database pool.. The next paragraphs describe acquisition and the processes performed to support this study.

Table 14. List of data sets stored in the database pool.

Data	**Data source**
Watershed Boundary	USDA-ARS (National Sedimentation Lab. Oxford, MS)
Land use	USDA-ARS (National Sedimentation Lab. Oxford, MS)
LIDAR	USGS (https://earthexplorer.usgs.gov/)
Hydrography	USEPA & USGS (https://www.epa.gov/waterdata/nhdplus-national-hydrography-dataset-plus)
Curve Number	USDA (Natural resources conservation service)
Streamflow	USGS (https://waterdata.usgs.gov/)
	USDA (https://quickstats.nass.usda.gov/)
N	USDA (https://plants.usda.gov/npk/main/)
	USDA (https://www.nass.usda.gov/Statistics_by_State/Mississippi/)
	NADP (http://nadp.sws.uiuc.edu/nadpdata/monthlyReport.asp/)
Soil	USDA (https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/)

4.4.2.1 LIDAR Data

Publicly available LIDAR (light detection and ranging) data sets, in Las format, were obtained from USGS (Figure 23. LIDAR data covering the Beasley Lake Watershed area (USGS). These datasets were used to generate a hydrologic network of streams and watershed slopes.

LIDAR measures a distance to a target object using a pulsed laser light. LIDAR provides spatial elevation data by measuring a laser light reflected from both on and above the bare ground.

The reflected laser lights are called returns. The returns from objects above the ground surface (such as trees and other vegetation covers) and from the bare ground are stored as 1st returns and 2nd returns, respectively. The bare ground returns (2nd return) were used to create the digital elevation model (DEM).

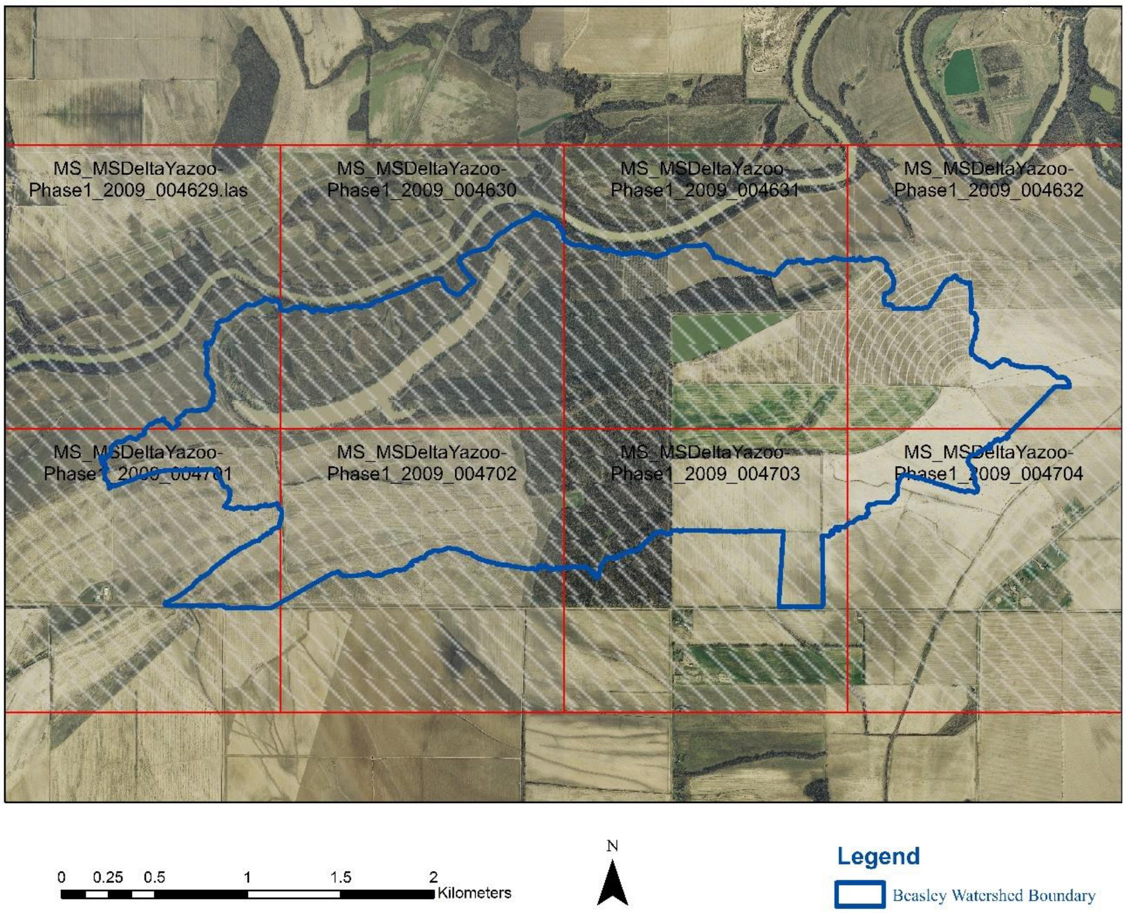

Figure 23. LIDAR data covering the Beasley Lake Watershed area (USGS).

4.4.2.2 Hydrographic Data

The process of establishing a hydrologic network of streams requires modifying the known DEM-based hydrography of the area. Hydrographic data are a digital representation of surface water pathways and their respective drainage features, such as flow network, watershed boundary, and related information. For this purpose, hydrographic data sets were obtained from a NHDPlus source (Figure 24). NHDPlus is a suite of application-ready geospatial products developed through a collaboration between the USGS and the USEPA. These datasets were available in medium resolution (30 m).

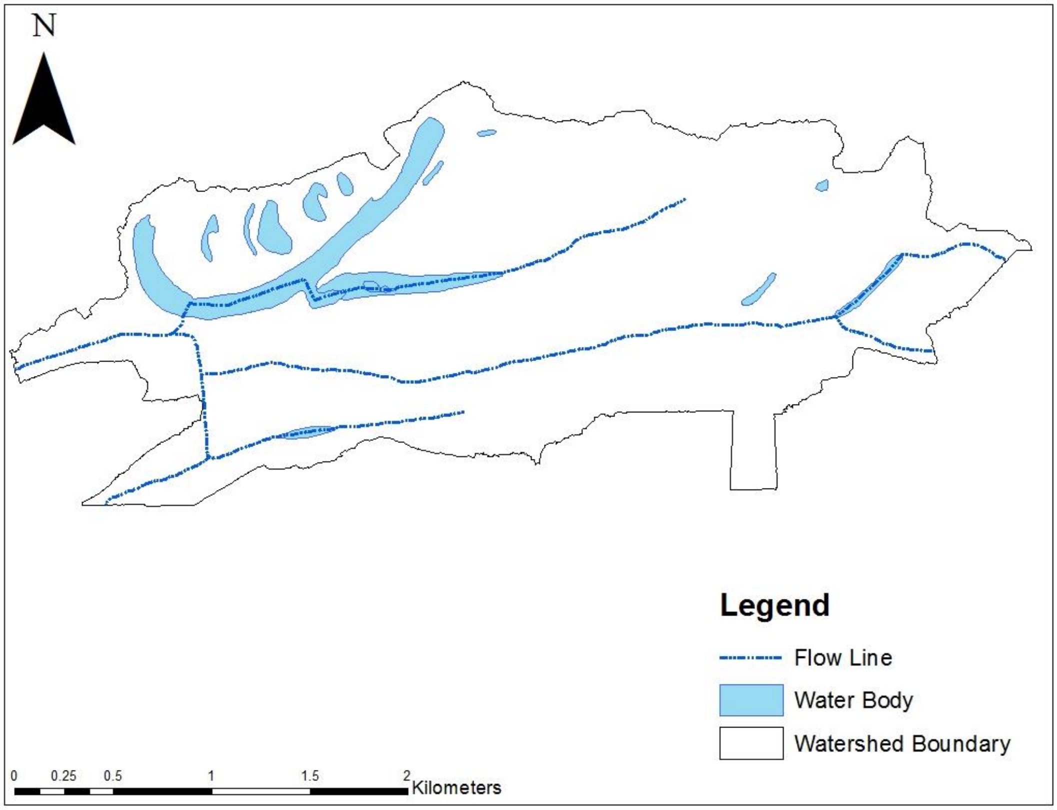

Figure 24. Hydrography of the Beasley Lake Watershed (processed from USGS NHDPlus version 2).
Source: Horizon System Corporations 2017

4.4.2.3 Streamflow Data

The mean monthly and mean annual discharge records for the index gauge at Big Sunflower River in Clarksdale was collected from the USGS (USGS 2017a). These datasets were calculated using records from 1935 to 2016. The major source of N in the Beasley Lake was fertilizer, which was mainly applied during crop plantation months (April and May). Discharge records for April and May were used for this analysis because it corresponds to the potential N export times.

4.4.2.4 Land Use Data

Land use data were obtained from USDA-ARS (USDA 2017a). This included field survey data that provide historical information on crop cover and conservation reserve programs. Historical data on BLW land use are summarized in Figure 15.

4.4.2.5 N Data

Information related to N was collected from the USDA documents and tools. The quantity of N applied as a fertilizer was obtained from state survey data (USDA 2017d). The amount of N removed by crop harvest was calculated using a nutrient content estimating tool, which calculates N removal based on crop yield information (USDA 2017c). Atmospheric deposition data were obtained from the National Atmospheric Deposition Program (NADP 2017).

4.4.2.6 Soil Data

Soil hydrologic data were collected from the Soil Survey Geographic Database (SSURGO) of the USDA (Figure 25). These data were used to determine the soil potential maximum retention (represented as S in Equation 23), which was used to evaluate suites of BMPs.

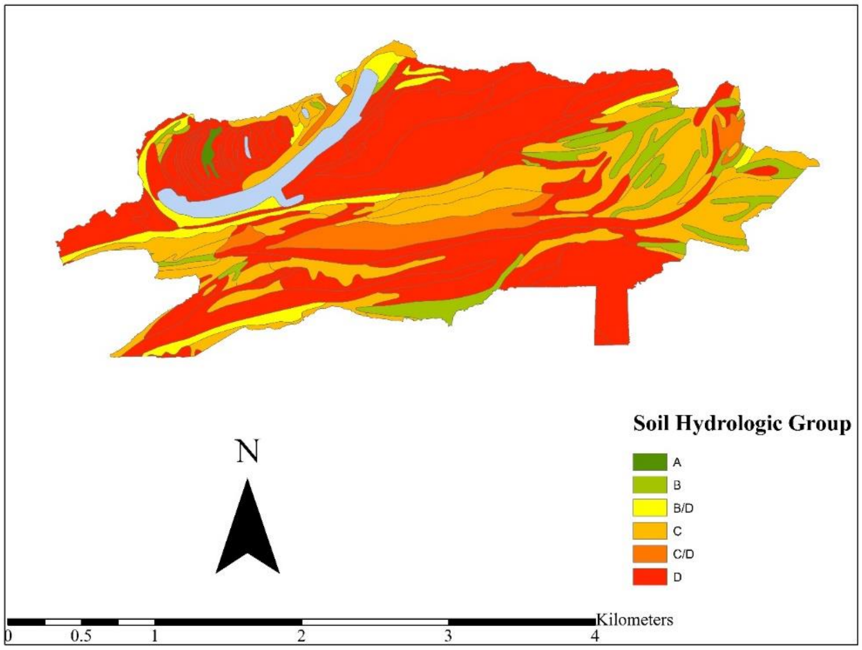

Figure 25. Hydrological soil map of the Beasley Lake Watershed.

4.4.3 Modeling Approach

A modeling framework was established in the ArcGIS 10.3.3 environment to calculate the N load exported into Beasley Lake and evaluate BMP scenarios. The model flowchart, from inputs, process flow, and output analysis, is presented in Figure 27. The input framework is comprised of the database pool and nutrient source reducing BMPs. The process framework integrated process-based approaches from yield quantification to exported load estimation methods. The output framework formed a decision analysis component where a nutrient reduction plan can be optimized by evaluating a BMP choice and placement. Further information on how a decision analysis was supported by the output framework can be found in Section 4.4.4.

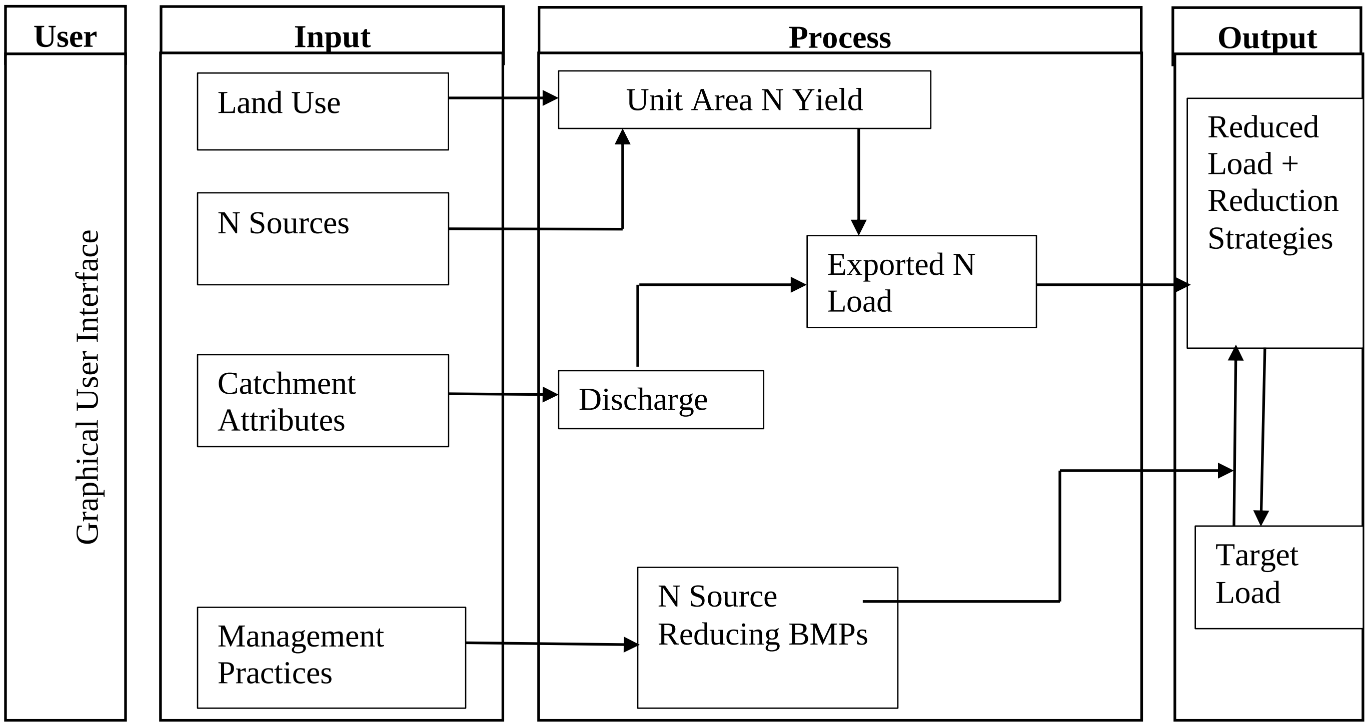

Figure 26. The modeling framework for nitrogen assessment.

4.4.4 Spatial Decision Analysis

A spatial decision analysis on N load reduction was performed for BLW to demonstrate the proposed methodology. BMPs differ in their performance, establishment cost, and site suitability. Maximizing efforts needed to reduce N involve a decision on conflicting objectives, such as performance, site suitability, and establishment cost. An environmental goal anticipates BMPs to be planned for maximum load reduction. Though the maximum expected performance of these practices could be achieved under controlled situations, the actual field performance varies with site conditions, and the cost associated with establishment would also vary accordingly. This could mean a single environmental target may not hold the best scenario. Therefore, a trade-off among performance, site suitability, and establishment cost is necessary for choice and placement of BMPs. An optimum benefit from a given management practice could be obtained by evaluating several scenarios of these trade-offs.

To support a decision on the trade-off among the targeting criteria of the present study, first, the critical watershed source sites were identified. Critical watershed sites for this research purpose were defined as watershed locations with the highest unit area yield, sub-basins with the highest total annual yield, and streams with the highest annual exported N loads. These sites help to visualize the potential source loads and to evaluate a range of BMPs placement options. BMPs for agricultural watersheds were categorized into in-field, edge of field, and in-stream control measures. The selection of these practices requires information on critical watershed sites. For example, information on a unit area yield is important to evaluate a suite of in-field practices, such as managing fertilizer application rate, conversion to no-till farming, or shift to cover crops. The total annual yield in the outlet of a given sub-basin provides information for selecting edge of field control measures. Similarly, knowledge of in-stream load is crucial for identification of effective in-stream control measures.

Second, suitable sites for BMP placement were determined. As part of the Mississippi Delta Management Systems Evaluation Area (MDMESA), BMPs known for their effectiveness in N reduction were established in BLW (Table 15).

This research evaluated BLW sites suitable for further expansion of selected BMPs. These include (i) establishment of forest and grass buffers and (ii) construction of a wetland. The performance of buffer strips is greatly affected by soil condition (Barling and Moore 1994). Buffer suitable sites were selected based on soil infiltration rate along with N yield information. A decision analysis was performed for a trade-off between buffer suitability and performance. A wetland intercepts runoff from its flow pathways and removes nutrients. Establishing a wetland at the site to intercept runoff with the highest N load was considered as the target criterion for site selection. A wetland site for this research was selected based on information on the exported N load.

Table 15. Description of selected BMPs.

Practice	N Removal efficiency	Establishment cost[a]	Unit cost applied in this study	Category	Source
Grass buffer	41%	\$415-\$988/ha & \$154/ha annualized opportunity cost	\$988/ha & \$154/ha	Edge of field	Tyndall and Bowman (2016); Helmers et al. (2008); Wieland et al. (2009)
Riparian Forest Buffer[b]	50-90%	\$538-\$1,800/ha and \$815/ha annualized opportunity cost	\$1,800/ha & \$815/ha	Edge of field	Lowrance et al. (1997); Tyndall and Bowman (2016); Wieland et al. (2009)
Wetlands	35-40%	\$247/ha & 19/ha annualized opportunity cost	\$247/ha & \$19/ha	Edge of field or in-stream	Mitsch et al. (2005); Tyndall and Bowman (2016)

[a] Establishment cost is an investment required to implement and maintain BMPs, and annualized opportunity cost is the loss of potential gain from land being taken out of production for BMP establishment.
[b]When riparian forest established along the flow pathways, it reduce the in-stream total nitrogen by 0.021 kg/m (Belt et al. 2014).

Third, three BMPs scenarios were developed with the aid of results from the critical watershed and BM suitability site evaluation (Table 16). The three BMP scenarios were compared based on performance and cost-effectiveness.

Table 16. Description of evaluated BMP scenarios.

Scenario	Description
Baseline scenario	The watershed is treated with 113 ha hardwood trees, 9 ha grass buffer, 0.5 ha wetland accommodating 8 ha drainage area, sediment retention pond, and 24% modified drainage lines
Scenario 1	A portion of watershed critical sites for edge of field measures was treated with grass buffer
Scenario 2	A portion of watershed critical sites for edge of field measures was treated with forest buffer
Scenario 3	A portion of watershed critical sites for edge of field measures was treated with grass buffer and a wetland was established in the critical watershed sites

4.5 RESULTS AND DISCUSSION

The SDSS outlined in section 4.1 through 4.3 and its application in BLW are discussed in this section. The first section describes delineation of streams and sub-basins, followed by results from N yield estimation. The third section discusses the exported N load estimation at a given reach, and the last section presents results from the spatial decision analysis on BMP choice and placement.

4.5.1 Stream and Sub-basin Delineation

The SSDS was built on the ArcGIS 10.3.3 environment. The flow pathways and their corresponding sub-basins were delineated, which served as a study framework for the subsequent steps of this research. This network of streams and sub-basins is presented in Figure 27. In order to provide an in-depth spatial analysis, the watershed was divided into 75 sub-basins. Information for each sub-basin was stored in a raster grid, which represents a 2.4 m by 2.4 m space. The computation of surface runoff and the corresponding N load were performed based on these grids.

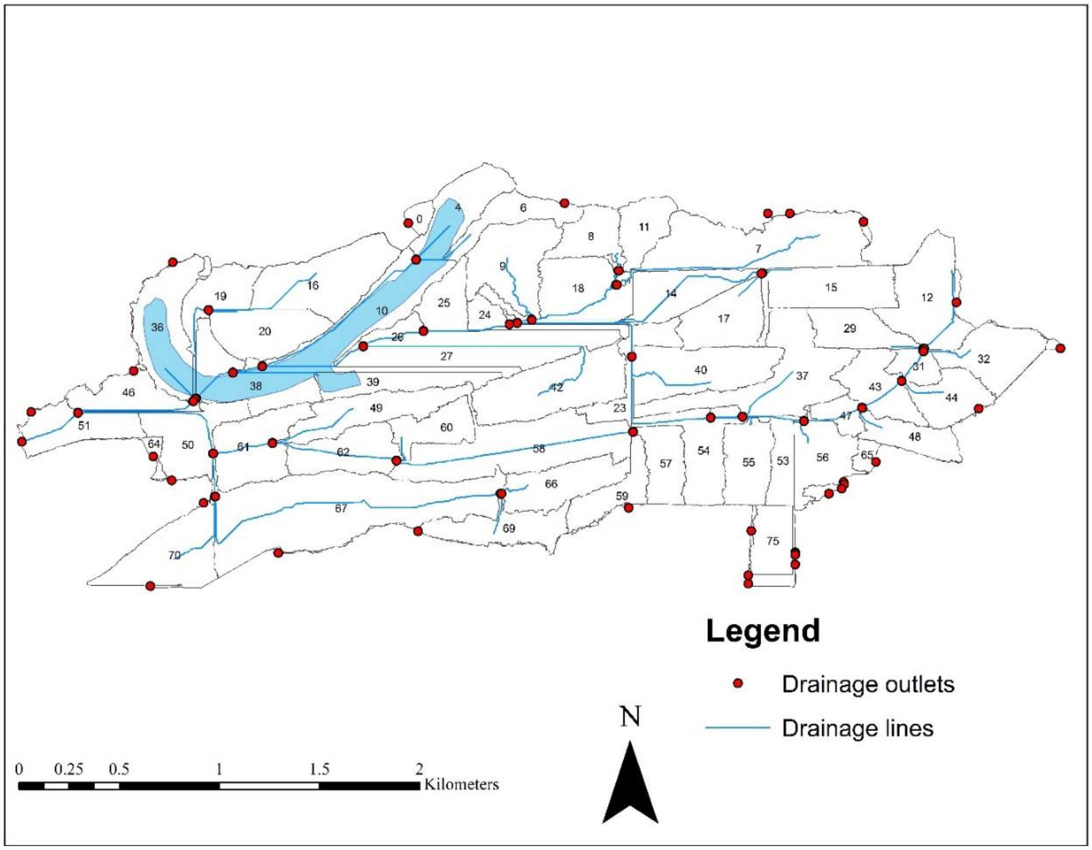

Figure 27. Hydrologic network of streams and sub-basins of the Beasley Lake Watershed.

4.5.2 Unit Area N Yield Estimation

The larger portion of BLW land was used to grow crops, followed by forest, CRP, and water, respectively (Figure 28). Agricultural runoff was the primary source of N into the Beasley Lake.

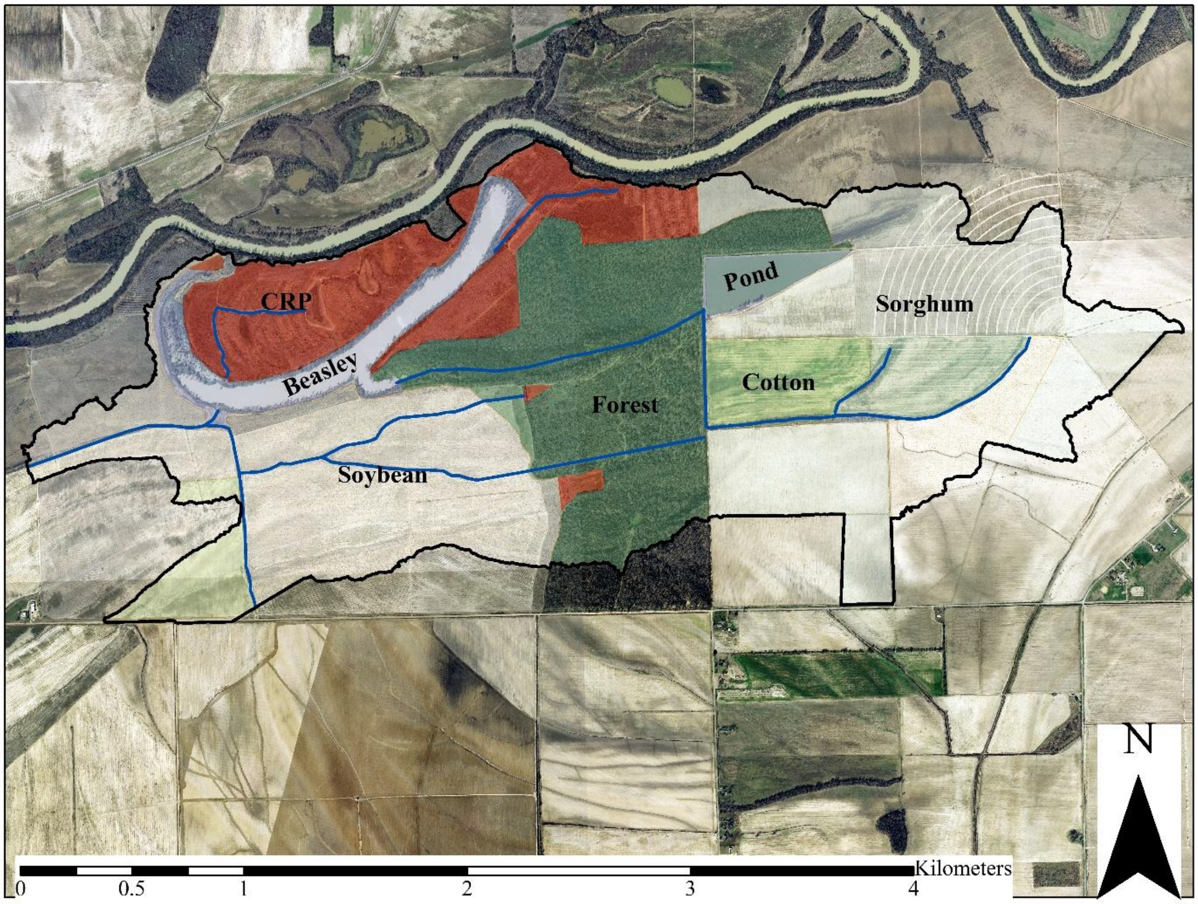

Figure 28. Land use and main drainage lines of the Beasley Lake Watershed.

Major crops cultivated in the BLW were soybean and corn. Fertilizer from these croplands was identified as the primary source of N. The N yield estimates for these crops are summarized in Table .

Table 17. Component estimates for Beasley Lake Watershed from cropland N budget.

Crop	**Applied fertilizer**	**Atmospheric deposition**	**Livestock manure**	**N fixed**	**Removed by crop harvest**	**Loss to ground water**	**Unit area yield (kg/ha/y)**
Soybean	15.0	2.6	0.0	72.8	45.3[a]	26.4	18.7
Corn	163.0	2.6	0.0	0.0	104	49.0	12.6

[a] Soybean is harvested in the Mississippi Delta as a green chop (Zhang and Boahen 2007)

The calculated yields were in units of kg/ha/y. This yield excluded the N removed by existing BMPs and loss to the atmosphere, which were later accounted in exported in-stream load calculations. Due to considerable data and information gaps for this study, estimated yields were only a simplified demonstration of the potential N available in the landscape. For instance, there was no known number of animal population in the BLW and the contribution from livestock was assumed to be insignificant. An example of the unit area yield calculations for the land cultivated with soybean is shown below.

Fertilizer application rate = 15 kg/ha/y

N fixed from the atmosphere = 72.8 kg/ha/y (CUCE 2008; Schipanski et al. 2010)

Atmospheric deposition = 2.6 kg/ha/y

N removed through crop harvest (crop yield, green chopping, was 199.93 kg/ha/y) = 45.3 kg/ha/y

Amount of N lost to ground water from fertilizer and fixation was estimated as 30% of the applied mass (Viers et.al. 2012) = 0.30 * (15.0 + 72.8) = 26.4 kg/ha/y

Unit area yield = $\sum \text{Fertilizer} + \sum \text{Livestock} + \sum \text{Atmospheric deposition} +$

$\sum \text{Fixed from the atmospheric} - \sum \text{Crop Harvest} - \sum \text{Ground water} - \sum \text{Atmospheric loss}$

Unit area yield = 15.0 + 0.0 + 2.6 + 72.8 – 45.3 -26.4– 0.0 = 18.7 kg/ha/y

The only identified N input to forest, CRP, and water land classes was identified as atmospheric deposition, which was estimated as 2.6 kg/ha/y.

N yield calculated at a grid level was mapped to sub-basin level using the weighted-area approach (Figure 29). These N load yields for sub-basins varied from 2.6 to 18.7 kg/ha/y. Soybean cultivation is the main contributor of N to Beasley Lake, followed by corn cultivation. From these results, the east part of the watershed was identified as the largest N contributor to Beasley Lake.

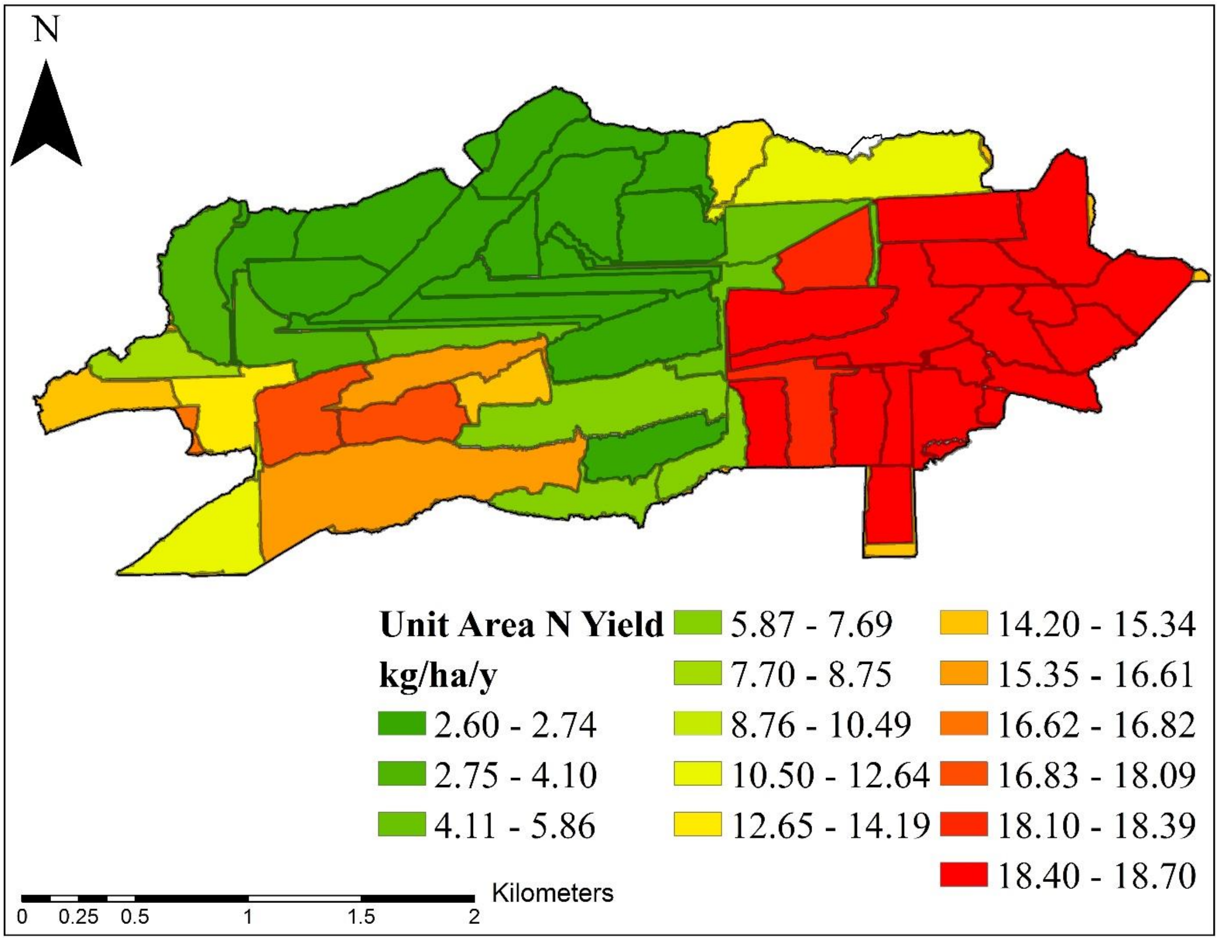

Figure 29. Unit area N yield of the Beasley Lake Watershed.

4.5.3 In-stream Exported N Load Estimation

The N load exported in-stream is presented in Figure 30. The load at a given stream reach represented the incremental load. The increamental load at a given stream reach was the total annual load added from its sub-basin and upstream reaches after subjected to BMPs and natural processes removal. Beasley Lake receives the largest portion of N load from two main outlets, labeled as 1 and 2. The flow towards outlet 1 passes through a riparian forest buffer, which removed up to 60% the N load from overland flow and 0.021 kg/m from in-stream (inferred from

Table 15. Description of selected BMPs.). Also, loss to the atmoshere, from in-stream through denitrifcation, was estimated at a rate of 0.2 $mg/m^2/h$. The flow at outlet 2 was regulated by a sediment retention pond that removed up to 40% of the incoming load. The total annual N load received, from outlet 1 (1,457 kg), outlet 2 (1,001 kg), and other outlets (117 kg), was estimated as 2, 575 kg. Yasarer et al. (2017) estimated the annual nitrogen load for the Beasley Lake in runoff is 3.7 kg/ha and the total annual load is 2,313 kg.

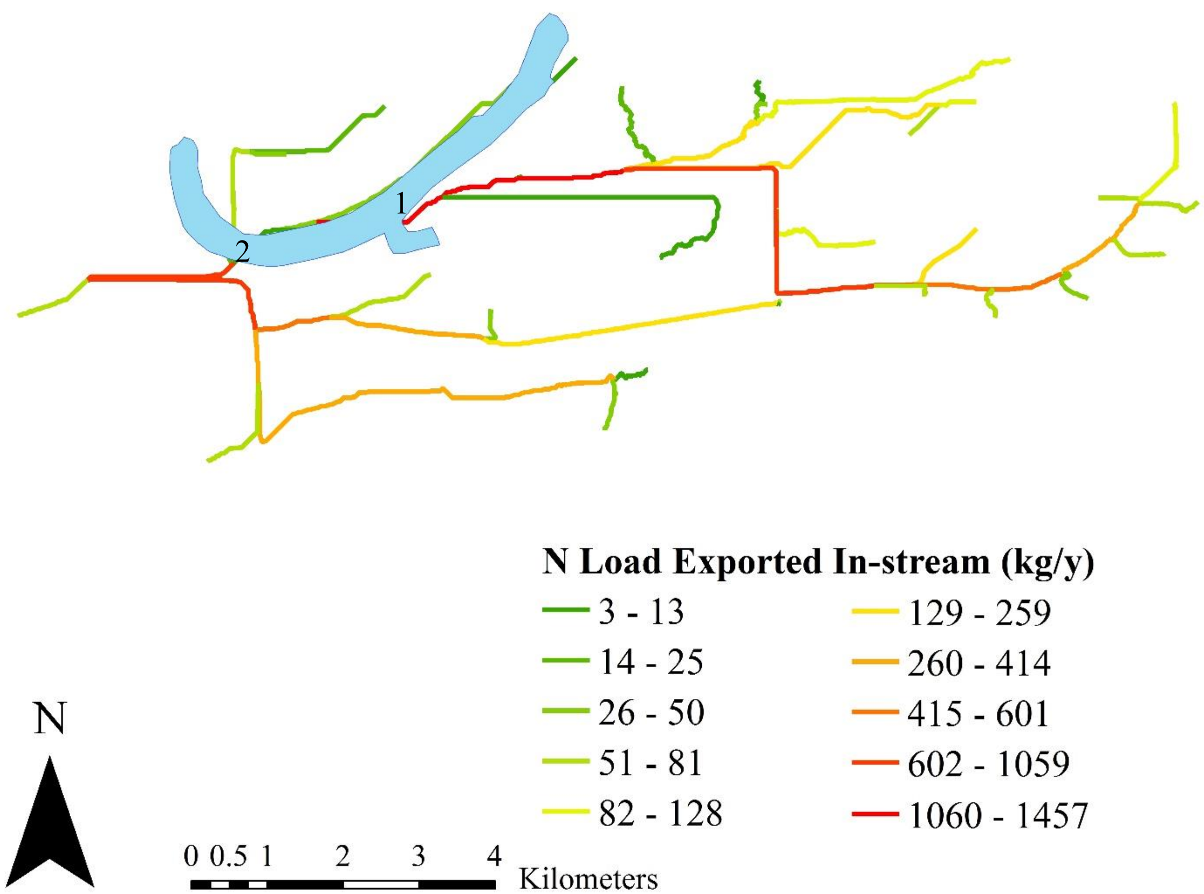

Figure 30. N load exported in-stream along flow pathways.

4.5.4 Results from the Spatial Decision Analysis

4.5.4.1 Critical Watershed Sites

Figure 31 depicts the critical watershed sites of the BLW. The unit area yield, the total annual yield from each sub-basin, and the N loads exported in-stream were spatially varied from 2.6-18.7 kg/ha/y, 0-753 kg/y, and 3-1,457 kg/y, respectively. Each of these values was divided into red, yellow, and green categories, which were in the order of most to least critical watershed sites for placement of BMPs. The most suitable critical sites fell in the unit area yield of 15.2-18.7 kg/ha/y, sub-basins with an annual total yield of 264-753 kg, and reaches with an exported in-stream load of 767-1,457 kg/y. These results provided crucial information to determine the level of effort required to achieve a target water quality improvement and served as a guide for choice and placement of BMPs. Better water quality would be achieved if a decision on BMP choice and placement were prioritized in consideration of such spatial information.

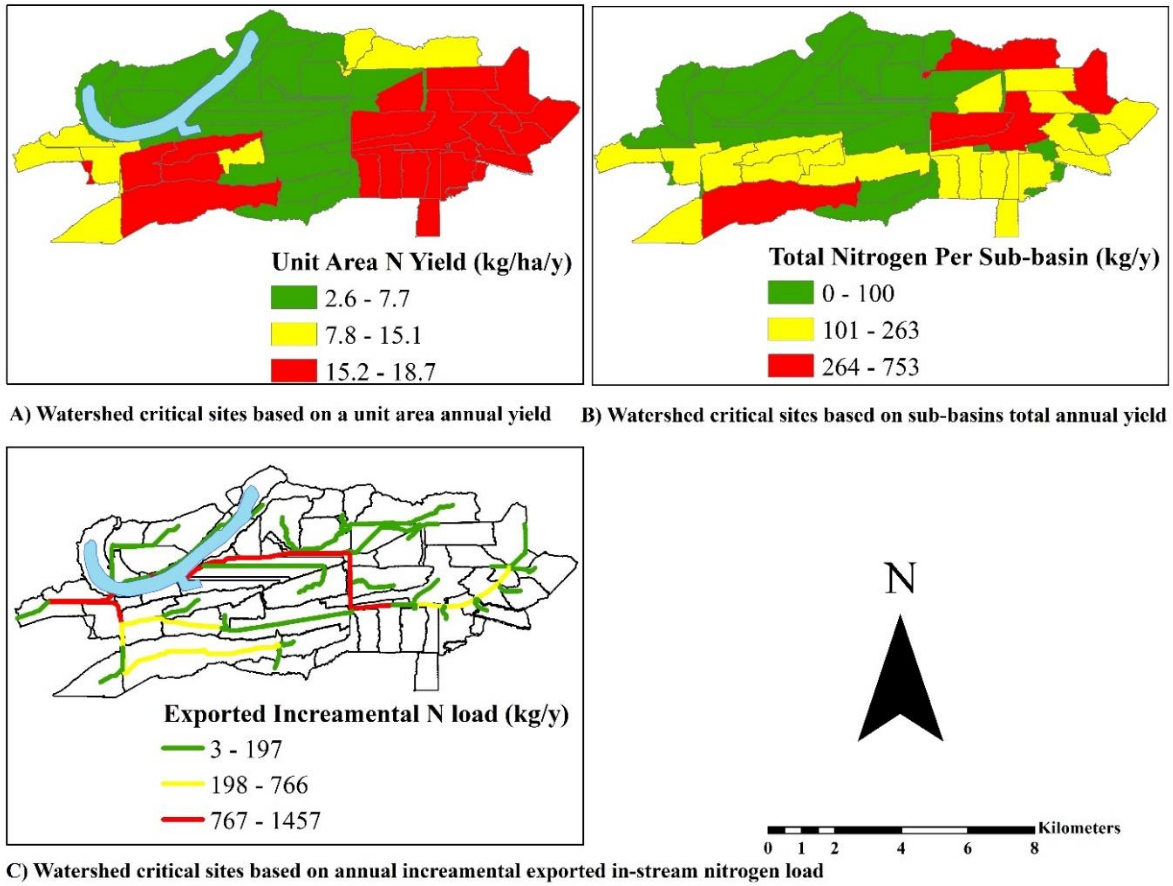

Figure 31. Critical watershed sites of the Beasley Lake Watershed.

4.5.4.2 Evaluation of BMP Scenarios

A decision on placement of BMP scenarios was aided by information on critical watershed sites and suitable location for BMPs. For this purpose, suitable sites for BMPs within the watershed were identified. The most to least suitable sites for buffer strips, determined based on an infiltration rate and total annual N yield, are shown in red, yellow, and green colors of Figure 32, respectively. The soil infiltration rate and the total annual N yield were varied from 0.15-2.00 cm/h and 0-753 kg, respectively. Sites in red color fell in infiltration rates of 1.33-2.00 cm/h and a total annual yield of 264-753 kg. Sites in yellow fell in infiltration rates of 0.67-1.33 cm/h and a total annual yield of 101-263 kg. The green shaded portion of the watershed fell in infiltration rates below 1.33

cm/h and total annual yields below 100 kg. Buffer placement in all BMP scenarios was prioritized to the red and yellow shaded sites of the watershed.

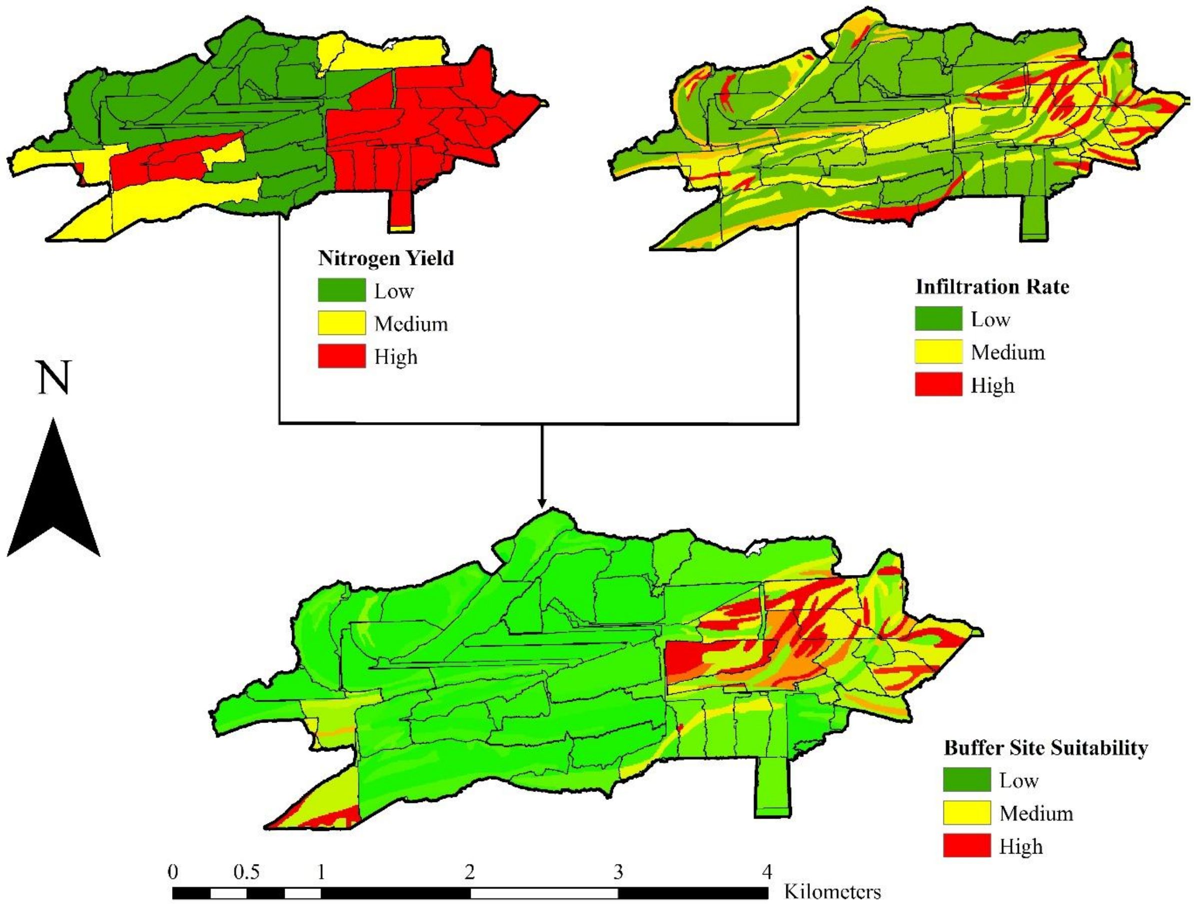

Figure 32. Suitable sites for establishment of buffer in the Beasley Lake Watershed.

An in-stream export coefficient was used to identify the potential wetland sites (Figure 33). The flow pathways were categorized into three categories: streams conveying 0.0-3.7% (green shaded), 3.8-16.1% (yellow shaded), and 16.2-56.6% (red shaded) of the total annual exported load into Beasley Lake. The red, yellow, and green shaded stream segments were identified as the most to least suitable sites for construction of wetland. A wetland placement was prioritized to the red shaded flow pathways.

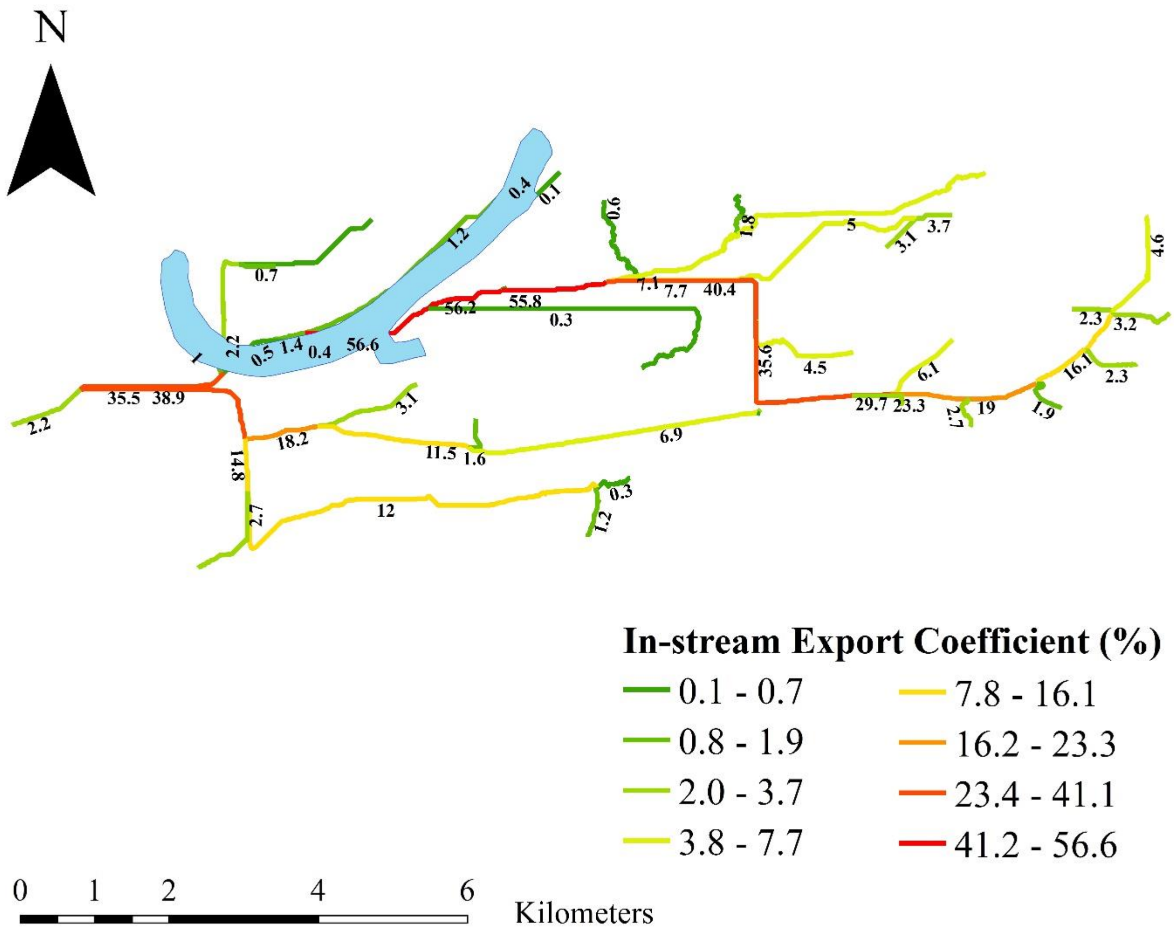

Figure 33. An export coefficient for stream reaches in the Beasley Lake Watershed.

Using information from watershed critical and BMP suitable sites, several placement options and their respective cost and performance were compared. For demonstration purposes, three BMP scenarios that meet a 25% source reduction criteria were compared (Figure 34). The allocation of BMPs was distributed into two main locations: the drainage area to outlet 1 and at outlet 2 (which were identified as the main flow pathways to the Beasley Lake). The upstream drainage area of outlet 1 holds a critical location for buffer strips. For the site, 109 ha of land was treated with grass buffer for scenario 1, 63 ha of land was treated with forest buffer for scenario 2, and 41 ha of land was treated with grass buffer for scenario 3. The critical sites in the drainage area of outlet 2 were similarly treated with 62 ha of land with grass for scenario 1, 16 ha of land with forest buffer for scenario 2, and 16 ha of land with forest grass for scenario 3. Moreover, a wetland was proposed along flow pathways to outlet 2 for scenario 3.

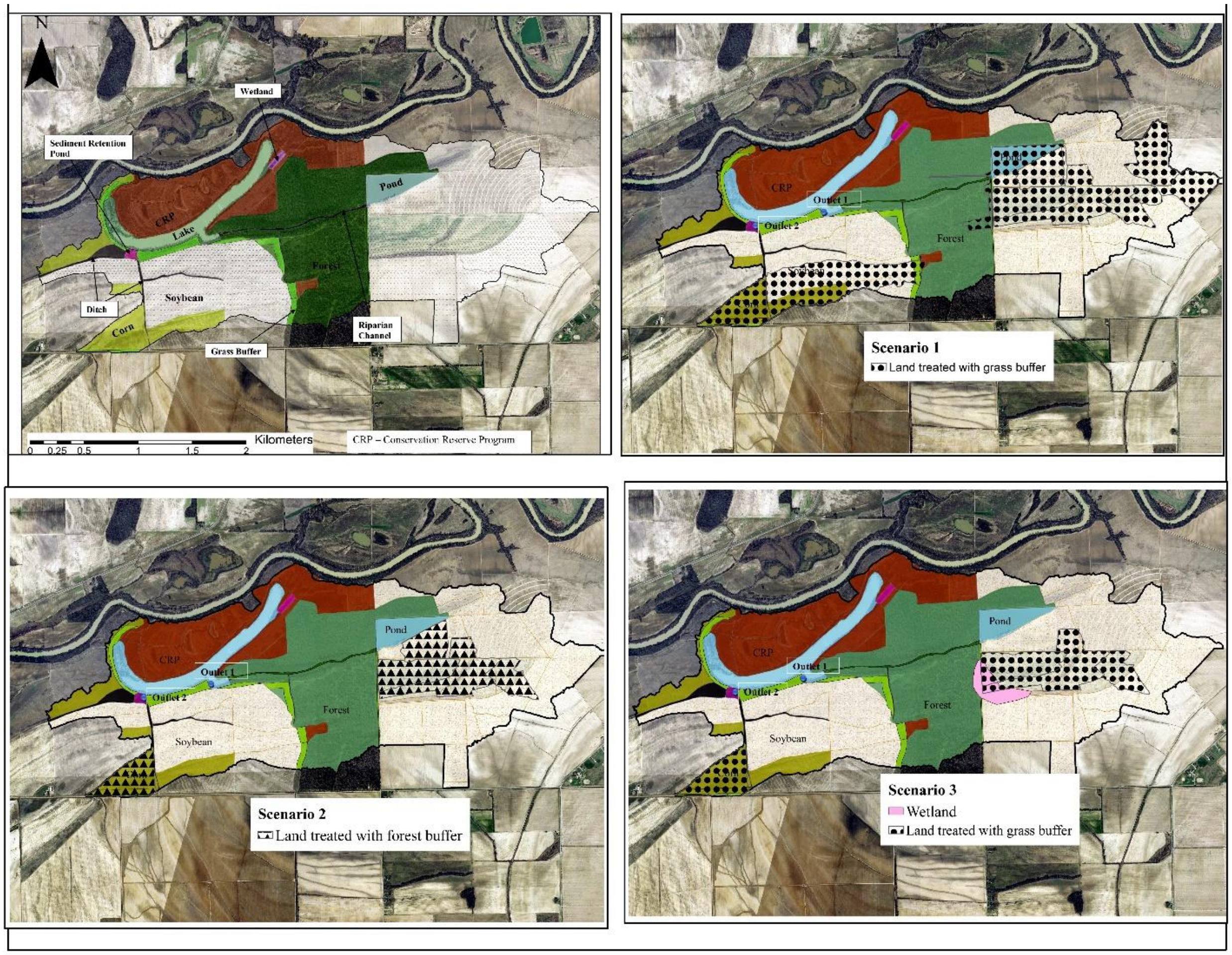

Figure 34. Spatial allocation of BMP scenarios in the Beasley Lake Watershed.

The estimated cost of applying the three BMP scenarios is presented Table . Due to an information gap for this research, the cost estimates were a general approximation and did not reflect the actual cost for Beasley Lake. As shown in Table 15. Description of selected BMPs., the establishment cost of a specific BMP varies where a higher establishment cost is corresponding to a higher performance. The unit cost estimates of buffers and a wetland for this study were associated with a cost required to establish a practice with its maximum performance. For a 50 m wide commonly used buffer strip, the establishment unit cost is $988/ha for a grass buffer and

$1800/ha for a forest buffer. The establishment cost of a wetland is $247/ha. The annualized opportunity cost of land taken out of production for grass buffer, forest buffer, and wetland establishment are $154/ha, $815/ha, and $19/ha, respectively. The total cost was calculated using these BMP unit costs.

Table 18. Estimated cost for establishing BMP scenarios.

	Practice	**Treated land (ha)**	**Establishment cost ($)**	**Annual opportunity cost ($)**
Scenario 1	Grass buffer	171	168,889	26,347
Scenario 2	Forest buffer	79	142,200	64,370
Scenario 3	Grass buffer	57	56,296	8,782
	& wetland	165	40,741	3,198

The three BMP scenarios were compared based on the N removal efficiency and the cost-effectiveness criteria (Table 19). The total annual N load exported into the Beasley Lake was reduced from 2,575 kg (Baseline scenario) to a maximum of 1,924 kg (Scenario 3) and a minimum of 2,023 kg (Scenario 2). According to the performance criterion, the best to worst BMP scenarios were Scenario 3, Scenario 1, and Scenario 2 with removal efficiencies of 25%, 24%, and 21%, respectively. Based on the cost-effectiveness criterion, Scenario 1, Scenario 2, and Scenario 3 were identified as the best to worst, respectively. An overall decision analysis was performed by introducing a trade-off criterion, named as the cost-to-performance effectiveness ratio ($/kg). According to the overall analysis, Scenario 1 was found as the best with the establishment cost-to-performance and the annual opportunity cost-to-performance ratios of 148 $/kg and 29 $/kg, respectively.

Table 19. Comparison of BMP scenarios.

Scenario	**Annual exported load (kg)**	**Removal (kg)**	**Removal efficiency (%)**	**Establishment cost to performance ($/kg)**	**Annual opportunity cost to performance ($/kg)**
Baseline scenario	2,575	0	0	0	0
Scenario 1	1,955	620	24	184	29
Scenario 2	2,023	552	21	185	84
Scenario 3	1,924	651	25	217	417

The decision analysis presented in this study provides a framework for optimizing choice and placement of BMPs. The spatial complexities of a watershed were better handled when the watershed system was broken down into smaller units and spatial details were considered. The three BMP scenarios demonstrated that such spatial details enable an optimum benefit of restoration by allowing more BMPs placement options.

4.6 CONCLUSIONS

Nutrient pollution management is a spatially complex task. In an agricultural watershed, nutrients entering into the receiving water body originate mainly from nonpoint sources. There are several management practices to reduce nutrients from sources. However, the choice and placement of these practices involve trade-offs among conflicting criteria: performance, site suitability, and establishment cost. The application of SDSS for such problems enables a flexible decision and provides an optimum benefit of a source reduction effort. The development of SDSS involves establishing a database pool, which stores information to assess nutrient pollution processes, and incorporating an analytical method for assessing the nutrient load under different conditions of the watershed.

In the present study, SDSS was developed for BLW to support N source reduction efforts. A terrain analysis was performed using LIDAR data to generate the hydrologic network of streams. The watershed was divided into smaller sub-basins to allow an in-depth spatial analysis. The N budget approach was applied to identify and estimate N sources. A simplified mass balance method was applied to estimate the exported load into the Beasley Lake. Three BMP scenarios were generated based on (i) critical watershed sites, locations with a relatively highest N yield and (iii) suitable sites for establishment of buffer strips and wetlands. The BMP scenarios were compared based on N removal efficiency and cost effectiveness.

From N yield and load information, it was possible to visualize the critical watershed sites, both in the landscape and flow pathways. Along with the critical watershed sites, the identified buffer and wetland suitable locations provided a crucial spatial information for BMPs placement options. This helped to visualize and to identify a given choice of BMPs and their placement that met a 25% export load reduction. The placement options were compared for the cost-effectiveness, and it was possible to minimize the investment cost. An overall decision was made by introducing a cost-to-performance criterion, which reflected the cost required to remove a unit mass of N load.

The presented study demonstrated that the watershed information necessary for restoration programs was spatially variable. The application of SDSS would simplify the watershed assessment by serving as a visualization tool for the complex spatial information. The approach presented this report could be an alternative method when considerable data and information are not available to support restoration plans with existing watershed models.

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CHAPTER V

CONCLUSIONS

5.1 OVERVIEW OF FINDINGS

This research, triggered by the existing U.S. EPA water quality management goals of lakes and rivers, demonstrated an alternative water quality assessment, recovery potential ranking, and restoration planning approaches to support identification and restoration of nutrient-impaired water bodies.

To investigate an alternative way to assess nutrient concentrations, 52 water quality indicators (surveyed under the U.S. EPA NLA program) were evaluated to identify easily measurable and statistically correlated indicators of TN and TP. From this analysis, pH, conductivity, and turbidity were identified as potential indicators of TN and TP. These indicators were used to develop artificial neural network-based prediction models. Model development was optimized using regional datasets that were obtained from a relatively homogenous environment. Regional models trained with larger datasets performed better than other networks. To understand the factors affecting the network accuracy, the correlation between the main model performance criterion (ASE) and four regional factors (total regional area to total number of datasets ratio, total regional water area to total number of datasets ratio, temperature, and precipitation) were examined. Model performance was improved when a network was trained with a dataset from a region with a lower temperature and precipitation variability. The use of larger datasets within a homogenous climatic region is recommended to further improve the accuracy of models that predict nutrient concentration.

Once the nutrient concentrations are assessed, the conditions of water bodies will be determined based on a designated use or water quality standard criteria. A lake or river that does not meet these criteria will be listed as an impaired water body. The next effort towards improving the water quality condition of impaired water bodies is to prioritize them for restoration activities and a total maximum daily load plan based on a watershed's ecological, stressor, and social indicators.

For this study, the recovery potential of 51 water bodies was assessed based on several ecological, stressor, and social indicators. The objective of this study was to evaluate the impact of social indicators on assessing the recovery potential of impaired water bodies. The 16 social indicators, representing QOL, were grouped into Socio-Economic, Organizational, and Planning and Information subcategories. An in-depth analysis on social indicators was performed on four watersheds in the Delta region of Mississippi (Lake Washington, Harris Bayou, Steele Bayou, and Coldwater River). In the particular watersheds studied, the Socio-Economic subcategory was observed to be the most impactful to the overall recovery potential when compared to the other two social subcategories. As a sensitivity analysis, a "what if" simulation was performed to explore alternatives to upgrade a watershed's social index and, consequently, the relative recovery potential of the watershed to a target level. This analysis is useful for understanding how particular social indicators of a community impact the relative potential for recovering a watershed, beyond just the ecological and stressor conditions. It also sheds light on assessing which social indicators can be improved.

A candidate water body for restoration can be further studied for TMDL development and a restoration plan. Such plans involve determining the pollution reduction target, also called a

TMDL goal, setting the discharge permit for point sources and planning as well as implementing restoration actions for nonpoint sources, and monitoring the progress of water quality improvements. To support these efforts, a spatial decision support system (SDSS) was developed.

From the recovery potential ranking results, the priority water body for restoration was Coldwater River, which was supposed to be a study site for SDSS demonstration. However, due to lack of information and data availability, the study was conducted for the Beasley Lake watershed. For SDSS development, the watershed information necessary to assess nutrient loads was stored as an updatable database pool. Nitrogen sources and exported loads were estimated by unit area load and mass balance methods, respectively. To be able to visualize best management practice placement (BMP) options, the exported nitrogen load and the watershed critical source sites were identified. For demonstration purpose, three BMP scenarios were proposed and evaluated that meet a 25% nitrogen load reduction plan. The watershed information enables to consider several BMP placement options. Using these options, BMP plans were optimized for performance and cost criteria. The proposed approach is an alternative to stand-alone models when information and resources are limited.

5.2. LIMITATIONS OF THE PRESENT STUDIES

Research presented in this dissertation attempted to address its objectives on the face of unavoidable limitations due to time, information, and resource constraints. These limitations are outlined below.

Limitations of the application of ANN for prediction of TN and TP concentrations

- In general, water quality data are not available in large amounts due to resource and time constraints of sampling. This research used the largest water quality record available in the nation. Model development processes in this study showed that the ANN generalizing ability was improved when larger datasets were used. The use of a dataset larger than the existing records would likely improve the model performance; however, this was limited by data availability.
- Network input variables in this research were selected primarily based on data availability. This research did not evaluate entire range of hydro-metrological and soil variables that govern the quality of water.

Limitations of the sensitivity analysis for recovery potential to QOL

- The U.S. EPA-RPS tool demonstrated several indicators to assess the watershed condition for a restoration action. The tool suggests expert judgment for selecting and weighting of indicators, which faces a higher degree of subjectivity in interpreting indicators. However, there was no concrete information to evaluate the indicators' relationship to a given recovery goal and to assign indicator weight accordingly. Because of this, our analysis was limited by an assumption that all indicators were equally relevant to the restoration goal.

- Moreover, social indicators were assumed to represent QOL. The literature stated that QOL is multidimensional and is often difficult to define. Because of this, this study was conducted without clear information on a complete range of indicators to represent QOL.

Limitations of the application of SDSS for Beasley Lake

- SDSSs are generally designed with complete information in order to allow attainable decision-making. In this research, stakeholder information was not incorporated due to an information gap. However, such information would have a remarkable impact on the final outcome. For example, analyzing BMP placement options without the knowledge of land ownership or land use rights might result in an unattainable plan.
- The main source of nitrogen for BLW is fertilizer from agricultural activities. The exported nitrogen load into Beasley Lake was assumed to be predominantly from crop planting times, which are April and May. The nitrogen load export analysis was performed based on the watershed condition in April and May. The crop cultivation calendar needs to be further checked (as this information was taken from general literature sources) and adjustments need to be made accordingly if there are any recent changes.
- The nitrogen transport processes were assumed to follow a steady state where a constant amount of nitrogen is lost as it travels a unit distance downstream. However, this has to be further validated with monitored data to check if the proposed method consistently produces a reasonable prediction.

5.3 RECOMMENDATIONS FOR FUTURE STUDIES

In order to address research shortcomings as discussed in Section 2, the following studies are suggested.

- To enhance the accuracy of regional TN and TP prediction models, two alternative tasks are recommended: (i) the use of larger datasets collected from climatologically homogenous areas. Recently invented wireless sensor technologies for real-time water quality monitoring can ease the sampling task to obtain larger datasets with minimum efforts. If this option does not produce the intended result, use the next option, (ii) the use of other hydro-metrological and soil variables to check if they are interrelated to TN and TP and use them as network input if the model accuracy improved to the desired level. Also, it is suggested to develop separate models for TN and TP predictions to check if the model performance improves.
- To provide an in-depth analysis on the impact of social indicators on assessing recovery potential of impaired water bodies, further information is required, such as relative relevance of indicators to a given restoration goal. The two likely main information sources are by learning from other restoration projects and by performing a thorough literature review and by working in-depth with several watersheds. More importantly, such watershed planning has a multi-disciplinary aspect and demands a deep understanding of social indicators, which is outside of this researchers' expertise. It is highly advisable to collaborate with other disciplines to perform this analysis.

- The SDSS is developed with publicly available information, regardless of the time of the survey. The database pool is updatable with new information. It is suggested to use up to date information to enhance the decision support system. For example, information on land ownership or rights, any changes in N application rates or land use, and/or other new data can be added and BMP placement options could be re-evaluated accordingly. Furthermore, field surveys are also highly recommended to obtain reliable information, such as monitoring N loads to validate the predicted loads and verifying the terrain because the existing analysis was performed based on the 2009 LIDAR data.

VITA

EDUCATION

Ph.D. in Engineering Science — Will Graduate in May 2018

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Dissertation: “A framework for assessing water quality, prioritizing recovery potential, and analyzing placement of best management practices”

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Thesis: “Understanding the condition of wastewater irrigation in community based irrigation schemes for Akaki River Basin, Ethiopia”

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- Develop nutrients concentration prediction models for U.S. lakes
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