Alabama Water Resources Research Institute
Annual Technical Report
FY 2013

Introduction

The Alabama Water Resources Research Institute (AL-WRRI) was created in 1964 by the Alabama Legislature. In 2007 the AL-WRRI was combined with the newly created Auburn University Water Resources Center (AU-WRC), and in 2008 it was designated as part of the Auburn University Center of Excellence for Watershed Management by EPA. The AU-WRC and AL-WRRI function as a single university-based interdisciplinary, problem-oriented research and technology center under one Director with support from the federal government through the USGS that enables the programs to address broad national needs and relevant industrial technology. The Alabama Water Resources Center and Research Institute coordinates research programs that contribute to the solutions of present and emerging water resources problems. In carrying out this mission, the Institute has developed a broadly based research, training, information transfer, and public service program involving personnel from many academic disciplines in the state's research universities

The Alabama Water Resources Center and Research Institute is one of 54 water resources institutes nationwide authorized by the federal Water Resources Research Act. The state-based Water Resources Research Institutes are located at land grant universities and function as a nation-wide network to promote research and information dissemination on the state's and nation's water resources problems.

Research Program Introduction

The essential ingredient for determining proper policies and practices is factual information. Often such information must be obtained by means of scientific research. The Institute conducts a program that stimulates, sponsors, and provides for research, investigation, and experimentation in the fields of water and of resources as they affect water, and encourages the training of scientists in the fields related to water.

Objectives of the AU-WRC and AL-WRRI are:

To plan, conduct and otherwise arrange for competent research that fosters (a) the entry of new research scientists into the water resources fields, (b) the training and education of future water scientists, engineers and technicians, (c) the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and (d) the dissemination of research results to water managers and the public.

To identify major research needs and develop for Alabama and the Southeastern Region short- and long-term research priorities. To encourage research applying to other environmental resources closely associated with water.

To maintain close consultation and collaboration with governmental agencies, public groups, and cooperate closely with other colleges and universities in the state that have demonstrated capabilities for research, information dissemination, and graduate training in order to develop a statewide program designed to resolve state and regional water and related land problems.

Forecasting toxic cyanobacterial blooms throughout the southeastern U.S.

Basic Information

Title:	Forecasting toxic cyanobacterial blooms throughout the southeastern U.S.
Project Number:	2011AL121G
Start Date:	9/1/2011
End Date:	8/31/2014
Funding Source:	104G
Congressional District:	3rd
Research Category:	Water Quality
Focus Category:	Models, Nutrients, Surface Water
Descriptors:	None
Principal Investigators:	Alan Elliott Wilson, Kevin Schrader, Russell Alan Wright

Publications

1. Wilson, Alan E.; Michael F. Chislock. In press. Ecological control of cyanobacterial blooms in freshwater ecosystems. in ed. Aloysio Ferrão-Filho,Cyanobacteria: Toxicity, ecology, and management. Hauppauge, New York, Nova Science Publishers, xx-xx.
2. Wilson, Alan E.; Michael F. Chislock. In press. Ecological control of cyanobacterial blooms in freshwater ecosystems. in ed. Aloysio Ferrão-Filho,Cyanobacteria: Toxicity, ecology, and management. Hauppauge, New York, Nova Science Publishers, xx-xx.
3. Wilson, Alan E.; Michael F. Chislock. In press. Ecological control of cyanobacterial blooms in freshwater ecosystems. in ed. Aloysio Ferrão-Filho,Cyanobacteria: Toxicity, ecology, and management. Hauppauge, New York, Nova Science Publishers, xx-xx.
4. Doster, Enrique; Chislock, Michael F.; Roberts, John; Kottwitz, Jack; and Wilson, Alan E. 2014. Recognition of an important water quality issue at zoos: prevalence and potential threat of toxic cyanobacteria. Journal of Zoo and Wildlife Medicine 45(1):174 177.
5. Kasinak, Jo Marie, 2013, Methods for monitoring and controlling freshwater harmful algal blooms, MS thesis, Department of Biological Sciences, Auburn University, Auburn, Alabama, 64 pages. Olsen, Brianna; Chris Smith; Michael Chislock; Jo Marie Kasinak; and Enrique Doster. 2013. Letter to the Editor: Association for the Sciences of Limnology and Oceanography (ASLO) 2013 Annual Meeting: Students' perspectives. ASLO Bulletin 22(3):83 84. Wilson, Alan; Michael Chislock, Enrique Doster; Russell Wright, Jack Kottwitz, Heather Walz, and Heidi Rose. 2013. Toxic algae threaten livestock health. The Alabama Cattleman June 2013:16 17.

ANNUAL TECHNICAL REPORT SYNOPSIS

The Terms and Conditions of the grants awarded under the Water Resources Research Act state that each institute shall prepare an Annual Program Report summarizing its activities during the reporting period under its base grant, and National Competitive Grant Program awards. The reporting period is March 1, through February 28. All Annual Reports must be submitted by 5:00 PM, Eastern Daylight Time, June 1, and must be submitted electronically. In order to do this we need your assistance by providing the following information about your current or recent WRRI-funded research project:

A. PROJECT TITLE:
   USGS Project 2011AL121G – Forecasting toxic cyanobacterial blooms throughout the southeastern U.S.
   Project website - http://wilsonlab.com/bloom_network/
B. PRIMARY PI(s): Name(s), Title(s) & Academic Rank(s)
   Alan E. Wilson, Associate Professor, Ph.D.
C. OTHER PI(s): Name(s), Title(s) & Academic Rank(s)
   Russell A. Wright, Associate Professor, Ph.D.
   Kevin Schrader, Microbiologist, Ph.D.
D. START DATE:
   1 October 2011
E. END DATE:
   30 September 2014
F. PROJECT OVERVIEW/SUMMARY: Provide a brief narrative overview or summary of the project.
   Using a novel collaborative approach, we are collecting water quality samples and associated data from 400+ diverse freshwater systems, including lakes, reservoirs, ponds, and rivers, throughout much of the eastern U.S. These samples will be analyzed by the PIs for phycocyanin (cyanobacteria), cyanobacterial toxins, off-flavors, and phytoplankton enumeration. Data generated from these efforts will be used to refine and build models aimed at forecasting blooms of freshwater cyanobacterial blooms. Although the focus of the current project is on the Southeast, we have quickly expanded our efforts beyond this region. We hope to continue this expansion throughout the 3-year project.
G. PROJECT OBJECTIVE(s): Briefly explain the project objectives.
   1) To enhance our network of water quality managers and scientists throughout the southeastern U.S. aimed at monitoring sites for toxic cyanobacterial blooms.
   2) To test and refine current models that forecast toxic cyanobacterial blooms and off-flavor events in freshwater lakes, reservoirs, rivers, and ponds throughout the Southeast.
   3) To train state and federal scientists, water quality managers, and aquaculturists on standard techniques to measure cyanobacterial toxin and phycocyanin concentrations and to identify and enumerate phytoplankton.

4) To train graduate and undergraduate students on field sampling and laboratory-based water quality analytical analyses.
5) To enhance our existing, user-friendly, interactive website where water quality managers and aquaculturists can determine the risk of their waterbodies for toxic cyanobacterial blooms and/or off-flavor events.

To create a model collaborative network that can be extended to other U.S. regions.

H. METHODOLOGIES: Briefly explain the research methodology used.

Sample sharing is central to the success of our project. We are also planning to share data among collaborators, but we are most excited about our approach for bringing together scientists in academia, agencies, and industry who all share a common concern – algal blooms. We are leveraging resources provided by our many colleagues throughout the eastern U.S. to collect and analyze water quality samples for us. In turn, we will analyze these samples for phytoplankton, cyanobacteria, and cyanobacterial toxins and off-flavors in order to build algal bloom forecasting models.

I. PRINCIPAL FINDINGS/RESULTS: Explain the results of findings of this research project.

Although our first full project year was unbelievably productive, I can honestly say that our second year has been even better. Our collaborator numbers (and associated sampling sites) continue to grow. In our second field season, we have almost 50 collaborators primarily from state agencies and universities in Alabama, Arkansas, Florida, Georgia, Kansas, Kentucky, Louisiana, Mississippi, North Carolina, Puerto Rico, South Carolina, Tennessee, and Texas. Instead of focusing our efforts on soliciting for more collaborators through presentations at regional, national and international meetings, in project year 2 we emphasized sample analyses. Although we proposed to get samples and data from 200 sites per year, we processed samples from almost double this number in 2012 (toxins = 389 waterbodies, phycocyanin = 363 waterbodies, off-flavors = 100 waterbodies) and will process samples from almost 400 sites for our 2013 season once our current analyses are done. Wilson planned to begin counting phytoplankton samples from the summer of 2012 during the spring of 2013, but he was awarded a highly competitive one semester fellowship at the University of North Carolina Global Research Institute where he was able to interact with other water resource scientists from around the world (http://gri.unc.edu/people/alan-wilson). In addition to conducting research, Wilson also helped organize a new course at UNC-CH, called Water in Our World. The phytoplankton counts are on the top of the priority list. Sample analyses have taken longer than we had predicted, in part because of the much higher sample numbers than expected. Once we get our second year of samples analyzed, we will begin the process of organizing our huge dataset. Through this project, we have also connected two regional water utilities regarding off-flavor analyses. One of my graduate students, Brianna Olsen, conducted an experiment aimed at determining how nutrient concentrations and ratios influence off-flavor production. Her data are the first to show the effects of nutrients on off-flavors and she is working on a manuscript that we will submit to Environmental Science & Technology early summer. Given the lack of data regarding abiotic and biotic effects on off-flavors, my lab is planning to invest time and resources into being able to analyze off-flavors ourselves. Another lab at Auburn University has

donated a relatively new GC-MS to my lab, and we are in the process of getting the infrastructure running. We hope to be analyzing our own off-flavor samples in the near future.

In addition to six conference presentations during the last project year, our team has published another research article, one MS thesis, and two other publications. All of these publications were led by student authors. We also have two manuscripts in review that were products of this project (Journal of Plankton Research and Journal of Aquatic Plant Management). One of these manuscripts validates the utility of our phycocyanin protocol for quickly quantifying cyanobacterial abundance in waterbodies of varying trophic state. We expect our project collaborators to find these publications useful for their research and water resource management. Our research team, including several undergraduate and graduate students, has also received numerous awards during the last project year. Wilson was awarded tenure with promotion during our last project year, as well.

Our outreach activities continue to be wildly successful. We held two water quality workshops during the spring of 2013 (Auburn and Chapel Hill) and another workshop in the spring of 2014 (Auburn) (see pictures from Chapel Hill 2013 and Auburn 2014 below). All workshops were well-attended (12-21 students each), and we received feedback showing that our students learned a lot about the project and our analytical and modeling approaches (surveys from past workshops are available). Wilson continues to lead outreach activities at daycares and prisons to educate unique audiences about water quality. Wilson was recently awarded an Auburn University outreach grant ($20,000) to extend our prison science seminar series for the next academic year. This project has engaged >25 Auburn University faculty with prison populations. Wilson gave a lecture about eutrophication during his visit.

J. NOTABLE AWARDS AND ACHIEVEMENTS. List any awards or recognitions for this research

PI HONORS AND AWARDS

Alan Wilson	Purdue University Scholar of Sustainability (declined)
Alan Wilson	Semester fellowship at UNC-CH Global Research Institute, $35,000
Alan Wilson	Auburn University outreach grant, $20,000

STUDENT HONORS AND AWARDS

Anja Rebelein	DAAD RISE fellowship (German Exchange program), $5,500
Brianna Olsen	Auburn University student travel grant, $300
Jo-Marie Kasinak	Sigma Xi Grants in Aid of Research grant, $600
Jo-Marie Kasinak	MidSouth Aquatic Plant Management Society Scholarship, $2,000
Enrique Doster	Auburn University Undergraduate Research Fellow award, $6,000

K. PUBLICATIONS GENERATED:

Number of Research Publications generated from this research project:	
Publication Category	Number
Articles in Refereed Journals	1
Book Chapters	0
Theses and Dissertations	1
Water Resources Institute Reports	0
Articles in Conference Proceedings	0
Other Publications	2

PROVIDE A CITATION FOR EACH PUBLICATION USING THE FOLLOWING FORMATS:

1. Articles in Refereed Scientific Journals Citation

Author (first author; last name, first name; all others; fist name, last name), Year, Title, Name of Journal, Volume(Number), Page Numbers.

1) Doster, Enrique; Chislock, Michael F.; Roberts, John; Kottwitz, Jack; and Wilson, Alan E. 2014. Recognition of an important water quality issue at zoos: prevalence and potential threat of toxic cyanobacteria. Journal of Zoo and Wildlife Medicine 45(1):174-177.

2. Book Chapter Citation

Author (first author; last name, first name; all others: first name, last name), Year, Title of chapter, "in" Name(s) of Editor "ed.", Title of Book, City, State, Publisher, Page Numbers.

None

3. Dissertations Citation

Author (last name, first name), Year, Title, "MS (Ph.D.) Dissertation," Department, College, University, City, State, Number of Pages.

Kasinak, Jo-Marie, 2013, Methods for monitoring and controlling freshwater harmful algal blooms, MS thesis, Department of Biological Sciences, Auburn University, Auburn, Alabama, 64 pages.

4. Water Resources Research Institute Reports Citation

Author (first author; last name, first name; all others: first name, last name), Year, Title, Name of WRRI, University, City, State, Number of Pages.

None

5. Conference Proceedings Citation

Author (first author; last name, first name; all others: first name, last name), Year, Title of Presentation, "in" Title of Proceedings, Publisher, City, State, Page Numbers.

None

6. Other Publications Citation

Author (first author; last name, first name; all others: first name, last name), Year, Title, other information sufficient to locate publications, Page Numbers (if in publication) or Number of Pages (if monograph).

1) Olsen, Brianna; Chris Smith; Michael Chislock; Jo-Marie Kasinak; and Enrique Doster. 2013. Letter to the Editor: Association for the Sciences of Limnology and Oceanography (ASLO) 2013 Annual Meeting: Students' perspectives. ASLO Bulletin 22(3):83-84.
2) Wilson, Alan; Michael Chislock, Enrique Doster; Russell Wright, Jack Kottwitz, Heather Walz, and Heidi Rose. 2013. Toxic algae threaten livestock health. The Alabama Cattleman June 2013:16-17.

PRESENTATIONS MADE:

Presenter(s) (last name, first name; all others presentation authors: first name, last name), Year, Title, other information sufficient to identify the venue in which the presentation was made.

1) Wilson, A. E., Kasinak, J-M., and B. Holt. 2014. Phycocyanin fluorometric analysis: a new method for estimating cyanobacterial abundance. NALMS Southeastern Lake and Watershed Management Conference. Asheville, North Carolina.
2) Stevens, K., D. Goodwin, and A. E. Wilson. 2014. Bridging a curriculum gap in prisoner education. Auburn University Outreach Symposium. Auburn, Alabama.
3) Kasinak, J-M.,, C. Bishop, and A. E. Wilson. 2013. Do grass carp consume *Lyngbya wollei*? MidSouth Aquatic Plant Management Society. Tunica, Mississippi.
4) Doster, E., M. F. Chislock, J. F. Roberts, J. Kottwitz, and A. E. Wilson. 2013. Recognition of an important water quality issue at zoos: prevalence and potential threat of toxic cyanobacteria. Honors College Research Colloquium. Auburn University, Auburn, Alabama.

5) Doster, E., M. F. Chislock, J. F. Roberts, J. Kottwitz, and A. E. Wilson. 2013. Recognition of an important water quality issue at zoos: prevalence and potential threat of toxic cyanobacteria. American Association of Zoo Veterinarians. Salt Lake City, Utah.
6) Chislock, M. F., K. G. LeMay, and A. E. Wilson. 2013. Ecological stoichiometry and the control of harmful cyanobacterial blooms: an empirical test of a well-established tenet. International Association of Great Lakes Research. Purdue University, West Lafayette, Indiana.

L. STUDENTS SUPPORTED (Complete the following table)

Number of Students Supported, by Degree	
Type	Number of students funded through this research project:
Undergraduate	10
Masters	2
Ph.D.	1
Post Doc	0

Number of Theses and Dissertations Resulting from Student Support:	
Master's Theses	1
Ph.D. Dissertations	0

M. RESEARCH CATEGORIES: (In column 1 mark all that apply)

	Research Category
X	Biological Sciences
	Climate and Hydrological Processes
	Engineering
	Ground Water Flow and Transport
	Social Sciences
X	Water Quality
X	Other: Modelling

N. FOCUS CATEGORIES (mark all that apply with “X” in column 1):

	ACID DEPOSITION	ACD
	AGRICULTURE	AG
	CLIMATOLOGICAL PROCESSES	CP
X	CONSERVATION	COV
	DROUGHT	DROU
	ECOLOGY	ECL
	ECONOMICS	ECON
X	EDUCATION	EDU
	FLOODS	FL
	GEOMORPHOLOGICAL PROCESSES	GEOMOR
	GEOCHEMICAL PROCESSES	GEOCHE
	GROUNDWATER	GW
	HYDROGEOCHEMISTRY	HYDGEO
	HYDROLOGY	HYDROL
	INVASIVE SPECIES	INV
	IRRIGATION	IG
	LAW, INSTITUTIONS, & POLICY	LIP
X	MANAGEMENT & PLANNING	M&P
X	METHODS	MET
X	MODELS	MOD
X	NITRATE CONTAMINATION	NC
	NONPOINT POLLUTION	NPP
X	NUTRIENTS	NU
	RADIOACTIVE SUBSTANCES	RAD
	RECREATION	REC
	SEDIMENTS	SED
	SOLUTE TRANSPORT	ST
X	SURFACE WATER	SW
X	TOXIC SUBSTANCES	TS
	TREATMENT	TRT
	WASTEWATER	WW
X	WATER QUALITY	WQL
	WATER QUANTITY	WQN
	WATER SUPPLY	WS

	WATER USE	WU
	WETLANDS	WL

O. DESCRIPTORS: (Enter keywords of your choice, descriptive of the work)
Algal blooms, cyanobacteria, off-flavor, toxin, microcystin, BMAA, cylindrospermopsin, saxitoxin, phytoplankton, modeling, forecasting, monitoring, network, collaboration

DEVELOPING AND CONTRASTING NUTRIENT CRITERIA THRESHOLDS FOR FOUR ALABAMA RESERVOIRS

Basic Information

Title:	DEVELOPING AND CONTRASTING NUTRIENT CRITERIA THRESHOLDS FOR FOUR ALABAMA RESERVOIRS
Project Number:	2013AL154B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	AL2
Research Category:	Water Quality
Focus Category:	Nutrients, Water Quality, Surface Water
Descriptors:	None
Principal Investigators:	Alan Elliott Wilson

Publication

1. None

ANNUAL TECHNICAL REPORT SYNOPSIS

The Terms and Conditions of the grants awarded under the Water Resources Research Act state that each institute shall prepare an Annual Program Report summarizing its activities during the reporting period under its base grant, and National Competitive Grant Program awards. The reporting period is March 1, through February 28. All Annual Reports must be submitted by 5:00 PM, Eastern Daylight Time, June 1, and must be submitted electronically. In order to do this we need your assistance by providing the following information about your current or recent WRRI-funded research project:

A. PROJECT TITLE:
   Developing and contrasting nutrient criteria thresholds for four Alabama reservoirs
B. PRIMARY PI(s): Name(s), Title(s) & Academic Rank(s)
   Alan Wilson, Associate Professor, Ph.D.
C. OTHER PI(s): Name(s), Title(s) & Academic Rank(s)
   Mark Elliott, Assistant Professor, Ph.D.
   Lynn Sisk, Water Quality Branch Chief, Alabama Department of Environmental Management
D. START DATE: 1 March 2013
E. END DATE: 28 February 2014
F. PROJECT OVERVIEW/SUMMARY: Provide a brief narrative overview or summary of the project.
   Using Classification And Regression Tree (CART) analysis, our research team developed and contrasted water quality nutrient criteria for three important water quality variables, algal abundance (as chlorophyll *a* concentration), dissolved oxygen concentration, and water clarity (as Secchi depth), for four economically-important reservoirs in northwestern Alabama across several spatial and temporal scales. Our analyses contributed to ADEM's commitment to develop nutrient criteria for 41 lakes and reservoirs associated with the State's major basins by 2013. Furthermore, this project builds upon and enhances existing partnerships between academics and water quality managers in Alabama and Tennessee and to the leveraging of resources across institutions and existing projects. Lastly, our proposed project explicitly targets two of the five priority research areas outlined by the Water Resources Council, including surface water quality and management.
G. PROJECT OBJECTIVE(s): Briefly explain the project objectives
   1. Develop nutrient criteria and retention time for four Alabama reservoirs, including Upper Bear Creek, Bear Creek, Little Bear Creek, and Cedar Creek, that focus on three outcomes, including algal abundance, dissolved oxygen concentration, or water clarity, across multiple spatial and temporal scales.
   2. Contrast nutrient criteria within and across the four focal reservoirs, as well as the newly developed nutrient criteria for the Tallapoosa watershed.
   3. Broadly train students (graduate and undergraduate at Auburn University and the University of Alabama), agency scientists (ADEM, TVA, EPA Region 4), and stakeholders in CART analysis.
   4. Widely disseminate our research plans and products through planned meetings with agency scientists and stakeholders, an oral presentation at the 2013 Alabama Water Resources Conference, and peer-reviewed and agency publications.

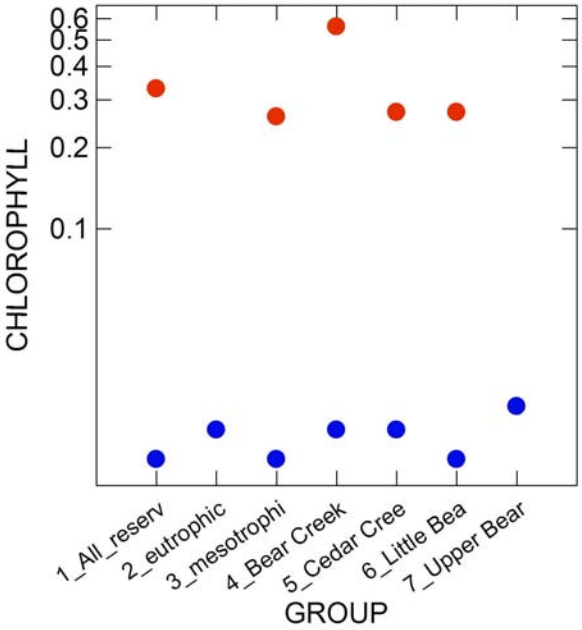
H. METHODOLOGIES: Briefly explain the research methodology used.
This project has been a collaborative effort involving scientists at Auburn University, University of Alabama, the Alabama Department of Environmental Management (ADEM), and the Tennessee Valley Authority (TVA). Discussions involving all PIs and participating agencies dictated which data would be included in our analyses. Data were provided to our team by ADEM and TVA scientists. Our graduate student, Tabatha Dye, organized the dataset. Mark Elliott calculated flow rates for each reservoir to be included in the analyses. Alan Wilson analyzed the data using CART analyses to develop nutrient criteria for each reservoir, for pairs of reservoirs based on productivity, and for all four reservoirs.

I. PRINCIPAL FINDINGS/RESULTS: Explain the results of findings of this research project.
Using CART analyses, we successfully achieved most of our project goals. We developed and contrasted nutrient criteria for our four target reservoirs. We trained one graduate student in data collection, organization, analysis, and presentation. No undergraduate students were supported in this project. We organized multiple stakeholder meetings at TVA in Decatur, AL (19 April 2013) and at ADEM in Montgomery, AL (8 March 2013 and 30 October 2013) to engage agency stakeholders in this project as well as to get their advice about our plans and to present our findings. Lastly, Tabatha Dye presented results from this project at the 2013 Alabama Water Resources Conference.

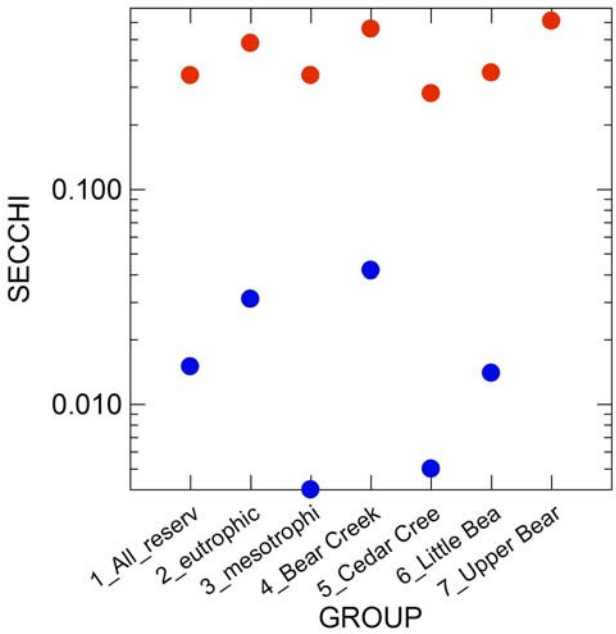
In general, we found relatively consistent nutrient criteria thresholds for total nitrogen (TN) or total phosphorus (TP) across our three response variables, including chlorophyll, transparency, and surface dissolved oxygen concentration for all reservoirs, pairs of reservoirs based on productivity, and each reservoir considered separately (see figures below, note log-transformed y-axes). The nutrient criteria for TN (0.2-0.8 mg/L) and TP (0.004-0.04 mg/L) are ecologically relevant and meaningful regarding water resource management. TP was a better predictor for nutrient criteria for chlorophyll in general across scales, while TN was a better predictor for nutrient criteria for surface dissolved oxygen concentration. TP and TN were useful for developing nutrient criteria for Secchi depth. As expected, more productive reservoirs showed nutrient criteria that were more consistent with elevated algal abundance and reduced transparency.

Since ADEM has not provided nutrient criteria they developed for these reservoirs using their own criteria, we have not been able to compare our findings with theirs'.

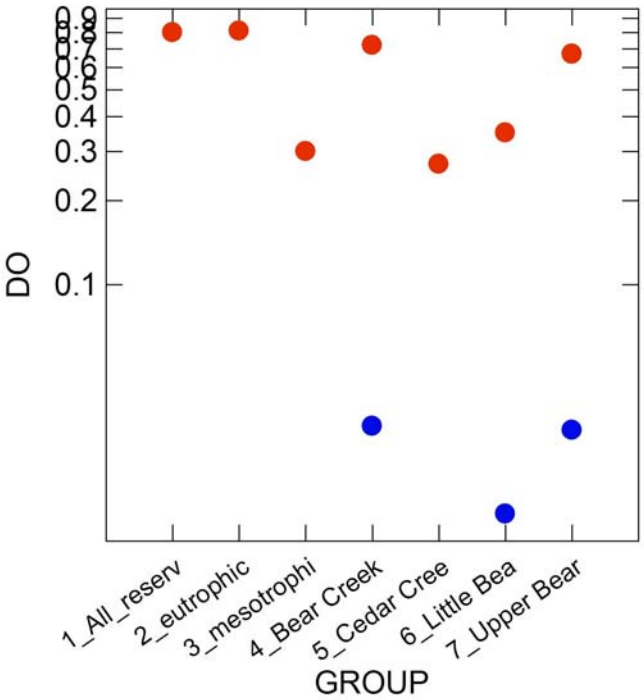
CHLOROPHYLL



SECCHI DEPTH



SURFACE DO



J. NOTABLE AWARDS AND ACHIEVEMENTS. List any awards or recognitions for this research.
None

K. PUBLICATIONS GENERATED:

Number of Research Publications generated from this research project:	
Publication Category	Number
Articles in Refereed Journals	0
Book Chapters	0
Theses and Dissertations	0
Water Resources Institute Reports	0
Articles in Conference Proceedings	0
Other Publications	0

L. PRESENTATIONS MADE:

Presenter(s) (last name, first name; all others presentation authors: first name, last name), Year, Title, other information sufficient to identify the venue in which the presentation was made.

Dye, Tabatha; Elliott, Mark; Sisk, Lynn; and Wilson, Alan E. 2014. Developing and contrasting nutrient criteria thresholds for four Alabama reservoirs. Alabama Water Resources Conference, Orange Beach, Alabama.

M. STUDENTS SUPPORTED (Complete the following table)

Number of Students Supported, by Degree	
Type	Number of students funded through this research project:
Undergraduate	0
Masters	0
Ph.D.	1
Post Doc	0

Number of Theses and Dissertations Resulting from Student Support:	
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N. RESEARCH CATEGORIES: (In column 1 mark all that apply)

	Research Category
X	Biological Sciences
X	Climate and Hydrological Processes
	Engineering
	Ground Water Flow and Transport
	Social Sciences
X	Water Quality
X	Other: Modelling

O. FOCUS CATEGORIES (mark all that apply with "X" in column 1):

	ACID DEPOSITION	ACD
	AGRICULTURE	AG
	CLIMATOLOGICAL PROCESSES	CP
X	CONSERVATION	COV
	DROUGHT	DROU
	ECOLOGY	ECL
	ECONOMICS	ECON
	EDUCATION	EDU
	FLOODS	FL
	GEOMORPHOLOGICAL PROCESSES	GEOMOR
	GEOCHEMICAL PROCESSES	GEOCHE
	GROUNDWATER	GW
	HYDROGEOCHEMISTRY	HYDGEO
X	HYDROLOGY	HYDROL
	INVASIVE SPECIES	INV
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X	MANAGEMENT & PLANNING	M&P
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X	MODELS	MOD
	NITRATE CONTAMINATION	NC
	NONPOINT POLLUTION	NPP
X	NUTRIENTS	NU
	RADIOACTIVE SUBSTANCES	RAD
	RECREATION	REC

	SEDIMENTS	SED
	SOLUTE TRANSPORT	ST
X	SURFACE WATER	SW
	TOXIC SUBSTANCES	TS
	TREATMENT	TRT
	WASTEWATER	WW
X	WATER QUALITY	WQL
	WATER QUANTITY	WQN
	WATER SUPPLY	WS
	WATER USE	WU
	WETLANDS	WL

P. DESCRIPTORS: (Enter keywords of your choice, descriptive of the work)
Water resource management, water quality, phytoplankton, modeling, forecasting, monitoring, collaboration, CART, regression, Secchi, nutrients, phosphorus, nitrogen, nutrient criteria

ASSESSMENT OF STORMWATER QUALITY THROUGH POROUS PAVEMENT SYSTEM

Basic Information

Title:	ASSESSMENT OF STORMWATER QUALITY THROUGH POROUS PAVEMENT SYSTEM
Project Number:	2013AL155B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	3
Research Category:	Engineering
Focus Category:	Non Point Pollution, Water Quality, Groundwater
Descriptors:	None
Principal Investigators:	Clifford R. Lange, Michael F. Hein

Publications

1. Author Dudala, Swarup, Clifford Lange, Mike Hein, Mark Daugherty, Comparison of Porous Pavements for Reducing Ground-Water Quality Impact, manuscript prepared for ASCE Journal of Environmental Engineering. (submission in July 2014)
2. Author (Dudala, Swarup), 2014 Assessment of Water Quality Through Porous Pavement Systems, "MS Dissertation," Department of Civil Engineering, Auburn University, AL, December, 2014.
3. Lange, Clifford, Mike Hein, Mark Dougherty. 2014, Assessment of Storm-water Quality through Porous Pavement Systems, Alabama WRII, Auburn University, AL. Under Preparation
4. Megan Lange, 2014 Removal of BTEX from Storm Water Using Nano-Particle Enhance Porous Concrete. Alabama State Junior Stockholm Water Prize Paper, 20 pages .
5. Megan Lange, 2014 Removal of BTEX from Storm Water Using Nano-Particle Enhance Porous Concrete. Alabama State Junior Stockholm Water Prize Paper, 20 pages .

ANNUAL TECHNICAL REPORT SYNOPSIS

The Terms and Conditions of the grants awarded under the Water Resources Research Act state that each institute shall prepare an Annual Program Report summarizing its activities during the reporting period under its base grant, and National Competitive Grant Program awards. The reporting period is March 1, through February 28. All Annual Reports must be submitted by 5:00 PM, Eastern Daylight Time, June 1, and must be submitted electronically. In order to do this we need your assistance by providing the following information about your current or recent WRRI-funded research project:

A. PROJECT TITLE: ASSESSMENT OF STORMWATER QUALITY THROUGH POROUS PAVEMENT SYSTEMS

B. PRIMARY PI(s):

Clifford Lange, Associate Professor, Department of Civil Engineering
Auburn University, Auburn, AL. langecr@auburn.edu
(334) 844-6275

Michael Hein, Professor, McWhorter School of Building Science, Auburn University, Auburn, AL. heinmic@auburn.edu
(334) 844-5380

Mark Dougherty, Associate Professor, Department of Biosystems Engineering, Auburn University, Auburn, AL. doughmp@auburn.edu
(334) 844-8939

C. OTHER PI(s): Name(s), Title(s) & Academic Rank(s)

D. START DATE: 4/01/13

E. END DATE: 3/20/14

F. **PROJECT OVERVIEW/SUMMARY**

In this project, the ability of porous pavements to remove urban contaminants was investigated. Field testing was completed using small test plots (6 ft. x 12 ft.) Concrete pavements were found to do a relatively good job at removing BTEX and other organics and removed heavy metals to a large degree. However, the porous concrete only poorly removed phosphorous and nitrogen compounds. Porous asphalt also removed organic contaminates to a large degree, but nutrients and metals passed through almost unchanged. Porous pavers had little effect on contaminant removal, and would allow urban contaminants to pass into the ground water. In general, porous pavements did not

do an acceptable job of removing common urban contaminants and could contribute to groundwater contamination.

G. **PROJECT OBJECTIVE(s):**

Urban storm water, because of its characteristically intense peak flows, is capable of washing and scouring accumulated debris and contaminants from the urban landscape. Because soil infiltration can only occur on vegetated or other pervious surfaces, all rainfall not otherwise intercepted, evaporated, or infiltrated becomes active urban runoff during a storm event, increasing stream flashiness, scouring embankments, and causing flood-related property damage and water impairment downstream (Dougherty et al, 2004, 2006). Surface-washed pollutants end up in urban stormwater systems as contaminated source water for downstream water bodies. By applying a source water protection approach to paved urban features, an assessment of this major contaminant pathway can be made.

Ecosystem improvements that mitigate urban storm water damage have included both quality and quantity protection practices. The proposed study focuses on pervious concrete (PC) and porous asphalt (PA) paving surfaces which are often used alongside impervious paved surface to both reduce and potentially treat urban storm water runoff flows. Pervious pavement technology has not been adequately evaluated with regard to pollutant removal efficiency. A 2009 WRRI funded study by the researchers reveals compelling initial results regarding pollutant removal. This follow-up study is necessary to confirm results and gather additional data regarding mitigation of storm water contaminants through various pervious and impervious pavements.

Building on the earlier study, researchers included key urban pollutants such as PAHs, metals, oil and grease, nutrients, sediment and other contaminants in the water source by monitoring before and after applications of storm water to the various pervious and impervious surfaces on site. Pollutant removal efficiency data generated by this study was helpful to communities, watershed groups, private industry, and other stakeholders working to protect, conserve or restore water quality.

H. METHODOLOGIES:

I. **Methods, Procedures, and Facilities:**

Porous pavement testing was conducted at the newly constructed Samford Avenue test facility. These facilities include a newly constructed and replicated pavement testing site on Auburn University campus instrumented with runoff and leachate collection and equipped with conventional landscape irrigation (Figure 1). Pervious and impervious pavements include photo-catalytic concrete, asphalt, and traditional concrete. Each 6” thick slab is 4 ft x8 ft and cast on a 4% slope to drain water to a center area of collection troughs. Each slab sits atop a 6” thick layer

of drainable sub-base of #57 crushed lime stone. The sub-base is separated from native soil by a poly sheet liner to collect and drain leachate to the collection troughs. .

The proposed experimental investigation includes collection of both leachate and surface runoff from pervious and impervious pavements to be evaluated in terms of contaminant removal rates. Each slab will receive a surface treatment of contaminants that is representative of expected amounts received under normal field conditions. Controlled spray events of ¾ inches per hour or 1 ½ inches per hour was used to simulate rain falls. It is anticipated that a half of the events was conducted at each rain fall rate. Water sample analysis will include first flush and event-mean concentrations of oil and grease, PAH, heavy metals (Pb, Cu, Zn, Cd, Cr, and Fe), sediments, nutrients (Ammonia-N, TKN, NO3-/NO2-nitrogen, phosphorus), chloride, coliform bacteria, and TDS. Field monitoring of storm water runoff and leachate will include temperature, hydraulic capacity, pH, and alkalinity. All analyses was conducted using EPA approved methodology.

Collection of leachate and surface runoff samples was conducted four times each month, with duplicate samples representing each side-by-side pavement surface (pervious and impervious). Surface and under-drain collection assemblies are in place at the field lab site available for proposed study in February 2013. Water application rates were monitored for each plot using one or more rain gauges. Collected samples were taken immediately to the Civil Engineering laboratory for analyses. Laboratory analytical methods are outlined in Table 1. The proposed time-line for the study is presented below, in Table 2.

Statistical analyses of the resulting (or more) data sets was performed to determine if the various types porous pavements produce significantly different water quality than the existing non-porous alternatives. The statistical analysis of the water quality data was summarize in a document that was useful in selecting appropriate pavement alternatives based on crucial water quality parameters.

Table 1. Water quality analyses

Parameter	Method	Analyte
Hydrocarbons	EPA1664	0.1/grease (1-20 mg/L)
	EPA 418.1	Total petroleum hydrocarbons (0.1-10 mg/L)
PAHs	EPA 8310	(0.01-10 mg/L)
Heavy metals	EPA 200.8	Pb, Cu, Zn, Cd, Cr, Fe
Cu (1-300 ug/L), Pb (2-200 ug/L), Zn (10-1000 ug/L), Cd (1-30 ug/L), Cr (1-100 ug/L), Fe (20-2000 ug/L)		
Sediments	EPA 160.2	(10-200 mg/L)
Nutrients	EPA 350.1	Ammonia – N
	EPA 351.2	TKN
	EPA 353.2	NO3- / NO2- - N
	EPA 365.4	Phosphorus (0.05-0.2 mg/L)
ICP nutrients		TN,P,K, Ca, Mg, S, Fe, Mn, Cu, Zn, B, Mo
Chloride	EPA 325.1	
TDS	EPA 160.1	
Bacteria	EPA 1600	Coliforms (colitert)
pH	EPA 150-1	
Alkalinity	EPA 310.1	

J. **PRINCIPAL FINDINGS/RESULTS: .**

1. Organic contaminants (i.e., BTEX, PAHs) were moderately removed by porous concrete and porous asphalt, but passed through porous pavers to an almost complete degree. This means that porous pavement technologies can remove a large degree of urban organics, and therefore help protect the groundwater from contamination. However, since a small amount passes through, there is some concern and need for more adsorptive pavements.
2. Nutrients and heavy metals are more water soluble and pass through porous pavement to a much higher degree. This would likely lead to groundwater contamination. New technologies, such as ion exchange material addition, should be investigated
3. Porous pavers are less likely to reduce contaminants passing through to the sub-surface.

K. **NOTABLE AWARDS AND ACHIEVEMENTS.**

Megan Lange, 2014 Removal of BTEX from Storm Water Using Nano-Particle Enhance Porous Concrete. 2014 Alabama State Junior Stockholm Water Prize – Currently competing for National Prize.

L. **PUBLICATIONS GENERATED:**

Number of Research Publications generated from this research project:	
Publication Category	Number
Articles in Refereed Journals	
Book Chapters	
Theses and Dissertations	1
Water Resources Institute Reports	1
Articles in Conference Proceedings	
Other Publications	1

1. Articles in Refereed Scientific Journals Citation

Author Dudala, Swarup, Clifford Lange, Mike Hein, Mark Daugherty, Comparison of Porous Pavements for Reducing Ground-Water Quality Impact, manuscript prepared for ASCE Journal of Environmental Engineering. (submission in July 2014)

2. Book Chapter Citation

None

3. Dissertations Citation

Author (Dudala, Swarup), 2014 Assessment of Water Quality Through Porous Pavement Systems, "MS Dissertation," Department of Civil Engineering, Auburn University, AL, December, 2014.

4. Water Resources Research Institute Reports Citation

Lange, Clifford, Mike Hein, Mark Dougherty. 2014, Assessment of Storm-water Quality through Porous Pavement Systems, Alabama WRII, Auburn University, AL. Under Preparation

5. Conference Proceedings Citation

None

6. Other Publications Citation

Megan Lange, 2014 Removal of BTEX from Storm Water Using Nano-Particle Enhance Porous Concrete. Alabama State Junior Stockholm Water Prize Paper, 20 pages .

M. **PRESENTATIONS MADE**:

Megan Lange, 2014 Removal of BTEX from Storm Water Using Nano-Particle Enhance Porous Concrete. Alabama State Junior Stockholm Water Prize Paper, 20 pages .STUDENTS SUPPORTED

Number of Students Supported, by Degree	
Type	Number of students funded through this research project:
Undergraduate	1
Masters	1
Ph.D.	
Post Doc	

Number of Theses and Dissertations Resulting from Student Support:	
Master's Theses	1
Ph.D. Dissertations	

N. **RESEARCH CATEGORIES:**

	Research Category
	Biological Sciences
x	Climate and Hydrological Processes
X	Engineering
	Ground Water Flow and Transport
	Social Sciences
X	Water Quality
	Other: Explain

O. **FOCUS CATEGORIES**

	ACID DEPOSITION	ACD
	AGRICULTURE	AG
	CLIMATOLOGICAL PROCESSES	CP
	CONSERVATION	COV
	DROUGHT	DROU
	ECOLOGY	ECL
	ECONOMICS	ECON
	EDUCATION	EDU
	FLOODS	FL
	GEOMORPHOLOGICAL PROCESSES	GEOMOR
	GEOCHEMICAL PROCESSES	GEOCHE
	GROUNDWATER	GW
	HYDROGEOCHEMISTRY	HYDGEO
	HYDROLOGY	HYDROL
	INVASIVE SPECIES	INV
	IRRIGATION	IG
	LAW, INSTITUTIONS, & POLICY	LIP
	MANAGEMENT & PLANNING	M&P
	METHODS	MET
	MODELS	MOD
	NITRATE CONTAMINATION	NC
X	NONPOINT POLLUTION	NPP
X	NUTRIENTS	NU
	RADIOACTIVE SUBSTANCES	RAD
	RECREATION	REC
	SEDIMENTS	SED
	SOLUTE TRANSPORT	ST
	SURFACE WATER	SW
	TOXIC SUBSTANCES	TS
	TREATMENT	TRT
	WASTEWATER	WW
X	WATER QUALITY	WQL
	WATER QUANTITY	WQN
	WATER SUPPLY	WS
	WATER USE	WU
	WETLANDS	WL

P. D**ESCRIPTORS: keywords descriptive of the work**

Storm water, Nutrients, BTEX, Metals, and Porous Pavements

GUIDANCE DOCUMENT FOR MORE COST-EFFECTIVE SAMPLING OF BIOLOGICAL RESPONSES TO NUTRIENT LOADS IN STREAMS AND RIVERS

Basic Information

Title:	GUIDANCE DOCUMENT FOR MORE COST-EFFECTIVE SAMPLING OF BIOLOGICAL RESPONSES TO NUTRIENT LOADS IN STREAMS AND RIVERS
Project Number:	2013AL156B
Start Date:	3/1/2013
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	7
Research Category:	Water Quality
Focus Category:	Water Quality, Ecology, Nutrients
Descriptors:	None
Principal Investigators:	Amelia K. Ward

Publications

1. Maestre, Alexander, Derek Williamson, Eman El-Sheikh, and Amelia Ward. 2014. "A Machine Learning Tool for Weighted Regressions in Time, Discharge, and Season." International Journal of Advanced Computer Science & Applications 5(3) 99-106
2. Maestre, Alexander, Derek Williamson, and Amelia Ward. 2013. "A Guidance Document for more Cost-Effective Sampling of Biological Responses to Nutrient Loads in Streams and Rivers." In 2013 Alabama Water Resources Conference. Perdido Beach, Orange Beach, Alabama, #21
3. Maestre, Alexander, Derek Williamson, Eman El-Sheikh, and Amelia Ward. 2014. "A Guidance Document for more Cost-Effective Sampling of Biological Responses to Nutrient Loads in Streams and Rivers." Document to be distributed in ADEM, GSA, and USGS offices in Alabama.

ANNUAL TECHNICAL REPORT SYNOPSIS

The Terms and Conditions of the grants awarded under the Water Resources Research Act state that each institute shall prepare an Annual Program Report summarizing its activities during the reporting period under its base grant, and National Competitive Grant Program awards. The reporting period is March 1, through February 28. All Annual Reports must be submitted by 5:00 PM, Eastern Daylight Time, June 1, and must be submitted electronically. In order to do this we need your assistance by providing the following information about your current or recent WRRI-funded research project:

A. PROJECT TITLE: Guidance Document for more Cost-Effective Sampling of Biological Responses to Nutrient Loads in Streams and Rivers
B. PRIMARY PI(s): Alexander Maestre, Postdoctoral Researcher. Derek Williamson, Director of the AERO Program, Associate Professor. Amelia Ward, Director of the Center for Freshwater Studies, Professor Emeritus
C. OTHER PI(s):
D. START DATE: March 1, 2013
E. END DATE: February 28, 2014
F. PROJECT OVERVIEW/SUMMARY: Provide a brief narrative overview or summary of the project.
G. PROJECT OBJECTIVE(s): The immediate goal was to develop a statistical and repeatable stream/river data analysis tool to perform two functions that can inform the Water Quality Assessment Process carried out by ADEM's Water Quality Branch, its partners, and by analogous groups in water agencies in other states. The first function is to present quantitative historical trends in stream flows, temperatures and, in stream-concentrations of nutrients and chlorophyll a. The second function is to use such historic trends in combination with real-time data to identify water quality sampling periods (within the normal sampling season) to be more likely to capture periods with strong biological responses.
H. METHODOLOGIES: The process of identification of historical trends and sampling periods was completed in three phases: This generalized guidance document is divided into three sections: (1) *development* of a tool and time series relationships for four well sampled locations in Alabama's rivers, (2) *demonstration* of the graphical outputs from the tool to inform modifications in traditional sampling periods, (3) step-by-step *example* for developing new time series in new locations to aid in deciding on better sampling periods.
I. PRINCIPAL FINDINGS/RESULTS:

- The Biological Sampling Tool (BST) was developed using the routines included in the USGS Weighted Regressions in Time, Discharge, and Season (WRTDS) methodology to improve the quality of the information available to determine the best periods of the year for conducting biological sampling. The graphical output generated by BST facilitates the generation of summary plots that relate trends in concentration and discharge with the potential changes in habitat, macroinvertebrate and fish communities.

- The current index period for sampling macroinvertebrates could be modified/expanded through long term analyses using BST. The current Standard Operating Procedure for aquatic macroinvertebrate community sample collection indicates that the index periods for benthic macroinvertebrates starts in late April and ends in early July (ADEM, 2010).
- BST provides information that assist water managers in the identification of water constituents to be sampled with discrete and continuous monitoring strategies.
- The use of tools like BST allows water resources managers to evaluate if current programs and practices are effective and helps improve the quality of rivers and streams throughout the state.

J. NOTABLE AWARDS AND ACHIEVEMENTS. [None]

K. PUBLICATIONS GENERATED:

Number of Research Publications generated from this research project:	
Publication Category	Number
Articles in Refereed Journals	1
Book Chapters	0
Theses and Dissertations	0
Water Resources Institute Reports	0
Articles in Conference Proceedings	1
Other Publications	1

PROVIDE A CITATION FOR EACH PUBLICATION USING THE FOLLOWING FORMATS:

1. Articles in Refereed Scientific Journals Citation

Author (first author; last name, first name; all others; fist name, last name), Year, Title, Name of Journal, Volume(Number), Page Numbers.

Maestre, Alexander, Derek Williamson, Eman El-Sheikh, and Amelia Ward. 2014. "A Machine Learning Tool for Weighted Regressions in Time, Discharge, and Season." International Journal of Advanced Computer Science & Applications 5(3) 99-106

5. Conference Proceedings Citation

Author (first author; last name, first name; all others: first name, last name), Year, Title of Presentation, "in" Title of Proceedings, Publisher, City, State, Page Numbers.

Maestre, Alexander, Derek Williamson, and Amelia Ward. 2013. "A Guidance Document for more Cost-Effective Sampling of Biological Responses to Nutrient Loads in Streams and Rivers." In 2013 Alabama Water Resources Conference. Perdido Beach, Orange Beach, Alabama, #21

6. Other Publications Citation

Author (first author; last name, first name; all others: first name, last name), Year, Title, other information sufficient to locate publications, Page Numbers (if in publication) or Number of Pages (if monograph).

Maestre, Alexander, Derek Williamson, Eman El-Sheikh, and Amelia Ward. 2014. "A Guidance Document for more Cost-Effective Sampling of Biological Responses to Nutrient Loads in Streams and Rivers." Document to be distributed in ADEM, GSA, and USGS offices in Alabama.

L. PRESENTATIONS MADE:

Presenter(s) (last name, first name; all others presentation authors: first name, last name), Year, Title, other information sufficient to identify the venue in which the presentation was made.

Maestre, Alexander, Derek Williamson, and Amelia Ward. 2013. "A Guidance Document for more Cost-Effective Sampling of Biological Responses to Nutrient Loads in Streams and Rivers." In 2013 Alabama Water Resources Conference. Perdido Beach, Orange Beach, Alabama, Poster Presentation

M. STUDENTS SUPPORTED (Complete the following table)

Number of Students Supported, by Degree	
Type	Number of students funded through this research project:
Post Doc	Alexander Maestre

Number of Theses and Dissertations Resulting from Student Support:	
Master's Theses	0
Ph.D. Dissertations	0

N. RESEARCH CATEGORIES: (In column 1 mark all that apply)

	Research Category
X	Biological Sciences
X	Climate and Hydrological Processes
	Engineering
	Ground Water Flow and Transport
	Social Sciences
X	Water Quality
	Other: Explain

O. FOCUS CATEGORIES (mark all that apply with "X" in column 1):

	ACID DEPOSITION	ACD
	AGRICULTURE	AG
X	CLIMATOLOGICAL PROCESSES	CP
	CONSERVATION	COV
	DROUGHT	DROU
X	ECOLOGY	ECL
	ECONOMICS	ECON
	EDUCATION	EDU
	FLOODS	FL
	GEOMORPHOLOGICAL PROCESSES	GEOMOR
	GEOCHEMICAL PROCESSES	GEOCHE
	GROUNDWATER	GW
	HYDROGEOCHEMISTRY	HYDGEO
X	HYDROLOGY	HYDROL
	INVASIVE SPECIES	INV
	IRRIGATION	IG
X	LAW, INSTITUTIONS, & POLICY	LIP
X	MANAGEMENT & PLANNING	M&P
	METHODS	MET
	MODELS	MOD
	NITRATE CONTAMINATION	NC
X	NONPOINT POLLUTION	NPP
X	NUTRIENTS	NU
	RADIOACTIVE SUBSTANCES	RAD
	RECREATION	REC

	SEDIMENTS	SED
	SOLUTE TRANSPORT	ST
X	SURFACE WATER	SW
	TOXIC SUBSTANCES	TS
	TREATMENT	TRT
	WASTEWATER	WW
X	WATER QUALITY	WQL
	WATER QUANTITY	WQN
	WATER SUPPLY	WS
	WATER USE	WU
	WETLANDS	WL

P. DESCRIPTORS: (Enter keywords of your choice, descriptive of the work)

Water Quality Tools, Index Periods, Biological Sampling, WRTDS

AWRRI Grant 2013AL156B
May 1, 2014

Guidance Document for More Cost Effective Sampling of Biological Responses to Nutrient Loads in Streams and Rivers

Alexander Maestre, Derek Williamson, and Amelia Ward
The University of Alabama

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1. Introduction

Water quality impairment in rivers and streams due to excessive loads of phosphorous and nitrogen is considered a major problem in waters of the U.S. Elevated concentrations of nutrients cause excessive growth of algae and aquatic plants which can generate large diurnal variations in the amount of dissolved oxygen and pH in the water column. The lack of oxygen in the water column can be harmful to fish and other aquatic organisms and also affect their behavior and growth due to changes in respiration (Lee et al., 2012). According to the Water Quality Assessment and Total Maximum Load Information website of the Environmental Protection Agency (EPA), approximately 101,269 miles of rivers and streams throughout the U.S. are impaired by nutrients. The leading causes of these impairments are primarily nutrient enrichment and elevated total phosphorous. In Alabama, the 2012 Alabama Integrated Water Quality Monitoring and Assessment Report indicates that at least 652 of the 11,810 assessed stream and river miles along the State are impaired by nutrients (ADEM, 2012).

In 2009, the Alabama Department of Environmental Management (ADEM) developed the Nutrient Criteria Implementation Plan for the State of Alabama (ADEM, 2009). The report indicates that ADEM has conducted several water quality studies and did not find significant correlations between nutrient loading and response variables and that work is being conducted to collect additional samples and refine the delineation of ecoregions. Biological responses to disturbances (including nutrient loads) are very complicated and have many species specific and site specific controls. Such complications have led to much variability in biological response monitoring programs (Moulton et al., 2002).

With such variations and complications, there is a need for quantitative guidance to establish a replicable sampling program grounded in science and recognizing cost constraints. Therefore, we have developed a methodology that determines sampling periods with the highest probability of conditions (water temperature and discharge) leading to observable biological responses. As there are many different biological responses to measure, we selected *chlorophyll a*, a fundamental unit of biological primary producer biomass that underlies many other higher-order responses. *Chlorophyll a*, therefore, acts as a surrogate or precursor to direct measurement of higher order organismal responses.

The immediate goal was to develop a statistical and repeatable stream/river data analysis tool to perform two functions that can inform the Water Quality Assessment Process carried out by ADEM's Water Quality Branch, its partners, and by analogous groups in water agencies in other states. The first function is to present quantitative historical trends in stream flows, temperatures and, in stream-concentrations of nutrients and *chlorophyll a*. The second function is to use such historic trends in combination with real-time data to shift water quality sampling periods (within the normal sampling season) to be more likely to capture periods with strong biological responses.

We modified an existing data modeling tool developed by the USGS that estimates daily concentrations and fluxes, and will predict the best sampling times (also referred to as index periods) in any given year to ensure year-to-year comparability. This tool is Weighted Regression on Temperature, Discharge, and Season (WRTDS) developed by USGS (Hirsh et al., 2010). The authors have used a related form of this method to predict nutrient loads in Alabama during extreme events (Maestre et al., 2012).

This generalized guidance document is divided into three sections: (1) *development* of a tool and time series relationships for four well sampled locations in Alabama's rivers, (2) *demonstration* of the graphical outputs from the tool to inform modifications in traditional sampling periods, (3) step-by-step *example* for developing new time series in new locations to aid in deciding on better sampling periods.

2. Biological Sampling locations in Alabama

Since 2010, the Alabama Department of Environmental Management (ADEM) creates a biennial Integrated Water Quality Assessment and Monitoring report as requested by the Environmental Protection Agency (EPA) (EPA, 2006) to describe the activities the Department performs as required by the Clean Water Act (CWA) sections 303(d), 305(b) and 314. These reports assist EPA in evaluate the percentage of watersheds assesses in the state, estimate the conditions of all waters in the state (surface and groundwater), changes overtime, progress towards the goal of fishable and swimmable waters, identification of impaired water bodies to support 303(d) listing, and prioritize assessments to confirm the location of impaired waters and high water quality streams (EPA, 2006).

States need to use multiple sources of information including chemical, biological, physical, and habitat (in addition to other sources) to classify all the waters of the state in one of five categories (EPA, 1994). These categories varied from waters that attain all the applicable water quality standards (category 1) to waters were pollutant has caused or is suspected of causing impairment (category 5). This process is known as water body categorization. Waters located in category 5 are considered the State's list of impaired waters or 303(d) list. The five categories are assigned to all rivers and streams, lakes and reservoirs, groundwater sources, and coastal waters of the state. In addition to the categorization, the assessment and monitoring report describes the activities conducted by ADEM to control nonpoint sources of pollution, and how the Department addresses water quality-related public health issues.

ADEM followed EPA recommendations of delineating the wadeable segments of the 12-digit hydrologic unit codes into smaller units known as Monitoring Units (MU). These wadeable units have been identified at each of the five major basin groups in the state: Alabama-Coosa-Tallapoosa River Basin (ACT), the Escatawpa-Tombigbee-Mobile River Basin (EMT), the Black Warrior and Cahaba River Basin (BWC), the Tennessee River Basin (TN), and the Southeast Alabama River Basin (SEAL). Biological sampling has been conducted at each of these basins in a five year rotation cycle. ADEM has been collecting macroinvertebrate, periphyton and fish community assessments in wadeable flowing rivers and streams of Alabama. (ADEM, 2012)

EPA recently recommended ADEM develop a Tiered Aquatic Life Uses (TALU) approach to measure the attainment of aquatic life goals by the correlation of stressors and biological responses. TALU is based on a method that describes the biological response to different levels of stressors known as the Biological Condition Gradient (BCG) method. This method considers multiple attributes of aquatic ecosystems including community structure, ecosystem function, organism condition, and temporal and spatial variations of stream size and connectivity.

The BCG is divided in multiple tiers representing the condition of the biological community in the y-axis versus to the sum of the stressors on the x-axis. It is expected that sites in excellent status would have high of biological condition with low levels of stressors. Sites with very poor status should be affected by a high level of stressors causing poor biological conditions. When the BCG is calibrated, water managers can use the model to interpret biological conditions and define aquatic life uses that protect and balance populations of shellfish, fish, and other aquatic organisms (EPA, 2005). Figure 1 shows an example of the BCG developed for sites located in the Ridge and Valley/Piedmont Ichthyoregion (or region of similar fish community structure and composition) developed by the Geological Survey of Alabama (GSA) (O'Neil et al. 2011a).

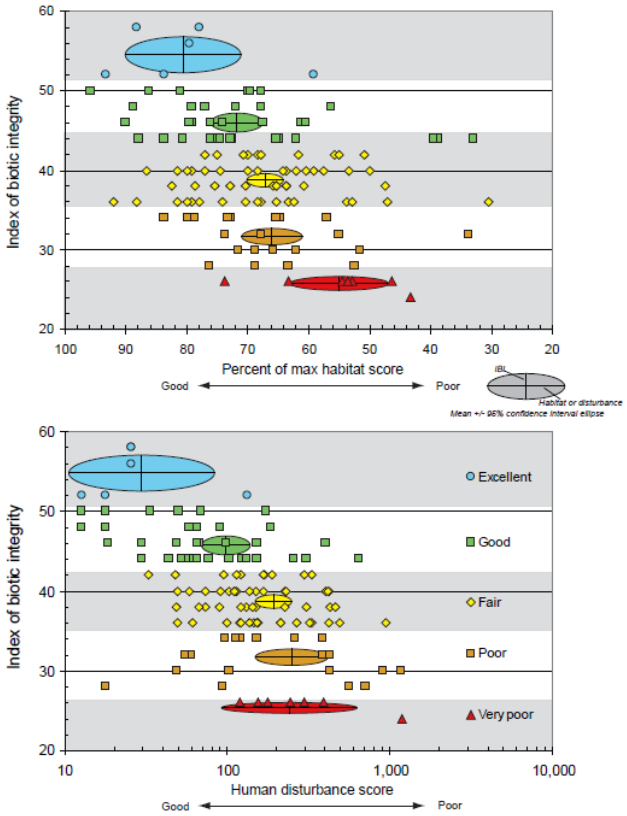

Figure 1. BCG for the sites in the Ridge and Valley/Piedmont Ichthyoregion (adapted from O'Neil et al. 2011a)

GSA in cooperation of ADEM and Alabama Department of Conservation and Natural Resources (ADCNR) has developed and calibrated the Index of Biological Integrity (IBI) and BGC models for five Icthyoregions. These Icthyoregions were developed by using more than 850 fish community samples and IBI throughout the state for almost 230 fish species. IBI and biological condition classifications using the BCG approach could be used to evaluate changes in biological conditions in rivers and streams of the state. Figure 2 shows the delineation of the five Icthyoregions and the mayor basins in the Alabama.

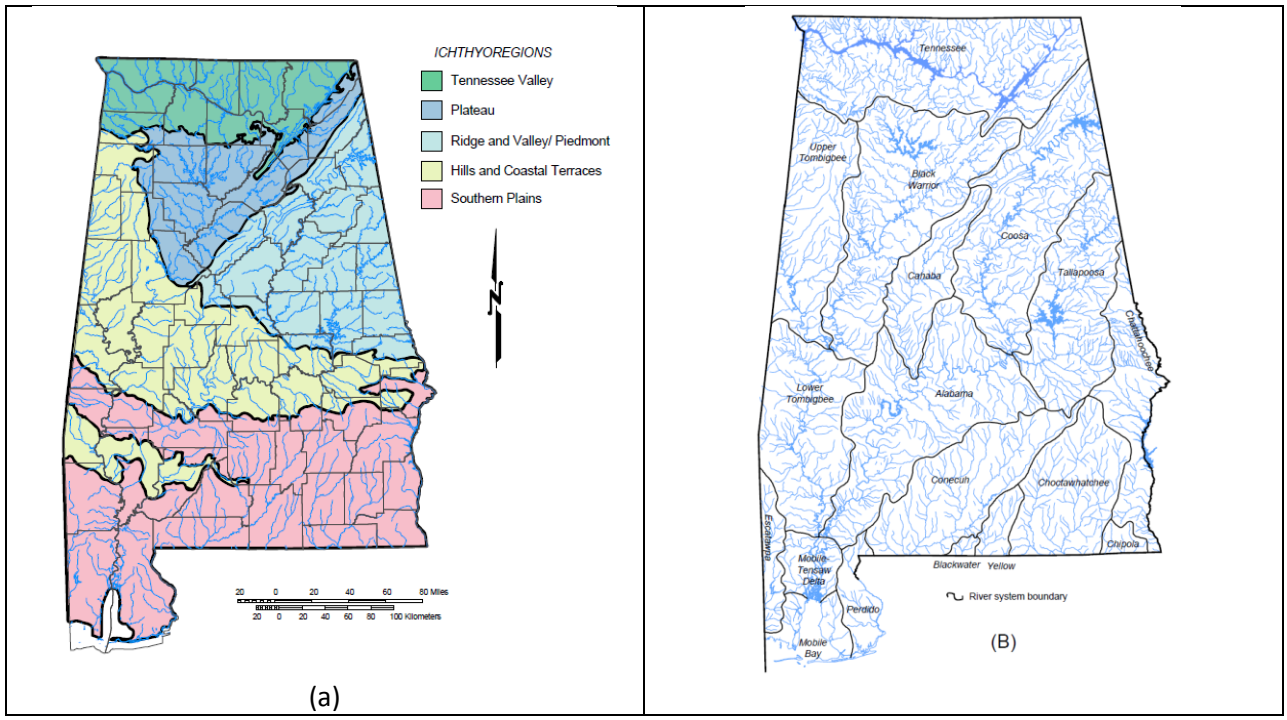

Figure 2. Alabama Ichthyoregions (draft) (a) and major basins in Alabama (b) (adapted from O'Neil et al. 2012, 2011b)

Since 2005 ADEM has been producing summaries and interpretation of the results of biological assessments of wadeable flowing sites in a 2-page report known as River and Stream Monitoring Program (RSMP) summary report. These reports include all the monitoring information collected at the site at the time the bioaseesment was conducted, including sampling date, habitat and macroinvertebrate assessment results. In many of the stations where RSMP were created, ADEM has been collecting monthly water quality samples to help identify stressors that may be affecting the biological communities.

To assess the overall condition of a sampled station, ADEM used the Intensive Multi-habitat Bioassessment Methodology (WMB-I) (ADEM, 2010). The WMB-I uses measures like taxonomic richness, community composition, and community tolerance to create a score that relates to the final condition of the macroinvertebrate community.

In addition, USGS has been conducting assessments of water quality and aquatic communities in several streams throughout the state. Results of these assessments have been documented in multiple scientific and water resources investigations reports (McPherson et al., 2002, 2004). Some of the rivers and streams assessed by USGS include Five Mile, Village, and Valley creeks in Jefferson County, as well as, Threemile creek near Mobile.

We decided to combine the results of the existent RSMP summary reports, the IBI and biological condition classifications generated by GSA, and Biotic Index values reported in the USGS reports as summaries of historical biological conditions in wadeable streams of Alabama.

For a specific sampling/monitoring station, the tool described in this document establishes a relationship between a combination of four parameters (current discharge, water temperature (when available), and nutrient and *chlorophyll a* concentration estimates) and the previous biological monitoring results. This tool could help managers to decide if there is a high probability of finding changes in biological responses by using a group of time series plots. In order to do that, the tool requires daily discharge records from an existing USGS stream station, the discrete historical concentrations of nitrate + nitrite-N and *chlorophyll a,* and the integrity classes determined by the BCG or conditions determined by the WMB-I methodology. The proposed method links all this information by using the results of biological stations located within catchments having the same Hydrologic Unit Code at level 8 (HUC-8).

3. Developing Context for an Illustrative Conceptual Example

To better understand the concept, let's assume that we would like to decide when is a good time to conduct biological sampling in MUs located near the station 02446500 (Sipsey River near Elrod). Figure 3 shows the description of this station generated by the National Water Information System (NWIS).

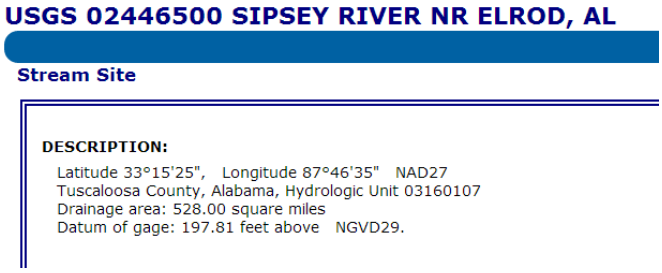

Figure 3. Stream site description of the USGS station 02446500 (Sipsey River near Elrod. Source: USGS NWIS website)

Figure 3 shows the location, total drainage area , datum gage, and elevation of this station , as well as the corresponding hydrologic unit. By using the HUC-8 code, it is possible to easily find if there have been any RSMP summary reports, fish sampling conduced by GSA, or USGS assessments conducted within this hydrologic unit. In the case of the Elrod station, it was found that that station 02446500 is located in the HUC-8 03160107, that there were four fish sampling campaings conducted in 2011, one macroinvertebrate assesment in 2007, and two more macroinvertebrate assessments in 2011. No USGS assessments were found within this hydrologic unit (Figure 4).

The USGS station located at the Sipsey River near Elrod has been collecting daily discharge records since September 1928. Samples of nitrate + nitrite-N and *chlorophyll a* have been collected by ADEM and USGS near or at the 02446500 station. It would be useful to have a graph that shows daily historical trends of water discharge, with daily estimates of nitrate + nitrite-N and *chlorophyll a* concentrations, plus historical or current biological integrity clasess of stations located in the same hydrologic unit.

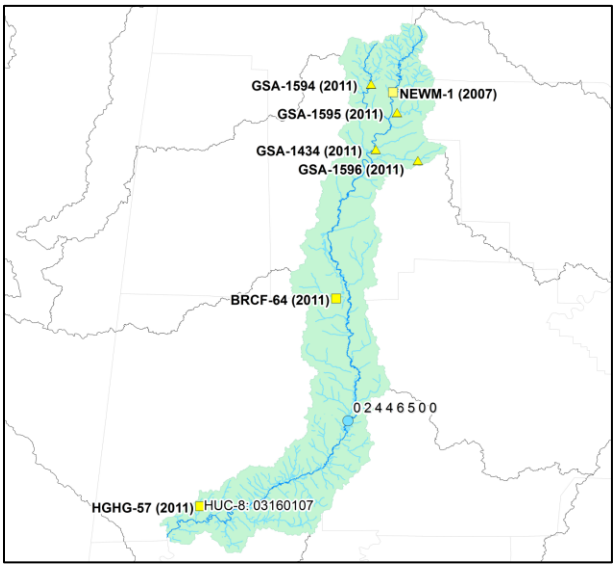

Figure 4. GSA fish stations (yellow triangles), ADEM macroinvertebrate sampling locations (yellow squares), and USGS stream station at Sipsey River near Elrod (blue circle) located within the HUC-8 Sipsey (03160107)

By including year to date records of water discharge and estimates of estimates of nitrate + nitrite-N and *chlorophyll a* concentrations, then water resources managers could decide if the following days are good for conducting biological sampling or not. Section 4 of this document shows the steps followed to generate the tool and how the time series of four stations in Alabama's rivers were completed. Section 5 describes how the graphical outputs generated with the tool could inform modifications in traditional sampling periods. Finally, Appendix 1 shows a detailed step by step example of how the tool can be used for estimating the sampling period near the station Cahaba River near Cahaba Heights.

4. Development of Biological Sampling Tool for Alabama Streams

Figure 5 shows the methodology used to develop the tool based on historical records of water temperature, discharge, and nitrate + nitrite-N concentration. The process of identification of the sampling periods was divided in three phases: (Phase 1) Completion of daily time series of discharge, stage, and temperature (if available) as well as generation of daily estimates of nitrate + nitrite-N and *chlorophyll a* concentrations; (Phase 2) Identification of previous biological sampling efforts; and (Phase 3) Interpretation of the output from the Biological Sampling Tool about the decision of conducting a biological sampling.

We conducted a query of how many USGS stations (in Alabama) have real time records of water discharge and water temperature, and at the same time have a nearby (might need to define nearby in terms of distance or location in the same or adjacent watershed or drainage area) ADEM station with a large number of nutrient and *chlorophyll a* samples. The following USGS stations meet those criteria:

Table 1. USGS stations used during the generation of the Guidance Document

USGS Station Number	Station Name	ADEM station nearby	Station ID (21AWIC)	Number of *Chlorophyll a* samples
02397530	COOSA RIVER AT STATE LINE, AL / GA (RESERVOIR)	WEIC-12	23	108
02419890	TALLAPOOSA RIVER NEAR MONTGOMERY WATER WORKS	TARE-1	164	87
02423160	CAHABA RIVER NEAR WHITES CHAPEL	C-1	443	93
02423425	CAHABA RIVER NEAR CAHABA HEIGHTS	C-2	444	91

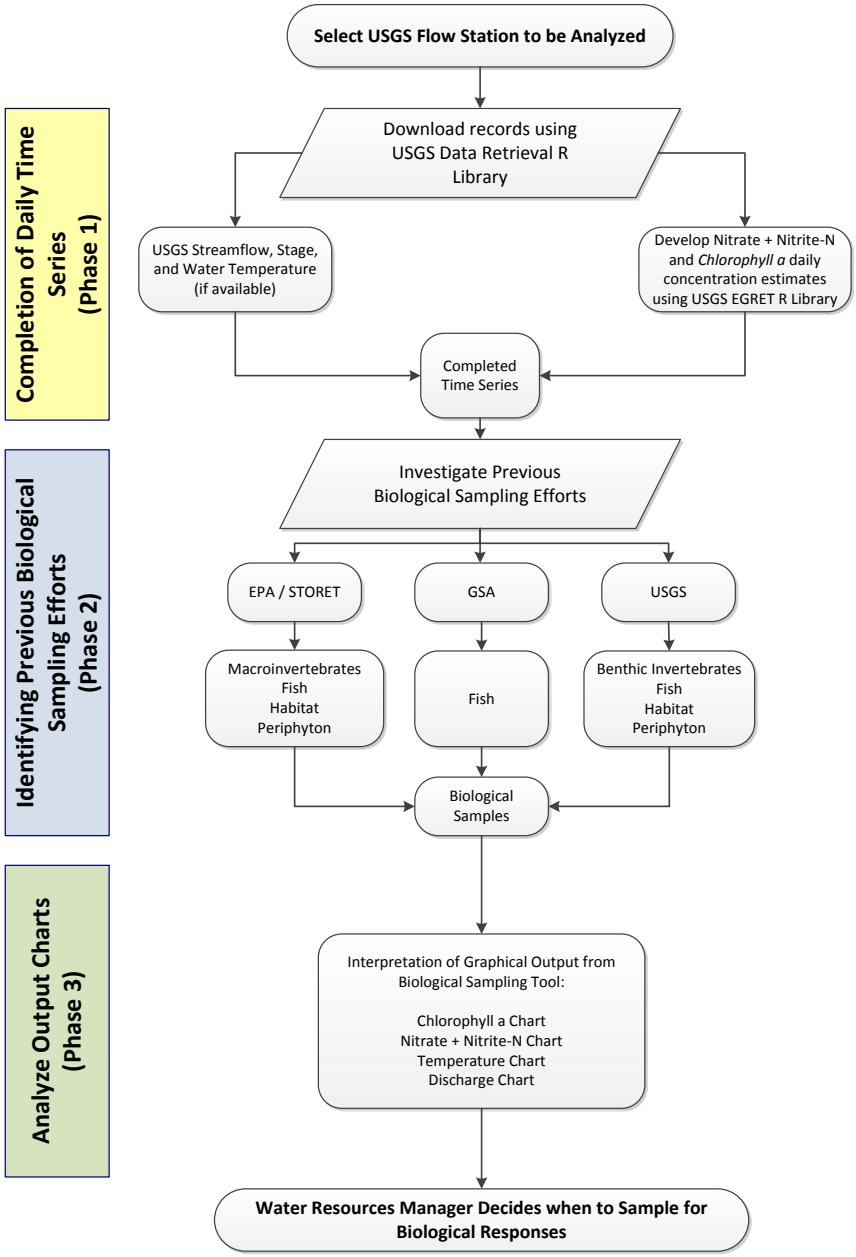

Figure 5. Methodology used to identify sampling periods for biological responses based on nutrient concentrations, discharge, and water temperature

For each of the stations included in Table 1, daily discharge, stage, and water temperature records from USGS stations were analyzed for completeness and presence of outliers or unusual records. Series with missing information were completed using regression methods, stage-discharge curves, and time series analyses. All these analyses were performed automatically using routines and libraries included in the statistical package R (R Core Team, 2013). As a result of Phase 1, daily water discharge and temperature were generated for three USGS stations (the station 02423425 does not have daily temperature records). One of these three stations (02397530, Coosa River at State Line) is located in the headwaters of Weiss Lake and it was affected by the reservoir. Records from the station 02397000 (Coosa River near Rome, GA) were used to simulate the discharge and temperature time series at the station 02397530. In addition to discharge, stage and temperature, we used the existent routines in WRTDS to generate daily time series of nutrients and *chlorophyll a* concentrations. The nutrient used in this analysis is nitrite + nitrate-N. A detailed explanation of how records were completed is described in Section 4.1.

Phase 2 consisted in identifying previous biological studies conducted on the Coosa, Tallapoosa, and Cahaba Rivers. During this phase of our research, we collected biological data stored in the EPA/STORET database, included in reports generate by the Geological Survey of Alabama, and water resources investigation reports created by USGS. Multiple routines were programmed in R (the same language used for the development of WRTDS) to make the records obtained from the previous three sources compatible with the routines developed by USGS for WRTDS.

These new routines (defined from this point forward as the **Biological Sampling Tool, BST**) used statistical regressions to identify trends and relationships between each of three daily parameters (discharge, water temperature, and estimated nutrient concentration) with nitrate + nitrite-N and *chlorophyll a* concentrations. BST generates plots that display the year to date conditions of the river at the desired station including the 5 and 95 percentile values for a specific parameter. The four parameters are Chlorophyll a and nitrite + nitrate-N concentration, water temperature, and water discharge. A detail explanation of these charts is presented in Section 5 of this document. Finally, Phase 3 consisted in evaluating the charts generated during Phase 2 to decide which are the best periods of sampling for biological responses based on one of the parameters described above and results from previous biological sampling efforts. The next section explains in detail how the time series of the four stations included in Table 1 were completed.

4.1. Guidance for Completion of Time Series

The top section of Figure 1 shows that the first step in creating this guidance document is the generation of complete daily time series of discharge and water temperature (when available). The tool described in this guidance document is able to automatically complete these time series. In order to run the BST, the user must provide the following information: the start date of analysis, the station number, and information of the nearby stations that will be used to complete the time series. The example included in this guideline is comprehensive, annotated, and provide easy step-by-step instructions to modify the input file of the R-script.

This section of the guidance document describes the current status of the daily data included in the two databases used by the tool: The National Water Information System (NWIS) from USGS, and the Store

and Retrieve Database (STORET) from EPA. STORET includes all the water quality, biological, and habitat data provided by ADEM. It is critical for water managers to have, regularly collected samples, without large periods of missing information, and to recognize the advantages of using continuous monitoring equipment. The current status of sampling efforts at four stations located in Alabama is presented below. The parameters used by the BST need to be collected daily. The USGS report for each of the USGS stations included in Table 1, discharge, river stage, and water temperature (when available) with a daily frequency. There is only one station in Alabama (USGS-02397530) that collected daily *chlorophyll a* records using the fluorometric method between April 2005 and January 2007. Nitrate + nitrite-N and *chlorophyll a* samples have been collected by ADEM approximately every month. Daily estimates of nitrate + nitrite-N and *chlorophyll a* were obtained using the WRTDS routines implemented in BST.

4.1.1. Identifying the Status of Daily Records

BST requires the periods of available observations at the station of interest. Sometimes stations are discontinued due to lack of funding or maintenance issues. In order to generate a complete time series, the user needs to specify the starting date of analysis and evaluate if available data from other stations can be used to complete the time series. Tables 2 to 5 show the periods of information available for each of the stations described in Table 1. Table 2 shows the parameters and periods of available data for the USGS station (02397530) located at the Coosa River near the state line between Alabama and Georgia.

Table 2. Periods of record available at the station USGS 02397530 and ADEM WEIC-12

Parameter	PCode (USGS)	Period Start	Period Ends	Frequency	Comments
Water Temperature Celsius	00010	1975-06-22	Current	Daily	
Discharge in cfs.	00060	N/A	N/A	Daily	No records available
Gage Height in ft.	00065	2005-01-14	Current	Daily	No records between 2009-10-01 and 2010-10-01
Chlorophyll, in situ, Fluorometric in μg /L	62361	2005-04-05	2007-01-25	Daily	
Chlorophyll a in μg/L		2002-04-23	2013-08-29	Approximately once a month	108 samples were collected by ADEM at station WEIC-12 and stored in the STORET database
Nitrate + Nitrite (as N) in mg/L	00630	1974-08-21	2014-01-14	Approximately once a month	A total of 463 samples were collected during this time period
Nitrate + Nitrite (as N) in mg/L		1991-02-01	2013-08-29	Approximately once a month	A total of 235 samples were collected during this time period. Samples collected by ADEM at station WEIC-12 were stored in the STORET database

Table 2 shows that the station 02397530 did not have discharge results because it is located at Weiss reservoir. Discharge and stage records from an upstream station located along the Coosa River (station 02397000, located in Rome, Georgia) were used to estimate the discharge values at station 02397530. Discharge records at the station 02397000 have been collected since 1896. Since 2007 the station has collected temperature, discharge, stage height, and precipitation records every 15 minutes. Recent years records at the station 02397000 can be considered very complete.

USGS collected daily records of *chlorophyll a* at the station 02397530 using the fluorometric method between April 2005 and January 2007. On the other hand, ADEM also collected *chlorophyll a* samples at a station near the station 02397530; however, the method used to calculate the concentration was the spectophotometric method. There have been several articles that discuss the differences between the fluorometric and the spectrophotometric methods (FDEP, 2011 and GOMA, 2013). In BST, it was decided to combine the results of both records (USGS and ADEM) to have a large number of samples in the dataset and be able to develop the seasonal patterns followed by *chlorophyll a*. Based on the periods of available samples described in Table 2, it was decided that the BST tool could use the available information at stations USGS 0239750, USGS 0239700, and ADEM WEIC-12 starting on 2002-04-23.

Table 3. Periods of record available at the station USGS 02419890 and ADEM TARE-1

Parameter	PCode (USGS)	Period Start	Period Ends	Frequency	Comments
Water Temperature Celsius	00010	2005-07-23	Current	Daily	
Discharge in cfs.	00060	1995-10-01	Current	Daily	
Gage Height in ft.	00065	1989-10-01	Current	Daily	
Chlorophyll, in situ, Fluorometric in μg /L	62361	N/A	N/A	N/A	No records available
Chlorophyll a in μg/L		2005-04-18	2013-06-06	Approximately once a month	A total of 87 samples were collected during this time period. Samples collected by ADEM at station TARE-1 were stored in the STORET database
Nitrate + Nitrite (as N) in mg/L	00630	1974-09-16	1974-09-16		Only one USGS sample collected at this site
Nitrate + Nitrite (as N) in mg/L		2005-04-18	2013-06-06	Approximately once a month	A total of 87 samples were collected during this time period. Samples collected by ADEM at station WEIC-12 were stored in the STORET database

The same logic was used for the station located along Tallapoosa River near Montgomery (USGS 02419890). The user first evaluates the data available at the station, finds potential relations between parameters (i.e., stage and discharge) and look for additional stations nearby to complete the time series. Table 3 shows the periods of record available for the station Tallapoosa River near Montgomery (USGS 02419890).

Unfortunately, no daily records of *chlorophyll a* using the fluorometric method were available. ADEM at the station TARE-1 has collected monthly samples of nitrate + nitrite-N and *chlorophyll a* analyzed using the spectrophotometric method. Daily *chlorophyll a* concentration estimates can be generated using the WRTDS method implemented in BST. Table 3 shows that temperature, stage, and discharge have been collected daily at station USGS 02419890 since July 2005. The time series of discharge, gage height, and temperature at this station were more than 97% complete. Table 4 shows the parameters ad periods of data available for the station 02423160 and ADEM C-1 that are located at the Cahaba River near Whites Chapel.

Table 4. Periods of record available at the station USGS 02423160 and ADEM C-1

Parameter	PCode (USGS)	Period Start	Period Ends	Frequency	Comments
Water Temperature Celsius	00010	2011-08-09	Current	Daily	
Discharge in cfs.	00060	2011-08-09	Current	Daily	
Gage Height in ft.	00065	2011-08-09	Current	Daily	
Chlorophyll, in situ, Fluorometric in μg /L	62361	N/A	N/A	N/A	No records available
Chlorophyll a in μg/L		2005-03-21	2013-06-05	Approximately once a month	A total of 93 samples were collected during this time period. Samples collected by ADEM at station C-1 were stored in the STORET database. Only 16 Samples were have been collected since 2011-09-07.
Nitrate + Nitrite (as N) in mg/L	00630	N/A	N/A	N/A	No records available
Nitrate + Nitrite (as N) in mg/L		2000-06-06	2013-06-05	Approximately once a month	A total of 122 samples were collected during this time period. Samples collected by ADEM at station C-1 were stored in the STORET database. Only 16 Samples have been collected since 2011-09-07.

Daily water temperature, discharge and gage height records were available for the station 02423160 with a percentage of completeness higher than 99%. Monthly samples of nitrate + nitrite-N and *chlorophyll a* using the spectrophotometric method have been collected since June 2000 and March 2005, respectively. Water quality parameters monitored by USGS at station 02423160 include specific conductance and dissolved oxygen that are reported every 15 minutes. No additional water quality constituents appear to be sampled daily by USGS at this station.

Based on the sampling records described in Table 4 it was considered that time series of discharge, and c*hlorophyll a* concentration could be generated since August 2011. Due to the low number of c*hlorophyll a* samples collected since August 2011 (only 16 samples), the estimated time series of c*hlorophyll a* will be very general based on monthly averages and temperature variations. It is unfortunate that more than 70 c*hlorophyll a* samples cannot be used in the tool because there are no discharge records available for the period 2005 to 2011. Discharge estimates can be generated using hydrological models, but the generations of these estimates are outside the scope of this guidance document.

Table 5. Periods of record available at the station USGS 02423425 and ADEM C-2

Parameter	PCode (USGS)	Period Start	Period Ends	Frequency	Comments
Water Temperature Celsius	00010	N/A	N/A	N/A	No records available
Discharge in cfs.	00060	1975-08-01	Current	Daily	No records were available for the period 1986-04-01 to 1996-07-27
Gage Height in ft.	00065	1975-08-01	Current	Daily	No records were available for the period 1986-04-01 to 1996-07-27
Chlorophyll, in situ, Fluorometric in μg /L	62361	N/A	N/A	N/A	No records available
Chlorophyll a in μg/L		2004-03-15	2013-06-05	Approximately once a month	A total of 91 samples were collected during this time period. Samples collected by ADEM at station C-2 were stored in the STORET database
Nitrate + Nitrite (as N) in mg/L	00630	N/A	N/A	N/A	No records available
Nitrate + Nitrite (as N) in mg/L		1991-02-01	2013-06-05	Approximately once a month	A total of 174 samples were collected during this time period. Samples collected by ADEM at station C-2 were stored in the STORET database

Finally, Table 5 shows the periods of record available for the station 02423425 Cahaba River near Cahaba Heights and ADEM station C-2. This station is used in this guidance document to provide a futuristic view of how estimates obtained with BST could be connected with the estimates generated by the NOAA River Forecast Network. One of the advantages of the River Forecast Network it that as part of their activities, they produce expected discharge and stages heights for up to 9 days ahead of the current stage.

USGS has been collecting stage and discharge records at station 02423425 since July 1996. Unfortunately there are no daily records of temperature and *chlorophyll a* at this station. *Chlorophyll a* estimates were generated using the discrete grab samples collected by ADEM at station C-2. *Chlorophyll a* samples have been collected since March 2004 whereas nitrate + nitrite-N, discharge and stage height have been collected previous to this date. For that reason, it was decided to generate the daily *chlorophyll a* and nitrate + nitrite-N daily concentration estimates starting on March 2004.

The identification of the sampling periods as shown in tables 2 – 5 is needed in the use of the routines included in BST. The most critical parameter in the tool is daily water discharge. Without this parameter is impossible to obtain the daily concentration estimates. In addition to discharge, the user needs to have enough observations of nitrate + nitrite-N and *chlorophyll a* to perform the parametric survival regressions executed in WRTDS. Once the period of time that includes daily discharge and discrete sampling events has being identified, the user needs to complete the water discharge; stage and temperature (if available) time series. BST includes routines that assist in the completion of the time series

The following subsections describe how the time series were completed for each of the four USGS stations in the generation of the sampling periods.

4.1.2. Completing Water Temperature Records

There are not too many USGS stations in Alabama that collect water temperature. Most of these stations are located near Birmingham. Water temperature time series could be completed using records from nearby stations or interpolated from data collected in the same station. Figure 6 shows the location of the stations in Alabama that have water temperature records.

The stations that have daily water temperature records are located at the Coosa River near the State Line (1), at the Chattahoochee River near Fort Gaines(1), near Harpersville (2), at the Tallapoosa River near Montgomery (1), and at the Cahaba and Little Cahaba Rivers near Birmingham (3). The stations located at the Sipsey Fork, Mulberry Fork, Turkey Creek, Fivemile Creek, and Village Creek also have records of daily water Temperature.

As example, suppose that it was required for the analysis to complete missing temperature records at the station 02397530. In general, water temperature records at the station Coosa River at State Line (02397530) are almost complete. Fortunately, there is a nearby station upstream that also collected daily water temperature records. The station Coosa River at Rome (02397000), located approximately 15 miles west of the station 02397530, has a good record of daily temperature since February 13 1986.

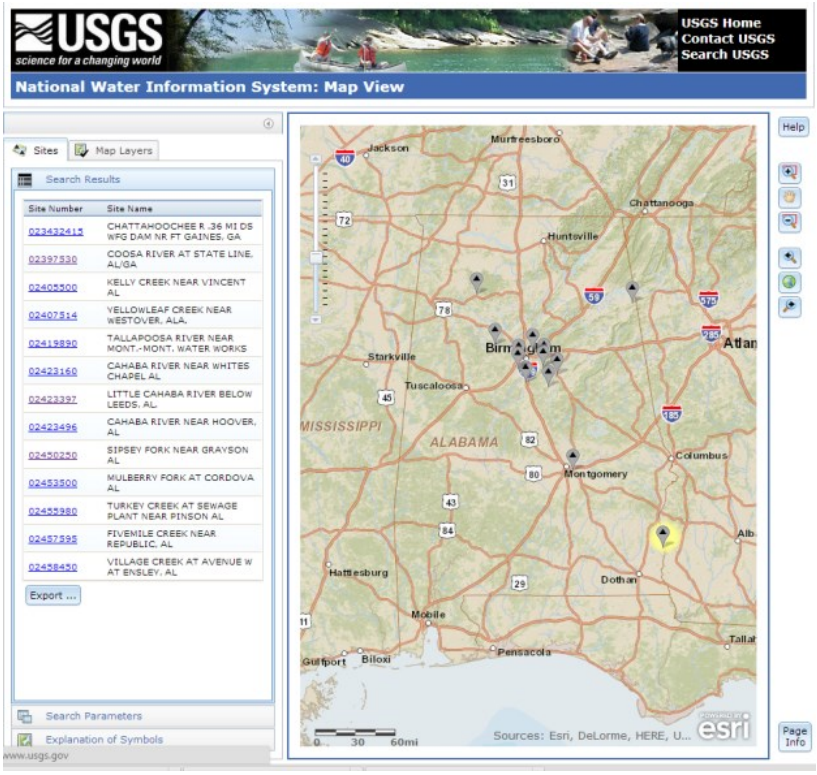

Figure 6. Stations in Alabama with water temperature records according to the National Water Information System (obtained from http://maps.waterdata.usgs.gov/mapper/nwisquery.html)

Figure 7 shows daily records of water at State Line and Rome stations. The figure also shows that water temperatures tend to be higher at State Line compared with Rome especially during the summer. Both time series are well defined with a small number of missing records. A linear regression was created to estimate water temperature at State Line based on the water temperature record at Rome. The results of the regression indicated an adjusted R-squared between both stations of 0.9667 (Figure 8). There were few cases were water temperature records were not available at both stations the same day. In those cases, water temperatures were estimated using a linear interpolation between existent records.

A similar procedure was conducted for the stations 02423160, and 02423425 both located along the Cahaba River. In both cases, data water temperature records from the station Cahaba River near Hoover (02423496) were used to complete the time series. More than 27,000 mean daily temperature records have been collected at the station 02423496 since November 1988. Missing water temperature records at the station Cahaba River near Hoover were completed using records from the station Little Cahaba River below Leeds (02423397) that has collected more than 18,000 mean daily temperature records since June 1995.

The station Tallapoosa River near Montgomery (02419890) did not have a nearby station with daily water temperature records. In this case, the alternative was to use multiple imputations using the R package Amelia (Honaker et al., 2011) to complete the time series. Multiple imputation is a technique

that reduces bias and increase efficiency of the estimates compared with listwise deletion (Honaker et al., 2011).

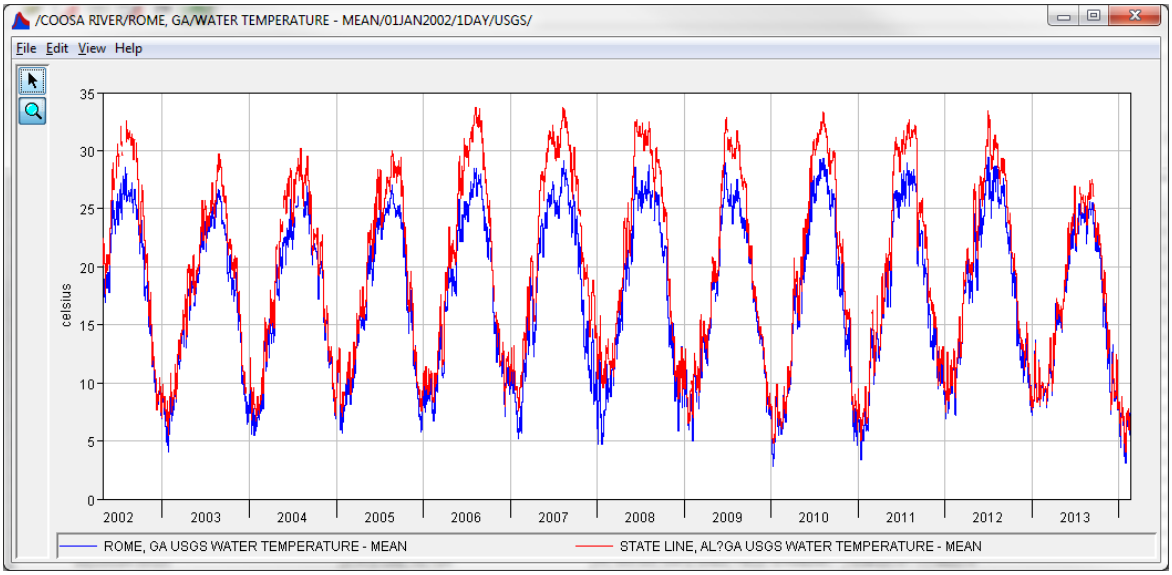

Figure 7. Stations in Alabama with water temperature records according to the National Water Information System (obtained from http://maps.waterdata.usgs.gov/mapper/nwisquery.html)

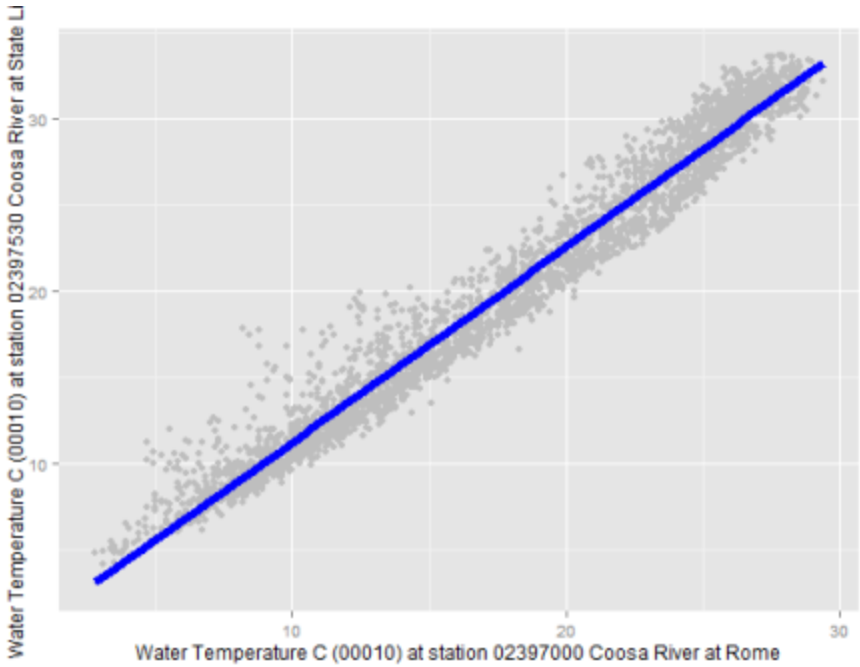

Figure 8. Stations in Alabama with water temperature records according to the National Water Information System (obtained from http://maps.waterdata.usgs.gov/mapper/nwisquery.html)

4.1.3. Completing Water Discharge Records

Fortunately, all the stations that have discharge records also have water height. The best method to estimate discharges based on stage records is the use of rating curves. A rating curve is a log-log plot that correlates discharge and stage. In general, rating curves need to be calibrated and depending on the conditions in the river it is possible to have more than one rating curve. In general, we recommend using the rating curve builder tool available in the USGS WaterWatch Toolkit website (http://waterwatch.usgs.gov/?id=ww_toolkit).

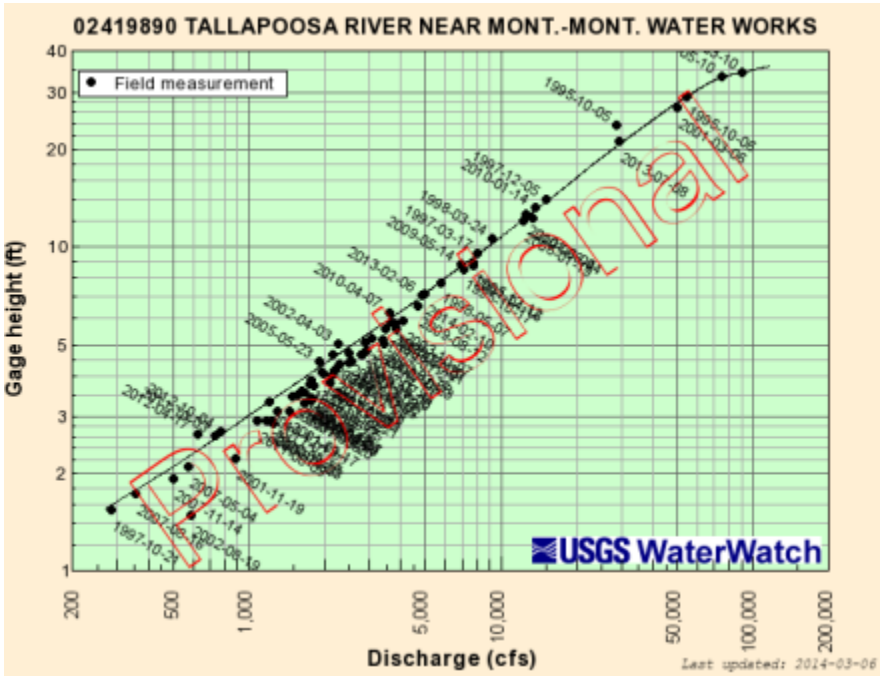

Figure 9. Provisional Rating Curve generated by the USGS WaterWatch Toolkit for the station USGS 02419890 (obtained from http://waterwatch.usgs.gov/index.php)

Figure 9 shows an example of the provisional rating curves generated for the station Tallapoosa River near Montgomery (02419890). In some cases both discharge and stage values were missing from the dataset, under these conditions, discharge estimates were calculated using linear interpolations between existing values. The only station in Table 1 that did not have any discharge records was the station 02397530 (Coosa River near State Line). As in the water temperature case, water discharge records from the station at Rome (02397000) were used to estimate the discharge values at 02397530. Estimated discharges at the station 02397530 might not be perfect because they need to include additional discharge contributions between Rome and State Line. However, for the purposes of this guidance document the discharge does not need to be exact, it just needs to indicate the periods of low, high flow, and the correlation with the *chlorophyll a* and nitrate + nitrite-N concentrations. For this reason, completion of discharge time series using the rating curve should be the first approach, but in cases stage values are not available the use of discharges from upstream or downstream stations may be adequate.

4.1.4. Completing *Chlorophyll a* Records

Daily *chlorophyll a* estimates were obtained by using multiple parametric survival regressions using the Weighted Regressions in Time Discharge and Season (WRTDS) as described by Hirsh et al (2010). The WRTDS method estimates daily concentrations based on survival regressions that select from a large dataset a window that fit some restrictions related to discharge, month of the year, and observed water discharge. The equation that relates the concentration with the discharge and time is:

$$\ln(c)=\beta_0 + \beta_1 t + \beta_2 \ln(Q) + \beta_3 \sin(2\pi t) + \beta_4 \cos(2\pi t) + \varepsilon \quad (1)$$

where c is the concentration of the water constituent in milligrams per liter, the β terms are the unknown regression coefficients, Q is the water discharge (m^3/s or ft^3/s), and t is the time (years) in decimal form. In the WRTDS method, ε is assumed to be a normally distributed term with a mean of zero and a standard deviation of σ_ε, (which is also known as the scale parameter or the standard deviation of the errors). In this guidance document, WRTDS was used to estimate *chlorophyll a* and nitrate + nitrite-N concentrations.

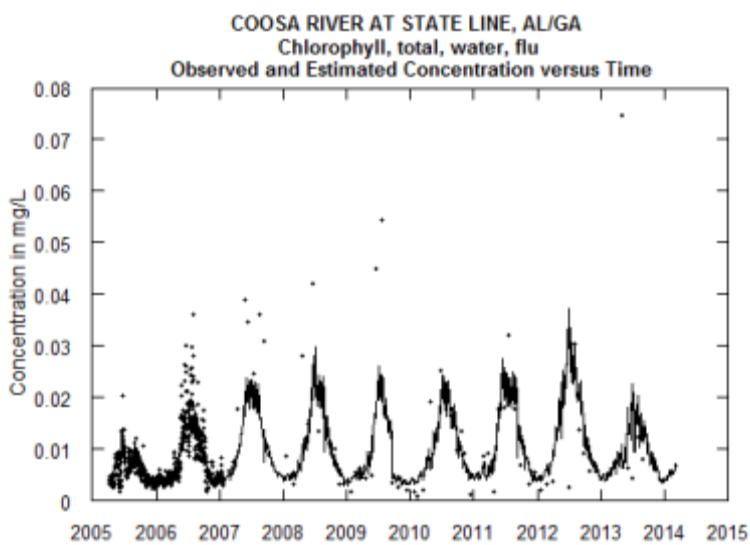

Figure 10. Estimated and observed c*hlorophyll a* concentrations using the method Weighted Regressions in Time Discharge and Season (WRTDS)

Figure 10 shows an example of one of the graphs generated by WRTDS. The figure includes the estimated (line) and observed (dots) *chlorophyll a* concentrations for the station Coosa River at State Line (02397530). One of the requirements of WRTDS is that the station should have at least 200 samples of the desired parameter collected in a period of approximately 20 years. The method also requires daily records of water discharge for the same period of time. One of the advantages of the station Coosa River at State Line is that daily *chlorophyll a* concentrations using the fluorometric method were collected for almost 2 years. These daily records describe how *chlorophyll a* changed during the year. In order to increase the number of *chlorophyll a* observations, both *chlorophyll a* concentrations calculated by fluorometric and spectrometric methods were combined.

Figure 11 shows an example of the correlation between water temperature and *chlorophyll a* at the station 02397530. Notice the correlation between c*hlorophyll a* concentrations and the change in water temperature. The variability of c*hlorophyll a* concentrations is proportional to the increase in water temperature. No major changes in *chlorophyll a* concentrations were observed at temperatures between 5 than 15 °C. On the other hand, at temperatures higher than 15 °C the median and standard deviation of *chlorophyll a* concentrations increased.

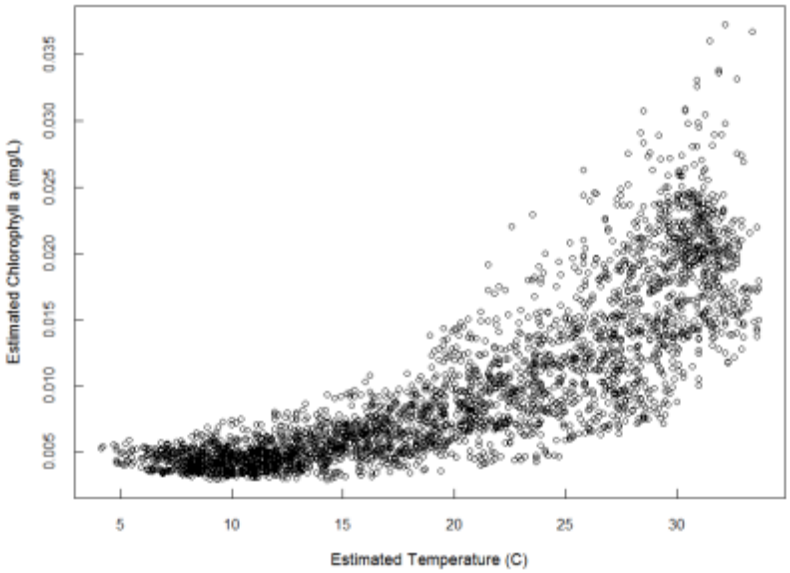

Figure 11. Exponential correlation between Temperature and estimated *chlorophyll a* at the station Coosa River at State Line (02397530)

Unfortunately, none of the other three stations had daily records of *chlorophyll a*. C*hlorophyll a* samples have been collected at the stations 02419890, 02423160, and 02423425 approximately once a month. This low frequency will not generate as good *chlorophyll a* concentration estimates as the observed at the station 02397530, but by using the discharge records WRTDS will provide a general trend of its behavior.

4.1.5. Completing Nitrate + Nitrite-N Records

Similar to the *chlorophyll a* case nitrate + nitrite-N concentrations were collected approximately once a month. Unfortunately daily nitrate + nitrite-N concentrations were not available for the four stations used in this analysis. At the moment of this guidance document no continuous real-time nitrate sensors have been installed in rivers and streams of Alabama. Daily nitrate + nitrite-N concentrations were estimated using the WRTDS method.

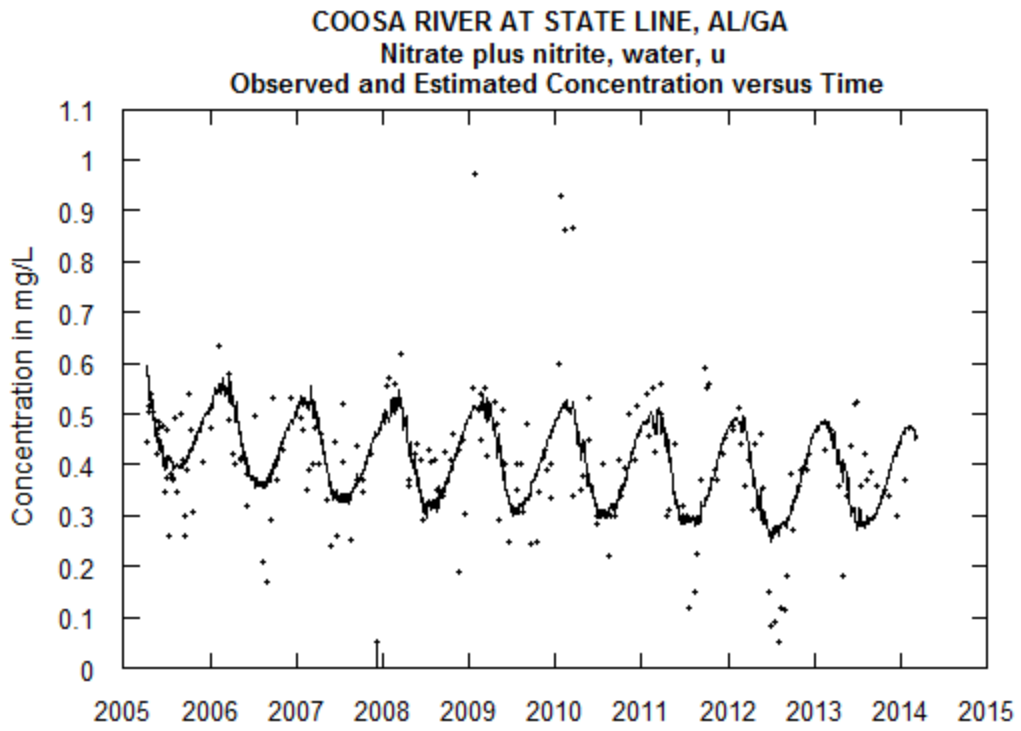

Figure 12. Estimated and observed Nitrate + Nitrite as N concentrations using the method Weighted Regressions in Time Discharge and Season (WRTDS)

4.2. Identifying Previous Biological Sampling Efforts

Since 2005, ADEM has been developing River and Streams Monitoring Program (RSMP) reports that summarize the results of bioassessments representative of the conditions of rivers and small streams in Alabama. These bioassessments were based on a protocol known as the Intensive Wadeable Multi-habitat Macroinvertebrate (WMB-I) bioassessment (ADEM, 2010). The WMB-I includes measures of taxonomic richness, taxonomic group composition, pollution tolerance, and feeding group composition (ADEM, 2014a). In addition to the bioassessments, ADEM conducts general observations and habitat assessments that provide an indication of the characteristics of the site and availability of habitat. Starting in 2010 ADEM developed and tested an Intensive Nonwadeable Macroinvertebrate Bioassessment Index (NWMBI).

ADEM has divided the sampling locations within the state in five basin groups sampled in a five year rotation. As part of the monitoring strategy, ADEM has identified six ecoregions and 25 sub-regions with similar land uses, natural vegetation, climate, hydrology, soil, and landform. The objective is to identify reference reaches that have been minimally impacted to be used as reference for other reaches located in the same ecoregion.

ADEM Water Quality Reports, as well as USGS Open File Reports were reviewed to develop a list of the most important parameters from previous habitat and macroinvertebrate assessments. A list of the water quality reports is available at http://www.adem.alabama.gov/programs/water/wqsurvey.cnt.

Another source of biological data was in the GSA open-file reports. These reports described habitat and biological assessments based on fish sampling during the development of the Index of Biotic Integrity (IBI) for the five Ichthyoregions shown in Figure 2. The development these IBI involved the identification of habitat conditions at the sampling station, and the calculation of the human disturbance gradient as explained in Section 4.2.2.

In addition to the habitat, macroinvertebrates, and fish sampling reports, additional information was found in USGS scientific, water resources, and open file reports that include comprehensive biological studies on the Autauga Creek Watershed (Mooty and Gill, 2011), Three Mile Creek Basin (McPherson et al., 2004), Fivemile Creek (Gill et al., 2007), and Village and Valley Creeks (McPherson et al., 2002). The following sections describe the results of previous biological sampling results that were included in the development of BST.

4.2.1. Habitat Assessment / Physical Characterization

A habitat assessment/physical characterization, field parameters, water quality samples, and stream flow measurements are required during the WMB-I sample collection (ADEM, 2010). There are major metrics involved in the rating of habitat assessment. Table 6 describes each of the metrics used in the habitat assessment. The first column in the table indicates the code used for BST to display the results of the model as shown in Section 5 of this document.

Table 6. Habitat Assessment Metrics Used in BST

BST CODE	Metric	Description
01	Instream Habitat Quality	Considers the physical, chemical, and biological conditions that affect the aquatic community
02	Sediment Deposition	Considers the accumulation of sediments in the stream. Heavy deposits of fine material cause the formation of bars
03	Sinuosity	It is the ratio between the channel length and the direct down valley length. It refers to the curviness of the channel
04	Bank and Vegetative Stability	Considers the stability of the banks and evidence of erosion or bank failure
05	Riparian Buffer	Considers the width of the natural vegetation along the channel
06	Overall Habitat Assessment	Overall habitat assessment based on the parameters included in the riffle/run or glide/pool field data sheets

The Instream Habitat Quality refers to the physical, chemical, and biological attributes that influence the structure and function of the aquatic community (EPA, 2006). It includes the identification of disturbance in the gradient in the main channel, the flow regimes, the soil type, the presence of large

woody debris etc. Sinuosity or curviness of the channel is associated with streams with low gradient located in flat areas. The stability of the banks is also important because unstable banks deposit considerable amounts of sediment in the stream during storm events. Riparian buffer corresponds to the buffer width of vegetation along the stream. Riparian buffers in good condition are wide, continuous, with large areas covered with native vegetation, areas that protect the bank and provide shade and cool temperatures to the steam.

Each parameter is scored according the capacity of protect the stream and provide the conditions for the aquatic community. ADEM has developed two different habitat assessment field sheets, one for riffle/run, and one for glide/pool. The riffle/run field data sheet has 12 habitat parameters allowing a maximum score of 240 points. The glide/pool has 11 habitat parameters with a total maximum score of 220 points. According to the total score, each parameter is rated as rated as optimal, suboptimal, marginal, or poor In addition, ADEM calculates an overall habitat assessment score. Table 6 only shows the habitat parameters included in the RSMP reports. Tables 7 and 8 shows the classification for each parameter included in Table 6 according to the type of assessment conducted.

Table 7. Score Classification for Habitat Assessments in riffle/run

Metric	Optimal	Suboptimal	Marginal	Poor
Instream Habitat Quality	> 65	53 – 65	40 – 52	< 40
Sediment Deposition	> 65	53 – 65	40 – 52	< 40
Sinuosity	> 84	65 – 84	45 – 64	< 45
Bank and Vegetative Stability	> 74	60 – 74	35 – 59	< 35
Riparian Buffer	> 89	70 – 89	50 – 69	< 50
Overall Habitat Assessment	> 65	53 – 65	40 – 52	< 40

Table 8. Score Classification for Habitat Assessments in glide/pool

Metric	Optimal	Suboptimal	Marginal	Poor
Instream Habitat Quality	> 70	59 – 70	41 – 58	< 41
Sediment Deposition	> 70	59 – 70	41 – 58	< 41
Sinuosity	> 84	65 – 84	45 – 64	< 45
Bank and Vegetative Stability	> 74	60 – 74	35 – 59	< 35
Riparian Buffer	> 89	70 – 89	50 – 69	< 50
Overall Habitat Assessment	> 70	59 – 70	41 – 58	< 41

4.2.2. Macroinvertebrate Assessments

In recent months, ADEM has been developing a Water Quality Assessment Methodology for the categorization of surface waters based on assessment results (Sisk, 2014). Results from the Integrated Water Quality Monitoring Assessment Report are submitted to Congress every two years. Data required for the assessment include the collection of in situ and laboratory measurements as well as biological components that is divided in four categories: Macroinvertebrates, fish tissue, habitat, and periphyton. In the previous section we covered the habitat category. In this section, it is included the Macroinvertebrate assessment. Periphyton will not be included in the current version of the guidance

document due to the few locations and samples collected for this category. However, as more samples are collected, periphyton results can be used to enhance the determination of index periods.

ADEM has published reports that include macroinvertebrate assessments since 1974 (ADEM, 1996). However, metrics and sampling methodology have been changed with time. The most common metrics used to detect changes in water quality is associated with richness and composition measures. These metrics included the number of EPT taxa (number of taxa in orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies)), and %EPT (percent of mayfly, stonfly, and caddishfly larva in total collection. ADEM Benthic Macroinvertibrate Bioassessments are generally conducted during the period late April though early July (ADEM, 2010). Table 9 shows the metrics used by ADEM which will be used as reference in this guidance document (ADEM, 2014a).

Table 9. Macroinvertebrate Assessment Metrics Used in BST [a]

BST CODE	Metric	Description
	CollectorTax	Number of Collector – Gatherer Taxa
	DomPTax	Percent of Dominant Taxa
	EPCPct	Percent of Ephemeroptera, Plecoptera, and Coleoptera individuals
	EPCPTax	Percent of Ephemeroptera, Plecoptera and Coleoptera taxa
	EPPct	Percent of Ephemeroptera and Plecoptera individuals
	EPTPctminusHB	Percent of EPT individuals, excluding Hydropsychidae and Baetidae
	EPTTax	EPT taxa
	FiltererPct	Percent Filtering Collectors
	NonInsPTax	Percent Non-insect taxa
	NutrientTolerantPct	Percent nutrient tolerant individuals
	PredatorsPct	Percent Predators
	Shannon	Shannon Diversity index
	TCPTax	Percent Trichoptera and Chironomidae taxa
	TolerantPTax	Percent of Tolerant Taxa
07	WMB-I Assessment Score	Intensive Wadable Macroinvertebrate Assessment score (0 – 100)
08	WMB-I Assessment Rating	Intensive Wadable Macroinvertebrate Assessment rating

a. Definitions based on the document Aquatic Macroinvertebrate Community Wadeable Multi-Habitat Bioassessment – Data Analysis SOP # 6004 (ADEM, 2014a)

The results from the macroinvertebrate bioassessments are transformed into scores that varied between (0 – 100). Values close to 100 are considered optimal, while values close to 0 are considered poor. According to the score assigned to each metric there is an overall WMB-I rating. ADEM assigns the ratings based on five bioregions determined by clustering ecoregions with similar characteristics. Table 10 shows the index values determined by the WMB-I scores at each bioregion (the delimitation of the ecoregions is presented in Griffith et al., 2001).

Table 10. Index Values based on WMB-I scores

Bioregion	Very Good	Good	Fair	Poor	Very Poor
Southwest Appalachians (Ecoregions 68)	> 79	59 – 79	39 – 58	20 – 38	< 20
Interior Plateau/Transition Hills (Ecoregions 71 and 65j)	> 72	44 – 72	29 – 43	15 – 28	< 15
Piedmont, Ridge Valley (Ecoregions 47 and 67)	> 85	70 – 85	47 – 69	23 – 46	< 23
Southeastern Plains-Hills (Ecoregions 65d, I, and q)	> 74	48 – 74	32 – 47	16 – 31	< 16
Southeastern Pains-Plains (Ecoregions 65a, b, f, g, and p)	> 73	46 – 73	31 – 45	15 – 30	< 15

4.2.3. Fish Assessments

As described previously in Section 2, GSA has calibrated the Index of Biotic Integrity for five Ichthyoregions in Alabama (O'Neil et al., 2006), (O'Neil and Shepard 2007, 2009, 2010, 2011a, 2011b, 2011c, 2012). IBI values are calculated by the identification of three metrics: species richness and composition metrics that includes metrics like the total number of species and total number of intolerant species; trophic composition metrics that describe the trophic dynamics of fish groups (i.e., proportion of individuals as top carnivores, proportion of individuals as omnivores); and fish abundance and condition metrics that evaluates mortality, abundance, and condition of the species (i.e., proportion of fish with disease, tumors, fin damage, and skeletal abnormalities) (Barbour et al., 1999).

Table 11 shows the classification of IBI scores to identify integrity class endpoints for each of the Ichthyoregions shown in Figure 2. The IBI integrity classes provide an idea of the overall status of the fish population at the sampling station (O'Neil and Shepard, 2012).

Table 11. IBI integrity classes for Alabama Ichthyoregions (from O'Neil and Shepard 2012)

Bioregion	Excellent	Good	Fair	Poor	Very Poor
Plateau	> 49	43 – 49	35 – 42	26 – 34	< 26
Southern Plains	> 49	44 – 50	36 – 43	26 – 35	< 26
Tennessee Valley	> 49	41 – 49	29 – 40	22 – 28	< 22
Ridge and Valley/Piedmont	> 49	43 – 50	35 – 42	27 – 34	< 27
Hills and Coastal Terraces	> 49	43 – 49	35 – 42	27 – 34	< 27

Several variables were calculated for each of the samples collected during the calibration of the IBI. The list includes sample number, sample date, drainage area, and population density amongst others. Table 12 shows a list of the variables calculated during the fish assessments that were included in BST.

Table 12. Fish Assessment Metrics Used in BST

BST CODE	Metric	Description
09	Human Disturbance Gradient (HDG)	In the BCG model (see Section 2) it is expected that sites affected by strong pressures in the aquatic environment will have low IBI values. The GSA developed a HDG based on eight metrics that include human density, phosphorous load, percent of urban, barren, pasture, and crop land uses, road density, and number of road crossings per kilometer of stream.
10	Total IBI Score	Total Index of Biotic Integrity
11	Integrity Classes	Integrity classes obtained from Table 11

4.2.4. Biological Ratings

Table 13 shows for each of the BST codes indicated above a symbol and rating based on the scores of the habitat and macroinvertebrate and fish assessments. These symbols will be used in the identification of the associations between the estimated concentration of *chlorophyll a* and nitrate + Nitrite-N, discharge, and previous biological assessments.

Table 13. Biological Rating and scores of Habitat and Macroinvertebrate Assessments

BST Code	Metric	Optimal or Excellent	Sub-optimal or Good	Marginal or Fair	Poor	Very Poor
01	Instream Habitat Quality	◆	◆	◆	◆	◆
02	Sediment Deposition	▼	▼	▼	▼	▼
03	Sinuosity	▲	▲	▲	▲	▲
04	Bank and Vegetative Stability	⊕	⊕	⊕	⊕	⊕
05	Riparian Buffer	*	*	*	*	*
06	Overall Habitat Assessment	■	■	■	■	■
07	WMB-I Assessment Rating	value	value	value	value	value
08	WMB-I Assessment Score	●	●	●	●	●
09	Human Disturbance Gradient (HDG)	value	value	value	value	value
10	Total IBI Score	value	value	value	value	value
11	Integrity Classes	☒	☒	☒	☒	☒

The next section describes how the ratings described by the BST codes will be used to connect previous biological sampling efforts with trends of water discharge, temperature, *chlorophyll a*, and nitrate + nitrite-N.

5. Results of the Biological Sampling Tool (BST)

The purpose of BST and hence of this guidance document is to find a relation between previous habitat and, fish and macroinvertebrate assessments with the concentration of *chlorophyll a*, nitrate + nitrite-N, and water discharge to identify the best periods of sampling based on current conditions of major rivers or streams. By identifying those periods we expect to provide a tool that help managers to decide when to conduct sampling at each of the basin groups.

An additional advantage of the methodology presented here is that allows the generation of figures that display long term trends of *chlorophyll a* and concentration of certain nutrients (i.e. nitrate + nitrite as N) with the most current readings and estimates at the stations described in Table 1. Figure 9 shows one of the figures developed by BST to help identify the best days of the current year for sampling biological responses.

Figure 9 shows the long term trends for *chlorophyll a* at the station USGS 02397530 (Coosa River at State Line). The long term trends the figure includes the 5 and 95% confidence interval of the daily estimated concentrations of *chlorophyll a*. The year to date estimated *chlorophyll a* is also plotted within the 5 and 95 percentile curves. One of the attractive features of this graph is that it includes the results of the biological efforts conducted in the past. The program calculates automatically the expected concentration of *chlorophyll a* the day the sample was collected. The samples are plotted the same month and day and follow the symbols and colors described in Table 8.

Six biological stations located near the station USGS 02397530 and the ADEM station WEIC-12. Each of these six biological stations collected samples in 2005 and 2010. The figure indicates that all the biological assessments were conducted in May. The 12 samples collected are not easily identified because more than one station was sampled on the same day. The figure shows a combination of the results of the overall habitat assessment (squares) and the WMB-I assessment score (circle). The 12 samples indicated that the overall habitat assessment at the six stations was either optimal or sub-optimal. However, the conditions of the intensive wadeable macroinvertebrate assessment varied from marginal to poor. Notice also that it seems that this year the expected *chlorophyll a* levels are close to the 95 percentile line indicating that elevated concentrations of *chlorophyll a* are expected in the stream causing a potential increase of activity in the stream and an increase in macroinvertebrate density (Sponseller et al. 2001).

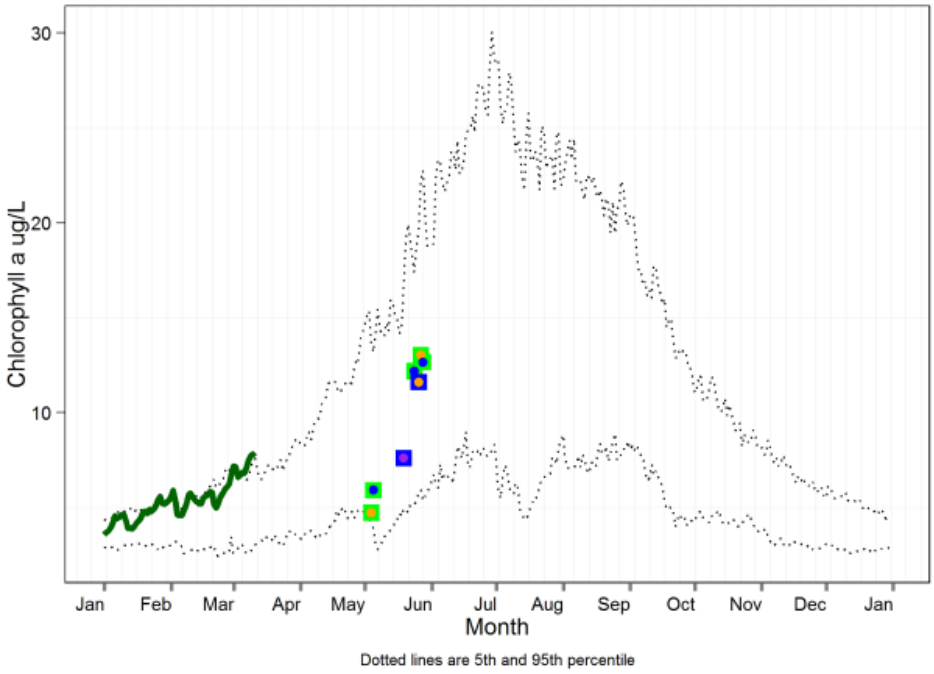

Figure 13. *Chlorophyll a* guidance figure for recent date (March13, 2014). The figure includes the sample results of biological campaigns conducted near Weiss Lake in 2005 and 2010

Figure 10 shows the results for nitrate + nitrite as nitrogen. Nutrient enrichment has been associated with changes in the response of ecological change (Gafner and Robinson, 2007). Long term simulations indicated that nitrate + nitrite-N concentrations in the station Coosa River at State Line have been declining recent years (See Figure 8). This reduction could indicate that responses that were observed in previous years will occur later this year affecting the macroinvertebrate assessment scores.

Figure 11 shows the trends in temperature of this year compared with previous years. Notice that the current year has been very cold compared with previous years (starting on 2002, see Table 2 and discussion about the selected period of analysis). Strong thermal variations can cause changes in the invertebrate community of small streams affecting life cycles, changes in development stages, and reduction of taxa observations (Cazaubon and Giudicelli, 1999). Water temperature appears to be correlated with temperature. As water temperatures increased in the spring and summer months, there is a reduction in Nitrate + Nitrite –N concentrations. Likewise, it was observed an increase in the concentration of *chlorophyll a* curing these two seasons, reaching a peak during the months of June and July.

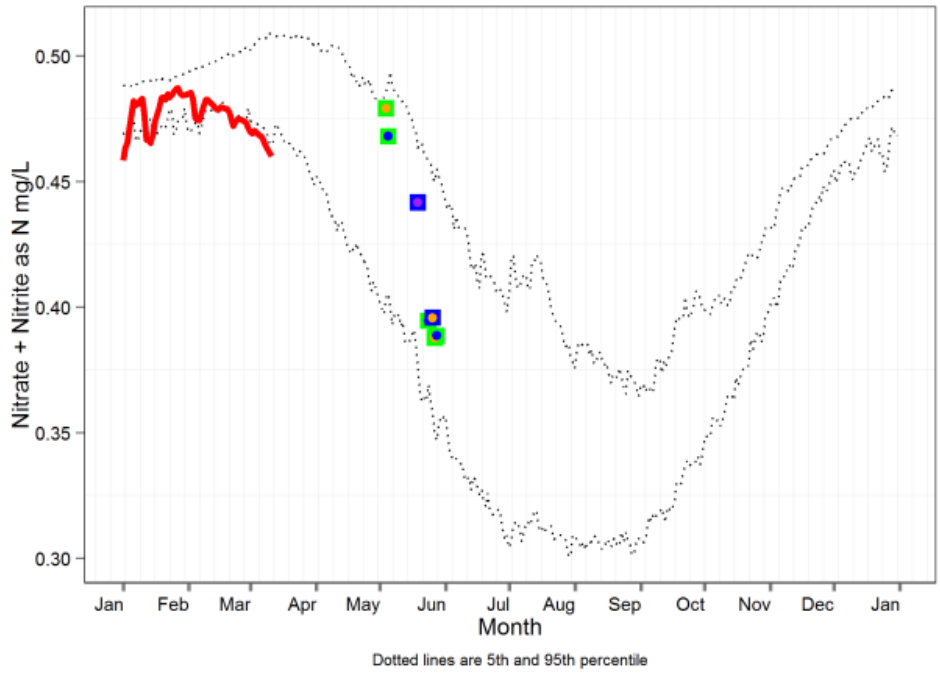

Figure 10. Nitrate + Nitrite as Nitrogen concentrations at station Coosa River near State Line. The figure includes the sample results of biological campaigns conducted near Weiss Lake in 2005 and 2010

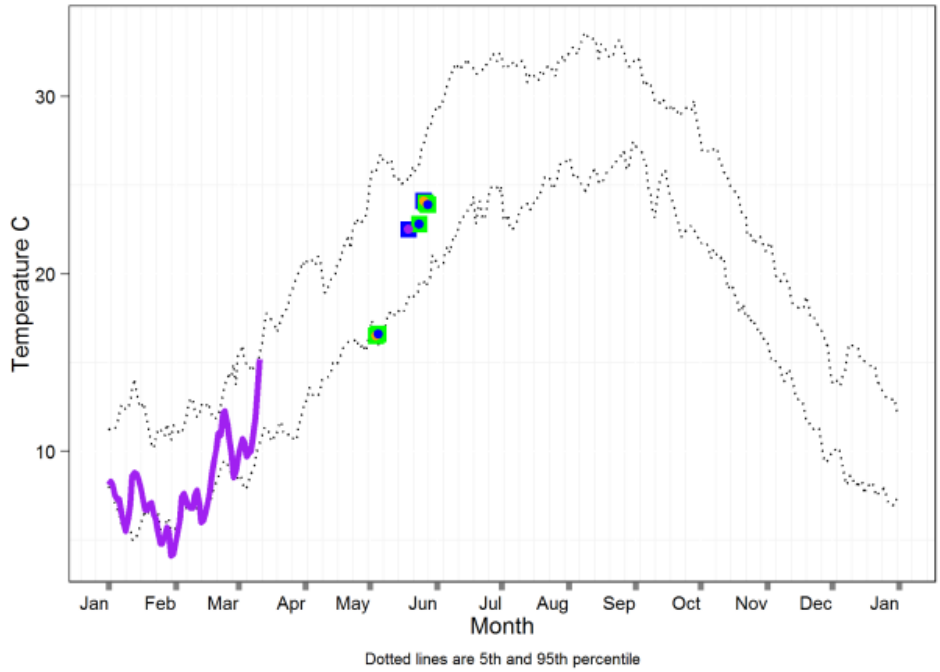

Figure 11. Current Temperature at station Coosa River near State Line. The figure includes the sample results of biological campaigns conducted near Weiss Lake in 2005 and 2010

Finally, Figure 12 shows the changes in water discharge at the Coosa River at Rome. In order to collect biological samples, it is important to have low flow values that allow scientist and biologists. In this case it can be observed that it is possible to have low levels of water at Rome any day of the year. It is logical to think that if the level of the water is low at Rome it is expected that the level of the water in the tributaries of the Coosa River near Rome are also at a low level.

Figure 12 also shows that there are two periods in the year that could have low flows and in the event there are storm events they do not have the probability of generating large discharges. The first period occurs in the month of June and the second is goes from first days of August to mid –September. Notice that there is a chance of having big storms in these two periods, but the duration of the rise and recession of the levels in the river is short and in general last lest than one week.

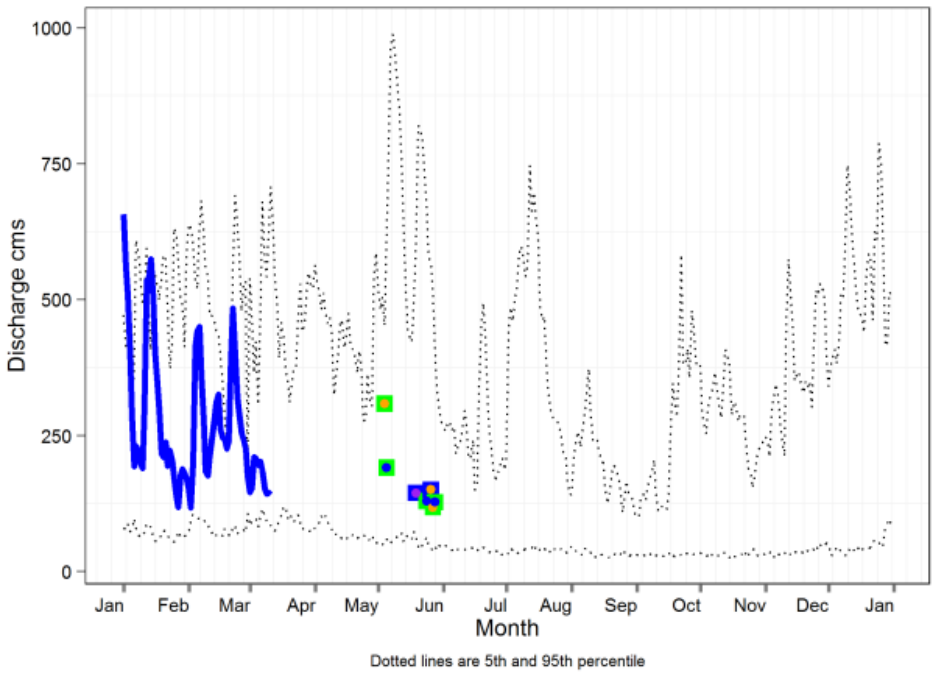

Figure 12. Current discharge at station Coosa River near State Line. The figure includes the sample results of biological campaigns conducted near Weiss lake in 2005 and 2010

6. Conclusions

- The Biological Sampling Tool (BST) developed from the USGS WRTS code, improves the quality of the information available to determine the best periods of the year for conducting biological sampling. The graphical output generated by BST facilitates the generation of summary plots that relate trends in concentration and discharge (generated by WRTDS) with the potential changes in habitat, macroinvertebrate and fish communities. The BST's capability of retrieving discharge and stage information in real time, assists managers in the identification of recent changes in flow and stage. For example, the use can easily identify if there have been multiple or major storm events recently upstream of the selected discharge station, or if there has been a long dry period. Both scenarios can be associated with other factors like accumulation or deposition of nutrients from atmospheric deposition, or lack of species due to an intense dry period. In addition, the possibility of generating water temperature plots increases the awareness of potential ecological impacts due to elevated temperatures. Finally, the manager can decide, based on the plots, if changes to the current index period will benefit the information provided by the biological sampling efforts. The development of complete daily time series, the use of complex figures that display current and historical physical and biological conditions, and the possibility of observing temporal trends all serve to increase the understanding of major changes in water quality in the rivers and streams of Alabama.

- The use of tools like BST allows water resources managers to evaluate if current programs and practices are effective and helps improve the quality of rivers and streams throughout the state. One example where BST can be helpful is during the analysis of the implementation of the nutrient criteria activities in the state. ADEM has selected, on some occasions, the use of the "reference condition" approach to evaluate the acceptable level of nutrients in streams (ADEM, 2014b). BST provides visual representation of Monitoring Units (MU) with similar characteristics within the same Hydrologic Unit Code. Future versions of the tool could provide automatic generation of watershed maps showing the results from BST similar to the one presented in Figure 4. The generation of plots and/or summary pages could help the state in tracking the implementation of the Nutrient Criteria Implementation Plan. BST was created in an open source software allowing programmers to expand/modify the routines developed in this document to tailor the needs of a specific water quality program.

- The current index period for sampling macroinvertebrates could be modified/expanded through long term analyses using BST. The current Standard Operating Procedure for aquatic macroinvertebrate community sample collection indicates that the index periods for benthic macroinvertebrates starts in late April and ends in early July (ADEM, 2010). BST includes the results of other biological efforts completed by GSA and USGS. By comparing the classification and habitat assessments conducted by USGS and GSA, it is possible to identify that changes/modification to the existing index (sampling) periods could allow more accurate

assessment of the biological impact of nutrient discharges on the macroinvertebrate community.

- BST provides information that assist water managers in the identification of water constituents to be sampled with discrete and continuous monitoring strategies. Recently, there has been a desire of some communities to stop their discrete monitoring programs and switch to continuous monitoring. However, the number of water constituents that can be monitored using sensors is limited. Definitely, discharge, temperature, nutrient, and *chlorophyll a* daily data is desired, but the equipment is expensive or inaccurate. The decision of stop monthly sampling affects the representativeness and variability of mathematical models used to generate daily estimates based on discrete sampling. Use of the BST informs the evaluation of: the frequency of discrete sampling campaigns, the parameters to be evaluated, and the potential relationships between water constituents.

- Estimates of *chlorophyll a* daily concentrations generated with WRTDS and BST could provide information about changes of *chlorophyll a* concentrations in major lakes and reservoirs. Rivers in Alabama are heavily controlled by dams. Algal blooms have been associated to increases of nutrient enrichment in water bodies. Identification of trends or peaks in *chlorophyll a* concentration estimates could be linked to increases in algal density in lakes and reservoirs or the presence of hyper-eutrophic ponds that discharge in rivers or streams.

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Appendix 1: Example Using the Biological Sampling Tool

The following appendix describe step by step how to use the Biological Sampling Tool (BST) in the identification of trends and observations of previous biological sampling efforts at the USGS station 02423425 (Cahaba River near Cahaba Heights). This station has been recording daily discharge records since July 1996.

ADEM has been collecting water quality samples near the station 02423425 at the station C-2 since 1991. *Chlorophyll a* samples have been collected at C-2 since 2004. Approximately 91 chlorophyll a samples have been collected. The station 02423425 is part of the NOAA River Forecast Network that provides predictions of water stage and discharge at this station up to four days in advance. Figure A-1 shows an example of the predicted stage values at the station USGS 02423425 including the minor, moderate, and major flooding stages.

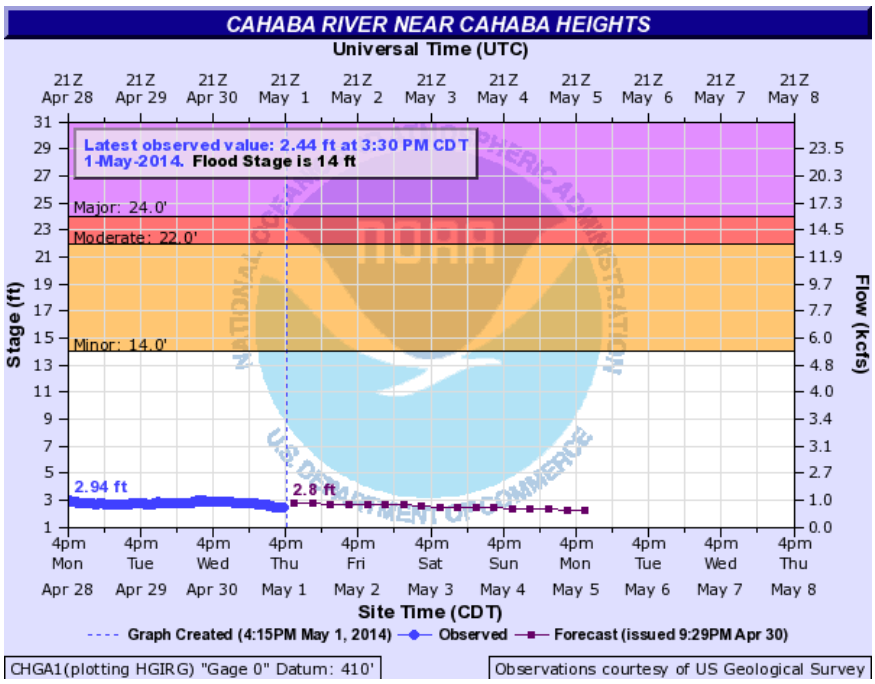

Figure A-1. Example of previous and predicted stage observations at the station USGS 02423425 located at the Cahaba River near Cahaba Heights (source: NOAA Advanced Hydrologic Prediction Service)

The first step in this example is to identify the location of the USGS station, the catchment associated to the Hydrologic Unit Code at level 8 (HUC-8), and the location of the ADEM, USGS, and GSA biological stations within the HUC-8.

Figure A-2 shows a map with the location of the station USGS 02423425, and biological stations for fish and macroinvertebrates monitored by GSA and ADEM.

Appendix 2 (Source Code)

```
## ------------------------------------------------------------------------------------
-
##
##                Guidance Document for More Cost-Effective Sampling of
##              Biological Responses to Nutrient Loads in Streams and River
##
##                                The University of Alabama
##                                       February 2014
##
##
## Routine: Complete the stage records for the station Coosa River at State Line AL/GA
## USGS 02397530. This routine uses data from the station Coosa River near Rome (USGS
## 02397000
##
## ------------------------------------------------------------------------------------
--
##
## Loading Default repository
local({r <- getOption("repos");
       r["CRAN"] <- "http://cran.r-project.org"; options(repos=r)})
##
## Installing packages
##
# install.packages(c("zoo","survival","methods","fields","spam","plyr","XML","RCurl"))
# install.packages("dataRetrieval", repos="http://usgs-r.github.com")
# install.packages("EGRET", repos="http://usgs-r.github.com")
# install.packages("ggplot2")
# install.packages("Amelia")
# install.packages("forecast")
library("zoo")
library("survival")
library("methods")
library("fields")
library("spam")
library("plyr")
library("RCurl")
library("dataRetrieval")
library("EGRET")
library("ggplot2")
library("Amelia")

##
#-------------------------------------------------------
# Reading data from stations and dates
#-------------------------------------------------------
savePath<-"./"
figurePath<-"./figures/"
cat("\n")
cat("*************************************************************\n")
cat("Reading Data from Coosa River State Line and Rome Stations...\n")
cat("*************************************************************\n")
cat("\n")
# the following lines indicate the number of the USGS Stations
staSL <- "02397530"
staRome <- "02397000"
STORET_Station <- "21AWIC-23"
ChlparamName <- "Chlorophyll a"
NitrogenParamName <- "Inorganic nitrogen (nitrate and nitrite) as N"
BiologicalFile <- "Biological_Weiss.csv"
```

```
# The following two lines are the starting and ending date of the simulation based on
the discharge values
StartDate<-"2002-04-25"
EndDate<-format(Sys.Date(),paste("%Y","-","%m","-","%d", sep=""))

##
##-------------------------------------------------------
## Modified Functions
##-------------------------------------------------------

getWQ_Station <- function (siteNumber, ParameterName, StartDate, EndDate, interactive
= TRUE)
{
    StartDate <- formatCheckDate(StartDate, "StartDate", interactive = interactive)
    EndDate <- formatCheckDate(EndDate, "EndDate", interactive = interactive)
    dateReturn <- checkStartEndDate(StartDate, EndDate, interactive = interactive)
    StartDate <- dateReturn[1]
    EndDate <- dateReturn[2]
    if (nzchar(StartDate)) {
        StartDate <- format(as.Date(StartDate), format = "%m-%d-%Y")
    }
    if (nzchar(EndDate)) {
        EndDate <- format(as.Date(EndDate), format = "%m-%d-%Y")
    }
    baseURL <- "http://www.waterqualitydata.us/Result/search?siteid="
    url <- paste(baseURL, siteNumber,
        "&startDateLo=", StartDate, "&startDateHi=", EndDate,
        "&countrycode=US&mimeType=tsv", sep = "")
    suppressWarnings(retval <- read.delim(url, header = TRUE,
        quote = "\"", dec = ".", sep = "\t", colClasses = c("character"),
        fill = TRUE))
    qualifier <- ifelse(((retval$ResultDetectionConditionText ==
        "Not Detected" & length(grep("Lower",
retval$DetectionQuantitationLimitTypeName)) >
        0) | (retval$ResultMeasureValue <
retval$DetectionQuantitationLimitMeasure.MeasureValue &
        retval$ResultValueTypeName == "Actual")), "<", "")
    correctedData <- ifelse((nchar(qualifier) == 0), retval$ResultMeasureValue,
        retval$DetectionQuantitationLimitMeasure.MeasureValue)
    test <- data.frame(as.Date(retval$ActivityStartDate, "%Y-%m-%d"))
       colnames(test) <- c("dateTime")
       test$CharacteristicName <- retval$CharacteristicName
             colnames(test) <- c("dateTime","CharacteristicName")
    originalLength <- nrow(test)
    test$qualifier <- qualifier
    test$value <- as.numeric(correctedData)

    test <- test[!is.na(test$dateTime), ]
    newLength <- nrow(test)
    if (originalLength != newLength) {
        numberRemoved <- originalLength - newLength
        warningMessage <- paste(numberRemoved, " rows removed because no date was
specified",
            sep = "")
        warning(warningMessage)
    }
    colnames(test) <- c("dateTime", "CharacteristicName", "qualifier", "value")
       dataout <- test[test$CharacteristicName == ParameterName,]
       cat(paste("\n","\n",sep = ""))
       cat(paste("\n","Number of ",ParameterName, " Samples: ", nrow(dataout),"\n",sep
= ""))
       cat(paste("\n","\n",sep = ""))
```

```
    data <- reshape(dataout, idvar = "dateTime", timevar = "CharacteristicName",
direction = "wide")
    data$dateTime <- format(data$dateTime, "%Y-%m-%d")
    data$dateTime <- as.Date(data$dateTime)
    return(data)
}

getSampleData_Station <- function (siteNumber, ParameterName, StartDate, EndDate,
interactive = TRUE)
{
    data <- getWQ_Station(siteNumber, ParameterName, StartDate, EndDate,
        interactive = interactive)
    compressedData <- compressData(data, interactive = interactive)
    Sample <- populateSampleColumns(compressedData)
    return(Sample)
}


getLegend <- function (Table, Parameter) {
  LegendT <-data.frame(Table$Date)
  LegendT[, c("Legendcol")] <- as.character("N_A")
  colnames(LegendT) <- c("Date","Legendcol")
  is.na(LegendT) <-c(2)
  for (i in 1: nrow(LegendT) ){
    if (!is.na(Parameter[i])){
      if (Parameter[i] == "Excellent"){ LegendT$Legendcol[i] <- "yellow"}
      if (Parameter[i] == "Optimal"){ LegendT$Legendcol[i] <- "green"}
      if (Parameter[i] == "Sub-optimal"){ LegendT$Legendcol[i] <- "blue"}
      if (Parameter[i] == "Good"){ LegendT$Legendcol[i] <- "blue"}
      if (Parameter[i] == "Marginal"){ LegendT$Legendcol[i] <- "orange"}
      if (Parameter[i] == "Fair"){ LegendT$Legendcol[i] <- "orange"}
      if (Parameter[i] == "Poor"){ LegendT$Legendcol[i] <- "purple"}
      if (Parameter[i] == "Very poor"){ LegendT$Legendcol[i] <- "red"}
    }
  }
  return(LegendT)
}



#
# ----------------------------------------------------------------
# Reading Temperature, Height, Discharge, and Chlorophyll Records
# ----------------------------------------------------------------
#
# Temperature
cat("\n")
cat("Summary Temperature (Celsius) Coosa River State Line GA/AL ...\n")
cat("\n")
SampleSLTemp<-getRDB1Data(constructNWISURL(staSL,"00010",StartDate,EndDate,'dv',format
= 'tsv'))
colnames(SampleSLTemp) <- c("Agency", "site_no", "datetime", "value", "qualifier")
print(summary(SampleSLTemp))


cat("\n")
cat("Summary Temperature (Celsius) Coosa River near Rome ...\n")
cat("\n")
SampleRomeTemp<-
getRDB1Data(constructNWISURL(staRome,"00010",StartDate,EndDate,'dv',format = 'tsv'))
colnames(SampleRomeTemp) <- c("Agency", "site_no", "datetime", "value", "qualifier")
print(summary(SampleRomeTemp))
#
```

```
#
# Gage Height
cat("\n")
cat("Summary Gage Height (feet) Coosa River State Line GA/AL ...\n")
cat("\n")
SampleSLHeight<-
getRDB1Data(constructNWISURL(staSL,"00065",StartDate,EndDate,'dv',format = 'tsv'))
colnames(SampleSLHeight) <- c("Agency", "site_no", "datetime", "value", "qualifier")
print(summary(SampleSLHeight))

cat("\n")
cat("Summary Gage Height (feet) Coosa River near Rome ...\n")
cat("\n")
SampleRomeHeight<-
getRDB1Data(constructNWISURL(staRome,"00065",StartDate,EndDate,'dv',format = 'tsv'))
colnames(SampleRomeHeight) <- c("Agency", "site_no", "datetime", "value", "qualifier")
print(summary(SampleRomeHeight))
#
#
# Chlorophyll
cat("\n")
cat("Summary Chlorophyll (fluorometric, 650-700 nanometers mg/L) Coosa River State
Line GA/AL ...\n")
cat("\n")
SampleSLChl<-getRDB1Data(constructNWISURL(staSL,"62361",StartDate,EndDate,'dv',format
= 'tsv'))
colnames(SampleSLChl) <- c("Agency", "site_no", "datetime", "value", "qualifier")
print(summary(SampleSLChl))

cat("\n")
cat("Summary Chlorophyll (fluorometric, 650-700 nanometers mg/L) Coosa River near Rome
...\n")
cat("\n")
SampleRomeChl<-
getRDB1Data(constructNWISURL(staRome,"62361",StartDate,EndDate,'dv',format = 'tsv'))
colnames(SampleRomeChl) <- c("Agency", "site_no", "datetime", "value", "qualifier")
print(summary(SampleRomeChl))
#
#
# Discharge
#
#
cat("\n")
cat("Summary Discharge (cfs) Coosa River near Rome ...\n")
cat("\n")
SampleRomeQ<-
getRDB1Data(constructNWISURL(staRome,"00060",StartDate,EndDate,'dv',format = 'tsv'))
colnames(SampleRomeQ) <- c("Agency", "site_no", "datetime", "value", "qualifier")
print(summary(SampleRomeQ))
#
# ----------------------------------------------------
# Creating a Dataframe with all the dates
# ----------------------------------------------------
#
z <- zoo(,as.Date(StartDate) + 1:(as.Date(EndDate) - as.Date(StartDate)))
zSLTemp <- zoo(SampleSLTemp[,4], SampleSLTemp[, 3])
z <- merge(z,zSLTemp)
remove(zSLTemp)
remove(SampleSLTemp)
zRomeTemp <- zoo(SampleRomeTemp[,4], SampleRomeTemp[, 3])
z <- merge(z,zRomeTemp)
remove(zRomeTemp)
remove(SampleRomeTemp)
```

```
zSLHeight <- zoo(SampleSLHeight[,4], SampleSLHeight[, 3])
z <- merge(z,zSLHeight)
remove(zSLHeight)
remove(SampleSLHeight)
zRomeHeight <- zoo(SampleRomeHeight[,4], SampleRomeHeight[, 3])
z <- merge(z,zRomeHeight)
remove(zRomeHeight)
remove(SampleRomeHeight)
zSLChl <- zoo(SampleSLChl[,4], SampleSLChl[, 3])
z <- merge(z,zSLChl)
remove(zSLChl)
remove(SampleSLChl)
zRomeChl <- zoo(SampleRomeChl[,4], SampleRomeChl[, 3])
z <- merge(z,zRomeChl)
remove(zRomeChl)
remove(SampleRomeChl)
zRomeQ <- zoo(SampleRomeQ[,4], SampleRomeQ[, 3])
z <- merge(z,zRomeQ)
remove(zRomeQ)
remove(SampleRomeQ)
#plain <-coredata(z)
colnames(z) <-
c("SL_Temp","Rome_Temp","SL_Height","Rome_Height","SL_Chlorophyll","Rome_Chlorophyll",
"Rome_Discharge")
plot(z, main = "Current Time Series at Coosa River Stations State Line (SL) and Rome")
Sys.sleep(2)
#
# ----------------------------------------------------
# calculating the fitted values
# ----------------------------------------------------
#
#
cat("\n")
cat("\n")
cat("Summary of Temperature regression between Rome and State Line Stations ...\n")
cat("\n")
lmfit <- lm (SL_Temp ~ Rome_Temp, data = z)
cat("\n")
cat("..............................................................................
...\n")
cat("\n")
print(summary(lmfit, correlation=TRUE))
cat("\n")
cat("..............................................................................
...\n")
cat("\n")
cat("\n")
cat("Plotting Regression Line ...\n")
cat("\n")

##
## Creating Figure of regression water temperature Coosa River State Line vs Rome
##
print( ggplot(z, aes(x = Rome_Temp, y = SL_Temp)) +
       ylab("Water Temperature C (00010) at station 02397530 Coosa River at State
Line") +
       xlab("Water Temperature C (00010) at station 02397000 Coosa River at Rome") +
       geom_point(col = c("grey")) +
       geom_smooth(method = "lm",col = c("blue"), lwd = 2) )

xsum = summary(lmfit, correlation=TRUE)
remove(lmfit)
xtable<-xsum["coefficients"]
```

```
remove(xsum)
outtable<-capture.output(xtable)
remove(xtable)
ktable<-strsplit(outtable[3], split = " ")
InterceptC<-unlist(ktable, recursive = T)
InterceptC1<-InterceptC[InterceptC != ""]
InterceptCoeff<-as.numeric(paste(InterceptC1[2]))
remove(ktable)
remove(InterceptC)
remove(InterceptC1)
#
ktable<-strsplit(outtable[4], split = " ")
RomeTempC<-unlist(ktable, recursive = T)
RomeTempC1<-RomeTempC[RomeTempC != ""]
RomeTempCoeff<-as.numeric(paste(RomeTempC1[2]))
remove(ktable)
remove(RomeTempC)
remove(RomeTempC1)
remove(outtable)
#
z <- merge(z,NA)
colnames(z) <-
c("SL_Temp","Rome_Temp","SL_Height","Rome_Height","SL_Chlorophyll","Rome_Chlorophyll",
"Rome_Discharge", "Completed_SL_Temp")

# Removing the last record if it is NA
while (is.na(z$Rome_Discharge[nrow(z)])){
       z <- z[1:(nrow(z)-1)]
}
#
# Completing Temperature Time Series with Regression
#
cat("\n")
cat("Completing Temperature Time Series ...\n")
cat("\n")
for (i in 1: nrow(z) ){
       if ( is.na(z$SL_Temp[i]) ) {
              if (!is.na(z$Rome_Temp[i])) {
                     z$Completed_SL_Temp[i] <- as.numeric(InterceptCoeff +
(RomeTempCoeff * z$Rome_Temp[i]))
              } else {
              }
       } else {
              z$Completed_SL_Temp[i] <- as.numeric(z$SL_Temp[i])
       }
}
remove(InterceptCoeff)
remove(RomeTempCoeff)
#
# Creating a Dataframe with all the data
#
#TempTable is a temporal table to extract the estimated temperatures
TempTable <-data.frame(((time(z))))
TempTable[, c("SL_Temp")] <- as.numeric(format(z$SL_Temp))
TempTable[, c("Completed_SL_Temp")] <- as.numeric(format(z$Completed_SL_Temp))
colnames(TempTable) <- c("date","SL_Temp","Completed_SL_Temp")
zz <-read.zoo(TempTable)
z1 <- zz
z1 <- na.approx(z1)

TemperatureTable <-data.frame(((time(z))))
TemperatureTable[, c("SL_Temp")] <- as.numeric(format(z$SL_Temp))
TemperatureTable[, c("Completed_SL_Temp")] <- as.numeric(format(z1$Completed_SL_Temp))
```

```
colnames(TemperatureTable) <- c("date","SL_Temp","Completed_SL_Temp")

# Copying completed time series to z and cleaning up ...
for (i in 1: nrow(z) ){
              z$Completed_SL_Temp[i] <-
as.numeric(TemperatureTable$Completed_SL_Temp[i])
}
remove(TempTable)
remove(zz)
remove(z1)


cat("\n")
cat("Plotting Temperature Time Series ...\n")
cat("\n")

zz <-read.zoo(TemperatureTable)
remove(TemperatureTable)

plot(zz, plot.type = "single", col = c("lightgray","blue"), lwd = c(4,1.5),
       ylab = "Temperature (00010) at 02397530 blue = estimated ; grey = observed)",
       xlab = "Date")

##
## Creating TIFF of completed time series water temperature Coosa River State Line
##
tiff(filename = paste(figurePath,staSL,"_","Completed_Water_Temperature.tiff", sep =
""), width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plot(zz, plot.type = "single", col = c("lightgray","blue"), lwd = c(4,1.5),
       ylab = "Temperature C(00010) at 02397530 blue = estimated ; grey = observed)",
       xlab = "Date")
Sys.sleep(2)
dev.off(as.integer(dev.cur()))
remove(zz)

##
## Completing Height Elevation at State Line Station
##
cat("\n")
cat("\n")
cat("Completing Water Height Time Series at Rome ...\n")
cat("\n")

Hlmfit <- lm (Rome_Discharge ~ Rome_Height, data = z)
cat("\n")
cat("..............................................................................
...\n")
cat("\n")
print(summary(Hlmfit, correlation=TRUE))
cat("\n")
cat("..............................................................................
...\n")
cat("\n")

cat("\n")
cat("Plotting Regression Line ...\n")
cat("\n")

##
## Creating Figure of regression water temperature Coosa River State Line vs Rome
##
print( ggplot(z, aes(x = Rome_Height, y = Rome_Discharge)) +
       ylab("Water Discharge cfs (00060) at station 02397000 Coosa River at Rome") +
```

```
       xlab("Water Height ft (00065) at station 02397000 Coosa River at Rome") +
       geom_point(col = c("grey")) +
       geom_smooth(method = "lm",col = c("blue"), lwd = 2) )

xsum = summary(Hlmfit, correlation=TRUE)
remove(Hlmfit)
xtable<-xsum["coefficients"]
remove(xsum)
outtable<-capture.output(xtable)
remove(xtable)
ktable<-strsplit(outtable[3], split = " ")
InterceptC<-unlist(ktable, recursive = T)
InterceptC1<-InterceptC[InterceptC != ""]
InterceptCoeff<-as.numeric(paste(InterceptC1[2]))
remove(ktable)
remove(InterceptC)
remove(InterceptC1)
#
ktable<-strsplit(outtable[4], split = " ")
RomeHeightC<-unlist(ktable, recursive = T)
RomeHeightC1<-RomeHeightC[RomeHeightC != ""]
RomeHeightCoeff<-as.numeric(paste(RomeHeightC1[2]))
remove(ktable)
remove(RomeHeightC)
remove(RomeHeightC1)
remove(outtable)
#
z <- merge(z,NA)
colnames(z) <-
c("SL_Temp","Rome_Temp","SL_Height","Rome_Height","SL_Chlorophyll","Rome_Chlorophyll",
"Rome_Discharge", "Completed_SL_Temp","Completed_Rome_Discharge")

#
# Completing Temperature Time Series with Regression
#
cat("\n")
cat("Completing Rome Discharge Time Series ...\n")
cat("\n")
for (i in 1: nrow(z) ){
       if ( is.na(z$Rome_Discharge[i]) ) {
              if (!is.na(z$Rome_Height[i])) {
                     z$Completed_Rome_Discharge[i] <- as.numeric(InterceptCoeff +
(RomeHeightCoeff * z$Rome_Height[i]))
              } else {
              }
       } else {
              z$Completed_Rome_Discharge[i] <- as.numeric(z$Rome_Discharge[i])
       }
}
remove(InterceptCoeff)
remove(RomeHeightCoeff)
#
# Creating a Dataframe with all the data
#
#TempTable is a temporal table to extract the estimated Discharge
TempTable <-data.frame(((time(z))))
TempTable[, c("Rome_Discharge")] <- as.numeric(format(z$Rome_Discharge))
TempTable[, c("Completed_Rome_Discharge")] <-
as.numeric(format(z$Completed_Rome_Discharge))
colnames(TempTable) <- c("date","Rome_Discharge","Completed_Rome_Discharge")
zz <-read.zoo(TempTable)
z1 <- zz
z1 <- na.approx(z1)
```

```
DischargeTable <-data.frame(((time(z))))
DischargeTable[, c("Rome_Discharge")] <- as.numeric(format(z$Rome_Discharge))
DischargeTable[, c("Completed_Rome_Discharge")] <-
as.numeric(format(z1$Completed_Rome_Discharge))
colnames(DischargeTable) <- c("date","Rome_Discharge","Completed_Rome_Discharge")
# Copying completed time series to z and cleaning up ...
for (i in 1: nrow(z) ){
             z$Completed_Rome_Discharge[i] <-
as.numeric(DischargeTable$Completed_Rome_Discharge[i])
}
remove(TempTable)
remove(zz)
remove(z1)

cat("\n")
cat("Plotting Temperature Time Series ...\n")
cat("\n")

zz <-read.zoo(DischargeTable)

plot(zz, plot.type = "single", col = c("lightgray","blue"), lwd = c(4,1.5),
       ylab = "Discharge (00060) at  02397000 (blue = estimated ; grey = observed)",
       xlab = "Date")
##
## Creating TIFF of completed time series water discharge Coosa River at Rome
##
tiff(filename = paste(figurePath,staRome,"_","Completed_Water_Discharge.tiff", sep =
""), width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plot(zz, plot.type = "single", col = c("lightgray","blue"), lwd = c(4,1.5),
       ylab = "Discharge (00060) at  02397000 (blue = estimated ; grey = observed)",
       xlab = "Date")
Sys.sleep(2)
dev.off(as.integer(dev.cur()))
remove(zz)
##
## Creating CSV file of completed time series water discharge Coosa River at Rome
##
DischargeTable <-data.frame(((time(z))))
DischargeTable[, c("Completed_Rome_Discharge")] <-
as.numeric(format(z$Completed_Rome_Discharge))
colnames(DischargeTable) <- c("date","Completed_Rome_Discharge")
write.csv(DischargeTable, file = "Discharge_02397000.csv", row.names = FALSE)
remove(DischargeTable)
##
## ------------------------------------------------------------------------------
## Creating CSV file of completed time series Chlorophyll Coosa River at State Line
## ------------------------------------------------------------------------------
##
# Chlorophyll Data from USGS
ChlorophyllTableT <-data.frame(((time(z))))
ChlorophyllTableT[, c("Remark")] <- ""
ChlorophyllTableT[, c("Value")] <- as.numeric(format(z$SL_Chlorophyll))
colnames(ChlorophyllTableT) <- c("date","Remark","Value")
ChlorophyllTable <- ChlorophyllTableT[!is.na(ChlorophyllTableT$Value),]
zUSGS <- read.zoo(ChlorophyllTable)


cat("\n")
cat("Obtaining Chlorophyll a data from station 21AWIC-23 WEIC-12 ...\n")
cat("\n")
# Chlorophyll Data from STORET
StoretSample <- getSampleData_Station (STORET_Station,ChlparamName,StartDate,EndDate)
```

```
zStoret <-read.zoo(StoretSample)
StoretSampleTable <-data.frame(((time(zStoret))))
StoretSampleTable[, c("Remark")] <- ""
StoretSampleTable[, c("Value")] <- as.numeric(format(zStoret$ConcHigh))
for (i in 1: nrow(zStoret) ){
       if ( as.numeric(zStoret$Uncen[i])  == 0) {
              StoretSampleTable$Remark[i] <- "<"
       }
}
colnames(StoretSampleTable) <- c("date","Remark","Value")
zStoret <-read.zoo(StoretSampleTable)
remove(StoretSampleTable)

cat("\n")
cat("Merging USGS and STORET Chlorophyll a data ...\n")
cat("\n")
# Merging both
m <- merge (zStoret, zUSGS, all = TRUE)
for (i in 1: nrow(m) ){
       if ( is.na(m$Value.zUSGS[i])) {
              m$Remark.zUSGS[i] <- m$Remark.zStoret[i]
              m$Value.zUSGS[i] <- m$Value.zStoret[i]
       }else{
              m$Remark.zUSGS[i] <- m$Remark.zUSGS[i]
              m$Value.zUSGS[i] <- m$Value.zUSGS[i]
       }
}

ChlorophyllTableT <-data.frame(((time(m))))
ChlorophyllTableT[, c("Remark")] <- m$Remark.zUSGS
ChlorophyllTableT[, c("Value")] <- (as.numeric(format(m$Value.zUSGS)))
colnames(ChlorophyllTableT) <- c("date","Remark","Value")
ChlorophyllTable <- ChlorophyllTableT[!is.na(ChlorophyllTableT$Value),]

remove(ChlorophyllTableT)
remove(zUSGS)
remove(StoretSample)
remove(zStoret)
remove(m)

# writing text file with Chlorophyll data
write.csv(ChlorophyllTable, file = "Clorophyll_02397530.csv", quote = FALSE, row.names
= FALSE)
remove(ChlorophyllTable)

cat("\n")
cat("Stating WRTDS calculations  Chlorophyll a...\n")
cat("\n")
##  ------------------------------------------------------------
##  ----------------- WRTDS CALCULATIONS ----------------------
##  ------------------------------------------------------------

##  Reading files
Sample<-getSampleDataFromFile("./", "Clorophyll_02397530.csv", hasHeader = TRUE,
separator = "," , interactive = TRUE)
Daily<-getDailyDataFromFile(".//", "Discharge_02397000.csv", qUnit = 1)

## ----------------------------------------------------
## merging discharge and concentration
## ----------------------------------------------------
##
removeDuplicates(Sample)
summary(Daily)
```

```
summary(Sample)
Sample<-mergeReport()
##
## ----------------------------------------------------
## Retrieving Metadata
## ----------------------------------------------------
##
INFO<-getMetaData(staSL,"62361", interactive = FALSE)
#
INFO$shortName <- substr(INFO$station.nm, 1, 48)
INFO$staAbbrev <- INFO$station.no
INFO$paramShortName <- substr(INFO$param.nm, 1, 30)
INFO$constitAbbrev <- INFO$paramNumber
##
##
## ----------------------------------------------------
## Concentration Plot
## ----------------------------------------------------
plot(Sample$DecYear, Sample$ConcAve, log="y",xlab = "Year", ylab = "Concentration
mg/L", main = paste(INFO$site.no,INFO$station," \n", INFO$param.nm))
Sys.sleep(1)
##
## Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","62361","_","C_vs_T.tif",sep =""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plot(Sample$DecYear, Sample$ConcAve, log="y",xlab = "Year", ylab = "Concentration
mg/L", main = paste(INFO$site.no,INFO$station, " \n", INFO$param.nm))
Sys.sleep(1)
#.Internal(dev.off(as.integer(dev.cur())))
dev.off(as.integer(dev.cur()))

##
## ----------------------------------------------------
## Discharge Plot
## ----------------------------------------------------
dischargePsubtitle <- expression(paste("Discharge in  ", m^3/s))
plot(Daily$DecYear,Daily$Q,log="y", type="l",xlab = "Year", ylab = dischargePsubtitle,
main = paste(INFO$site.no,INFO$station, " \n", "cubic meters per second"))
Sys.sleep(1)
##
## Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","62361","_","Q_vs_T.tiff",sep =""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plot(Daily$DecYear,Daily$Q,log="y", type="l",xlab = "Year", ylab = dischargePsubtitle,
main = paste(INFO$site.no,INFO$station, " \n", "cubic meters per second"))
Sys.sleep(1)
dev.off(as.integer(dev.cur()))

## ----------------------------------------------------
## Multi Plot Overview
## ----------------------------------------------------
multiPlotDataOverview()
Sys.sleep(1)
##
## Saving image as TIFF
tiff(filename =
paste(figurePath,staSL,"_","62361","_","MultiPlotDataOverview.tiff",sep =""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
multiPlotDataOverview()
Sys.sleep(1)
dev.off(as.integer(dev.cur()))
##
#
```

```
# ----------------------------------------------------
# ----------------------------------------------------
# MODEL SIMULATION
# ----------------------------------------------------
# ----------------------------------------------------
##
modelEstimation(localDaily = Daily, localSample = Sample, localINFO = INFO, windowY =
20, windowQ = 5,windowS = 0.5, minNumObs = 500, minNumUncen = 500)
AnnualResults<-setupYears()
# ----------------------------------------------------
# plotConcHist Plotting Concentration History
# ----------------------------------------------------
plotConcHist(startYear=2005,endYear=2015)
##
# Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","62361","_","plotConcHist.tiff", sep = ""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plotConcHist(startYear=2005,endYear=2015)
dev.off()
#
# ----------------------------------------------------
# plotConcTimeDaily Plotting Concentration Daily
# ----------------------------------------------------
plotConcTimeDaily(startYear=2005,endYear=2015)
##
# Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","62361","_","plotConcTimeDaily.tiff", sep =
""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plotConcTimeDaily(startYear=2005,endYear=2015)
dev.off()
#
#
cat("\n")
cat("Completing Chlorophyll Time Series for Station ...\n")
cat("\n")
z <- merge(z,Daily$ConcDay)
colnames(z) <-
c("SL_Temp","Rome_Temp","SL_Height","Rome_Height","SL_Chlorophyll","Rome_Chlorophyll",
"Rome_Discharge",
"Completed_SL_Temp","Completed_Rome_Discharge","Completed_SL_Chlorophyll")
ChlaDaily <- Daily
#
#
##
## ------------------------------------------------------------------------------------
## Creating CSV file of completed time series Inorganic Nitrogen in Coosa River at
State Line
## ------------------------------------------------------------------------------------
##
# InorganicN Data from USGS
USGSSample <- getSampleData(staSL,"00630",StartDate,EndDate)
zUSGS <-read.zoo(USGSSample)
remove(USGSSample)
InorganicNTableT <-data.frame(((time(zUSGS))))
InorganicNTableT[, c("Remark")] <- ""
InorganicNTableT[, c("Value")] <- as.numeric(format(zUSGS$ConcHigh))

for (i in 1: nrow(zUSGS) ){
       if ( as.numeric(zUSGS$Uncen[i])  == 0) {
              InorganicNTableT$Remark[i] <- "<"
       }
}
```

```
colnames(InorganicNTableT) <- c("date","Remark","Value")
InorganicNTable <- InorganicNTableT[!is.na(InorganicNTableT$Value),]
zUSGS <- read.zoo(InorganicNTable)

cat("\n")
cat("Obtaining Inorganic Nitrogen a data from station 21AWIC-23 WEIC-12 ...\n")
cat("\n")

# InorganicN Data from STORET
StoretSample <- getSampleData_Station
(STORET_Station,NitrogenParamName,StartDate,EndDate)
zStoret <-read.zoo(StoretSample)
StoretSampleTable <-data.frame(((time(zStoret))))
StoretSampleTable[, c("Remark")] <- ""
StoretSampleTable[, c("Value")] <- as.numeric(format(zStoret$ConcHigh))

for (i in 1: nrow(zStoret) ){
       if ( as.numeric(zStoret$Uncen[i])  == 0) {
              StoretSampleTable$Remark[i] <- "<"
       }
}

colnames(StoretSampleTable) <- c("date","Remark","Value")
zStoret <-read.zoo(StoretSampleTable)
remove(StoretSampleTable)

cat("\n")
cat("Merging USGS and STORET Inorganic Nitrogen data ...\n")
cat("\n")
# Merging both
m <- merge (zStoret, zUSGS, all = TRUE)
for (i in 1: nrow(m) ){
       if ( is.na(m$Value.zUSGS[i])) {
              m$Remark.zUSGS[i] <- m$Remark.zStoret[i]
              m$Value.zUSGS[i] <- m$Value.zStoret[i]
       }else{
              m$Remark.zUSGS[i] <- m$Remark.zUSGS[i]
              m$Value.zUSGS[i] <- m$Value.zUSGS[i]
       }
}

InorganicNTableT <-data.frame(((time(m))))
InorganicNTableT[, c("Remark")] <- m$Remark.zUSGS
InorganicNTableT[, c("Value")] <- (as.numeric(format(m$Value.zUSGS)))
colnames(InorganicNTableT) <- c("date","Remark","Value")
InorganicNTable <- InorganicNTableT[!is.na(InorganicNTableT$Value),]

remove(InorganicNTableT)
remove(zUSGS)
remove(StoretSample)
remove(zStoret)
remove(m)

# writing text file with Inorganic Nitrogen data
write.csv(InorganicNTable, file = "InorganicN_02397530.csv", quote = FALSE, row.names
= FALSE)
remove(InorganicNTable)


cat("\n")
cat("Stating WRTDS calculations Nitrate + Nitrite-N ...\n")
cat("\n")
```

```
##  ------------------------------------------------------------
##  ----------------- WRTDS CALCULATIONS ----------------------
##  ------------------------------------------------------------

##  Reading files
Sample<-getSampleDataFromFile("./", "InorganicN_02397530.csv", hasHeader = TRUE,
separator = "," , interactive = TRUE)
Daily<-getDailyDataFromFile(".//", "Discharge_02397000.csv", qUnit = 1)

## ----------------------------------------------------
## merging discharge and concentration
## ----------------------------------------------------
##
removeDuplicates(Sample)
summary(Daily)
summary(Sample)
Sample<-mergeReport()
##
## ----------------------------------------------------
## Retrieving Metadata
## ----------------------------------------------------
##
INFO<-getMetaData(staSL,"00630", interactive = FALSE)
#
INFO$shortName <- substr(INFO$station.nm, 1, 48)
INFO$staAbbrev <- INFO$station.no
INFO$paramShortName <- substr(INFO$param.nm, 1, 30)
INFO$constitAbbrev <- INFO$paramNumber
##
##
## ----------------------------------------------------
## Concentration Plot
## ----------------------------------------------------
plot(Sample$DecYear, Sample$ConcAve, log="y",xlab = "Year", ylab = "Concentration
mg/L", main = paste(INFO$site.no,INFO$station," \n", INFO$param.nm))
Sys.sleep(1)
##
## Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","00630","_","C_vs_T.tif",sep =""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plot(Sample$DecYear, Sample$ConcAve, log="y",xlab = "Year", ylab = "Concentration
mg/L", main = paste(INFO$site.no,INFO$station, " \n", INFO$param.nm))
Sys.sleep(1)
#.Internal(dev.off(as.integer(dev.cur())))
dev.off(as.integer(dev.cur()))

##
## ----------------------------------------------------
## Discharge Plot
## ----------------------------------------------------
dischargePsubtitle <- expression(paste("Discharge in  ", m^3/s))
plot(Daily$DecYear,Daily$Q,log="y", type="l",xlab = "Year", ylab = dischargePsubtitle,
main = paste(INFO$site.no,INFO$station, " \n", "cubic meters per second"))
Sys.sleep(1)
##
## Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","00630","_","Q_vs_T.tiff",sep =""),
     width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plot(Daily$DecYear,Daily$Q,log="y", type="l",xlab = "Year", ylab = dischargePsubtitle,
main = paste(INFO$site.no,INFO$station, " \n", "cubic meters per second"))
Sys.sleep(1)
dev.off(as.integer(dev.cur()))
```

```
## ----------------------------------------------------
## Multi Plot Overview
## ----------------------------------------------------
multiPlotDataOverview()
Sys.sleep(1)
##
## Saving image as TIFF
tiff(filename =
paste(figurePath,staSL,"_","00630","_","MultiPlotDataOverview.tiff",sep =""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
multiPlotDataOverview()
Sys.sleep(1)
dev.off(as.integer(dev.cur()))
##
#
# ----------------------------------------------------
# ----------------------------------------------------
# MODEL SIMULATION
# ----------------------------------------------------
# ----------------------------------------------------
##
modelEstimation(localDaily = Daily, localSample = Sample, localINFO = INFO, windowY =
20, windowQ = 5,windowS = 0.5, minNumObs = 150, minNumUncen = 150)
AnnualResults<-setupYears()
# ----------------------------------------------------
# plotConcHist Plotting Concentration History
# ----------------------------------------------------
plotConcHist(startYear=2005,endYear=2015)
##
# Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","00630","_","plotConcHist.tiff", sep = ""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plotConcHist(startYear=2005,endYear=2015)
dev.off()
#
# ----------------------------------------------------
# plotConcTimeDaily Plotting Concentration Daily
# ----------------------------------------------------
plotConcTimeDaily(startYear=2005,endYear=2015)
##
# Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","00630","_","plotConcTimeDaily.tiff", sep =
""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
plotConcTimeDaily(startYear=2005,endYear=2015)
Sys.sleep(2)
dev.off()
#
#
cat("\n")
cat("Completing Inorganic Nitrogen Time Series for Station ...\n")
cat("\n")
z <- merge(z,Daily$ConcDay)
colnames(z) <-
c("SL_Temp","Rome_Temp","SL_Height","Rome_Height","SL_Chlorophyll","Rome_Chlorophyll",
"Rome_Discharge",
"Completed_SL_Temp","Completed_Rome_Discharge","Completed_SL_Chlorophyll","Completed_S
L_InorganicN")
InorgNDaily <-Daily
#
#
## ******************************************************************************
## ------------------------------------------------------------------------------
```

```
## Creating Plots with Index Periods and Biological Data
## ------------------------------------------------------------------------------------
## ************************************************************************************
#
#
# Reading file with Biological Data
#
cat("\n")
cat("Reading Biological File ...\n")
cat("\n")
BioFile <- read.table(BiologicalFile,header=TRUE,sep=",",

colClasses=c('integer','character','character','character','character',

       'Date','character','numeric','numeric','integer',

       'character','integer','integer','integer','integer',

       'integer','integer','integer','character','character',

       'character','character','character','character',

       'character','character','character','character',

       'character','character','character','character')
  )
# Next line to check right format - commented
# sapply(BioFile, mode)

#
# creating Table with 366 days to include series up to date and Chlorophyll a
quantiles
#

YearlyTable <- as.data.frame(Daily$Date[Daily$DecYear >= 2012.00 & Daily$DecYear <
2013.00])
YearlyTable[, c("Day")] <- 0
YearlyTable[, c("Chla_LowerLimit")] <- 0
YearlyTable[, c("Chla_UpperLimit")] <- 0
YearlyTable[, c("Est_Chla")] <- 0
YearlyTable[, c("InorgN_LowerLimit")] <- 0
YearlyTable[, c("InorgN_UpperLimit")] <- 0
YearlyTable[, c("Est_InorgN")] <- 0
YearlyTable[, c("Q_LowerLimit")] <- 0
YearlyTable[, c("Q_UpperLimit")] <- 0
YearlyTable[, c("Est_Q")] <- 0
YearlyTable[, c("Temp_LowerLimit")] <- 0
YearlyTable[, c("Temp_UpperLimit")] <- 0
YearlyTable[, c("Est_Temp")] <- 0
Sys.sleep(2)
is.na(YearlyTable) <-c(5,8,11,14)
Sys.sleep(2)
colnames(YearlyTable) <-
c("Date","Day","Chla_LowerLimit","Chla_UpperLimit","Est_Chla",

"InorgN_LowerLimit","InorgN_UpperLimit","Est_InorgN",
                          "Q_LowerLimit","Q_UpperLimit","Est_Q",
                          "Temp_LowerLimit","Temp_UpperLimit","Est_Temp"
)

CurrentYear<-format(Sys.Date(),paste("%Y", sep=""))

ThisYearChla <- as.data.frame(ChlaDaily$ConcDay[ChlaDaily$DecYear >= CurrentYear])
```

```
colnames(ThisYearChla) <- c("Chla_Concentration")

ThisYearInorgN <- as.data.frame(InorgNDaily$ConcDay[InorgNDaily$DecYear >=
CurrentYear])
colnames(ThisYearInorgN) <- c("InorgN_Concentration")

ThisYearQ <- as.data.frame(ChlaDaily$Q[ChlaDaily$DecYear >= CurrentYear])
colnames(ThisYearQ) <- c("Q")

# create a dataframe with dates for temperature
# using the structure of a discharge file
Zdf <- data.frame(as.Date(index(z), "%Y-%m-%d"))
colnames(Zdf) <- c("Date")
Zdf[, c("Completed_SL_Temp")] <- as.numeric(format(z$Completed_SL_Temp))
if (file.exists("temp_series.csv")) { file.remove("temp_series.csv") }
write.table(Zdf,"temp_series.csv", sep = "," , row.names = FALSE, col.names = TRUE)
TempDaily <- getDailyDataFromFile(".//", "temp_series.csv", qUnit = 2)
remove(Zdf)

ThisYearTemp <- as.data.frame(TempDaily$Q[TempDaily$DecYear >= CurrentYear])
colnames(ThisYearTemp) <- c("Temp")

# Completing the table with confidence interval and current year Chlorophyll-a
cat("\n")
cat("Calculating confidence intervals  ...\n")
cat("\n")
for (i in 1: nrow(YearlyTable) ){
    YearlyTable$Day[i] <- i
    YearlyTable$Chla_LowerLimit[i] <- quantile(ChlaDaily$ConcDay[Daily$Day==i], probs
= c(0.05))
    YearlyTable$Chla_UpperLimit[i] <- quantile(ChlaDaily$ConcDay[Daily$Day==i], probs
= c(0.95))
      if (i <= nrow(ThisYearChla)){
      YearlyTable$Est_Chla[i] <- ThisYearChla$Chla_Concentration[i]
    }
}
remove(ThisYearChla)
BioFile[, c("Chla")] <- as.numeric(0)
for (i in 1: nrow(ChlaDaily) ){
       for( j in  1:nrow(BioFile) ){
              if ( as.numeric(ChlaDaily$Date[i]) == as.numeric(BioFile$Date[j]) ){
                     BioFile$Chla[j] <- ChlaDaily$ConcDay[i]
              }
       }
}



# Completing the table with confidence interval and current year Inorganic Nitrogen
for (i in 1: nrow(YearlyTable) ){
    YearlyTable$InorgN_LowerLimit[i] <- quantile(InorgNDaily$ConcDay[Daily$Day==i],
probs = c(0.05))
    YearlyTable$InorgN_UpperLimit[i] <- quantile(InorgNDaily$ConcDay[Daily$Day==i],
probs = c(0.95))
      if (i <= nrow(ThisYearInorgN)){
      YearlyTable$Est_InorgN[i] <- ThisYearInorgN$InorgN_Concentration[i]
    }
}
remove(ThisYearInorgN)
BioFile[, c("InorgN")] <- as.numeric(0)
for (i in 1: nrow(InorgNDaily) ){
       for( j in  1:nrow(BioFile) ){
              if ( as.numeric(InorgNDaily$Date[i]) == as.numeric(BioFile$Date[j]) ){
```

```
                    BioFile$InorgN[j] <- InorgNDaily$ConcDay[i]
              }
       }
}
#remove(InorgNDaily)


# Completing the table with confidence interval and current year Discharge
for (i in 1: nrow(YearlyTable) ){
    YearlyTable$Q_LowerLimit[i] <- quantile(ChlaDaily$Q[Daily$Day==i], probs =
c(0.05))
    YearlyTable$Q_UpperLimit[i] <- quantile(ChlaDaily$Q[Daily$Day==i], probs =
c(0.95))
      if (i <= nrow(ThisYearQ)){
      YearlyTable$Est_Q[i] <- ThisYearQ$Q[i]
    }
}
remove(ThisYearQ)
BioFile[, c("Q")] <- as.numeric(0)
for (i in 1: nrow(ChlaDaily) ){
       for( j in  1:nrow(BioFile) ){
              if ( as.numeric(ChlaDaily$Date[i]) == as.numeric(BioFile$Date[j]) ){
                    BioFile$Q[j] <- ChlaDaily$Q[i]
              }
       }
}
#remove(ChlaDaily)


# Completing the table with confidence interval and current year Temperature
for (i in 1: nrow(YearlyTable) ){
    YearlyTable$Temp_LowerLimit[i] <- quantile(TempDaily$Q[Daily$Day==i], probs =
c(0.05))
    YearlyTable$Temp_UpperLimit[i] <- quantile(TempDaily$Q[Daily$Day==i], probs =
c(0.95))
      if (i <= nrow(ThisYearTemp)){
      YearlyTable$Est_Temp[i] <- ThisYearTemp$Temp[i]
    }
}
remove(ThisYearTemp)

BioFile[, c("Temp")] <- as.numeric(0)
for (i in 1: nrow(TempDaily) ){
       for( j in  1:nrow(BioFile) ){
              if ( as.numeric(TempDaily$Date[i]) == as.numeric(BioFile$Date[j]) ){
                    BioFile$Temp[j] <- TempDaily$Q[i]
              }
       }
}
#remove(TempDaily)


# create a dataframe with dates for temperature
Tempdf <- data.frame(as.Date(BioFile$Date,"%Y-%m-%d"))
colnames(Tempdf) <- c("Date")
Tempdf[, c("Remark")] <- as.character("")
Tempdf[, c("ID")] <- as.numeric(format(BioFile$ID))
if (file.exists("temp_series.csv")) { file.remove("temp_series.csv") }
write.table(Tempdf,"temp_series.csv", sep = "," , row.names = FALSE, col.names = TRUE)
TempBioTemp <- getSampleDataFromFile(".//", "temp_series.csv", hasHeader = TRUE,
interactive = TRUE)
if (file.exists("temp_series.csv")) { file.remove("temp_series.csv") }
remove(Tempdf)
```

```
Tempdf <- data.frame(as.Date(TempBioTemp$Date,"%Y-%m-%d"))
colnames(Tempdf) <- c("DateY")
Tempdf[, c("ID")] <- as.numeric(format(TempBioTemp$ConcLow))
Tempdf[, c("Day")] <- as.numeric(format(TempBioTemp$Day))
Tempdf[, c("DecYear")] <- as.numeric(format(TempBioTemp$DecYear))
remove(TempBioTemp)
BioFile <- merge(BioFile, Tempdf, by = "ID")

# merging Biological Data with Yearly Table
cat("\n")
cat("Biological Data with Yearly Table  ...\n")
cat("\n")

YearlyTable[, c("County")] <- as.character("N_A")
YearlyTable[, c("Station_Description")] <- as.character("N_A")
YearlyTable[, c("StationName")] <- as.character("N_A")
YearlyTable[, c("StationID")] <- as.character("N_A")
YearlyTable[, c("BioDate")] <- as.character("N_A")
YearlyTable[, c("Basin_Name")] <- as.character("N_A")
YearlyTable[, c("PDF_Link")] <- as.character("N_A")
YearlyTable[, c("Instream_habitat_quality")] <- 0
YearlyTable[, c("Sediment_Deposition")] <- 0
YearlyTable[, c("Sinuosity")] <- 0
YearlyTable[, c("Bank_Vegetable_Stability")] <- 0
YearlyTable[, c("Riparian_buffer")] <- 0
YearlyTable[, c("Habitat_Score")] <- 0
YearlyTable[, c("Percentage_Habitat_Score")] <- 0
YearlyTable[, c("Instream_habitat_quality_R")] <- as.character("N_A")
YearlyTable[, c("Sediment_Deposition_R")] <- as.character("N_A")
YearlyTable[, c("Sinousity_R")] <- as.character("N_A")
YearlyTable[, c("Bank_Vegetable_Stability_R")] <- as.character("N_A")
YearlyTable[, c("Riparian_buffer_R")] <- as.character("N_A")
YearlyTable[, c("Percentage_Habitat_Score_R")] <- as.character("N_A")
YearlyTable[, c("WMB_I_Assessment_Score")] <- as.character("N_A")
YearlyTable[, c("BioSamplingChla")] <- 0
YearlyTable[, c("BioSamplingTemp")] <- 0
YearlyTable[, c("BioSamplingInorgN")] <- 0
YearlyTable[, c("BioSamplingQ")] <- 0
YearlyTable[, c("BioSamplingDay")] <- 0
YearlyTable[, c("BioSamplingDecYear")] <- 0

is.na(YearlyTable) <-c(15:41)

for ( i in 1: nrow(YearlyTable) ) {
       for ( j in  1:nrow(BioFile) ) {
              if ( as.numeric(YearlyTable$Day[i]) == as.numeric(BioFile$Day[j]) ) {
                     YearlyTable$County[i] <- BioFile$County[j]
                     YearlyTable$Station_Description[i] <-
BioFile$Station_Description[j]
                     YearlyTable$StationName[i] <- BioFile$StationName[j]
                     YearlyTable$StationID[i] <- BioFile$StationID[j]
                     YearlyTable$BioDate[i] <- BioFile$Date[j]
                     YearlyTable$Basin_Name[i] <- BioFile$Basin_Name[j]
                     YearlyTable$PDF_Link[i] <- BioFile$PDF_Link[j]
                     YearlyTable$Instream_habitat_quality[i] <-
BioFile$Instream_habitat_quality[j]
                     YearlyTable$Sediment_Deposition[i] <-
BioFile$Sediment_Deposition[j]
                     YearlyTable$Sinuosity[i] <- BioFile$Sinuosity[j]
                     YearlyTable$Bank_Vegetable_Stability[i] <-
BioFile$Bank_Vegetable_Stability[j]
                     YearlyTable$Riparian_buffer[i] <- BioFile$Riparian_buffer[j]
                     YearlyTable$Habitat_Score[i] <- BioFile$Habitat_Score[j]
```

```
                    YearlyTable$Percentage_Habitat_Score[i] <-
BioFile$Percentage_Habitat_Score[j]
                    YearlyTable$Instream_habitat_quality_R[i] <-
BioFile$Instream_habitat_quality_R[j]
                    YearlyTable$Sediment_Deposition_R[i] <-
BioFile$Sediment_Deposition_R[j]
                    YearlyTable$Sinousity_R[i] <- BioFile$Sinousity_R[j]
                    YearlyTable$Bank_Vegetable_Stability_R[i] <-
BioFile$Bank_Vegetable_Stability_R[j]
                    YearlyTable$Riparian_buffer_R[i] <- BioFile$Riparian_buffer_R[j]
                    YearlyTable$Percentage_Habitat_Score_R[i] <-
BioFile$Percentage_Habitat_Score_R[j]
                    YearlyTable$WMB_I_Assessment_Score[i] <-
BioFile$WMB_I_Assessment_Score[j]
                    YearlyTable$BioSamplingChla[i] <- BioFile$Chla[j]
                    YearlyTable$BioSamplingTemp[i] <- BioFile$Temp[j]
                    YearlyTable$BioSamplingInorgN[i] <- BioFile$InorgN[j]
                    YearlyTable$BioSamplingQ[i] <- BioFile$Q[j]
                    YearlyTable$BioSamplingDay[i] <- BioFile$Day[j]
                    YearlyTable$BioSamplingDecYear[i] <- BioFile$DecYear[j]
             }
       }
}

cat("\n")
cat("Plotting Final Figures  ...\n")
cat("\n")
library(scales)
dtPOSIXct <-as.POSIXct(YearlyTable$Date)

##
## ------------------------------------------------------------------------------
## Chlorophyll a Plot
## ------------------------------------------------------------------------------
##

LegendHabitat <- getLegend (YearlyTable, YearlyTable$Percentage_Habitat_Score_R)
LegendWMBI <- getLegend (YearlyTable, YearlyTable$WMB_I_Assessment_Score)

Chla_p <-  ggplot(YearlyTable, aes(x=dtPOSIXct)) +
  theme( panel.border = element_rect(colour = "black",fill = "transparent"),
       panel.background = element_rect(fill = "transparent"),
       panel.grid.major = element_blank()               ) +
  geom_line(aes(y = Chla_LowerLimit), colour = 'black', fill = NA, linetype =
"dotted") +
  geom_line(aes(y = Chla_UpperLimit), colour = 'black', fill = NA, linetype =
"dotted") +
  geom_line(aes(y = Est_Chla), colour = 'dark green', size =1.5, fill = NA) +
  geom_point(aes(y = BioSamplingChla), pch = 15, colour = LegendHabitat$Legendcol,
size = 4) +
  geom_point(aes(y = BioSamplingChla), pch = 19, colour = LegendWMBI$Legendcol, size =
2) +
  theme(axis.text.y = element_text(angle=0,hjust=1,color="black")) +
  theme(axis.text.x = element_text(angle=0,hjust=1,color="black")) +
  theme(axis.ticks.x = element_line(size=1)) +
  scale_x_datetime(breaks = "1 month", minor_breaks = "1 week", labels =
date_format("%b")) +
  xlab(expression(atop("Month",atop("Dotted lines are 5% and 95% Confidence
Intervals")))) +
       ylab("Chlorophyll a ug/L")

#          geom_vline(xintercept = as.numeric(as.POSIXct("2013-01-01")))
```

```
print(Chla_p)
#
cat("\n")
cat("Plotting Index Periods Based on Chlorophyll a ...\n")
cat("\n")
##
## Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","Index_Period_Chlorophylla.tiff",sep =""),
     width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
Chla_p
Sys.sleep(2)
dev.off()


##
## ------------------------------------------------------------------------------
## Inorganic N Plot
## ------------------------------------------------------------------------------
##

LegendHabitat <- getLegend (YearlyTable, YearlyTable$Percentage_Habitat_Score_R)
LegendWMBI <- getLegend (YearlyTable, YearlyTable$WMB_I_Assessment_Score)
NO2_NO3_p <-  ggplot(YearlyTable, aes(x=dtPOSIXct)) +
  theme( panel.border = element_rect(colour = "black",fill = "transparent"),
       panel.background = element_rect(fill = "transparent"),
       panel.grid.major = element_blank()               ) +
  geom_line(aes(y = InorgN_LowerLimit), colour = 'black', fill = NA, linetype =
"dotted") +
  geom_line(aes(y = InorgN_UpperLimit), colour = 'black', fill = NA, linetype =
"dotted") +
  geom_line(aes(y = Est_InorgN), colour = 'red', size = 1.5, fill = NA) +
  geom_point(aes(y = BioSamplingInorgN), pch = 15, colour = LegendHabitat$Legendcol,
size = 4) +
  geom_point(aes(y = BioSamplingInorgN), pch = 19, colour = LegendWMBI$Legendcol, size
= 2) +
  theme(axis.text.y = element_text(angle=0,hjust=1,color="black")) +
  theme(axis.text.x = element_text(angle=0,hjust=1,color="black")) +
  theme(axis.ticks.x = element_line(size=1)) +
  scale_x_datetime(breaks = "1 month", minor_breaks = "1 week", labels =
date_format("%b")) +
  xlab(expression(atop("Month",atop("Dotted lines are 5% and 95% Confidence
Intervals")))) +
       ylab("Nitrate + Nitrite as N mg/L")
#

print(NO2_NO3_p)


cat("\n")
cat("Plotting Index Periods Based on Inorganic Nitrogen a ...\n")
cat("\n")
##
##
## Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","Index_Period_InorganicN.tiff",sep =""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
NO2_NO3_p
Sys.sleep(2)
dev.off()

##
## ------------------------------------------------------------------------------
## Discharge Plot
```

```
## ------------------------------------------------------------------------------
##
LegendHabitat <- getLegend (YearlyTable, YearlyTable$Percentage_Habitat_Score_R)
LegendWMBI <- getLegend (YearlyTable, YearlyTable$WMB_I_Assessment_Score)
Q_p <-  ggplot(YearlyTable, aes(x=dtPOSIXct)) +
  theme( panel.border = element_rect(colour = "black",fill = "transparent"),
       panel.background = element_rect(fill = "transparent"),
       panel.grid.major = element_blank()               ) +
  geom_line(aes(y = Q_LowerLimit), colour = 'black', fill = NA, linetype = "dotted") +
  geom_line(aes(y = Q_UpperLimit), colour = 'black', fill = NA, linetype = "dotted") +
  geom_line(aes(y = Est_Q), colour = 'blue', size = 1.5, fill = NA) +
  geom_point(aes(y = BioSamplingQ), pch = 15, colour = LegendHabitat$Legendcol, size =
4) +
  geom_point(aes(y = BioSamplingQ), pch = 19, colour = LegendWMBI$Legendcol, size = 2)
+
  theme(axis.text.y = element_text(angle=0,hjust=1,color="black")) +
  theme(axis.text.x = element_text(angle=0,hjust=1,color="black")) +
  theme(axis.ticks.x = element_line(size=1)) +
  scale_x_datetime(breaks = "1 month", minor_breaks = "1 week", labels =
date_format("%b")) +
  xlab(expression(atop("Month",atop("Dotted lines are 5% and 95% Confidence
Intervals")))) +
       ylab("Discharge cms")

print(Q_p)

#
cat("\n")
cat("Plotting Index Periods Based on Discharge a ...\n")
cat("\n")
##
##
## Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","Index_Period_Discharge.tiff",sep =""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
Q_p
Sys.sleep(2)
dev.off()


##
## ------------------------------------------------------------------------------
## Temperature Plot
## ------------------------------------------------------------------------------
##
LegendHabitat <- getLegend (YearlyTable, YearlyTable$Percentage_Habitat_Score_R)
LegendWMBI <- getLegend (YearlyTable, YearlyTable$WMB_I_Assessment_Score)

Temp_p <-  ggplot(YearlyTable, aes(x=dtPOSIXct)) +
  theme( panel.border = element_rect(colour = "black",fill = "transparent"),
       panel.background = element_rect(fill = "transparent"),
       panel.grid.major = element_blank()               ) +
  geom_line(aes(y = Temp_LowerLimit), colour = 'black', fill = NA, linetype =
"dotted") +
  geom_line(aes(y = Temp_UpperLimit), colour = 'black', fill = NA, linetype =
"dotted") +
  geom_line(aes(y = Est_Temp), colour = "purple", size = 1.5, fill = NA) +
  geom_point(aes(y = BioSamplingTemp), pch = 15, colour = LegendHabitat$Legendcol,
size = 4) +
  geom_point(aes(y = BioSamplingTemp), pch = 19, colour = LegendWMBI$Legendcol, size =
2) +
  theme(axis.text.y = element_text(angle=0,hjust=1,color="black")) +
  theme(axis.text.x = element_text(angle=0,hjust=1,color="black")) +
```

```
  theme(axis.ticks.x = element_line(size=1.5)) +
  scale_x_datetime(breaks = "1 month", minor_breaks = "1 week", labels =
date_format("%b")) +
  xlab(expression(atop("Month",atop("Dotted lines are 5% and 95% Confidence
Intervals")))) +
       ylab("Temperature C")

print(Temp_p)

#
cat("\n")
cat("Plotting Index Periods Based on Temperature a ...\n")
cat("\n")
##
##
## Saving image as TIFF
tiff(filename = paste(figurePath,staSL,"_","Index_Period_Temp.tiff",sep =""),
      width = 2100, height = 1575, units = "px", res = 300, compression = c("lzw"))
Temp_p
Sys.sleep(2)
dev.off()
#dev.off(as.integer(dev.cur()))
```

Information Transfer Program Introduction

None.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	10	0	0	11
Masters	1	2	0	0	3
Ph.D.	1	1	0	0	2
Post-Doc.	0	0	0	0	0
Total	3	13	0	0	16

Notable Awards and Achievements

Alan Wilson Purdue University Scholar of Sustainability (declined) Alan Wilson Semester fellowship at UNC CH Global Research Institute, $35,000 Alan Wilson Auburn University outreach grant, $20,000Anja Rebelein DAAD RISE fellowship (German Exchange program), $5,500 Brianna Olsen Auburn University student travel grant, $300 Jo Marie Kasinak Sigma Xi Grants in Aid of Research grant, $600 Jo Marie Kasinak MidSouth Aquatic Plant Management Society Scholarship, $2,000 Enrique Doster Auburn University Undergraduate Research Fellow award, $6,000Megan Lange, 2014 Removal of BTEX from Storm Water Using Nano-Particle Enhance Porous Concrete. 2014 Alabama State Junior Stockholm Water Prize – Currently competing for National Prize

Publications from Prior Years